ORNL/TM-11339

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

The North Carolina Field Test: Experimental Plan

T. R. Sharp
M. P. Ternes

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM-11339

Energy Division

THE NORTH CAROLINA FIELD TEST: EXPERIMENTAL PLAN

T. R. Sharp
M. P. Ternes

Weatherization Assistance Program

August 1990

Prepared for the
Office of State and Local Assistance Programs
U.S. Department of Energy

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
Operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

The authors would like to express their appreciation to Ms. Mary Fowler, Director, and Ms. Veronica Johnson of the DOE Weatherization Assistance Program, Mr. Fred Singleton of the DOE Atlanta Support Office, Mr. Earnie Freeman of the DOE Office of Buildings and Community Systems, Messrs. Jeff Brown and Mr. Percy Carter of the State of North Carolina, and the North Carolina Alternative Energy Corporation for their support of the North Carolina Field Test. A special note of thanks to Mr. Mark Hopkins of the Alliance to Save Energy for his work in preparation of the concept paper from which the field test originated. Our appreciation is also extended to Mr. Francis Conlin of the North Carolina Alternative Energy Corporation and to Messrs. Mike MacDonald and Mike Gettings of the Oak Ridge National Laboratory for valuable commentary on the experimental plan.

ABSTRACT

The North Carolina Field Test will test the effectiveness of two weatherization approaches: the current North Carolina Low-Income Weatherization Assistance Program and the North Carolina Field Test Audit. The Field Test Audit will differ from North Carolina's current weatherization program in that it will incorporate new weatherization measures and techniques, a procedure for basing measure selection on the characteristics of the individual house and the cost-effectiveness of the measure, and also emphasize cooling energy savings. The field test will determine the differences of the two weatherization approaches from the viewpoints of energy savings, cost effectiveness, and implementation ease. This Experimental Plan details the steps in performing the field test. The field test will be a group effort by several participating organizations.

Pre- and post-weatherization data will be collected over a two-year period (November 1989 through August 1991). The 120 houses included in the test will be divided into a control group and two treatment groups (one for each weatherization procedure) of 40 houses each. Weekly energy use data will be collected for each house representing whole-house electric, space heating and cooling, and water heating energy uses. Corresponding outdoor weather and house indoor temperature data will also be collected.

The energy savings of each house will be determined using linear-regression based models. To account for variations between the pre- and post-weatherization periods, house energy savings will be normalized for differences in outdoor weather conditions and indoor temperatures. Differences between the average energy savings of treatment groups will be identified using an analysis of variance approach. Differences between energy savings will be quantified using multiple comparison techniques. The control group will be used to normalize for occupancy variations between the pre- and post-weatherization periods.

EXECUTIVE SUMMARY

This report documents the experimental plan for the North Carolina Field Test. The Field Test will test the effectiveness of two weatherization approaches: the current North Carolina Low-Income Weatherization Assistance Program and the North Carolina Field Test Audit. The field test is being conducted as part of Phase 1 of a project to revise the current measure selection process used in DOE's Low Income Weatherization Assistance Program (Project Retrotech). The Field Test Audit will differ from North Carolina's current weatherization program in that it will:

1. incorporate new weatherization measures and techniques,
2. incorporate a procedure for basing measure selection on the characteristics of an individual house and the cost-effectiveness of the measure, and
3. emphasize cooling energy savings.

The field test will determine the differences of the two weatherization approaches from the viewpoints of energy savings, costs effectiveness, and implementation ease. It will also determine if the additional requirements of the new audit are cost justified. Testing of the new audit approach will allow the feasibility and cost effectiveness of the latest weatherization techniques and methods to be determined.

The field test is being supported by the U.S. Department of Energy's (DOE) Office of State and Local Assistance Programs; the DOE Office of Buildings and Community Systems; and the DOE Atlanta Support Office. Organizations involved in the day-to-day activities of the field test include the North Carolina Department of Economic and Community Development (NC-DECD) - Energy Division, the North Carolina Alternative Energy Corporation (NCAEC), the Oak Ridge National Laboratory (ORNL), the Alliance to Save Energy, and three local Weatherization Assistance Program (WAP) providers (Franklin/Vance/Warren Opportunity, Johnston-Lee Community Action, and Four-County Community Services).

The North Carolina Field Test will be performed using 120 houses in eastern North Carolina. Conservation measures selected by the Field Test Audit will be installed in one-third of the houses (audit houses), measures selected following North Carolina's current WAP procedure will be installed in another third of the houses (current practice houses), and the remaining houses will serve as a control group (control houses). Testing will be conducted over a two-year period (November 1989 to August 1991). Weatherizations will be performed in the middle of the test period to allow approximately one year each for pre- and post-weatherization testing. Tests will be performed to determine the energy savings of individual houses and groups of houses (treatment groups). Pre- and post-weatherization testing will allow houses to serve as their own reference and thus, allow individual house savings to be determined.

Data will be collected through surveys and continuous monitoring. Typical survey data will consist of descriptive details of the house construction and its mechanical system(s), short-term performance evaluations of the building shell and/or mechanical system(s), and details of occupancy levels and patterns. Survey data will be used to document house characteristics and their impacts on energy use. Monitored data will include weekly measurements of the following energy uses: whole-house electricity, space heating, air conditioning, and water heating. In addition, outdoor weather data and house indoor temperature data will be recorded on an hourly basis.

Ultimately, all field data will be computerized and meshed to form the final data sets from which analyses will be done. The NC-DECD and the NCAEC will direct data collection and provide data to the ORNL for processing (error identification, correction, and meshing into final data sets).

Both survey information and performance data will be analyzed. Analyses will answer questions about house and occupant characteristics, weatherization measures, weatherization energy savings, and the performance of the two weatherization approaches. Survey information will be used to characterize house types, floor areas, wall, floor, and ceiling/attic constructions, space heating and cooling systems, occupancy levels, occupied periods, and other characteristics.

Linear regression techniques will be used to model the relations between energy use and indoor and outdoor conditions for the pre- and post-weatherization periods for each house. Individual house savings will be adjusted (normalized) for temperature variations (both indoor and outdoor) between the pre- and post-weatherization periods using the models, average outdoor temperature data based on historical records, and values for the indoor temperature. Normalization is done to keep influencing factors from masking or altering the resulting energy savings. Occupant related changes will be accounted for by measuring the before and after energy performance of the control houses. Groups of similar houses (houses with similar characteristics as identified by the characteristics data) will be pooled and analyzed to calculate group savings, compare the savings of the audit houses to the current practice houses, and identify the effect of selected variables on the savings. The ease of implementation of the two weatherization procedures will be compared based on the experience of the auditors and weatherization installers.

1. INTRODUCTION

1.1 BACKGROUND

In 1978, "Project Retrotech"[1] was published to provide local weatherization agencies a manual means of identifying what energy conservation (weatherization) measures could be installed in low-income homes to maximize the energy savings per dollar spent for weatherization. During the eleven years since its publication, weatherization technologies and program changes evolved such that revision or replacement of this audit was needed.[2] In 1988, the Department of Energy's (DOE) Weatherization Assistance Program (WAP) initiated a project with the Oak Ridge National Laboratory (ORNL) to improve the effectiveness of Project Retrotech. Based on assessment of the current measure selection techniques and the needs of local weatherization agencies, it was recommended that the Weatherization Assistance Program support the development of an upgraded technique.[2]

Following this recommendation, in 1989 the Weatherization Assistance Program approved a project to support development of a new technique for measures selection. The project would be done in two phases: (1) develop an upgraded WAP audit procedure and field test it against the current North Carolina weatherization procedure, and (2) expand the upgraded WAP audit procedure for use by all WAP agencies.

The ORNL is currently developing the new WAP audit procedure (the Field Test Audit) for Phase 1 of the project. This Experimental Plan documents the details of the field testing portion of Phase 1 (the North Carolina Field Test) which will test side-by-side the current North Carolina weatherization procedure and the new Field Test Audit.

1.2 FIELD TEST AND REPORT OBJECTIVES

The primary purpose of the North Carolina Field Test is to:

Determine the energy savings from the current North Carolina Low-Income Weatherization Assistance Program procedure[3] as compared to a new weatherization approach (the Field Test Audit) which incorporates new weatherization techniques and methods and is specifically designed to include cooling and domestic hot water energy saving measures as well as measures for heating energy savings.

The field test will determine the differences of the two weatherization approaches from the viewpoints of energy savings, cost effectiveness, and implementation ease. Testing of the new audit approach will allow the feasibility and cost effectiveness of the latest weatherization techniques and methods to be determined.

1.3 REPORT ORGANIZATION

Section 2 of this report provides general project details, including how the project will be done, the goals of the project, and the research questions that can be addressed using the project's results. Individual tasks and the responsible participants are listed in Section 2 along with a project schedule. Section 3 summarizes the two weatherization approaches that will be tested. Section 4 provides details of the test design including the size and the proportioning of the sample, the house and occupant characteristics required for inclusion, and how the sample will be obtained and assigned. Sections 5 and 6 summarize data collection details. Section 5 outlines the data required for the field test, the types of instrumentation required, and the general details of instrument installation. Section 6 discusses how the data will be collected, assembled, and verified. Section 7 details the analyses that will be performed on the collected data to characterize the test homes, occupants, and the energy savings on an individual house and group basis. Analyses to determine the cost effectiveness of the two weatherization schemes and the ease of implementation of new weatherization options and procedures are also discussed in Section 7.

2. PROJECT OVERVIEW

2.1 GENERAL APPROACH

The field test will be performed by the North Carolina Department of Economic and Community Development (NC-DECD) - Energy Division; the North Carolina Alternative Energy Corporation (NCAEC); the Oak Ridge National Laboratory (ORNL); the Alliance to Save Energy (ASE); and three local weatherization providers (Franklin/Vance/Warren Opportunity, Johnston-Lee Community Action, and Four-County Community Services). Financial support for the project will be provided by the DOE Office of State and Local Assistance Programs which administers the WAP; the DOE Office of Buildings and Community Systems; the DOE Atlanta Support Office; the NCAEC; and the NC-DECD.

The field test will be performed in counties in eastern North Carolina near Raleigh. One-hundred twenty houses meeting selected criteria will be monitored. Conservation measures selected by the North Carolina Field Test Audit will be installed in one-third of the houses (audit houses), measures selected following North Carolina's current WAP procedure will be installed in another third of the houses (current practice houses), and the remaining houses will serve as a control group (control houses). The inclusion of a control group allows many factors that may affect the validity of the experiment to be taken into account. Energy consumption changes in the weatherized houses may be due entirely to the conservation measures installed. On the other hand, other factors occurring during the test program may contribute to the change. A group of houses identical to the weatherized houses except that measures are not installed (a control group) will 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 audit and current practice groups to determine the actual savings induced by the conservation measures. A stratified random assignment procedure will be used to help achieve pre-weatherization equality between the three groups of houses.

The field test will be conducted over a two-year period. Pre- and post-weatherization testing will be performed to determine the change in energy use of individual houses. Pre-weatherization data will be collected on all houses during one winter and summer season (November 1989 to August 1990). Measures will be installed in the treatment houses in September and October 1990. Post-weatherization data will be collected on all houses during the following winter and summer seasons (November 1990 to August 1991).

Data collection will be based on the recommendations of the DOE's Single-Family Monitoring Protocol.[4] The following time-dependent data will be collected weekly in all the houses: house electricity use, space heating energy use, water heating electricity use, and air conditioning electricity use. Hourly indoor temperature data will be monitored in each house and hourly outdoor weather data will be collected at three sites near the houses. The following time-independent information will also be collected or measured during the field test: house and occupant descriptive information, changes that occurred in the descriptive information during the test, house infiltration rates, heating system performance, and descriptions and quality verifications of the conservation measures installed.

Linear regression techniques will be used to model the relation between space conditioning energy use and indoor and outdoor conditions for the pre- and post-weatherization periods for each house. For the winter seasons, the relationship between the space heating energy use and the indoor-outdoor temperature difference will be determined. For the summer seasons, the relations between air conditioning energy use and indoor-outdoor temperature difference and other weather variables will be determined. A house model is needed because (1) the time periods over which the data will be collected may not be equal or cover the entire winter and summer periods, (2) the weather conditions for the pre- and post-periods will likely be different, and (3) indoor temperatures maintained in each house over the two winter and summer periods will likely not be the same. Normalized annual energy consumptions for the pre- and post-periods will be estimated for each house using the models, average outdoor temperature data based on historical records, and values for the indoor temperature. For each house, the difference between these normalized energy consumptions will be the normalized annual change in energy use.

The performance of the Field Test Audit and current practice will be evaluated on an individual house and group basis. The change in energy use of each weatherized house will be adjusted by the change that occurred, on average, in the control houses. This adjustment accounts for changes in energy use due to changes in occupant behavior (an influencing factor other than the conservation measures). Individual house savings will be grouped and analyzed to determine group savings, to compare the savings of the audit houses to the current practice houses, and to identify the effect of selected variables on the savings.

Two technical reports outlining the results of the project will be published. The first report (an interim report) will present the pre-weatherization energy consumptions of the houses. Following the post-weatherization summer season, a second report will present results on the actual energy savings achieved by the conservation measures selected by the audit and current practice. Technical papers on the results will be presented at appropriate conferences. A separate memorandum will be prepared summarizing the results and presenting policy and program recommendations. A technical report discussing economic analysis techniques and recommended practices for use in weatherization audits will also be prepared. Finally, a training curriculum for the audit will be developed.

2.2 RESEARCH GOALS AND QUESTIONS

The goals of this field test were developed to meet some of the research needs of the Department of Energy's Weatherization Assistance Program. Research results should characterize the importance of cooling energy savings to local weatherization assistance programs. In addition, the results should identify more cost-effective weatherization measures and techniques that can be used to improve the value of services currently provided to low-income families.

The project has two primary goals:

(1) to determine any improved cost effectiveness resulting from a new audit which includes the latest in new weatherization measures and techniques and is directed toward cooling and water heating energy savings as well as space heating energy savings, and

(2) to determine the size of potential cooling energy savings as compared to potential heating energy savings from low-income weatherization in a hot and humid climate.

Results of this experiment should help to resolve the following issues in the three categories:

Energy Savings and Performance

1. What are the typical energy savings achieved from the current North Carolina WAP?

2. What are the typical energy savings achieved from the new Field Test Audit?

3. How does the cost-effectiveness of the two approaches compare for North Carolina conditions?

4. What are the advantages and disadvantages of using the new audit and its procedures?

5. How do the cooling energy savings from low-income weatherization compare to the heating energy savings?

Weatherization Measures

1. What are the most common energy saving measures installed in low-income houses in North Carolina under the existing WAP?

2. What are the most common energy saving measures recommended by the Field Test Audit? How do they differ from those installed under the existing North Carolina WAP?

House and Occupant Characteristics

1. What are the characteristics of the typical house and occupant(s) in the field test?

2. Were the two treatment groups and the control group equivalent relative to these house and occupant characteristics?

2.3 PROJECT PARTICIPANTS AND CONTRIBUTIONS

Project participants and their contributions (participants are listed in Section 2.1) are as follows:

1. The DOE Weatherization Assistance Program provides support to low-income weatherization assistance programs across the nation through regional offices such as the DOE Atlanta Support Office. This program is providing funding to support ASE and ORNL tasks.

2. A second DOE program, the Existing Buildings Efficiency Research (EBER) program of the Office of Building and Community Systems, actively promotes energy efficiency research for the nation's existing residential and commercial buildings. EBER is also providing funding to support ASE tasks and supporting ORNL tasks by contributing necessary monitoring equipment.

3. The DOE Atlanta Support Office is providing funds to support NC-DECD tasks.

4. The NCAEC is a state non-profit research organization working with electric utilities in North Carolina to improve energy efficiency. NCAEC will provide funds and manpower to acquire, install, maintain, and remove metering equipment, and assist in data collection.

5. The NC-DECD will manage the field test by conducting or coordinating all field test activities. In addition, they will provide funds to the participating WAP providers, i.e., the Community Action Programs who will perform the actual weatherizations.

6. The ASE is a national non-profit coalition of business, government, and public leaders dedicated to promoting energy use efficiency. The ASE provided the initial organizing of the project, will support the audit development through economic analysis work, will continue to provide management support to the project, and will prepare some of the project's publications.

7. The ORNL is a research laboratory whose primary role is to support governmental research programs. ORNL tasks will be to develop the Experimental Plan, the Field Test Audit, provide instrumentation and installation details, perform data analyses, and prepare reports documenting the project and its results.

8. The WAP providers will assist in house selection, data collection, audit the participating houses, and perform the weatherizations.

2.4 PROJECT TASKS AND SCHEDULE

The project has been organized into the three areas of Planning and Development, Field Testing, and Data Analysis and Results Dissemination. Twenty subtasks were identified in the three project areas. These are shown along with their scheduling in Fig. 2.1 and are described as follows:

1.0 Planning and Development

1.1 Organize Project - The primary function of this task is to develop a project concept paper which describes the project, its purpose and approach, its tasks, and the participants and their roles. The ASE, with input from project participants, completed their part of this task in March 1989. ORNL completed their project organization efforts in April 1989.

Project Tasks	1989						1990												1991											
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
1. PLAN & DEVELOPMENT																														
1.1 Organize project	Completed																													
1.2 Prepare Experimental Plan	xxx	xxx																												
1.3 Prepare economic analysis	xxx	xxx	xxx	xxx	xxx	xxx																								
1.4 Develop audit procedure	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx																			
1.5 Prepare curriculum					xxx	xxx	xxx	xxx	xxx	xxx	xxx																			
1.6 Prepare homeowner booklet					xxx	xxx	xxx	xxx	xxx	xxx	xxx																			
1.7 Train WAP crews												xxx																		
1.8 Manage project	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
2.0 FIELD TEST																														
2.1 Select field test homes	xxx	xxx	xxx																											
2.2 Instrument homes			xxx	xxx																										
2.3 Collect pre-retrofit data		xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx																
2.4 Audit field test homes													xxx	xxx	xxx															
2.5 Install conserv. measures/ conduct follow-up interview															xxx	xxx														
2.6 Collect post-retrofit data																	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx				
2.7 Remove instrumentation / conduct exit interview																											xxx	xxx	xxx	xxx
2.8 Install measures in control homes																											xxx	xxx	xxx	xxx
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
3.0 ANALYSIS & DISSEMINATION																														
3.1 Prepare interim report												xxx	xxx	xxx	xxx	xxx	xxx	xxx												
3.2 Prepare final report																										xxx	xxx	xxx	xxx	
3.3 Prepare summary report																													xxx	xxx
3.4 Disseminate test results			xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D

Fig. 2.1. Task scheduling for the three project areas of the North Carolina Field Test.

1.2 Prepare Experimental Plan - The Experimental Plan is a detailed plan of how the project, and particularly the field test, will be accomplished. ORNL prepared the plan which details the test design, participant roles, instrumentation needs and installation, required field data and collection methods, and data analyses. This report, the Experimental Plan, was completed in August 1989.

1.3 Prepare Economic Analysis - The ASE will prepare a report detailing how to use economic analysis in a weatherization audit. This report will provide important analysis methods that will be used by ORNL in completing the Field Test Audit. Completion of this task is scheduled for December 31, 1989.

1.4 Develop Audit Procedure - ORNL will develop the Field Test Audit with emphasis on hot and humid climate measures and will incorporate recently proven new weatherization measures and techniques. Scheduled completion of the audit is during the pre-weatherization test period on May 31, 1990.

1.5 Prepare Audit Training Curriculum - The ASE will prepare an audit training curriculum which will describe the objectives, activities, and the resources for training of weatherization crews to aid in collecting audit data and using the new weatherization audit. Completion date for this is May 31, 1990.

1.6 Prepare Homeowner Booklet - The ASE will prepare a homeowner booklet which will describe the importance of auditing, what an audit and weatherization can do for the homeowner, and how the homeowner can achieve the most savings from weatherization. The booklet will be prepared concurrently with the auditors training curriculum and completed at the same time, May 31, 1990.

1.7 Train WAP Crews - Both ORNL and the NC-DECD will assist in training WAP crews. ORNL will instruct the NC-DECD on performing the Field Test Audit and they in turn will train the individual weatherization crews through workshops. Training will likely include using blower doors, installing new measures (such as radiant barriers), and conducting heating system diagnostics (such as flue gas analysis). Training of WAP crews should be completed in June 1990.

1.8 Manage Project and Provide Technical Assistance - The NC-DECD will manage the field test and assist the WAP providers as needed. ORNL will provide technical assistance to the NC-DECD and the NCAEC. The ASE will assist the DOE WAP by conducting briefings and making project recommendations. This task will be distributed over the duration of the project.

2.0 Field Test

2.1 Select Field Test Homes - The NC-DECD will select test homes based on the criteria in the Experimental Plan (refer to Section 4). Participating WAP providers will assist by identifying homes in their service areas that qualify for the field test. The scheduled completion of this task is September 30, 1989, but enough test houses will need to be identified by July to allow the type and number of metering needed for the test to be estimated.

2.2 Instrument Homes - The ORNL and the NCAEC will support this task. ORNL will provide instrumentation and technical assistance to NCAEC regarding installation. NCAEC will provide additional instrumentation and will coordinate the installation of all instrumentation. Instrumentation installation is scheduled to be completed by October 31, 1989.

2.3 Collect Pre-retrofit Data - The NC-DECD will coordinate collection of entrance interview data on the house and occupants (August through October 1989). The NC-DECD will also coordinate collection of weekly monitored data, starting November 1, 1989. Pre-retrofit data will be delivered to the NCAEC for computer entry. The NCAEC will forward the data, as files on floppy disk(s), to ORNL for further processing. Pre-weatherization data collection will end on August 31, 1990.

2.4 Audit Field Test Homes - Following the pre-weatherization monitoring period, 40 homes will be audited using the Field Test Audit (treatment group 1), 40 homes will be audited using the current North Carolina WAP procedure (treatment group 2), and 40 homes will be audited using both procedures (control group) between July and September 1990. The weatherization audits will be conducted by the three weatherization providers.

2.5 Install Conservation Measures / Conduct Follow-Up Interview - The local WAP providers will install conservation measures according to the results of the audit procedure used for each of the 80 homes in the two treatment groups. Installation will occur at the end of the pre-weatherization monitoring period between September and October 1990. At the same time, the NC-DECD will coordinate the assessment of the installed measures (measures installed, costs, and quality) and the collection of follow-up interview data.

2.6 Collect Post-retrofit Data - The NC-DECD will coordinate collection of post-retrofit weekly monitored data. The data will be delivered to the NCAEC for computer entry and forwarding to ORNL. ORNL will process the monitored data which will include error checking and processing into a final storage format. Post-weatherization data collection will occur between November 1, 1990 and August 31, 1991.

2.7 Remove Instrumentation / Conduct Exit Interviews - At the conclusion of the monitoring, the NCAEC will remove and return instrumentation as needed. This includes collection of and returning the indoor temperature sensors to the ORNL. At the same time, the NC-DECD will coordinate exit interviews of each household. These should take place between September and December 1991.

2.8 Install Measures in Control Homes - For their participation in the project, the WAP providers will weatherize the control homes following test completion using the measures recommended by the most promising of the two audit techniques. Weatherizing these homes will be done concurrently with the instrumentation removal and exit interviews between September and December of 1991.

3.0 Analysis and Dissemination

3.1 Prepare Interim Report - ORNL will prepare an interim report at the end of the pre-weatherization monitoring period. The report will describe work through the half-way point of the field test, including a list of the installed retrofits and a summary of the pre-weatherization energy consumptions. Scheduled completion is December 31, 1990.

3.2 Prepare Final Report - ORNL will prepare the final report of the project. The report will summarize both pre- and post-weatherization work and will detail the final results of the project. Scheduled completion is November 30, 1991.

3.3 Prepare Summary Report - The ASE will prepare a summary report which will review project results and document policy and program recommendations based on these results. Scheduled completion for the summary report is December 31, 1991.

3.4 Disseminate Test Results - The ASE, the ORNL, and the NC-DECD will participate in dissemination of test results through presentations at appropriate conferences/meetings, publications, and by assisting other participants in preparing information for public release. This is an ongoing effort throughout the duration of the project.

3. CONSERVATION APPROACHES

3.1 NORTH CAROLINA'S CURRENT LOW-INCOME WEATHERIZATION ASSISTANCE PROGRAM

North Carolina's current weatherization program is limited to seven weatherization measures that are installed based on their prioritized ranking. The measures are ordered relative to their perceived cost-effectiveness. The measures in order of their prioritization are:

(1) infiltration measures,
(2) attic insulation,
(3) water heater, pipe, and floor insulation,
(4) duct insulation,
(5) underpinning (enclose the crawl space),
(6) storm windows, and
(7) storm doors.

Each measure is installed in order of priority until the allotted funds, up to $1400 per house on average (including administration costs), is expended or the next consecutive measure is unaffordable within spending limits. A higher priority measure must be fully installed before the next measure is considered.

Infiltration measures include caulking, adding new weatherstripping and replacing existing defective weatherstripping around windows and doors, repairing or replacing windows and doors in poor condition, and repairing holes in walls and floors. The identification of infiltration deficiencies and locations is made visually. Attic insulation is installed to a minimum of R-19 and a maximum of R-30. Attic insulation is installed in conjunction with installing appropriate attic vapor barriers and attic ventilation.

All uninsulated electric water heaters receive a water heater insulation wrap. Wrapping of fuel-fired water heaters is permissible. Hot water pipes and heating duct are also insulated. Houses with a crawl space receive floor insulation or underpinning depending on the height of the crawl space. The remaining measures, storm windows and doors, generally have a much longer payback and therefore are installed only on a limited basis.

3.2 THE FIELD TEST AUDIT

The Field Test Audit is being developed by the ORNL. The ASE is assisting in its development by providing recommendations on using economic analyses for measures selection. The new audit will be computerized to provide an easier, faster, and more accurate evaluation of the most appropriate measures for an individual house. This should substantially reduce the computational time normally required to evaluate specific measures. The new audit will have several features beyond traditional weatherization approaches. In addition to traditional measures, the Field Test Audit will include:

(1) new weatherization techniques and measures that have been found to improve current practice and often have attractive paybacks, such as blower-door guided infiltration reduction, radiant barriers, and heating equipment replacements,

(2) a procedure for selecting weatherization measures based on cost-effectiveness as related to the characteristics of the individual house,

(3) a method of evaluating the interaction of measures in the measure selection process, and

(4) an analysis of measures for reducing space cooling energy use.

By incorporating these features, the new audit will offer additional attractive weatherization measures and an improved basis for measures selection that will hopefully improve the overall cost-effectiveness of weatherization.

4. FIELD TEST DESIGN AND IMPLEMENTATION

4.1 EXPERIMENTAL DESIGN

One-hundred twenty houses meeting the eligibility requirements identified in Section 4.2 will be selected and weatherized according to a one-way classification design with three treatments. The primary factor of interest is the method used to select the weatherization measures for an individual house. The three levels of this factor (treatments) that will be tested are (1) measures selected by the North Carolina Field Test Audit (treatment 1), (2) measures selected using the procedures currently used in the North Carolina WAP (treatment 2), and (3) a control group in which no measures are installed. The 120 houses will be selected according to the procedure described in Section 4.3 and assigned to the three treatment groups according to the randomized procedure identified in Section 4.4. With this design, differences between treatment effects can be identified using a one-way analysis of variance.[5]

Pre- and post-weatherization testing will be used to determine the energy savings of the individual houses and, from these, the average savings of the treatment groups. Pre- and post-weatherization testing allows the houses to serve as their own reference and, thus, allows individual house savings to be determined. Pre- and post-testing is useful in conservation program evaluations where an on-off design cannot be employed, which is the case for this field test. The on-off design may be used whenever a system can be turned off so that the building operates as if the conservation measure had not been installed.[6]

4.2 HOUSE ELIGIBILITY

Houses included in the study population will be limited to those with the following characteristics:

1. The house must be located in the counties in which the WAP is administered by the three providers identified in Section 2.1 to centralize the project and to limit the number of agencies involved.

2. The house must be a single-family detached structure, but not a mobile home. Less is known of multifamily structures and mobile homes, both of which can be studied later.

3. The house must be heated during the winter primarily by natural gas, propane, kerosene, or fuel oil systems that are currently in operating condition. Secondary fuels (such as wood) or heating systems (such as portable kerosene and electric heaters) must not be used to substantially heat the house (use limited to half a day per week or in bathrooms). A survey of houses recently weatherized under the WAP in the field test service area indicated that heating systems other than the four identified were not sufficiently prevalent to warrant including in the study population (their inclusion would lead to increased variability between the houses and increased costs for the monitoring equipment). Additionally, the Field Test Audit may not be applicable to these other types of systems. Accurately measuring the amount of secondary fuel used to heat a house is difficult. Thus, extensive use of secondary fuels or systems increases the uncertainty of energy use determinations and can make such determinations impossible.

4. The house must be cooled during the summer by only one or two electric window air conditioners that are currently in operating condition. Two goals of the experiment are to determine the performance of an audit that includes conservation measures specifically designed to reduce cooling energy use and to determine the cooling energy savings achieved under the current WAP. Prior experience has indicated that most low-income houses, if air conditioned, are cooled by window air conditioners and that the use of more than two units per house is not sufficiently prevalent to warrant including in the study population.[7]

5. The house's potable water must be heated with electricity. The survey discussed above indicated that this is the most common type of water heating system in the service area. Inclusion of other systems would significantly alter the instrumentation approaches to be used to monitor the water heating and heating system energy consumptions.

6. The house must not be scheduled to receive conservation measures under any other weatherization program to help ensure that the only changes made to the houses during the testing period are the treatments identified in Section 4.1.

7. The occupants must be eligible for North Carolina's WAP at the time of being included in the test. A primary goal of the experiment is to determine if the audit procedure can significantly increase the energy savings and cost-effectiveness of state low-income WAPs.

8. The house must be occupied by the owner. 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 use 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.

9. The occupants must currently be paying their own fuel and electric bills and have regularly paid their bills in the past. The energy use behavior of people who pay their own energy bills may be different from those who do not pay them or have them paid through a relief program. Therefore, the performance of the conservation measures and selection methods in these houses may be different.

10. The occupants must not be planning an extended stay away from the house during the monitoring period, although 1-2 week vacations are acceptable. The energy consumptions of houses in which the occupants are away for an extended time period may be difficult to analyze using currently developed analysis techniques. In these homes, there may be insufficient data collected to characterize the house when it is occupied.

Narrowing the population of houses to those with these characteristics will allow more definitive results on the most common type of low-income houses in the service area, help ensure that the goals of the experiment are met, and make it easier to develop equivalent treatment groups.

4.3 SELECTION PROCEDURE

Because all the houses in the population of interest could not be studied, a sample of 120 houses representing the population will be chosen. This sample size was selected based on cost considerations and the number of treatment groups desired. Treatment group sizes were determined based on the expected error in estimating average house energy savings from weatherization.

Selection of the 120 houses will be performed by identifying individual houses conforming to the selection criteria, 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 was chosen because a more formal statistical technique such as random sampling will require time and funds that are not available. (In this latter approach, a much greater number of eligible homes than needed would have to be identified, and then 120 houses selected randomly from the developed list.)

The selection of houses should proceed in three steps:

1. Low-income households that may be eligible under North Carolina's WAP and that are in the counties served by the three providers participating in the field test need to be identified using any available resource. Possible resources include (a) lists of homes potentially eligible for the North Carolina WAP, North Carolina fuel assistance program, or utility troubled payment programs, and (b) outreach efforts by outreach workers.

2. Information on each of the houses as they are identified should be collected to determine their eligibility for the field test. A form similar to that shown in Fig. 4.1 ("North Carolina House Screening Checklist") could be used for this purpose. This checklist covers criteria 2-10 identified in Section 4.2. Information needed to complete the checklist can be obtained through client interviews (in person or over the telephone), house inspections, and income verifications.

3. The occupants of the houses eligible for the field test should be provided with a copy of the field test summary ("North Carolina Demonstration Project") shown in Fig. 4.2. If they are interested in participating in the field test, then the "Household Agreement Form" in Fig. 4.3 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.

4.4 ASSIGNMENT PROCEDURE

In order for the comparison between treatment groups to be valid, the three groups must be similar or equivalent. The 120 houses will be assigned to the three groups (40 houses to a group) at the end of the pre-weatherization period using a randomized procedure with stratification to ensure uniformity between groups. The assignments will be made after the pre-weatherization period to minimize the effect attrition will have on creating unequal groups. A procedure without stratification could be employed, but this method becomes progressively more unreliable as the number of houses becomes smaller. The strata to be used involves using two key variables that can significantly affect house energy use and the energy savings that might be achieved by the audit or current selection practice. The first variable, the type of heating system installed in a house, is important because systems are controlled differently and the way they deliver heat also differs. Additionally, conservation measures selected by the audit for a given house will likely depend on the house's heating system due to hardware and cost considerations. The second variable, the number of working air conditioners installed in the house, may affect the total cooling energy use from a capacity viewpoint and the manner in which the units are operated.

NORTH CAROLINA HOUSE SCREENING CHECKLIST

Name: ______________________ Phone number: __________

Address: ______________________________________

Questions needing a "yes" answer	Yes	No
Is the household eligible for North Carolina'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 heated primarily by fuel oil, natural gas, propane, or kerosene systems? (circle fuel)	____	____
Is the house air conditioned by only one or two electric window air conditioners? (circle #)	____	____
Is the primary heating system and at least one air conditioner in operating condition?	____	____
Is the house hot water heated by electricity?	____	____
Do the occupants currently pay their own fuel and electric bills and have they regularly paid them in the past?	____	____
Questions needing a "no" answer		
Is the house scheduled to receive conservation measures under another weatherization program?	____	____
Do the residents have any plans to move or be away from the house for an extended time period during the testing period (normal vacations of 1-2 weeks are acceptable)?	____	____
Is a secondary fuel (such as wood) or heating system (such as portable kerosene or electric heaters) used more than half a day per week to heat areas other than the bathrooms?	____	____

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

Is this house eligible for the field test? ____ Yes ____ No

Completed by: ______________________ Date: __________

Fig. 4.1. North Carolina house screening checklist.

NORTH CAROLINA DEMONSTRATION PROJECT

The North Carolina Department of Economic and Community Development-Energy Division, invites you to take part in a special demonstration project that will weatherize your home free of charge!

The demonstration project will evaluate different methods of selecting conservation measures to be installed in houses under the state's Weatherization Assistance Program. To evaluate the different methods, we will install conservation measures as recommended by the different methods in selected homes in counties in eastern North Carolina. Each of the 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 measures are routinely installed under the state's current weatherization program. Although we know that these measures reduce heating bills, we do not know how much cooling bills are reduced. Other measures may be recommended by a new selection method that we want to test. These measures may be specifically designed to reduce cooling energy consumption, or they may reduce both heating and cooling energy use. The actual savings obtained from the measures that may be recommended by the new selection method are not known. Thus, we need to find out how well the measures work in the North Carolina area.

The State of North Carolina is conducting the field test in cooperation with the following organizations:

1. Franklin/Vance/Warren Opportunity, Johnston-Lee Community Action, and Four-County Community Services - local providers of the state's Weatherization Assistance Program,

2. North Carolina Alternative Energy Corporation - a state non-profit research organization working with electric utilities in North Carolina to improve energy efficiency,

3. The Alliance to Save Energy - a national non-profit organization working to improve our nations's energy efficiency, and

4. Oak Ridge National Laboratory - a government-owned national research laboratory providing research and technical assistance to the project.

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

Fig. 4.2. Summary of the North Carolina Field Test for participating households.

1. This summer, technicians will install a few small, simple meters outside your house to monitor its energy use. A new wiring circuit may be installed to your air conditioners and hot water system (the circuit may be run around the outside of your house in conduit). An electric meter will be installed in the new circuits to monitor energy use of these appliances. An added benefit of new circuits is that they may upgrade and improve your current wiring system. A different type of meter will be installed to monitor the energy use of your heating system. In addition, a small meter about the size of a paperback book (about 6 x 2 x 4 inches) will be placed in the living area of your house to monitor the indoor temperature.

2. Weatherization measures will be installed in your home in the fall of 1990 or 1991. Before the measures are installed, an energy auditor will visit your house and collect information about your home, test the efficiency of your heating system, and find out where heat leaks out of your home using a special fan placed in your front door.

3. Energy use data will be collected from your house from November 1989 until October 1991. Once a week, a technician will read the meters installed outside your house. Once a month, the technician will read the meter installed inside your house. Once or twice a year, a technician will collect other data on your house using special instruments.

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

1. Weatherization measures will be installed in your house by the weatherization provider serving your area. There will be no charge to you for these services. We will pay for the full cost of the weatherization materials and labor. (You will still be responsible for paying your own fuel bills, 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 improve our weatherization program and better control home energy costs. Your participation in the study will make a big contribution to realizing these objectives. If you decide to participate in the demonstration program, please read, fill out, and sign the Household Agreement form.

Fig. 4.2. (continued)

HOUSEHOLD AGREEMENT FORM

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

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

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

1. allow the local weatherization provider 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 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 conservation measures;

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

5. allow technicians access to my property to read meters; and

6. make every effort to safeguard the small meters installed inside and outside my home to monitor indoor temperature and energy consumption.

I understand that the demonstration project will be conducted in two parts, which means that my house will be weatherized in either the fall of 1990 or the fall of 1991.

____________________________________ ______________________
(homeowner's signature) (date)

Fig. 4.3. Household agreement form.

The assignment of the 120 houses to the three treatment groups will be performed in three steps:

1. The type of heating system and number of air conditioners will be determined for each house. This information can be collected at the time the "North Carolina House Screening Checklist" is filled out by circling the correct choices in the fourth and fifth questions. This information will also be gathered as part of the survey data.

2. The houses will be classified into one of the following eight strata: natural gas heating system with one air conditioner, natural gas heating system with two air conditioners, propane heating system with one air conditioner, propane heating system with two air conditioners, oil heating system with one air conditioner, oil heating system with two air conditioners, kerosene heating system with one air conditioner, and kerosene heating system with two air conditioners.

3. A third of the houses in each of the eight strata will be randomly assigned to each treatment group. In this way, the same number of houses that have natural gas heating systems and one air conditioner, for example, will be assigned to each of the three treatment groups, making the groups similar with respect to the chosen variables.

5. DATA PARAMETERS AND MONITORING INSTRUMENTATION

The data to be collected for this field test correspond to the minimum data set specified in Ref. 4. The data to be collected can be divided into two types: survey data and time-sequential data. The survey data are similar to audit-type data in that they are essentially all collected by point-in-time measurements. The survey data typically include descriptive details of the house construction and its mechanical system(s), short-term performance evaluations of the building shell and/or mechanical system(s), and details of occupancy levels and patterns. The time-sequential data are recorded on a continual basis. Primarily, this includes energy consumption data, indoor temperature data, and outdoor temperature and other weather-related data. Weatherization providers, under NC-DECD direction, will collect all survey and time-sequential (continuous) data. The time schedule for data collection is presented in Fig. 5.1.

5.1 SURVEY INFORMATION

The field test will require the following survey data:

1. entrance interview information,
2. follow-up and exit interview information,
3. house shell and mechanical system performance information, and
4. weatherization measures listing and installation quality verification.

Collection of survey data will be the responsibility of NC-DECD with ORNL providing technical assistance.

The entrance interview is used to collect house and systems descriptive information summarizing the physical characteristics of the house, its mechanical systems (heating, cooling, water heating, etc.), and how the house is occupied. This information is needed to (1) assess the dependency of energy use on these factors, (2) document the house description for future

Required Data	1989 J	A	S	O	N	D	1990 J	F	M	A	M	J	J	A	S	O	N	D	1991 J	F	M	A	M	J	J	A	S	O	N	D
Entrance interview information		xxx	xxx	xxx																										
Follow-up information															xxx	xxx														
Infiltration measurements													xxx	xxx	xxx	xxx														
Heating system performance													xxx	xxx	xxx	xxx														
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Cooling system performance	xxx	xxx	xxx										xxx	xxx	xxx												xxx	xxx		
Weatherization measures list and quality verification															xxx	xxx														
Time-sequential measurements					xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx			xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx				
Exit interview information																											xxx	xxx	xxx	xxx
Monthly billing data															xxx												xxx			
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D

Fig. 5.1. Data requirements and corresponding collection schedule.

reference, (3) allow test results to be compared with other houses having similar characteristics, and (4) document the characteristics of the house and its occupants to which the results relate. Tables 5.1 through 5.3 list the general information types required for the survey data. The Survey Interview Form in Appendix A should be used to record the entrance interview data. Entrance interviews should be conducted between August and October of 1989.

Follow-up and exit interview information will be used to help identify any changes that have occurred during the testing that could significantly affect results. Table 5.4 lists the general information types in the follow-up and exit interviews. This information will consist primarily of identifying changes to the data collected on the Survey Interview Form. Follow-up interviews should be scheduled during the installation of weatherization measures (September to October 1990). Exit interviews should be scheduled during instrumentation removal (September to December 1991).

The house shell assessment consists of infiltration measurements to determine the air "tightness" of the building both before and after weatherization. These measurements can be used to (1) provide an indicator of the integrity of the building shell, (2) characterize secondary infiltration reductions that occur indirectly from another shell measure such as added wall insulation, and (3) provide an indicator that may be useful in any future study of the test results. Infiltration measurements should be performed using the blower-door fan-pressurization technique.[8,9] The technique essentially measures infiltration into and out of a house by depressurizing and pressurizing the interior space between 10 and 60 pascals (0.04 to 0.24 in. H_2O) below and above ambient outdoor pressures. Infiltration measurements should be made just before and immediately after weatherization (between July and October 1990). If possible, the measurements can be made when the house is being audited or weatherized.

The performance of mechanical systems should also be assessed. Air conditioner (AC) operation should be verified during each summer (July through September of 1989, 1990, and 1991). Window air conditioners can be checked for operation by measuring and comparing the indoor AC exhaust air temperature and the indoor room air temperature. The AC exhaust air temperature should be

Table 5.1. House descriptive information.

General
- House location
- House sketch, plan view
- House and roof type
- House style
- House foundation type
- Roof and external wall colors
- Percentage of each floor heated and cooled
- No. of floors

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. Space conditioning systems descriptive information

Heating system:	Type & fuel Distribution method and fluid Nameplate (rated) information Location
Cooling system:	Type & fuel Distribution method and fluid 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 and exit interview information

Major alterations or additions
- House
- Space conditioning systems or their operations
- Domestic hot water system

New conservation measures or practices employed

Additional appliances used or a change in use of previous appliances

Occupant changes
- Permanent number
- Age
- Average number at home during the day
- Owner or renter

at least 10°F lower than the room air temperature. The performance of space heating systems should be evaluated to verify that the heating systems are functioning properly and to determine operating efficiencies. Heating system assessment will consist of a visual check and a flue gas (efficiency) analysis for each unit. Heating system tests should be done on all houses during the auditing or weatherization periods (July through October 1990). Houses that receive a furnace tuneup or replacement as a conservation measure should have two, before and after, efficiency checks.

The remaining survey information is collected at the time the weatherization work is inspected. A list of installed measures and the individual costs of each measure should be prepared. The weatherization work is evaluated to assure that the work meets specifications and to assess the general quality of the installation. The installation assessment can be by visual inspection where possible or by measurements if needed (such as measuring attic insulation depth). If the installation is below specifications, correction should be made prior to the beginning of post-weatherization testing. Thus, installation checks will need to be done concurrently with weatherization installations (September and October 1990).

5.2 TIME-SEQUENTIAL MEASUREMENTS

Four energy use parameters will be measured continuously for each test house: total electricity use, space heating energy use, air conditioning electricity use, and water heating electricity use. The average indoor temperature will be monitored continuously in each house. Weather parameters will be monitored continuously using three weather stations. The time-sequential measurements will be made over the entire pre- and post-weatherization periods. The monitored parameters along with pertinent information relative to each are summarized in Table 5.5.

NCAEC, with utility assistance, will provide all watt-hour meters (for metering electricity for house total, air conditioning, and water heating energy uses) and select the brand and type of these meters. NCAEC will provide for calibration of each watt-hour meter. NCAEC will also acquire vapor meters for monitoring propane use and supply run time meters for

Table 5.5. Time-sequential data parameter requirements and information

Parameter		Units	Recording Frequency	Collection Frequency	Metering Instrument
Total electricity use		kWh	weekly	weekly	electric billing meter
Space heating energy use:	natural gas	ft^3	weekly	weekly	gas billing meter
	propane	ft^3	weekly	weekly	propane meter
	kerosene	gal	weekly	weekly	sight glass
	oil	gal	weekly	weekly	sight glass/run time meter
Air conditioner electricity use		kWh	weekly	weekly	watt-hour meter
Water heating electricity use		kWh	weekly	weekly	watt-hour meter
Indoor temperature		°F	hourly	monthly	Telog temperature recorder
Outdoor temperature		°F	hourly	monthly	data logger equipment
Outdoor relative humidity		%	hourly	monthly	data logger equipment
Horizontal insolation		$Btu/h\text{-}ft^2$	hourly	monthly	data logger equipment

metering oil consumption. ORNL will provide kerosene metering systems, indoor temperature devices, and weather data instrumentation. NCAEC will handle installation of all instrumentation. ORNL will provide technical assistance for instrument installation and will assist in the setup of weather stations.

5.2.1 House Total Electricity Use

House total electricity use will be measured continuously by the watt-hour meter that records whole-house electricity use for the servicing utility. House total electricity use will be manually read and recorded on a weekly basis. Meters should be accurate to within 3% over the duration of the project.

The standard billing data for each house should be acquired by the NCAEC from the accounting records of the servicing utility. Billing data should be collected and then forwarded to the ORNL at two times, the ends of the pre- and post-weatherization monitoring periods (September 1990 and September 1991).

5.2.2 Space Heating Fuel Use (natural gas, propane, kerosene, and oil)

A previous survey indicated that the majority of houses served by the Weatherization Assistance Program in the Raleigh area use natural gas, propane, kerosene, or fuel oil for space heating fuel. As a result, testing will be limited to homes using one of these four heating fuels. Fuel use will be measured continuously and recorded on a weekly basis.

Natural gas use should be read from the utility gas meters located at each house. NCAEC will be responsible for having utility gas meters calibrated to provide accuracy within 3%.

Since propane is usually sold to customers as a bulk liquid (like oil and kerosene), vapor meters are not typically installed at residential sites. Therefore, vapor meters will have to be installed at each house using propane fuel. Meters should be located adjacent the house in the propane supply line just before it enters the house. NCAEC will be responsible for acquiring and insuring the accuracy of propane meters to within 3%.

Instead of using a flow metering device (as initially planned), kerosene use will be measured using a sight glass installed at the storage tank on the fuel supply line. The ORNL will design a low-cost sight glass indicator for kerosene systems since a universal, easily-installed, off-the-shelf unit was not found. Consumption will be monitored by simply recording the tank level on a weekly basis and relating level changes to tank volumes. ORNL will procure all parts and supply them along with assembly and installation procedures to the NCAEC who will coordinate installation.

Fuel oil consumption will be measured using a sight glass (for above ground tanks which are the most abundant) or a run time meter (for below ground tanks). The run time meters are used to measure the on-time of the pump in the oil supply line. This pump turns on with the furnace and normally provides a relatively steady flow such that run time will provide an accurate measurement of oil consumption. ORNL will provide calibrated oil nozzles for pumped oil systems. The calibration will provide an oil consumption rate relative to the run time of the pump. NCAEC will be responsible for installation of the calibrated oil nozzles and run time meters.

5.2.3 Air Conditioner Electricity Use

Each house will have one to two window air conditioners. Air conditioner electricity use will be measured using a watt-hour meter. Watt-hour meters should be installed on a wall outside the house near the electrical panel box which houses the breakers that supply power to the air conditioner(s) if outdoors or a more suitable location as determined by the NCAEC. If desired, a new circuit(s) enclosed in approved outdoor conduit may be run outdoors along the wall of many houses to a new receptacle at each window air conditioner. Electric meters should be accurate to within 3% over the duration of the project.

5.2.4 Water Heating Electricity Use

Each house will have electric water heating. Water heating electricity use will be measured using a watt-hour meter. Watt-hour meters should be installed on a wall outside the house near the electrical panel box which houses the breakers that supply power to the water heater if outdoors or a more suitable location as determined by the NCAEC. If desired, a new circuit enclosed in approved outdoor conduit may be run outdoors along the wall of many houses to the water heater. Measurement accuracy within 3% is also needed.

5.2.5 Indoor Temperature

The indoor temperature of each house will be monitored using Telog's 2103 Ambient Temperature Recorder (specifications are 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 $1^{o}F$. During the summer periods, previous work has shown that the device should be located in the room having the window air conditioner.[7] If two air conditioners are present, the device should be located in the room with the air conditioner that best typifies the temperatures in the main living area of the house. During the winter, the device may have to be relocated if another area best typifies the wintertime temperatures in 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. Temperature recorders will be provided by the ORNL and installed by the NCAEC.

5.2.6 Ambient Weather Parameters

Four weather parameters will be measured at each of the three weather stations: outdoor temperature, relative humidity, insolation, and wind speed. Weather data will be recorded using a Campbell Scientific Model 21X Data Logger (specifications are provided in Appendix B). The data logger will record weather parameters continuously and store hourly averages on cassette tape. The NCAEC will select the sites for and set up the three weather stations. ORNL will provide the weather station components and assist in their set up.

The weather station instrumentation will consist of: a battery powered data logger, a battery powered tape recorder, a type T (copper-constantan) thermocouple, a humidity probe, a pyranometer, a radiation shield (s), and a wind anemometer. Sensors should be compatible with the data logger and selected to provide measurement of outdoor temperature accurately to within 1°F, humidity within 5% RH, solar radiation within 10 BTU/h-ft^2, and wind speed within 10%.

The temperature and humidity sensors of the weather stations should 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 a building and below roof level is preferred. A radiation shield should be used to protect the sensors from the sky and other significant radiation sources such as roofs, walls, driveways, patios, and the ground. The shield will also protect sensors from rain, hail, lightning, and other ambient conditions.

The pyranometer should be installed horizontally above the level of the roof, and in a position where nearby objects (houses, trees, poles, etc.) do not block radiation or reflect radiation to the sensor. Other meteorological equipment should be located below or north of the radiation sensor.

The wind speed indicator should be installed sufficiently above the level of the roof and away from any obstructions such as buildings, building contours (i.e., roof features), or trees that could disrupt the air flow at the sensor.

6. DATA MANAGEMENT

Although all data will not originate in a computer-based form, all data will eventually be managed and processed using computer-based systems. Data bases will be designed to store information in separate files. The links (relations) between separate files will be house ID numbers and the dates and times of the time-sequential data. The data bases will contain all data files in their final form (all files have been checked for accuracy and corrected as needed). Characterization of data and statistical analyses will use the data from these files.

6.1 SURVEY INFORMATION

Survey information will be collected through interviews, site visits, and limited measurements using sheet data forms. The Survey Interview Form is shown in Appendix A. Some additional survey information will likely be collected as part of the Field Test Audit procedure being developed. The data from completed survey forms will be entered into a computer database using a full-screen interactive data entry routine. The database system will be designed using the dBase III Plus Database Management System.* The system will display an image of each data collection form and will highlight the data entry areas. The operator simply types in a data value as it appears on the field data sheet. After a return, the data is automatically stored in the database and the cursor moves to the next data entry location. After all data on the display screen has been entered, a new form will appear for entry of the next sheet of data. This procedure is repeated until data for all houses has been entered.

ORNL will supply the database program to the NCAEC. The local weatherization providers will provide completed survey data forms to the NCAEC who will input the survey data to a computer. Once data entry is complete and the data has been stored in a data file, a copy of the data file should be put on a floppy disk and the disk forwarded to the ORNL. ORNL will do the final

*Licensed software of ASHTON.TATE, Torrance, CA.

data processing and storage. The flow of data processing for survey data is illustrated in Fig. 6.1.

6.2 TIME-SEQUENTIAL MEASUREMENTS

Time-sequential data will be collected using sheet data forms and computer-based data loggers. Weekly readings from each house (total electricity use, space heating fuel use, air conditioner electricity use, and hot water electricity use) will be logged on the data form shown in Fig. 6.2. The local weatherization providers will take the weekly readings and provide completed data forms to the NCAEC. NCAEC will handle this data the same way as survey information except that a different database program (also supplied by ORNL) will be used. Data files will be created using the automated database program and a copy of the data files on floppy disk will be forwarded to the ORNL for processing and final storage. Since the electric and fuel use meters are totalizing meters, data processing will include subtracting past consumption data from the latest received to determine actual weekly consumptions. Error checking, correction, and final storage of files will be part of the ORNL processing routine.

Computer-based data loggers (Campbell Model 21X) will be used to record weather data on an hourly basis. The data loggers have limited memory and therefore will be setup to write recorded data to cassette tape when the internal storage buffer of the logger is filled. Monthly, local weatherization providers will collect the cassette tapes and provide them to NCAEC for forwarding to ORNL. ORNL will move the data from the tape to computer disk. The data will then undergo final processing and storage.

Indoor temperature data will also be collected by a computer-based logger, the Telog Model 2103 Recorder. Monthly, weatherization providers will transfer the hourly data from each logger using hand-held data transfer units (DTU's) provided by ORNL. Data from up to 60 loggers can be stored in each DTU. The DTU is then exchanged for a new unit at the NCAEC who transfers the data from the filled unit to a computer using software supplied by ORNL. A disk(s) containing the temperature files is then forwarded to the ORNL where the temperature data will undergo final processing and storage. Six DTU's

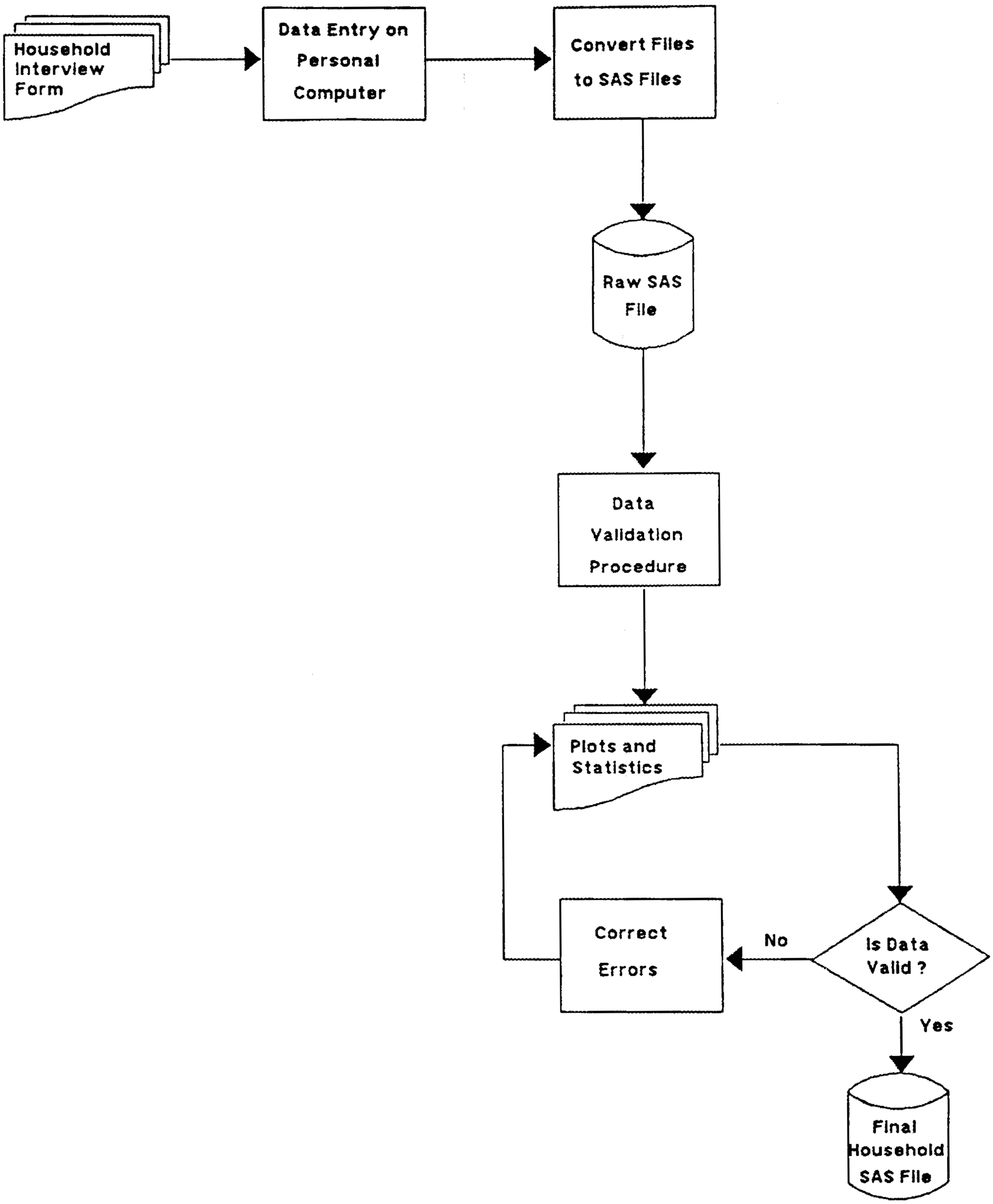


Fig. 6.1. Data management procedure for the survey information.

North Carolina Field Test
Weekly Metered Data

House ID: __________ House # & Street: ____________________

Date: __ __ / __ __ / ______ Time: ______:_______ a.m. ____
(mo / day / year) (hr : min) p.m. ____

House
Electric Meter __ __ __ __ __

Water Heater
Electric Meter __ __ __ __ __

Air Conditioner #1
Electric Meter __ __ __ __ __

Furnace Meter __ __ __ __ __

Air Conditioner #2
Electric Meter __ __ __ __ __

For above ground tanks,
enter numbers and mark level

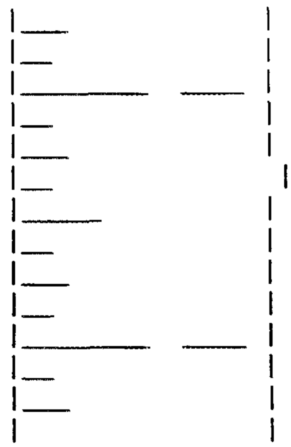


Fig. 6.2. Weekly field data collection form

will be required to insure that units are always available for data collection.

Processing of consumption, weather, and indoor temperature data will be done concurrently so that these files can be meshed together for final storage. As a result, each processed (working) file will contain all pertinent information relative to the weekly energy use of an individual house. The flow of data processing for time-sequential data is illustrated in Fig. 6.3.

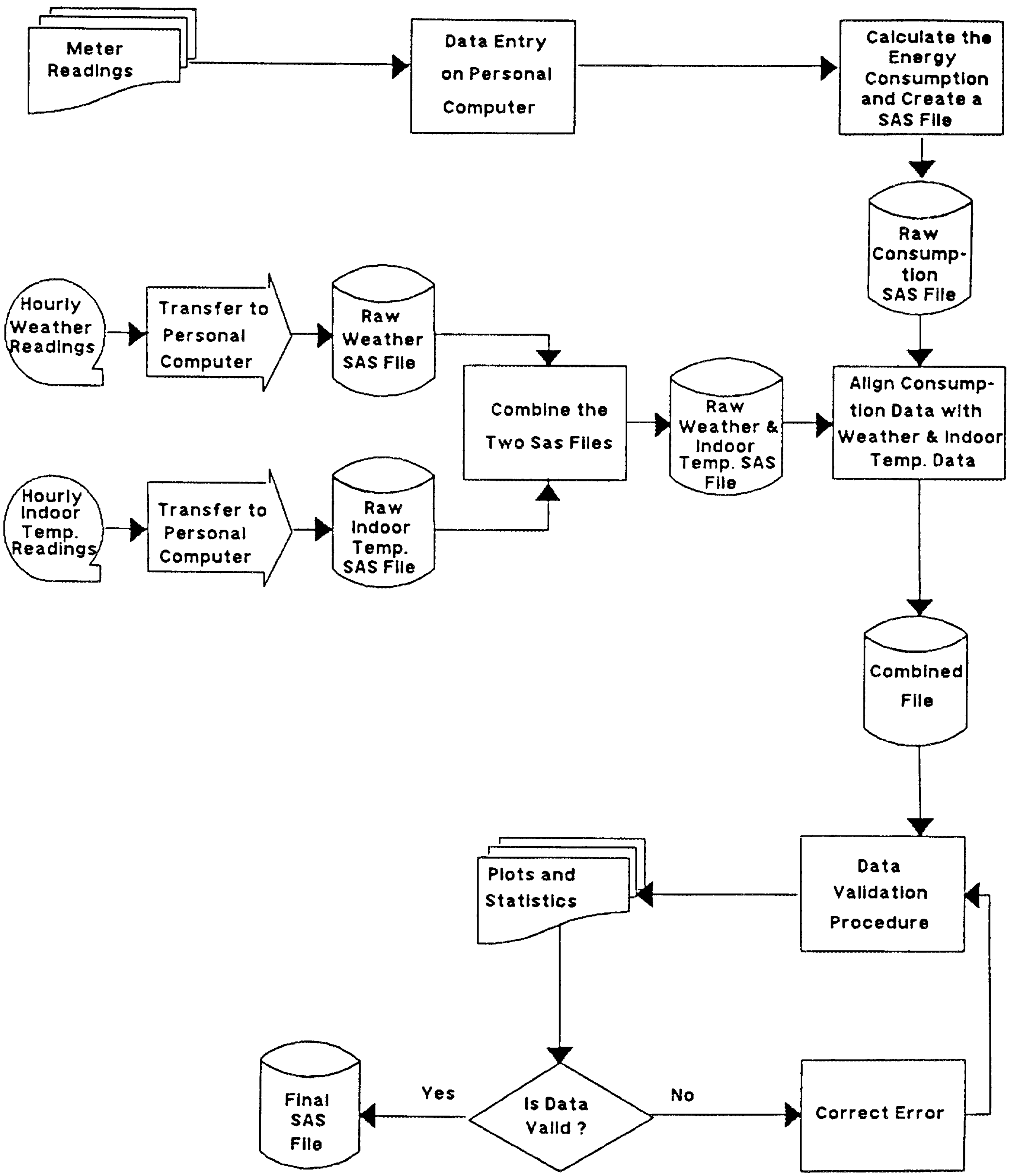


Fig. 6.3. Data management procedure for the time-sequential measurements.

7. DATA ANALYSIS

Data analysis will be done for both survey information and performance data. Analyses should answer questions about house and occupant characteristics, weatherization measures, weatherization energy savings, and the performance of the two weatherization approaches. The following subsections detail how these analyses will be done.

7.1 HOUSE AND OCCUPANT CHARACTERISTICS

Survey information will be used to characterize participating houses and their occupants. This will include house type, floor area, wall, floor, and ceiling/attic constructions, space heating and cooling systems, occupancy levels, occupied periods, and other characteristics. Summaries will be made in tabular and/or graphical form to illustrate differences between houses. Comparisons will be made between the pre- and post-weatherization thermal conditions of houses based on insulation levels, infiltration rates, and heating system efficiencies. Comparisons will be made between the two treatment groups and the control group. The comparisons will be used to organize houses into subgroups for analyzing performance data and also to identify differences between houses or groups of houses.

7.2 WEATHERIZATION MEASURES

Weatherization measures installed per the current WAP audit and the Field Test Audit will be summarized. This data will be taken from survey information and from the retrofit quality assessment. Summaries will include the most common measures installed by each approach. Comparisons between the two approaches will be investigated using tabular and graphical methods. The weatherization measures summary may help to explain any differences in energy savings between the two weatherization approaches.

7.3 ENERGY SAVINGS AND PERFORMANCE

The energy savings and the performance of the two weatherization approaches will be evaluated for both individual houses and groups of houses.

In addition, the performance of the approaches will be evaluated based on their cost effectiveness and their ease of implementation.

7.3.1 Individual House Savings

Outdoor and indoor temperatures, humidity, solar radiation, and occupancy levels are only some of the many factors that influence the energy use of an individual house. If during testing all of these factors could be held constant over time or caused to vary the same before and after, the annual energy savings due to weatherization would simply be the annual energy use before weatherization minus the annual energy use after. In reality, many of these factors vary significantly from one year to another (such as outdoor temperature) and therefore can dramatically increase or lower energy use in a specific year. If not accounted for, changes in these factors after weatherization can easily mask, inflate, or even show a negative energy savings. This experiment was designed to account for the major influences (or predictors) of house energy use that could be affordably measured (based on past ORNL experience).

Individual house savings will be adjusted (normalized) for differences in outdoor and indoor temperatures, occupant behavior, and possibly solar radiation and outdoor humidity. Occupant related changes will be accounted for by measuring the before and after energy performance of the control houses.

House energy use models will be determined that will relate the house energy use to outdoor and indoor temperatures for both the pre- and post-weatherization periods. Linear regression techniques will be used to determine the appropriate coefficients for each house model. House models will be used with average outdoor temperature data based on historical records and "typical" annual indoor temperatures determined from all houses to generate normalized annual energy uses for the before and after weatherization periods of each house. The weatherization savings will be the difference in the before and after energy use minus the average change in the energy consumptions of the control houses (to normalize for occupancy variations). The average change in the energy use of the control houses is simply the difference in the energy use predicted by the before period model and the after period model after adjusting for differences in indoor and outdoor temperatures as done in the treatment houses.

Indoor temperature values used for normalization could be based on the indoor temperatures of an individual house for the pre- or post-weatherization periods or some average value across all houses. An average value across all houses will be used so that each house can be normalized to a "typical" base. This should allow comparisons between houses to be made on a more equal basis.

7.3.2 Group Savings

A difference between the energy savings for the two treatment groups will be identified using a one-way analysis of variance approach. If the savings from the two groups are found different, this will allow an associated statistical confidence to be determined. Savings differences between groups will be quantified using a multiple comparison technique. The analysis of variance will then be expanded to allow identification of savings differences due to specific influences (such as heating system type, house size, or other characteristic). Groups of houses with similar characteristics will be identified from the house characteristics data.

7.3.3 Cost Effectiveness of Weatherization

The cost effectiveness of the two weatherization approaches will be compared. Program comparisons will be based on indicators of program effectiveness, such as energy or dollars saved per dollar expended. Thus, costs for both material and labor associated with each weatherization approach will be collected. Costs will be itemized relative to each measure or task. This will allow procedures common to both weatherization approaches, such as house audits or air-sealing, to be compared on a cost basis.

Actual measure costs will be compared to the assumed measure costs that were used in the Field Test Audit to determine the benefit to cost ratios used for selecting and prioritizing measures.

7.3.4 Implementation of the Audit Procedures

The ease of implementation of the two procedures will be compared based on the experience of the auditors and weatherization installers. Labor requirements for each procedure will be recorded in man-hours. Thus, information will be available for comparing the difficulty of auditing per each procedure and the difficulty of installing measures recommended by each. Some of the data regarding implementation ease will be subjective since it will be collected through questioning of auditors and weatherization installers.

8. REFERENCES

1. Project Retrotech: Home Weatherization Instructor's Guide. U.S. Department of Energy , DOE/CS-0040/1, 1978.

2. M. B. Gettings and J. O. Kolb, Survey Results and Recommendations for WAP Single- and Multi-family measure selection techniques, Draft Report, Oak Ridge National Laboratory, May 1989.

3. North Carolina Weatherization Assistance Guide. Standards and Techniques, North Carolina Department of Commerce, Assistance Guide 85-F, May 1985.

4. M. P. Ternes, Single-Family Building Retrofit Performance Monitoring Protocol: Data Specification Guideline," ORNL/CON-196, Oak Ridge National Laboratory, June 1987.

5. I. Miller and J. E. Freund, Probability and Statistics for Engineers, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1965.

6. G. V. Fracastoro and M. D. Lyberg, Guiding Principles Concerning Design of Experiments, Instrumentation, and Measuring Techniques, ISBN 91-540-3955-X, Swedish Council for Building Research, Stockholm, December 1983.

7. M. P. Ternes and P. S. Hu, The Oklahoma Cooling Retrofit Field Test: Experimental Plan, ORNL/TM-10761, Oak Ridge National Laboratory, January 1989.

8. "Methods for Determining Air Leakage Rate by Fan Pressurization Test," ASTM Standard E779-81, The American Society for Testing and Materials, Philadelphia.

9. ASHRAE Handbook: 1985 Fundamentals, Chapter 22, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, 1985.

APPENDIX A

SURVEY INTERVIEW FORM

The Survey Interview Form was developed to collect the house and system characteristics data and other interview data as described in Section 5.

SURVEY INTERVIEW FORM 8/18/89
ORNL

Experimental Program: North Carolina Field Test House ID: ________

Interviewer Name: ______________________________ Date: ___/___/___

Occupant Name: ______________________________

House # & Street: ______________________________

City: _______________ State: North Carolina Zip: _______________

County: _______________ Phone Number: (   ) _______________

Utility Distributors: Electric ______________________________
Nat'l. Gas ______________________________
Propane ______________________________
Oil ______________________________
Kerosene ______________________________

HOUSE

Type: ____ (MS - multi-story detached; RA - ranch (1 story) detached; SL - split level detached)

Direction front of house faces: ____ (N, NE, E, SE, S, SW, W, NW)

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

Predominant Roof Type: ____ (V - pitched roof with attic; F - flat roof; P-pitched roof & ceiling (no attic); X-other)

Is attic or roof cavity ventilated? ____ (V-vented,NV-not vented,Z-unknown)

Roof Color: ____ & Exterior Wall Color: ____ (L-light, M-medium, D-dark)

Number of rooms typically closed off: ____ Describe: ____________________

Floor Areas:

Floor	Total Area (ft2)	Heated* Area (ft2)	Cooled** Area (ft2)
Basement	________	________	________
First floor	________	________	________
Second floor	________	________	________
Other	________	________	________
Total	________	________	________

* Heated Area: Area of house minus closed off rooms.
** Cooled Area: Area of room with air conditioner (AC), or rooms if two ACs.

OCCUPANCY

Ownership: ____ (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 _____

SPACE HEATING SYSTEM

Space Heating Unit 1:

Manufacturer: ______________ Model: ___________ Approx. Age: ____ yrs

Fuel: ____ (G-nat'l gas, P-propane, K-kerosene, O1-#1 oil, O2-#2 oil)

Type: ____ SH-space heater; F-central furnace; FF-floor furnace; CH-ceiling heat; EB-electric baseboard; B-boiler; WHP-window/wall heat pump; X-other)

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

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

Input rating: _____________ & units: ____ (B-Btuh, GM-gal/min, X-other)

Output capacity: ___________ Btu/h Efficiency rating: _____ (if rated)

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

Answer Y or N:
Is this a converted coal unit? ____ or converted oil unit? ____
Is an intermittent ignition device used? ____
If oil fired, is a flame retention head burner used? ____
If a pilot is used, is it turned off during the summer? ____

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

Space Heating Unit 2:

Manufacturer: ______________ Model: ___________ Approx. Age: ____ yrs

Fuel: ____ (G-nat'l gas, P-propane, K-kerosene, O1-#1 oil, O2-#2 oil)

Type: ____ SH-space heater; F-central furnace; FF-floor furnace; CH-ceiling heat; EB-electric baseboard; B-boiler; WHP-window/wall heat pump; X-other)

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

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

Input rating: _____________ & units: ____ (B-Btuh, GM-gal/min, X-other)

Output capacity: ___________ Btu/h Efficiency rating: _____ (if rated)

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

Answer Y or N:
Is this a converted coal unit? ____ or converted oil unit? ____
Is an intermittent ignition device used? ____
If oil fired, is a flame retention head burner used? ____
If a pilot is used, is it turned off during the summer? ____

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

Space Heating Unit 3:

Manufacturer: ______________ Model: ___________ Approx. Age: ____ yrs

Fuel: ____ (G-nat'l gas, P-propane, K-kerosene, O1-#1 oil, O2-#2 oil)

Type: ____ SH-space heater; F-central furnace; FF-floor furnace; CH-ceiling heat; EB-electric baseboard; B-boiler; WHP-window/wall heat pump; X-other)

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

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

Input rating: _____________ & units: ____ (B-Btuh, GM-gal/min, X-other)

Output capacity: ___________ Btu/h Efficiency rating: _____ (if rated)

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

Answer Y or N:
Is this a converted coal unit? ____ or converted oil unit? ____
Is an intermittent ignition device used? ____
If oil fired, is a flame retention head burner used? ____
If a pilot is used, is it turned off during the summer? ____

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

Auxiliary heating use:

(use, average hours per week)

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

Distribution System

Total length of ducts or piping; _____feet

Length of ducts or piping in unconditioned space: _____ feet

Insulation thickness of ducts in unconditioned space: _____ inches

Thermostat

Manufacturer: _____ Model: _____

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

Number of thermostats: _____

COOLING SYSTEM

Air Conditioner #1:

Manufacturer: ______________________ Model: ____________________

Fuel: E Output capacity: __________ Btu/h

Approximate age: __________ years Voltage: _______ 110 or 220

Location: _________________ (which room)

Air Conditioner #2:

Manufacturer: ______________________ Model: ____________________

Fuel: E Output capacity: __________ Btu/h

Approximate age: __________ years Voltage: _______ 110 or 220

Location: _________________ (which room)

HOT WATER SYSTEM

Manufacturer: ______________________________ Model: ___________________________

Fuel Type: ____ (E-electric; G-nat'l gas; P-propane, O-oil, M-mixed; X- other)

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

Heater Type: ____ (R - standard residential; B - boiler; X - other; Z - unknown)

Tank Size: _____ gallons Water Temperature (measure): _____°F

Input: ____________ watts Recovery: _______

External 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 (identify)	____	________

Fuel: E - electricity; G - nat'l. gas; P - propane; X - other

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

ATTIC or ROOF (if no attic)

Sub-area	Area (ft2)	Construction	Insulation	Insulation thickness (in.)
1	______	______________	____________	__________________
2	______	______________	____________	__________________
3	______	______________	____________	__________________
4	______	______________	____________	__________________

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

Insulation: 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 (ft2)	Construction /Siding	Cavity Insulation	Cavity Insulation thickness(in.)	Insulating Sheathing
1	______	______/______	____________	______________	____________
2	______	______/______	____________	______________	____________
3	______	______/______	____________	______________	____________
4	______	______/______	____________	______________	____________

Construction: FR - frame; CB - concrete block; X - other

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

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

Insulating sheathing: F-foam:rigid; FBD-fiberboard:mineral, wood, or vegetable; FG-fiberglass:rigid; X-other; N - none

SUB FLOOR

Sub-area	Area (ft2)	Type	Status	Insulation	Insulation thickness (in.)	Percent carpeted
1	____	____	____	____	____	____
2	____	____	____	____	____	____
3	____	____	____	____	____	____
4	____	____	____	____	____	____

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

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

Insulation: 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: (none if slab-on-grade)

Sub-area	Area (ft2)	Type	Insulation	Insulation thickness (in.)	Above ground area (ft2)
1	____	____	____	____	____
2	____	____	____	____	____
3	____	____	____	____	____
4	____	____	____	____	____

Type: CB - concrete block; MA - masonry (concrete); P - pillars;
S - stone; X - other

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

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

WINDOWS AND 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 (ft2)		Multi-pane area (ft2)	
	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)	______	______	______	______

Are storm doors installed? _____ Y or N

COMPLETE FOR OIL AND KEROSENE SYSTEMS ONLY!

8/18/89

House ID ____ Type of heating fuel(circle): #2 oil #1 oil kerosene
(to identify, ask for bills or call distributor)

Circle fuel tank location: Buried / Above-ground

Is fuel pumped by a pump on the furnace? Y or N

FOR ABOVE GROUND TANKS ONLY (stop here if buried):

Distance from ground to bottom of tank: _____in. (0 if on ground)

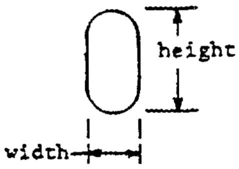
(IMPORTANT: All Measurements Below This Line Should Be Within 1/16")

Round tanks: diameter(OD) _______in. & length _______in.

Ob-round tanks (see sketch):

height _____in.

width _____in.

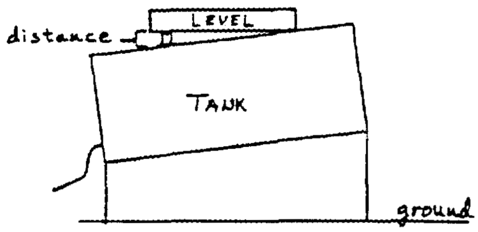


Circle type of tank ends: (for inset ends, measure inset)

Flat	Curved in (bumped in)	Curved out (bumped out)	Inset ____in.

Check tank levelness, use 24" level (24" only). Set level on top of tank (avoid ridges in tank wall) and add spacing material under one end to bring to level. Insure level is in line with the tank. Measure distance from top of the tank to the bottom of the raised end of the level (see sketch).

Top of tank to bottom of level: ______ in.



Slope of tank: (circle one) (see sketches) 1) toward furnace line, or 2) away from furnace line

SKETCH OF HOUSE LAYOUT

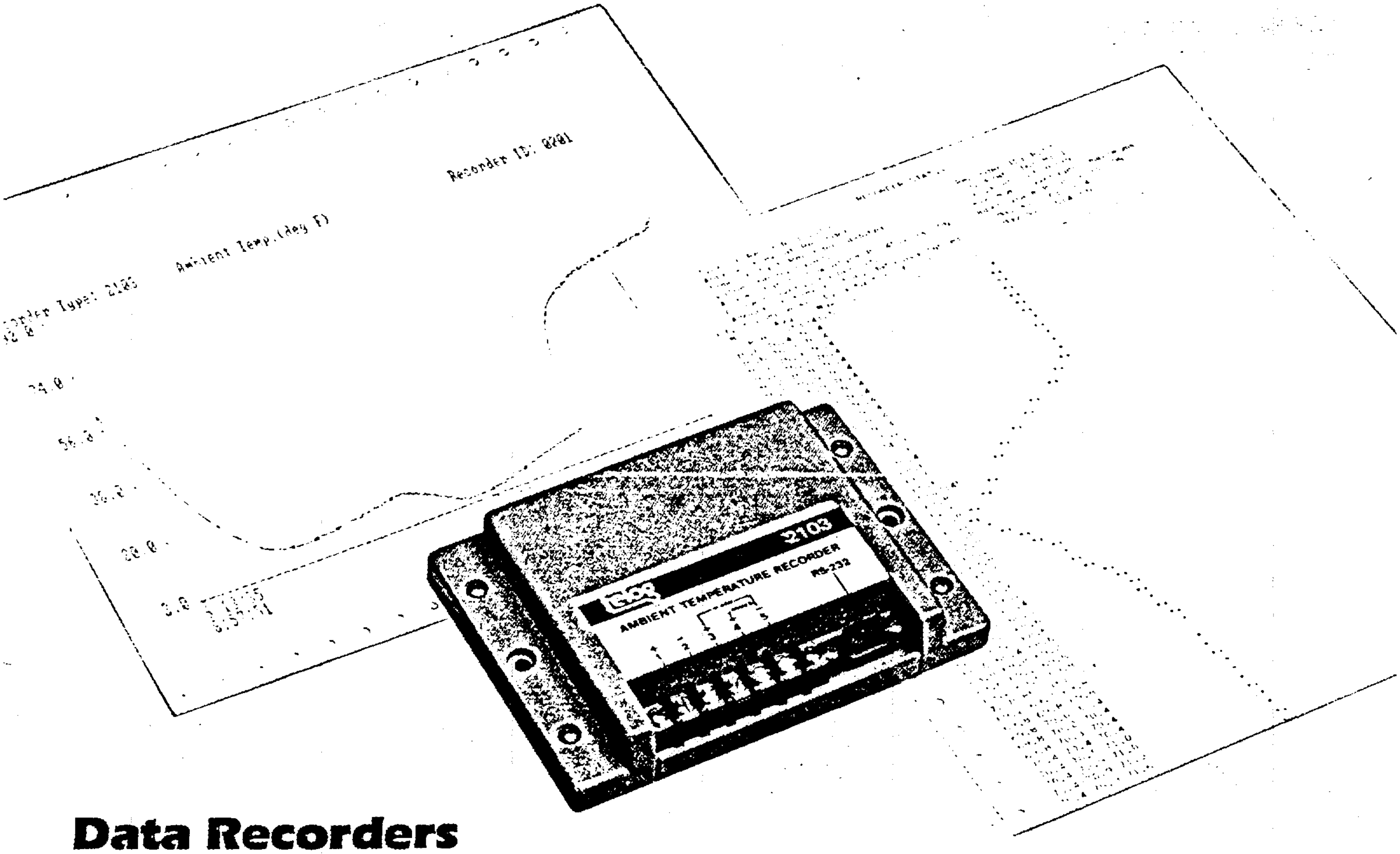
House ID: _____

APPENDIX B

DATA LOGGER SPECIFICATIONS

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

telog

Model 2103

Specifications

MEASUREMENT

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

RECORDING

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

ALARM

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

SERIAL INTERFACE

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

POWER

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

ENVIRONMENTAL & MECHANICAL

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

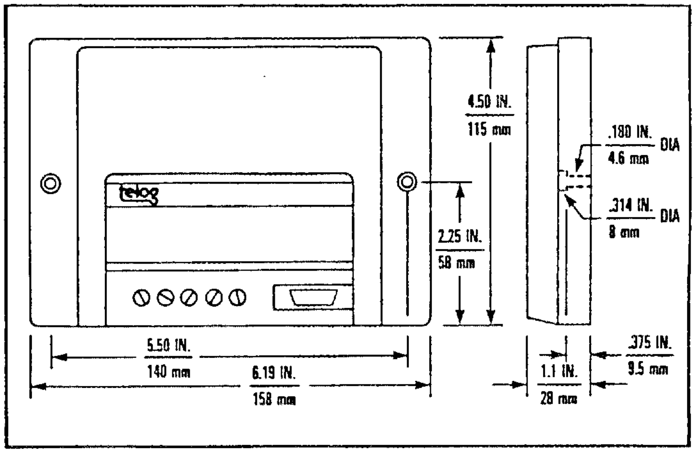
SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE

PROGRAMMABLE PARAMETERS

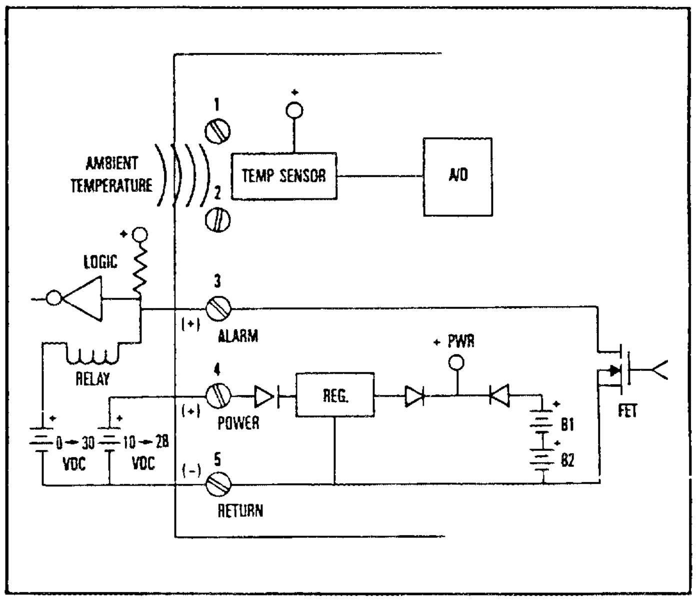
Interval Period:	1 to 65535 seconds (18.2 hours)
Interval Resolution:	1 second
Computed Data:	any combination of the average, minimum or maximum per interval
Calendar Time:	mo/day/yr hr:min:sec
Alarm Thresholds:	High and/or Low, 1 DEG resolution
Unit ID Number:	4 digit alpha-numeric

IBM-PC is a registered trademark of International Business Machines

Model 2103 MOUNTING DIMENSIONS



FUNCTIONAL CONNECTION DIAGRAM



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

telog

What to order

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

Product descriptions

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

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

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

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

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

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

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

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

Custom products

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

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


SERIAL I/O
EXCITATION
CAO
CONTROL
PULSE INPUTS
21X MICROLOGGER
CAMPBELL
SCIENTIFIC
INC.
DURACELL
interface

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. Expansion of 21X memory allows storage of up to 19,200 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 −40 to −60 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 23 instructions for measurements and control output, 39 instructions for data processing, and 9 instructions for program control.

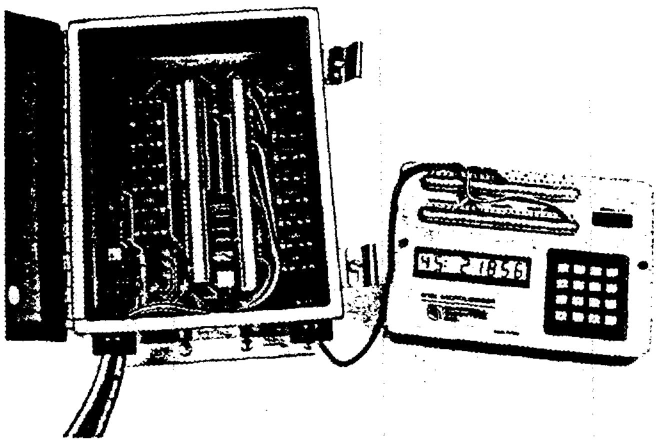
Data storage includes 28 locations for input and user-processed data, 64 locations for intermediate values, and 896 final storage locations. Data storage can be re-allocated by the user. Each input location and each intermediate location uses 4 bytes of RAM and each final storage location uses 2 bytes of RAM. All expansion RAM is allocated for data storage.

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.

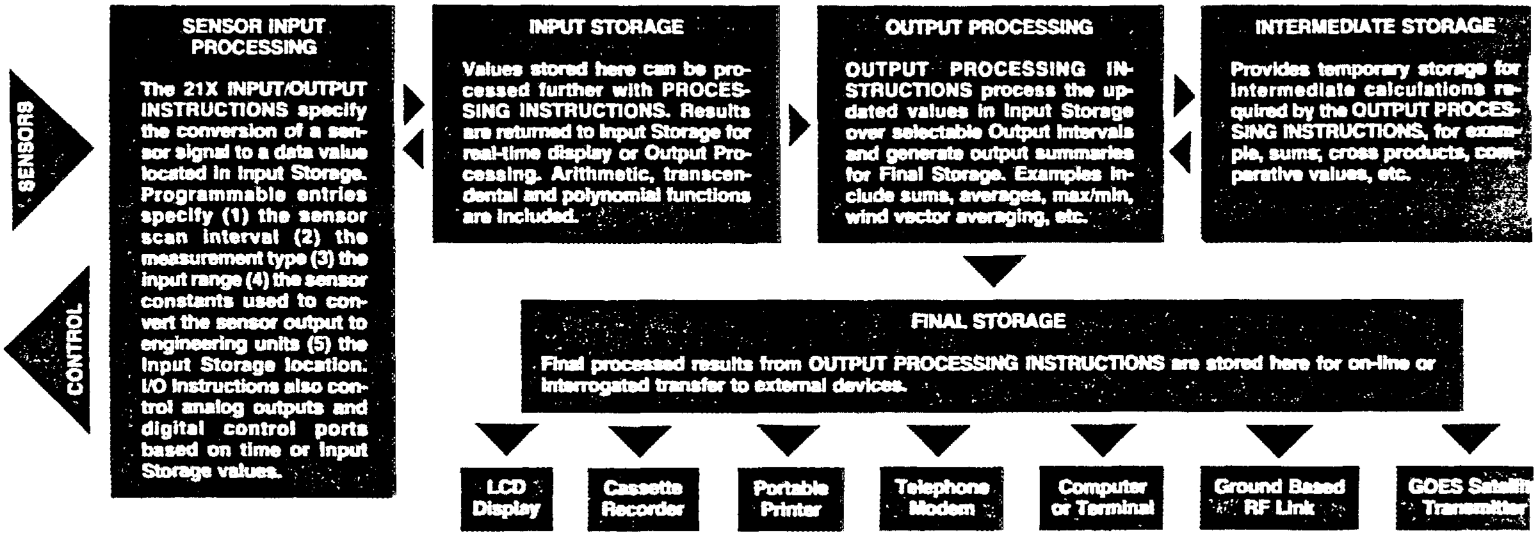
Memory sockets are available on the 21X CPU board allowing the addition of 44K bytes of memory for a total of 64K bytes. An expanded system with 24K bytes of ROM and 40K bytes of RAM can store 19,200 values in the final storage area.



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 ARGYLE 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.

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: 20 mA at ±5 volts, 50 mA at ±2.5 volts.

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
6 millivolts	1 Hz to 100 Hz
10 millivolts	0.5 Hz to 1000 Hz
20 millivolts to 20 volts	0.3 Hz to 2000 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, 4k RAM, expandable in increments of 8k of RAM or ROM up to a total of 64k. Standard 21X stores 896 low resolution data points in Final Memory. 19,200 data points with fully expanded RAM.

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 October 1984

INTERNAL DISTRIBUTION

1-9. T. R. Sharp
10. M. P. Ternes
11. J. M. MacDonald
12. G. E. Courville
13. W. R. Mixon
14. R. B. Shelton
15. T. J. Wilbanks
16. R. S. Carlsmith
17. V. D. Baxter
18. M. A. Brown
19. J. O. Kolb
20. M. A. Kuliasha
21. H. A. McLain
22. G. O. Rogers
23. M. Schweitzer
24. ORNL Patent Office
25. Central Research Library
26. Document Reference Section
27-29. Laboratory Records
30. Laboratory Records - RC

EXTERNAL DISTRIBUTION

31. Charles Baxter, New York Support Office, U.S. Dept. of Energy, 26 Federal Plaza, Suite 3437, New York, NY 10007
32. Wayne Belgrave, New York Support Office, U.S. Dept. of Energy, 26 Federal Plaza, New York, NY 10007
33. Gene Brady, Council on Economic Opportunity - Luzerne County, 211 S. Main Street, Wilkes-Barre, PA 18701
34. Jeff Brown, North Carolina Dept. of Economic and Community Development, 430 North Salisbury Street, Raleigh, NC 27611
35. Ronald J. Brown, Kansas City Support Office, U.S. Dept. of Energy, 911 Walnut Street, 14th Floor, Kansas City, MO 64106
36. Bruce G. Buchanan, Computer Science Dept., University of Pittsburgh, 206 Mineral Industries Building, Pittsburgh, PA 15260
37. Bill Burke, Dept. of Housing Rehabilitation, 318 S. Michigan Avenue, Chicago, IL 60604
38. Curtis E. Carlson, Jr., Dallas Support Office, U.S. Dept. of Energy, 1440 West Mockingbird Lane, Suite 400, Dallas, TX 75247
39. Percy Carter, North Carolina Dept. of Economic and Community Development, 430 North Salisbury Street, Raleigh, NC 27611
40. Francis Conlin, North Carolina Alternative Energy Corp., P.O. Box 12699, Research Triangle Park, NC 27709
41. Rozella Copeland, Franklin/Vance/Warren Opportunity, Inc., P.O. Box 1453, Henderson, NC 27536
42. John J. Cuttica, Gas Research Institute, 8600 W. Bryn Mawr Avenue, Chicago, IL 60631
43. Jean Diggs, Dept. of Energy, CE-232, FORSTL, 1000 Independence Avenue, S.W., Washington, D.C. 20585

44. Martha Dixon, Loans and Grants Division, San Francisco Operations Office, U.S. Dept. of Energy, 1333 Broadway, Oakland, CA 94612
45. Mary Fowler, Dept. of Energy, CE-232, FORSTL, 1000 Independence Avenue, S.W., Washington, D.C. 20585
46. E. C. Freeman, Dept. of Energy, CE-133, FORSTL, 1000 Independence Avenue, S.W., Washington, D.C. 20585
47. Waymon Gainey, Johnston-Lee Community Action, Inc., P.O. Drawer 711, Smithfield, NC 27577
48. James Gardner, Dept. of Energy, CE-232, FORSTL 1000 Independence Avenue, S.W., Washington, D.C. 20585
49. Cathy Ghandehari, Dept. of Health and Social Services, P.O. Box 7851, 1 West Wilson Street, Madison, WI 53707
50. Richard Greene, Four-County Community Services, Inc., P.O. Box 988, Laurinburg, NC 28352
51. Allan Hirsch, Dynamac Corp., The Dynamac Building, 11140 Rockville Pike, Rockville, MD 20852
52. Jack Hruska, Community Action Team, 474 Milton Way, St. Helens, OR 97051
53. Al Hymer, Denver Support Office, U.S. Dept. of Energy, P.O. Box 26247 - Belmar Branch, Lakewood, CO 80226
54. Kenneth Johnson, Chicago Operations Office, U.S. Dept. of Energy, 9800 South Cass Avenue, Building 201, Argonne, IL 60439

55-59. Veronica Johnson, Dept. of Energy, CE-232, FORSTL 1000 Independence Avenue, S.W., Washington, D.C. 20585

60. William Kaplan, Philadelphia Support Office, U.S. Dept. of Energy, 1421 Cherry Street, Philadelphia, PA 19102
61. Vicki Locklear, Four-County Community Services, Inc., P.O. Box 988, Laurinburg, NC 28352
62. D. E. Morrison, 333 Oxford Road, East Lansing, MI 48823
63. Raymond Nihill, National Fuel Gas, 2484 Seneca Street, Buffalo, NY 14210
64. William S. Owens, Franklin/Vance/Warren Opportunity, Inc., P.O. Box 1452, Henderson, NC 27536
65. Steve Payne, Dept. of Community Development, Ninth and Columbia, GH-51, Olympia, WA 98504
66. William Prindle, The Alliance to Save Energy, 1725 K Street, N.W., Suite 914, Washington, D.C. 20006-1401
67. Wanda Rachels, Atlanta Support Office, U.S. Dept. of Energy, 730 Peachtree St., N.E., Suite 876, Atlanta, GA 30309
68. Ken Rauseo, Executive Office of Communities and Development, Leverett Saltonstall Bldg., 100 Cambridge St., Suite 1404, Boston, MA 02202
69. George Robinson, East Central CAA, P.O. Box 589, 859 East Third Street, Forest, MS 39074
70. Hugh Saussy, Boston Support Office, U.S. Dept. of Energy, Boston Federal Office Bldg., 10 Causeway Street, Room 1197, Boston, MA 02222-1035

71. Fred Singleton, Dept. of Energy, Atlanta Support Office, 730 Peachtree St., N.E., Suite 876, Atlanta, GA 30380
72. Patrick Sweeney, Division of Economic Opportunity, New York State Dept. of State, 162 Washington Avenue, Albany, NY 12231
73. Kathy Vega, Richland Operations Office, U.S. Dept. of Energy, 825 Jadwin Avenue, P.O. Box 550, Richland, WA 99352
74. Marie Watson, Johnston-Lee Community Action, Inc., P.O. Drawer 711, Smithfield, NC 27577
75. Martin Williams, Dept. of Economics, Northern Illinois University, DeKalb, IL 60115
76. Magi York, Mid-Iowa Community Action, 1500 East Linn Street, Marshalltown, IA 50158
77. Office of the Assistant Manager for Energy Research and Development, DOE-ORO, P.O. Box 2001, Oak Ridge, TN 37831-8600

78-87. OSTI, Department of Energy, P.O. Box 2002, Oak Ridge, TN 37831