5. Energy saving potential

If we suppose that the mean values of energy consumption can become maximum values through a serious energy management program, we can expect large energy savings.

In France (4), energy consumption in health care buildings was estimated in 1981 as 10 % of the tertiary sector.

It was reported in 1983 by Grumman and Butkurs (5) a 27 % energy saving after a 6 year's energy management program in a 1100 bed hospital.

Ing. L. WULLAERT (6) after a 5 year's energy management program, in a 918 beds hospital reduces the gas consumption by 42 % and the electricity consumption by 21 %.

These were examples among a lot of others showing how large can be this energy - and money - saving potential.

Considering the Belgian situation, a 25 % energy saving can represent one more nurse for 100 beds (at 1984 energy prices).

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SOLAR ENERGY USE IN OCCUPIED SINGLE-FAMILY HOUSES IN GERMANY

LANDSTUHL - A PILOT PROJECT FOR THE IMPLEMENTATION OF ENERGY-SAVING CONSTRUCTION METHODS

H. ERHORN, J. REISS, D. OSWALD
Fraunhofer-Institut für Bauphysik
(Bereich Wärme/Klima)
Director: o.Prof.Dr.-Ing.habil. K.A. Gertis
D-7000 Stuttgart, West Germany

Objectives

About 15% of the primary energy consumed in the Federal Republic of Germany account for heating private households. In this respect, there are still many possibilities to cut down on energy consumption, in both renovating old buildings and in raising new ones. In the long run, the heating energy demand for dwellings in the Fed. Rep. of Germany could be reduced to less than a third of today's consumption by consequently applying all of the advanced building concepts and technologies presently available (1) which hitherto have been applied only with hesitation, however.

Of impeding influence are mainly the lack of know-how concerning the various possibilities of implementing low-energy building concepts as well as reservations against risks concerning functionality and economy of new techniques and last, but not least, the lack of demonstration buildings. It was for these reasons that the Federal Ministry for Research and Technology (BMFT) decided to give a concrete demonstration of the practical implementation by funding the present pilot project.

The pilot project is aimed at

- implementing promising solutions for single-family dwellings with low energy consumption
- proving functionality, efficiency and economy of the new technologies and building concepts
- pointing out technical problems within the new systems and contributing to their elimination
- establishing the economical, legal, and social framework for the large-scale application of energy-saving methods of construction.

Scope of the Project

From among several concepts supplied by an architectural competition held especially for this purpose, 12 designs were selected and built in a development area and its vicinity provided by the city of Landstuhl. The venture was subsidized with federal innovation grants. Besides, ten additional buildings comparable to the design concepts selected from the architectural competition, but located in other parts of Germany, and three conventional reference houses were included in the research project.

In these buildings, various concepts of energy-saving construction methods were realized. Most of the buildings have an excellent thermal insulation. The following summary shows how often different components are present in the 25 project houses:

Passive Technologies

17 x large south-front glazings
13 x temporary thermal insulation
10 x solar greenhouses
4 x pebble-bed storages
1 x Trombe wall

Active Technologies

15 x ventilation systems
13 x solar collectors
6 x heat pumps
2 x hybrid components
1 x ground pipe

All houses are occupied and provided with extensive measuring equipment, the following data being continuously collected:

- all weather data required
- all the heating energies necessary for the system's evaluation
- all air temperatures in the different parts of the buildings
- all measurable internal heat gains
- all opening positions of windows, doors, and temporary thermal insulation devices in representative buildings
- all the characteristic data of the active systems.

In addition, tracer-gas measurements are carried out on the air change in the buildings. On the whole, there are 150,000 single measurements available for analysis. Further, accompanying studies on builders' and occupiers' investment preferences and users' behaviour give information about the general acceptance of resp. obstacles in introducing new technologies, about handling problems and their effects on the quality of housing. The "Solar Office Landstuhl" which was established during the project has been in charge of consulting the local participants in the project. Besides, it has been assigned the task to introduce experiences gained in the project into the designing practice by providing free consultation for architects and builders and by arranging presentations.

State of the Project

Measurements have been carried out as early as the heating season of 1984/85 when the first houses were completed. In the meantime, all the houses involved in the project have been completed and occupied. Hence, measurements performed in the heating period of 1985/86 supplied the first comparable results. Based on the energy consumptions thus determined and a detailed occupants' profile it could be pointed out in which way further reductions in heating energy consumption are to be attained by either technically improving the buildings or heating installations or by changing the occupants' behaviour.

Results of the Measurement and Investigation Programme

Heating Period of 1985/86

Since the individual project buildings differ in size and location, it was necessary to normalize the measured data, i.e. to render them independent of parameters in order to be able to compare the respective heating energy consumption rates. The comparable specific heating energy consumption is determined by way of the measured heating energy consumption related to the room floor area and to the measured degree day number of the building. In **Fig. 1** the specific heating energy consumption rates of the model houses are opposed to those of the reference buildings. For comparison, the specific heating energy demand of a medium-sized single family house acc. to (2) is presented, meeting the thermal insulation requirements as specified in the current regulations on thermal insulation (WSVO).

As may be seen in Fig. 1, the mean specific heating energy consumption is about the same for both the investigated model houses and the reference buildings. In case of the model houses, a greater range of heating energy consumption was measured which is definitely a consequence of occupants' behaviour. Energy-conscious "living with the house" will further reduce the heating energy consumption, whereas lacking energy-consciousness will result in a distinctly higher consumption (e.g. by cross-heating a solar greenhouse in the cold season with warm air from the living room). As compared to the heating energy consumption of buildings made of elements meeting the requirements as specified in the statutory regulations on energy-saving thermal insulation, almost all of the model houses and all the reference buildings consumed less heating energy within the period of measurements.
This proves the investigated objects' high quality of insulation.
The highest consumption of heating energy was found in a model house with a design mainly featuring energy storage instead of thermal insulation, a house that had been included in the study precisely for this reason. The house with the second highest heating energy consumption had a facade with adventitious openings due to constructional defects and problems in the execution of the work which resulted in substantial ventilation heat losses.

Since, due to the climatic conditions in West Germany, the contribution of solar energy to space heating has to remain only a very limited one, buildings must have an excellent thermal insulation in order to prevent significant heat losses. In order to control ventilation heat losses, ventilation openings for the necessary air change should only be placed in defined, controllable positions (e.g. window joints, ventilation grids) in the building envelope.

Based on an energy price of 0.10 DM/kWh and on average German climate conditions (degree day number = 3500 Kd), heating costs amount to a monthly average of about only 0.75 DM/m² for buildings with the same thermal insulation standard as the model houses. For the most economical buildings, values below 0.50 DM/(m²·month) were determined. In such buildings, heating costs are still affordable, even with significantly rising energy prices.

Summer of 1986

In addition to measuring the rates of consumption, the buildings' performance under summer temperatures has also been a subject of investigation. In Fig. 2, the mean values out of the ten highest air temperatures recorded in south-orientated living-rooms of model houses and reference buildings in the summer of 1986 are presented. Evidently, temperatures in some of the model houses considerably exceeded temperatures in the conventional buildings. In some cases, occupants responded to this situation by mounting additional shading devices. In general, the increased temperatures did not provoke complaints and could mostly be compensated for by cross-ventilating or opening rooms onto the greenhouses.

Prospects

The present pilot project will be terminated by mid 1987. By then, data on two heating periods and one summer period will be available. The accompanying studies on users' behaviour are to find out whether model houses influence their occupants' lifestyles, i.e. whether there is a different way of living in solar houses as compared to conventional buildings. In view of the present results it is to be expected that the rates of heating energy consumption in the considered buildings will be significantly lower than in buildings meeting only the minimum requirements as stipulated in the statutory regulations on energy-saving thermal insulation. It has been confirmed that efficient use of solar energy depends on high-quality thermal insulation. Accordingly, a high standard of thermal insulation allows greater freedom in energy-conscious architectural design, e.g. by integrating large glazings, as well as rational utilization of energy by minimizing the rate of energy consumption.

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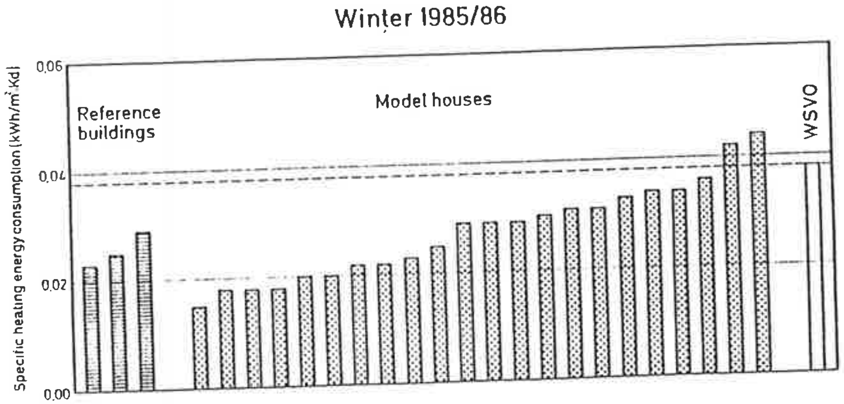

Fig. 1. Specific heating energy consumption rates of the reference buildings and model houses recorded during the heating season of 1985/86 to be compared to the specific heating energy consumption of a conventional medium-sized single family house complying with the thermal insulation requirements as specified in the current regulations on thermal insulation (WSVO) acc. to (2).

Note: specific heating energy consumption = heating energy consumption / room floor area x degree day number

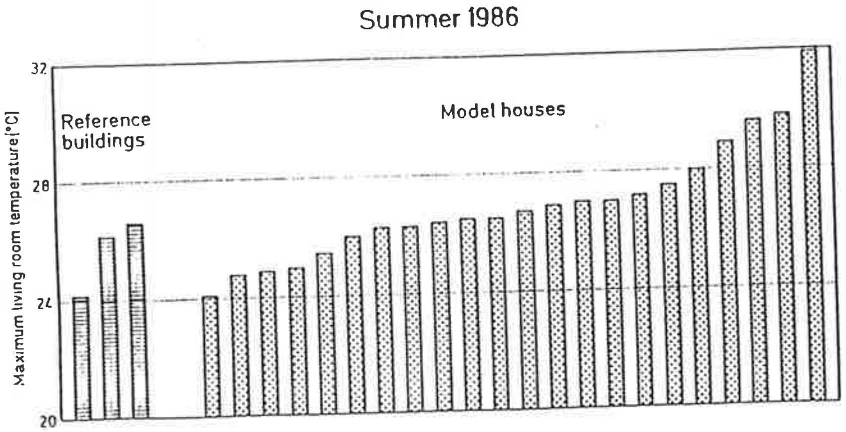

Fig. 2. Maximum mean air temperatures (average of the ten highest values recorded) in south-facing living rooms of reference buildings and model houses in summer of 1986. The values are related to the respective location and have not been normalized.

LARGE-SCALE FIELD MEASUREMENTS OF ELECTRICAL ENERGY CONSUMPTION

S.G. HAUSER, R.S. CROWDER
Pacific Northwest Laboratory
Richland, Washington 99352, USA

Introduction

For those researchers, engineers, and architects who have tried to understand the energy consumption patterns in buildings, the need for empirical data is obvious. In the residential sector, some data exits mostly for experimental type houses, but very little for occupied homes. Even less data exists in the commercial sector. Models have been used with mixed success and with limitations. This paper describes a program designed specifically for large-scale metering of buildings. It represents the largest metering effort of its type in the world. We will first discuss the objectives and goals that were established for the program, followed by a discussion of the data logging technology used. Finally, we will discuss the methods used for data reduction and analysis, and conclude with some "lessons learned" from our experience.

Objectives

In 1983, a program was established at the Pacific Northwest Laboratories (PNL) to collect end-use information on electrical energy consumption for residences and commercial buildings. The program known as the End-use Load and Conservation Assessment Program (ELCAP) is sponsored by the Bonneville Power Administration (BPA) to inform their decision making processes. BPA is a regional federal agency which is responsible for generating and marketing electricity to public and private utilities. The objectives of this program are two fold. First, it provides information which can be used to determine patterns of energy consumption for various types of users. These patterns provide an empirical basis for forecasting future energy demands more accurately. The second objective is to evaluate and assess the effectiveness of particular conservation programs or technologies. By measuring energy consumption at the end-use level, both of these objectives are met.

Goals

ELCAP has several goals to meet the objectives described above. Three of the primary goals are:

- to develop a metering technology
- to develop data management techniques
- to develop analysis software

When the program was initiated, the existing technology for submetering electricity was both too expensive and unreliable to consider a x100 building metering experiment. To be successful, the metering technology had to be inexpensive enough to meter on the order of 1000 sites, to meter multiple end-uses individually, to record hourly as well as lower time resolutions, to have the same accuracy as standard utility meters, and to meter meteorological conditions.

Metering up to 1000 sites on an hourly basis for several years produces very large data volumes. We set as our goal to maintain a greater than 90% data capture and accuracy rate while minimizing manpower needs.

To make the data useful to utility analysts we set as our goal to support a large number of users with wide and easy access to the data at any time. With such a large amount of data this required new and innovative techniques for both managing the data and analyzing it.

Data Collection

The current data collection network consists of over 700 data loggers installed in buildings geographically dispersed in Washington, Oregon, Idaho, and Montana. Three separate versions of the data logger were designed to allow for the diversity of buildings. A 16 channel version(1) is installed in 450 residences measuring space heating, water heating, refrigeration, laundry, lights, and sometimes other uses. For many of the sites the logger also records meteorological conditions, indoor temperature, and wood stove use.

The commercial buildings are much more diverse requiring from 30 to over 200 separate channels recording up to 22 different end-uses. The commercial data logger can accept up to seven 8-channel boards which can be combined for a total of 56 available channels per unit. A line drawing of the commercial data logger is shown in Figure 1. The largest commercial building we have metered is about 90,000 sq m (1,000,000 sq ft) and requires eight separate data loggers.

The third version of the data logger has 15 channels with many improved features like increased memory and the ability to daisy chain the loggers together to minimize data collection costs. These units are currently being used in apartment houses where one unit is installed in each apartment with a central unit used as the main communication device.

The data logger technology is based on the use of a Motorola single-chip microprocessor with additional battery-backed memory for data storage. A standard serial interface allows the unit to connect to a modem for telecommunications and on-site checkout. Special signal conditioning circuits allow direct connection of commercially available meteorological sensors with the data logger. The watt-metering consists of voltage and current sampling transformers whose signals are multiplied in real time to yield a voltage directly proportional to the power being consumed. The data logger stores a average value of watts for the integration period, usually one hour.

A central computer located at PNL is set up to automatically contact each of the data loggers when their memory is about 50% full. Standard voice grade phone lines transmit the control signals to each data logger which identify it, check the clock, and set the integration period. Once the data is collected from the data logger, it is converted into engineering units and stored in the central on-line archive.

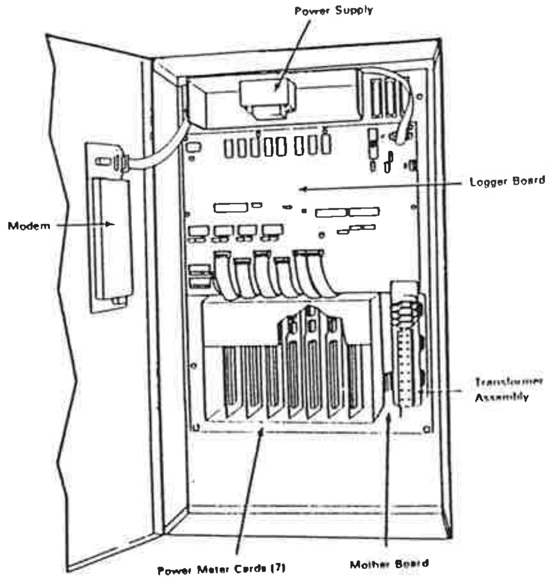

Figure 1. Layout of Digital Field Data Acquisition System

To assist in the analysis of the engineering data each site is usually inspected and pertinent values recorded. For example, we obtain information on floor area, insulation levels, window type and area, roof type, space heating type, etc. Dozens of other values are obtained and stored in the central computer. Occupants are also surveyed to determine demographic values such as income, education, and attitudes toward energy conservation (2,3).

Data Reduction

As each site is installed, careful documentation is made of each channel measured, its rated size, and the type of load it represents. This documentation is digitized and stored in the central computer for use in converting the digitized data into engineering units. The instrument installation and data conversions are so complex that mistakes are common. To combat these problems, the total power to the building is metered, in addition to all power being consumed by individual end-uses(4). Comparisions of these redundant measurements provide a powerful tool for verifiying the correctness of the data before it is released to analysts. Artifical intelligence techniques have been applied to the time consuming task of verifying the data and have resulted in a savings of 40% over the original manual method of inspecting the data(5).

The challenge does not end after the quality of the data is assured. Simply managing a data base of this size, currently 150 million data points and growing by 3.2 million data points per week, is a monumental task. No single commercial package provided all the features required to solve our problem. Our data management system is a combination of custom software and a commercial relational data base package. To save disk space, the engineering data is stored using a special compressed format which uses 1/6 to disk space required by standard ASCII format. The characteristics and demographic data are stored in a relational data base which allows greater flexibility when selecting relevant portions of the data.

Data Analysis

Although the purpose of this paper is not to present, in any exhaustive sense, the many types of analysis that is being done with the collected data, it is important to show what typical results of this type of data collection program can be(6,7). The analyses can be split into two general types. The first is the routine analysis which is meant to provide general insights into the energy consumption of a building or group of buildings. Figures 2 through 4 give examples of this type of analysis for a single commercial building for the month of June 1986. The data represents a 600 sq m (6,500 sq ft) office building in a mild climate. Figure 2 shows the percentage of energy consumption for each of the seven separate end-uses. The mixed HVAC accounts for both the primary cooling and the fans. The heating end-use accounts for the primary resistance heat only. The specialty end-use accounts for a main frame computer in this building. Cooling for the computer room is included in the mixed HVAC.

Figure 3 shows the energy consumption for each day of the month. One can find the weekend/non-working days by looking at the changes in interior lighting consumption.

Figure 4 shows the average daily profile for this building by averaging all 30 records/days for each hour of the day. One can see the morning heating peak followed by a large afternoon cooling peak. The lighting profile follows working hours closely and the computer profile is flat as one would expect.

These types of plots can also be shown for residential buildings, however, of more interest in the residential sector are the combined profiles of a large number of buildings. Table 1, as an example, shows the mean share of energy consumption for an entire year for 112 residences. Other refers to lights, refrigeration, cooking, etc.

The second type of analysis is more exploratory in nature. Certain techniques are used to address a particular problem or issue(8,9). For example, if one is interested in determining the dependence of energy consumption of a particular residence on outdoor temperature, one can do a scatter plot of all the hourly values vs. delta T between the indoor and outdoor air dry bulb temperature. Figure 5 shows an example of this type of plot for a particular site. Other techniques we have been using involve principal component analysis, robust regressions, and pattern matching.

Site 286 6/1/86 to 6/30/86

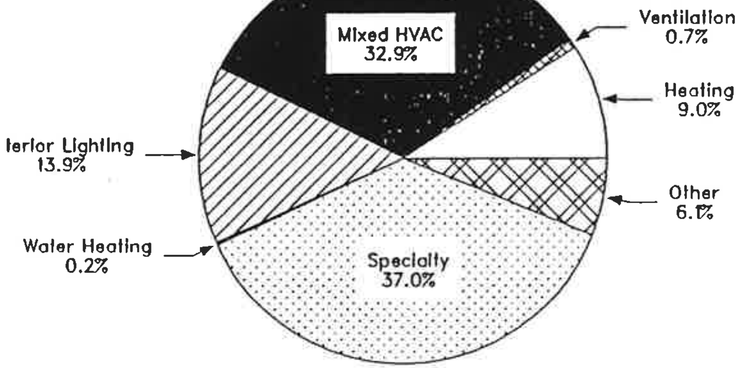

Figure 2. Share of Total Electricity Consumption 8,636 KWH by End-use

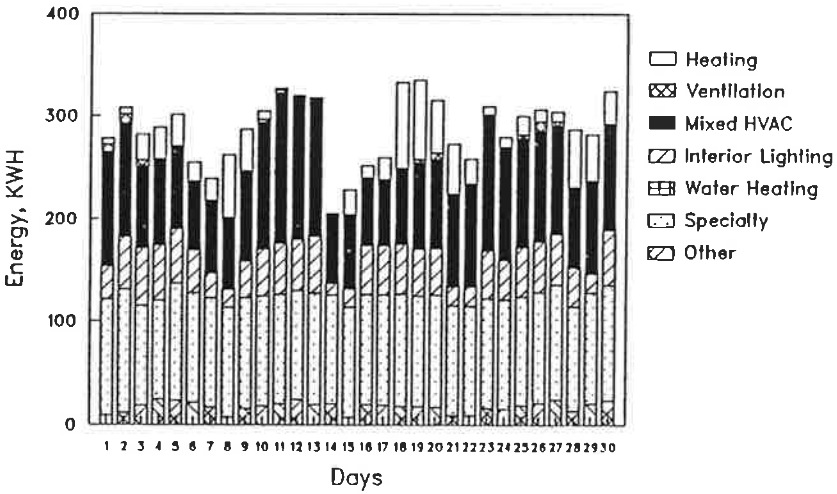

Figure 3. Total Electricity Consumption by End-use

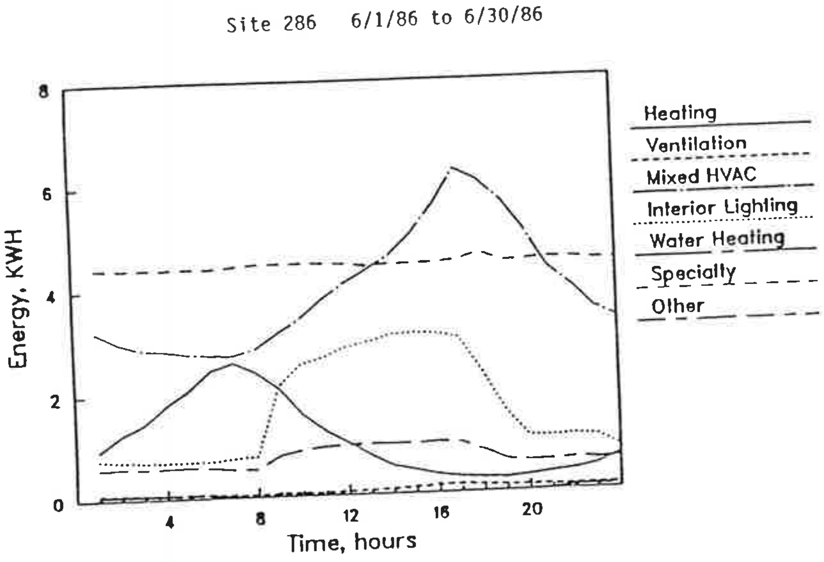

Figure 4. Average Daily Electricity End-use Profile

	HVAC n =112	Hot Water n =107	Other n =112
Mean Load KWH	8,363	4,754	7,781
Mean Share (%)	37.2	24.4	39.4
Variance of Share	18.8	10.8	15.2
Median Share (%)	37	24.5	37

Table 1. Residential Data for 112 Buildings

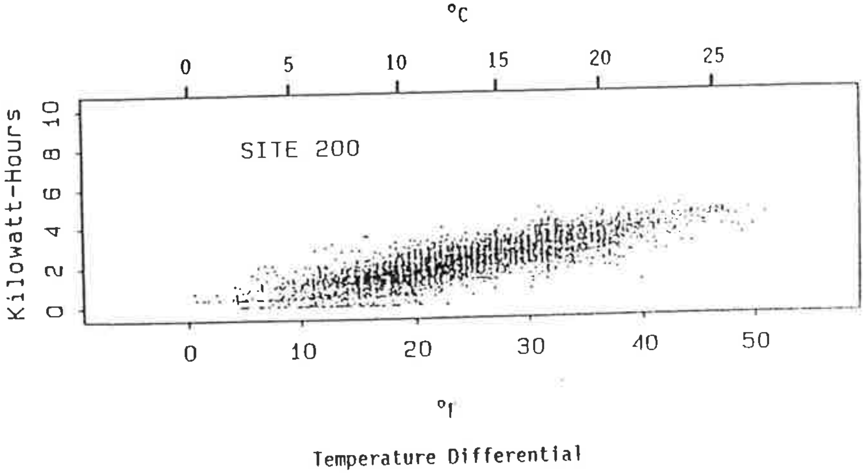

Figure 5. Scatterplots of Hourly Energy Consumption Versus Temperature

Lessons Learned

As a result of the three plus years since this program was started, and the hundreds of megabytes of data that is a testimony to it's success, we will briefly discuss some of the lessons we have learned along the way.

First, and likely the most important, is to plan very carefully before you begin. Although this sounds simple it has tremendous payoff in both time and money. The objectives and goals you have for the data collection effort should be driven by the type of analyses you plan to perform. The more specific your analyses goals are the more likely you can control both the schedule and the costs of the data collection effort.

Second is to develop standard procedures for all parts of the project. The larger the project, the more important this becomes. You must still have the flexibility to deal with anomalies since each building is different, but as the exception and not the rule.

Third is to not underestimate the data management requirements. The lack of appropriate computer hardware and software will more likely limit the success of the project than the data logging equipment or anything else associated with the installation.

Fourth is to focus on the reliability of the equipment and the quality of the data collected. One of our colleagues has said that it is easier to recover from a bad analysis than it is from bad data. Automated procedures for data quality checking are a must.

Last is to make sure that the data can be easily accessed by the analysts who will most use it. This may be the hardest one to achieve because of the diversity of issues that data of this nature can address. Many different analysts will become involved, each with their own preferred software and interface requirements.

Acknowledgement

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EMPIRICAL CHARACTERIZATION OF RESIDENTIAL ENERGY USE

G. M. Stokes and E. W. Pearson
Pacific Northwest Laboratory
Richland, Washington 99352, USA

Statement of the Problem

Until recently, the major data sets available for studying residential energy consumption at the household level were utility billing data. Although these data cover very large samples, the time resolution is on the order of a month, and no end-use disaggregation is available. Over the past few years, however, a number of studies involving collection of higher-time resolution data with extensive end-use disaggregation have been carried out. The availability of such data makes possible much more detailed understanding of residential energy consumption. However, analytical techniques designed for application to minimally disaggregated data sets collected for very large samples are not likely to be well suited to the end-use data.

In this paper we describe a general approach to analysis of high-time resolution end-use data, and illustrate that approach with examples drawn from a thermal performance characterization project. This approach has three features that distinguish it from traditional work in the building energy field:

- It is model-free. Basic empirical characterizations of the data are highly flexible and are not based on fitting parameters to simple models.
- It is sequential, with initial simple characterizations derived from highly aggregated data, and subsequent refinements based on detailed analyses of disaggregated data.
- It emphasizes the use of classification techniques as opposed to aggregation techniques in interpreting the data.

This paper exhibits this general approach by summarizing a series of investigations into residential thermal performance during which a number of specific analysis techniques, as well as the approach itself, were developed.

The Basis of the Analysis

Thermal Performance Analysis

In undertaking our investigation of residential thermal performance, we had several goals. Using an end-use disaggregated data set collected at hourly resolution (described in more detail below), we wished to:

- characterize the individual thermal performance of several hundred disparate residences
- compare the thermal performance of groups of these residences distinguished on the basis of construction techniques and, in particular, on the basis of installed conservation measures
- determine the impact on space heating requirements of several factors that affect thermal performance, including local climate, the use of wood heating equipment, temperature control strategy, residential thermal integrity, internal loads, and patterns in occupant behavior.

Even partial completion of this set of tasks would be valuable for both forecasting and conservation planning.

The Data Set

The data used in this analysis comes from the End-use Load and Conservation Assessment Program (ELCAP) sponsored by the Bonneville Power Administration (BPA) and managed by the U.S. Department of Energy's Pacific Northwest Laboratory (operated by Battelle Memorial Institute). ELCAP is a collection of metering projects that have common data collection and data acquisition protocols. The individual projects within ELCAP are designed to resolve a series of issues in both energy conservation resource assessment and program evaluation for the residential, commercial, and multifamily sectors. Descriptions of various aspects of the program may be found in a variety of references (1-4). The sample of buildings was intended to provide representative cases from all of the major demographic and structural groups in BPA's service area.

The residential sample consists of approximately 440 structures. The sample has two major segments: a sample drawn from the 1983 Pacific Northwest Residential Energy Survey (PNWRES) (5-8) and a large sample (>100) of homes built as part of BPA's Residential Standards Demonstration Project (9). The PNWRES-based portion of the sample is predominantly owner-occupied, detached, site-built homes with permanently installed electrical space heating equipment. The data were collected using a data acquisition system (10) developed by Pacific Northwest Laboratory which was specially adapted to ELCAP for BPA. The measurements consist of up to 16 true power measurements made at the electrical distribution panel in each residence and one to three indoor air temperature measurements. This permitted disaggregation of most major end-uses, including refrigeration, space heating, water heating, etc. For those residences with wood-burning equipment, a sensor was installed to monitor usage of that equipment. At approximately 10 percent of the residences small meteorological stations were also installed, permitting the measurement of outside air temperature, wind speed and direction, indoor relative humidity, and total horizontal insolation. While the data collection interval is adjustable, the bulk of the data is being collected at hourly resolution.

The Thermal Performance Analysis

In line with the general approach described above, the thermal performance analysis has proceeded in several steps, as follows:

- development of a model-free characterization of thermal performance for each residence, designed to be as closely related as possible to the thermal integrity of the structure
- aggregation of this characterization across groups of structures to permit performance comparisons between groups of residences
- refinement of the characterizations of individual structures based on day-type classifications derived from the hourly data
- application of these results to important forecasting or conservation planning issues such as the impact of wood heat use or control strategy (e.g. setback behavior) on residential energy consumption.

Each of these steps is discussed below.

Model Free Characterization of Thermal Performance

Our most useful characterization of individual residences is an estimated annual space heating energy consumption under certain standard conditions. This estimate is derived from a scatterplot of daily space heating load against daily average inside-outside temperature difference. After eliminating from the scatterplot points representing days on which wood heat was used, or on which the occupants were not present, a robust, nonparametric curve is fit to the scatterplot using the "lowess" procedure (11-13) (see Figure 1). This curve provides a relationship between spaceheating loads and inside-outside temperature difference. Given an assumed inside temperature (single value or time series of daily average values), convolution of this curve with a standard set of climate data provides an estimated annual energy consumption. The estimate so derived is partially standardized, in that differences in external temperature, mean interior temperature, vacancy patterns, and frequency of use of auxiliary heating sources have been removed. Internal heat gains, solar effects, and many details of control strategy and occupant behavior do affect these estimates. However, they do appear to represent a much more readily comparable characterization of structures than is obtainable by the usual practice of fitting a linear model to total load data. Details of this procedure, along with a discussion of its strengths and limitations, are available elsewhere (11).

Figure 2 shows the use of this measure for comparison of two groups of residences constructed under a demonstration program for a strong construction conservation standard under consideration for implementation in the Pacific Northwest region of the United States and a third group of existing residences. This and related results have been used both to test the predictions of the engineering models used to design the standards, and to serve as the basis for investigation of the role that various

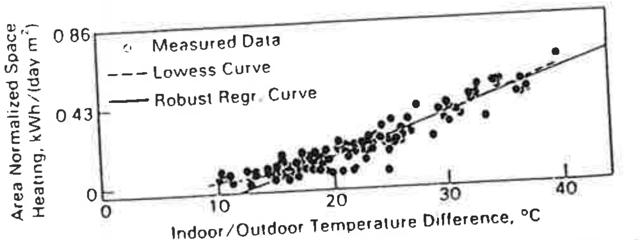


Fig. 1. A typical data set for the analysis of thermal performance of residence. The data is from the 1985/86 heating season.

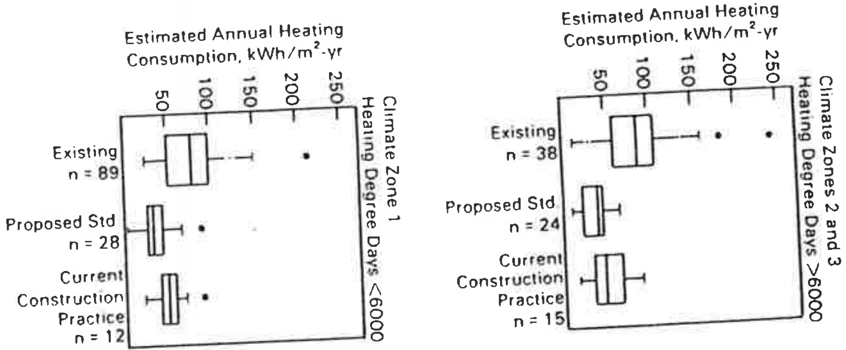


Fig. 2. Annualized heating consumption for existing homes, homes constructed to a possible energy conservation standard, and homes constructed to a standard characteristic of current construction practices in the Pacific Northwest

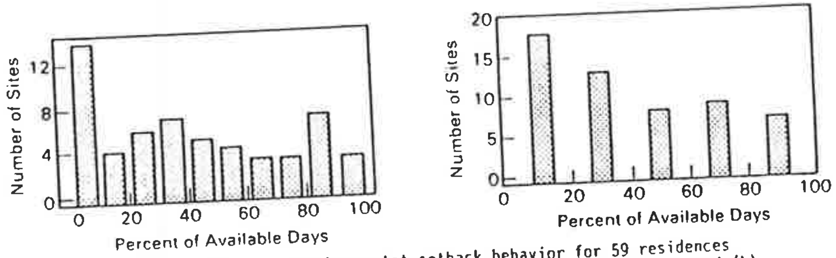


Fig. 3. The frequency of thermostat setback behavior for 59 residences inferred from interior temperature data for (a) weekdays, and (b) weekends

factors taken in determining actual energy consumption. It should be noted, incidentally, that for a substantial fraction of the sites studied, standard linear models provide neither an accurate characterization of the data nor a useful predictive tool. This is particularly true for very well insulated homes or homes with large thermal capacitance.

Characterizing Occupant Behavior

As indicated above, an analysis of the daily data yields a description of a residence that can be used to infer an annualized heating energy consumption for each residence. The interesting point about this approach is that the inferred energy consumption reflects the performance of the residence as it is operated by the occupants. To gain further insight into the role of occupancy patterns in determining thermal performance, we have focussed on the analysis of the hourly data record. The current discussion will emphasize the effects of thermostat setback behavior and wood stove use, but the concepts are generalizable to other aspects of occupant behavior, such as internal gains or vacancy.

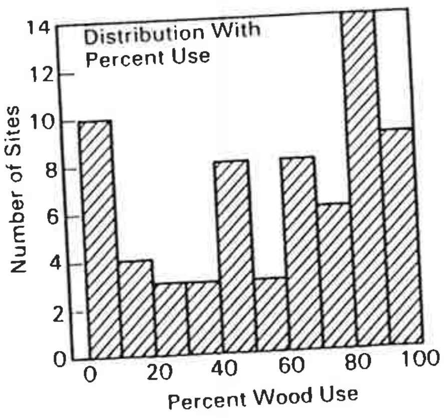
The approach is to use the hourly data to classify individual days based on inferred occupant behavior. The effect of these different occupant behaviors on space-heating energy consumption can then be described. In performing this analysis, one modification of the above approach is required. As previously noted, the use of the cross-envelope temperature differential as the predictor of energy consumption incorporates important elements of the occupant behavior in the resulting inferences. For the current analysis we will be examining the effect of occupant behavior on the relationship between space-heating energy consumption and outside air temperature. While a somewhat less precise predictor of space-heating energy consumption, the exterior temperature is a measure that is independent of occupant behavior.

There are two results which follow from the above analytic approach. The classification of days gives an indication of the frequency of particular occupant behaviors, while the intercomparison of days allows one to estimate the magnitude of the effects of the behavior on energy consumption.

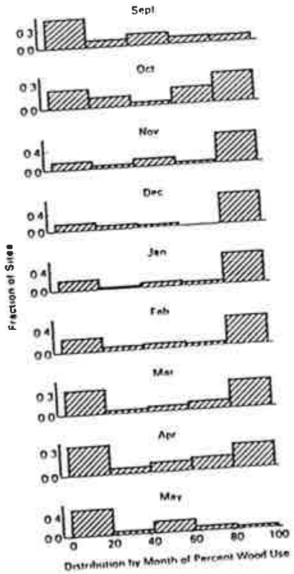
The classification of days according to thermostat set-back behavior was based on an analysis of the interior temperature data using a tree-matching approach (14). The results are shown in Figure 3.

The analysis of the use of wood stoves by the residences was based on an examination of the hourly record from the wood stove sensor (15). The results of this analysis is shown in Figure 4.

Thus, use of the fully disaggregated data set permits refinement of the standardized estimates of annual space heating energy consumption, estimation of the impact that various occupant behaviors have on that annual consumption, and understanding of the variability in day-to-day energy consumption. Thus important questions such as estimation of potential changes in energy requirements associated with fuel switching, or the effect on both total load and hourly load profiles of setbacks or other control strategies can be investigated.



a.



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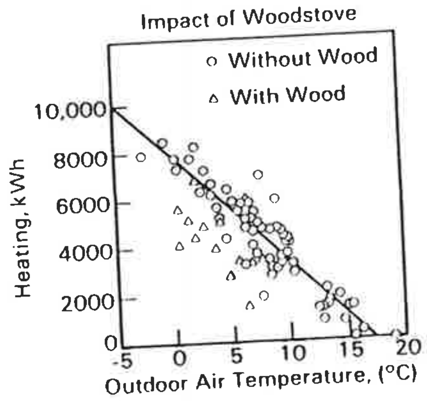

c.

Fig. 4a. The frequency of use of wood stoves for 68 residences with installed wood-burning equipment during the 1985/86 heating season

4b. The evolution of the frequency of wood stove use through the 1985/86 heating season as seen in the same residences described Fig. 3

4c. The effect of wood stove heat on the consumption of electricity for a single residence. The (o) denote days with no wood stove use, while the (Δ) show days with wood stove use. For this residence, during the period illustrated, wood stove use reduced the expected space heating energy required by an average of 27%.

Discussion of the Results

The investigations from which the results presented here have been excerpted illustrate the power of a systematic approach in which aggregated data are used to derive model-free characterizations, useful for summaries and for comparisons across groups of residences. More detailed analyses, based on the fully resolved data, can then be employed to elucidate important details regarding the role of various factors in determining energy consumption.

Further, use of patterns in the hourly data to classify days appears to be a simple and powerful method of distinguishing these various factors.

Currently, the concept of a day type is primarily applied to situations in which one wishes to distinguish between week days and weekends. In a sense this simple classification scheme is just a surrogate for analysts feeling that week days and weekend days are behaviorally different. By using hourly and higher time resolution data the concept of day types can be extended in many interesting ways. For example the identification of "wood stove use" days, "thermostat setback" days, "nobody home" days, "laundry" days, and others offers unique insight into both the frequency of and overall effect of those specific behaviors that modify residential energy consumption.

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