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The National Fuel Gas End-Use Efficiency Field Test: Experimental Plan

M. P. Ternes
P. S. Hu

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FOR THE UNITED STATES
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THE NATIONAL FUEL GAS END-USE EFFICIENCY FIELD TEST: EXPERIMENTAL PLAN

M. P. Ternes
P. S. Hu

Existing Buildings Research Program

September 1988

Prepared for the
Office of Buildings and Community Systems
U.S. DEPARTMENT OF ENERGY

Prepared by the
OAK RIDGE NATIONAL LABORATORY
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ABSTRACT

The National Fuel Gas End-Use Efficiency Field Test will be performed to (1) determine the performance and cost-effectiveness of a new audit-directed retrofit procedure, and (2) develop and validate analysis techniques for evaluating conservation programs that can use the daily house gas use data that can be economically collected by gas telemetering equipment. The audit procedure is designed to improve conservation programs by including mechanical system retrofits as retrofit options in addition to building envelope retrofits, determining the most cost-effective retrofits for each house through individual analysis, and following a rational decision process to determine the investment level of each house. This report is an experimental plan presenting a detailed description of the audit procedure, specific research goals and questions to be addressed by the field test, the responsibilities of the six field test participants, 16 tasks required to complete the field test, a detailed description of the experimental design, house selection and assignment procedures, a detailed description of the data to be collected and the instrumentation to collect it, a data management procedure to store the data and check it for errors, and analysis procedures to be employed to study the collected data.

Pre- and post-retrofit data will be collected over a two-year period (January 1988 to April 1989). Fifty low-income homes in Buffalo, New York, will receive conservation measures as selected by the audit procedure; 50 additional houses will serve as a control group. The following data will be collected weekly in all the houses: house gas use, house electricity use, heating system gas use, and hot water system gas use. Also to be collected are hourly indoor temperature data in all the houses, daily house gas use in approximately 90 of the houses, hourly outdoor temperature data at three sites near the houses, and survey type information. Analysis procedures using a house model and linear regression techniques will be employed to determine the annual energy savings in the individual houses normalized for outdoor temperature, indoor temperature, internal load, and occupant behavior changes. An analysis of variance approach will be employed to calculate group savings and to identify the effect of selected variables on the savings. The cost-effectiveness of the audit procedure will be determined using appropriate economic analysis methods and the normalized energy savings.

EXECUTIVE SUMMARY

The objectives of the National Fuel Gas End-Use Efficiency Field Test are to (1) determine the performance and cost-effectiveness of an audit-directed retrofit procedure designed to improve weatherization programs, and (2) develop and validate analysis techniques for evaluating conservation programs that can use the more frequent billing data collected by gas telemetering equipment. The following organizations are participating in the test: National Fuel Gas Distribution Corporation; U.S. Department of Energy, Office of Buildings and Community Systems; Oak Ridge National Laboratory; Alliance to Save Energy; New York State Department of Public Service; and Wisconsin Energy Conservation Corporation. The purpose of this experimental plan is to present the detailed objectives and method of the project.

New approaches to selecting conservation measures in low-income programs are needed to overcome program limitations and to improve cost-effectiveness. The audit-directed retrofit procedure to be tested was designed to enhance conservation programs by including mechanical system retrofits as conservation measure options in addition to building envelope retrofits, analyzing houses individually to determine the most cost-effective retrofits for that particular house, and following a rational decision process to determine investment levels for each house. A detailed description of the audit procedure is provided in the plan.

Periodic evaluations of conservation programs are needed to monitor program effectiveness and to identify areas for improvement. Evaluations using monthly billing data are often performed because the billing data are routinely collected by utilities and can be readily analyzed. However, the analysis is constrained by the limited nature of the data. Recent advances in meter technology offer the potential for recording daily gas use as inexpensively as monthly billing data are now collected. However, to fully realize the benefits offered by this new equipment for evaluation purposes, analysis techniques must be developed and validated.

The field test will be conducted over a two-year period. Pre-retrofit data will be collected on all the homes during one winter season (January to April 1988). Conservation measures will be installed in the treatment group of houses during the summer of 1988. Post-retrofit data will be collected on all the homes during the following winter season (October 1988 to April 1989). Three technical reports outlining the results of the project will be published: an interim report, a final report on the performance of the audit procedure, and a final report on the analysis techniques developed for use with the telemetered data. The responsibilities of the individual field test participants and 16 tasks required to complete the test are presented in the plan.

One hundred low-income houses in Buffalo, New York, will be studied: 50 houses will receive a mix of conservation measures as selected by the audit procedure (installed cost of the measures will not exceed $55,000 for the 50 houses), and the remaining 50 houses will serve as a control group. The houses selected for inclusion in the field test must meet 15 selection criteria to ensure that the experimental objectives are met, to make the experiment easier to perform, and to improve the accuracy of the results. A stratified random assignment procedure will be used to help achieve pre-retrofit equality between the treated and control groups of houses.

The following data will be collected weekly in all the houses: house gas use, house electricity use, heating system gas use, and hot water system gas use. The house gas use will be monitored using a recently calibrated meter. The house electricity use will be monitored using the existing electric billing meter. The heating system and hot water system gas uses will be monitored using run-time meters once the gas consumption rates of the equipment are measured. Hourly indoor temperature data will be collected in all the houses using a battery operated temperature sensing and recording device.

Telemetering equipment will be installed in approximately 90 of the houses to record daily house gas use. Hourly outdoor temperature data will be collected at three sites near the houses using thermocouple and data logging equipment. The following survey information will also be collected or measured during the field test: house and occupant descriptive information, information on changes that occurred in the descriptive information during the test, house infiltration rates, heating system operating efficiencies, and retrofit installation quality verification and retrofit listing.

Data management procedures will be developed to store the data and to check it for errors. Data will first be entered into microcomputer-based storage. Energy consumptions will then be automatically calculated. Weekly energy consumptions and hourly temperature data will be merged to form compiled data sets that will be used in the analysis. The following validation procedures will be implemented throughout this process: automatic range checks, automatic logic checks, and visual examinations of plotted data.

The survey information will be used to characterize the houses and occupants studied and to answer questions regarding the implementation of the audit procedure. Occupant characteristics of interest are the number of household members and their ages. Important characteristics of the houses are their construction details and pre-retrofit thermal condition. Information pertinent to the implementation of the audit includes the measures recommended by the audit for installation, the measures actually installed, the estimated and actual cost to install each measure, and the energy savings and benefit-to-cost ratio predicted for each recommended measure.

The performance of the audit procedure will be evaluated on an individual basis and group basis. The annual energy savings measured in the audit houses will be compared to predicted values. The cost effectiveness of the retrofits installed in the audit houses (which depends on annual energy savings, installation costs, retrofit lifetime, and other economic parameters) will also be examined. The annual energy savings for an individual house will be defined to be its observed annual energy savings normalized for outdoor temperature, indoor temperature, internal load, and occupant behavior changes. The pre- and post-retrofit data must be used with a house model to determine this savings for several reasons: (1) the time periods over which the data are collected may not be equal nor cover the entire winter season, (2) the weather conditions for the two periods may be different, and (3) indoor temperatures and internal loads maintained in each house over the two periods may not be the same. Linear regression techniques will be used to estimate the parameters for a simple model correlating heating system gas consumption to indoor-outdoor temperature difference and internal load. Pre- and post-retrofit normalized, annual heating energy consumptions will then be estimated using the model parameters, average outdoor temperature data based on historical records, and assumed values for the indoor temperature and internal load. The change in energy consumption is the difference between these annual consumptions. The change in energy use of the audit houses will be further normalized by the change occurring in the control houses to account for occupant changes induced by factors other than the retrofit installation. The individual house savings will be analyzed using an analysis of variance approach to calculate group savings and to identify the effect of selected variables on the savings.

THE NATIONAL FUEL GAS END-USE EFFICIENCY FIELD TEST: EXPERIMENTAL PLAN

1. INTRODUCTION

1.1 Background

Utilities, state weatherization offices, and regulators face two common questions in designing and evaluating residential energy programs:

1. How can cost-effective efficiency measures be best selected to reduce energy costs in households participating in the program?

2. How can the costs for program evaluations be reduced without compromising technical detail?

Most low-income conservation programs are not as cost-effective as possible because the same amount of money is spent in each home to install a standard list of conservation measures. This procedure wastes program funds by over-investing in some homes while under-investing in others. In addition, mechanical system improvements that improve efficiency (such as new furnaces and vent dampers) are seldom included in the standard list of measures, even though significant energy savings can result.

New approaches to selecting conservation measures in low-income programs are needed to improve the effectiveness of the programs by overcoming the limitations described above. These new approaches should incorporate the following principles: (1) building-envelope and mechanical-system retrofits should be given equal consideration, (2) houses should be analyzed individually to determine the most cost-effective retrofits for that particular house, and (3) a rational decision process for selecting the investment level for each house should be followed.

The Oak Ridge National Laboratory (ORNL) has developed an audit-directed retrofit procedure[1,2] based on the three principles outlined above. Home weatherization installers analyze houses individually to determine which building-envelope and gas furnace-system retrofits are most cost-effective rather than adhering to a fixed priority list approach. The analyses performed on each house includes diagnostic testing and determining the benefit-to-cost (B/C) ratio for each possible retrofit. The B/C ratios are used to select retrofits and to determine the investment level for each house in a group of houses. Because houses receive different retrofits and various amounts of money are spent on each house, the procedure can significantly enhance program energy savings per investment dollar.

The audit-directed procedure was tested in the Low-Income Weatherization Assistance Program conducted by Wisconsin in 1985.[3,4] Results showed that the procedure, which used an expanded list of building-envelope and heating-system retrofits, doubled the cost-effectiveness of the program as compared with the priority system formerly used in 1982. Additional testing is required to verify the savings and program improvements achieved from audit-directed conservation programs based on the previously identified principles, especially in a different climate and a different housing stock from that found in Wisconsin.

Periodic evaluations of conservation programs are needed to monitor program effectiveness and to identify areas for improvement. Currently, evaluations using monthly billing data can be performed less expensively than evaluations using more detailed data (either more frequently collected data and/or additional data parameters) because billing data are routinely collected by utilities. However, the level of analysis that can be performed with monthly billing data and, hence, the information that can be obtained from such evaluations is limited.

Monthly billing data averages out driving forces such as indoor-outdoor temperature difference and internal load over such a long period of time that it can be difficult to determine their effect on heating or cooling system performance. Current analysis techniques for determining heating energy savings require billing data to be collected over a full heating season or, more typically, at least a year before and after retrofit installation. This occurs because only a few monthly data points can be collected over a heating season, and baseload energy use must be separated from heating energy use. Additionally, analysis results based on billing data have been insufficient to assess the overall effectiveness of most conservation measures or to explain why deviations between monitored and predicted retrofit energy savings occur.

Recent advances in meter technology offer the potential for more frequent, lower-cost data collection. New telemetering equipment[5] records gas use on a daily basis and can transfer the recorded data over phone lines automatically once a month. Thus, utilities can collect daily house gas consumption data as readily and as inexpensively as monthly billing data are now collected. However, to fully realize the benefits offered by this new equipment for evaluation purposes, analysis techniques that utilize the more frequently collected data to obtain improved results must be developed and validated.

1.2 PURPOSE

The National Fuel Gas End-Use Efficiency Field Test will be performed in Buffalo, New York to address the two problems identified in Sect. 1.1. Specific objectives of the project will be to (1) determine the performance and cost-effectiveness of an audit-directed retrofit procedure similar to that developed by ORNL, and (2) develop analysis techniques for evaluating conservation programs that can use the more frequent data collected by gas telemetering equipment and validate the techniques by comparing results to those obtained from analysis of submetered data.

The purpose of this experimental plan is to present the detailed objectives and method of the project. Experimental results will be presented in future reports as the project is performed.

1.3 REPORT ORGANIZATION

Section 2 summarizes the goals and responsibilities of the project participants and the tasks and schedule of the field test. An overview of the audit-directed retrofit procedure and how it will be implemented in the field test are discussed in Sect. 3. Section 4 reviews the experimental design for the project and discusses the sampling plan and assignment procedure to be followed to implement the design. Section 5 identifies the data to be collected and the means of collecting the data. This is followed by a discussion of the data management system, designed to store the collected data and check it for errors, in Sect. 6. Section 7 presents the analysis approach that will be used to determine the performance of the audit.

2. PROJECT OVERVIEW

2.1 APPROACH

The field test will be performed by the National Fuel Gas (NFG) Distribution Corporation, ORNL, Alliance to Save Energy (ASE), Wisconsin Energy Conservation Corporation (WECC), and the New York State Department of Public Service (NYSDPS). Financial support for the project will be provided by NFG and the U.S. Department of Energy (DOE), Office of Buildings and Community Systems (DOE-OBCS).

One hundred low-income homes in Buffalo, New York, will be studied: 50 homes will be assigned to a treatment group and the remaining 50 homes will be assigned to a non-treatment or control group. The homes in the treatment group will receive a mix of conservation measures as selected by the improved audit procedure, with the installed cost of the measures not to exceed $55,000 for the 50 houses. The houses in the control group will not receive conservation measures. Data collected from the control homes will be analyzed to determine the variation in heating energy consumption due to other factors.

The following data will be collected from all the houses: house gas use, house electricity use, heating system gas use, hot water system gas use, and house indoor temperature. These data will be collected manually once a week with the exception of the indoor temperature data. The instrumentation monitoring the indoor temperature will automatically record the hourly indoor temperature; these data will be manually retrieved once a month. In approximately 90 of the houses, telemetering equipment will be installed to record house gas use on a daily basis. In addition, the hourly outdoor temperature will be automatically collected at three sites and manually retrieved once a month.

The field test will be conducted over a two-year period. Pre-retrofit data will be collected on all homes during one winter season (January to April 1988). Conservation measures will be installed in the treatment group of houses during the summer of 1988 (June and July). Post-retrofit data will be collected on all homes during the following winter season (October 1988 to April 1989).

Three technical reports outlining the results of the project will be published. The first report (an interim report) will identify the conservation measures selected by the audit procedure with their predicted energy savings and present the pre-retrofit heating energy consumptions of the houses. Following the post-retrofit heating season, a second report will present results on the actual energy savings achieved by the audit procedure. A third report will present the analysis techniques developed to use the telemetering data in building retrofit projects and the results of their validation. Technical papers will also be prepared and presented at appropriate conferences. Finally, a separate memorandum will be presented to NFG and NYSDPS summarizing field test results and providing recommendations for future consideration.

2.2 RESEARCH GOALS AND QUESTIONS

The field test's objectives (identified in Sect. 1.2) and general design (identified in Sect. 2.1) were formulated to meet the specific research goals of the participating organizations. All participants are interested in improving residential conservation programs and identifying the energy conservation measures that really work. DOE, ORNL, and ASE are specifically interested in determining whether an audit-directed retrofit procedure, based on the principles identified in Sect. 1.1, can increase the performance and cost-effectiveness of state and utility weatherization programs through the use of better technology and improved concepts. These organizations are also interested in increasing the information that can be obtained from evaluations and lowering their costs. NFG and NYSDPS are specifically interested in investigating methods for conducting utility sponsored low-income weatherization programs and determining the potential impact of these methods on the rate payers. NFG is also interested in better understanding the performance of retrofits in their geographic area to better serve the conservation needs of their customers and the rate payers. Additionally, the field test will put NFG in compliance with New York State Public Service Commission's Opinion #86-9, Case 29088, requiring NFG to develop a Demonstration Energy Conservation Program.

In order to meet the goals and objectives required of the field test, an analysis of the data collected should lead to conclusions regarding the following issues:

Study Background

1. What were the general characteristics of the houses and occupants studied? How did the treatment and control groups compare with regard to these characteristics?

2. What improvements were identified during the field test that might increase the effectiveness of the audit procedure or the field test itself?

Audit Procedure Implementation

1. What measures were installed under the audit procedure and how were they distributed among the houses? Were any measures considered by the audit not installed?

2. What were the costs of installing the retrofits in the individual houses? How were the costs distributed among the houses, the individual retrofit options, and the major retrofit categories (infiltration control, other building-envelope retrofits, heating-system retrofits, and hot water retrofits)?

3. How did the above measures and costs (and their distributions) compare to those that have historically been installed in low-income programs?

4. How accurately did the audit procedure recommend measures that could be installed and predict the actual costs required to install the measures?

5. What were the energy savings predicted by the audit procedure for the installed measures?

6. What were the B/C ratios predicted by the audit procedure for the installed measures?

7. Are there any significant relationships between the predicted savings, the annual energy cost, and the installation cost of the measures?

Audit Procedure Performance

1. What were the annual energy savings of the individual houses and the audit group taken as a whole for two cases: (a) normalized to the actual indoor temperatures and base loads of the houses, and (b) normalized to indoor conditions as assumed in making the energy saving predictions (65°F pre-retrofit balance point and no change in the indoor temperature between the pre- and post-retrofit periods)?

2. How accurately were the individual house and group energy savings predicted by the audit procedure?

3. What was the cost-effectiveness of the audit-directed retrofit procedure on a per house and group basis?

4. Are there any significant relationships between the measured savings, the retrofit installation costs, and the pre-retrofit annual energy cost?

Telemetered Data Analysis

1. What are the analysis techniques that can utilize telemetered data?

2. How do annual, normalized energy savings calculated using telemetered data compare to savings calculated using weekly submetered data and monthly billing data?

3. Is additional information gained or lost from using telemetered data?

2.3 PROJECT RESPONSIBILITIES

The following are the field test responsibilities of the six field test participants:

1. NFG is a major gas utility in New York. NFG will fund and implement the on-site portion of the project. This includes selecting and auditing the houses, providing and installing meters, collecting data, and contracting to install conservation measures. NFG will fund WECC to perform its responsibilities described below.

2. DOE is the federal department responsible for promoting energy efficiency research. DOE-OBCS will fund ORNL and ASE to perform their responsibilities described below.

3. ASE is a non-profit coalition of business, government, and consumer leaders dedicated to increasing the efficiency of energy use. ASE will develop the concept plan, provide comment on project documents, disseminate information on the project, and prepare the memorandum for NFG and NYSDPS.

4. ORNL is the lead federal research organization on single-family retrofit technologies. ORNL will develop the experimental plan, supply indoor temperature and weather instrumentation, assist in installing the provided instrumentation, develop and maintain a data base of all collected data that also checks the data for errors as they are collected, analyze the data, and prepare the three technical reports.

5. NYSDPS is the state department responsible for regulating state utilities. NYSDPS will manage the field test at the state level and ensure that information about the field test is made available to other New York state offices.

6. WECC is a non-profit organization that has performed research and evaluations on weatherization programs and retrofit strategies. WECC will prepare a customized version of the audit-directed retrofit procedure (based on the design concepts outlined in Refs. 1 and 2), provide technical training, and provide technical assistance.

2.4 PROJECT TASKS AND SCHEDULE

The project has been organized into the following 16 general tasks (see Fig. 2.1):

```
------------------------------------------------------------------------------------------------------------------------------
                                :      1987        :               1988                 :               1989                 :
                Tasks           : J  A  S  O  N  D : J  F  M  A  M  J  J  A  S  O  N  D : J  F  M  A  M  J  J  A  S  O  N  D :
--------------------------------:------------------:------------------------------------:------------------------------------:
 1. Concept paper               :====X             :                                    :                                    :
 2. Experimental plan           :      ============:=X                                  :                                    :
 3. Select households           :         =====X   :                                    :                                    :
 4. Install instrumentation     :           =====X:                                    :                                    :
 5. Data base system            :         =========:=X                                  :                                    :
 6. Collect pre-retrofit data   :                  :==========X                         :                                    :
 7. Customize audit             :                 .:   ========X                        :                                    :
 8. Audit training              :                  :          X                         :                                    :
 9. Audit houses                :                  :            ==X                     :                                    :
10. Install measures            :                  :               =====X               :                                    :
11. Prepare pre-retrofit report :                  :            ==============X         :                                    :
12. Collect post-retrofit data  :                  :                            ========:==========X                         :
13. Prepare final reports       :                  :                                    :            ===========X            :
14. Disseminate information     :         =====X   :                           =====X   :                        ===========X:
15. Remove instrumentation      :                  :                                    :            =====X                  :
16. Retrofit control houses     :                  :                                    :                  ========X         :
------------------------------------------------------------------------------------------------------------------------------
```

Fig. 2.1. National Fuel Gas end-use efficiency field test schedule.

1. Prepare a Concept Paper - Based on discussions with project participants, ASE will prepare a project concept paper that will be reviewed by NFG, ORNL, and NYSDPS. The plan will describe the project, need, approach, measures, roles of each organization, task plan, timeline, and budget. A final version of the concept paper will be drafted based on comments received. This task was completed in August, 1987, prior to development of this plan.

2. Prepare an Experimental Plan - ORNL will develop a detailed experimental plan outlining how the field test will be conducted. The plan will expand on the ideas outlined in the concept paper and will present detailed information on instrumentation, data collection, and analysis techniques. Each participating organization will review and comment on the document. The first draft of the plan was completed in October, 1987, to allow each participating organization to review and comment on the document.

3. Select Field Test Households - NFG will select appropriate households for participation in the field test by December, 1987, using the household selection criteria and following the procedure identified in this document.

4. Install Instrumentation - NFG will provide and install all the instrumentation required to monitor the energy consumptions of the individual households. ORNL will provide the instrumentation required to monitor the indoor and outdoor temperatures and will assist NFG in its installation. All instrumentation will be installed by January 1, 1988. NFG will maintain all the instruments with technical assistance provided by ORNL.

5. Develop Field Test Data Base System - ORNL will develop a data base system to manage the field test data by January 15, 1988. The system will check the data for errors as it is collected and store the data in a format that can readily be used in analysis.

6. Collect Pre-Retrofit Data - Pre-retrofit data will be collected from January 1, 1988 to April 15, 1988. Using forms provided by ORNL, NFG will collect all the required pre-retrofit field data (both survey information and monitored data collected from the installed instrumentation) and mail the data to ORNL as it is collected. ORNL will enter the data into the data base.

7. Customize the Audit-Directed Retrofit Procedure - WECC will custom design and deliver to NFG a computerized audit procedure for the climate and houses to be encountered in the field test by the end of April, 1988. The procedure will be based on the design concept outlined in Refs. 1 and 2.

8. Provide Audit Procedure and Retrofit Training - WECC will provide training workshops for NFG staff and weatherization installers in April 1988. The workshops will explain how to use the audit procedure (including how to perform the blower door and heating system steady-state efficiency measurements) and provide any special instruction needed for installing the conservation measures.

9. Audit Field Test Homes - NFG will audit all the field test houses in May, 1988, using the procedure outlined in the training workshops. ORNL will assign the houses to either the treatment or control group following the procedure outlined in this document. NFG will then select the conservation measures to be installed in the treatment houses based on the audit results. Copies of the audit input and output information will be provided to ORNL.

10. Install Selected Conservation Measures - NFG will install the conservation measures selected by the audit procedure in the treatment homes in June and July, 1988. NFG will inspect each

retrofitted house to ensure proper installation of the conservation measures. Information on the actual measures installed in each house will be sent to ORNL.

11. Prepare a Pre-Retrofit Data Analysis Report - ORNL will prepare an interim report presenting the pre-retrofit heating energy consumptions of the houses. The report will also outline the measures recommended by the audit, their predicted energy savings, and the measures actually installed in each home. The first draft of the report will be completed by October, 1988, to allow each participating organization to review and comment on the document.

12. Collect Post-Retrofit Data - Post-retrofit data will be collected from October 15, 1988 to April 15, 1989. Using forms provided by ORNL, NFG will collect all the required post-retrofit field data (both survey information and monitored data collected from the installed instrumentation) and mail the data to ORNL as it is collected. ORNL will enter the data into the data base.

13. Prepare Final Analysis Reports - ORNL will prepare a final analysis report based on the data collected during the field test. The report will compare actual energy savings to audit predictions to determine the performance and cost-effectiveness of the audit procedure. ORNL will prepare a second report describing the analysis techniques developed for the telemetered data and the results of their validation. The first draft of these reports will be completed by September, 1989, to allow each participating organization to review and comment on the documents.

14. Disseminate Field Test Information and Results - ASE will prepare and distribute a series of press releases and other documents that cover the progress and results of the field test throughout

the experiment. ORNL will prepare papers on the field test for technical journals. ASE will prepare a memorandum summarizing the field test results and providing a list of recommendations for consideration by NFG and NYSDPS.

15. Remove Instrumentation - NFG will remove all the field test instrumentation from the monitored houses by the end of June, 1989.

16. Install Retrofit Measures in Control Group Houses - NFG will install appropriate conservation measures in the control group of houses at the end of the test and before October, 1989, following the audit procedure and/or based on the insights gained in retrofitting and analyzing the previously treated houses.

3. AUDIT-DIRECTED RETROFIT PROCEDURE

3.1 OVERVIEW

The audit-directed retrofit procedure to be used in the field test is based on the principles identified in Refs. 1 and 2 and will be similar to the procedure tested in Wisconsin.[3,4] The chief distinction of this procedure, as contrasted with a set list of priorities, is that each house is analyzed individually to determine the most cost-effective conservation measures. The analysis performed on each house includes diagnostic testing and determining the B/C ratio for each possible retrofit. An additional distinction of the audit procedure is that it includes a rational decision process to determine investment levels for each house in order to improve conservation program expenditures. Under this procedure, houses receive different retrofits, and various amounts of money are spent on each house in order to achieve maximum program energy savings per investment dollar. The procedure previously tested in Wisconsin has subsequently been modified by WECC to improve the accuracy of the energy savings predictions, to include additional retrofits (including hot water-system measures) and an improved method of performing infiltration reduction work, to address additional types of heating systems other than gas furnaces, and to make it generally easier to use.

3.2 DETAILED DESCRIPTION

The audit-directed retrofit procedure uses characteristics of the houses, the climate, and an array of potential retrofits to select appropriate retrofits for individual houses. The procedure combines the retrofit selection process with a management system that provides a framework for administration, organization, and reporting. The version of the procedure developed by WECC is computerized using a

LOTUS 123 spreadsheet and is specifically designed for use in low-income weatherization programs. This version also considers a wide range of possible retrofits designed to reduce heating and hot water energy consumption.

Mechanical-system conservation measures are considered along with building-envelope and hot water-system measures in the audit procedure. Building-envelope retrofits considered by the procedure include installing (1) ceiling insulation, (2) exterior wall insulation, (3) storm windows, (4) storm doors, (5) floor insulation, (6) exterior foundation insulation, (7) interior foundation insulation, (8) sill box insulation, and (9) infiltration reduction measures. Mechanical retrofits to the heating systems include (1) replacing a standing pilot with an intermittent ignition device, (2) installing an electro-mechanical full-closure vent damper, (3) installing a thermally-activated vent damper, (4) installing a secondary condensing heat exchanger, (5) replacing an atmospheric burner with a gas power burner, (6) implementing an outdoor reset control scheme, (7) cleaning and tuning the heating system, and (8) replacing the existing system with high-efficiency equipment. Retrofits to the hot water system include (1) adding an insulation blanket to the water tank, (2) insulating hot water lines, (3) reducing the hot water temperature, (4) installing low-flow shower heads, and (5) installing a vent damper.

The first step in implementing the procedure is to collect the following house data and enter it into the audit: (1) occupant information, (2) health and safety information, (3) building-envelope data, and (4) heating and hot water system data. The heating system data includes determining the steady-state efficiency of presently installed gas- or oil-fired systems through a flue gas analysis. Household fuel consumption records are also obtained from the local utility.

In the second step, the following are calculated for each retrofit considered by the procedure with the exception of the infiltration reduction measures: (1) installation cost (materials plus labor), (2) energy and cost savings, (3) simple payback period, and (4) B/C ratio. The infiltration reduction measures are handled differently from the remaining retrofits as discussed in Sect. 3.3. All the calculations are computerized, thereby alleviating routine and repetitive numerical tasks. The installation costs are calculated using local labor and materials costs for each retrofit. Energy savings are determined using regional average degree day data and a calculation method that examines each retrofit individually as opposed to an approach in which the entire building is modeled. The savings of the building-envelope retrofits are estimated by calculating the heat loss reduction corrected for heating system efficiency and degree days. Mechanical-system retrofit savings are estimated by calculating efficiency changes and normalized heating consumptions using previous billing data. A B/C ratio greater than 1.0 indicates that the retrofit saves more money through energy savings than it costs to install; a retrofit with a B/C ratio less than 1.0 will not save as much money as it costs.

In the third step, retrofits with B/C ratios higher than a predetermined value for the retrofit program (at least 1.0) are selected for installation once the interactions between retrofits are considered. Retrofit interactions become important when both heating-system and building-envelope retrofits are used. For instance, ceiling insulation saves energy by reducing the amount of heat needed to keep a house warm, while improving the efficiency of a furnace reduces the amount of fuel needed to deliver the required heat. The interaction between these two retrofits causes their combined energy savings to be less than the sum of the savings each would achieve alone. Retrofit interactions are also important when the same piece of equipment can be modified by different mechanical measures. For example, installing an intermittent ignition device or installing a new high-efficiency furnace may both be cost-effective retrofits. However, because a new furnace is already equipped with an ignition device, these two retrofits cannot be performed on the same piece of equipment at the same time.

In the audit procedure, retrofits are generally selected in decreasing order, based on their B/C ratio. Interactions between heating-system and building-envelope retrofits are handled by recalculating the B/C ratios for the retrofits that interact. Retrofits are selected if the recalculated B/C ratio is greater than the predetermined value for the retrofit program. Interactions between heating-system retrofits only are handled somewhat differently. The mechanical retrofit with the highest B/C ratio is selected first (if its ratio is also greater than the predetermined value for the retrofit program). Other mechanical retrofits with lower B/C ratios that interact are then dropped from consideration. The mechanical retrofit with the next highest B/C ratio is then selected, and the process continues until all mechanical retrofits with B/C ratios greater than the predetermined value for the retrofit program are either selected or dropped from consideration. There is one exception to this process; installation of a new high-efficiency heating system can be selected at the exclusion of other interacting mechanical retrofits with higher B/C ratios. For this to occur, the B/C ratio for the heating system replacement must be greater than the predetermined value for the retrofit program and the replacement must meet one of the following two conditions: (1) its B/C ratio must be greater than a preselected "interaction" value, or (2) its simple payback period must be less than a preselected value. The interaction value and simple payback value are chosen by the user based on judgement and experience. The B/C ratio "interaction" value is greater than the B/C ratio value predetermined for the retrofit program.

The average amount of money spent on a house in the program and the overall cost-effectiveness of the program are controlled indirectly through the selection of the minimum B/C ratio value for the retrofit program. By raising the value, only the more cost-effective retrofits will be installed in each house. This reduces the average amount of money spent per house and the total savings for the house, but increases the program's effectiveness. By lowering the value, more retrofits will be installed, on average, in the houses. This increases the average amount spent per house and the savings for the house, but lowers the program's cost-effectiveness. The B/C ratio value needed to obtain an average expenditure per house or program effectiveness is best determined through the implementation of a small pilot program or through a trial and error process.

In the fourth and final step, the retrofits selected by the audit are listed in a workorder that can be used by the weatherization installer. The workorder identifies the work to be performed, estimates the amount of material and labor required for each retrofit, and provides a cost estimate for the job. Follow-up work is then performed as part of the audit procedure to update the workorder by indicating the work actually performed and its actual cost.

3.3 INFILTRATION REDUCTION PROCEDURE

The installation of infiltration reduction measures is handled separately from the selection and installation of the remaining retrofits in the audit procedure. A specially trained crew is assigned the task of performing all infiltration testing and retrofit work, which can be performed in one visit. Using this practice, auditors do not have to perform infiltration tests on the houses during the data collection phase. For the field test, the infiltration work will be performed before the remaining retrofits are installed.

The infiltration reduction work is performed following a blower-door-guided infiltration reduction procedure.[6,7] The intent of the procedure is to increase the efficiency of infiltration measures through the use of a blower door to locate house leaks and by prescribing how much infiltration work is cost effective.

The crew begins the procedure by first checking to ensure that no moisture problems currently exist. The crew then determines the air leakage rate of the house, using a calibrated blower door, at 50 pascal of depressurization. Expenditure levels and air leakage rate reduction goals for each house are set based on economic considerations using the measured air leakage rate and algorithms or tables developed by WECC. Homes whose air leakage rate is less than a minimum value receive no treatment (except to seal leaks that directly affect comfort) due to their low cost-effectiveness and to avoid moisture and indoor air quality problems. Homes that have an air leakage rate greater than the minimum value are assigned reduction goals that vary with the leakiness of the house. Major leaks in the house are sealed while the blower door is in place to help locate the leaks and to track the air leakage rate during retrofit. The homes are sealed until the air leakage rate reduction goal or expenditure limit is met. A final air leakage rate measurement is then made.

3.4 AUDIT CONSIDERATIONS IN THE FIELD TEST

The audit procedure will be customized by WECC for use in the field test. This customization will entail (1) including additional house and heating system types, (2) including or deleting retrofits for consideration, (3) developing a data collection sheet for the audit information, (4) installing specific material, labor, and fuel costs and weather data for the Buffalo area, (5) selecting values of the B/C ratio and simple payback period to be used to determine if a furnace replacement should take precedence over other mechanical retrofits with higher B/C ratios, (6) incorporating new default and minimum values as needed, (7) developing new expenditure level and air leakage rate reduction tables for the infiltration reduction procedure, (8) modifying the workorder and other report forms, and (9) designing and refining the overall audit procedure to meet the needs of the field test and NFG.

The value of the B/C ratio used as a cut-off for the selection of the individual retrofit measures (the predetermined value for the retrofit program) will be chosen jointly by the project participants after the houses are audited. As a minimum, the value will be chosen such that the retrofit costs (which include the costs of the retrofit installations, infiltration measures, and initial blower door measurements, but excludes the costs of conducting the audit) do not exceed $55,000 for the 50 treatment houses. A higher value than this may be chosen, however, to improve the anticipated cost effectiveness of the program.

The input, output, and follow-up information collected through the implementation of the audit procedure will be provided to ORNL for analysis. These data are contained in the LOTUS files created for each house in performing the audit. This information must include the identification of the measures recommended by the audit, the measures actually installed, the estimated and actual installation cost for each recommended measure, and the energy savings and B/C ratio predicted for each recommended measure.

4. FIELD TEST DESIGN

4.1 EXPERIMENTAL DESIGN

One hundred houses meeting the criteria outlined in Sect. 4.2 will be monitored. Pre- and post-retrofit testing will be employed to determine the change in heating energy consumption following the installation of conservation measures in the individual houses. Further, a one-way classification design will allow an analysis of variance approach to be used to analyze the consumption changes.[8]

Energy consumption data will be collected in individual houses before and after conservation measures are installed. These data must be analyzed using a house model to determine annual energy consumption changes in the houses because the before and after periods may cover different lengths of time, may not include the entire winter period, and may be climatically different. Pre- and post-retrofit testing allows the houses to serve as their own reference; therefore, energy consumption changes of individual houses can be studied in addition to determining group savings. This design is useful in conservation program evaluations where an on-off design[9] cannot be employed, which is the case for this field test. The on-off design may be used whenever the retrofit consists of a system, or a component, that can be turned off so that the building operates as if the retrofit did not exist.

The one-way classification design divides the field test houses into "treatment" groups in order that the effect of the treatments can be studied. The effect of two "treatments" on heating energy consumption will be studied: the installation of conservation measures following the audit-directed retrofit procedure (audit or treated group) and the installation of no weatherization measures (control group). The inclusion of a control group allows many factors that may affect the validity of the experiment to be taken into account.[10] Energy changes in the treated houses may be due entirely to the conservation measures that were installed. On the other hand, other factors occurring during the testing program may contribute to the change. These factors can become more important the longer the interval is between testing periods. A group of houses identical to the treated houses but that are not retrofitted can be used to account for these other factors by determining their change in energy use over the same time period. The changes in the control group can then be compared to the changes measured in the treated houses to determine retrofit induced savings.

In order for the comparisons between the "treatment" groups of houses to be valid, the two "treatment" groups must be similar or equivalent. The 100 houses could be divided into two "treatment" groups of 50 houses each through a purely random assignment procedure. This procedure ensures uniformity when a large number of houses is involved, but becomes progressively more unreliable as the number of houses becomes smaller. The use of random assignment with stratification is an improved procedure for achieving pre-retrofit equality between the "treatment" groups.

In the stratified random assignment procedure to be employed, the 100 houses will be classified into one of the four sub-groups or "strata" identified in Fig. 4.1. These strata will be developed using two key variables that can significantly affect the heating energy consumption and the energy savings that might be achieved by the audit: the type of heating system installed in the house (furnace or boiler) and the level of pre-retrofit gas consumption of the house (the upper or lower 50th percentile). One-half of the houses from each classification will then be assigned to the audit or control

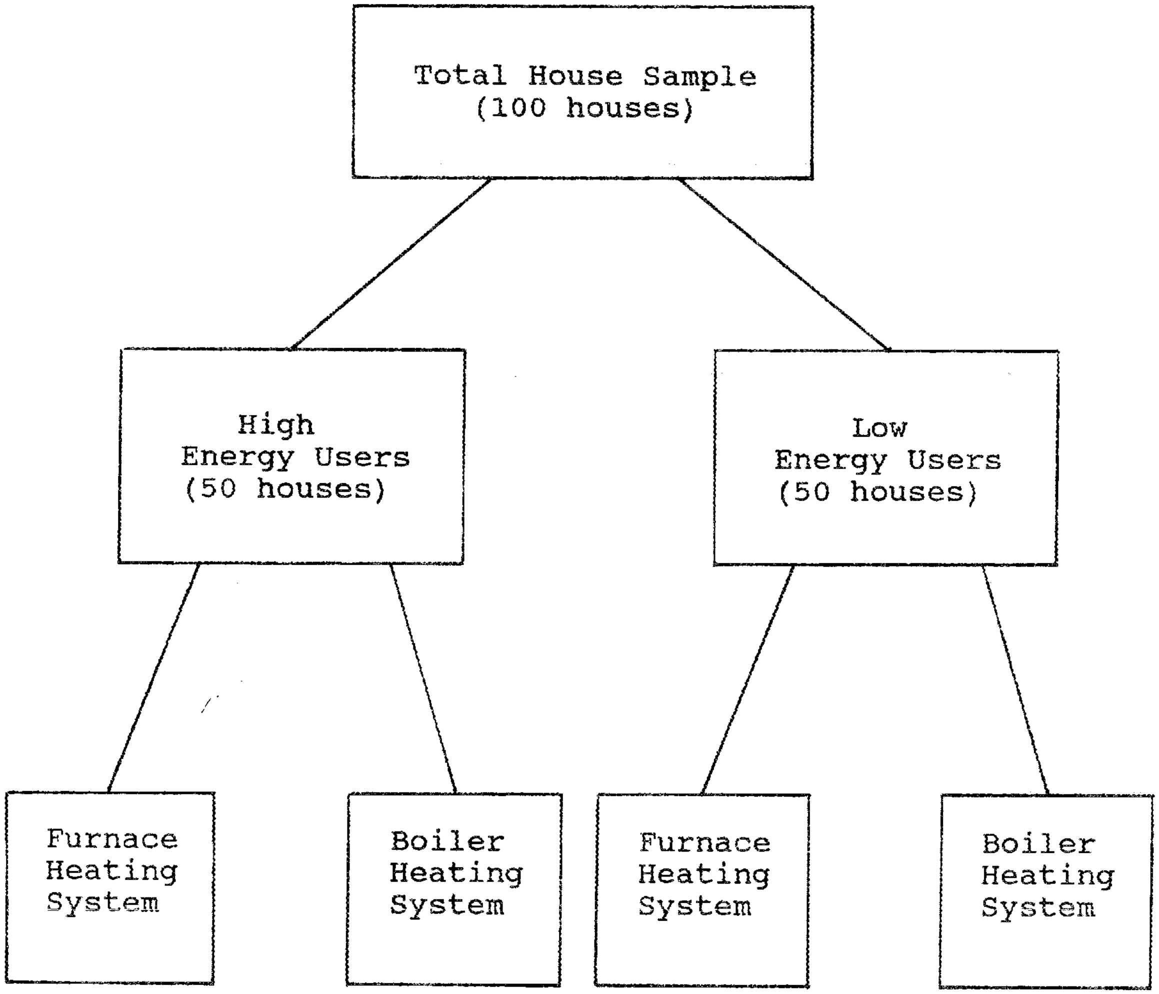


Fig. 4.1. Four classification groups to be used in stratifying the field test houses.

group randomly. In this way, the same number of houses that have a furnace and are high energy users, for example, will be assigned to the two groups, making the groups similar with respect to the chosen variables. The total number of houses in each classification will not be controlled and, thus, will likely be different. The assignment of the 100 houses to the two "treatment" groups should be performed following the detailed procedure outlined in Sect. 4.3.

The most important part of this procedure is the selection of the variables. The choice of an indiscriminate number of variables creates too many sub-groups containing only a few houses; this makes the selection of houses more critical or the assignment of houses to the "treatment" groups awkward. Variables that actually affect energy use or savings and whose values vary among the houses should be chosen to make the stratification effective. An incorrect choice of variables does not invalidate the study; in this case, the stratification method is ineffective and just degenerates to the purely random method mentioned above.

For this study, stratification using two variables was determined to be appropriate. The type of heating system installed in the house is important because the control of the systems and the way they deliver heat are different. Additionally, the retrofits selected by the audit for a given house will depend on the house's heating system due to hardware and cost considerations. Pre-retrofit house gas consumption is important because the average consumption of the houses in the audit and control groups should be the same. Other variables, such as house size and number of occupants, are less important than the two variables chosen.

4.2 SAMPLING PLAN

In order that understandable results can be obtained from the study and research goals of the experiment can be met, the population of houses to be studied will be limited to those having the following characteristics:

1. the occupants must be a resident of Erie County, New York;
2. gas service must be provided by NFG;
3. the occupants must be eligible for the Low-Income Home Energy Assistance Program (LIHEAP) at the time of being included in the field test (based on their 1987 Income Tax Statement);
4. the house must be heated primarily with natural gas;
5. gas service must be turned on;
6. the primary gas heating system must be in operating condition;
7. the house must not be scheduled to receive retrofits under either the State's WAP or NFG's Savings Power Loan Program and must not have received weatherization by these programs in the last 5 years;
8. the house must be a single-family detached home, but not a mobile home;
9. the house must be occupied by the owner;
10. the occupants must currently be paying their own fuel bills (bills are not being paid by the county through vouchers);
11. the primary heating system of the house must either be a gas furnace or a hot water boiler;
12. the house's potable water must be heated with natural gas;
13. the occupants must not be planning an extended stay away from the house during the winter monitoring periods (a 1-2 week vacation is acceptable);
14. secondary fuel (such as wood or kerosene) must not be used to substantially heat the house (use of a supplemental fuel a half day per week or in the bathroom is acceptable); and

15. the monthly gas consumption over the past year must be weather dependent (can be correlated to outdoor temperature).

The first seven criteria define the population of houses needed to meet the basic objectives of the experiment, while the remaining criteria narrow the population to make the experiment easier to perform or to improve the accuracy of the results. The importance of each of these characteristics is described below.

The houses will be limited to those located in Erie County, New York (the county containing Buffalo) to centralize the experiment and to remain within NFG's service territory. A primary goal of the experiment is to determine the benefits realized from the audit procedure by low-income families and NFG. If the benefits are significant, then additional low-income homes may be retrofitted following the audit using LIHEAP funds and/or through programs administered by NFG. Consequently, the households to be studied must be selected from the pool of families eligible for LIHEAP funds and their houses must be primarily heated with natural gas supplied by NFG. Gas service must be turned on and the primary gas heating system must be in operating condition to ensure that the houses are heated with gas. The houses must not be scheduled to receive retrofits under another retrofit program to ensure that the only changes made to the houses during the testing period are those recommended by the audit procedure. The houses must not have received weatherization under any other program within the last 5 years because this is a usual requirement of programs that would utilize the audit procedure.

The houses meeting the above characteristics still form a rather non-homogeneous group; for instance, they may be quite different with respect to their house and occupant characteristics. Thus, several characteristics that further narrow the population were identified to obtain more definitive results on the most common type of low-income housing found in NFG's service area. Narrowing the study will also make it easier to develop equivalent audit and control groups.

The study will focus on owner-occupied, single-family, detached homes whose occupants currently pay their own fuel bill. The energy use behavior of renters can be different from occupants that own their own home; thus, the performance of the audit in these homes can also be different. In addition, renters may be more likely to move during the experiment than homeowners. Test houses in which the occupants move will have to be dropped from the study due to the changes in energy consumption that can result from a change in occupancy. Dropping houses from the study should be avoided, if possible, to maintain the integrity of the experimental design. The energy use behavior of people who pay their own fuel bills may also be different from those who have their bills paid by the county through vouchers; thus, the performance of the audit procedure in these homes can also be different. Homes other than single-family detached are significantly different structures such that energy use and audit performance might be affected. In addition, the audit is not applicable to these other house types at this time.

The study will focus on houses equipped with either gas furnaces or hot water boilers. Mr. Ray Nihill of NFG estimated that 60% of the low-income houses in the Buffalo area heated by gas have forced or gravity hot air furnaces, 30% hot water boilers, and the remaining 10% either steam boilers, space heaters, or floor furnaces. The latter three types are not sufficiently prevalent to warrant including in the study population. In addition, the audit may not be applicable to houses equipped with these types of heating systems. The house's potable water must also be heated with natural gas (the predominant equipment type), mainly to make instrumenting the test houses easier.

The remaining characteristics help ensure that the energy consumptions of the houses can be determined as accurately as possible using currently developed analysis techniques. Accurately measuring the amount of secondary fuel used to heat a house is difficult, especially for such fuels as wood or kerosene. Thus, extensive use of such fuels increases the uncertainty of energy use determinations and can make such determinations impossible. The energy use of houses whose occupants will be away for extended periods of time during the winter monitoring periods may be very difficult to analyze. There may be insufficient data collected to characterize the house when it is occupied. A 1-2 week vacation, though, would be acceptable. A basic assumption in the analysis techniques to be employed is that the space heating gas consumption is dependent on the outdoor temperature. If this assumption is not true for a particular house, then its measured energy use data cannot be analyzed by the methods which will be employed. Thus, houses in which the occupants use secondary fuels extensively to heat the house, the occupants are planning an extended stay away from the house during the monitoring period, and the monthly gas consumptions over the past year do not depend on the outdoor temperature will not be included in the study population.

Because all the houses in the population of interest cannot be studied, a sample of houses representing the population must be chosen for inclusion in the field test. Based primarily on cost considerations, the size of this sample will be limited to 100 houses.

Selection of the 100 houses will be performed by identifying individual houses conforming to the population characteristics described above, determining if the occupants are willing to participate in the field test, and accepting them if they consent until the 100 house quota is reached. This "quota sample" approach (a type of selection called a "chunk" in Ref. 11) was chosen as it was unlikely that a more formal statistical sampling technique such as random sampling could be employed. A randomized selection procedure would require the identification of a much greater number of eligible homes than needed, and then randomly selecting 100 houses from the developed list. This would require time and funds which are not available.

The selection of houses should proceed in four steps:

Step #1. Low-income households which may be eligible under LIHEAP need to be identified using any available resource.

Step #2. The form provided in Fig. 4.2 should be filled out for each of the houses as they are identified to determine their eligibility for the field test. Information needed to complete the checklist should be obtained through telephone interviews.

Step #3. Criterium 15 should be verified for the houses determined to be eligible under Step #2. If the house meets this final criterium, then a site visit to the house should be made to complete Step #4. The monthly energy consumptions for the past year should be regressed against the total degree days for the billing period assuming a linear relation. If the correlation coefficient (r^2) of this regression is greater than 0.75, then the house may be used in the field test. (The value of 0.75 was chosen to exclude houses with space heating gas consumption independent of outdoor temperature.) Only actual meter readings should be used in this analysis. For example, if the gas meter was read in January and March but estimated for February, then January's reading should be subtracted from March's reading to obtain one data point representing a two month interval. The corresponding degree days for this data point would be the total for February and

Hello, Mr. or Mrs.______(Account Name)______. This is ______(Rep. Name)______ from National Fuel Gas. National Fuel is conducting a special demonstration project that could weatherize your home free of charge. The project will evaluate a new home energy audit by comparing a home's energy usage before and after it is weatherized. You already meet some of the criteria necessary to participate in the program. May we ask you some simple questions which will further qualify your home for free weatherization?

(If yes continue, if no go to last paragraph.)

List Name ______________ Account# ______________

Address ______________ City ______________

Phone ______________ Zip Code ______________

				Correct Answer
1.	Do you live in a single-family home?	___Yes	___No	Y
2.	Is the home detached from another home or apartment? (But not a mobile home.)	___Yes	___No	Y
3.	Are you the owner?	___Yes	___No	Y
4.	Is the home heated by a natural gas furnace in working order?	___Yes	___No	Y
5.	Is there a gas hot water tank in working order?	___Yes	___No	Y
6.	Has the home been weatherized by a state or utility funded program in the last 5 years?	___Yes	___No	N
7.	Do you plan to move within the next 2 years?	___Yes	___No	N

(If questions are answered correctly)

Your home meets the preliminary qualifications to participate. What time of day is most convenient for a National Fuel representative to visit you to further explain the program. (Time________). Thank you for your time. Good-by.

(If questions are not correctly answered)

Your home does not meet the necessary qualifications to participate in the test. Thank you for your time and have a nice day.

Fig. 4.2. Checklist for screening possible project participants.

March. Some special considerations may need to be taken if the present occupants have not lived in the house for at least a year.

Step #4. The occupants of the houses that may be used in the field test should be provided with a copy of the "Interview Fact Sheet for End-Use Efficiency Field Test" listed in Fig. 4.3. If they meet all the field test criteria and are interested in participating in the field test, then the "Agreement" and "Affidavit," provided in Figs. 4.4 and 4.5, should be completed and forwarded to the person maintaining the field test files. The houses should be assigned a unique three-digit number as they are accepted into the field test.

4.3 ASSIGNMENT PROCEDURE

The assignment of the 100 houses to either the audit or control groups should be performed in four steps:

Step # 1. The type of heating system installed in each house should be determined and noted.

Step #2. Using the regression coefficients determined during the third step of the selection procedure and the number of degree days for a typical year in Buffalo, the annual amount of gas consumed for heating for each house should be determined. The houses in the upper and lower 50th percentile should then be identified.

Step #3. The 100 houses should be classified into the four groups identified in Fig. 4.1.

INTERVIEW FACT SHEET FOR END-USE EFFICIENCY FIELD TEST

(1) The program is mandated by the Public Service Commission.

(2) Reason: It is to evaluate a new home energy audit approach developed by the United States Department of Energy. The audit will provide more accurate fuel savings figures and prioritize which energy conservation measures should be installed in the home.

(3) National Fuel is working this project in cooperation with the following organizations:

1. Alliance to Save Energy, a national non-profit organization working to improve our nation's energy efficiency,

2. New York Department of Public Service, the state regulator of utilities, and

3. Oak Ridge National Laboratory, a research organization providing engineering assistance to the project.

(4) One hundred sites will be selected by National Fuel personnel. To participate in this program you must meet the following criteria:

(A) Must have received "HEAP" > 150% poverty or below guidelines at time of entering program.

Yes No

(B) Must be an Erie County resident.

Yes No

(C) Must be an active National Fuel heating customer.

Yes No

(D) Must have a natural gas furnace or boiler and water heater in operating condition.

Yes No

(E) Must be a single-family home.

Yes No

Fig. 4.3. Project summary to be presented to the possible project participants.

(F) Must be the owner of the home (no mobile homes).

Yes No

(G) Must not have plans for any structural additions (including attic and basement rooms).

Have Plans No Plans

(H) Must not be scheduled for any weatherization work within the next two years other than work performed under this program.

(I) Must not use, or intend to use, a secondary fuel to heat the house (occasional electric space heater or fireplace use is acceptable); (electric space heater 1/2 a day per week is unacceptable).

Secondary Heat Exists No Secondary Heat

(J) Must not have plans to move or to be away from home for an extended time during the next two years (normal vacations are no problem during heating season).

(K) The monthly gas consumption must be weather dependent.

WHAT THE CUSTOMER SHOULD EXPECT DURING THIS PROGRAM

(1) This year, National Fuel will install a new or recalibrated gas meter. A contractor will install two 24-volt time-elapse meters connected to both the furnace and hot water tank. The meters will be hung in a basement window which can be easily read from the exterior of the home. A small (approximately 6 x 2 x 4 in.) Temp-Cube (temperature recorder) will be placed in the home living area to monitor indoor temperature.

(2) The gas meter, electric meter, and both time-elapse meters will be read weekly by a meter reader from DMC Energy. The Temp-Cube will be read on a monthly basis.

(3) Next spring energy auditors will visit your house to conduct an energy audit. The auditors will collect information about your home, test your furnace's efficiency and find out where heat leaks out of your home. The detector uses a special fan that is placed in your front doorway for about an hour.

Fig. 4.3. (continued)

(4) Weatherization measures recommended by the audit will be installed in your home, either next summer or during the following summer of 1989. The homes to be insulated each summer will be chosen by Oak Ridge National Laboratory.

(5) In return for participating in the demonstration program, the following assurances are made:

(A) Your home will receive an energy audit to determine which conservation measures are cost-effective to install in your home.

(B) Based on the audit results, recommended weatherization measures will be installed in your house by a contractor chosen by National Fuel. There will be no charge to you for these services. National Fuel will pay for the full cost of the audit and weatherization materials and labor.

(C) Information collected about your home will only be used for research purposes and will remain confidential. No information will be released without your prior approval.

This is an important research study that will help us learn how to better control home energy costs. Your participation in the study will make a big contribution to realizing that objective.

(6) National Fuel will arrange with you times when contractors and meter readers will visit your home.

THE FOLLOWING MUST BE RETURNED TO NATIONAL FUEL

(1) CUSTOMER AFFIDAVIT

(2) CUSTOMER APPLICATION

Fig. 4.3. (continued)

AGREEMENT

Agreement made this _____ day of __________, 1987, between NATIONAL FUEL GAS DISTRIBUTION CORPORATION with an office located at 10 Lafayette Square, Buffalo, New York 14203 (hereinafter referred to as "NATIONAL FUEL") and ______________________________ residing at ____ (hereinafter referred to as "HOMEOWNER").

WHEREAS, NATIONAL FUEL is committed to assisting its customers in energy conservation.

WHEREAS, a NATIONAL FUEL representative has described to the HOMEOWNER NATIONAL FUEL's End Use Efficiency Field Test and Weatherization Program.

WHEREAS, the HOMEOWNER has expressed a desire to participate in NATIONAL FUEL's End Use Efficiency Field Test and Weatherization Program.

WHEREFORE, the parties mutually agree as follows:

1. HOMEOWNER agrees:

(a) to allow his/her residential premises located at __________________________ (hereinafter referred to as "test site") to be used as a test premise by NATIONAL FUEL for the purpose of its End Use Efficiency Field Test and Weatherization Program.

(b) to allow NATIONAL FUEL or its agents or contractors access to the test site to install, monitor and remove small energy use meters.

(c) to allow NATIONAL FUEL access to the test site on a weekly basis during the test period in order to read the small energy use meters. (Note - whenever possible, meters will be installed in such a way as to be read from outside the house.)

(d) to allow NATIONAL FUEL or its agents to conduct an energy audit during a time period to be scheduled by NATIONAL FUEL.

(e) to allow NATIONAL FUEL, its agents or contractor to install the energy conservation measures recommended as a result of the energy audit.

Fig. 4.4. Agreement form to be signed by the project participant.

(f) to allow NATIONAL FUEL to conduct this test program at the test site free of charge.

(g) to allow NATIONAL FUEL to release all information regarding energy use obtained from the test site.

(h) to make every effort to safeguard all the equipment installed by NATIONAL FUEL or its agents at the test site.

2. NATIONAL FUEL agrees:

(a) to test and monitor the efficiency of designated gas equipment located at the test site.

(b) to install or have its agents or contractors install free of charge the energy conservation measures recommended as a result of the energy audit.

3. The test period shall be for two (2) years commencing on the date of installation of the energy use meters by NATIONAL FUEL, its agents or contractors.

4. The HOMEOWNER shall not assign any interest in this Agreement without the prior written consent of NATIONAL FUEL. Any assignment without prior written permission shall be void and totally ineffective for all purposes.

5. The HOMEOWNER hereby agrees to release and forever discharge and convenant not to sue NATIONAL FUEL, its affiliate companies, its officers and members, and the officers and members of its affiliate companies, of and from any and every claim, demand, action or right of action, of whatsoever kind or nature, either in low or in equity arising from, out of or by reason of any bodily injury or personal injuries known or unknown, death and/or property damage resulting to or to result from any accident or incident which may occur as a result of defective manufacture of the equipment or any non-negligent activities in connection with the end Use Efficiency Field Test and Weatherization Program.

The HOMEOWNER expressly agrees that this Release, and waiver is intended to be as broad and inclusive as permitted by the laws of the State of New York and that if any portion thereof is held invalid, it is agreed that the balance shall, notwithstanding, continue in full legal force and effect.

Fig. 4.4 (continued)

6. Either party may terminate the Agreement upon thirty (30) days notice to the other party.

7. As to any term of this Agreement, New York law shall apply.

8. This Agreement is intended by the parties to be a complete, exclusive statement of the terms of their Agreement; it supersedes all prior agreements, written or oral.

DATED:

NATIONAL FUEL GAS DISTRIBUTION
CORPORATION

By ____________________________ ____________________________

Title: __________________________ Title: __________________________

Fig. 4.4 (continued)

National Fuel

In reply please address to

AFFIDAVIT

I, ____,

residing at ______________________ do hereby certify that

in the year 1987 I received a payment under the Home Energy

Assistance Program.

____
Signature

____
Witnessed By

____
Date

Fig. 4.5. Affidavit form to be signed by the project participants.

Step #4. Half the houses in each of the four groups should be randomly assigned to the treatment group. The remaining houses are then assigned to the control group. This final step will be performed after the pre-retrofit data are collected and just before the audits are performed in order to minimize the effect attrition may have on creating unequal treatment and control groups.

The expected error in estimating the average house savings achieved by the audit procedure by means of a random sample of size 50 (only 50 of the 100 houses will be retrofitted) can be estimated using the following equation[8] and assuming similar results as those obtained from the previous field test of the audit:[3]

$$E = (Z_{\alpha/2}\ s)/n^{1/2},$$

where

- E - magnitude of the error of estimate;
- $Z_{\alpha/2}$ - number associated with the $1-\alpha/2$ percentile point of the standard normal distribution;
- s - standard deviation of the average house savings; and
- n - number of houses in the sample.

In the previous field test, the average house savings were found to be 207 therms/year with a standard deviation of 263 therms/year. (This large standard deviation is due mostly to the fact that, in using the audit procedure, some houses receive many retrofits and others receive relatively few.) Using a value of 263 for "s" and "α" equal to 0.10, the error of estimating the average house savings achieved by the audit by means of the average savings of the 50 house sample will be less than 61 therms/year with a probability of 90%. If the sample size decreases to 40 houses due to attrition, the error will increase to 68 therms/year.

5. DATA PARAMETERS AND MONITORING INSTRUMENTATION

The data to be collected in this field test includes, for the most part, the minimum data specified in Ref. 12. The data can be divided into two classifications: survey information and time-sequential measurements. Survey information represents data collected before, during, or after the experiment through discussions with the homeowner, visual observations, and some limited measurements. Time-sequential measurements are monitored continuously with instrumentation throughout the experimental period. A schedule for collecting these data is provided in Fig. 5.1.

5.1 SURVEY INFORMATION

The following survey information is to be collected in the field test:

1. house and occupant descriptive information,
2. follow-up interview information,
3. house infiltration measurements,
4. metered space heating system mechanical performance, and
5. retrofit installation quality verification and retrofit listing.

The descriptive information documents the physical characteristics of the house and space heating equipment as well as the behavioral characteristics of the occupants. This information is needed for the following reasons: (1) to clearly establish the characteristics of the houses and occupants from which the data and results were obtained and to which the results may reasonably be generalized, (2) to estimate the internal loads required in the analysis, (3) to determine the dependency of retrofit performance on house or occupant characteristics, (4) to allow the test results to be compared with

	'87	1988												1989				
	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
1. Descriptive information		X																
2. Follow-up information						X												X
3. Infiltration measurements		X										X	X					
4. Heating system steady-state efficiency measurements							X	X										
5. Retrofit installation quality verification								X										
6. Retrofit listing								X										
7. Time sequential measurements		X	X	X	X						X	X	X	X	X	X	X	
8. Monthly billing data						X												X
9. Gas heat content		X	X	X	X						X	X	X	X	X	X	X	
10. Gas consumption rate calibrations	X											X	X					

Fig. 5.1. Schedule indicating when specific information or data are to be collected.

Table 5.1. House descriptive information.

General
Experimental program
House identifier
Interviewer
Date of interview
Occupant's name and phone number
House location
Utility distributors
House
Type
Number of floors
Foundation and roof type
Roof and external wall colors
Number and description of rooms typically closed off
Total and heated floor areas
Evaluation of factors affecting air infiltration
Plan view sketch
Occupancy
Ownership
Length of time at residence
Permanent number by age group
Average number at home during the day
Heating system
Type
Fuel
Distribution fluid and method
Nameplate information (manufacturer, model, input and output capacities, and efficiency)
Age
Location
Coal or oil conversion unit
Energy efficiency devices present (vent damper and IID)
Pilot light use pattern
Auxiliary heat use
Distribution system
Total length of ductwork or piping
Length of ductwork or piping in unconditioned spaces
Insulation thickness

Table 5.1 (continued)

Thermostat
Type
Number
Nameplate information (manufacturer and model)
Hot water system
Fuel
Storage type
Heater type
Nameplate information (manufacturer, model, tank size, input capacity, and recovery)
Hot water temperature
Blanket thickness
Location
Appliances
Type
Fuel
Location
Insulation
Location and area
Construction
Type and thickness
Siding type (for walls)
Carpeted area (for sub-floor)
Windows, glass doors, and non-glass external doors
Window type
Window treatments
Area measurements per external wall facing
Number of window panes
Non-glass door type

results obtained from other studies, and (5) to allow the data set to be used in future studies. Table 5.1 lists the specific information requirements for this classification. An Entrance Interview Form (Appendix A) was developed to gather all the information. Included in the form are the descriptive terms appropriate for each item. For example, the house type can be characterized as either being multi-story detached, ranch detached, split level detached, attached, or mobile home. The descriptive information should be collected in either January, 1988 or when the houses are audited in May, 1988.

The follow-up interview information identifies changes that may have occurred in the above characteristics during the testing program. Changes could affect the conclusions of the experiment and, thus, need to be known in order that they can be evaluated. A Follow-Up Interview Form will be developed to collect the information identified in Table 5.2. The follow-up interview information should be obtained at the end of the testing period in May, 1989.

The house infiltration measurements serve as descriptive variables characterizing the house air leakage rate with and without the retrofits installed. These measurements (1) more completely characterize the house, (2) quantify secondary effects of retrofits (such as infiltration reduction due to installing attic insulation), and (3) provide information which may be useful in future examinations of the data set. The fan pressurization technique using a blower door should be utilized because repeatable results are easily obtained at standard conditions. References 13 and 14 describe a standard fan pressurization technique that should be followed. Basically, the flow at 0.04 in. H20 (10 Pa) to 0.24 in. H20 (60 Pa) in increments of 0.04 in. H20 (10 Pa) are measured with the blower door pressurizing and depressurizing the house. These infiltration measurements are in addition to any measurements to be made under the audit's infiltration

Table 5.2. Follow-up interview information.

Major alterations or additions
House
Space heating system or its operation
Domestic hot water system
New conservation measures or practices employed
Additional equipment used or change in use of previous equipment
Auxiliary heating equipment
Appliances
Occupant changes
Permanent number
Age
Average number at home during the day
Ownership

reduction procedure for several reasons: (1) these measurements are intended to represent the air leakage rates of the houses before and after all retrofits are installed, not just the infiltration reduction measures, (2) more information is required, and (3) similar data on the control houses is desired. The pre-retrofit measurements should be made in all the houses at the time the houses are audited and the post-retrofit measurements when the quality of the retrofit installation is verified, as discussed below.

The mechanical operation of the space heating systems are metered to determine their actual operating characteristics. These measurements serve as a check on the nameplate information provided by the manufacturer, ensure that the mechanical equipment is operating properly, and are important variables needed in the analysis equations if internal loads are considered. For this field test, this entails measuring the steady-state efficiency of the gas fired furnaces or boilers by performing a flue gas analysis. (The efficiency of condensing furnaces should not be measured because this measurement is difficult to make on this type of equipment.) A measurement needs to be taken on the current system, and a second measurement needs to be taken if a mechanical retrofit was performed (a clean and tune, new furnace, etc.). Because measurements on the current systems are performed for the audit, they do not have to be duplicated in any of the test houses (all test houses will be audited at the same time, but only half will be retrofitted between the pre- and post-retrofit periods). The second measurements taken on the systems receiving mechanical retrofits should be performed when the quality of the retrofit installations is checked, as discussed below.

Verifying the retrofit installation quality is essentially a post-retrofit inspection to ensure that the retrofits have been installed according to specifications. If a retrofit has not been correctly installed, or completely, additional work should be performed until the installation is satisfactory. The installation can be checked through visual inspection or measurements can also be made (checking the depth of attic insulation or performing a second flue gas analysis, for example). Verifying the retrofit installation quality needs to be performed in all the treated houses in July, 1988, which is soon after the installations are completed and before the post-retrofit monitoring period begins. The retrofits actually installed in the houses and their costs need to be documented in July, 1988, by inserting the information into the computerized audit program.

5.2 TIME-SEQUENTIAL MEASUREMENTS

Five data parameters will be monitored in each of the field test houses: house gas use, house electricity use, heating system gas use, hot water system gas use, and house indoor temperature. In addition, outdoor temperature will be measured at three sites. All these parameters will be used directly in the analysis equations presented in Sect. 7. Local weather data will be collected to supplement the other collected data, but will not be used in the analyses performed under this study. Table 5.3 summarizes the requirements of each data parameter. Data collection should begin by January 1, 1988, and will continue until April 15, 1988 for the pre-retrofit period, and, for the post-retrofit period, should begin by the week of October 17, 1988 and continue until April 15, 1989.

5.2.1 House Gas Use

NFG will provide and install in each test house a recently calibrated meter to measure the house gas use to within an accuracy of 3%. The brand of meter will be left to the discretion of NFG. These

Table 5.3. Time-sequential data parameter requirements and information.

Data Parameter	Quantity to be measured	Recording frequency	Collection frequency	Measuring instrumentation	Comments
House gas use	gas use, ft^3	weekly	weekly	gas billing meter	all houses
		monthly	yearly	gas billing meter	all houses
		daily	monthly	telemetering equipment	some houses
House electricity use	electric use, kWh	weekly	weekly	electric billing meter	all houses
Heating system gas use	run-time, hours	weekly	weekly	run-time meter	all houses
Hot water system gas use	run-time, hours	weekly	weekly	run-time meter	all houses
Indoor temperature	temperature, °F	hourly	monthly	Telog temperature recorder	all houses
Outdoor temperature	temperature, °F	hourly	monthly	data logger equipment	three sites
Other weather parameters	------	hourly	monthly	provided by local weather station	

meters will be manually read once a week by NFG, with the reading being recorded on the data collection sheet provided in Sect. 6. The data collection sheets will be forwarded to ORNL weekly.

The normal billing data collected by NFG for accounting purposes should also be forwarded to ORNL. At the end of each monitoring period (May 1988 and May 1989), the billing data for the previous two years should be downloaded from NFG's records using their standard programs and sent to ORNL. Figure 5.2 is an example of the data obtained from the downloading procedure and its format.

In a majority of the houses (approximately 90), the Metscan Telephony Based System[5] will be employed to read the house gas billing meter once a day (representing the house gas use from midnight to midnight). A remote monitoring device will be installed in each of these houses to record the daily readings and to initiate communication to the data collection network once a month. The data collection network receives the daily data from the remote monitoring devices via local telephone exchange, stores the data, and generates reports. NFG will provide and install all the equipment required to collect these daily data. NFG will provide ORNL with the daily data once a month as it is collected using the report shown in Fig. 5.3. It should be emphasized that house gas use should still be manually recorded once a week as described above in these houses.

The house gas consumptions are measured in units of ft^3 of gas. In order to convert the house consumptions (and other submetered consumptions to be discussed below) into units of energy, the heat content of the gas must be known. NFG will provide data monthly on the heat content of their gas.

IK685ZZ

NATIONAL FUEL
BILL INVESTIGATION

DATE: 10/29/87
TIME: 09:15:29

ACCT NUM - 164702203000
CUST NAME -
STREET -
TOWN CODE - TNEO
PHONE NUM -

METER NUM - 12074717
METER KIND - X22440
BASE LOAD - 2.5
DEGREE DAY FACTOR - 0.0104
PRESENT READING - 90.1

BILL TYPE	CONSUMPTION	NET AMOUNT	BILLING DATE	DEGREE DAYS	GAS COST RATE	CONS PER DD
EST	6.0	36.23	10-23-87	341	-1.02942	0.0103
EST	3.2	22.26	09-24-87	70	-0.93021	0.0100
EST	2.5	18.14	08-25-87	1	-1.07853	0.0000
ACT	2.0	14.79	07-28-87	4	-1.43859	-0.1250
EST	2.8	18.65	06-29-87	27	-1.42053	0.0111
ACT	3.5	22.01	05-29-87	308	-1.41533	0.0032
EST	7.4	39.85	04-29-87	464	-1.44598	0.0106
ACT	7.6	40.77	03-30-87	867	-1.44484	0.0059
EST	18.0	90.34	02-27-87	1346	-1.31248	0.0115
ACT	24.5	135.78	01-28-87	1103	-0.74082	0.0199
MC	12.9	74.38	12-29-86	1034	-0.75167	0.0101
ADJ	4.4	28.98	11-24-86	660	-0.85228	0.0029
TOTAL	94.8	542.18		6225		0.0104
EST	5.5	34.77	10-23-86	297	-0.85758	0.0101
EST	4.0	26.82	09-24-86	151	-0.85549	0.0099
EST	2.6	19.73	08-25-86	5	-0.69433	0.0200
ACT	0.7	9.48	07-28-86	14	-0.27923	-0.1286
EST	3.3	25.06	06-27-86	77	-0.28950	0.0104
ACT	9.2	59.66	05-29-86	226	-0.27151	0.0296
EST	7.7	50.46	04-27-86	336	-0.24266	0.0094
EST	11.8	72.46	03-31-86	1004	-0.27209	0.0093
ACT	21.7	131.27	02-27-86	1292	-0.15525	0.0149
EST	14.5	90.42	01-28-86	1336	-0.10153	0.0090
EST	12.1	76.39	12-27-85	1063	-0.10100	0.0090
ACT	3.5	25.86	11-22-85	548	-0.07663	0.0018
TOTAL	96.6	622.38		6569		0.0101

REMARKS: --

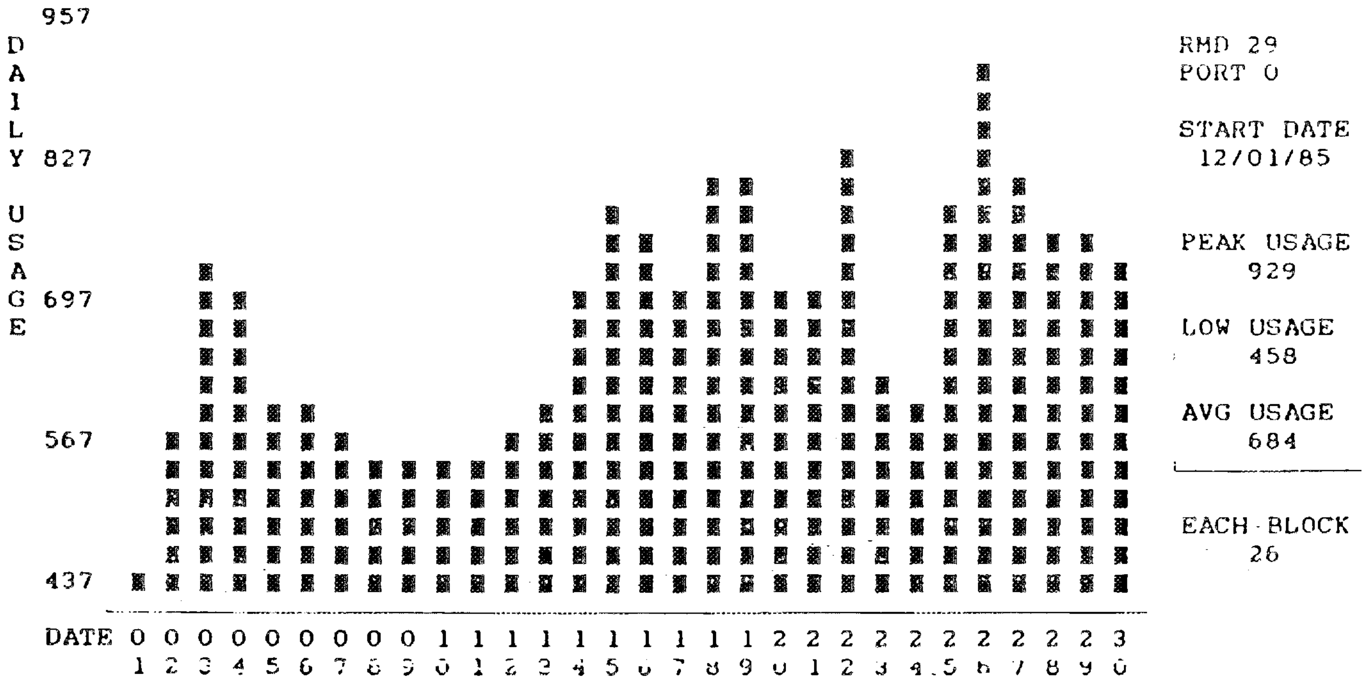
Fig. 5.2. Format of the monthly billing data obtained in downloading information from NFG's records.

METSCAN METER READING SYSTEM

DAILY USAGE GRAPH

RMD: 29 PORT: 0

12/01/85 - 12/30/85



ALL USAGE IN CUBIC FEET

*** DAILY USAGE COUNTS AND READINGS ***

DATE	USAGE	READING	DATE	USAGE	READING
12/01/85	458	292789	12/17/85	708	302970
12/02/85	589	293378	12/18/85	821	303791
12/03/85	746	294124	12/19/85	802	304593
12/04/85	711	294835	12/20/85	706	305299
12/05/85	598	295433	12/21/85	705	306004
12/06/85	615	296048	12/22/85	846	306850
12/07/85	575	296623	12/23/85	637	307487
12/08/85	562	297185	12/24/85	602	308089
12/09/85	548	297733	12/25/85	775	308864
12/10/85	549	298282	12/26/85	929	309793
12/11/85	549	298831	12/27/85	817	310610
12/12/85	572	299403	12/28/85	754	311364
12/13/85	609	300012	12/29/85	769	312133
12/14/85	706	300718	12/30/85	738	312871
12/15/85	793	301511			
12/16/85	751	302262			

Fig. 5.3. Format in which the daily billing meter data will be provided.

5.2.2 House Electricity Use

The existing electric billing meter installed in each house will be used to monitor the house electricity consumption. Although these meters will not be recalibrated, they should generally provide an accuracy of 3%. These meters will be manually read once a week by NFG. The reading will be recorded on the data collection sheet provided in Sect. 6, which will subsequently be forwarded to ORNL weekly.

5.2.3 Heating System Gas Use

Because the gas consumption rate of the heating equipment to be encountered in the field test should be steady whenever the unit is operating, the heating system gas use will be monitored in each house by measuring its operating time using elapsed-time (run-time) meters. In this monitoring technique, the meter is installed in the thermostat control circuit, in parallel with the solenoid valve controlling the gas supply valve, so that power is supplied to the meter whenever power is supplied to the valve. Usually, the thermostat control circuit is a 24 volt DC system, so that a 24 volt DC elapsed-time meter would need to be installed. NFG will provide and install the meters; no particular brand of meter is recommended. These meters will be manually read once a week by NFG, with the reading being recorded on the data collection sheet provided in Sect. 6. The data collection sheets will be forwarded to ORNL weekly.

In order to convert the operating time to a gas consumption, the consumption rate of the equipment must be known. The combined gas consumption rate of the heating system's main burner and pilot is readily measured using the house gas billing meter and following the procedure outlined in Appendix B. During the pre-retrofit period, these measurements need to be made in December, 1987, when the monitoring instruments are installed. The measurements should be repeated in November or December, 1988, during the post-retrofit period. Pre- and post-retrofit measurements are needed to make sure the rate has not changed from one year to the next or to determine the rate of a new heating system.

The error of measuring the weekly heating system gas use with this method is estimated to be 5%.

5.2.4 Hot Water System Gas Use

The hot water system gas use in each house can be measured using elapsed-time meters in a manner similar to that for the heating system. In this case, however, the meter cannot be installed directly into the hot water system's control circuit because it is different. Instead, the meter is wired in series with a gas pressure switch, with voltage being supplied from any continuously available source (house current, 24 volt transformer operating from house current, or the heating system's 24 volt transformer). The pressure switch is installed to sense the gas pressure in the gas line downstream of the control valve leading to the burner and configured to close when the pressure rises slightly above atmospheric pressure. With this configuration, power is supplied to the meter whenever gas is supplied to the hot water tank. In many hot water systems, a pressure tap is provided on the control box which can be used to connect the pressure switch. Depending on the power source chosen, a 110 volt AC or 24 volt DC meter would be used. All equipment required for this metering technique will be provided and installed by NFG. These meters will be manually read once a week by NFG. The reading will be recorded on the data collection sheet provided in Sect. 6, which will subsequently be forwarded to ORNL weekly.

The gas consumption rate of the hot water system must also be known in order to convert the operating time into a gas consumption. The rate is measured using the house gas billing meter in a manner similar to that for the heating system. Details of the correct procedure are outlined in Appendix B. These rates should be determined at the same time the heating system consumption rates are measured.

5.2.5 Indoor Temperature

The indoor temperature of each test house will be monitored using Telog's 2103 Ambient Temperature Recorder (literature is provided in Appendix C). These devices include a temperature sensor and microprocessor based electronics to calculate and store the average hourly temperature and have been found (through testing) to be accurate to within 1°F. The device will be located in either the main living area of the house (as possibly typified by the location of the television set) or next to the thermostat controlling the heating system. The placement of the device should minimize its exposure to radiant energy from the sun, exterior walls and windows, lamps, and other significant radiators. The device should also not be exposed to heat sources such as vents or appliances in the surrounding area. The devices will be provided by ORNL and installed by NFG. The devices will have to be removed at the end of the pre-retrofit period and re-installed before the start of the post-retrofit period in order that they can be used in another ORNL experiment.

The hourly data stored by the devices will be collected once a month by NFG using two data transfer units provided by ORNL. Data from up to 60 devices can be stored in each of the data transfer units. These data will be transfered to a floppy diskette using ORNL supplied software and NFG's microcomputer. The diskette will then be provided to ORNL monthly.

5.2.6 Outdoor Temperature

The hourly outdoor temperature at three selected sites will be monitored. The sites will be distributed among the test houses so that the outdoor temperature at each house can be represented by the data collected from at least one site. The selected sites will be NFG field offices.

The instrumentation to be used at each site includes a battery powered data logger, a battery powered tape recorder, a type T (copper-constantan) thermocouple, and a radiation shield. This equipment will measure the outdoor temperature accurately to within 1°F. Literature on the data logger, tape recorder, and radiation shield are presented in Appendix C. The sensors will be located where they are unaffected by heat sources or sinks in the surrounding area and where the ambient air is well mixed with the surrounding air. A sensor location on the north side of the building and below roof level is preferred. The radiation shield will be used to protect the sensor from the sky and other significant radiators such as roofs, walls, driveways, patios, and the ground. The shield will also protect the sensor from rain, hail, lightning, and other ambient conditions. The equipment required for these measurements will be provided by ORNL and will be installed by NFG and ORNL.

The instrumentation will measure the average hourly outdoor temperature at each site and automatically store the data on cassette tape at periodic intervals. NFG will collect the tapes from the sites once a month and mail them to ORNL.

5.2.7 Other Weather Data

Hourly weather data other than the outdoor temperature (such as wind speed, wind direction, solar radiation, and humidity) will be obtained from the local weather station by ORNL once a month.

5.2.8 Special Considerations

The location of the installed metering is very important to minimize the efforts required for data collection. The house gas billing meter, house electric billing meter, heating system elapsed-time meter, and hot water system elapsed-time meter will be read simultaneously once a week. These meters must be located outside or located where they can be read from the outside in order that the meter reader does not have to enter the house each week. The scheduling required to arrange for in house meter reading will be difficult and expensive, and will eventually lead to the significant loss of data. Because the readings need to be made simultaneously, the occupants cannot be used to read the inside meters.

Gas meters located in the test houses should be equipped with remote reading devices to avoid the need to enter the house. Standard devices with the display located outside and requiring manual reading are preferred over the telemetering equipment in order that the four weekly measurements in each house can be collected simultaneously. The houses to have telemetering equipment installed should not currently have an indoor gas meter or remote device installed: the telemetering equipment will interfere with the remote reading device, requiring its removal.

The electric billing meter may also be located inside the home. As this meter is not under NFG's control, a remote readout device on the electric meter cannot be installed. In this case, the only option will be to schedule a time each week to enter the house.

The elapsed-time meters measuring the heating system and hot water system operating times will be located in the house. However, during installation, the meters themselves should be installed so that their dial faces can easily be read from the outside, perhaps through the basement window.

Another consideration that needs to be addressed is measuring the gas consumption rates of the heating systems and hot water systems when the telemetering equipment is in place. This equipment may prohibit the lowest dial from being read; thus, the calibrations could not be easily performed as the next sized dial would not be sufficiently accurate to perform the tests in a reasonable period of time. As a result, the telemetering equipment will have to be removed and reinstalled each time the calibrations are performed if the lowest dial cannot be read.

6. DATA MANAGEMENT

This chapter will describe the data management procedures for both the time-sequential measurements and the survey information. Data bases will be designed to store these data separately. The links (relations) between separate data bases will be household IDs and dates and times of the time-sequential data.

6.1 TIME-SEQUENTIAL MEASUREMENTS

Figure 6.1 demonstrates the flow of the data management procedure for the time-sequential measurements. This procedure is described in detail below.

House gas consumption, house electricity consumption, heating system gas consumption, and hot water system gas consumption are time-sequential data parameters that will be monitored using billing meters or elapsed time meters. These meters display the integrated total gas consumption, electricity consumption, or run-time of the equipment. The energy consumptions for a selected time interval must be determined by subtracting the reading at the beginning of the interval from the reading at the end of the interval and, if appropriate, multiplying the difference by a conversion factor (the gas consumption rate in the case of the heating system and hot water system sub-meters).

The current readings of these meters will be manually recorded once a week by NFG using the data form provided in Fig. 6.2 and forwarded to ORNL. These data will be immediately entered into a computer data base using microcomputer based data entry software developed by ORNL. The full screen interactive data entry system will

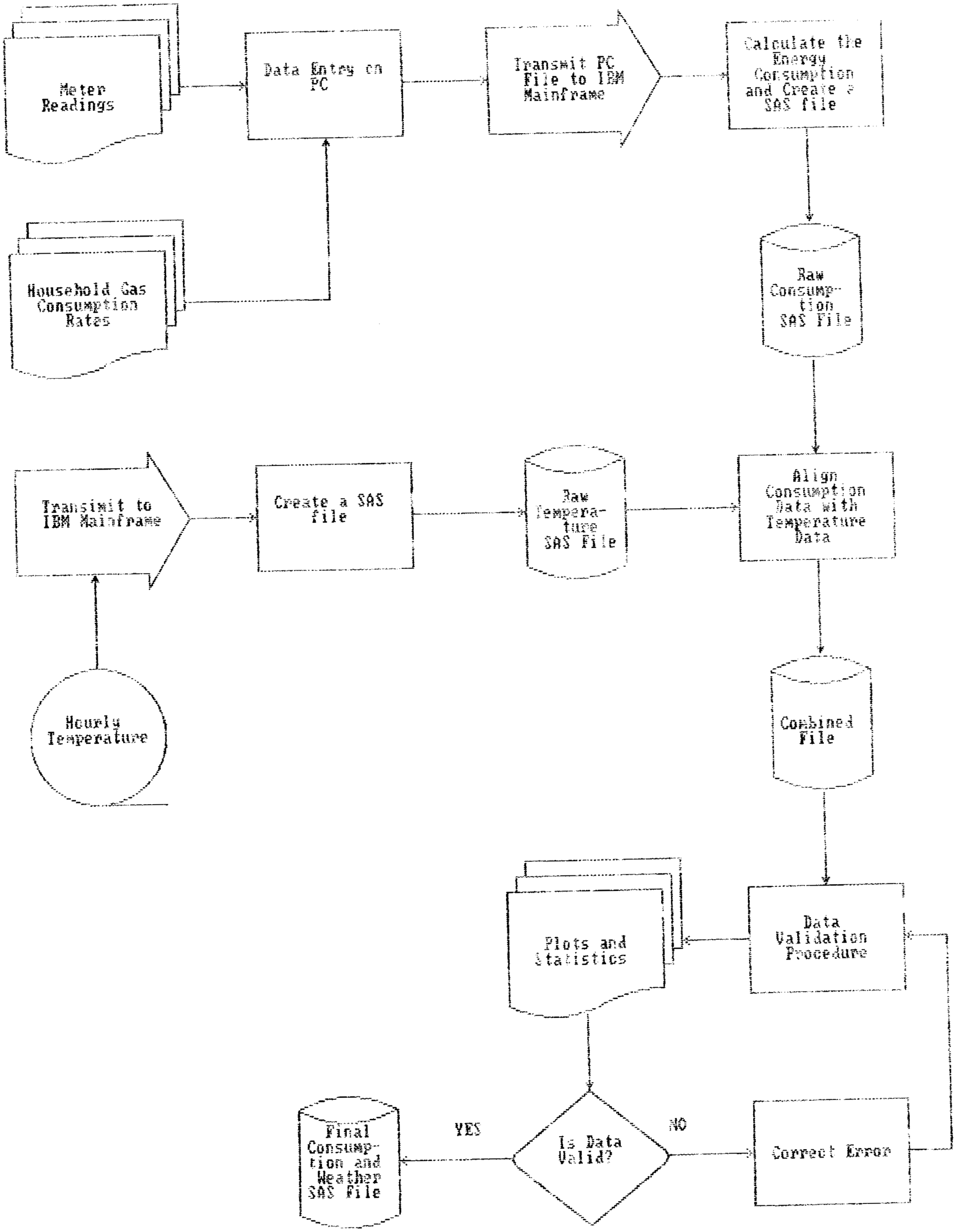


Fig. 6.1. Data management procedure for the time-sequential measurements.

NFG End Use Efficiency Field Test
Buffalo, New York
Weekly Meter Data

House ID: ______________ Address: ________________

DATE OF READING: / / TIME OF READING: __ __:__ __
(mo/day/yr) (hr.min)
a.m._____ p.m._____

Meter Readings

Gas Meter:__ __ __ __00 Electric Meter:__ __ __ __ __

Furnace Submeter:__ __ __ __ __.__ Hot Water Submeter:__ __ __ __ __.__

Fig. 6.2. Weekly field data collection form.

be designed using the dBASE III Plus Database Management System. Basically, a query screen, identical to the data form, will appear on the terminal monitor and prompt the user for the inputs. The operator enters the information at the available blank spaces and presses the carriage return key to store the information in a weekly data base. A blank query screen will then reappear for the next record (data form). This procedure will be repeated until all the records for the week have been entered. This system not only facilitates entering the data, but also allows browsing, editing, and deleting of information in the weekly data base.

The energy consumptions for the current recording period will be automatically calculated using the current readings, previous readings, and appropriate conversion factors or household gas consumption rates. The conversion factors, identified by their respective house IDs, will be stored in a separate file. The energy consumptions for the current recording period will be calculated and then merged with the previously calculated consumptions in a raw consumption file.

In addition to monitoring the four energy consumptions identified above in each house, the hourly indoor temperature will be monitored in each house and hourly outdoor temperatures will be monitored at three different sites. The indoor temperature data will be continuously stored in the meters, read once a month, and forwarded to ORNL on floppy diskettes. The outdoor temperature data will be continuously stored on cassette tape and forwarded to ORNL monthly in this form. A software package provided by the manufacturer will then be used to transfer the data from cassette to the microcomputer. The weekly consumption data will need to be aligned with the hourly indoor and outdoor temperatures because, in the analysis to be performed (see Sect. 7), an average indoor and outdoor temperature corresponding to each recording period (to the nearest hour) will be needed. Due to manpower and equipment constraints, the hourly indoor temperature data cannot be recorded on the hour, and the energy consumption meters in the various houses will be read at different times and on different dates. This complicates the calculations required to determine the average temperatures for the recording periods corresponding to each house. For example, if the consumption readings from household A are collected at 3:40 p.m., November 23, and 10:30 a.m., November 30, and the hourly outdoor temperatures are recorded on the hour, then the average outdoor temperature between November 23 at 4:00 p.m. and November 30 at 11:00 a.m. needs to be calculated. The hourly temperature data will be transferred into a raw temperature file. A procedure will then be employed to align individual household consumption data with the hourly indoor and outdoor temperature data and to store the merged data in a combined file.

Data validation procedures will be implemented during the processes described above. The validations will include range checks, logic checks, and visual examination of plotted data (such as between consumption and outdoor temperature). The following checking will occur automatically on the raw consumption and temperature files:

weekly consumption data:

(1) house gas use >0,
(2) house electricity use >0,
(3) heating system gas use >0,
(4) hot water system gas use >0,
(5) house gas use > heating system gas use plus hot water system gas use;

indoor temperature data:

55°F < indoor temperature < 90°F;

outdoor temperature data:

(1) $-20°F <$ outdoor temperature $< 70°F$,

(2) data logger battery voltage > 10 volts,

(3) data logger program signature is constant,

(4) year = 1988 or 1989,

(5) 0 < julian date < 366,

(6) 0 < time < 2400.

If an error is detected, the data point will be flagged and examined by project staff. If the errors originate from the monitoring instruments, then actions will be taken to correct them to ensure data quality in future data collection. If the error stems from the data recording procedure, procedures will be used to estimate or recalculate the actual data.

All these procedures (i.e., data entry, data transferring, data validating, converting meter readings to consumption, and data aligning) will be performed regularly upon receiving the data from NFG. Statistical Analysis System (SAS) software residing on a microcomputer will be used as the tool for the majority of the data manipulations and data validations.

6.2 SURVEY INFORMATION

The survey information identified in Sect. 5.1 will be collected from individual participating households through interviews, site visits, and limited measurements. These data will be transferred to a data base residing on a microcomputer using a full screen interactive data entry system and procedures similar to that described in Sect. 6.1. The time-sequential and survey data will be combined only when it is necessary to identify the relationship between survey information and energy consumption or savings. Figure 6.3 illustrates the flow of the data management procedure for the survey information.

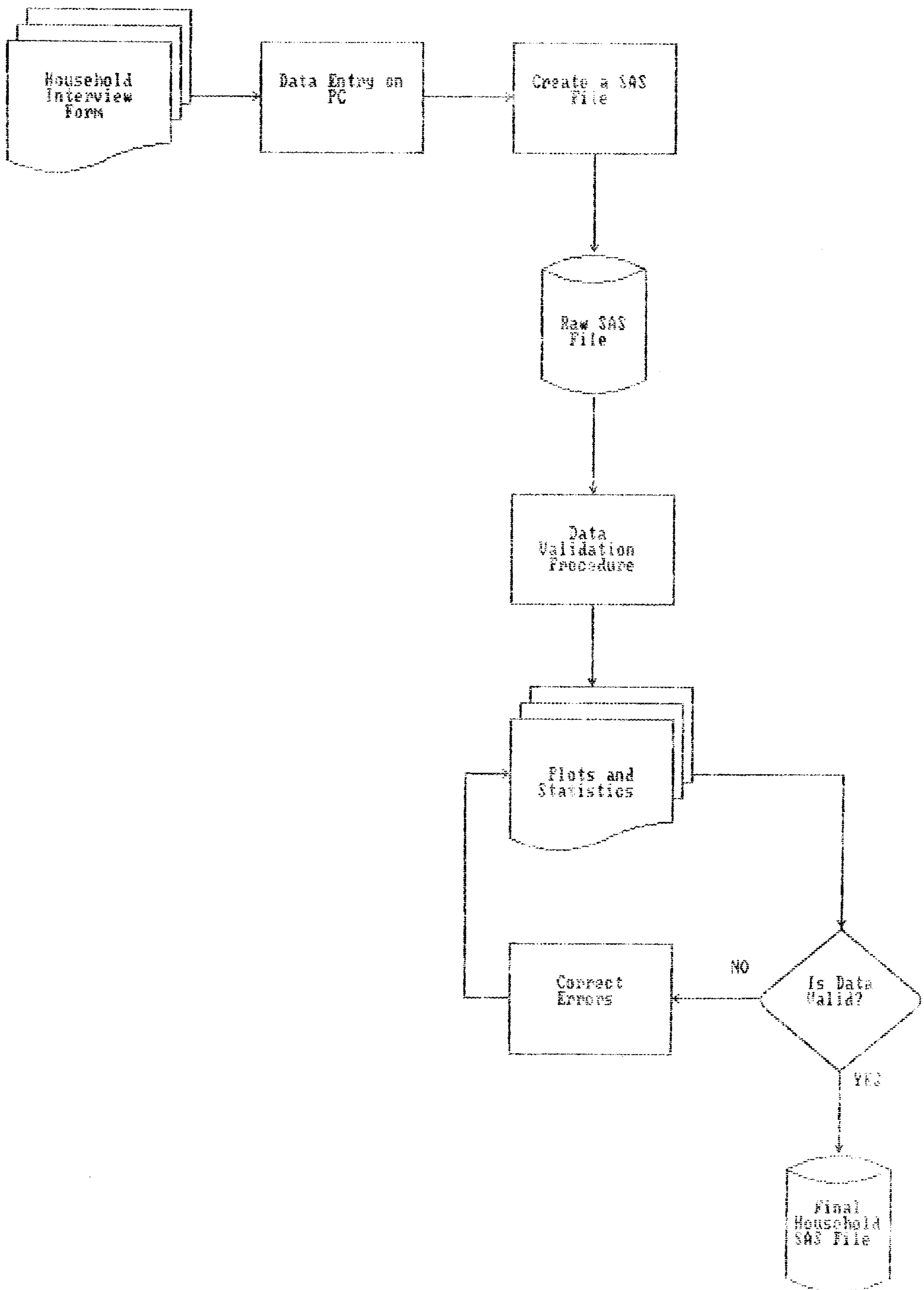


Fig. 6.3. Data management procedure for the survey information.

7. DATA ANALYSIS

Section 2.2 identified a number of specific research questions that must be addressed at the conclusion of the field test. These questions were grouped into four categories: physical characteristics of the houses and occupants, implementation of the audit procedure, performance of the audit procedure, and use of the telemetered data. The following subsections will present the approaches to be employed to address these questions.

7.1 PHYSICAL CHARACTERISTICS OF THE HOUSES AND OCCUPANTS

The general physical characteristics of the houses and occupants will be evaluated by tabulating and graphing the survey data. Occupant characteristics of interest are the number of household members and their ages. Important characteristics of the houses are their floor areas, age, type, number of floors, and foundation type. The pre-retrofit thermal condition of the houses will be summarized by studying the amount of attic, wall, and floor insulation installed, the heating system efficiencies, the infiltration rates, the amount of ductwork located in uninsulated spaces, and the pre-retrofit energy consumptions (determined from the analysis of the pre-retrofit submetered data). The appliances found in these homes will also be summarized.

7.2 IMPLEMENTATION OF THE AUDIT PROCEDURE

Questions regarding the implementation of the audit procedure will be addressed using data collected under the audit procedure after it has been tabulated and graphed. The information to be analyzed includes the measures recommended by the audit procedure for installation, the measures actually installed, the estimated and actual cost to install each measure, and the energy savings and B/C ratio predicted for each recommended measure. The measures recommended by the audit procedure will be compared to measures recommended by NFG's current audit.

7.3 PERFORMANCE OF THE AUDIT PROCEDURE

The performance of the audit-directed retrofit procedure will be evaluated on an individual and group basis. The annual energy savings measured in the audit houses will be compared to predicted values. The cost effectiveness of the retrofits installed in the audit houses (which depends on annual energy savings, installation costs, and retrofit lifetime) will also be examined. The analysis procedures to determine the annual energy savings in individual houses, the savings in the audited houses as a group, and cost-effectiveness will be discussed separately. In the analytical procedures discussed, appropriate statistical analyses will be performed in order that the uncertainty associated with the final answers can be stated.

7.3.1 Individual House Savings

The annual energy savings can be defined as "the annual amount of energy saved by a retrofit if all factors are kept constant except for the retrofit itself." This definition is applicable if the true retrofit effect (the savings actually induced by the retrofits only) is of interest. The retrofit effect is not the same as the observed annual energy savings, as this latter savings is influenced by differences in outdoor and indoor climate, occupant behavior changes following retrofit installation, and changes in occupancy. For this study, the retrofit effect will be considered to be the observed annual energy savings normalized for outdoor temperature, indoor temperature, internal load, and occupant behavior changes.

To calculate the retrofit effect observed in the audited houses, the change in annual energy consumption of the individual audited and control houses (normalized for outdoor temperature, indoor temperature, and internal load) must be determined. These changes cannot be directly determined from the pre- and post-retrofit data for several reasons: (1) the time periods over which the data were collected may not be equal nor cover the entire winter season, (2) the pre-and post-retrofit weather conditions will likely be different, and (3) indoor temperatures and internal loads maintained in each house over the two periods may not be the same. Consequently, a house model must be employed to correct for these conditions. The following model derived by considering an energy balance on the house will be employed:

$$(n\ E) + I = k\ (Ti - To),$$

where the variables are defined to be

- n - the efficiency of the heating system,
- E - the energy consumption of the heating system,
- I - the internal load of the house,
- k - a factor to be determined by regression,
- Ti - the indoor temperature, and
- To - the outdoor temperature.

The internal load will be defined to be the energy input due to all electric appliances, lights, and gas appliances other than the heating and hot water systems. This quantity will be found by subtracting the heating system and hot water system gas consumptions from the total house gas consumption and adding this difference to the house electricity consumption. The factor k is roughly equivalent to the overall heat loss coefficient of the house and includes such effects as wind-induced infiltration and heat flows due to radiation.

Linear regression techniques will be used to estimate the value of k for the pre- and post-retrofit periods for each house using the pre- and post-retrofit data, respectively. The pre- and post-retrofit annual heating energy consumptions will then be estimated using the respective values of k, the respective values of n (if the heating system efficiencies did not change, then the values of n would be the same; if, for example, a new furnace was installed, the pre- and post-retrofit values of the efficiency would be different), average outdoor temperature data based on historical records, and assumed values for the indoor temperature and internal load. The change in annual energy consumption of the house due to the installation of the retrofit measures (normalized for outdoor temperature, indoor temperature, and internal load) is then equal to the pre-retrofit heating consumption minus the post-retrofit consumption. The retrofit effect of the audited houses is not simply equal to this change in energy consumption; rather, the retrofit effect of the audited houses is equal to their change in energy consumption adjusted by the average change in energy consumption of the control houses. As discussed in Sect. 4.1, this final adjustment normalizes for occupant changes not induced by the retrofit installation, allowing the savings actually induced by the retrofits only to be determined.

The values for the indoor temperature and internal load could be based on average values maintained during the pre-retrofit period or on values used in the audit to predict the retrofit energy savings. Use of the former values normalize the energy consumptions in each house to its own pre-retrofit conditions while the latter values normalize the energy consumptions in all the houses to some average house characteristics. The latter values will be used to allow the retrofits from the individual houses to be compared to each other and to the predicted values on an equal basis.

A relaxed definition of the annual energy savings could include energy savings resulting from occupant behavior changes induced by the retrofit installations. In this case, the savings would be normalized for outdoor temperature and by the control houses, but not for indoor temperature and internal load. The annual energy savings defined in this manner would be of interest if a programmatic perspective is desired. Calculation of the savings defined in this manner will be performed by using values for the indoor temperature and internal load based on pre-retrofit data to calculate energy consumptions before retrofit installation, and values based on post-retrofit data to calculate consumptions after retrofit installation.

7.3.2 Group Savings

The individual house savings will be analyzed using an analysis of variance approach to calculate group savings and to identify the effect of selected variables on the savings. The energy savings of the control houses will be determined and used in the individual and group savings normalizations to account for occupant behavior effects not induced directly by the retrofits. The average savings due to the installation of the retrofit measures in the audited group of houses will be of interest. Additionally, the effect of other variables on the measured savings (such as pre-retrofit energy consumption and type of heating system) will also be investigated.

7.3.3 Cost Effectiveness

The B/C ratio of the retrofit measures will be determined using standard economic procedures to represent the actual cost effectiveness of the measures. This ratio will be determined for the individual houses and the group of audited houses using the normalized energy savings, actual installation costs, estimated retrofit lifetimes, and other economic parameters as required.

7.4 USE OF THE TELEMETERED DATA

The benefits and disadvantages of telemetered data will be studied by comparing energy savings determined from an analysis of the daily telemetered data with the savings determined from analyses using weekly submetered data and monthly billing data. The analysis techniques that will be used to determine the energy savings using the weekly submetered data were presented in Sect. 7.3. Monthly billing data will be analyzed using the Princeton Scorekeeping Method (PRISM).[15] In this method, monthly house fuel consumptions are regressed against monthly heating degree days to normalize the consumptions for outdoor temperature.

Under this field test, techniques to analyze the daily telemetered data are to be developed and validated; consequently, specific methods will not be presented in this report. However, the methods will most likely resemble the above analyses in that the daily house gas consumptions will be normalized for the outdoor temperature using regression techniques and an appropriate temperature term.

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APPENDIX A

ENTRANCE INTERVIEW FORM

Appendix A. ENTRANCE INTERVIEW FORM

The form presented in this appendix was developed to collect the descriptive information specified in Sect. 5.

ENTRANCE INTERVIEW FORM
ORNL

Experimental Program: NFG End-Use Efficiency Field Test House ID: ___

Interviewer Name: ______________________ Date: __________

Name: ____

Street Address: ______________________________

City: Buffalo State: NY Zip Code: ______

County: Erie Phone Number: ( ) __________

Utility Distributors:
Electric ______________________
Gas National Fuel Gas Company
Oil ______________________
Other ______________________

HOUSE

Type: ____ (MS - multi-story detached; RA - ranch detached;
SL - split level detached; SA - attached; MH - mobile home)

Number of Floors (including basement): ___ Approximate Age: ____ years

Predominant Roof Type: ___ (P - pitched roof; F - flat roof;
V - ventilated attic; X - other)

Roof Color: __________ Exterior Wall Color: __________

Number of rooms typically closed off: _____
Description: ________________________________

Heated floor area:

Floor	Total Area (ft^2)	Heated Area (ft^2)
Basement	______	______
First floor	______	______
Second floor	______	______
Third floor	______	______
Other	______	______
Total	______	______

OCCUPANCY

Ownership: _OW_ (OW - own; RE - rent)

Length of time at this address: ___ years

Number of occupants, by age group:

Preschool	____
School age	____
Adult, not retired	____
Adult, retired	____
Total	____

Number of occupants generally home during the day:

weekday	____
weekend	____

HEATING SYSTEM

Manufacturer: ________________ Model: ________________

Fuel: _G_ (G - gas; O - oil; E - electricity; W - wood; C - coal; L - LP; S - solar; X - other)

Type: ____________ (B - boiler; F - furnace; FF - floor furnace; SH - space heater; A - central air-to-air heat pump; W - water coupled heat pump; WHP - window or wall heat pump; CH - ceiling heat; EB - electric baseboard; D - district heating; X - other)

Distribution fluid: ___ (S - steam; W - water; A - air; Z - unknown; X - other)

Distribution method: ___ (G - gravity; F - forced; Z - unknown)

Input capacity: ________ Btu/h Output capacity: ________ Btu/h

Efficiency rating: ______ Approximate age: ______ years

Location: ____ (NC - non-conditioned space or outside air intake provided; IC - intentionally conditioned space; UC - unintentionally conditioned space)

Is this a converted coal unit: ____ (Y - yes; N - no)

Is this a converted oil unit: ____ (Y - yes; N - no)

HEATING SYSTEM (continued)

Is a vent damper present: ____ (T - thermal; E - electric; N - no; NA - not applicable)

Is an IID present? ___ (Y - yes; N - no)

If oil fired, has a flame retention head burner been installed? NA (Y - yes; N - no; NA - not applicable)

For an oil boiler, what subtype is it? NA (WB - wet base; DB - dry base; NA - not applicable)

If a pilot light is present, is it turned off during the summer? ____ (Y - yes; N - no; NA - not applicable)

Auxiliary heat use (hours per week, average):

portable electric heater	______
fireplace	______
fireplace insert	______
wood stove	______
kerosene/LPG room heater	______
built-in zone heater	______

DISTRIBUTION SYSTEM

Total length of ducts or piping: _____ feet

Length of ducts or piping in unconditioned space: ____ ft

Insulation thickness of ducts in unconditioned space: ___ inches

THERMOSTAT

Manufacturer: ______________________ Model: ________________

Type: ____ (R - regular; C - clock; N - none; X - other)

Number of units: _____

HOT WATER SYSTEM

Manufacturer: ______________________ Model: ________________

Fuel Type: _G_ (E - electricity; G - gas; O - oil; M - mixed; X - other)

Storage: ___ (T - storage tank; L - tankless; Z - unknown)

Heater Type: ___ (B - boiler; R - residential type; L - solar; W - boiler in winter; S - separate generator in summer; Z - unknown; X - other)

Tank Size: ____ gallons Temperature (measured): ____°F

Input: ______________ Btu/h Recovery: _______

Blanket insulation thickness: _____ inches

Location: ____ (NC - non-conditioned space or outside air intake provided; IC - intentionally conditioned space; UC - unintentionally conditioned space)

APPLIANCES

Appliance	Fuel	Location
Cooking range	______	____________
Conventional oven	______	____________
Microwave oven	______	____________
Clothes washer	______	____________
Clothes dryer	______	____________
Refrigerator/	______	____________
Separate freezer	______	____________
Dishwasher	______	____________
Whole house fan	______	____________
Attic fan	______	____________
Other	______	____________

Fuel: E - electricity; G - gas; X - other; N - other

Location: NC - non-conditioned space or outside air air intake provided; IC - intentionally conditioned space; UC - unintentionally conditioned space

ATTIC

Sub-area	Area (ft^2)	Construction	Insulation Type	Insulation Thickness (in.)
1	______	____________	__________	______________
2	______	____________	__________	______________
3	______	____________	__________	______________
4	______	____________	__________	______________

Construction: AF - attic floor; KW - knee wall; SC - sloped or cathedral ceiling

Insulation type: BC - blown cellulose; BF - blown fiberglass; TF - batt fiberglass; BR - blown rock wool; TR - batt rock wool; RB - rigid board; X - other; N - none

EXTERIOR WALLS

Sub-area	Area (ft^2)	Construction	Siding	Insulation type	Insulation thickness (in.)
1					
2					
3					
4					

Construction: FR - frame; MA - masonry (concrete); CB - concrete block; BR - brick; X - other

Siding: W - wood; BR - brick; SN - stone; SC - stucco; SI - aluminum, steel, or vinyl siding; M - metal; SH - shingle; SL - slate; N - none; X - other

Insulation type: BC - blown cellulose; BF - blown fiberglass; TF - batt fiberglass; RB - rigid board; BR - blown rock wool; TR - batt rock wool; X - other; N - none

SUB FLOOR

Sub-area	Area (ft^2)	Type	Status	Insulation type	Insulation thickness (in.)	Percent carpeted
1						
2						
3						
4						

Type: B - basement; S - slab; C - crawl space; X - other

Status: NC - non-conditioned space; IC - intentionally conditioned space; UC - unintentionally conditioned space

Insulation type: TF - batt fiberglass; TR - batt rock wool; RB - rigid board; X - other; N - none

FOUNDATION

Predominant type: ___ (B - basement; S - slab; C - crawl space; X - other)

Foundation Walls:

Sub-area	Area (ft^2)	Construction	Insulation type	Insulation thickness (in.)	Above ground area (ft^2)
1					
2					
3					
4					

Construction: CB - concrete block; C - concrete; S - stone; X - other

Insulation type: TF - batt fiberglass; RBI - interior rigid board; RBE - exterior rigid board; FI - interior foam; FE - exterior foam; X - other; N - none

Are the sill boxes or band joists insulated: ___ (Y - yes; N - no; NA - not applicable)

WINDOWS AND GLASS DOORS

Predominant window type: ___ (CA - casement; DH - double hung; FX - fixed; X - other)

Are external shades, shutters, or films installed? ___ (Y - yes; N - no)

	Single-pane area (ft^2)		Multi-pane area (ft^2)	
	w/o storm windows	with storm windows	w/o storm windows	with storm windows
Front of house				
Left side of house				
Right side of house				
Back of house				
Basement (all sides)				

NON-GLASS DOORS

Orientation	Regular door area (ft^2)	Regular door with storm door or thermall insulated door area (ft^2)
Front of house		
Left side of house		
Right side of house		
Back of house		

INFILTRATION RATE EVALUATION FACTORS

Building component	Good	Average	Poor
Windows and doors	☐ Window and door frames caulked. Window and door sashes well fitting and weather-stripped or storm windows and doors with good fit.	☐ Window and door frames caulked or window and door sashes weatherstripped or poorly fitting storm doors and windows.	☐ No caulking on window and door frames. No weather-stripping. No storm doors or windows.
Walls and electrical outlets	☐ Ceiling and floor joints and corners well sealed. Electrical outlets with gaskets. No holes around plumbing penetrations.	☐ Some cracks in ceiling and floor joints and corners. No gaskets on electrical outlets. Fewer than three plumbing penetrations with holes around them.	☐ Many cracks in ceiling, floor joints, and corners. No gaskets on electrical outlets. Three or more plumbing penetrations with holes around them.
Attic floor (ceiling)	☐ No cracks in attic floor. No air shafts around flues. No holes around ducts, pipes, or wiring penetrating attic floor. No recessed light fixtures. No trap door or weatherstripped trap door to attic.	☐ Some cracks in attic floor. No air shafts around flues. Some holes around ducts, pipes, or wiring penetrating attic floor. Fewer than three recessed light fixtures. Unweatherstripped trap door to attic.	☐ Many cracks in attic floor. Air shafts around flues. Holes around ducts, pipes, or wiring penetrating attic floor. More than three recessed light fixtures. Uncovered attic access.
Heating system and water heater	☐ Both furnace and water heater electric. If fossil fuel fired, both in unconditioned space.	☐ One fossil fuel-fired unit in living space with vent damper. The other in unconditioned space.	☐ At least one fossil fuel-fired unit in living space without vent damper.
Fireplace or wood stove	☐ Sealed combustion wood stove or fireplace with well-fitting damper and glass doors or no fireplace.	☐ Poorly sealed wood stove or fireplace with either well-fitting damper or glass doors.	☐ Both a wood stove and fireplace or a fireplace with poorly fitting damper and no glass doors.
Ductwork and floor	☐ No ductwork and few floor penetrations or all ductwork in conditioned space and no floor penetration.	☐ Ductwork in conditioned basement and few floor penetrations.	☐ Ductwork in unconditioned space and many floor penetrations.
Vents in conditioned space	☐ No undampered vents and fewer than three dampered vents.	☐ Fewer than three undampered vents or at least three dampered vents.	☐ More than three undampered vents.
Lifestyle	☐ Fewer than six entrances and exits per day.	☐ Six to thirteen entrances and exits per day.	☐ More than thirteen entrances and exits per day.

TYPE OF FUEL

APPLIANCE	GAS	ELEC	OTHER	AGE
FURNACE				
WATER HEATER				
RANGE				
DRYER				
BARBECUE				
OTHER (LIST)				

TYPE OF FUEL

APPLIANCE	GAS	ELEC	OTHER	AGE
FURNACE				
[illegible]				
RANGE				
DRYER				
BARBECUE				
OTHER (LIST)				

APPENDIX B

GAS CONSUMPTION RATE CALIBRATION PROCEDURE

Appendix B. GAS CONSUMPTION RATE CALIBRATION PROCEDURE

The steps outlined in the procedure listed below should be followed to measure the gas consumption rates of the heating and hot water systems.

Step 1: Measure the Gas Consumption Rate of the Heating System - Turn off all the other gas appliances in the house, including their pilot lights. Turn on the heating system. After the heating system has run for a few minutes, record the time (in seconds) required for the lowest dial on the house gas billing meter (either 1/2, 1, or 2 cubic feet) to complete one to ten revolutions (the number of revolutions should be chosen in order that the elapsed time is approximately five minutes). Ensure that the heating system runs constantly during the data collection phase of this step and that the other appliances remain off. The gas consumption rate of the heating system is equal to the dial size multiplied by the number of revolutions and 3600, and divided by the elapsed time.

Dial size (1/2, 1, or 2 cubic feet):_______
Number of revolutions _______
Elapsed time (seconds):_______
Heating system gas consumption rate (ft^3/h):_______

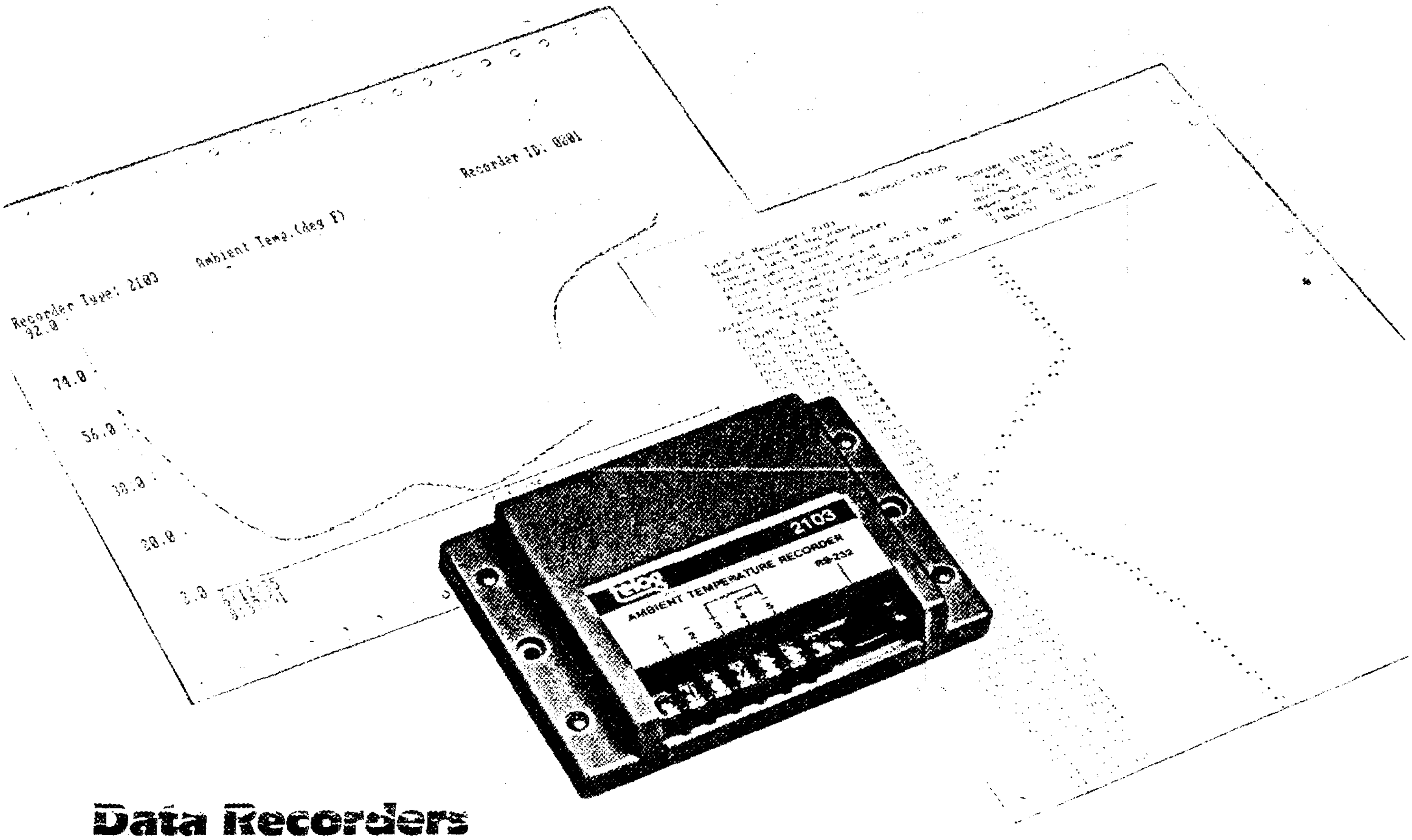
Step 2: Measure the Gas Consumption Rate of the Hot Water System - Turn the heating system and its pilot light off. Relight the hot water system's pilot light and turn the system on, leaving all the other appliances and their pilot lights off. After the hot water system has run for a few minutes, record the time required for the lowest dial on the house gas billing meter to complete one to ten revolutions (the number of revolutions should be chosen in order that the elapsed time is approximately five minutes). Ensure that the hot water system runs constantly during the data collection phase of this step and that the other appliances remain off. The gas use rate of the hot water system is equal to the dial size multiplied by the number of revolutions and 3600, and divided by the elapsed time.

Dial size (1/2, 1, or 2 cubic feet):________
Number of revolutions:________
Elapsed time (seconds):________
Hot water system gas consumption rate (ft^3/h):________

APPENDIX C

MANUFACTURER'S LITERATURE ON SELECTED MONITORING INSTRUMENTATION

2100 SERIES FAMILY BROCHURE



Data Recorders for industry and the environment

Telog 2100 Series Data Recorders provide an accurate, reliable and economical means of obtaining time history records of field data.

The Telog Recorder is a battery-powered electronic instrument designed for unattended measuring and recording of input signals. Its key features include one year battery operation, rugged watertight construction, user-programmable measurements, report-ready computer-generated records, high reliability and low cost. Telog Recorders can replace strip chart recorders in many applications.

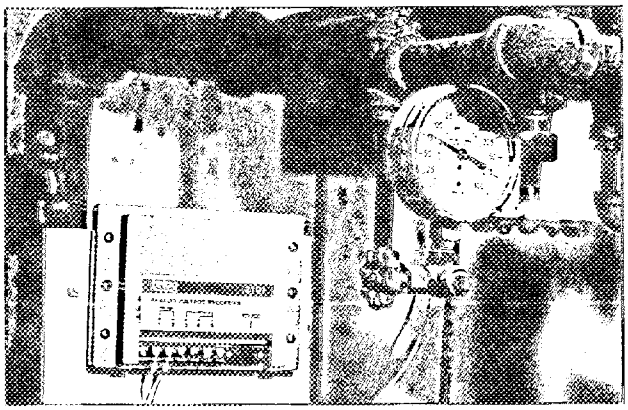
The Telog recorder samples the input signal from an external sensor once per second. At user-programmed intervals, the recorder computes and stores one or more user-selected data values (any combination of average, minimum or maximum). Up to 2000 values will be saved in memory spanning a total measurement period from 10 minutes to over 4 years. Data is transferred to a computer for further analysis, display, printout and archiving. Telog provides inexpensive software support for a variety of popular portable and personal computers.

Each model of the 2100 Series is dedicated to a specific measurement to optimize the recorder's price/performance ratio. The Series includes models for analog voltage, current loops, ambient temperature, thermocouples, RTDs, pulse counting, humidity, shock, wind speed & direction and others. Detailed information on each product is provided by individual 2100 Series data sheets.

FEATURES

- **One year battery life**
- **Watertight, rugged construction**
- **Interfaces with portable and personal computers**
- **User programmable**
- **Low cost**
- **Models specifically for:**
  - **Analog voltage**
  - **Current loops**
  - **Temperature**
  - **Humidity**
  - **Flow, pressure, level**
  - **Wind speed and direction**
  - **Custom and OEM versions**

The Telog Recorder... tough enough to use anywhere



The Telog 2100 Recorder is tough enough to go wherever the sensor is located. Typical applications include use in furnace rooms, refrigerated trailers, atop telephone poles and down manholes. With the exception of the interface connectors, all components are sealed in a compartment protected from rain, dust and EMI/RFI.

The recorder is powered for up to one year by two internal lithium batteries. It may also be powered by external 10 to 28 VDC in which case the internal batteries will provide back-up power as needed for up to 5 years.

The recorder also provides an alarm. The alarm is triggered whenever the measured input signal exceeds a user-programmable upper and/or lower threshold value. The alarm output may be used to control a local relay or interrupt a computer.

User programmable

The Telog recorder measures the input signal once per second. The user programs the recorder to compute and save data at intervals ranging from one second to 18 hours. The data can be any combination of the average, minimum or maximum for each interval.

The recorder has a memory capacity of 1600 or 2000 values, depending on the specific model. When the recorder's memory capacity is reached, the oldest data is overwritten by new data. The recorder therefore always has the most recent information in memory. This makes it very useful as an upset or catastrophy monitor.

For example, the user may choose to record the average and maximum temperature every 10 minutes. The memory capacity would be reached in 7 days. If the user selects hourly averages, the recorder would store 83 days of data.

In addition to programming the interval period and desired statistics, the user also programs the recorder's calendar clock, recorder identification number, and alarm thresholds.

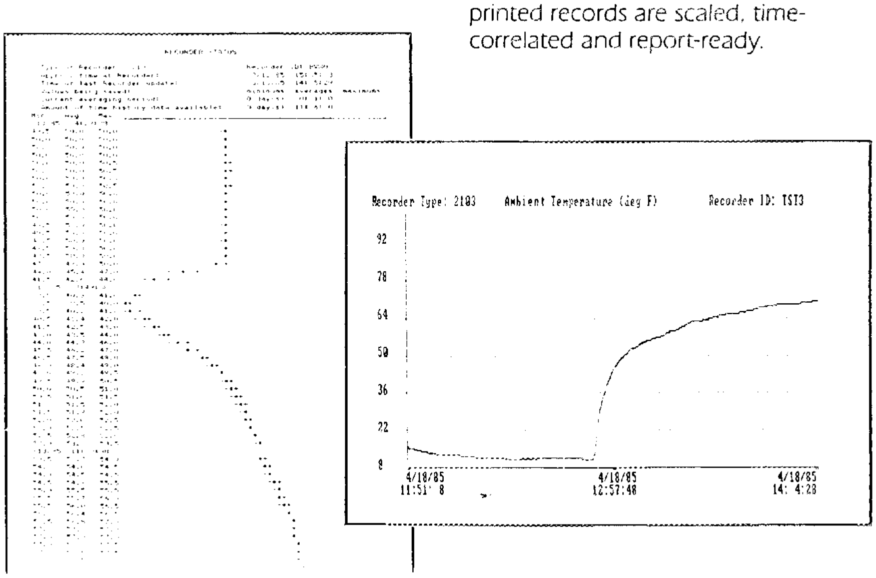
Programming the recorder is a simple task and may be performed when the unit is connected to the user's computer. The recorder itself has no user controls or adjustments.

Computer compatible output

The Telog recorder communicates with computers via an RS-232 compatible interface operating at either 300, 1200, or 9600 Baud. It will automatically adjust to the baud rate of the computer.

Telog supplies and supports inexpensive software for a variety of popular portable and personal computers. Programming and interrogating the recorder with the user's computer is very convenient. The user simply responds to menu prompts; the computer does all the work.

Once the computer has the recorder's data, it can display a detailed graph, generate a choice of hard copy records, or store the data in a file for future reference. The printed records are scaled, time-correlated and report-ready.

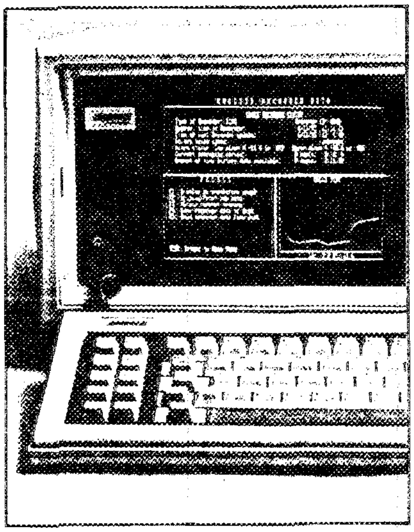


Data collection and analysis products

Telog 201/202 data transfer units

Telog recorders may often be permanently installed at a measurement site. The rugged, battery-operated Telog Data Transfer Unit (DTU), provides an easy, economical means of retrieving recorder data from the field for later analysis.

The user simply connects the DTU to a recorder and presses one button. Data is automatically transferred to the DTU within a few seconds. Information from up to 15 recorders can be collected by a 201, and up to 60 recorders by a 202. This data can then be transferred to the user's computer and analyzed using Telog-supplied support software.



IBM-PC, XT, AT and compatibles

Telog provides software support for the IBM-PC and compatibles including most computers operating under MS-DOS. The minimum requirements are a single disk drive, 256K RAM, serial interface and a graphics card.

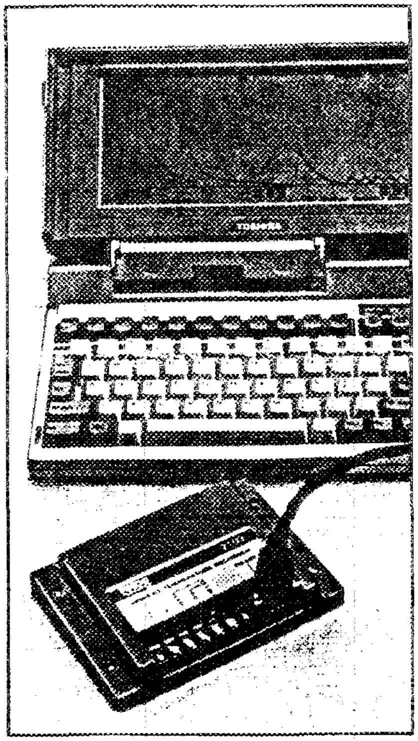
The PC can directly interrogate 2100 series recorders, or the Data Transfer Unit, display the data in three different graphics formats, send data to a printer in two different formats and save data on disk for future reference.

Portable computers

An IBM-PC compatible portable computer can be used to directly interrogate the Telog recorder at the measurement site. This permits the user to view real-time data, verify calibration and reprogram the recorder if desired.

The user may also display a time history of data from the recorder and save the data set to disk. This data may then be transferred to the user's tabletop or mainframe computer when the user returns to the office.

Contact Telog or your local Telog Representative to inquire about computer compatibility of specific IBM-PC compatible computers.



telog®

TELOG INSTRUMENTS INC.
P.O. Box 240
West Henrietta, N.Y. 14586
Phone: 716-359-1110

What to order

A minimum Telog recording system consists of three purchased components: one or more Telog recorders, a software package for the user's computer, and an interface cable to connect the recorder to the computer. Each software package will support all 2100 Series Recorders in production at the time of sale.

Product descriptions

R-21xx
DATA RECORDER—See individual 2100 Series Data sheets.

A-201
DATA TRANSFER UNIT—Transfers data from 2100 Series Recorders to computers operating Telog 2100 Series Support Software. Contains 32K of battery backed RAM.

A-202
DATA TRANSFER UNIT—Transfers data from 2100 Series Recorders to computers operating Telog 2100 Series Support Software. Contains 128K of battery backed RAM.

PS-21-1
POWER SUPPLY ADAPTOR—Converts 110VAC Line Power to 9 volts DC to directly power a 2100 Recorder. Plugs into standard 110VAC power outlet.

B-21/xx
BATTERY—Replacement batteries for 2100 Series Recorders. Batteries are sealed lithium 3 volt cells. Two each required per recorder.

S-21PC
Software for IBM-PC/XT/AT and compatible computers. Supports all 2100 Series Recorders and the Data Transfer Units. Minimum configuration is 1 disk drive, 256K RAM, serial RS 232 interface, and graphics card

C-21F
RS-232 serial interface cable to connect 2100 Series Recorders to user's computer. Terminates in a 25-pin 'D' connector with female pins. Compatible with IBM-PC, IBM-PC/XT and other computers.

C-21AT
Same as C-21F above except terminates in a female 9-pin connector which is compatible with the IBM-PC/AT.

Custom products

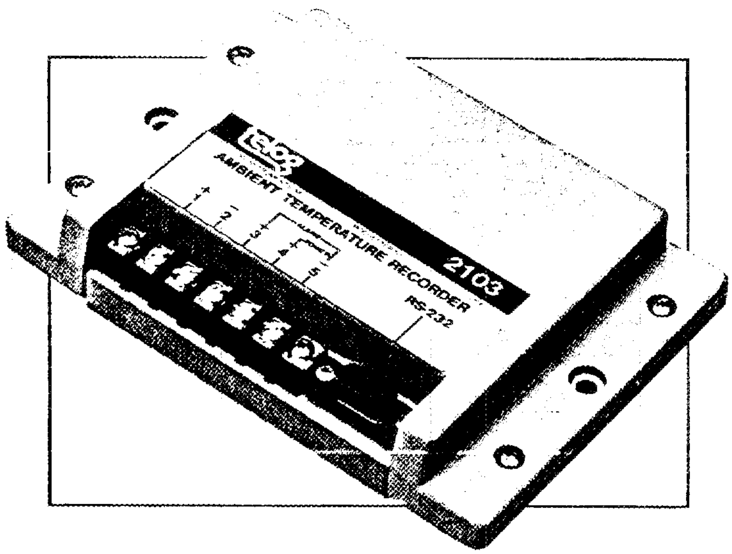
In addition to the standard products described above, Telog will support the development of custom products, software and communication networks. Contact the TELOG customer service group at the address below for additional information.

TELOG INSTRUMENTS INC.
P.O. Box 240
West Henrietta, N.Y. 14586
Phone: 716-359-1110

Ambient Temperature Recorder
Model 2103

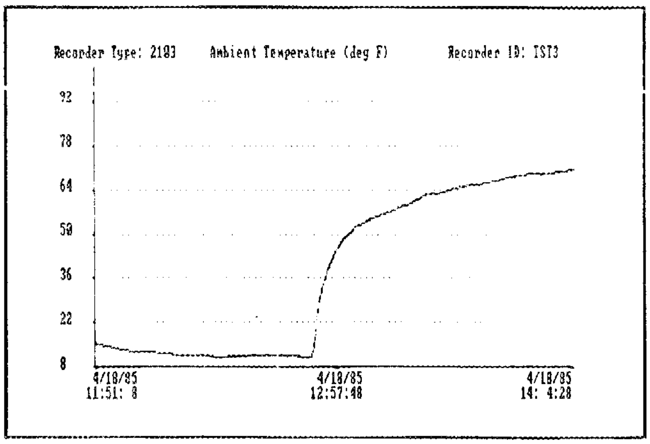
FEATURES

- Records Amplitude History Of Ambient Temperature
- Computer Compatible Output Data–IBM-PC's, Portables, etc.
- 18 Month Battery Life
- Rugged Watertight Construction



The Telog Ambient Temperature Recorder provides an accurate, reliable and economical means of obtaining a history of ambient temperature in environmental and industrial applications.

The Model 2103 is an electronic recording system that measures the temperatures of its environment with an integral temperature sensor. The recorder converts its measurements to a series of amplitude data values stored in solid state memory. A computer is then used to collect the data from the recorder and produce report-ready printed records. Information on supported computers and capabilities is provided in the Telog 2100 Series Family Brochure.



Typical Output Record

Sampling the input signal once per second, the recorder will compute and save up to 2000 averages, minimums or maximums. The user selects the desired statistics and computation interval which ranges from 1 second to 18 hours. For example, if the hourly average and maximum temperature are saved, 33 days of data will be recorded. When the recorder's memory reaches capacity, it begins to overwrite the oldest data with new data. The data transferred to computer is therefore always the most recent.

There is also an alarm output which can be used to control an external relay or interrupt a computer if the input signal goes above or below user-programmed thresholds. It operates on an electronic switch to ground.

Two small lithium batteries will operate the recorder for 18 months. It can also operate from external 10 to 28 vdc power in which case the internal batteries will provide back-up power for 5 years. Batteries can be easily changed with the aid of a screwdriver.

Except for battery replacement, the recorder is maintenance-free. There are no user accessible controls or adjustments requiring user attention. Programmed parameters are transferred to the recorder's memory when connected to the user's computer.

The Telog 2103 offers many advantages over traditional chart recorders and data acquisition systems. The unit is small, rugged, watertight, self-powered, and maintenance-free. The computer-generated output records are time-correlated, scaled, annotated and report-ready.

APPLICATIONS

TEMPERATURE RECORDING OF:

- Transportation of
  - Refrigerated Foods
  - Chemicals
  - Livestock
- Computer Rooms
- Refrigerators
- Freezers
- Environmental Studies

Model 2103

Specifications

MEASUREMENT

Range:	−25° to 60°C (−13° to 140°F)
Resolution:	0.33°C (0.6°F)
Accuracy:	± 0.33°C (0.6°F), 0° to 50°C ± 0.7°C (1.2°F), −25° to 60°C

RECORDING

Sample Rate:	1 per second
Clock Accuracy:	0.01%
Memory Size:	2000 values

ALARM

Type:	FET switch to ground
Maximum Voltage:	30 volts
Maximum Current:	100 ma
ON/OFF Impedance:	10 ohm/1 megohm

SERIAL INTERFACE

Type:	RS-232C compatible. Requires RTS
Baud Rates:	300, 1200, 9600; auto-selected
Bit Format:	1 start, 8 data, 1 stop
Connector:	9 pin Sub 'D' socket

POWER

Battery Type:	2 lithium 3v, 1A-Hr Duracell #DL-2N or Sanyo #CR-2N
Operating Life:	18 months @ 25°C or above 12 months @ −25°C
Battery Shelf Life:	5 years
External Power:	10 to 28 vdc @ 5ma

ENVIRONMENTAL & MECHANICAL

Operating Temp:	−25° to +60°C
Storage Temp:	−40° to +70°C
Humidity:	0 to 95% non-condensing short-term complete immersion in water
Size:	4.3" x 6" x 1"
Enclosure Material:	Zinc-Aluminum
Weight:	2 lbs.

SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE

PROGRAMMABLE PARAMETERS

Interval Period:	1 to 65535 seconds (18.2 hours)
Interval Resolution:	1 second
Computed Data:	any combination of the average, minimum or maximum per interval
Calendar Time:	mo/day/yr hr:min:sec
Alarm Thresholds:	High and/or Low, 1 DEG resolution
Unit ID Number:	4 digit alpha-numeric

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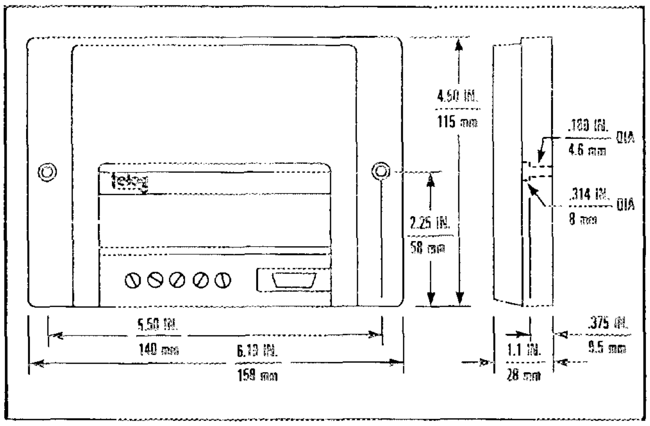
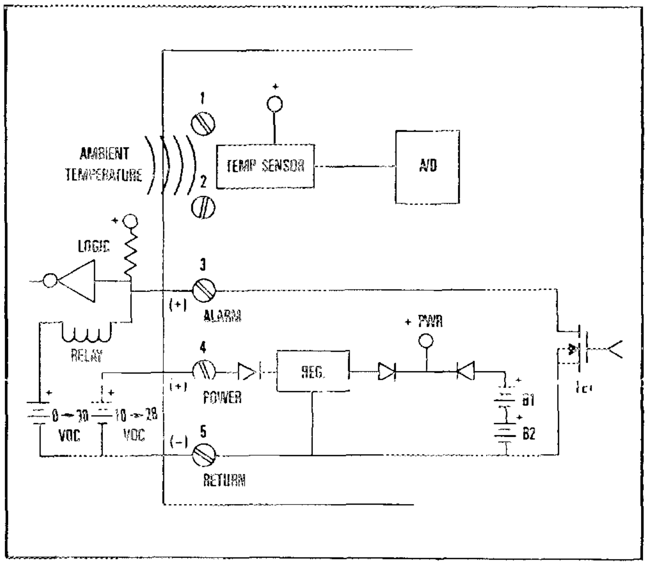
Model 2103 MOUNTING DIMENSIONS



FUNCTIONAL CONNECTION DIAGRAM



Telog Instruments Inc.
2 Drumlin Square
West Henrietta, NY 14586
Phone: 716-359-1110

21X MICROLOGGER

A Rugged, Powerful Little Datalogger

The 21X is a textbook sized, D cell powered precision datalogger. The term "MICROLOGGER" is descriptive of this MICRO-computer based dataLOGGER's MICRO-size, MICRO-power and sub-MICRO-volt sensitivity. It is the combination of a micro-computer, clock, multimeter, calibrator, scanner, frequency counter, controller, and signal generator all in one small box. Small size, low power and the ability to operate in environmental extremes were primary design objectives for portable, remote operation.

SIGNIFICANT FEATURES

PERFORMANCE VERSUS COST: Measurement and processing throughput in excess of 100 channels per second and sensitivity of ½ of a microvolt at 25 channels per second at a remarkably low price.

PERFORMANCE VERSUS SIZE: Sixteen analog and four pulse counting channels plus all the features described here packaged smaller and lighter (including batteries) than the CRC Handbook of Chemistry and Physics.

PERFORMANCE VERSUS POWER CONSUMPTION: Scanning and processing all 16 channels at 1 minute intervals, the 8 alkaline D cells last about 6 months. The rechargeable batteries in the 21XL provide 2 months' operation per charge under the same conditions.

SENSITIVITY AND MEASUREMENT SPEED: Fourteen bit precision on 5 software selectable ranges. 0.33 microvolt resolution at 37 milliseconds per channel with 100 nanovolt RMS input noise. At 2.5ms per channel the input noise is 1.2 microvolt RMS.

SENSOR COMPATIBILITY WITHOUT EXTERNAL SIGNAL CONDITIONING: Linearized thermocouple measurements at 7.3 milliseconds per channel resolve to within 0.05 deg. C. Bridge excitation voltage selectable within a ±5 V range at .67 mV resolution. Resistance bridge measurements such as RTDs, load cells, pressure transducers, foil strain gages and thermistors optimize accuracy using AC excitation and ratiometric techniques. AC excitation also minimizes polarization errors in soil moisture, salinity, conductivity, and RH sensors. Four pulse counting channels accommodate magnetic pulse flow meters, photochopped or switch closure devices and incremental shaft encoders directly.

EXPANDABILITY: Analog inputs are expandable in 32 channel increments to a maximum of 192 channels using the Model AM32 Relay Scanner.

REAL-TIME DATA PROCESSING: User programmed processing includes linearization, algebraic and transcendental functions, engineering unit scaling, averaging, maximum/minimum, totalizing, standard deviation, wind vector integration with direction sigma, histograms, and more.

REMOTE PROGRAMMING: Programs, parameters and direct commands can be entered directly from the keyboard or via the serial communications port from a remote computer or terminal.

FLEXIBLE DATA STORAGE AND TRANSFER: Data is stored in memory for transfer to the display, cassette, printer, modem, or directly to a computer. Standard 21X memory allows storage of 19,328 data values. The cassette recorder stores up to 180,000 values on one side of a C60 cassette at a maximum rate of 100 values per second.

ANALOG AND DIGITAL CONTROL OUTPUTS: Two continuous analog outputs with 14 bit resolution are available for strip chart recorders or proportional control. Six digital outputs can be set based on time or processed input levels.

PROTECTED INPUTS AND OUTPUTS: All panel connections are protected from electrical transients using spark gaps or transzorbs.

OPERATION IN HARSH ENVIRONMENTS: -25 to +50 deg. C. 0 to 90% relative humidity. The 21X packaging provides protection from excessive humidity and contaminants. On special order, 21X's will be tested and guaranteed to operate over a -55 to +85 deg. C temperature range.

STANDARD CONFIGURATION

The standard 21X Micrologger includes 16 single ended analog inputs (any pair configurable as a differential input), 4 pulse counting inputs, 4 switched excitation outputs, 2 continuous analog outputs and 6 digital control outputs.

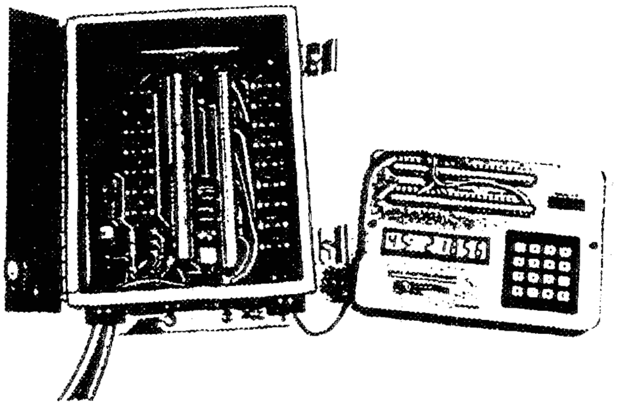
21X processing includes 22 instructions for measurements and control output, 39 instructions for data processing, and 9 instructions for program control.

Data storage includes 28 locations for input and user-processed data, 64 locations for intermediate values, and 19,328 final storage locations. Data storage can be reallocated by the user. Each input location and each intermediate location uses 4 bytes of RAM and each final storage location uses 2 bytes of RAM.

A 9 pin D type connector on the front panel is used for serial data communication to cassette tape, memory module, modem or printer. It is also used for system programming via remote terminal or computer.

EXPANSION

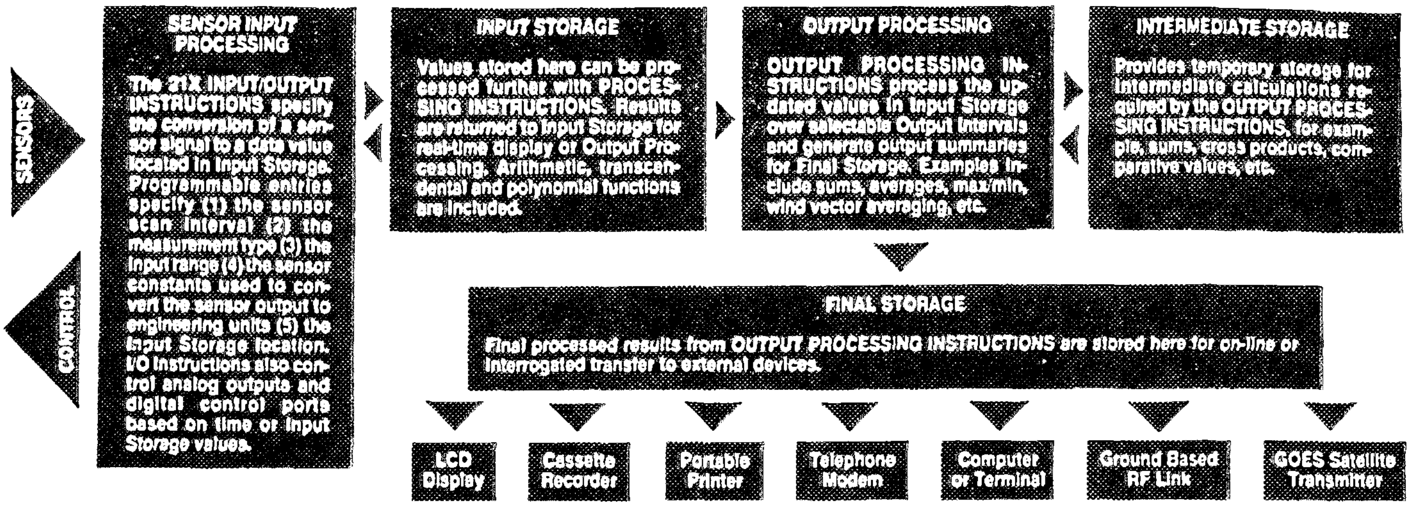
Analog inputs can be added in 32 channel increments using the Model AM32 Relay Scanner. Up to 6 AM32s can be added for an additional 192 analog channels



21X Micrologger with the Model AM32 Relay Scanner for channel expansion.

COVER PHOTOGRAPH

The 21X is shown with D cells and some of the directly compatible sensors including a load cell, platinum resistance thermometer, thermocouple, silicon pyranometer and a pressure transducer. Background material is the official CAMPBELL of ARGYLL tartan.



SUMMARY OF 21X INSTRUCTIONS

The input and output processing capabilities of the 21X are determined by the programs contained in the Applications Programmable Read Only Memory (PROM). The following is a brief description of the instructions contained in the standard applications PROM.

INPUT/OUTPUT INSTRUCTIONS

INSTR. NO. — DESCRIPTION

1 SINGLE ENDED VOLTS: Measures voltage of a single-ended input with respect to ground.

2 DIFFERENTIAL VOLTS: Measures voltage difference between Hi and Lo inputs of a differential channel.

3 PULSE COUNT: Counts pulses from digital logic outputs, low level magnetic transducers or switch closures.

4 EXCITE, DELAY AND MEASURE: Applies excitation voltage, delays a specified time and then makes a single ended voltage measurement.

5 AC HALF BRIDGE: Provides AC excitation and measures the ratio of sensor to applied excitation voltage.

6 FULL BRIDGE: Applies excitation and measures the ratio of bridge output to excitation voltage.

7 THREE WIRE HALF BRIDGE: Applies excitation and measures the ratio of the voltage across the sensor resistance to the voltage across the bridge completion resistor. Correction is made for lead wire loss according to the measured loss across one of the two current carrying wires.

8 DIFFERENTIAL VOLTS WITH EXCITATION. Applies excitation voltage, delays a specified time and then makes a differential voltage measurement.

9 FULL BRIDGE WITH MEASURED EXCITATION: Provides excitation and measures the ratio of bridge output to excitation voltage as measured at the bridge.

10 BATTERY VOLTAGE: Reads 21X's internal battery voltage.

11 107 TEMPERATURE PROBE: Measures temperature for −40°C to +60°C range using a Model 107 thermistor probe.

12 207 RH PROBE: Measures relative humidity in a 12 to 97% range using a Model 207 RH probe.

13 TC TEMPERATURE (SE): Measures temperature using one of four common thermocouple types and a user specified reference junction temperature. The thermocouple voltage measurement is single ended.

14 TC TEMPERATURE (DIF): Measures temperature using one of four common thermocouple types and a user specified reference junction temperature. The thermocouple voltage measurement is differential.

16 PLATINUM R.T.D. TEMPERATURE: Converts RTD bridge measurement to temperature according to DIN Specification 43760 for -200°C to +850°C range.

17 INPUT PANEL TEMPERATURE: Measures the temperature of the input panel's thermistor. Used for TC reference temperature

18 TIME: Loads current time into an input location for use in processing

19 SIGNATURE: Used for detection of program change and or ROM failure.

20 PORT SET: Sets binary output port "high," "low," "according to" or "opposite of" a specified program flag.

21 ANALOG OUTPUT: Sets a continuous analog output channel to a DC voltage determined by a measured or processed value

22 EXCITATION WITH DELAY: Applies excitation for a specified delay followed by a second delay period with excitation off before a subsequent measurement. Can also be used for program delay only.

26 TIMER: Measures elapsed time between specified points in the program or from a keyboard initiated event to a point in the program.

PROCESSING INSTRUCTIONS

For this group of instructions, parameters X and Y are input locations containing source data and Z is an input location into which the result is stored. F is a fixed value specified as a parameter in the program.

30	Z = F	36	Z = X*Y	42	Z = 1/X
31	Z = X	37	X = X*F	43	Z = ABS(X)
32	Z = Z + 1	38	Z = X/Y	44	Z = FRAC(X)
33	Z = X + Y	39	Z = SQRT(X)	45	Z = INT(X)
34	Z = X + F	40	Z = LN(X)	46	Z = X MOD F
35	Z = X − Y	41	Z = EXP(X)	47	Z = X ↑ Y
				48	Z = SIN(X)

49 SPATIAL MAXIMUM: Determines the maximum of a set of input values.

50 SPATIAL MINIMUM: Determines the minimum of a set of input values.

51 SPATIAL AVERAGE: Computes the average of a set of input values.

52 STANDARD DEVIATION: Calculates the standard deviation over time of an input value.

53 SCALING ARRAY WITH MULTIPLIER AND OFFSET: Scales four consecutive input values by four slopes and offsets entered as program parameters.

55 5TH ORDER POLYNOMIAL: Computes the polynomial function $F(x) = C0 + x(C1 + x(C2 + x(C3 + x(C4 + x(C5)))))$ where C0 through C5 are user entered coefficients.

56 SATURATION VAPOR PRESSURE: Calculates saturation vapor pressure from air temperature.

57 WET-DRY TEMPERATURE VAPOR PRESSURE: Calculates vapor pressure from wet and dry bulb temperature and atmospheric pressure.

58 LOW PASS FILTER. Computes the time based filter function $F(x) = Wx + (1 - W)y$ where W is a user entered weighting function (between 0 and 1) and y is the previous F(x).

59 RESISTANCE FROM BRIDGE OUTPUT: Calculates the sensor resistance from a half or full bridge measurement where the sensor is only a single resistance element of the bridge.

OUTPUT PROCESSING INSTRUCTIONS

INSTR. NO. — DESCRIPTION

70 SAMPLE: Records input values in final storage.

71 AVERAGE: Records the time average of input values in final storage.

72 TOTALIZE: Records the sum of input values in final storage.

73 MAXIMIZE: Records the maximum value and or time of maximum in final storage.

74 MINIMIZE: Records the minimum value and or time of minimum in final storage.

75 HISTOGRAM: Records in final storage, the fraction of time a value was within a number of contiguous sub-ranges (frequency distribution). An option obtains the average value of a 2nd parameter when the 1st parameter is within the corresponding sub-range (e.g., wind speed rose).

76 WINDVECTOR: Calculates average wind speed, mean wind vector magnitude and direction, the standard deviation of direction and records the results in final storage.

77 REAL TIME: Records current day, hour, minute and or seconds in final storage.

78 HIGH LOW RESOLUTION: Specifies data to be recorded in final storage as either high resolution (5 digit) or low resolution (4 digit).

79 SAMPLE ON MAX OR MIN: Records a set of consecutive input values in final storage that were present in input locations at the time of Max or Min as determined by prior execution of Instr. 73 or 74.

PROGRAM CONTROL INSTRUCTIONS

INSTR. NO. — DESCRIPTION

85 SUBROUTINE: Marks a series of instructions as a subroutine which may be accessed from elsewhere in the program.

86 DO COMMAND: Unconditionally executes a specified command.

87 LOOP: Repeats a sequence of instructions a specified number of times or until some condition is met. The time between passes through the loop may be delayed in multiples of the execution interval.

88 IF X COMPARED TO Y: Compares X and Y and executes a specified command if the result is true.

89 IF X COMPARED TO F: Compares X to fixed value F and executes a specified command if the result is true.

91 IF FLAG: Checks Flag status and if Flag is set performs the specified command.

92 IF TIME. Executes the specified command at the beginning of, or a specified number of minutes into, a real time interval.

94 ELSE: Labels a set of instructions to be executed if a comparison is false.

95 END: Marks end of a loop, subroutine, or if then/else comparison.

DATA RETRIEVAL

All items referred to by model number in this section are available from Campbell Scientific, Inc. unless stated otherwise.

USING A PRINTER

The Model CR56 portable thermal printer provides hardcopy in field applications where power is limited and tolerance to temperature extremes is required. Any computer printer with an RS-232 serial interface can be connected to the 21X using either a Model SC95 Short Haul Modem or a Model SC32 RS-232 Interface.

USING A CASSETTE TAPE

A good quality, AC biased audio recorder such as CSI's Model RC35 can be used to record data from the 21X. The Model SC92 Interface Connector provides switched 6 volt power to the tape recorder and conditions the serial output level for standard dynamic microphone inputs.

Data is stored in a binary format using error detection and correction codes for maximum reliability. Storage capacity of one side of a standard C60 cassette tape is 180,000 data values at 16 bits per value. The tape recorder can be left with the 21X for data recording or used as a transfer device to collect data previously stored in the 21X's internal memory.

Data is transferred from tape using an audio recorder and the Model C20 Cassette Computer Interface. The C20 includes two RS232 ports for interfacing to any type of computer from large time-share systems to small microcomputers. Baud rate, format, parity and port assignment are selectable through front panel switches. Eight baud rates ranging from 110 to 19,200 are available. The C20's default communications commands can be redefined via a terminal or computer. The C20 also generates tapes from terminal entered or computer stored information.

The Model PC201 Clock-SI/O-Tape Read Card allows direct reading of CSI data tapes using the IBM PC or PCXT computer without the C20 interface.

USING DIRECT LINE, SWITCHED NETWORK OR RF COMMUNICATION

For direct connection between the 21X and a computer or printer with an RS232 interface, the Model SC95C Short Haul Calling Modem and SC95A Answer Modem are used. These provide electrically isolated connection using two conductor wires over distances up to three miles.

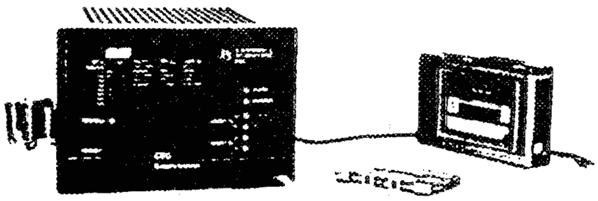
For RF telemetry, a Model DC95 RF modem is used in conjunction with an RF transceiver. The RF modem can communicate with any one of 255 other data stations on the same frequency. Connections to the transceiver include the microphone, remote speaker, transmit activation and carrier detect.

Communication over the switched telephone network requires an FCC registered direct connect modem. CSI's Model DC103A Answer Modem is used with the 21X while any standard Bell 103 type 300 baud modem may be used on the calling end. Either the RF modem or short haul modem can be cascaded with the DC103A modem for extension of a switched telephone network line to RF links or dedicated lines.

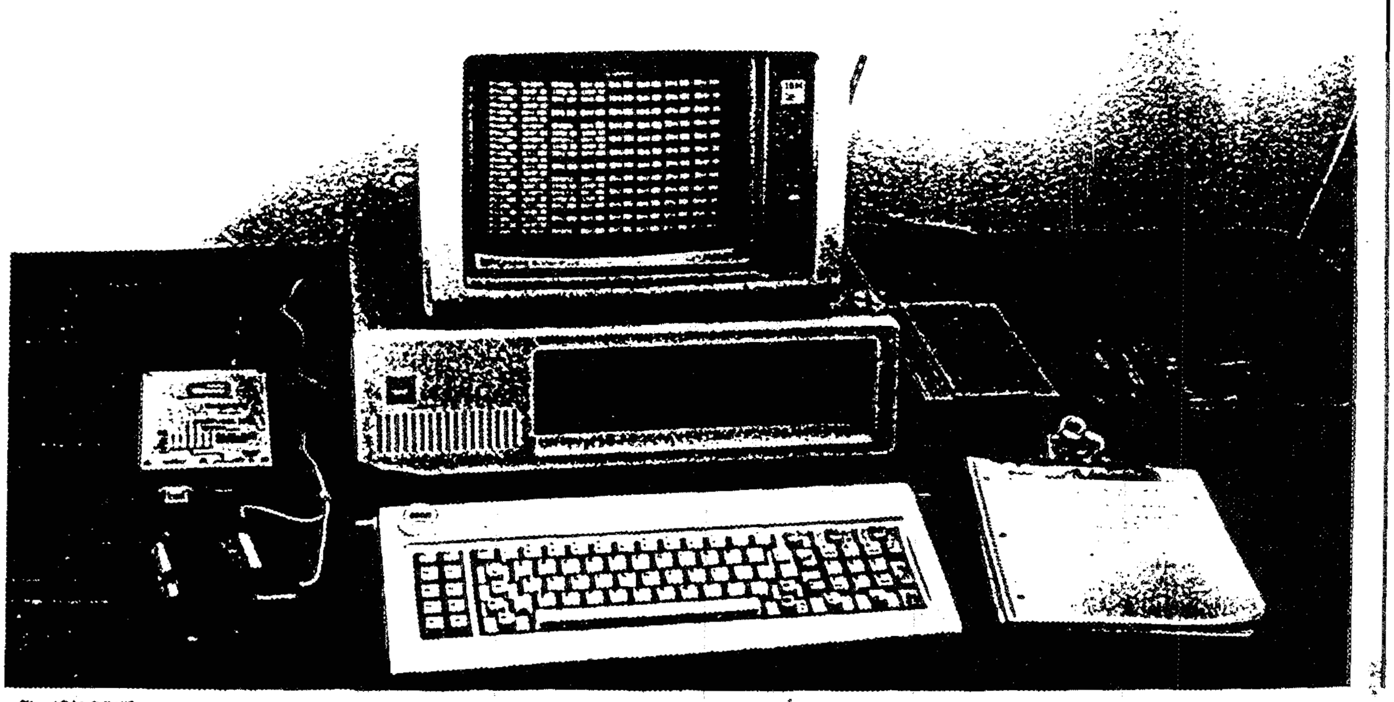
CSI's telecommunication options for the IBM PC and compatible computers provide software and hardware for unattended interrogation of CSI dataloggers over switched telephone lines, RF links or dedicated lines.

USING SATELLITE OR METEOR BURST COMMUNICATION

Hardware and software are available for interfacing the 21X to commercially available GOES and ARGOS satellite transmitters and meteor burst RF transceivers.



The Model C20 Cassette Computer Interface with recorder for playback, tape, patchcords and RS-232 cables.



The IBM PCXT computer as configured for reading data from Cassette or Memory Module (left side) and for telecommunications using the Hayes Smartmodem 1200 and the Model SMX126 Serial Data Multiplexer to provide access to other modems.

SPECIFICATIONS

The following electrical specifications are valid for an ambient temperature range of −25 deg. C to +50 deg. C unless otherwise specified.

ANALOG INPUTS

NUMBER OF CHANNELS: 8 differential or up to 16 single ended using one differential channel for each two single ended channels.

CHANNEL EXPANDABILITY: The Model AM32 Relay Scanner multiplexes 32 differential channels through a single 21X differential channel. Up to 6 AM32 scanners can be added to a 21X for 192 additional analog channels.

VOLTAGE MEASUREMENT TYPES: Single-ended or differential. A thermistor at the input terminals provides reference junction compensation for thermocouple measurements.

ACCURACY OF VOLTAGE MEASUREMENTS AND ANALOG OUTPUT VOLTAGES: 0.1% of FSR, 0.05% of FSR (0 to 40 deg. C).

RANGE AND RESOLUTION: Ranges are software selectable for any channel. Resolution for single ended measurements is twice the value shown.

Full Scale Range	Resolution
±5 volts	333. microvolts
±0.5 volts	33.3 microvolts
±50 millivolts	3.33 microvolts
±15 millivolts	1. microvolt
±5 millivolts	0.33 microvolts

INPUT SAMPLE RATES: The fast A/D conversion uses a 250us signal integration time and the slow conversion uses a 16.666ms signal integration time (one power line cycle period). Differential measurements include a second sampling with reversed input polarity to reduce thermal offset and common mode errors. The following intervals do not include the self-calibration measurement which occurs once per instruction. Input sample rates should not be confused with system data throughput rates.

Fast single-ended voltage:
2.4 milliseconds/channel
Fast differential voltage:
3.7 milliseconds/channel
Slow single-ended voltage:
18.8 milliseconds/channel
Slow differential voltage:
37.0 milliseconds/channel
Fast differential thermocouple:
7.3 milliseconds/channel

INPUT NOISE VOLTAGE:
Fast differential — 0.83 microvolts RMS
Slow differential — 0.1 microvolts RMS

COMMON MODE RANGE: ±5 volts.

COMMON MODE REJECTION: >140 dB (DC to 100 Hz)

NORMAL MODE REJECTION: 70 dB (60 Hz with slow differential measurement).

INPUT CURRENT: 2 nanoamps max.

INPUT RESISTANCE: 200 gigohms

ANALOG OUTPUTS

NUMBER OF ANALOG OUTPUTS: 4 switched, 2 continuous.

DESCRIPTION: Switched and continuous. A switched output is active only during a measurement and is switched off (high impedance) immediately following the measurement. Only one switched output can be active at any one time. The 2 continuous outputs hold a preset voltage until updated by an analog output command.

RANGE: ±5 volts.

RESOLUTION: 0.67 millivolts

ACCURACY: Same as voltage input

OUTPUT CURRENT
Switched: 20 mA @ ±5V, 50 mA @ ±2.5 V
Continuous: same @ +V, 5 mA @ −V

RESISTANCE AND CONDUCTIVITY MEASUREMENTS

ACCURACY: 0.035% (0.02% 0 to 40 deg. C) of full scale bridge output provided the matching bridge resistors are not the limiting factor. The excitation voltage should be programmed to match the bridge output with a full scale input voltage range.

MEASUREMENT TYPES: 6 wire full bridge, 4 wire full bridge, 4 wire, 3 wire and 2 wire half bridge. High accuracy, low impedance bridge measurements are ratiometric with dual polarity measurements of excitation and output to eliminate thermal emfs. AC resistance and conductivity measurements use a 750us excitation pulse with the signal integration occurring over the last 250us. An equal duration pulse of opposite polarity is applied for ionic de-polarization.

PULSE COUNTERS

NUMBER OF PULSE COUNTER CHANNELS: 4 eight bit or 2 sixteen bit, software selectable.

MAXIMUM COUNT RATE: 2550 Hz, eight bit counters; 250 kHz, sixteen bit counters. Pulse counter channels are scanned at a maximum rate of 10 Hz.

MODES: Programmable modes are switch closure, high frequency pulse and low level AC.

SWITCH CLOSURE MODE
MINIMUM SWITCH CLOSED TIME:
3 milliseconds.
MINIMUM SWITCH OPEN TIME:
4 milliseconds.
MAXIMUM BOUNCE TIME:
1 millisecond open without being counted.

HIGH FREQUENCY PULSE MODE
MINIMUM PULSE WIDTH:
2 microseconds.
MAXIMUM INPUT FREQUENCY:
250 kilohertz.
VOLTAGE THRESHOLDS:
The count is incremented when the input voltage changes from below 1.5 volts to above 3.5 volts.
MAXIMUM INPUT VOLTAGE:
±20 volts.

LOW LEVEL AC MODE
This mode is used for counting frequency of AC signals from magnetic pulse flow transducers or other low voltage, sine wave outputs.

MINIMUM AC INPUT VOLTAGE:
6 millivolts RMS
INPUT HYSTERESIS:
11 millivolts.
MAXIMUM AC INPUT VOLTAGE:
20 volts RMS.
FREQUENCY RANGE:

AC Input Voltage (RMS)	Range
20 millivolts	1 Hz to 100 Hz
50 millivolts	0.5 Hz to 400 Hz
150 millivolts to 20 volts	0.3 Hz to 1000 Hz

(consult factory if higher frequencies are desired)

DIGITAL CONTROL OUTPUTS

The 21X includes 6 digital control outputs that can be set or reset on command.

OUTPUT VOLTAGES
(no load): High — 5 volts ± 1 volt.
Low — <0.1 volt.

OUTPUT RESISTANCE
400 ohms

TRANSIENT PROTECTION

All input and output connections are protected using spark gaps connected directly to a heavy copper bar on the circuit card between the two input terminal strips. The 12 volt power input and charger inputs are protected with transzorbs.

CPU AND INTERFACE

PROCESSOR: HITACHI 6303 CMOS 8 bit microprocessor.

MEMORY: 16K ROM, 40K RAM, expandable to 24K ROM with an extended software option. Standard 21X stores 19,328 low resolution data points in Final Memory.

DISPLAY: 8 digit LCD (0.5" digits).

PERIPHERAL INTERFACE: 9 pin D-type connector on the panel for connection to cassette recorder, modem, printer, or RS232 adapter. The serial interface can be programmed for baud rates of 300, 1200, 9600 and 76,800.

CLOCK ACCURACY: ±1 minute per month.

MAXIMUM PROGRAM EXECUTION RATE: The 21X Programming Table can be executed in sync with real time at a maximum rate of 80 per second. Typical throughput rates allow 1 measurement with linear scaling and transfer to tape at this rate with no interruption.

SYSTEM THROUGHPUT: Data throughput is the rate at which a signal can be measured, processed and stored in Final Memory. The rate is reduced by additional processing or when data is transferred to Cassette Tape or through the 21X serial port.

Throughput to the cassette tape is 100 data values per second. During tape transfer, 25% of the CPU's time is required. Therefore, program execution is uninterrupted if the user-entered program requires less than 75% of the CPU's time.

ASCII data values (10 characters per value) can be transmitted via the serial port at 9600 baud with a throughput of approximately 100 values per second with 15% CPU utilization. Faster throughput rates are possible if CSI's binary format is transmitted (consult factory).

Each time a new measurement instruction is specified, time for two additional measurements is required for self-calibration. Therefore, using more repetitions in fewer instructions increases throughput.

SYSTEM POWER REQUIREMENTS

VOLTAGE: 9.6 to 15 volts.

TYPICAL CURRENT DRAIN: 1.0 mA quiescent, 25 mA during processing, and 60 mA during analog measurement.

INTERNAL BATTERIES: 8 Alkaline D cells with 7 amp hour capacity. The Model 21XL includes sealed lead acid batteries with 2.5 amp hour capacity per charge.

EXTERNAL BATTERIES: Any 12 volt external battery can be connected as a primary power source with the internal batteries providing backup while changing external batteries.

OPERATION FROM OTHER SOURCES: The Model 21XL includes a battery charging circuit that can be connected to 15 to 30 VDC indefinitely to maintain a full charge on the batteries without degradation. The charging circuit includes temperature compensation for maintaining optimum charging voltage at temperature extremes. A 110 VAC to 15 VDC wall transformer is provided with the 21XL.

PHYSICAL SPECIFICATIONS

SIZE: 8.2" X 5.7" X 3.3". Input terminal strips extend 0.45" above the panel surface.

WEIGHT: 6.2 lbs

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IBM PC DATA STORAGE AND RETRIEVAL OPTIONS

- Model PC201
  Clock SIO Tape Read Card
- Model PC205
  Telecommunications Software
- Model PC203
  Power-up Control Box
- Model PC206
  Datalogger Support Software

PC201 CLOCK—SERIAL I/O—TAPE READ CARD

The PC201 Card and an audio cassette recorder are used to play back data from cassette tapes generated by CSI dataloggers, format the data and store it on disk. The card contains a battery powered clock that sets the IBM clock on power up. An Asynchronous Communications Adapter is included which can be configured as COM1 or COM2 for communication with RS232 peripherals. PC201 software prompts the user for the required information needed to read the cassette and store data in a specified file. A Maximum Timing Deviation display allows the user to optimize volume and head alignment during tape read. CSI's original format (I) is also accommodated.

TELECOMMUNICATIONS CONTROLLER FUNCTIONS AND PC205 SOFTWARE

The PC205 Telecommunications Software provides interrogation of CSI dataloggers over switched telephone lines, RF links or dedicated lines. The appropriate modem is required (e.g., the Hayes Smart Modem, the DC95 RF Modem or the SC95C Calling Short Haul Modem). Data is stored in disk files specified by the user. The user prompts help create a status file containing necessary parameters and station phone numbers. Once the file is created, the station is called by specifying the file. New data is automatically appended to the specified data file and formatted in ASCII with comma delimiters for compatibility with other programs.

Using the PC201, PC205, PC203 Power Control Box, and the appropriate modem, the IBM can operate in an unattended mode. A status file is created in the PC205 software and the time for the next call is stored in the PC201 card. At the specified time the PC201 switches the PC203, powering up the IBM. The PC205 software then steps through the commands, interrogates the datalogger and stores the data in a file.

PC206 DATALOGGER SUPPORT SOFTWARE

The PC206 Software package consists of three separate programs. They are called EDLOG (Program Editor), TERM (Terminal Emulator), and SPLIT (Data Split, Merge and Report Generation Program).

EDLOG allows the user to develop and document programs for Campbell Scientific CR7, CR7X and 21X Dataloggers. Full editing features allow the user to insert, delete, move, copy and mark programming instructions. In line documentation is provided or the user may insert his own comments. A complete listing of datalogger instructions may be displayed on the screen to aid the user in selecting programming instructions. Alphanumeric labels may be assigned to input locations to aid in program debugging and readability.

TERM provides computer/datalogger communication for data retrieval, real time display of data and downloading/uploading of datalogger programs. Datalogger type, interface options and baud rate are specified by the user and saved in a parameter file which may be used by TERM or PC205 Telecommunications software for auto dialing.

SPLIT will select data from a data file or several data files and combine the data into a report file. The user can specify range checking on each selected element that will be flagged if it is out of range. Also, the report may be given a name with labels for each column of data. SPLIT allows the user to output the report file to be compatible with popular spreadsheet programs. This program will split data produced by the CR21, 21X, CR7 and CR7X.

COMPUTER REQUIREMENTS

- IBM PC/XT/AT or compatibles
- One full length slot for PC201 Card
- PC-DOS or MS-DOS operating system
- Minimum of 256K bytes of RAM

21X EXTENDED SOFTWARE LIBRARY

The 21X extended software is contained in an optional PROM on the 21X CPU board.

OPTION ESX1:

- 54 BLOCK MOVE
- 61 INDIRECT INDEXED MOVE
- 62 COVARIANCE/CORRELATION
- 90 STEP LOOP INDEX
- 96 ACTIVATE SERIAL DATA OUTPUT
- 97 INITIATE TELECOMMUNICATIONS
- 98 SEND CHARACTER
- *D MODE: SAVE OR LOAD PROGRAM, PROGRAM-ON-POWER-UP OPTION
- *C MODE: SECURITY
- ALL EXTENDED TELECOMMUNICATION COMMANDS

OPTION ESX2:

- 23 BURST MEASUREMENT
- 54 BLOCK MOVE
- 60 FFT
- 61 INDIRECT INDEXED MOVE
- 62 COVARIANCE/CORRELATION
- 90 STEP LOOP INDEX
- 96 ACTIVATE SERIAL DATA OUTPUT
- *D MODE: SAVE OR LOAD PROGRAM
- ALL EXTENDED TELECOMMUNICATION COMMANDS

DESCRIPTION

23 BURST MEASUREMENT – Instruction 23 repeats voltage measurements on a set of channels, with excitation, if desired. Parameters specify the number of repetitions, and the repetition rate. Recording of values can be triggered by a digital input or a specified measurement threshold. The minimum sample time per channel is 970 us allowing a maximum single channel sample rate of 1030 Hz. Measurement results may be stored in Input Storage or the raw A/D data transmitted via the serial port.

54 BLOCK MOVE -- Executes a "block move" of data in Input locations. The source and/or destination of the data may be either contiguous or equally spaced Input locations.

60 FFT -- This program does a Fast Fourier Transform on a set of data contained in N contiguous Input storage locations where N is 2 raised to an intergral power up to N=8192 (2^{13}). If the original data set is not known to be periodic with an intergral number of periods in the data set, then it is necessary to apply a taper to the beginning and end of the data. A parameter specifies an option that applies a four term Blackman-Harris taper and a correction on spectral values to compensate for the effect of the taper.

61 INDIRECT INDEXED MOVE – Moves Input data from location X to location Y where X and Y are values stored in specified Input locations. The values of X and/or Y may be indexed to a loop counter.

62 COVARIANCE/CORRELATION – This instruction calculates 1) means, 2) variances, 3) standard deviations, 4) covariances, and 5) correlations for a set of input values and stores selected results in Input Storage. Subintervals are allowed for convenient high pass filtering.

90 STEP LOOP INDEX – When used within a loop, instruction 90 increments the index counter by a specified amount after the first time through the loop, allowing indexed input locations to be incremented by the specified step.

96 ACTIVATE SERIAL DATA OUTPUT – Instruction 96 is used instead of *4 to conditionally control output of Final Storage data to printer or tape. After the most recently recorded data is transmitted, further output is disabled until Instruction 96 is executed again. This instruction also allows Final Storage Format (binary) data to be transmitted as the printer output.

97 INITIATE TELECOMMUNICATIONS – Instruction 97 enables the 21X to initiate telecommunications under program control. Parameters include the R.F. Modem I.D. numbers and telephone numbers required to call the network controller. A specified number of randomly timed retries occur if the communication link is not successfully made. After the link is established, a datalogger I.D. number is transmitted and control is transferred to the network controller.

98 SEND CHARACTER – This instruction sends a character to the Serial port, preceding a data Output Array, and is used when transmitting to a device requiring command initialization.

MODE FUNCTIONS

*D MODE: SAVE OR LOAD PROGRAM – The *D Mode saves the user's program on tape or printer or loads the program from tape (using the SC93 Tape Read/Write Interface), modem or computer into the 21X. The ESX1 *D contains the PROGRAM-ON-POWER-UP option used to output the user's program with additional code to a PROM programmer. When this PROM is installed in the 21X, the user's program is loaded on datalogger power-up.

*C MODE: SECURITY – The *C Mode is used to protect the user's program from unauthorized or accidental change. Once security is activated, a user entered 4 digit pass word must be entered before the program can be altered.

TELECOMMUNICATION COMMANDS

J TOGGLE FLAGS and SET UP FOR K COMMAND – Upon receiving a J command, the 21X is ready to receive a series of 1 byte values which toggle flags, and tell the 21X if a subsequent K command is to send Final Storage and which, if any, Input locations to send.

K CURRENT INFORMATION – The 21X sends, in binary, time and the Input and Final Storage data specified in the J command.

CAMPBELL SCIENTIFIC, INC.
P.O. Box 551 • Logan, Utah 84321 • (801) 753-2342 • TLX 453058

GILL MULTI-PLATE RADIATION SHIELD

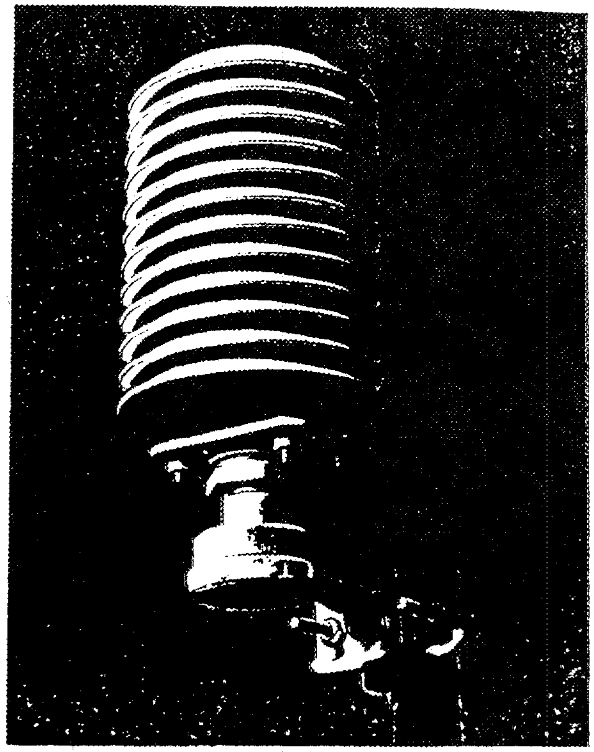
The Gill Multi-Plate Radiation Shield is a naturally ventilated shield designed for ambient temperature, dew point temperature, and relative humidity sensors. The convenient size and light weight of this shield make it useful for a wide range of applications. It is especially well suited for field studies where power is limited.

Different sensor mounting configurations allow the shield to accommodate most commercially available temperature sensors. Several commonly used dew point and relative humidity sensors can also be easily mounted in this shield. Sensors are mounted vertically within the shield.

Model 41002 has a 1 inch standard tapered pipe thread for sensor mounting. A matching threaded hex plug is used to hold the sensor. When specified with the order, this fitting is predrilled to accommodate the desired sensor. If the sensor is not specified, an undrilled fitting is provided. Model 41004 has a 33 mm (1.30 in) I.D. cavity which accepts several types of sensor mounting adapters. A Universal Sensor Adapter is normally supplied for mounting sensors up to 10 mm (0.39 in) diameter. For larger diameters up to 26 mm (1.02 in) a Probe Adapter Ring is substituted. Two small screw clamps are used to hold the sensor adapter in position. Both radiation shield models have an offset type mounting bracket with a V-block and U-bolt which allows the shield assembly to be easily attached to a vertical pipe of any diameter between 25-50 mm (1-2 in). This mounting configuration permits easy access for sensor installation and servicing.

Twelve white opaque molded plastic discs permit easy air passage through the shield but the unique disc profile provides positive blockage of direct and reflected solar radiation. The thermoplastic disc material is a special formulation for maximum weatherability. This material provides high reflectivity, low thermal conductivity, and low heat retention.

The shield assembly is 12 cm diameter by 27 cm overall height. The twelve shield discs are mounted on three support studs with 11 mm separation between plates.



Wind tunnel tests with artificial radiation indicate that under conditions of low air movement (1 m/s) and maximum solar radiation, the temperature sensor is maintained within 1.5C° of ambient. With winds at 2 m/s the error is reduced to less than 0.7C° and with winds of 3 m/s the error is 0.4C° or less. These results have been independently verified in field tests.

SPECIFICATIONS: MODEL 41002/41004 MULTI-PLATE RADIATION SHIELD

SENSOR CLEARANCE:
- Model 41002 – 29 mm (1.14 in) diameter × 12 cm (4.7 in) length
- Model 41004 – 32 mm (1.26 in) diameter × 12 cm (4.7 in) length

RADIATION ERROR:
- Under radiation intensity of 1080 W/m^2
- Dependent upon wind speed (ventilation rate) –
  - 0.4C° (0.7F°) RMS @ 3 m/s (6.7 mph)
  - 0.7C° (1.3F°) RMS @ 2 m/s (4.5 mph)
  - 1.5C° (2.7F°) RMS @ 1 m/s (2.2 mph)

MATERIAL:
- White thermoplastic UV stabilized for long term weatherability
- Gloss white painted aluminum mounting bracket (with molded plastic V-block and stainless steel U-bolt)

DIMENSIONS:
- Overall – 12 cm (4.7 in) diameter × 27 cm (10.6 in) height
- Plates – 2 mm (0.08 in) thick × 11 mm (0.44 in) spacing

MOUNTING:
- V-block and U-bolt fit vertical pipe 25-50 mm (1-2 in) diameter

WEIGHT:
- Net Weight – 0.7 kg (1.4 lbs)
- Shipping Weight – 1.4 kg (3 lbs) approx.

ORDERING INFORMATION:

GILL MULTI-PLATE RADIATION SHIELD – 1 in N.P.T. SENSOR MOUNTING HEX PLUG (UNDRILLED)	CAT NO 41002	$158.00
HEX PLUG – MACHINED TO SPECIFIED SENSOR DIA – 26 mm (1.02 in) MAXIMUM	ADD SUFFIX "P"	N/C
JUNCTION BOX-MACHINED TO SPECIFIED SENSOR DIA – 10 mm (0.39 in) MAXIMUM	ADD SUFFIX "Z"	30.00
GILL MULTI-PLATE RADIATION SHIELD – UNIVERSAL SENSOR ADAPTER CLAMPS PROBES UP TO 10 mm (0.39 in) DIAMETER	CAT NO 41004	158.00
PROBE ADAPTER RING* – MACHINED TO SPECIFIED SENSOR DIA – 26 mm (1.02 in) MAXIMUM	ADD SUFFIX "G"	N/C
JUNCTION BOX* – MACHINED TO SPECIFIED SENSOR DIA – 10 mm (0.39 in) MAXIMUM	ADD SUFFIX "Z"	30.00

*SUPPLIED IN PLACE OF UNIVERSAL SENSOR ADAPTER

ORNL/TM-10760

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