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The Oklahoma Cooling Retrofit Field Test: Experimental Plan

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ABSTRACT

The Oklahoma Cooling Retrofit Field Test will be performed to determine the magnitude of the cooling-energy savings attributed to the installation of conservation measures as typically installed by Oklahoma's Low-Income Weatherization Assistance Program (WAP) and the additional savings that can be achieved by the installation of two cooling retrofit measures: replacement of low-efficiency window air conditioners with high-efficiency units and installation of attic radiant barriers. This report is an experimental plan presenting the 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, the experimental design, the data requirements and the instrumentation to collect the data, 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 (May 1988 to September 1989). One hundred twenty low-income homes in Tulsa, Oklahoma will be studied in the field test: 30 homes will be assigned to a non-treatment or control group in which no retrofit measures will be installed, 30 homes will receive weatherization measures as currently performed under Oklahoma's WAP, 30 homes will receive weatherization measures as currently performed under Oklahoma's WAP plus an attic radiant barrier, and 30 homes will receive weatherization measures as currently performed under Oklahoma's WAP plus a high-efficiency window air conditioner in replacement of a less efficient unit. The following data will be collected weekly in all the houses: house electricity use, house gas use, and air conditioner electricity use. Also to be collected are hourly indoor temperature data in all the houses, hourly weather data at three selected sites near the houses, and survey information. Analysis procedures using a house model and regression techniques will be employed to determine the energy savings in the individual houses normalized for ambient weather, indoor temperature, 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 retrofits will be determined using appropriate economic analysis methods and the normalized energy savings.

EXECUTIVE SUMMARY

The objectives of the Oklahoma Cooling Retrofit Field Test are to determine the magnitude of the cooling energy savings attributed to the installation of conservation measures as typically installed by Oklahoma's Low-Income Weatherization Assistance Program (WAP) and the additional savings that can be achieved by the installation of two cooling retrofit measures: replacement of low-efficiency window air conditioners with high-efficiency units and installation of attic radiant barriers. The following organizations are participating in the field test: Oklahoma Department of Commerce, Division of Community Affairs and Development; Public Service Company of Oklahoma; Wa-Ro-Ma Tri-County Community Action Foundation; U.S. Department of Energy, Office of Buildings and Community Systems and Office of State and Local Assistance Programs; Oak Ridge National Laboratory; and Alliance to Save Energy. The purpose of this experimental plan is to present the detailed objectives and method of the project.

For families living in southern states characterized by having hot and humid summer climates, an appreciable amount of a family's energy costs occur during the cooling season. Despite this fact, research directed at improving the efficiency of buildings in hot and humid climates has not received the same focus as in cold climates. The ability of commonly installed retrofits, such as attic insulation and storm windows, to reduce cooling energy consumption is not well documented by field tests. Further, the performance of measures specifically designed to reduce cooling costs have not been thoroughly tested.

Radiant barriers installed in attics of houses offer the potential of reducing residential cooling costs by reducing radiation heat transfer across the attic air space. Although the effectiveness of radiant barriers in reducing heat flows through ceilings has been clearly demonstrated, the seasonal/annual thermal performance of

radiant barriers remains in question and must be determined through further testing. Replacing a low-efficiency air conditioner with a more efficient unit also offers the potential for reducing residential cooling costs by requiring less electricity consumption to provide the same amount of cooling. Although limited studies have been performed to examine this type of retrofit, additional testing is required in different housing stocks and climates.

Low-income WAPs, as performed in almost all southern states, primarily install building shell retrofits such as attic insulation, storm windows, and air infiltration reduction. Although these measures may reduce cooling costs, their inclusion in the programs is based primarily on their ability to reduce heating costs. The energy savings and cost-effectiveness of these WAPs could be improved once the effect of these measures on cooling costs is understood or by including other conservation measures specifically designed to reduce cooling costs.

The field test will be conducted over a two-year period. Pre-retrofit data will be collected on all the homes during one summer (May to September 1988). Conservation measures will be installed in the treatment groups of houses during the winter of 1988-89. Post-retrofit data will be collected on all the homes during the following summer season (May to September 1989). Interim and final reports outlining the results of the project will be published. The responsibilities of the individual field test participants and 16 tasks required to complete the test are presented in the plan.

One hundred twenty low-income homes in Tulsa, Oklahoma will be studied: 30 homes will be assigned to a non-treatment or control group in which no retrofit measures will be installed, 30 homes will receive weatherization measures as currently performed under Oklahoma's low-income WAP, 30 homes will receive weatherization measures as currently performed under Oklahoma's WAP plus an attic radiant barrier, and 30 homes will receive weatherization measures as currently performed under Oklahoma's WAP plus a high-efficiency window air conditioner in replacement of a less efficient unit. The houses selected for inclusion in the field test must meet 11 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 group houses.

The following data will be collected weekly in all the houses: house electricity use, house gas use, and air conditioner electricity use. The house electricity use will be monitored using a recently calibrated meter. The house gas use will be monitored using the existing gas billing meter. The air conditioner electricity use will be monitored using a recently calibrated watt-hour meter. Hourly indoor temperature data will be collected in all the houses using a battery-operated temperature sensing and recording device. Hourly outdoor temperature, humidity, and incident radiation will be automatically collected at three sites using a variety of weather instrumentation 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, air conditioner operating parameters, and retrofit installation quality verification and retrofit listing.

Data management procedures will be developed to store the collected data and check it for errors. Data will first be entered into storage on a personal computer. 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 examination of plotted data.

The survey information will be used to characterize the houses and occupants studied and to answer questions regarding the installation of the conservation measures. 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 installation of the conservation measures includes the measures recommended by Oklahoma's audit procedure for installation, the measures actually installed, and the actual cost to install each measure. Procedures used to install the attic radiant barriers and high-efficiency window air conditioners and any difficulties encountered during their installation will also be documented.

The cooling season energy savings of the conservation measures will be evaluated on an individual and group basis. The cost effectiveness of the measures (which depends on energy savings, installation costs, retrofit lifetime, and other economic parameters) will also be examined. The energy savings for an individual house will be defined to be its observed energy savings normalized for outdoor weather conditions, indoor temperature, 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 summer season, (2) the weather conditions for the two periods may be different, and (3) indoor temperatures 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 air conditioner electricity consumption to outdoor-indoor temperature difference and other weather variables. Pre- and post-retrofit normalized cooling electricity consumptions will then be estimated using the model parameters, average weather data based on historical records, and assumed values for the indoor temperature. The change in energy consumption is the difference between these electricity consumptions. The change in energy use of the retrofitted 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 installations. 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 OKLAHOMA COOLING RETROFIT FIELD TEST: EXPERIMENTAL PLAN

1. INTRODUCTION

1.1 BACKGROUND

For families living in southern states characterized by having hot and humid summer climates, an appreciable amount of the family's energy costs occur during the cooling season. Information obtained from the Oklahoma Department of Commerce (ODC) indicates that the cost for electricity during the summer is up to half of a family's total space conditioning costs in Oklahoma. Despite this fact, research directed at improving the efficiency of buildings in hot and humid climates has not received the same focus as in cold climates. The ability of commonly-installed retrofits, such as attic insulation and storm windows to reduce cooling energy consumption, is not well documented by field tests. Further, the performance of measures specifically designed to reduce cooling costs have not been thoroughly tested.

Radiant barriers installed in attics of houses offer the potential of reducing residential cooling costs by reducing radiation heat transfer across the attic air space. The current status of research on radiant barriers is summarized in Ref. 1: "Experiments by a number of groups (limited to laboratory experiments and field tests involving small numbers of unoccupied houses or test cells) have clearly demonstrated that radiant barriers are effective in reducing heat flows through ceilings of buildings, especially under conditions where the building is cooled. While the results are in qualitative agreement in indicating heat flow reductions, there is controversy regarding the magnitude of the thermal performance of radiant barriers." The U.S. Department of Energy (DOE) and the Oak Ridge National Laboratory (ORNL), along with other organizations, are currently developing a Radiant Barrier Research Plan. One research item tentatively identified as being important is the "need to determine the seasonal and annual performance of radiant barrier systems. Most of the existing field data have been obtained over time periods of a few days or weeks. Thus, the results of the field tests may not be directly interpretable into seasonal/annual performance."[1]

Replacing a low-efficiency air conditioner with a more efficient unit also offers the potential for reducing residential cooling costs by requiring less electricity consumption to provide the same amount of cooling. The energy efficiency ratio (EER), defined as the Btu/h of heat extracted per watt of energy input to the air conditioner, is a common method of expressing the efficiency of air conditioners. The EER of units built before 1977 was, on average, about 6 or under, whereas units built today can have EERs of 10 or greater. Modeling studies performed by ORNL[2,3] confirmed that significant energy savings could be obtained economically by installing high-efficiency air conditioners in southern climates. A current field test in Austin, Texas and funded, in part, by ORNL, is designed to study the savings and cost effectiveness of this type of retrofit in 10 houses. However, additional testing is required in different housing stocks and climates.

Because information is lacking about the performance of conservation measures to reduce cooling costs, weatherization programs performed by states and utilities in hot and humid climates may not be as effective as possible. Low-Income Weatherization Assistance Programs (WAPs) as performed in almost all southern states primarily install building shell retrofits such as attic insulation, storm windows, and air infiltration reduction. Although these measures may reduce cooling costs, their inclusion in the programs is based primarily on their ability to reduce heating costs. The energy savings and cost-effectiveness of these WAPs could be improved once the effect of these measures on cooling costs is understood. The WAPs could also be improved by including other conservation measures specifically designed to reduce cooling costs. Utility programs also suffer due to a lack of performance information because reliable recommendations cannot be made to homeowners.

1.2 FIELD TEST AND REPORT OBJECTIVES

The overall objective of the Oklahoma Cooling Retrofit Field Test is to determine the performance of retrofit measures in reducing cooling energy consumption. Specific objectives of this field test will be to determine (1) the magnitude of the cooling-energy savings attributed to the installation of conservation measures as typically installed by Oklahoma's Low-Income WAP, and (2) the additional savings that can be achieved by the installation of two cooling retrofit measures: replacement of low-efficiency window air conditioners with high-efficiency units and installation of attic radiant barriers.

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. The retrofits currently installed under Oklahoma's Low-Income WAP and the two specific cooling measures that will be studied are described 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 cooling performance of the studied retrofits.

2. PROJECT OVERVIEW

2.1 APPROACH

The field test will be performed by Wa-Ro-Ma Tri-County Community Action Foundation, ORNL, Public Service Company of Oklahoma (PSO), Alliance to Save Energy (ASE), and the ODC Division of Community Affairs and Development. Financial support for the project will be provided by ODC; DOE, Office of Buildings and Community Systems (DOE-OBCS) and Office of State and Local Assistance Programs (DOE-OSLAP); and PSO.

One hundred twenty low-income homes in Tulsa, Oklahoma, will be studied: 30 homes will be assigned to a non-treatment or control group in which no retrofit measures will be installed, 30 homes will receive weatherization measures as currently performed under Oklahoma's Low-Income WAP, 30 homes will receive weatherization measures as currently performed under Oklahoma's WAP plus an attic radiant barrier, and 30 homes will receive weatherization measures as currently performed under Oklahoma's WAP plus a high-efficiency window air conditioner in replacement of a less efficient unit. Data collected from the control homes will be analyzed to determine the variation in electricity consumption due to other factors.

The following data will be collected from all the houses: house electricity use, house gas use, air conditioner electricity 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 addition, the hourly outdoor temperature, humidity, and incident radiation 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 summer season (May to September, 1988). Conservation measures will be installed in the treatment groups of houses during the following winter. Post-retrofit data will be collected on all the homes during the next summer season (May to September, 1989).

Two technical reports outlining the results of the project will be published. The first report (an interim report) will present the pre-retrofit cooling electricity consumptions of the houses. Following the post-retrofit cooling season, a second report will present results on the actual electricity savings achieved by the conservation measures. Technical papers will also be presented at appropriate conferences. Finally, a separate memorandum will be presented to ODC, PSO, and state, community, and utility weatherization program managers summarizing the 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 and ORNL are specifically interested in understanding how homes operate in hot and humid climates and determining the ability of retrofit measures to reduce cooling energy consumption. DOE and ORNL are especially interested in air conditioner replacements and attic radiant barrier installations. In addition to the work cited earlier on replacement air conditioners, ORNL has also performed research on attic radiant barriers in three unoccupied homes for the past several years and is planning to initiate additional field tests and modeling efforts in the future. DOE, ORNL, and ASE are also interested in developing a new residential audit for southern climates patterned after the audit concepts developed by ORNL[4,5] and similar to a subsequent audit developed and tested for a northern climate.[6] The field test results will aid in the development of such a new audit and will be made available to the research community to help researchers better understand the performance of single-family residential buildings. The ODC and Wa-Ro-Ma are interested in determining the cooling energy consumption reductions obtained from Oklahoma's current Low-Income WAP and the specific cooling measures that could be included in their program to help reduce high electricity consumptions associated with summer cooling. PSO is interested in accurately informing their customers about the best methods to reduce cooling costs. PSO's residential customers have not saved as much energy as expected from recommended conservation measures and have been slow to upgrade to high-efficiency appliances. The field test will provide PSO with the experience and information needed to better predict energy savings and encourage the adoption of air conditioner upgrades.

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 retrofit measures or the field test itself?

Conservation Measures

1. What measures were installed in the treatment houses under Oklahoma's Low-Income WAP? How were they distributed among the houses and the three treatment groups?

2. How were the attic radiant barriers installed? Were there any problems or limitations encountered during installation?

3. What procedures were followed in replacing low-efficiency window air conditioners with high-efficiency units? Were there any problems encountered in their installation?

4. What were the costs of installing the retrofit measures in the individual houses? How were the costs distributed among the houses and the individual retrofit options?

Energy Savings and Performance

1. What were the seasonal energy savings of the individual houses and the treatment groups for two cases: (1) normalized to the actual indoor temperatures of the houses, and (2) normalized to fixed indoor temperatures representative of a typical house.

2. What was the cost-effectiveness of the conservation measures on a per house and group basis?

3. Are there any significant relationships between the measured savings, the retrofit installation costs, and the pre-retrofit seasonal energy costs?

2.3 PROJECT RESPONSIBILITIES

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

1. DOE is the federal department responsible for promoting energy efficiency research. DOE-OBCS will provide funds to ORNL and ASE to perform their responsibilities described below. DOE-OSLAP will provide the State of Oklahoma with funds to weatherize the field test homes through the Low-Income WAP.

2. ODC manages the state's Low-Income WAP. ODC will manage the field test at the state level, coordinating the involvement of PSO and the local weatherization program provider, Wa-Ro-Ma. ODC will also fund Wa-Ro-Ma to perform its responsibilities described below and provide the necessary funds to install the retrofit measures through the WAP.

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, conduct field test training for Wa-Ro-Ma staff and weatherization installers, disseminate field test results, and draft recommendations for residential conservation programs.

4. ORNL is the lead federal research organization on single-family retrofit technologies. ORNL will develop the experimental plan, supply indoor temperature monitoring equipment and weather instrumentation, train and assist personnel in installation and use of the equipment, develop and maintain a data base of all collected data that also checks the quality of the data, analyze the data, and prepare interim and final technical reports.

5. PSO is a major electric utility in the state. PSO will provide funds to Wa-Ro-Ma to install air conditioner submeters; install recently calibrated house electric meters; and provide personnel to install indoor temperature and weather monitoring equipment, maintain field equipment, and collect indoor temperature and weather data.

6. Wa-Ro-Ma Tri-County Community Action Foundation is the local weatherization provider in part of greater Tulsa and will be the on-site field coordinator for the project. Specifically, Wa-Ro-Ma will identify low-income homes that meet the field test criteria and interview each household, install air conditioner submeters, collect field data, audit and assess each house, install conservation measures, and remove instrumentation at the end of the test.

2.4 PROJECT TASKS AND SCHEDULE

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

1. Prepare a Concept Paper - Based on discussions with project participants, ASE will prepare a project concept paper that will be reviewed by ORNL, ODC, PSO, and Wa-Ro-Ma. The plan will describe the project, need, approach, measures, roles of each organization, task plan, time-line, and budget. A final version of the concept paper will be drafted based on comments received. This task was completed in November, 1987, prior to the 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. The first draft of the plan was completed in January, 1988, to allow each participating organization to review and comment on the document.

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                                : 1987 :                 1988                 :                 1989                 : 90:
            Tasks               : 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 : J :
--------------------------------:------:------------------------------------:------------------------------------:---:
 1. Concept paper               :=X    :                                    :                                    :   :
 2. Experimental plan           :  ====:=X                                  :                                    :   :
 3. Select households           :  ====:=====X                              :                                    :   :
 4. Install instrumentation     :      :      =======X                      :                                    :   :
 5. Data base system            :      :      =======X                      :                                    :   :
 6. Analysis procedure          :      :      ========X                     :                                    :   :
 7. Collect pre-retrofit data   :      :             ============X          :                                    :   :
 8. Prepare pre-retrofit report :      :                         ==========X:                                    :   :
 9. Project training            : X    :                                    : X                                  :   :
10. Audit houses                :      :                                    :   ==X                              :   :
11. Install measures            :      :                                    :      =====X                        :   :
12. Collect post-retrofit data  :      :                                    :             =============X         :   :
13. Prepare final report        :      :                                    :                           =========:=X :
14. Remove instrumentation      :      :                                    :                           ==X      :   :
15. Retrofit control houses     :      :                                    :                              ==X   :   :
16. Disseminate information     :      :                                    :                                    :==X:
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Fig. 2.1. Oklahoma cooling retrofit field test schedule.

3. Select Field Test Households - Wa-Ro-Ma will select appropriate households for participation in the field test by the end of February, 1988, using the household selection criteria and following the procedure identified in this document.

4. Install Instrumentation - PSO will install recently calibrated meters on all the field test houses. PSO will fund Wa-Ro-Ma to contract with electricians to submeter the air conditioners in each house. ORNL will provide the instrumentation required to monitor the indoor temperature and ambient weather conditions and will assist PSO in its installation. All instrumentation will be installed by May 15, 1988. PSO will maintain all the instrumentation 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 May 15, 1988. The system will check the data for errors and store the data in a format that can readily be used in analysis.

6. Develop Detailed Analysis Procedure - ORNL will develop the details of the analysis procedure to be used to determine the energy savings of the installed retrofits by June 1988.

7. Collect Pre-Retrofit Data - Pre-retrofit data will be collected from May 15, 1988 to September 15, 1988. PSO will collect the indoor temperature and ambient weather data. With forms provided by ORNL, Wa-Ro-Ma will collect all remaining pre-retrofit data which includes house and air conditioner energy consumptions and the survey data. All data will be forwarded to ORNL as it is collected. ORNL will enter the data into the data base.

8. Prepare a Pre-Retrofit Data Analysis Report - ORNL will prepare an interim report presenting the pre-retrofit cooling electricity

consumptions of the houses. The first draft of the report will be completed by January, 1989, to allow each participating organization to review and comment on the document.

9. Provide Project Training - ASE will arrange technical training workshops for energy auditors and weatherization crews on using blower doors and installing attic radiant barriers. Blower door training was provided in November, 1987; attic radiant barrier installation training will be provided by February 1989.

10. Audit Field Test Houses - Wa-Ro-Ma will audit all the field test houses in February, 1989, using the procedure currently employed in the WAP, and will select the conservation measures to be installed as dictated by the audit. Copies of the audit information will be provided to ORNL.

11. Install Conservation Measures - ORNL will assign the houses to the appropriate treatment groups in February, 1989. In March and April, 1989, Wa-Ro-Ma will install blower-door-guided infiltration reduction measures and other conservation measures in the homes in the three treatment groups as determined from the audit. In addition, they will install attic radiant barriers in one treatment group and replace a low-efficiency air conditioner with a high-efficiency unit in another treatment group. Wa-Ro-Ma 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.

12. Collect Post-Retrofit Data - Post-retrofit data will be collected from May 15, 1989 to September 30, 1989. PSO will collect the indoor temperature and ambient weather data. With forms provided by ORNL, Wa-Ro-Ma will collect all remaining post-retrofit data which includes house and air conditioner energy consumptions and the survey data. All data will be forwarded to ORNL as it is collected. ORNL will enter the data into the data base.

13. Prepare Final Analysis Report - ORNL will prepare a final analysis report based on the data collected during the field test. The report will present the seasonal energy savings of the conservation measures and their cost-effectiveness. The first draft of the report will be completed in January, 1990, to allow each participating organization to review and comment on the document.

14. Remove Instrumentation - Instrumentation will be removed from all the field test homes by November 1989. PSO will provide personnel to remove the indoor temperature and ambient weather instrumentation from the field test homes and return it to ORNL at the end of the field test. Wa-Ro-Ma will remove the air conditioner submeters and return the equipment to PSO.

15. Install Retrofit Measures in Control Group of Houses - Wa-Ro-Ma will install appropriate conservation measures in the control group of houses at the end of the field test and before December, 1989, following the current WAP audit procedure and/or based on the insights gained in retrofitting and analyzing the previously treated houses.

16. Disseminate Field Test Information and Results - ASE will prepare a brief on project results and implications, and disseminate it to ODC, PSO, and weatherization program managers nationwide. Results will also be reported at weatherization, utility, and other appropriate conferences by ORNL and ASE.

3. CONSERVATION MEASURE DESCRIPTIONS

3.1 OKLAHOMA'S CURRENT LOW-INCOME WAP

The Oklahoma Low-Income WAP typically installs a standard set of weatherization measures in each low-income home serviced by the program. Although normally thought of as measures to reduce heating energy consumption, they may also have the side benefit of reducing cooling costs. These measures include infiltration reduction, attic insulation, and storm windows.

Installing measures to reduce air infiltration is an important part of the Oklahoma program and is typically the first measure selected. For this field test, infiltration reduction work will be performed following a blower-door-guided infiltration reduction procedure. 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. A specially trained 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 for the procedure. 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.

The second measure typically performed under the Oklahoma program is to increase each home's attic insulation level (using blown insulation) until the value of its thermal resistance is R-19; this procedure will be used in the three treatment groups of houses. Attics will be properly vented and minor roof leaks repaired. No other insulation measures will be employed.

Storm windows are the final measure considered by the program and will be used in the treatment group of houses. Existing storm windows will be repaired if possible. Combination storm and screen windows will be installed on windows where no storm exists or where the existing storm is beyond repair until the allowable house expenditure limit set by the WAP is reached.

3.2 ATTIC RADIANT BARRIERS

An attic radiant barrier consists of a single sheet of material with one or two reflective (low emissivity) surfaces. For example, the barrier used by ORNL in its radiant barrier studies had a kraft paper center with a thin aluminum coating on each side. The purpose of the radiant barrier is to reduce the far-infrared-radiation heat transfer occurring between the roof of the house and the top of the attic insulation (or the attic floor if no insulation is installed), and thereby reduce the total heat transfer through the ceiling. The barrier is usually installed so that at least one of the reflective surfaces faces a large air space. Three configurations have typically been employed: (1) laying the barrier horizontally on top of the attic floor or attic insulation with the reflective surface facing up, (2) attaching the barrier to the underside of the roof rafters, or bottom of the top chords of the roof trusses, so that the reflective surface faces the attic floor, and (3) attaching the barrier to the underside of the roof rafters or truss chords so that the reflective surface faces the roof. In installing the barriers, considerations may also need to be made to ensure that the attic and any spaces created by the barrier are adequately ventilated.

ASE will utilize members of the Reflective Insulation Manufacturers Association (RIMA) to train Wa-Ro-Ma and weatherization personnel on how to properly install an attic radiant barrier in the test homes. The brand of barrier to be installed, the installation configuration to be employed, and ventilation requirements to be followed will be chosen based on RIMA's recommendations, input and advice from other researchers, and the attic designs to be encountered.

3.3 AIR CONDITIONER REPLACEMENTS

Mr. Larry Wisdom of Wa-Ro-Ma indicated that the low-income homes in the Tulsa, Oklahoma area are predominately cooled by one or two window air conditioners. Under this retrofit option, one window air conditioner per house with an EER less than or equal to 7 will be replaced by a high-efficiency unit. The high-efficiency unit will be of the same capacity as the original unit and will meet the following minimum efficiency standards for room air conditioners (product class: without reverse cycle and with louvered sides) as stipulated in the National Appliance Energy Conservation Act of 1987 recently passed by the U.S. Congress:

Less than 6,000 Btu/h	8.0 EER
6,000 to 7,999 Btu/h	8.5 EER
8,000 to 13,999 Btu/h	9.0 EER
14,000 to 19,999 Btu/h	8.8 EER
20,000 and more Btu/h	8.2 EER

The unit to be replaced must have an EER less than or equal to 7 to ensure that a low-efficiency unit is being replaced. The value of the EER for the current unit will be determined from manufacturers' literature in conjunction with Wa-Ro-Ma's evaluation of the operating condition of the unit. In some cases, a house might not receive a new unit because the existing units would have efficiencies greater than 7.

In houses with two air conditioning units installed, the unit in the main living area of the house will be replaced first if it meets the efficiency requirements described above.

The capacity of the replacement unit will be the same as the original unit for two reasons: (1) savings could be artificially obtained by installing lower capacity units, and (2) increased electricity use could result from the installation of larger capacity units. If central air conditioning systems were being replaced, then installing units that are properly sized (which could be different from the original) would be a valid approach. However, with window units, such an approach is not feasible because the original units may not have been installed with the intention of providing complete air conditioning throughout the house and the sizing procedure is complicated by the zoned nature of their use.

The brand of air conditioner to be used will be determined at a later data, with cost being a primary criterium in its selection. Although the units will meet the minimum efficiency standards stated above, it is hoped that units with efficiencies greater than these minimum values could be employed in the field test.

4. FIELD TEST DESIGN

4.1 EXPERIMENTAL DESIGN

One hundred twenty 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 cooling electricity 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 (Ref. 7).

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 electricity consumption changes in the houses because the before and after periods may cover different lengths of time, may not include the entire summer 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[8] 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 four "treatments" on cooling electricity consumption will be studied: the installation of retrofits as normally performed under Oklahoma's Low-Income WAP, the installation of retrofits as normally performed in the WAP plus the installation of an attic radiant barrier, the installation of retrofits as normally performed in the WAP plus the installation of a high-efficiency window air conditioner in replacement of a low-efficiency unit, 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.[9] Energy changes in individual 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 four "treatment" groups must be similar or equivalent. The 120 houses could be divided into four "treatment" groups of 30 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 within known statistical limits.

In the stratified random assignment procedure to be employed, the 120 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 cooling electricity consumption and the electricity savings that might be achieved by the conservation measures: the number of working window air conditioner units installed in the house (one or two) and the level of pre-retrofit

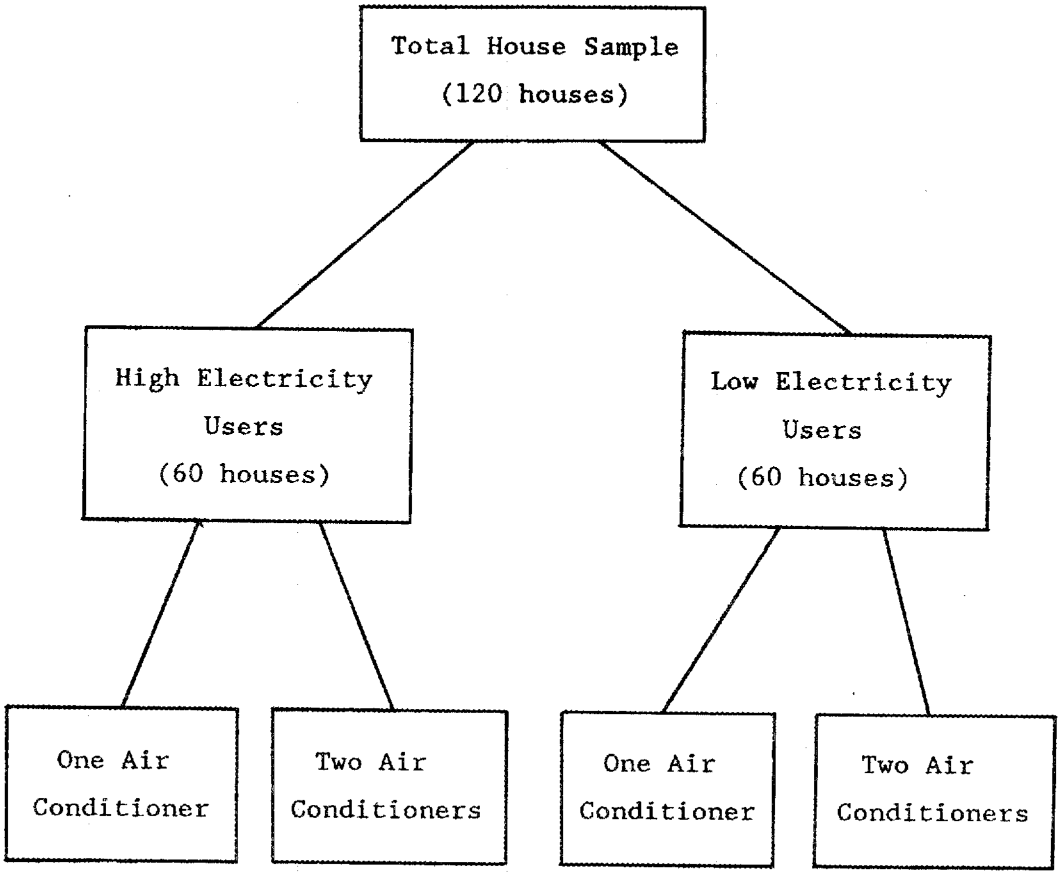


Fig. 4.1. Four classification groups to be used in stratifying the 120 field test houses.

electricity consumption required by the house during the summer (the upper or lower 50th percentile). A fourth of the houses from each classification will then be assigned to each of the "treatment" groups randomly. In this way, the same number of houses that have one air conditioner and have high electricity consumptions during the summer, for example, will be assigned to each of the four "treatment" groups, making the groups similar with respect to the chosen variables. The only control is in equally dividing the houses according to electricity consumption. The total number of houses in each classification will not be controlled and, thus, will likely be different because selection of houses will not depend on whether they have one or two air conditioning units. The assignment of the 120 houses to the four "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 number of working window air conditioners installed in the house may affect the way in which the units are operated. Additionally, because only one air conditioner will be replaced per house, the replacement represents either all or half (approximately) of the installed cooling capacity depending on the number of air conditioners installed in the house. Pre-retrofit summer electricity consumption is important because the average consumption in the four "treatment" groups of houses should be the same. Other variables such as house size, number of occupants, or number of floors are less important than the two variables chosen.

4.2 SAMPLING PLAN

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

1. the houses must be located in either Tulsa, Rogers, or Wagner Counties, Oklahoma;
2. electric service must be provided by PSO;
3. the occupants must be eligible for Oklahoma's Low-Income WAP at the time of being included in the field test;
4. the house must be cooled during the summer by electrical air conditioning equipment that is currently in operating condition;
5. electric service must be turned on;
6. the house must not be scheduled to receive retrofits under any other weatherization program;
7. the house must be a single-family detached house, but not a mobile home;
8. the house must be occupied by the owner;
9. the occupants must currently be paying their own electric bills and must have regularly paid their bills in the past;
10. the house must be cooled by only one or two electric window air conditioners; and
11. the occupants must not be planning an extended stay away from the house during the summer monitoring periods (May 15 to September 30), although a 1-2 week vacation is acceptable.

The first six 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 in the identified counties and in PSO's service territory to centralize the experiment and to remain within the working boundaries of the two field test participants. Primary goals of the experiment are to determine how much the cooling electricity consumption is reduced in low-income households by Oklahoma's current WAP and what further reductions can be obtained from the installation of radiant barriers or high-efficiency air conditioners. Consequently, the households to be studied must be selected from the pool of families eligible for Oklahoma's Low-Income WAP and the houses must currently be cooled during the summer by electric air conditioning equipment. Electric service must be turned on and the air conditioning equipment must be in operating condition to ensure that the houses are being cooled during the summer. 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 the treatments identified in Sect. 4.1.

The houses meeting the above characteristics still form a rather non-homogenous 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 this area. Narrowing the study will also make it easier to develop equivalent "treatment" groups.

The study will focus on owner-occupied, single-family, detached homes whose occupants currently pay their own fuel bill and have regularly paid their bill in the past. The energy use behavior of renters can be different from occupants that own their own home; thus, the performance of the conservation measures in these houses 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 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 electric bills may also be different from those who do not pay them or who have them paid through a relief program; thus, the performance of the conservation measures in these homes can also be different. Homes other than single-family detached are significantly different structures such that energy use and retrofit performance might be affected.

The study will focus on houses equipped with only one or two window air conditioners. Mr. Larry Wisdom of Wa-Ro-Ma indicated that the majority of low-income homes in the Tulsa area are cooled by between one and four window air conditioners. However, the use of three and four air conditioners is not sufficiently prevalent to warrant including in the study population (their inclusion would lead to increased variability between the houses and increased costs for monitoring equipment).

Houses in which the occupants are planning an extended stay away from the house during the summer monitoring period will not be included in the study population. The energy consumptions of these houses may be difficult to analyze using currently developed analysis techniques because there may be insufficient data collected to characterize the house when it is occupied. A one- to two-week vacation, though, would be acceptable.

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 120 houses.

Selection of the 120 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 120-house quota is reached. This "quota sampling" approach (a type of selection called a "chunk" in Ref. 10) 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 120 homes from the developed list. This would require time and funds which are not available.

The selection of houses should proceed in three steps:

Step #1. Low-income households which may be eligible under Oklahoma's Low-Income WAP and that are in the three identified counties and in PSO's service territory need to be identified using any available resource.

Step #2. The "Oklahoma Field Test House Screening Checklist" (Fig. 4.2) should be filled out for each of the houses as they are identified to determine their eligibility for the field test. This checklist covers criteria 3-11 identified in this section. Information needed to complete the checklist can be obtained through occupant interviews, house inspections, income verifications, and consultations with PSO.

Step #3. The occupants of the houses that are eligible for the field test should be provided with a copy of the field test summary ("Oklahoma Demonstration Project") listed in Fig. 4.3. If they are interested in participating in the field test, then the "Household Agreement Form" provided in Fig. 4.4 should be completed and forwarded to the person maintaining the field test files. The houses should be numbered sequentially from 1 to 120 as they are accepted into the field test.

OKLAHOMA FIELD TEST HOUSE SCREENING CHECKLIST

Name ____

Address ____

Phone number ______________________

Questions needing a "yes" answer	Yes	No
Is the household eligible for Oklahoma's Low-Income Weatherization Assistance Program?	____	____
Is the home a single-family detached house, but not a mobile home?	____	____
Is the house occupied by the owner?	____	____
Is the house air conditioned by only one or two electric window air conditioners?	____	____
Is the house's electricity service turned on and at least one air conditioner in operating condition?	____	____
Are the occupants currently paying their own electric bill and have they paid their bill regularly in the past?	____	____

Questions needing a "no" answer	Yes	No
Is the house scheduled to receive retrofits under any other weatherization program?	____	____
Do the residents have any plans to move or be away from the house for an extended time period during the next two summers (normal vacations of 1-2 weeks are not a problem)?	____	____

If questions needing a "yes" answer are answered yes, and the "no" questions are answered no, then the house is eligible for inclusion in the field test.

Is this house eligible? ____ Yes ____ No

Completed by: ____________________ Date ____________

Fig. 4.2. Checklist for screening possible project participants.

OKLAHOMA DEMONSTRATION PROJECT

Wa-Ro-Ma Tri-County Community Action Foundation invites you to take part in a special demonstration project that will weatherize your home free of charge!

The demonstration project will evaluate the effect of selected weatherization measures on cooling energy consumption. To evaluate the measures, we will install the weatherization measures of interest in selected homes in the Tulsa area. Each of these houses will be equipped with small meters to measure energy use. By comparing the home's energy use before and after the weatherization, we will determine how much energy is saved.

All of the weatherization measures to be installed have been evaluated previously and are safe and reliable. Several of the weatherization measures are routinely installed under state funded weatherization programs; although we know that these measures reduce heating bills, we do not know how much cooling bills are reduced by these measures. Other measures specifically designed to reduce cooling energy consumption are being considered for inclusion in the programs, but the actual savings obtained by these measures are not known. Thus, we need to find out how well the measures work in the Tulsa area.

Wa-Ro-Ma is conducting the field test in cooperation with the following organizations:

1. Public Service Company of Oklahoma - the local electric utility,

2. Oklahoma Department of Commerce - manager of the state's weatherization programs,

3. Alliance to Save Energy - a national nonprofit organization working to improve our nation's energy efficiency, and

4. Oak Ridge National Laboratory - a research organization providing engineering assistance to the project.

If you decide to participate in the demonstration project, the following will occur:

1. This spring, technicians will install a few small, simple meters in your house to monitor its energy use.

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

2. Weatherization measures will be installed in your home during either the 1988-89 winter or after the summer of 1989. Before the measures are installed, an energy auditor will visit your house and collect information about your home. For one of the measures, a leak detector will be used to find out where heat leaks out of your house. The detector uses a special fan that is placed in your front door for about an hour.

3. Energy use data will be collected from your house during the summers of 1988 and 1989.

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

1. Weatherization measures will be installed in your house by Wa-Ro-Ma. There will be no charge to you for these services. Wa-Ro-Ma will pay for the full cost of the weatherization materials and labor. (You will still be responsible for paying your own electric bill, however.)

2. All the information collected about your house will only be used for research purposes and will remain confidential. No information regarding you 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. If you decide to participate in the demonstration program, please read, fill out, and sign the household agreement form.

Fig. 4.3. (continued)

HOUSEHOLD AGREEMENT FORM

I, ______________________________, residing at
(homeowner's name)

____
(street address) (city, state, and zip)

agree to participate in the demonstration project described by the Oklahoma Demonstration Project sheet. I agree to

1. allow Wa-Ro-Ma to release information on my home's energy use to researchers so that they can conduct their evaluation;

2. provide researchers, energy auditors, and weatherization technicians access to my home during reasonable hours (a Wa-Ro-Ma or Public Service Company of Oklahoma staff person will phone me to schedule these times) during the demonstration;

3. answer interview questions and allow my house to be audited and weatherized using selected measures;

4. allow technicians to install, maintain, and remove small energy use meters in my home;

5. allow meter readers from Wa-Ro-Ma or Public Service Company weekly access to my property to read meters (wherever possible, meters will be installed so they can be read from outside the house); and

6. make every effort to safeguard the small meters installed by Wa-Ro-Ma or Public Service Company in my home to monitor energy consumption.

I understand that the demonstration project will be conducted in two parts, which means that my house either will be weatherized between the summers of 1988 and 1989 or may not be weatherized until after the summer of 1989.

______________________________ ______________
(homeowner's signature) (date)

______________________________ ______________
(Wa-Ro-Ma representative) (date)

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

4.3 ASSIGNMENT PROCEDURE

The assignment of the 120 houses to the four "treatment" groups should be performed in four steps:

Step #1. At the time the "Oklahoma Field Test House Screening Checklist" (Fig. 4.2) is filled out, the number of air conditioners installed in the house should be determined and noted on the form by circling the appropriate type in the fourth question.

Step #2. The five monthly electric bills from June through October 1987 should be obtained and the average electricity consumption per summer month determined (kWh/month). The houses in the upper and lower 50th percentile should then be identified.

Step #3. The 120 houses should be classified into the four blocking groups identified in Fig. 4.1.

Step #4. A fourth of the houses in each of the four blocking groups should be randomly assigned to each "treatment" group. Steps 2-4 are performed after the pre-retrofit data are collected in order to minimize the effect attrition may have on creating unequal "treatment" groups.

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. 11. The major exception is that the energy consumption of the hot water system will not be submetered. 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 homeowners, 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 descriptive information,
2. space conditioning system descriptive information,
3. entrance interview information,
4. follow-up interview information,
5. house infiltration measurements,
6. metered air conditioning system mechanical performance, and
7. retrofit listing and installation quality verification.

The descriptive and entrance interview information documents the physical characteristics of the house and air conditioning equipment as well as the behavioral characteristics of the occupants. This information is needed for the following reasons: (1) to determine the dependency of retrofit performance on house or occupant characteristics, (2) to allow the data set to be used in future studies, (3) to allow the test results to be compared with results obtained from other studies, and (4) to clearly establish the

Information or data	1988								1989											
	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
1. Descriptive and interview information	X																			
2. Follow-up information						X												X		
3. Infiltration measurements	X												X							
4. Air conditioner measurements	X												X							
5. Retrofit installation quality verification												X								
6. Retrofit listings												X								
7. Time sequential measurements	XXXXXXXXXXXXX												XXXXXXXXXXXXXX							
8. Monthly billing data						X												X		

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

characteristics of the houses and occupants from which the data and results were obtained and to which the results may reasonably be generalized. Tables 5.1 to 5.3 list the specific information requirements for these classifications. 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 and entrance interview information will be collected in May 1988 at the beginning of the first summer's monitoring period.

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 5.4. The follow-up interview information will be obtained at the end of each testing period (October 1988 and 1989). The information can be obtained through telephone contacts, mailings, or direct contacts.

The house infiltration measurements serve as descriptive variables characterizing the house air leakage rate with and without the retrofits installed. These measurements (1) quantify secondary effects of retrofits (such as infiltration reduction due to installing attic insulation), (2) more completely characterize the house, and (3) provide information which may be useful in future examinations of the data set. The fan pressurization technique using a blower door will be utilized because repeatable results are easily obtained at standard conditions. References 12 and 13 describe a standard fan pressurization technique that should be followed. Basically, the flow at 0.04 in. H_2O (10 Pa) to 0.24 in. H_2O (60 Pa) in increments of 0.04 in. H_2O (10 Pa) are measured with the blower door pressurizing and

Table 5.1. House descriptive information.

- General
    - House location
    - House sketch, plan view
    - House type
    - House style
    - House foundation type
    - Roof and external wall colors
    - Percentage of each floor cooled
    - Evaluation of factors affecting the air infiltration rate
- Insulation
    - Location and area
    - Insulation type and thickness
    - Construction
    - Percentage of bottom floor carpeted
- Windows, glass doors, and non-glass external doors
    - Area measurements per external wall facing
    - Number of window panes and storm windows
    - Non-glass door type
- Major appliances
    - Domestic hot water system
        - Type
        - Location
        - Hot water temperature
        - Nameplate (rated) information
        - Blanket thickness
    - Other major appliances
        - Type
        - Fuel
        - Location per type

Table 5.2. Air conditioner descriptive information.

Main cooling system
Type
Nameplate (rated) information
Location

Table 5.3. Entrance interview information.

Occupant information
Permanent number by age group
Average number at home during the day
Owner or renter
Length of time at residence
Space conditioning system information
Equipment age
Thermostat schedule
Utility distributors
Zoning practices
Rooms closed off
Schedule of closings

Table 5.4. Follow-up interview information.

Major alterations or additions
House
Air conditioning system or its operation
Domestic hot water system
New conservation measures or practices employed
Additional appliances used or change in use of previous appliances
Occupant changes
Permanent number
Age
Average number at home during the day
Owner or renter

depressurizing the house. These infiltration measurements are in addition to any measurements to be made under Oklahoma's infiltration reduction procedure for several reasons: (1) more information is required, (2) similar data on the control houses is desired, and (3) 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. The measurements will be made at the beginning of each summer's testing period (May 1988 and 1989).

The mechanical operation of the air conditioning units are metered to determine their actual operating characteristics. These measurements serve as a check on the nameplate information provided by the manufacturer and help ensure that the units are operating properly. For this field test, this entails measuring the electrical power draw of the unit using the installed submeters and measuring the inlet and outlet air temperatures across the evaporator and condenser. Measurements need to be taken on all units at the beginning of each monitoring period (May 1988 and 1989).

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, additional work needs to 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, for example). Verifying the retrofit installation quality needs to be performed in all the treated houses in April, 1989, which is soon after the installations are completed and before the post-retrofit monitoring period begins. The retrofits actually installed in the houses also need to be documented in April, 1989, by noting on the audit forms the measures performed.

5.2 TIME-SEQUENTIAL MEASUREMENTS

Four data parameters will be monitored in each field test house: house electricity use, house gas use, air conditioner electricity use, and house indoor temperature. In addition, ambient weather parameters such as temperature, humidity, and horizontal insolation will be monitored at three sites and collected from the nearest official weather station. All these data parameters will likely be required to perform the intended analysis. Table 5.5 summarizes the requirements of each data parameter. Data collection will begin May 15 and continue until September 15 in 1988 for the pre-retrofit period and, for the post-retrofit period, begin May 15 and continue until September 30, 1989.

5.2.1 House Electricity Use

PSO will provide and install in each test house a recently calibrated meter to measure the house electricity consumption to within an accuracy of 3%. The brand of meter will be left to the discretion of PSO. These meters will be manually read once a week by Wa-Ro-Ma, 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 PSO for accounting purposes will also be forwarded to ORNL. At the end of each monitoring period (October 1988 and 1989), the billing data for the previous two years should be downloaded from PSO's records using their standard programs and sent to ORNL.

Table 5.5. 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
House electricity use	electric use, kWh	weekly	weekly	electric billing meter	all houses
		monthly	yearly	electric billing meter	all houses
Air conditioner electricity use	electric use, kWh	weekly	weekly	billing type submeter	all houses
Indoor temperature	temperature, ^oF	hourly	monthly	Telog temperature recorder	all houses
Outdoor temperature	temperature, ^oF	hourly	monthly	data logger equipment	selected sites
Outdoor humidity	relative humidity, %	hourly	monthly	data logger equipment	selected sites
Horizontal insolation	energy flux, Btu/h-ft^2	hourly	monthly	data logger equipment	selected sites
Additional weather data	------	hourly	monthly	provided by local weather station	

5.2.2 House Gas Use

The existing gas billing meter installed in each house will be used to monitor the house gas 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 Wa-Ro-Ma. 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 Air Conditioner Electricity Use

The electricity consumption of the air conditioners in the test houses will be submetered using recently calibrated electric type billing meters accurate to within 3%. PSO will provide the meters, develop the installation method, and fund Wa-Ro-Ma to contract out for their installation. The brand of meter to use for this application will be left to the discretion of PSO. In houses with two air conditioners, the units will be metered separately. These meters will be manually read once a week by Wa-Ro-Ma, with the reading being recorded on the data collection sheet provided in Sect. 6. The data collection sheets will be forwarded to ORNL weekly.

5.2.4 Indoor Temperature

The indoor temperature of each test house will be monitored using Telog's 2103 Ambient Temperature Recorder (literature is provided in Appendix B). 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 $1^{\circ}F$. The device will be located in the room where the air conditioner is located. If two air conditioners are installed in the house, the device will be located in the room with an air conditioner that best typifies the main living area of the house. 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 or cold sources such as vents or appliances in the surrounding area. The devices will be provided by ORNL and installed by personnel provided by PSO. The devices will have to be removed at the end of the pre-retrofit period and reinstalled 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 PSO personnel 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 transferred to floppy diskette using ORNL supplied software and PSO's personal computer. The data diskettes will then be provided to ORNL monthly.

5.2.5 **Ambient Weather Parameters**

The following ambient weather parameters at three sites will be monitored: temperature, humidity, and horizontal insolation. The sites will be distributed among the test houses so that the weather conditions at each house can be represented by the data collected from at least one site. The selected sites will be PSO substations.

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, a humidity probe, pyronometer, and radiation shields. This equipment will measure the outdoor temperature accurately to within $1^{o}F$, the humidity to within 5% RH, and the solar radiation to within 10 $Btu/h\text{-}ft^2$. Literature on the equipment to be used to make these measurements are presented in Appendix B. The equipment required for these measurements will be provided by ORNL and will be installed by PSO and ORNL.

The temperature and humidity sensor 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 sensors 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 solar radiation measurement will represent the total radiation incident on a horizontal surface. The sensor will be installed horizontally, above the level of the roof, and in a position where nearby objects (houses, trees, etc.) do not block radiation or reflect excess radiation to the sensor. Other nearby meteorological equipment should be below or at least to the north of the solar sensor.

The instrumentation will measure the average hourly value for each parameter at each site and automatically store the data on cassette tape at periodic intervals. PSO personnel will collect the tapes from the sites monthly and mail them to ORNL. Hourly weather data will also be obtained from the nearest official weather station by ORNL once a month.

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 databases 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, and air conditioner electricity consumption are time-sequential data parameters that will be monitored using billing meters. These meters display the integrated total gas consumption or electricity consumption 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.

The current readings of these meters will be manually recorded once a week by Wa-Ro-Ma 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 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).

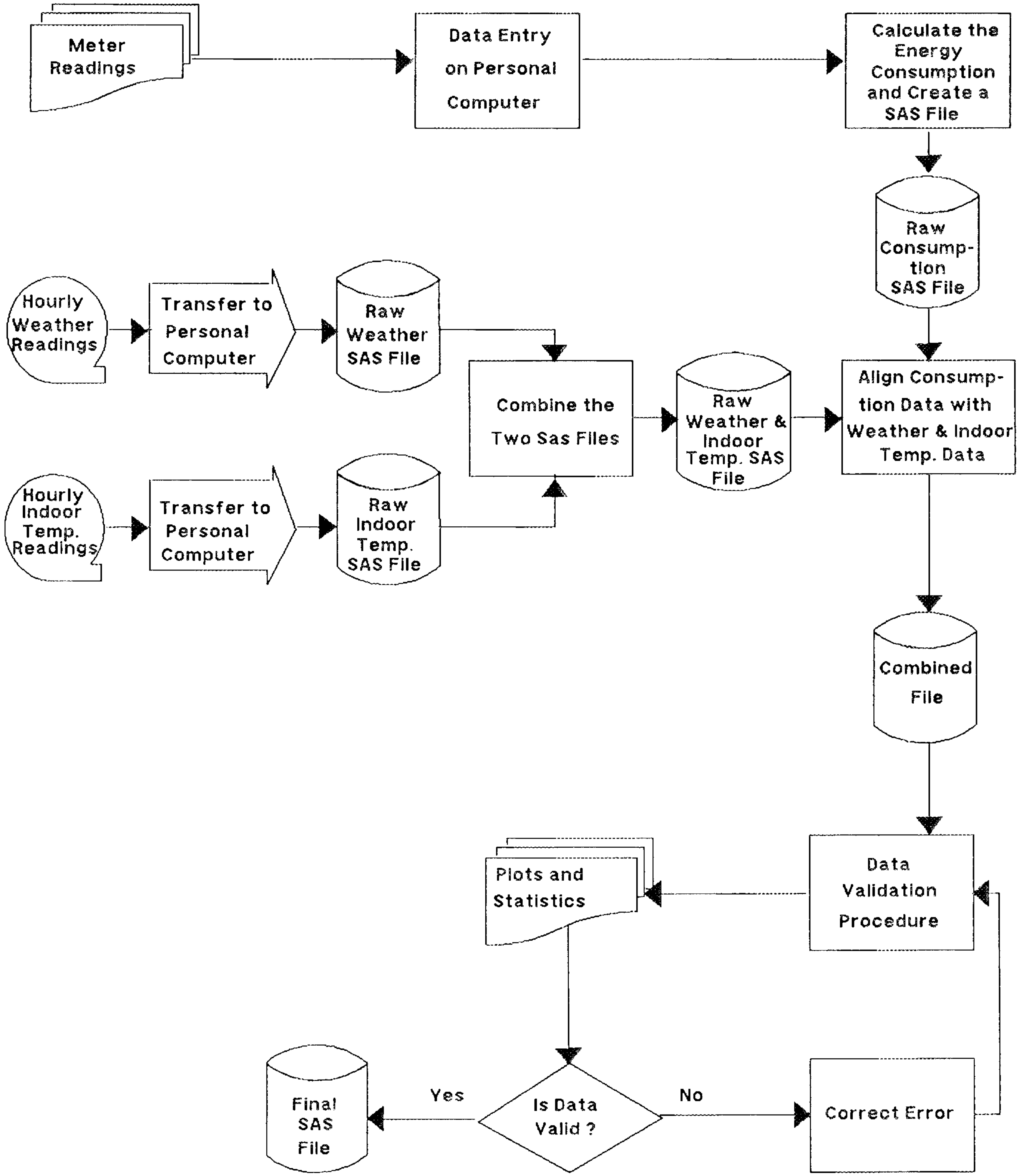


Fig. 6.1. Data management procedure for the time-sequential measurements.

Oklahoma Cooling Retrofit Field Test

Weekly Meter Data

House ID: ____________________ Address: __________________________

Date: __ __ /__ __ /__ __ (mo/day/year)

Time: _____: _____ (hr : min) a.m. _____ p.m. _____

Meter Readings:

Electric meter: __ __ __ __ __

Gas meter: __ __ __ __ 0 0

AC submeter #1: __ __ __ __ __

AC submeter #2: __ __ __ __ __

Fig. 6.2. Weekly field data collection 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 and previous readings. The energy consumptions will then be merged with the previously calculated consumptions in a raw consumption file.

In addition to monitoring the three energy consumptions identified above in each house, the hourly indoor temperature will be monitored in each house and hourly ambient weather parameters will be monitored at three sites. The indoor temperature data will be continuously stored in the meters, read once a month, and forwarded to ORNL on floppy diskettes. The weather 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 personal computer. The weekly consumption data will need to be aligned with the hourly indoor temperature and weather data because, in the analysis to be performed, an average indoor temperature and average weather data 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., June 23 and 10:30 A.M., June 30 and hourly outdoor temperatures are recorded on the hour, then the average outdoor temperature between June 23 at 4:00 P.M. and June 30 at 11:00 A.M needs to be calculated.

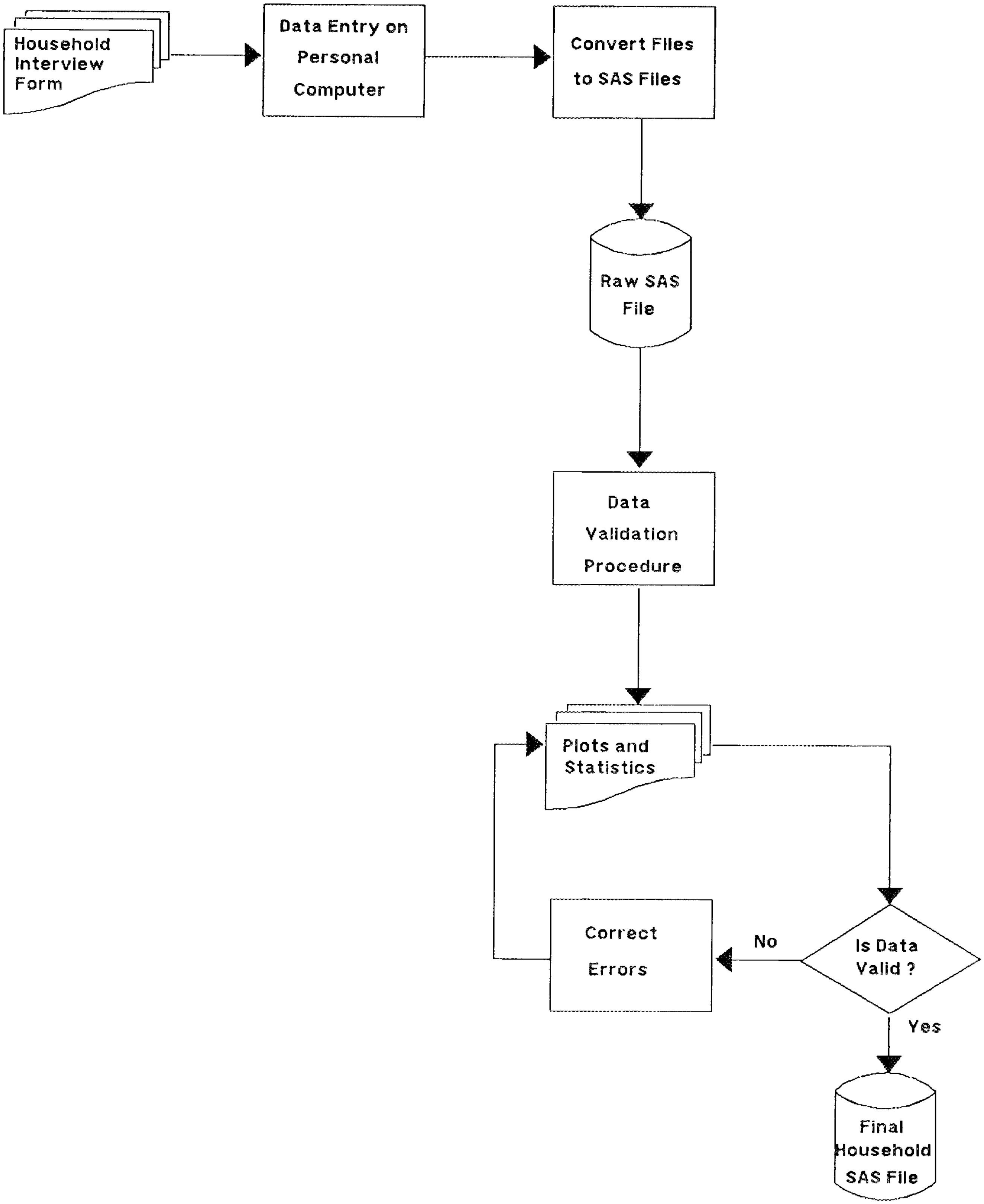
The hourly indoor temperature and weather data will be transferred into a raw temperature and weather file. A procedure will then be employed to align individual household consumption data with the hourly indoor temperature and weather data and to store the merged data in a combined file.

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. If an error is detected, the data point will be flagged and examined by the 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 Wa-Ro-Ma or PSO. Statistical Analysis System (SAS) software residing on a personal computer 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 personal computer 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.



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 three categories: study background, conservation measures, and energy savings and performance. The following subsections will present the approaches to be employed to address these questions.

7.1 STUDY BACKGROUND

The study background generally pertains to documenting the general physical characteristics of the houses and occupants. These characteristics 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, style, and foundation type. The pre-retrofit thermal condition of the houses will be summarized by studying the existing amount of attic, wall, and floor insulation installed, the cooling system efficiencies, the infiltration rates, and the pre-retrofit energy consumption during the summer (determined from the analysis of the pre-retrofit submetered data). The appliances found in these homes will also be summarized.

7.2 CONSERVATION MEASURES

Questions regarding the conservation measures that were installed will be addressed using data collected under Oklahoma's audit procedure and the retrofit verification process 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, and the actual cost to install each measure. Procedures used to install the attic radiant barriers and high-efficiency air conditioners and any difficulties encountered during their installation will be documented following discussions with the weatherization crews.

7.3 ENERGY SAVINGS AND PERFORMANCE

The performance of the conservation measures will be evaluated by determining the seasonal energy savings in the treated houses and examining the cost-effectiveness of the retrofits (which depends on retrofit annual energy savings, installation costs, and retrofit lifetime), both on an individual and group basis. The analysis procedures to determine the seasonal energy savings in individual houses, the savings in the treated houses as a group, and cost-effectiveness will be discussed separately. In the analytical procedures discussed, appropriate statistical analysis will be performed in order that the uncertainty associated with the final answers can be stated.

7.3.1 Individual House Savings

The seasonal energy savings can be defined as "the seasonal 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 seasonal 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 seasonal energy savings normalized for ambient weather conditions, indoor temperature, and occupant behavior changes.

To calculate the retrofit effect observed in the treated houses, the change in seasonal energy consumption of the individual treated and control houses (normalized for selected weather parameters and indoor temperature) 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 summer season, (2) the pre- and post-retrofit weather conditions will likely be different, and (3) indoor temperatures 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.

Under Task 6 identified in Sect. 2.4, an appropriate house model and details of the analysis required to determine individual house savings will be formulated. The need for this task arises because standard analysis procedures applicable to determining cooling season retrofit savings have not been developed as is more generally the case for determining heating season savings.

The analysis procedure will likely be similar to that employed to determine heating season savings though. A house model derived by considering an energy balance on the house will be employed so that the electricity use of the air conditioners can be expressed as a function of normalization parameters of interest (indoor and outdoor temperature, outdoor humidity, and solar insolation) and coefficients associated with the parameters. Linear regression techniques will be used to estimate the value of the coefficients for the pre- and post-retrofit periods for each house using the pre- and post-retrofit data, respectively. The pre- and post-retrofit cooling electricity consumptions will then be estimated using the respective values of the coefficients, average ambient weather data based on historical records, and assumed values for the indoor temperature. The change in cooling electricity consumption of the house due to the installation of the retrofit measures (normalized for weather parameters and indoor temperature) is then equal to the pre-retrofit electricity consumption minus the post-retrofit consumption. The retrofit effect of the treated houses is not simply equal to this change in energy consumption; rather, the retrofit effect of the treated 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 behavior 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 could be based on average values maintained during the pre-retrofit period or on values typically assumed to be average for most households. 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 on an equal basis.

A relaxed definition of the seasonal 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 ambient weather conditions and by the control houses, but not for indoor temperature. The seasonal 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 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 and compare group savings and to identify the effect of selected variables on the savings. The electricity 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 treated groups of houses will be of interest. Additionally, the effect of other variables on the measured savings (such as pre-retrofit energy consumption and number of air conditioners) 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 groups of treated houses using the normalized electricity savings, actual installation costs, estimated retrofit lifetimes, and other economic parameters as required.

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Appendix A

ENTRANCE INTERVIEW FORM

The form presented in this appendix was developed to collect the house and air conditioning system descriptive information and the entrance interview information specified in Sect. 3.

ENTRANCE INTERVIEW FORM
ORNL

Experimental Program: Oklahoma Cooling Retrofit Field Test House ID: ______

Interviewer Name: ______________________________ Date: __________

Name: ______________________________

Street Address: ______________________________

City: Tulsa State: Oklahoma Zip Code: ______

County: Tulsa Phone Number: ( ) ______________

Utility Distributors: Electric Public Service Company of Oklahoma
Gas ______________________________
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: ______________________________

Cooled floor area:

Floor	Total Area (ft^2)	Cooled 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 ____

COOLING SYSTEM

System 1:

Manufacturer: ____________________ Model: ____________________

Fuel: E

Type: _____ (WAC - window air conditioner; WHP - window heat pump)

Output capacity: ______________ Btu/h

Approximate age: ______________ years

Location: ____________________

Submeter k_h: __________ Rev.: __________ Time: __________

Indoor temperature: _______ °F Outlet temperature: ________ °F

Outdoor temperature: ______ °F Outlet temperature: ________ °F

System 2:

Manufacturer: ______________________ Model: ________________

Fuel: E

Type: _____ (WAC - window air conditioner; WHP - window heat pump)

Output capacity: ____________ Btu/h

Approximate age: ____________ years

Location: ________________

Submeter k_h: ________ Rev.: ________ Time: ________

Indoor temperature: ______ °F Outlet temperature: _______ °F

Outdoor temperature: _____ °F Outlet temperature: _______ °F

HOT WATER SYSTEM

Manufacturer: ______________________ Model: ________________

Fuel Type: ___ (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	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)

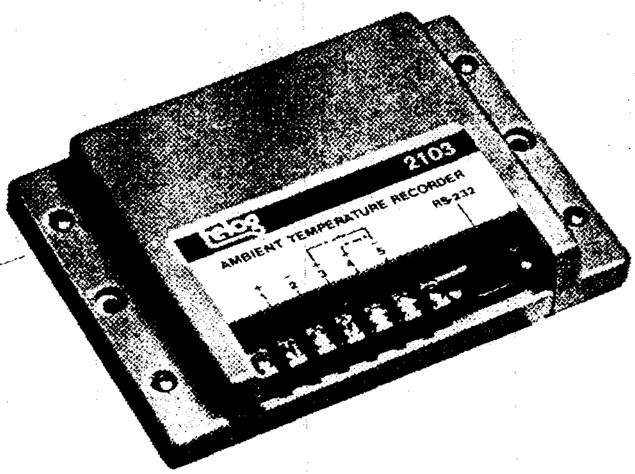
	Single-pane area (ft^2)		Multi-pane area (ft^2)	
	w/o storm windows	with storm windows	w/o storm windows	with storm windows
Front of house	___	___	___	___
Left side of house	___	___	___	___
Right side of house	___	___	___	___
Back of house	___	___	___	___
Basement (all sides)	___	___	___	___

Appendix B

MANUFACTURER'S LITERATURE ON SELECTED MONITORING EQUIPMENT

telog

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.

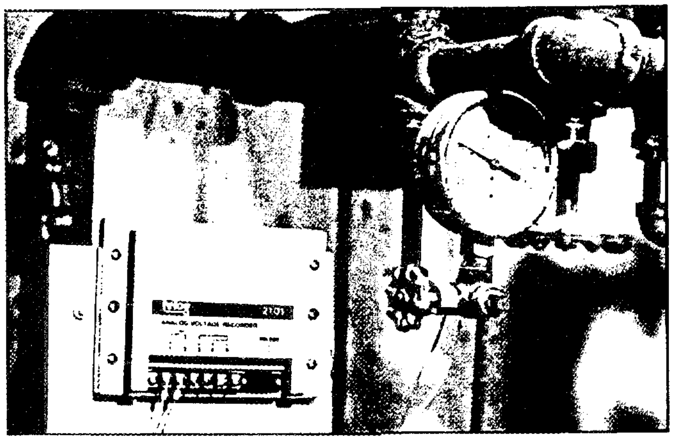
The Telog recorder samples the input signal from an external sensor once per second. At user-programmed intervals, the recorder computes and stores one or more user-selected data values (any combination of average, minimum or maximum). Up to 2000 values will be saved in memory spanning a total measurement 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.

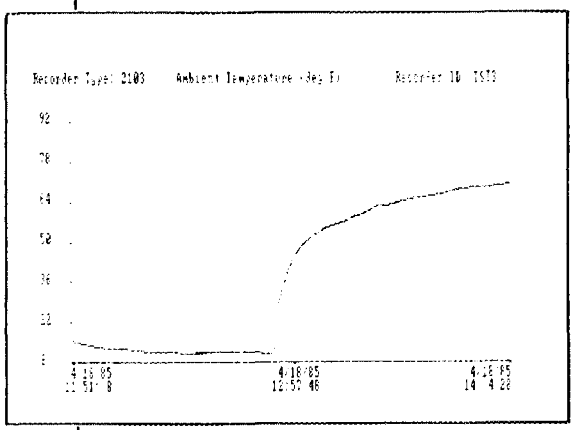
Programming the recorder is a simple task and may be performed when the unit is connected to the user's computer. The recorder itself has no user controls or adjustments.

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.

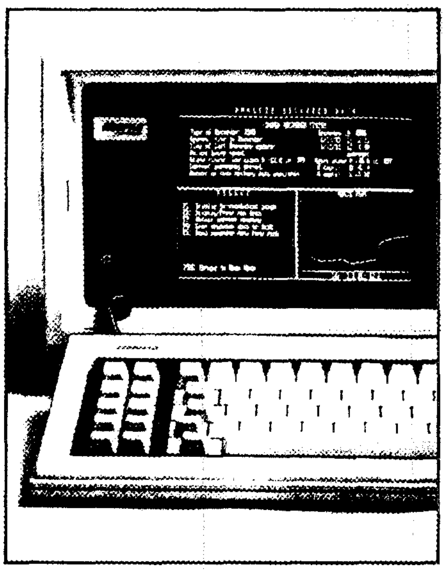


Data collection and analysis products

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.

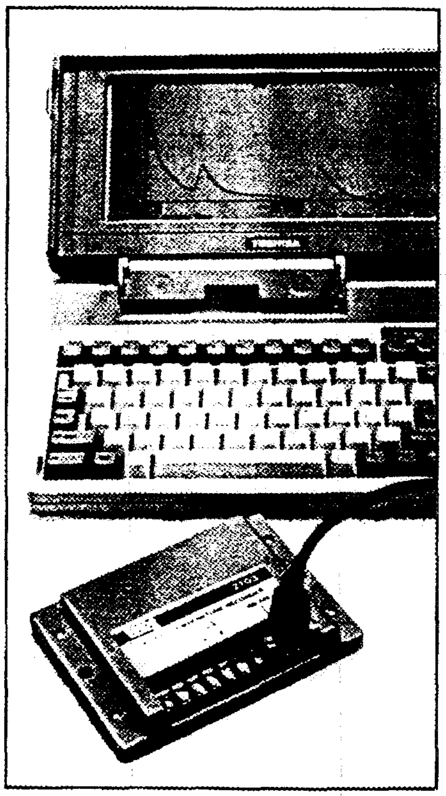
The PC can directly interrogate 2100 series recorders, or the Data Transfer Unit, display the data in three different graphics formats, send data to a printer in two different formats and save data on disk for future reference.

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.

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MS-DOS is a registered trademark of MICROSOFT.

TELOG INSTRUMENTS INC.

P.O. Box 240
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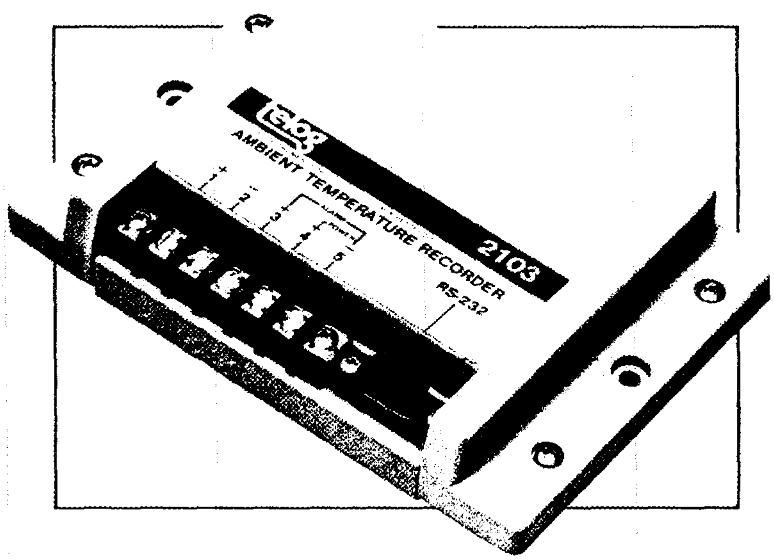
Phone: 716-359-1110

telog

Ambient Temperature Recorder
Model 2103

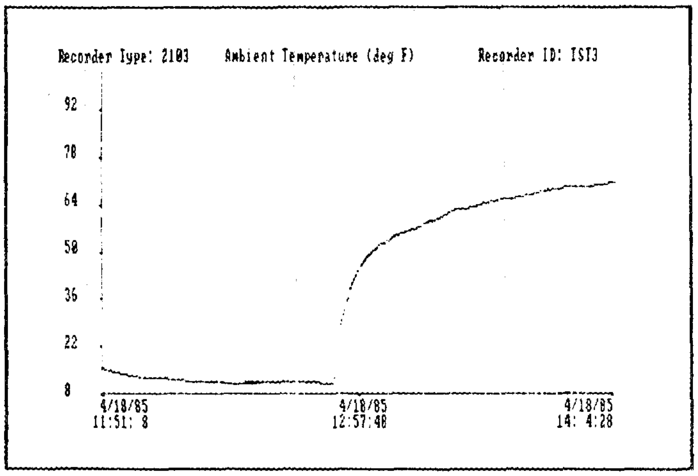
FEATURES

- **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**

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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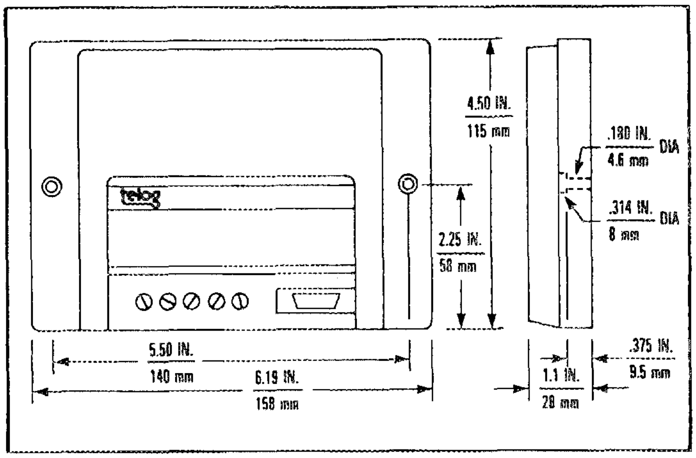
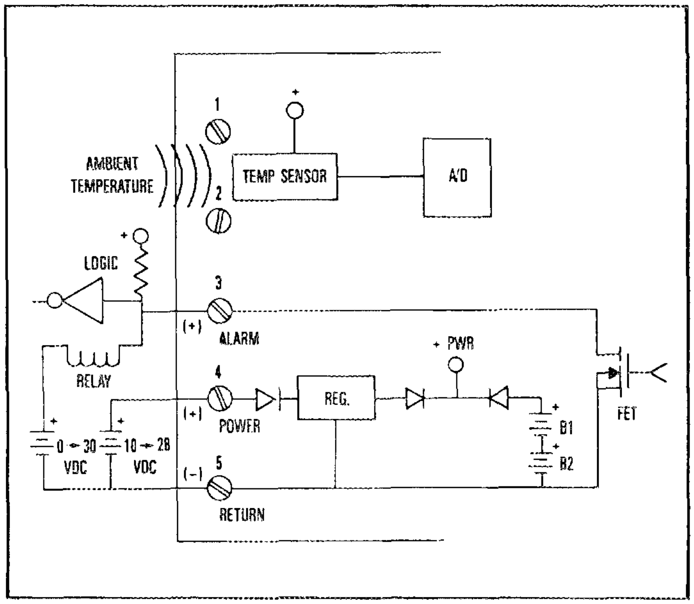
Model 2103 MOUNTING DIMENSIONS



FUNCTIONAL CONNECTION DIAGRAM



Telog Instruments Inc.
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West Henrietta, NY 14586
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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 ⅓ 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.

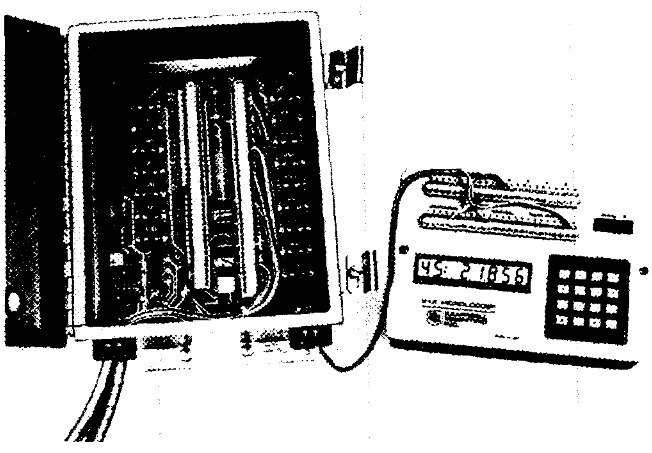
21X processing includes 22 instructions for measurements and control output, 39 instructions for data processing, and 9 instructions for program control.

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

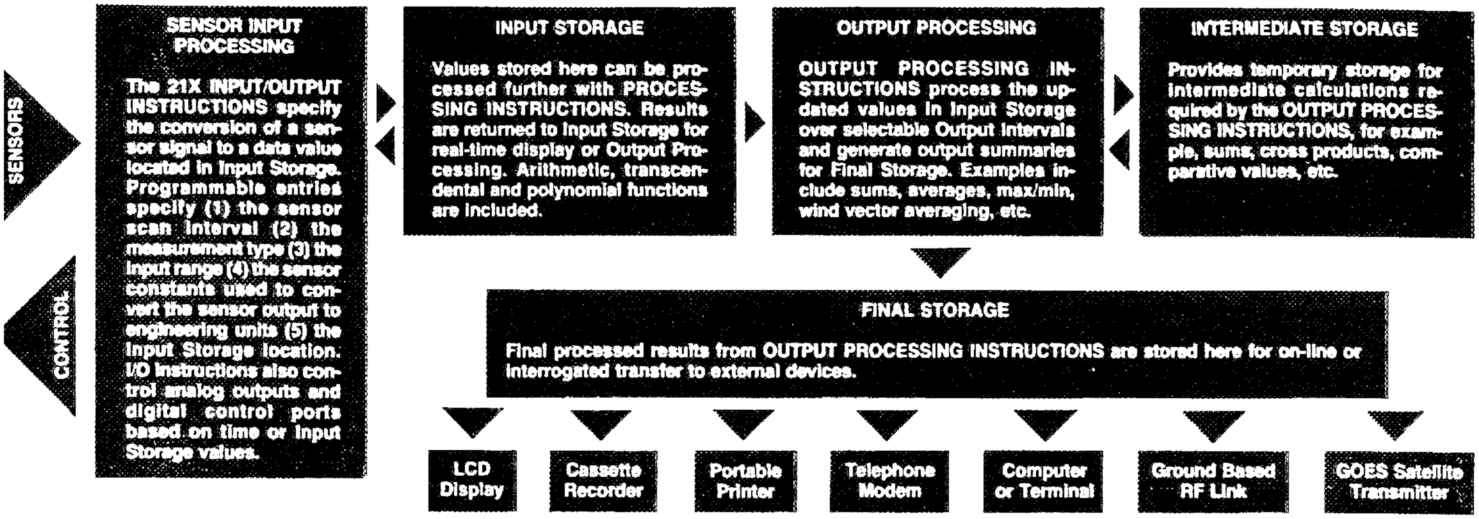
Analog inputs can be added in 32 channel increments using the Model AM32 Relay Scanner. Up to 6 AM32s can be added for an additional 192 analog channels.



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.

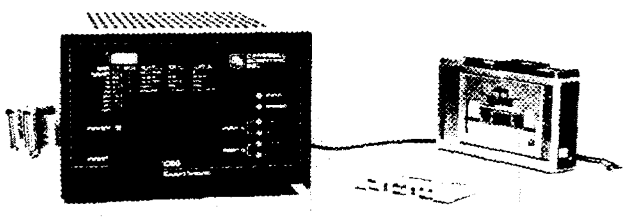
For RF telemetry, a Model DC95 RF modem is used in conjunction with an RF transceiver. The RF modem can communicate with any one of 255 other data stations on the same frequency. Connections to the transceiver include the microphone, remote speaker, transmit activation and carrier detect.

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 16 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

Reprinted December 1985

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.
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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-10761

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