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MARTIN MARIETTA

EXPERIMENTAL PLAN FOR THE SINGLE-FAMILY STUDY

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Weatherization Assistance Program

MANAGED BY
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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EXECUTIVE SUMMARY

Background

The most recent national evaluation of the energy savings resulting from the U. S. Department of Energy (DOE)'s Weatherization Assistance Program (WAP) was completed in 1984 based on consumption data for households weatherized in 1981 (Peabody, 1984). A process evaluation that focused on the number of homes weatherized per dollar was completed in 1987 based on weatherization activities in the 1985 program year (Schweitzer et al., 1987). WAP regulations and operations have changed substantially since these studies were conducted. New funding sources, management principles, audit procedures, and energy-efficiency measures and an increased emphasis on training, technical assistance, and client education have been incorporated into the program in the last decade. In addition, new initiatives, incentives, opportunities, methods, and technologies are on the horizon. Many of these factors have been studied in isolation or at a local level; however, no recent work has assessed their integrated, national program impact or potential. As a result, a more timely and comprehensive national-level evaluation of the WAP is needed to provide policy makers and program implementers with the up-to-date, credible, and reliable information they need for effective decision making and cost-effective operations. DOE's Weatherization Assistance Program Division has asked Oak Ridge National Laboratory to help design and conduct this evaluation.

The national evaluation of the WAP consists of five separate studies that are part of the overall evaluation (see Beschen and Brown, 1990). The Single-Family Study is one of three studies that will estimate program energy savings and cost effectiveness in principal WAP submarkets. It focuses on single-family and small (2- to 4-unit) multifamily homes that heat or cool with gas or electricity. The Fuel-Oil Study (Ternes, Levins, and Brown, 1990) focuses on single-family homes in the Northeast that heat with fuel oil. The High-Density Multifamily Study (MacDonald and Brown, 1990) focuses on large (5 or more unit) buildings using all fuel types. This report presents the experimental plan for the Single-Family Study, which will be conducted over the next three years (1991-1993).

Study Goals

The Single-Family Study is designed to accomplish five goals:

- estimate the energy saved nationwide by the program one, two, and three years after participation;
- assess nonenergy impacts, such as comfort, safety, and housing affordability;
- assess program cost effectiveness;
- analyze factors that influence energy savings, nonenergy impacts, and cost effectiveness; and
- identify promising WAP opportunities for the future.

These goals encompass many significant issues. They focus on producing the most useful and practical information for program policy, management, and implementation that can be obtained for reasonable costs. Understanding how the program is operating establishes the groundwork for planning and operating more effectively in the future at all levels of program decision making. For example, evaluation results should help focus training and technical assistance efforts, identify the client groups that future program efforts should target more specifically, indicate what service delivery procedures are most effective for particular building types, characterize the packages of measures that should be considered in different climate zones, and provide estimates of the level of energy savings that can be expected per public dollar spent.

Evaluation Methods and Outcomes

The Single-Family Study will estimate energy savings for a nationally representative sample of single-family and small multifamily homes weatherized in the 1989 program year (typically April 1989 to March 1990). Savings will be estimated directly from gas and electric utility billing records with the Princeton Scorekeeping Method (PRISM). The study also will assess nonenergy impacts (e.g., health, comfort, and housing affordability), estimate the cost effectiveness of weatherization, and analyze factors influencing these outcomes.

Although energy savings will be estimated directly from fuel consumption records only for gas and electrically heated or cooled homes, homes using other fuels (such as wood, fuel oil, coal, kerosene, and propane) will be studied too. For homes using fuels other than gas and electricity, however, no effort will be made to gather fuel consumption records. Often these fuel consumption records are nonexistent. In any case, the cost of trying to collect whatever records might be available would be extremely high and the utility and reliability of the information low. Some useful data on dwellings that do not heat/cool with gas and electricity can be obtained. For example, information on the dwelling characteristics, weatherization measures installed, and the costs of the measures can be obtained from agency records. This information can be analyzed to produce indirect estimates of energy savings. The indirect estimates will be inferred from existing studies (where available) and developed from an analysis of gas and electrically heated or cooled dwellings with similar characteristics and packages of measures. Indirect estimates of savings for the Single-Family Study's sample of dwellings that heat with fuel oil will be developed from the results of the Fuel-Oil Study, which is one of the five studies that constitute the National Evaluation.

The Single-Family Study characterizes more households than do the other submarket studies (fuel oil and high-density multifamily) because it focuses on the two most commonly used heating fuels (gas and electricity); the two major building types addressed by the WAP (single-family homes and 2- to 4-unit multifamily dwellings); and both rental and owner-occupied housing. In addition, data and analyses will be conducted selectively on the remaining dwellings in the weatherization client base. Thus, the entire population of single-family and small multifamily dwellings weatherized in the 1989 program year will be characterized in terms of a few variables (e.g., dwelling characteristics, installed weatherization measures, and costs). An effort also will be made to combine both primary and secondary data on energy savings to develop a national estimate for this population.

The study will assemble a large nationally representative data base. A cluster sampling approach will be used, in which 400 subgrantees are selected in a first stage and about 20,000 weatherized homes are selected in a second stage. A control group of about 10,000 homes that are eligible for but have not yet received services will be drawn from the waiting lists of the same 400 local agencies. Data will be collected on more homes than are required for the energy savings estimates because high sample attrition rates are expected and because data on weatherization procedures, measures, and costs are needed for all fuel types. Only about half of the homes heat with gas or electricity and many of these will have incomplete or inaccessible fuel consumption records. The target final sample sizes, for gas and electrically heated homes which will produce national estimates of energy savings that have a 10% error relative to the mean at a 90% confidence level, are approximately 6,500 weatherized homes and 3,000 control homes.

To ensure that the Single-Family Study is able to identify factors affecting impacts and promising opportunities for future program development, two purposively selected groups of subgrantees will be studied: 1) subgrantees that install cooling measures (such as air conditioning tune-ups or window film), and 2) exemplary subgrantees that use state-of-the-art technologies and service delivery procedures (such as advanced audit techniques, blower-door tests, infrared scanners, extensive client education, etc.). These two groups of subgrantees will be analyzed (along with the randomly selected national sample) to identify the most effective program elements in specific circumstances and to describe some exemplary program types for particular situations. The analysis may show which strategies are best for specific target groups. How prevailing climate and household characteristics affect optimal savings strategies will also be discussed.

The Single-Family Study will include a review of recent literature. This review will compile and analyze evaluation results that are already available on low-income weatherization programs operated by both States and utilities. Conducting a careful literature review will help ensure that key issues are properly addressed and that the interpretation of findings is informed by the experience gained by others. Another purpose of the literature review is to gather information that can be used for the secondary analysis of energy savings in dwellings that heat with wood, coal, fuel oil, propane, or kerosene, and in mobile homes.

A somewhat unusual methodological feature of our experimental design is that housing units will not be dropped from the analysis because of occupancy changes. Most evaluations of weatherization impacts remove housing units with occupancy changes from the sample because of the large fluctuations in energy consumption that may result. There are, however, several important reasons to retain units with occupancy changes. Examining only stayers may, for example, misrepresent energy savings because of attrition bias. In this study, housing units both with and without occupancy changes will remain in the sample. They will be examined both collectively and separately in the analysis.

Study Phases

The study will be conducted in **three phases.** The **first phase** will produce statistically rigorous estimates of program energy savings and indicators of cost effectiveness for the program as a whole and for three climate regions (very cold with little or no cooling, cold with moderate cooling, and hot with substantial cooling), two fuel types (gas and electricity), and two building types (single-family homes and 2- to 4-unit multifamily dwellings). Additional climate-region breakdowns (e.g., hot/humid vs. hot/arid climates) will be studied, but at lower levels of statistical rigor. Where reliable indirect energy savings estimates are available, estimates of energy savings and cost effectiveness are planned for homes that heat with fuels other than gas and electricity. An assessment of program-induced improvements in energy affordability will be provided, and program impacts on fuel assistance payments, fuel cutoffs, and utility customer arrearages will be estimated using utility information where available. The representative national sample of homes weatherized by the WAP in the 1989 program year (PY) will be the treatment group for this phase. The control group will be selected from agency waiting lists of WAP-eligible homes that have not yet been weatherized. Two purposive samples of subgrantees selected either because they install cooling measures or because of their exemplary performance will supplement the representative national sample. The energy savings and cost-effectiveness achieved in dwelling units weatherized by these subgrantees will be compared to national averages in the phase one analysis.

The **second phase** of the study will collect and analyze on-site field data and will include a process evaluation of exemplary local weatherization agencies. Energy-savings results from phase one will be used to guide the selection of exemplary local agencies and a subsample of treatment and control group homes for this phase. The on-site data will include furnace efficiency testing, blower-door testing, and an occupant interview (which includes ratings of impacts on comfort, safety, and housing affordability). This information will be used to interpret the energy savings and benefit/cost results, particularly for homes with especially high or low savings. The on-site data will also be used to help quantify nonenergy impacts including safety (e.g., by analyzing the incidence of unsafe conditions) and comfort (e.g., by assessing air infiltration rates and the incidence of unheated rooms). Factors associated with high energy savings and cost effectiveness will be identified at both the dwelling unit and agency level. A process evaluation of several high-performing agencies will be conducted in this phase to identify the factors associated with their success.

The **third phase** of the Single-Family Study will determine the persistence of energy savings over time. Three years of postretrofit energy consumption (1990-1992) will be analyzed to assess long-term savings and the influence of occupant mobility. Treatment and control groups from phase one will be used to the extent possible. Additional control units will probably be needed for the persistence analysis, however.

Three reports will be produced corresponding to the three phases of the study. Each report will contain an executive summary targetted to audiences interested in the study's overall findings. The main body of the reports will describe in greater detail the methodology and findings, focusing on results that are of most interest to weatherization program managers, practitioners, and policy makers. Useful and practical information will be highlighted, such as the level of energy savings that has been achieved in specific types of buildings and the service delivery procedures and packages of measures that have been most effective for particular market segments. Technical details of the evaluation will be presented in appendices.

ABSTRACT

The national evaluation of the Weatherization Assistance Program (WAP) consists of five separate studies that are part of the overall evaluation (See Beschen and Brown, 1990). The Single-Family Study is one of three studies that will estimate program energy savings and cost effectiveness in principal WAP submarkets. This report presents the experimental plan for the Single-Family Study, which will be implemented over the next three years (1991-1993).

The Single-Family Study will directly estimate energy savings for a nationally representative sample of single-family and small multifamily homes weatherized in the 1989 program year. Savings will be estimated from gas and electric utility billing records using the Princeton Scorekeeping Method (PRISM). The study will also assess nonenergy impacts (e.g., health, comfort, safety, and housing affordability), estimate cost effectiveness, and analyze factors influencing these outcomes. For homes using fuels such as wood, coal, fuel oil, kerosene, and propane as the primary source of space conditioning, energy savings will be studied indirectly.

The study will assemble a large nationally representative data base. A cluster sampling approach will be used, in which about 400 subgrantees are selected in a first stage and weatherized homes are selected in a second stage. A control group of homes that are eligible for but have not yet received services will be drawn from the waiting lists of the same 400 local agencies.

To ensure that the Single-Family Study is able to identify promising opportunities for future program development, two purposively selected groups of subgrantees will be included: 1) subgrantees that install cooling measures (such as more efficient air conditioning equipment or radiant barriers), and 2) exemplary subgrantees that use state-of-the-art technologies and service delivery procedures (such as advanced audit techniques, blower door tests, infrared scanners, extensive client education, etc.). These two groups of subgrantees will be analyzed (along with the randomly selected national sample) to identify the most effective program elements in specific circumstances and to describe exemplary program features.

The study will be conducted in **three phases**. The **first phase** will estimate national program energy savings and cost effectiveness for the year following the 1989 program year. Energy savings will also be estimated for three climate regions, two fuel types (gas and electricity), and two building types (single-family and small multifamily dwellings).

The **second phase** of the study involves a process evaluation of exemplary local weatherization agencies and the collection and analysis of on-site field data. Energy-savings results from phase one will be used to guide the selection of exemplary local agencies and a subsample of treatment and control group homes for this phase. The on-site data will include furnace efficiency testing, blower door testing, and an occupant interview. This information will be used to interpret the energy savings and benefit/cost results, particularly for homes with especially high or low savings, and to quantify the nonenergy impacts of the WAP.

The **third phase** of the Single-Family Study will determine the persistence of energy savings over time. Three years of postretrofit energy consumption (1990-1992) will be analyzed to assess long-term savings and the influence of household mobility.

Three reports will be produced corresponding to the three phases of the study.

EXPERIMENTAL PLAN FOR THE SINGLE-FAMILY STUDY

1. INTRODUCTION

The most recent national evaluation of the energy savings of the U. S. Department of Energy (DOE)'s Weatherization Assistance Program (WAP) was completed in 1984 based on consumption data for households weatherized in 1981 (Peabody, 1984). A process evaluation that focused on the number of homes weatherized per dollar spent was completed in 1987 based on weatherization activities in the 1985 program year (Schweitzer, et al., 1987). WAP regulations and operations have changed substantially since these studies were conducted. New funding sources, management principles, audit procedures, energy-efficiency measures, and an increased emphasis on training, technical assistance, and client education have been incorporated into the program in the last decade. In addition, new initiatives, incentives, opportunities, methods, and technologies are on the horizon. Many of these factors have been studied in isolation or at a local level; however, no recent work has assessed their integrated, national program impact or potential. As a result, a more timely and comprehensive national level evaluation of the WAP is needed to provide policy makers and program implementers with the up-to-date, credible, and reliable information they need for effective decision making and cost-effective operations. Recognizing the importance of an up-to-date assessment of the Weatherization Assistance Program (WAP), the U. S. Department of Energy (DOE) asked Oak Ridge National Laboratory (ORNL) to help design and conduct a national WAP evaluation.

The overall plan for the National Evaluation of the WAP, which consists of five separate studies, is described in Beschen and Brown (1990). Experimental plans also are being developed for each of the five separate studies. One of the studies will characterize the WAP network's activities and capabilities. A second will develop a profile of the served and unserved portions of the WAP eligible population and the expansion of WAP resources through leveraging of external funding sources. Three studies will estimate program energy savings and cost effectiveness in principal WAP submarkets.The Single-Family Study estimates impacts for single-family and small (2- to 4-unit) multifamily homes (using gas and electricity). The Fuel-Oil Study estimates impacts for single-family homes in the Northeast that heat with fuel oil (Ternes, Levins, and Brown, 1991). The High-Density Multifamily Study estimates impacts for large (5 or more units) buildings using all fuel types (MacDonald and Brown, 1991).

This report presents the experimental plan for the Single-Family Study, which will be conducted over the next three years (1991-1993). It describes the goals and objectives, methodology, key elements, and expected outcomes of the Single-Family Study.

2. OVERVIEW: GOALS, METHODS, AND PHASES

The Single-Family Study has five major goals and will be conducted in three phases. The methods that will be used in the three phases are interrelated. The highlights of the goals, methods, and phases are summarized in this section. More detailed discussions of the goals and methods of phase one (Sec. 3), phase two (Sec.4) and phase three (Sec. 5) are presented in the sections that follow. Section 6 summarizes the key elements and expected outcomes of the study, and Section 7 presents some information on project implementation.

2.1 Goals

The five major goals of the Single-Family Study are to:

- estimate the energy saved nationwide by the program one, two, and three years after participation;
- assess nonenergy impacts, such as comfort, safety, and housing affordability;
- assess program cost effectiveness;
- analyze factors that influence energy savings, nonenergy impacts, and cost effectiveness; and
- identify promising WAP opportunities for the future.

These goals cover significant issues and focus on producing useful and practical information for program planning, implementation and management that can be obtained for reasonable costs. Understanding how the program is operating establishes the groundwork for planning future efforts. For example, evaluation results could help to identify the market segments that future program efforts should target, the service delivery procedures that are effective in particular markets, the packages of measures that should be considered in different climates, and the level of energy savings that is achievable for specific types of dwellings.

The primary purpose of the Single-Family Study is to evaluate the energy savings and cost effectiveness of the WAP as applied to the program's largest submarkets: single-family homes and small (2- to 4-unit) multifamily housing units. The Single-Family Study will characterize more housing units than the other principal submarket studies because it is national in scope and it focuses on the two most frequently weatherized building types and the two most commonly used heating fuels (gas and electricity). The study also will include select data and analyses on housing units using other fuels in order to better characterize weatherization activities, costs, and the weatherization client base. It will provide estimates of program energy savings for housing units weatherized in the 1989 Program Year (PY), including savings one to three years after weatherization (directly measured for housing units that heat with gas or electricity and indirectly estimated for the remaining housing units). In addition, this study will assess nonenergy impacts (e.g., safety, comfort, and housing affordability), cost effectiveness, factors influencing savings, and promising opportunites for the program.

2.2 Methods

The Single-Family Study will analyze retrospective data on a representative national sample of single-family and small multifamily housing units that were weatherized in PY 1989 (April 1989 to March 1990). Data also will be collected on a control group of housing units selected from among eligible households on agency waiting lists that have not yet received services. Several options were considered before choosing this control group design. Appendix A summarizes the pros and cons of the four methods of control group selection that were considered.

Our definitions of single-family and small (2- to 4-unit) multifamily dwelling units follow those used by the Residential Energy Consumption Survey (RECS) (Energy Information Administration, 1989):

> [A] single-family housing unit [is] a structure that provides living space for one household or family. The structure may be detached, attached on one side (semidetached), or attached on two sides. Attached houses are considered single-family houses as long as the house itself is not divided into more than one housing unit and has an independent outside entrance. A single-family house is contained within walls that go from the basement (or ground floor, if there is no basement) to the roof. (A mobile home with one or more rooms added is classified as a single-family home.)

Although the RECS definition of single-family units includes mobile homes only if rooms have been added, mobile homes will be included in our study whether or not a room has been added. It is unlikely that separate estimates of energy savings for mobile homes can be obtained with primary data, however, because they constitute less than 10% of the dwellings weatherized to date and they typically do not heat with gas or electricity.

The RECS definition of a small multifamily dwelling is as follows:

> [A] house or building with two to four housing units is a structure that is divided into living quarters for two, three, or four families or households. This category also includes houses originally intended for occupancy by one family (or for some

other use) that have since been converted to separate dwellings for two to four families. Typical arrangements in these types of living quarters are separate apartments downstairs and upstairs, or one apartment on each of three or four floors.

In adherence to these definitions, row houses and side-by-side duplexes (twins) are single-family houses, whereas over-and-under duplexes are small multifamily. High-density multifamily units (i.e., dwellings with more than five units) will not be included in the Single-Family Study. They will be analyzed in a separate study.

Primary data on fuel consumption will be collected and analyzed with the Princeton Scorekeeping Method (PRISM) only for housing units that heat/cool with gas or electricity. No effort will be made to gather fuel consumption records for dwellings using other fuels (such as wood, coal, fuel oil, kerosene, and propane). These fuel consumption records are often nonexistent, the cost of trying to collect whatever records might be available would be extremely high, and the utility and reliability of the information would be low. Some data on dwellings that do not heat with gas and electricity will be collected. For example, information on the dwelling characteristics, weatherization measures installed, and the costs of the measures will be obtained from agency records. This information will be analyzed to produce indirect estimates of energy savings. The indirect estimates will be inferred from existing studies (where available) and developed from an analysis of gas and electrically heated dwellings with similar characteristics and packages of measures. Thus, single-family and small multifamily housing units will be included in the study regardless of the fuel type used. This approach will make it possible to characterize the entire population of single-family and small multifamily dwellings weatherized in PY 1989 on several important variables.

To ensure that the Single-Family Study is able to identify factors affecting impacts and promising opportunites for future program development, two purposively selected groups of subgrantees will be studied: 1) subgrantees that install cooling measures (such as air conditioning tune-ups or window film), and 2) exemplary subgrantees that use state-of-the-art technologies and service delivery procedures (such as advanced audit techniques, blower door tests, infrared scanners, extensive client education, etc.). The results achieved by the exemplary group will be analyzed to help draw conclusions about the impacts of specific program elements and configurations. These conclusions will be used to identify the most effective program elements in specific circumstances and to describe some exemplary program types for particular situations (Sec. 3.7). The analysis may show which strategies are best for specific target groups. The effects of prevailing climate and household characteristics on optimal savings strategies also will be discussed.

2.3 Study Phases

The Single-Family Study will be conducted in three phases. The first phase will produce statistically rigorous estimates of program energy savings and cost-effectiveness for the program as a whole, and for three climate regions (Fig. 1), two fuel types (gas and electricity), and two building types (single-family and 2- to 4-unit multifamily dwellings). More detailed subregional breakdowns also will be conducted. For example in the southern climate zone, differences in results in hot and arid zones and hot and humid zones will be examined. Savings estimates for these subregional climate zones will have less statistical precision, however, than those for the entire southern climate zone (See Appendix B). Estimates of energy savings and cost effectiveness for remaining housing units (e.g., mobile homes and dwellings heated primarily with wood, coal, propane, kerosene, or fuel oil) are planned where reliable indirect energy savings estimates are available or can be developed. A sample of housing units weatherized by the WAP in PY 1989 will be the treatment group for this phase. A control group will be selected from

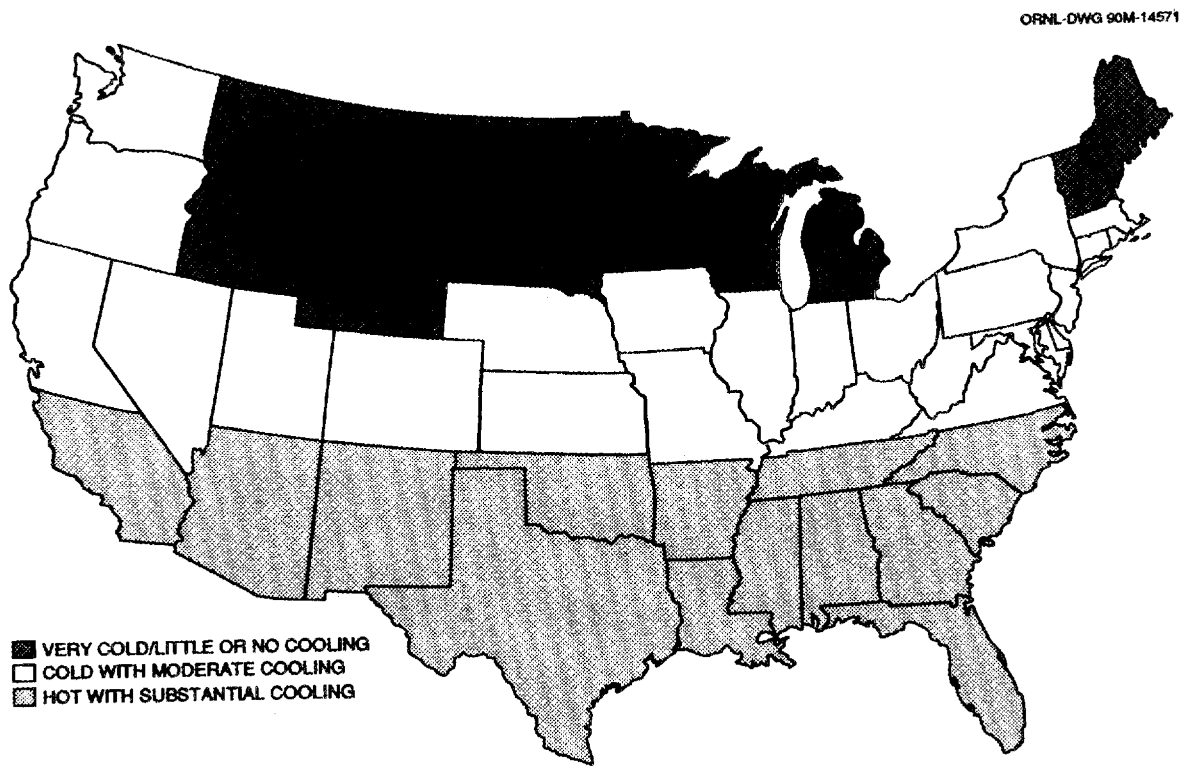

Fig. 1. Climate zones for the Single-Family Study.

agency waiting lists of income-eligible households occupying dwellings that have not yet been weatherized by WAP. Thus, phase one will focus on the estimation of energy savings for the first postretrofit year for housing units weatherized in 1989. Phase one also will analyze program cost effectiveness for PY 1989.

The second phase of the study involves a process evaluation of exemplary local weatherization agencies and the collection and analysis of on-site field data on dwelling unit and occupant characteristics. Energy-savings results from phase one will be used to guide the selection of exemplary local agencies and a subsample of treatment and control group housing units for this phase. The on-site data, which will be collected with an audit protocol (Appendix C) and an occupant survey (Appendix D), will help identify the factors that account for phase one variations in energy savings and benefit/cost results, particularly for the outliers (i.e., housing units with especially high or low savings). This information will be used to interpret the energy savings and benefit/cost results and to quantify the nonenergy impacts of WAP. The on-site audit data, which includes blower door and furnace efficiency tests, also will be used to characterize the energy efficiency of treatment and control households. The occupant survey, because it uses the 1990 Residential Energy Consumption Survey (RECS) format for most questions, will provide data for our subsample that can be compared with national statistics.

The third phase of the Single-Family Study will look at the persistence of energy savings over time. Three years of postretrofit energy consumption (1990-1992) will be analyzed to assess long-term savings and the influence of household mobility. Each of these three phases is described in more detail below and illustrated in Figs. 2 and 3.

3. PHASE ONE: ANALYSIS OF FIRST YEAR ENERGY SAVINGS AND COST EFFECTIVENESS

Phase one will begin with a literature review. Conducting a careful literature review will help ensure that key issues are properly addressed, that plans for the evaluation benefit from the lessons of previous approaches, and that the interpretation of findings is informed by the experience gained by others. Another purpose of the literature review is to gather information that can be used for a secondary analysis of energy savings in dwellings that heat with wood, coal, fuel oil, propane, or kerosene, and in mobile homes. Although a literature review is an important first step, such a review cannot provide sufficient information about program accomplishments because there is no current national-level evaluation and the available State evaluations do not give a nationally comprehensive or consistent picture. The phase one literature review will compile and analyze evaluation

Phase	Estimate Energy Savings	Assess Nonenergy Impacts	Assess Cost-Effectiveness	Analyze Contributing Factors	Define Promising Opportunities
1	●	○	●	○	●
2		●		●	○
3	●		●	○	○

○ = minor focus ● = major focus

Fig. 2. Single-Family Study goals by phase.

results that are already available on low-income weatherization programs operated by both States and utilities. The review will supplement the Meridian Corporation (1989) and Schlegel (1990) reviews and will emphasize evaluations completed after 1988. Because a careful literature review will help ensure that key issues are properly addressed by the Single-Family Study, this task will begin before primary data collection is initiated.

3.1 Experimental Design

To accurately measure the energy savings due to the WAP, one must control other factors influencing housing-unit energy consumption. Fuel prices, occupant behavior, and changes in weather patterns are especially important short-run influences on consumption. In the Single-Family Study, weather effects will be controlled with the Princeton Scorekeeping Method, which produces weather-adjusted measures of consumption (Fels, 1986). The influences of occupant behavior and price changes on consumption will be controlled by comparing two groups of WAP-eligible housing units -- one that received weatherization retrofits in PY 1989 (the treatment group) and one that has not yet been weatherized by WAP (the control group). To the extent that the treatment group and the control group of housing units and household occupants are initially equivalent (this

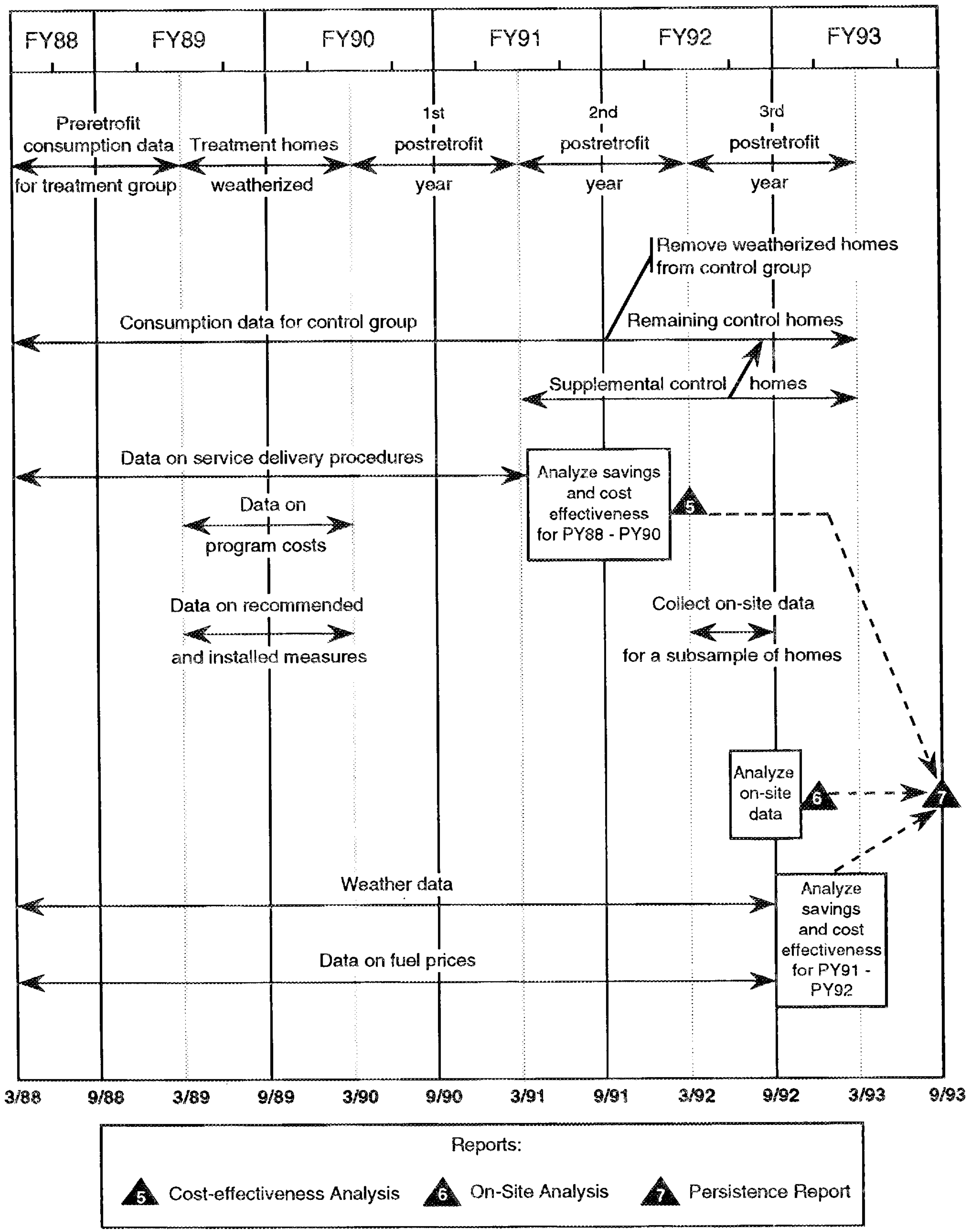

Fig. 3. Schedule for the Single-Family Study.

assumption will be tested), differences in their weather-adjusted fuel savings can be validly attributed to the services provided by the WAP.

A somewhat atypical and methodologically interesting feature of our experimental design is that housing units will not be dropped from the analysis because of occupancy changes. Most evaluations of weatherization impacts remove housing units with occupancy changes from the sample because of the large fluctuations in energy consumption that may result. If a new family moves into a housing unit, consumption may double or be cut in half even with no change in the unit's energy-efficiency characteristics. There are, however, several reasons to retain units with occupancy changes:

- a primary purpose of the WAP is to increase the energy efficiency of the low-income housing stock, and this occurs with or without occupancy changes;
- low-income housing units have especially high occupant turnover rates, and an uncertain attrition might result if all housing units with occupancy changes were eliminated (high attrition could be especially damaging to the phase three persistence analysis);
- housing units with occupancy changes and housing units without occupancy changes may have different energy-related characteristics, because movers tend to differ from stayers (e.g., they belong to different age groups or neighborhoods); and
- there is some evidence that examining only stayers may misrepresent energy savings because of attrition bias (Blasnick, 1989).

Another benefit of examining the energy consumption of housing units with changes in occupancy is that there will be an opportunity to estimate the impact of client education. Housing units with and without occupants who received client education could be matched on dwelling characteristics in an effort to isolate the impacts of the educational offerings on energy consumption and energy-related behaviors. In our study, housing units with and without occupancy changes will remain in the sample. They will be examined both collectively and separately in the analysis.

3.2 Sampling

The Single-Family Study will use representative national samples of 1) subgrantees, 2) single-family and small multifamily housing units weatherized by these subgrantees in PY 1989, and 3) a comparable control group of WAP-eligible housing units selected from agency waiting lists.

Because of the difficulty and expense of obtaining data from large numbers of utilities and subgrantees (approximately 1,100 operate in the continental U.S.) a cluster sampling technique is the most practical approach. The Single-Family Study will first select a sample of approximately 400 subgrantees; more than 20,000 housing units will then be selected from these sampled subgrantees in order to ensure complete data on 6,500 gas and electrically heated housing units. Data will be collected on more homes than are required for the energy savings estimates because high sample attrition rates are expected and because data on weatherization procedures, measures, and costs are needed for all fuel types. Only about half of the homes heat with gas or electricity and many of these will have incomplete or inaccessible fuel consumption records. This sampling strategy and its statistical basis are explained in Appendix B.

To ensure that the sample represents all major geographic regions within the continental United States, the sampling frame is stratified both by three major climate zones (Fig. 1) and by smaller geographic areas that are contained within the three climate zones (Table 1). The sample is designed so that estimates of mean savings nationally and for each of the three major climate zones shown in Fig. 1 can be provided with the same precision (i.e., within a 10% error relative to the mean at a 90% confidence level). Estimates of mean savings for the subregional areas (located within the three major climate zones) will have lower precision. The subregional areas shown in Table 1 have no particular analytical significance. They will be used simply to ensure that the sample of subgrantees is distributed across the whole United States. Other geographic groupings can be used in the analysis as desired.

The sampling frame is also stratified by the size of the subgrantee. Size is measured as the number of dwellings weatherized entirely or in part with DOE funds or with funds from other sources (except Low Income Home Energy Assistance Program funds) that were used according to DOE WAP regulations in PY 1989. Data on the PY 1989 production of weatherized homes, by subgrantee, were obtained from State weatherization program managers. This information was used to develop the sampling frame for the study and to arrive at the necessary sample sizes as shown in Appendix B.

To ensure that the evaluation is able to identify factors affecting impacts and promising opportunites for future program development, two purposively selected groups of subgrantees will be added to the sample: 1) subgrantees that use cooling measures (such as air conditioning tune-ups or window film), and 2) exemplary subgrantees that are selected by program experts. The exemplary subgrantees will be selected from the nominations of program experts and will include local agencies operating in each of the three climate regions. A sufficient number of homes will be sampled from these exemplary agencies to test the claim that they operate better-than-average programs by calculating energy savings and cost-effectiveness measures. A process evaluation of exemplary subgrantees with highly effective programs will be conducted in phase two to identify the most effective program elements for specific circumstances and to develop model program types for particular situations.

3.3 Data Collection

Several major data collection efforts are necessary for the first phase. Data will be collected from grantees, subgrantees, households weatherized in PY 1989, control group households, utilities, and the National Climatic Data Center (NCDC). The data required from each of these sources are described in the sections that follow. There may be some overlap between the data available from the subgrantees and that from the households. For

Table 1. Subregional Geographic Areas Used for Sample Stratification

Region 1. Very cold with little or no cooling

11	12	13
Idaho	Minnesota	Maine
Montana	Michigan	Vermont
Wyoming	Wisconsin	New Hampshire
North Dakota		
South Dakota		

Region 2. Cold with moderate cooling

21	22	23	24	25
Washington	Utah	Illinois	West Virginia	New York
Oregon	Colorado	Indiana	Virginia	Massachusetts
Nevada	Nebraska	Iowa	Delaware	Connecticut
Northern California	Kansas	Ohio	Maryland	Rhode Island
		Kentucky	Pennsylvania	
		Missouri	New Jersey	
			District of Columbia	

Region 3. Hot with substantial cooling

31		32
Arkansas	Georgia	Southern California
Louisiana	South Carolina	Arizona
Tennessee	North Carolina	New Mexico
Mississippi	Florida	Texas
Alabama		Oklahoma

example, bill waivers and information on primary heating fuel may be available from subgrantees or may have to be obtained directly from households. In general, efforts to collect data will begin at the grantee and subgrantee levels and move to the household level only when necessary. Data on fuel consumption and on weather can only be provided by the utilities and by NCDC, respectively.

The collection and management of the large data sets obtained from the variety of sources discussed in the following sections is an extensive and complicated effort. Data must be collected on about 20,000 housing units weatherized in PY 1989 and on about half as many control-group housing units. Data also must be collected from 49 grantees, approximately 400 subgrantees, more than 800 utilities, and the NCDC data center. A machine-readable file of utility billing records must be developed for each housing unit and matched to the data on weather, costs, retrofit measures, and service delivery procedures obtained from the other sources. Protocols for screening and cleaning the data must be developed and applied. The collection and preparation of these data sets is the most expensive and time consuming part of this phase of the study.

3.3.1 Grantees

Data collection for the Single-Family Study began in October of 1990. The grantees were asked to provide information on how many single-family and 2- to 4-unit multifamily dwellings each of their subgrantees weatherized in 1989. The dwellings to be included in the count were weatherized entirely or in part with DOE funds or with funds from other sources, such as State monies, that were used according to DOE WAP regulations. Homes that received services entirely from funding sources that did not follow DOE regulations, or entirely from Low Income Home Energy Assistance Program (LIHEAP) funding were not included in the count. This information on the number of homes weatherized by the DOE program was used to construct the sampling frame for phase one as described in Appendix B.

In addition, grantees will be asked to provide information on their program costs so that the cost of State-level activities such as administration, training, technical assistance, and education can be incorporated into the cost-effectiveness analysis. Finally, information will be collected on State-level procedures such as approved audits and eligibility criteria.

3.3.2 Subgrantees

Subgrantees will be asked for information on PY 1989 weatherized housing units and for assistance in identifying a control group from waiting lists. Names, addresses, and a signed bill waiver allowing access to utility billing records must be obtained for each of the treatment and control-group housing units in the sample. Basic information on each selected housing unit, such as primary heating fuel, occupant characteristics, housing type (i.e., single-family, 2- to 4-unit multifamily, or high-density multifamily), and weatherization status (i.e., whether and when the housing unit was weatherized) must be obtained.

Information on service delivery procedures (e.g., marketing and outreach, audit type, use of contractors vs. in-house crews, use of blower doors), measures installed, and costs must be collected at both the agency level and the housing-unit level. For example, at the agency level, data are needed on the average administrative cost per housing unit weatherized by the subgrantee in 1989, and at the housing-unit level, data are needed on the labor and materials costs for each dwelling in the sample. Information on measures installed must also be collected at the agency level (e.g., what percentage of housing units received cooling measures or furnace improvements) and at the housing-unit level (e.g., whether each sampled house received cooling measures or furnace improvements). Some of the agency-level data will be collected by a separate study -- the network capability study. Additional agency data and dwelling unit data will be collected from the subgrantees (using the data collection forms shown in Appendix E).

3.3.3 Households

In phase one, households weatherized in 1989 will be contacted by mail only when the subgrantee cannot provide the necessary information. Telephone follow-up will be used as needed. Similarly, control group households will be contacted only when the subgrantee cannot provide the necessary information. The essential information that will be obtained from households if the subgrantee cannot provide it includes

- billing history waivers,
- primary heating fuel,
- building type (single-family, 2- to 4-unit multifamily, or high density multifamily), and
- occupancy changes (mover vs. stayer).

Where possible, requests for information from households will come from their subgrantees.

3.3.4 Utilities

Billing histories from utilities are the source of primary data on energy consumption for this study. Utilities may also provide information on the use of LIHEAP payments, customer arrearages, and fuel cutoffs. After the housing units in the sample are identified and bill waivers obtained from them, the utilities serving these housing units will be contacted and asked to provide billing histories.

Although billing data are the best source of information on gas and electricity consumption, there are some important complicating factors that must be considered in their use. First, the time periods separating meter readings are of variable length (e.g., some may be monthly and some bimonthly); thus, different households will have different beginning and ending dates for a meter-reading (billing) cycle. Because calendar months rarely correspond to the cycle months, no monthly summary data can be used. Instead, daily weather data must be matched to the days for which consumption data are obtained, and each household's weather-adjusted estimates of consumption must be computed separately.

A second complication is that different utilities keep records in different formats (some hard-copy and some computerized); therefore, records must be reformatted into a standard system. Inaccurate or missing billing data may result from meters' not being read when scheduled, from estimated readings, or from changes in housing unit occupancy or utility accounting procedures. Errors like these are best handled by eliminating housing units with inadequate billing histories from the data base. Some initially selected housing units may be high-density multifamily dwellings, which will be dropped from the single-family sample. These units will be sampled for the high-density multifamily study. Sample attrition of about 40% from all sources can be expected in the Single-Family Study.

3.3.5 National Climatic Data Center

The National Climatic Data Center compiles data from each weather station in the United States. A report (local climatological data) is published each month for each station. Computer tapes of these data will be obtained directly from NCDC. Utilities will be asked to identify the weather station most appropriate for areas they serve.

3.4 Energy Savings Analysis

The fuel consumption and weather data will be analyzed with the Princeton Scorekeeping Method (Fels, 1986). PRISM uses utility bills from before and after retrofit installation, together with average daily temperatures from a nearby weather station for the same time periods, to determine a weather-adjusted index of consumption labeled normalized annual consumption (NAC). Analogous to an automobile miles-per-gallon rating based on a standard driving cycle, the NAC index indicates what energy consumption would be under typical weather conditions. The total energy savings are then derived from the differences in the NAC for pre- and post-weatherization periods. An energy conservation effect is thus neither masked by a cold winter nor exaggerated by a warm one.

To isolate the savings attributable to the program from changes in consumption that would have occurred without the program, the PRISM method will also be applied to a control group of houses. Both gross savings and net savings will be presented. Gross savings are based on the PRISM results for the treatment group alone. Net savings are obtained by comparing changes in control group consumption to those of the treatment group. Because control group consumption may increase or decrease during the study period, net savings may be either higher or lower than gross savings. The analysis will be updated for succeeding years to track the persistence of savings (phase three).

After data are collected and analyzed with PRISM for a nationally representative sample of gas and electrically heated/cooled households, estimates of program energy savings will be made for the nation as a whole, for the three climate regions shown in Fig. 1, for two fuel types (gas and electricity), and for two building types (single-family and 2- to 4-unit multifamily dwellings). The climate regions shown in Fig. 1 are based on State boundaries that reflect statewide heating and cooling degree day conditions, but local climates may cause particular subgrantees and their weatherized housing units to be classified differently from the State in which they are located. In addition, subgrantee data may be grouped into any geographical pattern desired for analytical purposes. In the southern climate zone, for example, differences between results for hot arid zones and hot humid zones will be examined. Mean savings estimates for the three climate regions in Fig. 1 will have a 10% error relative to the mean at a 90% confidence level. Estimates of mean savings for smaller geographical regions will have less precision. A sufficient number of homes from the two purposive samples (agencies that install cooling measures and agencies nominated as exemplary) will be analyzed to produce savings and cost-effectiveness estimates that can be reliably compared to national and regional averages.

3.5 Nonenergy Impact Analysis

The 1976 legislation establishing the WAP stated the importance of reducing the impact of high fuel costs on low-income households, particularly those of the elderly and handicapped. An assessment of program-induced improvements in the affordability of heating and cooling will be conducted by combining fuel cost data with information on household income (collected from local agencies). If information on rent and mortgage payments is available from these agencies, it will be possible to estimate the impact of WAP on the percent of household income spent on housing costs. The impact of weatherization on housing affordability will be assessed in greater detail during phase two when rent and mortgage data will be collected during the occupant survey. Impacts on safety and comfort will also be assessed in phase two, based on the on-site audit and occupant survey data.

Utility billing data will be used, where possible, to examine how low-income weatherization affects fuel assistance payments, fuel cutoffs, and utility customer arrearages. Analyses of arrearages are difficult to implement for several reasons. First, besides the usual data needed to conduct an energy savings analysis, additional data on the amount, source, and kind of energy assistance and an accounting of financial and energy debts are needed to reconstruct payment histories. Second, many of the necessary data are private; consequently, customer cooperation is essential. Third, the additional data are not maintained in readily available databases. Fourth, it has been shown that the factors that are correlated with reduction in energy consumption are probably different from the factors that are correlated with the reduction of arrearages (Hexter, Barnett, and Grothe, 1989). Similarly, decisions (and abilities) to pay energy bills are different from decisions to reduce energy use. Fifth, some State public utility commissions authorize a "surcharge" on energy and demand rates so that utilities can recover losses from arrearages and nonpayments. It is not clear how this policy might affect arrearages or energy use.

During phase one of the study, a methodology for assessing how WAP affects fuel assistance, fuel cutoffs, and arrearages will be refined and implemented. The analysis may be further developed during phase two, when on-site visits and surveys will make it easier to obtain customer cooperation in reconstructing payment histories and assessing the impact of WAP on arrearages.

3.6 Cost-Effectiveness Analysis

Analysis of cost effectiveness requires using the estimates of program-induced energy savings, data on fuel prices, and data on other program benefits and costs. In addition, appropriate assumptions concerning discount rates, efficiency-measure and housing-unit lifetimes, and fuel price escalation rates must be developed. To the extent that nonenergy impacts can be estimated in monetary terms, these will be incorporated into the cost-effectiveness analysis.

3.6.1 Benefits

The major goal of the WAP is to help low-income households save energy and cope with rising fuel prices. In addition to reductions in energy consumption, benefits of the program may include

- increasing the availability of affordable housing;

- maintaining or enhancing the property values of dwelling units;
- enhancing the livability of dwellings;
- extending the lifetime of dwellings;
- improving thermal comfort and promoting safer home environments, especially for elderly and handicapped individuals who often have special health needs;
- allowing low-income families to use a larger portion of their incomes for essential nonenergy expenditures, e.g., rent/house payments, food and medical care;
- reducing utility arrearages and the probability of utility cutoffs;
- reducing the environmental impacts of energy production and consumption;
- reducing oil imports; and
- stimulating local economies by providing jobs and commerce in weatherization materials (i.e., indirect economic benefits).

To the extent possible, each of these potential benefits will be assessed. The indirect economic benefits (and costs) will be estimated by applying an input/output methodology similar to the one being developed for New York State's Weatherization Assistance Program.

3.6.2 Costs

Program cost data will be collected at the subgrantee and State levels. Commonly used program cost categories include: administration, program support, labor, and materials. Because the categories and procedures used for generating detailed cost breakdowns vary and because the accuracy of the breakdowns is often unclear, the focus will be on obtaining total cost information at both the program and the housing unit levels. Efforts will be made to handle cost data as consistently as possible among agencies (see Appendix E).

3.6.3 Cost-Effectiveness Indicators

The cost effectiveness of a retrofit investment can be determined with a variety of approaches. Although a basic comparison between measured energy savings and the costs of achieving them is always involved, a number of other inputs are usually needed as well. Key assumptions include the expected lifetime of the housing unit and of the retrofit measures, a discount rate that reflects the time value of money, and estimated fuel price escalation rates. Because there is significant uncertainty in these key assumptions, sensitivity analysis will be used to estimate a range of cost effectiveness under varying conditions.

Once the key assumptions about retrofit lifetimes, discount rates, and fuel price escalation rates are selected, a variety of cost-effectiveness indicators can be calculated with standard formulas. The Single-Family Study will produce cost-effectiveness indicators such as benefit/cost (B/C) ratios, cost of conserved energy (CCE) estimates, and net present value (NPV). These cost-effectiveness indicators will be developed by climate region, housing type, and fuel type. A societal perspective that estimates benefits achieved per public dollar spent will be emphasized.

3.7 Analysis of Factors Influencing Savings and Cost Effectiveness

Phase one will contain an initial analysis of the factors that explain variations in savings and cost effectiveness. This analysis will be expanded in phase two when on-site data become available. The three main approaches to the analysis of factors in phase one are discussed in this section.

First, a variety of factors will be examined as potential determinants of net savings and benefit/cost ratios. Explanatory factors may include

- regional differences, e.g., fuel prices, cost of living, and climate (heating and cooling degree days);
- dwelling unit characteristics before weatherization, e.g., levels of insulation, energy consumption, and age of unit;
- occupant characteristics, e.g., thermostat setpoint temperatures and household demographics;
- packages of retrofit measures installed, e.g., the inclusion of furnace retrofits and the extensiveness of house tightening and insulating;
- service delivery differences, e.g., audit procedures, contractors vs. in-house crews, and client education offered;
- methods of client selection, outreach, and marketing, e.g., identifying high-priority clients (such as the elderly or high energy users) vs. "first come, first served" clients;
- use of sophisticated diagnostic and evaluation procedures, e.g., use of blower doors, infrared scanners, and evaluations to measure goal attainment; and
- State program characteristics identified by Schweitzer et al., (1987), e.g., length of delay in State reimbursement of expenditures and degree of flexibility allowed subgrantees in the selection of measures.

These explanatory factors will be cross-tabulated with energy savings and benefit/cost ratios to test their effects.

Second, the purposively selected sample of exemplary subgrantees who were nominated by program experts will be studied. The energy savings and cost effectiveness of their programs will be compared to national averages to determine whether or not they in fact operated superior programs in PY 1989. In addition, high-performing programs may also be identified among the randomly sampled subgrantee agencies that constitute the bulk of the data for this study. The analysis will proceed to identify the program elements that distinguish these exemplary programs from more typical program features. The analysis may help to identify strategies that are best for specific target groups and housing situations. This part of the analysis is designed to provide a view and perhaps a vision of those program components that can improve future performance. Analysis of the results achieved with exemplary technologies and procedures will facilitate the kind of forward thinking that is needed. High-performing program configurations will offer exemplary models for future replication. Several types of exemplary program models will probably exist because the effectiveness of an approach depends upon the context in which it operates. This information can be used to select technologies and procedures that may warrant monitoring, training, or promotional efforts in the years ahead. A detailed process evaluation of a subset of these exemplary agencies will be conducted in phase two.

The third approach to the analysis of factors that explain energy savings and benefit/cost ratios will use multivariate statistical models to estimate the independent influence of single variables, controlling for the influence of other factors. Results can be used to compare the importance of variables in determining the effectiveness of the program. For example, regression results might show that client selection procedures have more influence on energy savings than audit procedures. This analysis will be conducted with subgrantee and housing-unit data. Specifically, three types of models will be developed: 1) models that use subgrantee characteristics to explain variations, 2) models that use housing unit characteristics to explain variations, and 3) models that use combinations of subgrantee and housing unit characteristics to explain variations.

3.8 Definition of Opportunities

Defining promising future program directions is an important goal of the WAP evaluation. Identifying particularly effective technologies, diagnostic procedures, and management practices may lead to improvements in the program's future performance. As described in Section 3.7, the Single-Family Study will assess the impacts of specific program elements and configurations to identify the most effective program elements and some exemplary program types.

Both the eligible client profile and the WAP network capabilities study will compile information on advanced technologies and practices. This information will form a compendium of innovative ideas and an assessment of their current levels of use. The eligible client profile will also provide information on the numbers and types of remaining unweatherized housing units that will be combined with savings estimates by submarkets from the Single-Family, Fuel-Oil and High-Density Multifamily Studies. A key focus of the final comprehensive report for the total WAP evaluation will be defining promising future directions by combining data on the distribution of the remaining eligible population with submarket-specific energy savings estimates.

4. PHASE TWO: EXPANDED ANALYSIS OF OUTLIERS, INFLUENCING FACTORS, AND NONENERGY IMPACTS

The **second phase** of the Single-Family Study involves an expanded analysis of outliers, influencing factors and nonenergy impacts. Unlike the large-scale statistical analysis of phase one, phase two involves an in-depth examination of a smaller number of subgrantees and homes, relying upon on-site field data and process evaluations.

4.1 Study Design

This phase involves comparisons among four groups of housing units (Fig. 4). The emphasis is on identifying factors accounting for differences among the groups examined. Each comparison addresses a unique set of issues.

First, conditions in participant housing units will be compared with those of a matched control group of eligible but not yet weatherized housing units. These comparisons will help to quantify some of the nonenergy impacts of weatherization, particularly comfort and safety impacts and the effects of the WAP on housing affordability, fuel assistance, fuel cutoffs, and arrearages. Assessing these nonenergy impacts is greatly facilitated by on-site inspections and interviews, and by comparing actual conditions before weatherization (the control group) with conditions after weatherization (the treatment group).

Second, treatment group housing units with especially high or low savings and with especially high or low cost effectiveness will be compared with housing units that have more typical savings and cost effectiveness. The focus here is on explaining differences in program performance across homes--why do some homes produce greater energy savings than other homes, and why is weatherization more cost effective in some homes than in others.

Third, comparisons will be made between a subset of exemplary local agencies and more typical subgrantees. This involves a process evaluation of exemplary agencies to document their operations (e.g., service delivery procedures, diagnostic techniques, measures installed, etc.) based on interviews with agency personnel, a review of agency records, field visits with weatherization crews and contractors, and audits of some of their high-performing homes weatherized in 1989. The focus here is on state-of-the-art weatherization practices and the identification of promising future directions for the WAP.

Fourth, characteristics of housing units and households that participated in the WAP during PY 1989 will be compared with national statistics describing the WAP-eligible

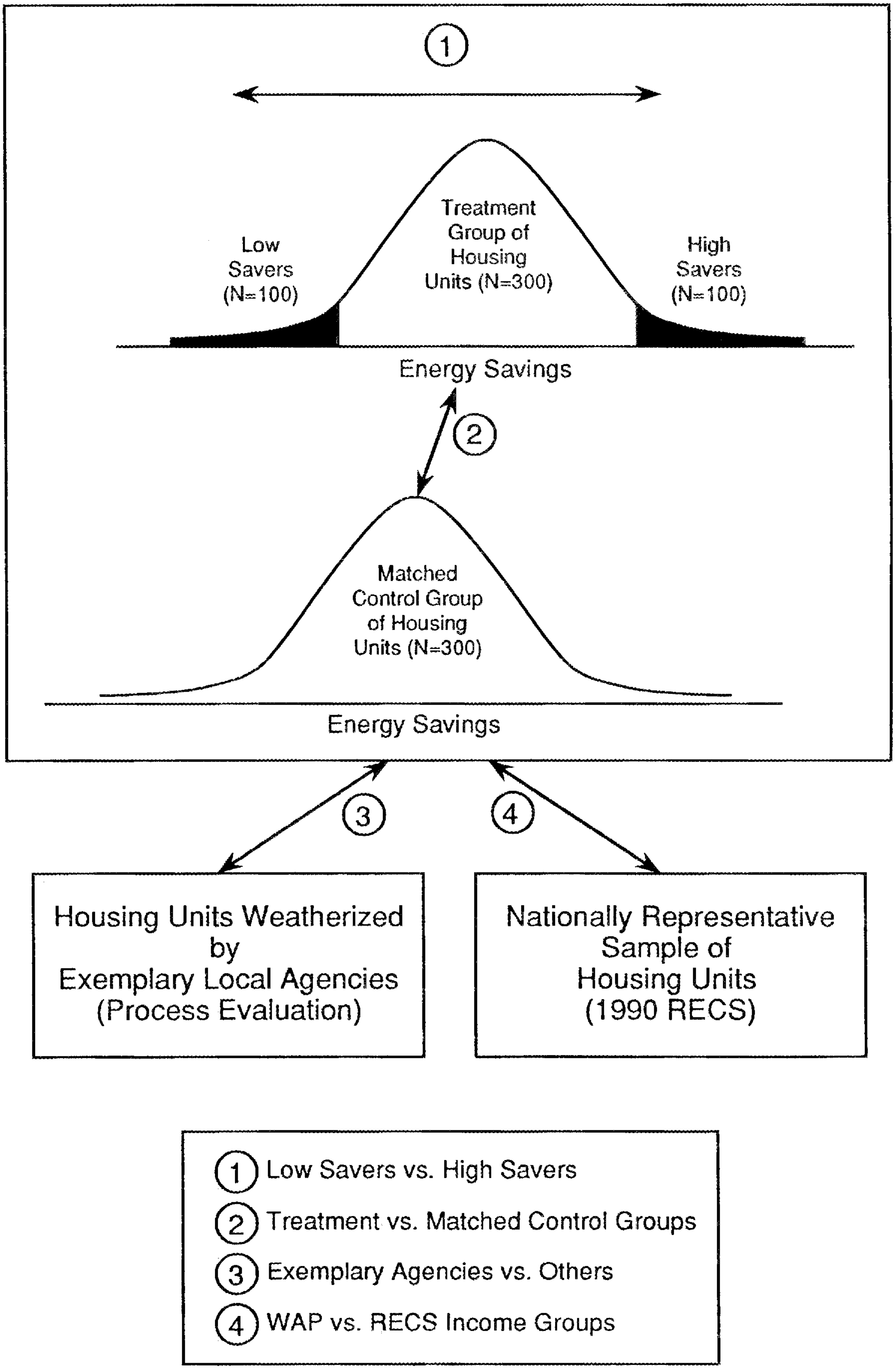

Fig. 4. Comparisons between four types of housing units for phase two.

population at large, using results of the 1990 RECS. It will be possible, for instance, to compare energy-related behaviors (such as thermostat management and the use of supplemental fuels) for homes weatherized by WAP, eligible homes that have not yet participated in the WAP, and nationally representative samples of other income groups.

4.2 Sampling

As in phase one, cluster sampling will be used to identify the housing units for on-site data collection. By first identifying a sample of subgrantees and then selecting housing units from the sampled agencies, the transportation and logistical costs associated with the field work can be greatly reduced. Two samples of subgrantees will be studied.

The first set of agencies will be randomly drawn from the 400 subgrantees sampled in phase one, using a stratified design to ensure proper representation by agency size and climate zone. The energy savings estimates generated in phase one, will be used to select four subsamples of housing units from these agencies (1) 300 treatment housing units, (2) 300 matched control-group housing units, (3) 100 treatment housing units with especially high savings, and (4) 100 treatment housing units with low (or negative) savings.

The 300 treatment housing units and 300 matched control housing units will be selected to produce a representative distribution of energy savings. These housing units will provide a norm or base for comparison with dwellings that had unusual results. The treatment and control group homes will be selected as matched pairs. Each pair of housing units will be drawn from the same subgrantee and will have similar pre-weatherization consumption levels, household composition, and housing characteristics. Matched pairs of housing units result in reduced variation in energy savings and enable smaller samples to be used to test differences across groups. The additional "control" offered by the matching strategy is felt to be particularly important for this phase of the Single-Family Study, where the sample sizes are smallest. The 100 housing units with especially high and 100 with especially low savings will be selected for comparison with the more typical units.

The second set of agencies will be drawn from the exemplary subgrantees identified in phase one. This small sample of 5 to 10 agencies will be drawn to illustrate the different configurations of service delivery procedures employed by the exemplary agencies, and to represent each of the three major climate zones. A small sample of housing units will be drawn from each of these exemplary subgrantees to represent the kinds of weatherization procedures that have lead to superior cost effectiveness and energy savings.

The sample size for the phase two study is determined primarily by budget constraints. It is too costly to collect on-site data for a large, nationally representative sample of housing units. The phase two sample is, therefore, a purposive one designed to facilitate the four comparisons shown in Fig. 4.

4.3 Data Collection

Three types of on-site data will be collected: dwelling-unit characteristics (including measurements sufficient to calculate the envelope UA, furnace characteristics, and air infiltration rates), occupant characteristics (dealing with behavioral and demographic factors that may influence energy savings results and with client perceptions of nonenergy impacts), and service delivery procedures used by subgrantees. Each of these data collection efforts is discussed in the following sections.

4.3.1 Dwelling-Unit Characteristics

An array of dwelling unit information, including dwelling size, age, structural type, size of conditioned space, insulation type, and size and placement of door and window areas, will be collected during on-site audits using the audit protocol shown in Appendix C. Data collected during the on-site audit will be used to help interpret and explain the phase one energy savings and benefit/cost ratios. Simulations of energy savings and benefit/cost ratios may also be completed.

The data that will be collected on heating systems is discussed in detail in Ternes et al. (1991). For gas furnaces and boilers, a flue gas analysis will follow developed procedures that are described in Appendix D. For electric space-heating systems, steady-state efficiencies can be assumed to be 100% and, thus, do not need to be measured. These systems include electric furnaces, wall and floor heaters, baseboard heaters, imbedded cable heat, and cord-connected portable heaters. The coefficient of performance (COP) of heat pump systems also will not be measured. Accurate field measurements are difficult to make because of uncertainty associated with determining the amount of delivered heat. Obtaining measurements suitable for comparisons is difficult because COPs are a function of ambient coil temperatures. To investigate reasons for variability between houses, the type of electric space-heating system could be an important explanatory variable and will be recorded.

Space-heating systems will be inspected to assess the WAP impacts on health and safety. Items to be examined include operation of control systems, cleanliness of heat exchangers and fans, belt wear, air filters, cracked heat exchangers, and flue and chimney condition. A carbon monoxide (CO) analysis may also be performed to identify fossil fuel systems operating with incomplete combustion. Inspection of gas furnaces for cracked heat exchangers and CO emissions into the building will produce information relevant to health and safety concerns. Data collected on heating equipment should be useful in explaining variations in energy savings among housing units and in quantifying furnace-related health and safety characteristics.

Impacts on air leakage rates will be assessed by comparing blower-door testing results in weatherized vs. control group housing units. This testing will measure the impact of weatherization on rates of air infiltration. The air-leakage measurement procedure is described in Appendix D.

4.3.2 Occupant Characteristics

The occupant survey uses the 1990 RECS format for some questions. Using the RECS format will make it possible to compare results for our subsample with national statistics. Survey data will include information on housing characteristics (e.g., type of heating equipment, year built, and whether rental or owner-occupied); heating fuels (types and intensity of use); household demographics including turnover; behaviors affecting the size of the conditioned living space; thermostat management practices; events affecting energy use (e.g., heating system breakdowns and fuel cutoffs); client perceptions of impacts on health, safety, comfort, and affordability of energy bills; and client awareness of and use of fuel assistance programs.

Survey data on housing characteristics, heating fuels, household demographics, behaviors affecting the size of the conditioned living space, thermostat management practices, and events affecting energy use will be used in a cross-sectional analysis designed to identify factors that produce especially high or low savings. Client perceptions of program effects on comfort, safety, and the affordability of fuel bills will be used to help quantify these impacts. Client awareness of and use of fuel assistance programs will be examined to identify interactions between these programs and the WAP.

4.3.3 Subgrantee Procedures

Process evaluations of a sample of exemplary subgrantees will be conducted to document in considerable detail the subgrantee procedures that have lead to superior performance. The process evaluations will include on-site interviews with agency personnel, reviews of agency records, field visits with weatherization crews and contractors, and on-site audits of weatherized homes.

5. PHASE THREE: PERSISTENCE OF ENERGY SAVINGS

The **third phase** of this study will look at the persistence of energy savings over time. Three years of energy savings results, 1990-1992, will be analyzed to determine the persistence of savings. Information on persistence is important for determining the long-range cost effectiveness and energy savings potential of the WAP. The persistence study may also provide an opportunity to analyze long-term price effects.

5.1 Experimental Design

This phase follows the same experimental design as phase one: changes in consumption in a treatment group of housing units weatherized in PY 1989 will be compared with changes in consumption in a control group of housing units not yet weatherized. The control-group housing units identified in phases one and two will be tracked and consumption data collected throughout the three postretrofit years of the third phase. If a control-group housing unit is weatherized before phase three ends, it will be dropped from the sample. Additional control-group dwellings will be added from 1992 and 1993 waiting lists as needed.

5.2 Sampling

Phase three is a follow-up study of the sample of weatherized housing units studied in phase one. Three years of postretrofit data will be collected on as many of the housing units in the initial phase one samples as possible, but substantial attrition can be expected. Any bias associated with this attrition will be reported and dealt with. The survey of occupants, conducted in phase two, will provide information on occupant behavior and energy-related changes in the housing units that may help interpret phase three results.

5.3 Data Collection

Data collection in phase three will follow the same procedures as phase one. Utility billing data and NCDC weather data for three postretrofit years will be collected and processed in the same way that the first-year data are handled in phase one.

5.4 Energy Savings and Cost-Effectiveness Analysis

The same procedures used in phase one (PRISM and the development of cost-effectiveness indicators such as B/C ratios, CCE, and NPV) will be applied to the additional follow-up data. The phase two audit protocol (Appendix C) and occupant survey (Appendix D) may provide a check on important confounding factors such as changes in supplemental fuel use, in size of the conditioned space, and in the number and ages of household members, and may make it possible, in some cases, to examine changes in housing unit and household characteristics that affect energy savings results over the long run.

6. KEY ELEMENTS AND OUTCOMES

The key elements of the Single-Family Study are summarized in Table 2. Altogether the Single-Family Study depends on a very extensive data collection effort that includes:

- data on program costs, installed measures, and service delivery procedures from about 400 subgrantees for 20,000 homes using all fuel types;
- several years of gas and electric billing histories for about 6,500 weatherized and 3,000 control-group housing units and fuel price data from more than 800 utilities;
- data on occupant characteristics and behavior based on an on-site survey;
- data on building characteristics from on-site visits; and
- detailed process evaluation of several exemplary agencies.

These data will be carefully screened and subjected to data quality checks. They will be organized in well-documented databases that can be made available to interested parties in such a manner that the identity of all respondents (whether grantees, subgrantees, or individual householders) remains anonymous.

Three reports that correspond to the three phases of the study will be produced (Figs. 2 and 3). Each report will contain an executive summary targetted to audiences interested in the study's overall findings. The main body of the reports will describe in greater detail the methodology and findings, focusing on results that are of most interest to weatherization program managers, practitioners, and policy makers. Useful and practical information will be highlighted, such as the level of energy savings that has been achieved in specific types of buildings and the service delivery procedures and packages of measures that have been most effective for particular market segments. Technical details of the evaluation will be presented in appendices.

The first report will analyze program energy savings and cost effectiveness for the year following weatherization in PY 1989. Estimates of energy savings and cost effectiveness will be generated with primary data at the national level and for a variety of market segments, including three different climate zones, two fuel types, and two building types. The national-level and three-climate-zone estimates of energy savings will be within 10% of the actual savings, at the 90% confidence level. In addition, a secondary analysis of savings for fuels other than electricity or gas will be presented. Cost effectiveness will

Table 2. Key Elements of the Single-Family Study

GOALS

- Characterize weatherization activities and costs
- Estimate energy savings--one, two, and three years after weatherization
- Assess nonenergy impacts
- Assess cost effectiveness
- Identify factors influencing savings
- Define future opportunities

SAMPLING

- Nationally representive sample of households
- Cluster sample - begin with about 400 subgrantees
- Three climate regions
- Single-family homes and 2- to 4-unit multifamily dwellings
- Stratification by subgrantee size and subregional geographic areas
- Waiting lists of eligibles for control group
- Begin with treatment group of 20,000 homes weatherized in 1989 (expect high attrition)
- Begin with control group of 10,000 eligible homes (expect high attrition)
- Purposive sample of exemplary subgrantees
- Purposive sample of subgrantees that install cooling measures

METHODS

- Mail survey of subgrantees (data from agency files)
- PRISM analysis of household gas and electric consumption data from utilities
- Cost effectiveness analysis - B/C ratios, CCE and NPV
- Analysis of factors - multivariate models, process evaluation
- On-site data for a subsample of homes - furnace efficiency, blower door testing, occupant surveys

be measured using indicators such as benefit/cost ratios, estimates of the cost of conserved energy, and net present value. A range of assumptions concerning future fuel prices, retrofit and housing unit lifetimes, and discount rates will be used in a sensitivity analysis.

Finally, this report will discuss factors that cause energy savings and cost effectiveness to vary. To the extent that savings and benefit/cost ratios vary in systematic ways, insights concerning the most promising future program directions will result. Such information may be useful for identifying the market segments that future program efforts should target and the types of measures and service delivery procedures that should be emphasized.

The second report will present an expanded analysis of the factors that determine energy savings and cost effectiveness at both the dwelling unit and agency level. Housing units with especially high and low savings and cost-effectiveness results will be compared to dwelling units with typical results to identify the factors accounting for the differences. A process evaluation will compare the operational procedures of a sample of exemplary subgrantee agencies to those of more typical agencies. This process evaluation will identify state-of-the-art weatherization practices and promising future directions for the WAP.

The second report also will analyze the WAP's nonenergy impacts on comfort, safety, housing affordability, fuel assistance needs, fuel cutoffs and arrearages. These impacts will be measured by comparing WAP-weatherized dwellings to matched samples of eligible but not yet weatherized homes. The report will present on-site audit data on air leakage rates, the incidence of unsafe conditions, and furnace efficiency ratings. An occupant survey will provide information on energy-related behaviors and client ratings of comfort and energy affordability. In addition, characteristics of homes weatherized in the 1989 PY will be compared to national statistics on income-eligible and noneligible homes provided by the 1990 RECS survey.

The third report will examine the persistence of energy savings by estimating energy savings two and three years after weatherization. Three years of energy savings results, 1990-1992, will be analyzed. Cost-effectiveness indicators will also be developed. Information on persistence is important for determining the long-range cost effectiveness and energy savings potential of the WAP. Estimates of the total amount of energy saved by the program can be developed from these annual savings estimates.

Results from all three phases of the Single-Family Study (as well as findings from the Fuel-Oil and High-Density Multifamily Studies) will be integrated into the evaluation's comprehensive final report (Beschen and Brown, 1990).

7. PROJECT IMPLEMENTATION

The WAP Evaluation Project is being carried out by ORNL at the request of DOE. The names, addresses, and telephone numbers of the DOE and ORNL project managers and of the Single-Family Study's principal investigators are shown in Table 3. Marilyn Brown is the project manager for the five-study program evaluation effort and is also a principal investigator for the Single-Family Study. Linda Berry and Dennis White also are principal investigators for the Single-Family Study.

Table 3. Staff for the Single Family Study

DOE Project Manager	ORNL Project Manager
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ORNL Principal Investigators

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APPENDIX A
Selection of the Control Group

Table A1. Pros and Cons of Alternative Control Group Designs for the Single-Family, Small Multifamily Study*

1. Waiting list of WAP eligible participants (those on lists in November 1990)	*2. WAP participants weatherized in 1990 program year: April 1990-March 1991*	*3. LIHEAP participants over the past year, whose homes have not been weatherized by WAP*	*4. WAP participants weatherized in 1988 program year: April 1988-March 1989*
•a small and variable portion of control group will provide a comparison for on-site visits or the persistence analysis; will need to supplement	**•does not provide a control group for the on-site visits or persistence analysis; a second control group would be necessary for the on-site visits**	•good portion of control group will not have been weatherized by Spring 1992--providing control group for on-site visits and the persistence analysis	**•does not provide a control group for the on-site visits or persistence analysis; a second control group would be necessary for the on-site visits**
•don't need to check with subgrantees to exclude WAP-weatherized homes, but need to check date of weatherization in 1991-92	•don't need to check with subgrantees to exclude weatherized homes	•must check with subgrantees to exclude WAP-weatherized homes; need to check both in 1990 and again in 1991-92 for use in the on-site visits and persistence analysis	•don't need to check with subgrantees to exclude WAP-weatherized homes
•provides profile of the unserved population	•does not provide profile of the unserved population	•provides profile of the unserved population; occupants have already been qualified	•does not provide profile of the unserved population
•selection process is like the process for the treatment group	•selection process is like the process for the treatment group	**•does not have comparable self-selection bias to the treatment group**	•selection process is like the process for the treatment group
•may not have enough homes on the waiting lists at all locations; can supplement		•elderly and handicapped may be underrepresented compared to weatherized homes; may over-represent rental units; homes may be in worse shape than average eligible, unserved homes	
•lists can underrepresent the elderly and handicapped because they are weatherized first			

*Bold lettering designates a major flaw in a control group design.

APPENDIX B
Sampling Plan

APPENDIX B
A NATIONAL TWO-STAGE CLUSTER SAMPLING PLAN FOR THE SINGLE-FAMILY STUDY

I. INTRODUCTION: GOALS AND ASSUMPTIONS

To estimate nationwide program energy savings, the single-family study requires a representative national sample of the 1989 WAP weatherized households. A representative comparison group of housing units waiting to be weatherized also must be selected. Both samples must be designed to ensure that variability in the service delivery procedures of community action program (CAP) agencies or subgrantees is captured and that variability by climate zone and by housing type (i.e., single-family and 2-4 unit multifamily) is included. Stratification on the variables of climate zone and subregions, subgrantee size (in number of households weatherized in the 1989 program year) and housing type will be employed to ensure the coverage of these potential sources of variation in energy savings.

Because of the difficulty and expense of contacting large numbers of subgrantees (there are approximately 1,100 operating in the continental U.S.) and utilities for data, a cluster sampling technique is the most practical approach. Therefore, a two-stage cluster sample, in which the CAPs are selected in a first stage and the households are selected in a second stage, will be employed.

The estimate of the required sample size developed here is based on the assumption that the standard deviation in the percentage energy savings is about twice the mean for the treatment households (Hirst, White, Goeltz and McKinstry, 1985; Elmroth, Forslund and Rolen, 1984; Goldberg, 1986). Assumptions about the variation in savings between CAPs were developed from two sources: (i) the pattern shown in the recent literature review conducted by Meridian Corporation, which reported a distribution of average savings that ranged from 8.5% to 21% (Meridian Corporation, 1989), and (ii) the distribution of households weatherized by each CAP developed by Schweitzer, Rayner, Wolfe, Mason, Ragins, and Cartor (1987). It is also assumed that the mean savings for households will be estimated within an error relative to the mean of 10% with a confidence interval of 90%. Thus, if the mean household savings is estimated at 15%, its true value will be 13.5% to 16.5% at the 90% confidence level.

II. NOTATION AND STRATIFICATION

We can describe the population in terms of levels.

<u>Level 1.</u> Single-family WAP Nationwide Population of Housing Units

Let $M_{....}$ = the number of housing units weatherized by WAP in 1989.

<u>Level 2.</u> Climate Zones and Subregion Areas

There are three nonoverlapping climate zones which have been partitioned into a total of 10 subregion geographic areas for the housing units weatherized by WAP in 1989. Climate zone 1 consists of three subregions; climate zone 2 consists of five subregions; and climate zone 3 consists of two subregions. The focus is on the subregions which are numbered from 1 to 10. These subregions are approximations of climate regions based on state boundaries that reflect state-wide heating and cooling degree day conditions.

Let $M_{z...}$ = the number of housing units weatherized by WAP in 1989 in the z^{th} subregion climate zone where $z = 1, 2, 3, ..., 10$.

Thus $M_{1...}$ = the number of housing units weatherized by WAP in 1989 in the 1^{st} subregion climate zone.

$M_{2...}$ = the number of housing units weatherized by WAP in 1989 in the 2^{nd} subregion climate zone.

$M_{3...}$ = the number of housing units weatherized by WAP in 1989 in the 3^{rd} subregion climate zone.

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$M_{10...}$ = the number of housing units weatherized by WAP in 1989 in the 10^{th} subregion climate zone.

Note: $M_{....} = M_{1...} + M_{2...} + M_{3...} + M_{4...}$.

Relative to the three climate zones, note that

$M_1' = M_{1...} + M_{2...} + M_{3...}$ = the number of housing units weatherized by WAP in 1989 in climate zone 1.

$M_2' = M_{4...} + M_{5...} + M_{6...} + M_{7...} + M_{8...}$ = the number of housing units weatherized by WAP in 1989 in climate zone 2.

$M_3' = M_{9...} + M_{10...}$ = the number of housing units weatherized by WAP in 1989 in climate zone 3.

Level 3. Category of CAPs

Each subregion climate zone can be partitioned into six categories of CAPs according to size, i.e., the number of housing units weatherized by the CAP in 1989.

Let $M_{zc..}$ = the number of housing units weatherized by WAP in 1989 in the c^{th} category of CAPs for the z^{th} subregion climate zone where

$c = 1 =$ CAPs with 59 or less housing units weatherized by WAP in 1989.

$c = 2 =$ CAPs with between 60-100 housing units weatherized by WAP in 1989.

$c = 3 =$ CAPs with between 101-249 housing units weatherized by WAP in 1989.

$c = 4 =$ CAPs with between 250-399 housing units weatherized by WAP in 1989.

$c = 5 =$ CAPs with between 400-899 housing units weatherized by WAP in 1989.

$c = 6 =$ CAPs with more than 900 housing units WAP in 1989.

Thus $M_{z1\cdot\cdot}$ = the number of housing units weatherized by WAP in 1989 in the 1^{st} category of CAPs for the z^{th} subregion climate zone.

$M_{z2\cdot\cdot}$ = the number of housing units weatherized by WAP in 1989 in the 2^{nd} category of CAPs for the z^{th} subregion climate zone.

$M_{z3\cdot\cdot}$ = the number of housing units weatherized by WAP in 1989 in the 3^{rd} category of CAPs for the z^{th} subregion climate zone.

$M_{z4\cdot\cdot}$ = the number of housing units weatherized by WAP in 1989 in the 4^{th} category of CAPs for the z^{th} subregion climate zone.

$M_{z5\cdot\cdot}$ = the number of housing units weatherized by WAP in 1989 in the 5^{th} category of CAPs for the z^{th} subregion climate zone.

$M_{z6\cdot\cdot}$ = the number of housing units weatherized by WAP in 1989 in the 6^{th} category of CAPs for the z^{th} subregion climate zone.

Note: $M_{z\cdots} = M_{z1\cdot\cdot} + M_{z2\cdot\cdot} + M_{z3\cdot\cdot} + M_{z4\cdot\cdot} + M_{z5\cdot\cdot} + M_{z6\cdot\cdot}$.

<u>Level 4</u>. CAPs

Each category of CAPs is partitioned into individual CAPs.

Let $M_{zcd\cdot}$ = the number of housing units weatherized by WAP in 1989 in the d^{th} CAP in the c^{th} category of CAPs for the z^{th} subregion climate zone where $d = 1, 2, \cdots, N_{zc}$.

Note: $N_{z\cdot} = N_{z1} + N_{z2} + N_{z3} + N_{z4} + N_{z5} + N_{z6}$ and
$N_{\cdot\cdot} = N_{1\cdot} + N_{2\cdot} + N_{3\cdot} + \ldots + N_{10\cdot}$.

For the three climate zones, note that

$N_1' = N_{1\cdot} + N_{2\cdot} + N_{3\cdot}$,

$N_2' = N_{4\cdot} + N_{5\cdot} + N_{6\cdot} + N_{7\cdot} + N_{8\cdot}$, and

$N_3' = N_{9\cdot} + N_{10\cdot}$.

<u>Level 5</u>. Stratification of Each CAP

Each CAP is partitioned into a stratum (1) of single-family units and a stratum (2) of small multifamily housing units weatherized by WAP in 1989.

Let M_{zcdt} = the number of type t housing units weatherized by WAP in 1989 in the d^{th} CAP in the c^{th} category of CAPs for the z^{th} subregion climate zone where $t = 1$ (single) and $t = 2$ (multi).

Thus M_{zcd1} = the number of single-family units weatherized by WAP in 1989 in the d^{th} CAP in the c^{th} category of CAPs for the z^{th} subregion climate zone, and

M_{zcd2} = the number of small multifamily housing units weatherized by WAP in 1989 in the d^{th} CAP in the c^{th} category of CAPs for the z^{th} subregion climate zone.

Note: $M_{zcd\cdot} = M_{zcd1} + M_{zcd2}$

An overview of the five levels is given in Figure 1.

Y_{zcdti} = the percent energy savings for the i^{th} housing unit of the t^{th} type in the d^{th} CAP of the c^{th} category of the z^{th} subregion.

Then we have the following (unknown) totals:

$Y_{zcdt\cdot} = \sum_{i=1}^{M_{zcdt}} Y_{zcdti}$ = the total percent energy savings for the housing units weatherized by WAP in 1989 of the t^{th} type in the d^{th} CAP of the c^{th} category of the z^{th} subregion.

$Y_{zcd\cdot\cdot} = Y_{zcd1\cdot} + Y_{zcd2\cdot}$ = the total percent energy savings for the housing units weatherized by WAP in 1989 in the d^{th} CAP of the c^{th} category of the z^{th} subregion.

$Y_{zc\cdots} = \sum_{d=1}^{N_{zc}} Y_{zcd\cdot\cdot}$ = the total percent energy savings for the housing units weatherized by WAP in 1989 in the c^{th} category of the z^{th} subregion.

$\bar{\bar{Y}}_{zc} = \frac{Y_{zc\cdots}}{M_{zc\cdot\cdot}}$ = the average percent energy savings per housing unit in the c^{th} category of the z^{th} subregion.

$Y_{z\cdots\cdot} = \sum_{z=1}^{6} Y_{zc\cdots}$ = the total percent energy savings for the housing units weatherized by WAP in 1989 the z^{th} subregion.

CAP CATEGORIES
(Number of Housing Units Weatherized)

Subregions	1 (59 or less)	2 (60-100)	3 (101-249)	4 (250-399)	5 (400-899)	6 (900 +)	
1	$N_{11} = 10$ $M_{11\cdot\cdot} = 250$	$N_{12} = 7$ $M_{12\cdot\cdot} = 510$	$N_{13} = 23$ $M_{13\cdot\cdot} = 3788$	$N_{14} = 3$ $M_{14\cdot\cdot} = 890$	$N_{15} = 1$ $M_{15\cdot\cdot} = 426$	$N_{16} = 0$ $M_{16\cdot\cdot} = 0$	$N_{1\cdot} = 44$ $M_{1\cdot\cdot\cdot} = 5864$
2	$N_{21} = 10$ $M_{21\cdot\cdot} = 190$	$N_{22} = 5$ $M_{22\cdot\cdot} = 371$	$N_{23} = 41$ $M_{23\cdot\cdot} = 7224$	$N_{24} = 21$ $M_{24\cdot\cdot} = 6813$	$N_{25} = 15$ $M_{25\cdot\cdot} = 7885$	$N_{26} = 2$ $M_{26\cdot\cdot} = 3056$	$N_{2\cdot} = 94$ $M_{2\cdot\cdot\cdot} = 25539$
3	$N_{31} = 0$ $M_{31\cdot\cdot} = 0$	$N_{32} = 0$ $M_{32\cdot\cdot} = 0$	$N_{33} = 11$ $M_{33\cdot\cdot} = 2019$	$N_{34} = 7$ $M_{34\cdot\cdot} = 2005$	$N_{35} = 4$ $M_{35\cdot\cdot} = 1697$	$N_{36} = 0$ $M_{36\cdot\cdot} = 0$	$N_{3\cdot} = 22$ $M_{3\cdot\cdot\cdot} = 5721$
Climate Zone 1 Totals	$N'_{11} = 20$ $M'_{11} = 440$	$N'_{12} = 12$ $M'_{12} = 881$	$N'_{13} = 75$ $M'_{13} = 13031$	$N'_{14} = 31$ $M'_{14} = 9708$	$N'_{15} = 20$ $M'_{15} = 10008$	$N'_{16} = 2$ $M'_{16} = 3056$	$N'_{1} = 160$ $M'_{1} = 37124$
4	$N_{41} = 33$ $M_{41\cdot\cdot} = 933$	$N_{42} = 17$ $M_{42\cdot\cdot} = 1407$	$N_{43} = 22$ $M_{43\cdot\cdot} = 3707$	$N_{44} = 5$ $M_{44\cdot\cdot} = 1537$	$N_{45} = 0$ $M_{45\cdot\cdot} = 0$	$N_{46} = 0$ $M_{46\cdot\cdot} = 0$	$N_{4\cdot} = 77$ $M_{4\cdot\cdot\cdot} = 7584$
5	$N_{51} = 8$ $M_{51\cdot\cdot} = 260$	$N_{52} = 9$ $M_{52\cdot\cdot} = 748$	$N_{53} = 17$ $M_{53\cdot\cdot} = 2382$	$N_{54} = 6$ $M_{54\cdot\cdot} = 2060$	$N_{55} = 3$ $M_{55\cdot\cdot} = 1638$	$N_{56} = 0$ $M_{56\cdot\cdot} = 0$	$N_{5\cdot} = 43$ $M_{5\cdot\cdot\cdot} = 7088$
6	$N_{61} = 7$ $M_{61\cdot\cdot} = 339$	$N_{62} = 42$ $M_{62\cdot\cdot} = 3417$	$N_{63} = 97$ $M_{63\cdot\cdot} = 16341$	$N_{64} = 28$ $M_{64\cdot\cdot} = 8282$	$N_{65} = 10$ $M_{65\cdot\cdot} = 5301$	$N_{66} = 3$ $M_{66\cdot\cdot} = 7045$	$N_{6\cdot} = 187$ $M_{6\cdot\cdot\cdot} = 40725$
7	$N_{71} = 4$ $M_{71\cdot\cdot} = 90$	$N_{72} = 13$ $M_{72\cdot\cdot} = 1023$	$N_{73} = 60$ $M_{73\cdot\cdot} = 10152$	$N_{74} = 28$ $M_{74\cdot\cdot} = 8900$	$N_{75} = 18$ $M_{75\cdot\cdot} = 9814$	$N_{76} = 4$ $M_{76\cdot\cdot} = 6561$	$N_{7\cdot} = 127$ $M_{7\cdot\cdot\cdot} = 36540$
8	$N_{81} = 2$ $M_{81\cdot\cdot} = 97$	$N_{82} = 17$ $M_{82\cdot\cdot} = 1342$	$N_{83} = 67$ $M_{83\cdot\cdot} = 10633$	$N_{84} = 34$ $M_{84\cdot\cdot} = 10202$	$N_{85} = 12$ $M_{85\cdot\cdot} = 6879$	$N_{86} = 1$ $M_{86\cdot\cdot} = 1200$	$N_{8\cdot} = 133$ $M_{8\cdot\cdot\cdot} = 30353$
Climate Zone 2 Totals	$N'_{21} = 54$ $M'_{21} = 1719$	$N'_{22} = 98$ $M'_{22} = 7937$	$N'_{23} = 263$ $M'_{23} = 43215$	$N'_{24} = 101$ $M'_{24} = 30981$	$N'_{25} = 43$ $M'_{25} = 23632$	$N'_{26} = 8$ $M'_{26} = 14806$	$N'_{2} = 567$ $M'_{2} = 122290$
9	$N_{91} = 114$ $M_{91\cdot\cdot} = 4201$	$N_{92} = 56$ $M_{92\cdot\cdot} = 4438$	$N_{93} = 75$ $M_{93\cdot\cdot} = 11776$	$N_{94} = 11$ $M_{94\cdot\cdot} = 3403$	$N_{95} = 2$ $M_{95\cdot\cdot} = 1385$	$N_{96} = 0$ $M_{96\cdot\cdot} = 0$	$N_{9\cdot} = 258$ $M_{9\cdot\cdot\cdot} = 25203$
10	$N_{10,1} = 42$ $M_{10,1\cdot\cdot} = 1323$	$N_{10,2} = 26$ $M_{10,2\cdot\cdot} = 2038$	$N_{10,3} = 37$ $M_{10,3\cdot\cdot} = 5501$	$N_{10,4} = 10$ $M_{10,4\cdot\cdot} = 3008$	$N_{10,5} = 3$ $M_{10,5\cdot\cdot} = 1473$	$N_{10,6} = 0$ $M_{10,6\cdot\cdot} = 0$	$N_{10\cdot} = 118$ $M_{10\cdot\cdot\cdot} = 13343$
Climate Zone 3 Totals	$N'_{31} = 156$ $M'_{31} = 5524$	$N'_{32} = 82$ $M'_{32} = 6476$	$N'_{33} = 112$ $M'_{33} = 17277$	$N'_{34} = 21$ $M'_{34} = 6411$	$N'_{35} = 5$ $M'_{35} = 2858$	$N'_{36} = 0$ $M'_{36} = 0$	$N'_{3} = 376$ $M'_{3} = 38546$
							$N_{\cdot\cdot} = 1103$ $M_{\cdot\cdot\cdot\cdot} = 197960$

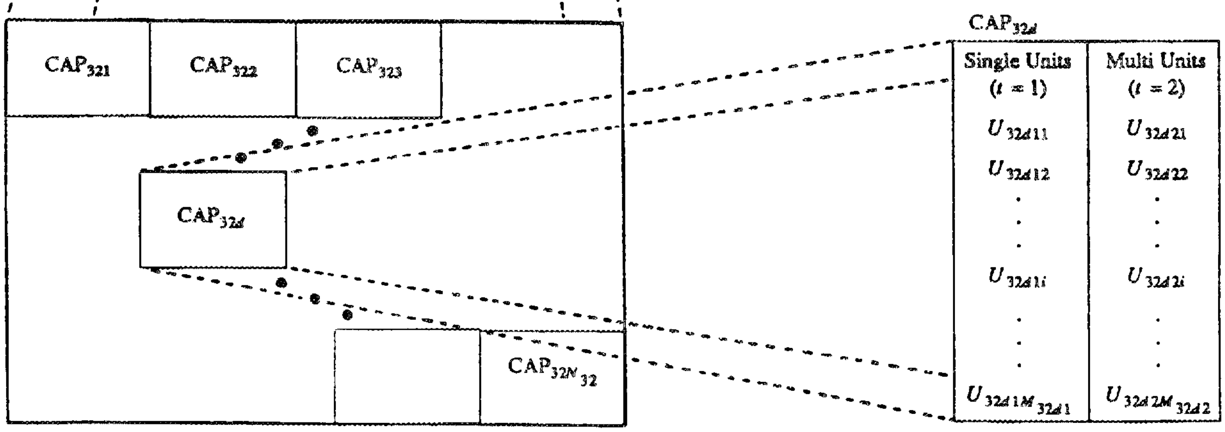

Figure 1. Overview of WAP Sampling Frame With Stratification by Climate Zone and Subregions, CAP Size, and Housing Type.

$$\overline{\overline{Y}}_z = \frac{Y_{z....}}{M_{z...}}$$ = the average percent energy savings per housing unit in the z^{th} subregion.

For the three climate zones, let

$$Y_1' = Y_{1....} + Y_{2....} + Y_{3....},$$

$$Y_2' = Y_{4....} + Y_{5....} + Y_{6....} + Y_{7....} + Y_{8....},$$

$$Y_3' = Y_{9....} + Y_{10....},$$

$$\overline{\overline{Y}}_1' = \frac{Y_1'}{M_1'}, \ \overline{\overline{Y}}_2' = \frac{Y_2'}{M_2'}, \text{ and } \overline{\overline{Y}}_3' = \frac{Y_3'}{M_3'}.$$

And for the nation, let

$$Y_{.....} = \sum_{z=1}^{10} Y_{z....}$$ = the total percent energy savings for the $M_{....}$ housing units weatherized by WAP in 1989 in the Nationwide WAP for 1989.

Finally, $\overline{\overline{Y}} = \frac{Y_{.....}}{M_{....}}$ = the average percent energy saving per housing unit for WAP during the given time period.

The primary objective is to estimate $\overline{\overline{Y}}$ based on a nationally representative sample of housing units weatherized by WAP in 1989.

III. STRATIFIED TWO-STAGE CLUSTER SAMPLING PLAN

Step 1. As we saw earlier, there are 60 strata (10 subregions × 6 CAP categories) as given below. Lower case m and n refer to sample sizes.

CAP CATEGORIES
(Number of Housing Units Weatherized)

Subregions	1 (59 or less)	2 (60-100)	3 (101-249)	4 (250-399)	5 (400-899)	6 (900 +)	
1	n_{11} $m_{11\cdot\cdot}$	n_{12} $m_{12\cdot\cdot}$	n_{13} $m_{13\cdot\cdot}$	n_{14} $m_{14\cdot\cdot}$	n_{15} $m_{15\cdot\cdot}$	n_{16} $m_{16\cdot\cdot}$	$n_{1\cdot}$ $m_{1\cdot\cdot\cdot}$
2	n_{21} $m_{21\cdot\cdot}$	n_{22} $m_{22\cdot\cdot}$	n_{23} $m_{23\cdot\cdot}$	n_{24} $m_{24\cdot\cdot}$	n_{25} $m_{25\cdot\cdot}$	n_{26} $m_{26\cdot\cdot}$	$n_{2\cdot}$ $m_{2\cdot\cdot\cdot}$
3	n_{31} $m_{31\cdot\cdot}$	n_{32} $m_{32\cdot\cdot}$	n_{33} $m_{33\cdot\cdot}$	n_{34} $m_{34\cdot\cdot}$	n_{35} $m_{35\cdot\cdot}$	n_{36} $m_{36\cdot\cdot}$	$n_{3\cdot}$ $m_{3\cdot\cdot\cdot}$
Zone 1	n'_{11} m'_{11}	n'_{12} m'_{12}	n'_{13} m'_{13}	n'_{14} m'_{14}	n'_{15} m'_{15}	n'_{16} m'_{16}	$n'_{1\cdot}$ m'_{1}
4	n_{41} $m_{41\cdot\cdot}$	n_{42} $m_{42\cdot\cdot}$	n_{43} $m_{43\cdot\cdot}$	n_{44} $m_{44\cdot\cdot}$	n_{45} $m_{45\cdot\cdot}$	n_{46} $m_{46\cdot\cdot}$	$n_{4\cdot}$ $m_{4\cdot\cdot\cdot}$
5	n_{51} $m_{51\cdot\cdot}$	n_{52} $m_{52\cdot\cdot}$	n_{53} $m_{53\cdot\cdot}$	n_{54} $m_{54\cdot\cdot}$	n_{55} $m_{55\cdot\cdot}$	n_{56} $m_{56\cdot\cdot}$	$n_{5\cdot}$ $m_{5\cdot\cdot\cdot}$
6	n_{61} $m_{61\cdot\cdot}$	n_{62} $m_{62\cdot\cdot}$	n_{63} $m_{63\cdot\cdot}$	n_{64} $m_{64\cdot\cdot}$	n_{65} $m_{65\cdot\cdot}$	n_{66} $m_{66\cdot\cdot}$	$n_{6\cdot}$ $m_{6\cdot\cdot\cdot}$
7	n_{71} $m_{71\cdot\cdot}$	n_{72} $m_{72\cdot\cdot}$	n_{73} $m_{73\cdot\cdot}$	n_{74} $m_{74\cdot\cdot}$	n_{75} $m_{75\cdot\cdot}$	n_{76} $m_{76\cdot\cdot}$	$n_{7\cdot}$ $m_{7\cdot\cdot\cdot}$
8	n_{81} $m_{81\cdot\cdot}$	n_{82} $m_{82\cdot\cdot}$	n_{83} $m_{83\cdot\cdot}$	n_{84} $m_{84\cdot\cdot}$	n_{85} $m_{85\cdot\cdot}$	n_{86} $m_{86\cdot\cdot}$	$n_{8\cdot}$ $m_{8\cdot\cdot\cdot}$
Zone 2	n'_{21} m'_{21}	n'_{22} m'_{22}	n'_{23} m'_{23}	n'_{24} m'_{24}	n'_{25} m'_{25}	n'_{26} m'_{26}	$n'_{2\cdot}$ m'_{2}
9	n_{91} $m_{91\cdot\cdot}$	n_{92} $m_{92\cdot\cdot}$	n_{93} $m_{93\cdot\cdot}$	n_{94} $m_{94\cdot\cdot}$	n_{95} $m_{95\cdot\cdot}$	n_{96} $m_{96\cdot\cdot}$	$n_{9\cdot}$ $m_{9\cdot\cdot\cdot}$
10	$n_{10,1}$ $m_{10,1\cdot\cdot}$	$n_{10,2}$ $m_{10,2\cdot\cdot}$	$n_{10,3}$ $m_{10,3\cdot\cdot}$	$n_{10,4}$ $m_{10,4\cdot\cdot}$	$n_{10,5}$ $m_{10,5\cdot\cdot}$	$n_{10,6}$ $m_{10,6\cdot\cdot}$	$n_{10\cdot}$ $m_{10\cdot\cdot\cdot}$
Zone 3	n'_{31} m'_{31}	n'_{32} m'_{32}	n'_{33} m'_{33}	n'_{34} m'_{34}	n'_{35} m'_{35}	n'_{36} m'_{36}	$n'_{3\cdot}$ m'_{3}
							$n_{\cdot\cdot}$ $m_{\cdot\cdot\cdot\cdot}$

Step 2.

<u>Stage 1.</u> Within stratum "zc" and independently of the other strata, select a simple random sample of n_{zc} CAPs. We will have

$$\mathrm{CAP}_{zc1},\ \mathrm{CAP}_{zc2},\ \cdots,\ \mathrm{CAP}_{zcd},\ \cdots,\ \mathrm{CAP}_{zcn_{zc}}$$

Note here that $d = 1, 2, \cdots, n_{zc}$. We do this 60 independent times. The total number of CAPs selected is

$$
\begin{aligned}
n_{..} &= n_{1\cdot} + n_{2\cdot} + n_{3\cdot} + \cdots + n_{10\cdot} \\
&= (n_{11} + n_{12} + n_{13} + n_{14} + n_{15} + n_{16}) + \\
&\quad (n_{21} + n_{22} + n_{23} + n_{24} + n_{25} + n_{26}) + \\
&\quad (n_{31} + n_{32} + n_{33} + n_{34} + n_{35} + n_{36}) + \cdots + \\
&\quad (n_{10,1} + n_{10,2} + n_{10,3} + n_{10,4} + n_{10,5} + n_{10,6})
\end{aligned}
$$

Stage 2. For the d^{th} selected CAP from stratum zc in Stage 1, select a simple random sample of m_{zcd1} single housing units weatherized by WAP in 1989 and independently select m_{zcd2} small multi housing units weatherized by WAP in 1989. We will have

$t = 1$	$t = 2$
u_{zcd11}	u_{zcd21}
u_{zcd12}	u_{zcd22}
$\vdots$	$\vdots$
u_{zcd1i}	u_{zcd2i}
$\vdots$	$\vdots$
$u_{zcd1m_{zcd1}}$	$u_{zcd2m_{zcd2}}$

Note: $m_{zcd\cdot} = m_{zcd1} + m_{zcd2}$ = the total number of housing units weatherized by WAP in 1989 (single and multi) selected from the d^{th} sample CAP from category c of subregion z.

$m_{zc\cdot\cdot} = \sum_{d=1}^{n_{zc}} m_{zcd\cdot}$ = the total number of housing units weatherized by WAP in 1989 (single and multi) selected from category c of subregion z.

$m_{z\cdot\cdot\cdot} = \sum_{c=1}^{6} m_{zc\cdot\cdot}$ = the total number of housing units weatherized by WAP in 1989 (single and multi) selected from subregion z.

$m_{\cdot\cdot\cdot\cdot} = \sum_{z=1}^{10} m_{z\cdot\cdot\cdot}$ = the total number of sample housing units weatherized by WAP in 1989.

IV. ESTIMATION OF THE TOTALS AND $\bar{\bar{Y}}$

1. We have the following sample statistics for the d^{th} selected CAP from stratum zc.

   1.1 $\bar{y}_{zcd1}$ – sample mean percent energy savings for single housing units weatherized by WAP in 1989.

   s^2_{zcd1} – sample variance for the percent energy savings for single housing units weatherized by WAP in 1989.

   $\hat{Y}_{zcd1\cdot} = M_{zcd1}\bar{y}_{zcd1} =$ an estimate of the total percent energy savings for single housing units weatherized by WAP in 1989 for the d^{th} selected CAP from stratum zc.

   1.2 $\bar{y}_{zcd2}$ – sample mean percent energy savings for multi housing units weatherized by WAP in 1989.

   s^2_{zcd2} – sample variance for the percent energy savings for multi housing units weatherized by WAP in 1989.

   $\hat{Y}_{zcd2\cdot} = M_{zcd2}\bar{y}_{zcd2} =$ an estimate of the total percent energy savings for multi housing units weatherized by WAP in 1989 for the d^{th} selected CAP from stratum zc.

2. $\hat{Y}_{zcd\cdot\cdot} = \hat{Y}_{zcd1\cdot} + \hat{Y}_{zcd2\cdot}$.

$$Var(\hat{Y}_{zcd\cdot\cdot}) = M^2_{zcd1}\left(\frac{M_{zcd1} - m_{zcd1}}{M_{zcd1}}\right)\frac{S^2_{zcd1}}{m_{zcd1}} + M^2_{zcd2}\left(\frac{M_{zcd2} - m_{zcd2}}{M_{zcd2}}\right)\frac{S^2_{zcd2}}{m_{zcd2}}$$

and

$$V\hat{a}r(\hat{Y}_{zcd\cdot\cdot}) = M^2_{zcd1}\left(\frac{M_{zcd1} - m_{zcd1}}{M_{zcd1}}\right)\frac{s^2_{zcd1}}{m_{zcd1}} + M^2_{zcd2}\left(\frac{M_{zcd2} - m_{zcd2}}{M_{zcd2}}\right)\frac{s^2_{zcd2}}{m_{zcd2}}$$

Note that S^2_{zcd1} and S^2_{zcd2} are "population variances" for the strata in the d^{th} CAP and s^2_{zcd1} and s^2_{zcd2} are the corresponding "sample variances" as defined above.

3. An estimator of $Y_{zc\cdots}$, the total percent energy savings for the housing units weatherized by WAP in 1989 in the c^{th} CAP size category of the z^{th} subregion, is

$$\hat{Y}_{zc\cdots} = \frac{N_{zc}}{n_{zc}}\sum_{d=1}^{n_{zc}} \hat{Y}_{zcd\cdot\cdot} \qquad \text{(See Cochran, page 303, (11.21).)}$$

with sampling variance

$$Var(\hat{Y}_{zc}\ ) = N^2_{zc}\left(\frac{N_{zc} - n_{zc}}{N_{zc}}\right)\frac{S^2_{zc(B)}}{n_{zc}} + \frac{N_{zc}}{n_{zc}}\sum_{d=1}^{N_{zc}} Var(\hat{Y}_{zcd\cdot\cdot})$$

$$\text{where } S^2_{zc(B)} = \frac{\sum_{d=1}^{N_{zc}} (Y_{zcd\cdot\cdot} - \bar{Y}_{zc})^2}{N_{zc} - 1} \quad \text{and } \bar{Y}_{zc} = \frac{Y_{zc\cdots}}{N_{zc}}$$

and the estimated sampling variance

$$V\hat{a}r(\hat{Y}_{zc\cdots}) = N^2_{zc}\left(\frac{N_{zc} - n_{zc}}{N_{zc}}\right)\frac{s^2_{zc(B)}}{n_{zc}} + \frac{N_{zc}}{n_{zc}}\sum_{d=1}^{N_{zc}} V\hat{a}r(\hat{Y}_{zcd\cdot\cdot})$$

$$\text{where } s^2_{zc(B)} = \frac{\sum_{d=1}^{n_{zc}} (\hat{Y}_{zcd\cdot\cdot} - \hat{\bar{Y}}_{zc})^2}{n_{zc} - 1} \quad \text{and } \hat{\bar{Y}}_{zc} = \frac{\sum_{d=1}^{n_{zc}} \hat{Y}_{zcd\cdot\cdot}}{n_{zc}} .$$

4. An estimator of $Y_{z\cdots\cdot}$, the total percent energy savings for the housing units weatherized by WAP in 1989 in the z^{th} climate zone, is

$$\hat{Y}_{z\cdots\cdot} = \sum_{c=1}^{6} \hat{Y}_{zc\cdots}$$

with sampling variance

$$Var(\hat{Y}_{z\cdots\cdot}) = \sum_{c=1}^{6} Var(\hat{Y}_{zc\cdots})$$

and estimated sampling variance

$$V\hat{a}r(\hat{Y}_{z\cdots\cdot}) = \sum_{c=1}^{6} V\hat{a}r(\hat{Y}_{zc\cdots}) .$$

For the three climate zones, take the estimators

$$\hat{Y}'_1 = \sum_{z=1}^{3} \hat{Y}_{z\cdots}, \quad \hat{Y}'_2 = \sum_{z=4}^{8} \hat{Y}_{z\cdots}, \quad \text{and } \hat{Y}'_3 = \sum_{z=9}^{10} \hat{Y}_{z\cdots}$$

with respective sampling variances

$$\text{Var}(\hat{Y}'_1) = \sum_{z=1}^{3} \text{Var}(\hat{Y}_{z\cdots}), \quad \text{Var}(\hat{Y}'_2) = \sum_{z=4}^{8} \text{Var}(\hat{Y}_{z\cdots}), \quad \text{and } \text{Var}(\hat{Y}'_3) = \sum_{z=9}^{10} \text{Var}(\hat{Y}_{z\cdots})$$

and respective estimated sampling variances

$$\hat{\text{Var}}(\hat{Y}'_1) = \sum_{z=1}^{3} \hat{\text{Var}}(\hat{Y}_{z\cdots}), \quad \hat{\text{Var}}(\hat{Y}'_2) = \sum_{z=4}^{8} \hat{\text{Var}}(\hat{Y}_{z\cdots}), \quad \text{and } \hat{\text{Var}}(\hat{Y}'_3) = \sum_{z=9}^{10} \hat{\text{Var}}(\hat{Y}_{z\cdots})$$

5. An estimator of $Y_{.....}$, the total percent energy savings for the $M_{....}$ housing units weatherized by WAP in 1989, is

$$\hat{Y}_{.....} = \sum_{z=1}^{10} \hat{Y}_{z....}$$

with sampling variance

$$Var(\hat{Y}_{.....}) = \sum_{z=1}^{10} Var(\hat{Y}_{z....}).$$

and estimated sampling variance

$$\hat{Var}(\hat{Y}_{.....}) = \sum_{z=1}^{10} \hat{Var}(\hat{Y}_{z....}) \ .$$

6. Finally, an estimator of $\bar{\bar{Y}}$, the average percent energy savings per housing unit weatherized by WAP during the given period, is

$$\hat{\bar{\bar{Y}}} = \frac{\hat{Y}_{.....}}{M_{....}}$$

with sampling variance

$$Var(\hat{\bar{\bar{Y}}}) = \frac{1}{M^2_{....}} Var(\hat{Y}_{.....})$$

and estimated sampling variance

$$\hat{Var}(\hat{\bar{\bar{Y}}}) = \frac{1}{M^2_{....}} \hat{Var}(\hat{Y}_{.....})$$

(From 3 and 4 respectively, we can produce estimates of $\bar{\bar{Y}}_{zc}$, $\bar{\bar{Y}}_z$, $\bar{\bar{Y}}'_1$, $\bar{\bar{Y}}'_2$, and $\bar{\bar{Y}}'_3$.)

V. SAMPLE SIZES

The desire is to determine $n_{..}$ the total number of CAPs to be selected for the sample and $m_{....}$ the total number of housing units weatherized by WAP in 1989 to be selected at the the second stage so that $\hat{\bar{\bar{Y}}}$ is within B of $\bar{\bar{Y}}$ with probability $1 - \alpha$, i.e., assuming that the sample estimate of the mean is within 10% of its true value with 90% probability.

Assuming that $\hat{\bar{\bar{Y}}}$ is normally distributed, we have

$$B = Z_{\frac{\alpha}{2}} \sqrt{Var(\hat{\bar{\bar{Y}}})} = \frac{Z_{\frac{\alpha}{2}}}{M_{....}} \sqrt{Var(\hat{Y}_{.....})}$$

Thus

$$(M....)B = Z_{\frac{\alpha}{2}}\sqrt{Var(\hat{Y}.....)}$$

$$\Longrightarrow (M....)B = Z_{\frac{\alpha}{2}}\sqrt{\sum_z\sum_c Var(\hat{Y}_{zc}...)}$$

$$\Longrightarrow (M....)B = Z_{\frac{\alpha}{2}}\sqrt{\sum_z\sum_c\left[N_{zc}^2\left(\frac{N_{zc}-n_{zc}}{N_{zc}}\right)\frac{S_{zc(B)}^2}{n_{zc}} + \frac{N_{zc}}{n_{zc}}\sum_{d=1}^{N_{zc}} Var(\hat{Y}_{zcd}..)\right]}$$

$$\Longrightarrow (M....)B = Z_{\frac{\alpha}{2}}\sqrt{\sum_z\sum_c\left[N_{zc}^2\left(\frac{N_{zc}-n_{zc}}{N_{zc}}\right)\frac{S_{zc(B)}^2}{n_{zc}} + \frac{N_{zc}}{n_{zc}}\sum_{d=1}^{N_{zc}}\left\{M_{zcd1}^2\left(\frac{M_{zcd1}-m_{zcd1}}{M_{zcd1}}\right)\frac{S_{zcd1}^2}{m_{zcd1}} + M_{zcd2}^2\left(\frac{M_{zcd2}-m_{zcd2}}{M_{zcd2}}\right)\frac{S_{zcd2}^2}{m_{zcd2}}\right\}\right]}\ .$$

For all CAPs, let m_{zcd1} be a fixed fraction f_2 of M_{zcd1}, and similarly let m_{zcd2} be the same fixed fraction f_2 of M_{zcd2}. (For example, f_2 might be .05 or .1, which means that 5% or 10% of the housing units weatherized in 1989 by each selected CAP would be selected for the sample.) Thus the above equation becomes

$$(M....)B = Z_{\frac{\alpha}{2}}\sqrt{\sum_z\sum_c\left[N_{zc}^2\left(\frac{N_{zc}-n_{zc}}{N_{zc}}\right)\frac{S_{zc(B)}^2}{n_{zc}} + \frac{N_{zc}}{n_{zc}}\sum_{d=1}^{N_{zc}}\left\{M_{zcd1}\left(\frac{(1-f_2)}{f_2}\right)S_{zcd1}^2 + M_{zcd2}\left(\frac{(1-f_2)}{f_2}\right)S_{zcd2}^2\right\}\right]}\ .$$

Assuming all variances within each CAP are equal, $S_{zcd1}^2 = S_{zcd2}^2 = S_{(w)}^2$, the equation becomes

$$(M....)B = Z_{\frac{\alpha}{2}}\sqrt{\sum_z\sum_c\left[N_{zc}^2\left(\frac{N_{zc}-n_{zc}}{N_{zc}}\right)\frac{S_{zc(B)}^2}{n_{zc}} + \frac{N_{zc}}{n_{zc}}\frac{(1-f_2)}{f_2}S_{(w)}^2\sum_{d=1}^{N_{zc}}\left\{M_{zcd1}+M_{zcd2}\right\}\right]}\ .$$

$$= Z_{\frac{\alpha}{2}}\sqrt{\sum_z\sum_c\left[N_{zc}^2\left(\frac{N_{zc}-n_{zc}}{N_{zc}}\right)\frac{S_{zc(B)}^2}{n_{zc}} + \frac{N_{zc}}{n_{zc}}\frac{(1-f_2)}{f_2}S_{(w)}^2 M_{zc}..\right]}\ .$$

Letting $n_{zc} = \frac{N_{zc}}{N..}n..$ and assuming all $S_{zc(B)}^2 = S_{(B)}^2$, the above becomes

$$(M....)B = Z_{\frac{\alpha}{2}}\sqrt{\sum_z\sum_c\left[N_{zc}^2\left(\frac{N_{zc}-\frac{N_{zc}}{N..}n..}{N_{zc}}\right)\frac{S_{(B)}^2}{\frac{N_{zc}}{N..}n..}\right] + \frac{(1-f_2)}{f_2}S_{(w)}^2\sum_z\sum_c\left(\frac{N_{zc}}{\frac{N_{zc}}{N..}n..}M_{zc}..\right)}$$

$$= Z_{\frac{\alpha}{2}}\sqrt{\sum_z\sum_c\left[N_{zc}\frac{\left(1-\frac{n..}{N..}\right)}{\frac{n..}{N..}}S_{(B)}^2\right] + \frac{(1-f_2)}{f_2}S_{(w)}^2\frac{N..}{n..}M....}\ .$$

Letting $f_1 = \frac{n_{..}}{N_{..}}$, we have

$$(M_{....})B = Z_{\frac{\alpha}{2}} \sqrt{\frac{(1-f_1)}{f_1} S^2_{(B)} N_{..} + \frac{(1-f_2)}{f_2} S^2_{(w)} \frac{1}{f_1} M_{....}}$$

which we solve for f_1. Thus we have

$$f_1 \frac{(M^2_{....})B^2}{Z^2_{\frac{\alpha}{2}}} = (1-f_1) S^2_{(B)} N_{..} + \frac{(1-f_2)}{f_2} S^2_{(w)} M_{....}$$

$$f_1 \left[\frac{(M^2_{....})B^2}{Z^2_{\frac{\alpha}{2}}} + S^2_{(B)} N_{..} \right] = S^2_{(B)} N_{..} + \frac{(1-f_2)}{f_2} S^2_{(w)} M_{....}$$

$$\Longrightarrow f_1 = \frac{S^2_{(B)} N_{..} + \frac{(1-f_2)}{f_2} S^2_{(w)} M_{....}}{\frac{(M^2_{....})B^2}{Z^2_{\frac{\alpha}{2}}} + S^2_{(B)} N_{..}}$$

$$\Longrightarrow f_1 = \frac{S^2_{(B)} + \frac{(1-f_2)}{f_2} S^2_{(w)} \bar{M}_{....}}{\frac{(\bar{M}_{....})(M_{....})B^2}{Z^2_{\frac{\alpha}{2}}} + S^2_{(B)}} \qquad \text{where } \bar{M}_{....} = \frac{M_{....}}{N_{..}}.$$

Once we know f_1, then $n_{..} = f_1 N_{..}$.

EXAMPLE: Assume $\bar{\bar{Y}} = .15$.

* Let $M_{....} = 197{,}960$, $N_{..} = 1{,}103 \implies \bar{M}_{....} = 180$. That is, the average number of housing units weatherized per CAP in 1989 is approximately 180.

Let $B = .1(\bar{\bar{Y}}) = (.1)(.15) = .015$.

** Let $S_{(w)} = 1.5(\bar{\bar{Y}}) = (1.5)(.15) = .225$.

*** Let $S_{(B)} = 20$.

Let $1 - \alpha = .90 \implies Z_{\frac{\alpha}{2}} = 1.645$.

Let $f_2 = .05$. That is, assume that 5% of the weatherized housing units in each selected CAP are sampled.

Thus

$$f_1 = \frac{(20)^2 + \left(\frac{1-.05}{.05}\right)(.225)^2(180)}{\frac{(180)(197{,}960)}{(1.645)^2}(0.015)^2 + (20)^2} = .17$$

$$\implies \frac{n_{..}}{N_{..}} = .17 \implies n_{..} = .17N_{..} = .17(1103) = \underline{188 \text{ CAPs}}.$$

Also if $\bar{M} = 180 \implies m_{....} = (.05)180(188) =$
<u>1692 housing units weatherized by WAP in 1989 for the sample!</u>

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* Based on Schweitzer, et al., 1987.

** Based on Hirst, White, Goeltz, and McKinstry, 1985; Elmroth, Forslund, and Rolen, 1984; Goldberg, 1986.

*** Based on Meridian Corporation 1989, and Schweitzer, et al., 1987. The value of $S_{(B)}$ depends on the number of housing units weatherized in each CAP. To account for the decrease in the average number of weatherized housing units weatherized per CAP from an earlier analysis, we multiply the previous value of 30 by the ratio of the new average CAP size by the previous average CAP size. Thus, use $S_{(B)} = \left(\frac{180}{272}\right)(30) = 20$.

Now assume the following.

Table 1.

Climate Zones	# of Housing Units in Population	%	Number of CAPs in Population	%
1	$M_1' =$ 37,124	19	$N_1' =$ 160	15
2	$M_2' =$ 122,290	62	$N_2' =$ 567	51
3	$M_3' =$ 38,546	19	$N_3' =$ 376	34
	$M_{....} =$ 197,960		$N_{..} =$ 1,103	

Then the $n_{..} = 188$ CAPs and $m_{....} = 1{,}692$ housing units weatherized by WAP in 1989 would be roughly distributed as

Table 2.

Climate Zones	# of Housing Units in Sample	# of CAPs in Sample
1	$m_1' = (.19)(1692) = 321$	$n_1' = (.15)(188) \approx$ 28
2	$m_2' = (.62)(1692) = 1049$	$n_2' = (.51)(188) \approx$ 96
3	$m_3' = (.19)(1692) = 321$	$n_3' = (.34)(188) \approx$ 64

Letting $f_2 = .1$ and the other quantities remain the same, we obtain $f_1 \approx .14$, $n_{..} = .14N_{..} = .14(1103) = \underline{154}$ CAPs.

If $\overline{M} \approx 180 \Longrightarrow m_{....} \approx (.1)(180)(154) =$
2772 housing units weatherized by WAP in 1989 for the sample!

The $n_{..} = 154$ CAPs and $m_{....} = 2772$ housing units weatherized by WAP in 1989 would be roughly distributed as

Table 3.

Climate Zones	# of Housing Units in Sample	# of CAPs in Sample
1	$m_1' = (.19)(2772) = 527$	$n_1' = (.15)(154) \approx$ 23
2	$m_2' = (.62)(2772) = 1719$	$n_2' = (.51)(154) \approx$ 79
3	$m_3' = (.19)(2772) = 527$	$n_3' = (.34)(154) \approx$ 52

On the other hand and for the i^{th} climate zone, if we determine n_i' and m_i' so that $\hat{\bar{\bar{Y}}}_i'$ will be within 10% of $\bar{Y}_i'$ with probability .90 for $i = 1, 2,$ and 3, we obtain the following results from three separate computations.

Table 4.

Climate Zones	$f_2 = .05$ m_i'	n_i'	$f_2 = .1$ m_i'	n_i'
1	1,206	104	2,088	89
2	1,717	159	2,938	136
3	948	184	1,432	140
	$m_{....} = 3{,}871$	$n_{..} = 447$	$m_{....} = 6{,}458$	$n_{..} = 365$

The values of n_i' and m_i' in Table 4 at each zone level were obtained from the equation

$$f_{i1}' = \frac{S_{(B)}^2 + \dfrac{(1-f_2)}{f_2} S_{(w)}^2 \bar{M}_i'}{\bar{M}_i'(M_i')\dfrac{B^2}{Z_{\frac{\alpha}{2}}^2} + S_{(B)}^2}$$

where $\bar{M}_i' = \dfrac{M_i'}{N_i'}$, $S_{(B)} = 26, 24,$ and 11, respectively, for climate zones 1, 2, and 3.

The equation for f_{i1}' (for the i^{th} climate zone) followed algebraically and by a series of assumptions starting with the equation

$$B = Z_{\frac{\alpha}{2}} \sqrt{Var(\hat{\bar{\bar{Y}}}_i')} = \frac{Z_{\frac{\alpha}{2}}}{M_i'} \sqrt{Var(\hat{Y}_i')}$$

just as the equation for f (for the nation) followed algebraically and by a series of assumptions (the same) starting with the equation

$$B = Z_{\frac{\alpha}{2}} \sqrt{Var(\hat{\bar{\bar{Y}}})} = \frac{Z_{\frac{\alpha}{2}}}{M_{....}} \sqrt{Var(\hat{Y}_{....})}.$$

As an alternative to Table 4, if n_i' and m_i' are determined so that $\hat{\bar{\bar{Y}}}_i'$ will be within 15% of $\bar{\bar{Y}}_i'$ with probability .90 for $i = 1$, 2, and 3, we obtain the results in Table 5 from three separate computations.

Table 5.

Climate Zones	$f_2 = .05$ m_i'	n_i'
1	719	62
2	918	85
3	484	94
	$m_{....} = 2121$	$n_{..} = 241$

In conclusion, if every CAP in category 6 is selected during the first step and assuming proportional allocations within the i^{th} climate zone of the n_i' CAPs required for $f_2 = .1$, the final number of CAPs to be selected and the final distribution of the CAPs is given in Table 6. Note that the final value for $n_{..}$ is 365.

Based on the indicated assumptions in Table 2 and Table 4, the number of CAPs to be selected at stage 1 is $n_{..} = 365$ with $n_1' = 89$ being selected from climate zone 1, $n_2' = 136$ being selected from climate zone 2, and $n_3' = 140$ being selected from climate zone 3. This choice of $n_{..}$, n_1', n_2', n_3' provides the following precisions:

— that the national estimate $\hat{\bar{\bar{Y}}}$ will be within 10% of the true value with 90% probability, and

— that each climate zone estimate $\hat{\bar{\bar{Y}}}_i'$ will be within 10% of the respective true value with 90% probability.

For each CAP selected, 10% of the single family units and 10% of the multifamily units are to be selected at stage 2.

In conclusion, if every CAP in category 6 is selected during the first step and assuming proportional allocations within the i^{th} climate zone of the n_i' CAPs required for $f_2 = .1$, the final number of CAPs to be selected and the final distribution of the CAPs is given in Table 6. Note that the final value for $n_{..}$ is 365 .

In implementing the sampling plan described above, a sample of 400 subgrantees was selected randomly in stage one to allow for some attrition. The same relative distribution was maintainted as is shown in Table 6. To allow for sample attrition during data collection, an effort also will be made to collect information on about twice the number of housing units needed for the final analysis. With these allowances for sample attrition, the numbers of subgrantees and housing units with complete data that are included in the final analysis should meet the requirements set out in Table 6.

Table 6. Final Sample Distributions of CAPs to be Selected at Stage One.

	CAP CATEGORIES						
Subregions	1 (59 or less)	2 (60-100)	3 (101-249)	4 (250-399)	5 (400-899)	5 (900+)	
1	$n_{11}=5$	$n_{12}=4$	$n_{13}=12$	$n_{14}=3$	$n_{15}=1$	$n_{16}=0$	
2	$n_{21}=5$	$n_{22}=3$	$n_{23}=23$	$n_{24}=11$	$n_{25}=8$	$n_{26}=2$	
3	$n_{31}=0$	$n_{32}=0$	$n_{33}=5$	$n_{34}=4$	$n_{35}=3$	$n_{36}=0$	
Zone 1	$n'_{11}=10$	$n'_{12}=7$	$n'_{13}=40$	$n'_{14}=18$	$n'_{15}=12$	$n'_{16}=2$	$n'_{1}=89$
4	$n_{41}=7$	$n_{42}=4$	$n_{43}=5$	$n_{44}=2$	$n_{45}=0$	$n_{46}=0$	
5	$n_{51}=2$	$n_{52}=2$	$n_{53}=4$	$n_{54}=2$	$n_{55}=2$	$n_{56}=0$	
6	$n_{61}=2$	$n_{62}=9$	$n_{63}=20$	$n_{64}=6$	$n_{65}=2$	$n_{66}=3$	
7	$n_{71}=2$	$n_{72}=2$	$n_{73}=12$	$n_{74}=6$	$n_{75}=4$	$n_{76}=4$	
8	$n_{81}=2$	$n_{82}=4$	$n_{83}=13$	$n_{84}=7$	$n_{85}=2$	$n_{86}=1$	
Zone 2	$n'_{21}=15$	$n'_{22}=26$	$n'_{23}=54$	$n'_{24}=23$	$n'_{25}=10$	$n'_{26}=8$	$n'_{2}=136$
9	$n_{91}=40$	$n_{92}=20$	$n_{93}=27$	$n_{94}=4$	$n_{95}=3$	$n_{96}=0$	
10	$n_{10,1}=15$	$n_{10,2}=10$	$n_{10,3}=13$	$n_{10,4}=4$	$n_{10,5}=4$	$n_{10,6}=0$	
Zone 3	$n'_{31}=55$	$n'_{32}=30$	$n'_{33}=40$	$n'_{34}=8$	$n'_{35}=7$	$n'_{36}=0$	$n'_{3}=140$
							$n_{..}=365$

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New Computations for Second Stage Sampling Fractions in the "National Two-Stage Cluster Sampling Plan for the Single-Family Study"

June 21, 1991

1 Introduction

This technical note is an addendum to "Section V, Sample Sizes" of Appendix B - "A National Two-Stage Cluster Sampling Plan for the Single-Family Study." Section V of Appendix B gave detailed discussion and computations for determination of $n_{..}$ the total number of CAPs to be selected for the sample and $m_{....}$ the total number of housing units weatherized by WAP in 1989 to be selected at the second stage. Both $n_{..}$ and $m_{....}$ were determined so that the estimate of energy savings $\hat{\bar{\bar{Y}}}$ would be within $B = 10\%$ of $\bar{\bar{Y}}$ the true energy savings with probability $1 - \alpha = .90$ at the national level and with certain precision requirements at each of three climate zone levels. The target values of $m_{....}$ and $n_{..}$ are given in Table 4 of Appendix B and are given below for convenience assuming the second stage sampling fraction is $f_2 = .1$.

Climate Zones	m'_i	n'_i
1	2,088	90
2	2,938	136
3	1,432	139
	$m_{....} = 6,458$	$n_{..} = 365$

Early results of the first stage of sampling revealed that the number of gas/electric single-family home units was less than originally thought. This is an important consideration because energy savings estimates will be based completely on gas/electric records. Such data are not available for non-gas/electric single- family home units. Thus before selection of the sample at the second stage, given the sample of CAPs selected at the first stage, and with new estimates of the numbers of gas/electric single-family home units in the various CAPs, it was decided to compute new sampling fractions for the second stage of sampling. This memo documents the details and provides the bases for the second stage sampling fractions which were employed.

2 New Second Stage Sampling Fractions

Proceeding as in Section V of Appendix B but given $n_{..} = 364$ which was proportionately allocated among the various strata, the desire is to determine $m_{....}$ or equivalently the second stage sampling fractions for gas/electric single-family home units so that $\hat{\bar{\bar{Y}}}$ is within B of $\bar{\bar{Y}}$ with probability $1 - \alpha$.

Assuming that $\bar{\bar{Y}}$ is normally distributed, we have

$$B = Z_{\frac{\alpha}{2}} \sqrt{Var(\hat{\bar{\bar{Y}}})} = \frac{Z_{\frac{\alpha}{2}}}{M_{....}} \sqrt{Var(\hat{Y}_{....})} \tag{1}$$

In the notation of Section V, this can be written as

$$\begin{aligned}(M_{....})B \;=\; & Z_{\frac{\alpha}{2}} \left[\sum_z \sum_c \left\{ N_{zc}^2 \left(\frac{N_{zc} - n_{zc}}{N_{zc}} \right) \frac{S_{zc(B)}^2}{n_{zc}} \right. \right. \\ & + \frac{N_{zc}}{n_{zc}} \sum_{d=1}^{N_{zc}} \left[M_{zcd1}^2 \left(\frac{M_{zcd1} - m_{zcd1}}{M_{zcd1}} \right) \frac{S_{zcd1}^2}{m_{zcd1}} \right. \\ & \left. \left. \left. + M_{zcd2}^2 \left(\frac{M_{zcd2} - m_{zcd2}}{M_{zcd2}} \right) \frac{S_{zcd2}^2}{m_{zcd2}} \right] \right\} \right]^{\frac{1}{2}}\end{aligned} \tag{2}$$

For cell (stratum) zc (see Figure 1 of Section V), let

$$k_{zc} = N_{zc}^2 \left(\frac{N_{zc} - n_{zc}}{N_{zc}} \right) \frac{1}{n_{zc}} = N_{zc} \left(\frac{N_{zc}}{n_{zc}} - 1 \right)$$

and

$$f_{zc} = \frac{N_{zc}}{n_{zc}}.$$

Note that there are 10 zones x 6 categories = 60 strata altogether and that the values of k_{zc} and f_{zc} are known. (See Tables C and D of this memo.)

Based on entered sample data received by ORNL as of 02/12/1991, Table A gives the proportion of gas and electric units in the lists of home units from the CAPs for various strata. Specifically, the numbers in the different cells are computed as

$$\frac{\begin{pmatrix}\text{total number of gas and electric units over all sample} \\ \text{CAPs for which data had been entered in cell } zc\end{pmatrix}}{\begin{pmatrix}\text{ORNL's total original estimate of gas and electric units} \\ \text{over the same sample CAPs}\end{pmatrix}}.$$

No data had been entered for empty strata as of 02/12/1991.

Table A
Estimates of the Proportions (Ratios) of New Counts of Units to Original Counts by Zone and Category

Categories (c)

Zones (z)	1	2	3	4	5	6
1		.74	.48			
2		.14	.58	.96	.57	
3						
4	.17	.79	.12			
5			.83			
6	.53	.39	.77	.90	.87	
7	.05	.16	.54	.93		
8			.35	.38	.13	
9	.55	.49	.47	.23		
10	.78	.87	.88	.76	.25	

As can be seen from Table A, the proportions are quite varied but all are less than one. By summing over all numerators in the strata and dividing that by the sum of all of the denominators among the cells gives

$$\frac{\text{7,929 gas or electric units}}{\text{13,453 ORNL's corresponding original estimate of units}} = .59.$$

Table B gives new values of $M_{zc..}$'s which were obtained from the original $M_{zc..}$'s (see Figure 1 of Appendix B) multiplied by .59.

In equation (2), let $f_{zcd1} = m_{zcd1}/M_{zcd1}$ and $f_{zcd2} = m_{zcd2}/M_{zcd2}$ which are to be specified by ORNL. Note that f_{zcd1} and f_{zcd2} are the second stage sampling fractions. Thus equation (2) becomes

$$(M_{....})\,B = Z_{\frac{\alpha}{2}}\left[\sum_{z}\sum_{c}\left\{k_{zc}S^2_{zc(B)} + f_{zc}\sum_{d=1}^{N_{zc}}\left[M_{zcd1}\left(\frac{1-f_{zcd1}}{f_{zcd1}}\right)S^2_{zcd1} + M_{zcd2}\left(\frac{1-f_{zcd2}}{f_{zcd2}}\right)S^2_{zcd2}\right]\right\}\right]^{\frac{1}{2}} \qquad (3)$$

As in Appendix B,

take $S^2_{zc(B)} = 26$ for $c = 1,2,3,4,5,6$ and $z = 1,2,3$ (Climate Zone 1)
$S^2_{zc(B)} = 24$ for $c = 1,2,3,4,5,6$ and $z = 4,5,6,7,8$ (Climate Zone 2)
and $S^2_{zc(B)} = 11$ for $c = 1,2,3,4,5,6$ and $z = 9,10$ (Climate Zone 3).
Also take $B = (.1)(\bar{\bar{Y}}) = (.1)(.15) = .015$
and $S^2_{zcd1} = S^2_{zcd2} = (1.5)\bar{\bar{Y}} = .225$ for all $zcd1$ and $zcd2$.

Thus equation (3) becomes

$$(M_{....})\,B = Z_{\frac{\alpha}{2}}\left[\sum_{z=1}^{3}\sum_{c}k_{zc}(26) + \sum_{z=4}^{8}\sum_{c}k_{zc}(24) + \sum_{z=9}^{10}\sum_{c}k_{zc}(11) + \sum_{z}\sum_{c}f_{zc}\sum_{d=1}^{N_{zc}}\left\{M_{zcd1}\left(\frac{1-f_{zcd1}}{f_{zcd1}}\right) + M_{zcd2}\left(\frac{1-f_{zcd2}}{f_{zcd2}}\right)\right\}(.225)\right]^{\frac{1}{2}} \qquad (4)$$

If we let $f_{zcd1} = f_{zcd2} = f_{(\sim 6)}$ for $c = 1,2,3,4,5$ and $z = 1,2,3,\ldots,10$
and $f_{zcd1} = f_{zcd2} = f_{(6)}$ for $c = 6$ and $z = 1,2,3,\ldots,10$,
then equation (4) becomes

$$(M_{....})\,B = Z_{\frac{\alpha}{2}}\left[(26)\sum_{z=1}^{3}\sum_{c}k_{zc} + (24)\sum_{z=4}^{8}\sum_{c}k_{zc} + (11)\sum_{z=9}^{10}\sum_{c}k_{zc} + (.225)\left(\frac{1-f_{(\sim 6)}}{f_{(\sim 6)}}\right)\sum_{z}\sum_{c=1}^{5}f_{zc}\sum_{d=1}^{N_{zc}}\{M_{zcd1} + M_{zcd2}\} \right. \qquad (5)$$

Table B

New Estimates of $M_{zc..}$ for Gas/Electric

Home Units Weatherized by WAP in 1989

Cap Categories (c)

Subregion Zones (z)	1	2	3	4	5	6		
1	$M_{11..}=148$ $N_{11}=10$ $n_{11}=5$	$M_{12..}=301$ $N_{12}=7$ $n_{12}=4$	$M_{13..}=2235$ $N_{13}=23$ $n_{13}=12$	$M_{14..}=525$ $N_{14}=3$ $n_{14}=3$	$M_{15..}=251$ $N_{15}=1$ $n_{15}=1$	$M_{16..}=0$ $N_{16}=0$ $n_{16}=0$		
2	$M_{21..}=112$ $N_{21}=10$ $n_{21}=5$	$M_{22..}=219$ $N_{22}=5$ $n_{22}=3$	$M_{23..}=4262$ $N_{23}=41$ $n_{23}=23$	$M_{24..}=4020$ $N_{24}=21$ $n_{24}=1$	$M_{25..}=4652$ $N_{25}=15$ $n_{25}=8$	$M_{26..}=1803$ $N_{26}=2$ $n_{26}=2$		
3	$M_{31..}=0$ $N_{31}=0$ $n_{31}=0$	$M_{32..}=0$ $N_{32}=0$ $n_{32}=0$	$M_{33..}=1191$ $N_{33}=11$ $n_{33}=5$	$M_{34..}=1183$ $N_{34}=7$ $n_{34}=4$	$M_{35..}=1001$ $N_{35}=4$ $n_{35}=3$	$M_{36..}=0$ $N_{36}=0$ $n_{36}=0$		
Climate Zone 1 Totals	$M'_{11}=260$ $N'_{11}=20$ $n'_{11}=10$	$M'_{12}=520$ $N'_{12}=12$ $n'_{12}=7$	$M'_{13}=7688$ $N'_{13}=75$ $n'_{13}=40$	$M'_{14}=5728$ $N'_{14}=31$ $n'_{14}=18$	$M'_{15}=5904$ $N'_{15}=20$ $n'_{15}=12$	$M'_{16}=1803$ $N'_{16}=2$ $n'_{12}=2$		$M'_1=21903$ $N'_1=160$ $n'_1=89$
4	$M_{41..}=550$ $N_{41}=33$ $n_{41}=7$	$M_{42..}=830$ $N_{42}=17$ $n_{42}=4$	$M_{43..}=2187$ $N_{43}=22$ $n_{43}=5$	$M_{44..}=907$ $N_{44}=5$ $n_{44}=2$	$M_{45..}=0$ $N_{45}=0$ $n_{45}=0$	$M_{46..}=0$ $N_{46}=0$ $n_{46}=0$		
5	$M_{51..}=153$ $N_{51}=8$ $n_{51}=2$	$M_{52..}=441$ $N_{52}=9$ $n_{52}=2$	$M_{53..}=1405$ $N_{53}=17$ $n_{53}=4$	$M_{54..}=1215$ $N_{54}=6$ $n_{54}=2$	$M_{55..}=966$ $N_{55}=3$ $n_{55}=2$	$M_{56..}=0$ $N_{56}=0$ $n_{56}=0$		
6	$M_{61..}=200$ $N_{61}=7$ $n_{61}=2$	$M_{62..}=2016$ $N_{62}=42$ $n_{62}=9$	$M_{63..}=9641$ $N_{63}=97$ $n_{63}=20$	$M_{64..}=4886$ $N_{64}=28$ $n_{64}=6$	$M_{65..}=3128$ $N_{65}=10$ $n_{65}=2$	$M_{66..}=4157$ $N_{66}=3$ $n_{66}=3$		
7	$M_{71..}=53$ $N_{71}=4$ $n_{71}=2$	$M_{72..}=604$ $N_{72}=13$ $n_{72}=2$	$M_{73..}=5990$ $N_{73}=60$ $n_{73}=12$	$M_{74..}=5251$ $N_{74}=28$ $n_{74}=6$	$M_{75..}=5790$ $N_{75}=18$ $n_{75}=4$	$M_{76..}=3871$ $N_{76}=4$ $n_{76}=4$		
8	$M_{81..}=57$ $N_{81}=2$ $n_{81}=2$	$M_{82..}=792$ $N_{82}=17$ $n_{82}=4$	$M_{83..}=6273$ $N_{83}=67$ $n_{83}=13$	$M_{84..}=6019$ $N_{84}=34$ $n_{84}=7$	$M_{85..}=4059$ $N_{85}=12$ $n_{85}=2$	$M_{86..}=708$ $N_{86}=1$ $n_{86}=1$		
Climate Zone 2 Totals	$M'_{21}=1013$ $N'_{21}=54$ $n'_{21}=15$	$M'_{22}=4683$ $N'_{22}=98$ $n'_{22}=26$	$M'_{23}=25496$ $N'_{23}=263$ $n'_{23}=54$	$M'_{24}=18278$ $N'_{24}=101$ $n'_{24}=23$	$M'_{25}=13943$ $N'_{25}=43$ $n'_{25}=10$	$M'_{26}=8736$ $N'_{26}=8$ $n'_{26}=8$		$M'_2=72149$ $N'_2=567$ $n'_2=136$
9	$M_{91..}=2479$ $N_{91}=114$ $n_{91}=40$	$M_{92..}=2618$ $N_{92}=56$ $n_{92}=20$	$M_{93..}=6948$ $N_{93}=75$ $n_{93}=27$	$M_{94..}=2008$ $N_{94}=11$ $n_{94}=4$	$M_{95..}=817$ $N_{95}=2$ $n_{95}=2$	$M_{96..}=0$ $N_{96}=0$ $n_{96}=0$		
10	$M_{10,1..}=781$ $N_{10,1}=42$ $n_{10,1}=15$	$M_{10,2..}=1202$ $N_{10,2}=26$ $n_{10,2}=10$	$M_{10,3..}=3246$ $N_{10,3}=37$ $n_{10,3}=13$	$M_{10,4..}=1775$ $N_{10,4}=10$ $n_{10,4}=4$	$M_{10,5..}=869$ $N_{10,5}=3$ $n_{10,5}=3$	$M_{10,6..}=0$ $N_{10,6}=0$ $n_{10,6}=0$		
Climate Zone 3 Totals	$M'_{31}=3260$ $N'_{31}=156$ $n'_{31}=55$	$M'_{32}=3820$ $N'_{32}=82$ $n'_{32}=30$	$M'_{33}=10,194$ $N'_{33}=112$ $n'_{33}=40$	$M'_{34}=3783$ $N'_{34}=21$ $n'_{34}=8$	$M'_{35}=1686$ $N'_{35}=5$ $n'_{35}=5$	$M'_{36}=0$ $N'_{36}=0$ $n'_{36}=0$		$M'_3=22743$ $N'_3=376$ $n'_3=138$
								$M_{....}$ 116,796 $N_{..}$ 1103 $n_{..}$ 363

$$+ (.225)\left(\frac{1-f_{(6)}}{f_{(6)}}\right)\sum_{z} f_{z6}\sum_{d=1}^{N_{z6}}\{M_{z6d1}+M_{z6d2}\}\Bigg]^{\frac{1}{2}} .$$

Noting that $M_{zcd1} + M_{zcd2} = M_{zcd.}$, equation (5) becomes

$$\begin{aligned}(M_{....})B &= Z_{\frac{\alpha}{2}}\Bigg[(26)\sum_{z=1}^{3}\sum_{c} k_{zc} + (24)\sum_{z=4}^{8}\sum_{c} k_{zc} + (11)\sum_{z=9}^{10}\sum_{c} k_{zc} \\ &\quad + (.225)\left(\frac{1-f_{(\sim 6)}}{f_{(\sim 6)}}\right)\sum_{z}\sum_{c=1}^{5} f_{zc}\sum_{d=1}^{N_{zc}} M_{zcd.} \\ &\quad + (.225)\left(\frac{1-f_{(6)}}{f_{(6)}}\right)\sum_{z} f_{z6}\sum_{d=1}^{N_{z6}} M_{z6d.}\Bigg]^{\frac{1}{2}} \qquad (6) \\ &= Z_{\frac{\alpha}{2}}\Bigg[(26)\sum_{z=1}^{3}\sum_{c} k_{zc} + (24)\sum_{z=4}^{8}\sum_{c} k_{zc} + (11)\sum_{z=9}^{10}\sum_{c} k_{zc} \\ &\quad + (.225)\left(\frac{1-f_{(\sim 6)}}{f_{(\sim 6)}}\right)\sum_{z}\sum_{c=1}^{5} f_{zc}M_{zc..} \\ &\quad + (.225)\left(\frac{1-f_{(6)}}{f_{(6)}}\right)\sum_{z} f_{z6}M_{z6..}\Bigg]^{\frac{1}{2}} .\end{aligned}$$

Values of $f_{zc}M_{zc..} = \frac{N_{zc}}{n_{zc}}M_{zc..}$ are given in Table C, and values of k_{zc} are given in Table D.

From Tables C and D, we observe

$$\sum_{z}\sum_{c=1}^{5} f_{zc}M_{zc..} = 397,247.22$$

$$\sum_{z} f_{z6}M_{z6..} = 10,539$$

$$\sum_{z=1}^{3}\sum_{c} k_{zc} = 133.75$$

$$\sum_{z=4}^{8}\sum_{c} k_{zc} = 2,077.86$$

Table C
Values of $f_{zc}M_{zc..}$

c

Zones (z)	1	2	3	4	5	6
1	296.00	526.75	4283.75	525.00	251.00	–
2	224.00	365.00	7597.48	7674.55	8722.50	1803.00
3	–	–	2620.20	2070.25	1334.67	–
4	2592.86	3527.50	9622.80	2267.50	–	–
5	612.00	1984.50	5971.25	3645.00	1449.00	–
6	700.00	9408.00	46758.85	22801.33	15640.00	4157.00
7	106.00	3926.00	29950.00	24504.67	26055.00	3871.00
8	57.00	3366.00	32330.00	29235.14	24354.00	708.00
9	7065.15	7330.40	19300.00	5522.00	817.00	–
10	2186.80	3125.20	9238.62	4437.50	869.00	–

$$\sum_{z=9}^{10}\sum_{c} k_{zc} = 664.79$$

Thus, equation (6) becomes

$$\begin{aligned}(116,796)(.015) &= Z_{\frac{\alpha}{2}}\Big[(26)(133.75) + 24(2077.86) + (11)(664.79) \\ &\quad + \left(\frac{1-f_{(\sim 6)}}{f_{(\sim 6)}}\right)(.225)(397,247.22) \\ &\quad + \left(\frac{1-f_{(6)}}{f_{(6)}}\right)(.225)(10,539)\Big]^{\frac{1}{2}}.\end{aligned} \tag{7}$$

Hence

$$Z_{\frac{\alpha}{2}} = \frac{1751.94}{\left[60,658.83 + \left(\frac{1-f_{(\sim 6)}}{f_{(\sim 6)}}\right)89,380.6245 + \left(\frac{1-f_{(6)}}{f_{(6)}}\right)(2,371.275)\right]^{\frac{1}{2}}}. \tag{8}$$

Table D
Values of k_{zc}

Zones (z)	c = 1	2	3	4	5	6
1	10.00	5.25	21.08	0	0	–
2	10.00	3.33	32.09	19.09	13.13	0
3	–	–	13.20	5.25	1.33	–
4	122.57	55.25	74.80	7.50	–	–
5	24.00	31.50	55.25	12.00	1.50	–
6	17.50	154.00	373.45	102.67	40.00	0
7	4.00	71.50	240.00	102.67	63.00	0
8	0	55.25	278.31	131.14	60.00	0
9	210.90	100.80	133.33	19.25	0	–
10	75.60	41.60	68.31	15.00	0	–

Table E gives the probability $1-\alpha$ for two pairs of $f_{(\sim 6)}$ and $f_{(6)}$ using equation (8).

With a focus on estimating energy savings for Climate Zone 1 only ($z = 1,2,3$), we have

$$(M_1')B = Z_{\frac{\alpha}{2}} \left[26 \sum_{z=1}^{3} \sum_{c} k_{zc} + (.225) \left(\frac{1 - f_{(\sim 6)}}{f_{(\sim 6)}} \right) \sum_{z=1}^{3} \sum_{c=1}^{5} f_{zc} M_{zc..} + (.225) \left(\frac{1 - f_{(6)}}{f_{(6)}} \right) \sum_{z=1}^{3} f_{z6} M_{z6..} \right]^{\frac{1}{2}}$$

we obtain

$$Z_{\frac{\alpha}{2}} = \frac{328.545}{\left[3477.5 + \left(\frac{1-f_{(\sim 6)}}{f_{(\sim 6)}} \right) (8210.50875) + \left(\frac{1-f_{(6)}}{f_{(6)}} \right) (405.675) \right]^{\frac{1}{2}}}. \qquad (9)$$

Table F gives the probability $1 - \alpha$ for selected pairs of $f_{(\sim 6)}$ and $f_{(6)}$ using equation (9).

Table E
Values of Probability 1-α for
Two Cases Using Equation (8)

$f_{(\sim 6)}$	$f_{(6)}$	$Z_{\frac{\alpha}{2}}$	Probability $1-\alpha$
.3	.15	3.28	99^{+}%
.1	.05	1.83	93^{+}%

Table F
Values of Probability 1-α for
Four Cases Using Equation (9)

$f_{(\sim 6)}$	$f_{(6)}$	$Z_{\frac{\alpha}{2}}$	Probability $1-\alpha$
.10	.05	1.13	74^{+}%
.15	.05	1.37	83%
.16	.08	1.45	85%
.20	.05	1.57	88^{+}%

Table G
Values of Probability 1-α for
Four Cases Using Equation (10)

$f_{(\sim 6)}$	$f_{(6)}$	$Z_{\frac{\alpha}{2}}$	Probability $1-\alpha$
.10	.05	1.30	81%
.15	.05	1.58	89%
.16	.08	1.654	90$^+$%
.20	.05	1.81	93%

With a focus on estimating energy savings for Climate Zone 2 only ($z = 4,5,6,7,8$), we have

$$(M_2')B = Z_{\frac{\alpha}{2}}\left[(24)\sum_{z=4}^{8}\sum_{c}k_{zc} + (.225)\left(\frac{1-f_{(\sim 6)}}{f_{(\sim 6)}}\right)\sum_{z=4}^{8}\sum_{c=1}^{5}f_{zc}M_{zc..} + (.225)\left(\frac{1-f_{(6)}}{f_{(6)}}\right)\sum_{z=4}^{8}f_{z6}M_{z6..}\right]^{\frac{1}{2}}.$$

We obtain

$$Z_{\frac{\alpha}{2}} = \frac{1082.235}{\left[49868.64 + \left(\frac{1-f_{(\sim 6)}}{f_{(\sim 6)}}\right)(67,694.355) + \left(\frac{1-f_{(6)}}{f_{(6)}}\right)(1965.6)\right]^{\frac{1}{2}}}. \qquad (10)$$

Table G gives the probability $1-\alpha$ for selected pairs of $f_{(\sim 6)}$ and $f_{(6)}$ using equation (10).

With a focus on estimating energy savings for Climate Zone 3 ($z = 9,10$), we have

$$(M_3')B = Z_{\frac{\alpha}{2}}\left[(11)\sum_{z=9}^{10}\sum_{c}k_{zc} + (.225)\left(\frac{1-f_{(\sim 6)}}{f_{(\sim 6)}}\right)\sum_{z=9}^{10}\sum_{c=1}^{5}f_zM_{zc..} + 0\right]^{\frac{1}{2}} \qquad (11)$$

we obtain

Table H
Values of Probability 1-α for
Five Cases Using Equation (12)

$f_{(\sim 6)}$	$f_{(6)}$	$Z_{\frac{\alpha}{2}}$	Probability $1-\alpha$
.10	0	.95	66%
.15	0	1.18	76%
.16	0	1.22	78%
.20	0	1.38	83%
.25	0	1.56	88%

$$Z_{\frac{\alpha}{2}} = \frac{341.145}{\left[7312.69 + \left(\frac{1-f_{(\sim 6)}}{f_{(\sim 6)}}\right)(13,475.62575)\right]^{\frac{1}{2}}}. \tag{12}$$

Table H gives the probability $1-\alpha$ for selected pairs of $f_{(\sim 6)}$ and $f_{(6)}$ using equation (12).

The following recommendations were made in view of the previous computations.

Recommendations:

(i) To use $f_{(\sim 6)} = .3$ and $f_{(6)} = .15$ for the gas/electric home units in the stratified random sample of CAPs selected at Stage 1.

(ii) To use $f_{(\sim 6)} = .2$ and $f_{(6)} = .10$ for the non-gas/electric home units in the stratified random sample of CAPs selected at Stage 1.

(iii) To use the same fractions in (i) and (ii) for the same home units found in the "exemplary sample" and in the "cooling sample."

APPENDIX C
Audit Protocol

Auditor: ____________________
Date: ____________________

HOUSE CHARACTERISTICS SURVEY

IDENTIFICATION

House ID: ______________ Subgrantee name: ____

Occupant name: ____ Phone number: ___________________

Occupant address: ____

GENERAL

Type: ______ SFD - single-family detached MFS - small (2-4 units) multifamily MH - manufactured or
SFA - single-family attached MFL - large (>4 units) multifamily mobile home

A single-family housing unit is a structure that provides living space for one household or family. The structure may be detached, attached on one side, or attached on two sides. Attached houses are considered single-family houses as long as the house itself is not divided into more than one housing unit and has an independent outside entrance. A single-family house is contained within walls that go from the basement (or ground floor, if there is no basement) to the roof. A mobile home with one or more rooms added is a single-family home. Row houses and side-by-side duplexes (twins) are typically single-family houses.

A small multifamily house or building is a structure that is divided into living quarters for two, three, or four families or households. This category also includes houses originally intended for occupancy by one family (or for some other use) that have since been converted to separate dwellings for two to four families. Typical arrangements in these types of living quarters are separate apartments downstairs and upstairs, or one apartment on each of three or four floors. Over-and-under duplexes are typically in this category.

A mobile or manufactured home is a structure that has all the facilities of a dwelling unit but is built on a movable chassis. It may be placed on a permanent or temporary foundation and may contain one room or more. If rooms are added to the structure, it is considered a single-family home.

Are the following systems shared with other housing units: space-heating system _______ (Y,N)
space-cooling system _______ (Y,N)
water-heating system _______ (Y,N)

If SFA, number of attached housing units: _______ (NA, 1, 2, ...) (typically 2 or less)

House ID: ______

FLOOR AREAS AND VOLUMES

Floor	Total area (ft^2)	Intentionally heated area (ft^2)	Intentionally air-conditioned area (ft^2)	Volume (ft^3)
Basement				
First floor				
Second floor				
All other floors				
Total				

An intentionally heated (air conditioned) space is one with equipment and/or distribution outlets designed to maintain a desired temperature in the space. An unintentionally heated (air conditioned) space is one that is heated primarily from equipment jacket and/or distribution losses (there is little control over the resulting temperature). A space is not heated (air conditioned) if there is no source of heating to alter the natural temperature of the space. For example, a basement heated primarily from equipment jacket and/or distribution system losses is not considered to be an intentionally heated space. A window air conditioner cools only the room the unit is installed in, not adjacent rooms.

Number of intentionally heated stories: ______ (1, 1.5, 2, 2.5, 3, 3.5, 4 or more)

DOORS AND WINDOWS

Number of exterior doors: ______

Window glazing type	Frame type	Storm window	Area (ft^2)

Window glazing type	
SP	single pane
DP	double pane
TP	triple pane
GB	glass block

Frame type	
W	wood
M	metal
IM	improved metal
V	vinyl
X	other
N	none

Storm window	
W	wood
M	metal
X	other
N	none

House ID: ______

ATTICS

FINISHED ATTIC AREAS			
		Existing insulation	
	Area (ft²)	Type	Depth (inches)
Outer ceiling joist			
Collar beam			
Kneewall			
Roof rafter			

UNFINISHED ATTIC AREAS			
		Existing insulation	
Attic type	Floor area (ft²)	Type	Depth (inches)

Areas pertain to attic areas adjacent to intentionally heated or air-conditioned spaces. For example, the area above an unconditioned garage should not be included.

Existing insulation type	
BC	blown cellulose
BF	blown fiberglass
FB	fiberglass batt
RB	rigid board or foam
BRW	blown rock wool
RWB	rock wool batt
X	other
N	none

Attic type	
F	floored
U	unfloored
C	cathedral

House ID: ______

EXTERIOR WALLS

Wall exposure	Exterior type	Wall type	Gross wall area (ft^2)	Insulated sheathing (Y/N)	Existing insulation	
					Type	Depth (inches)

The type of load bearing structure is the wall type. The type of facing on the wall is the exterior type.

Wall exposure	
O	outside
N	non-conditioned attic space
B	buffered space (garage, etc.)
C	conditioned space

Exterior type	
WO	wood or masonite
AL	aluminum, steel or vinyl
ST	stucco
BR	brick or stone
SH	shingle
RA	rolled asphalt
X	other
N	none

Wall type	
PF	platform frame
BF	balloon frame
BL	block
ST	stone or masonry
X	other

Insulation type	
BC	blown cellulose
BF	blown fiberglass
FB	fiberglass batt
RB	rigid board or foam
BRW	blown rock wool
RWB	rock wool batt
X	other
N	none

House ID: _______

FOUNDATION SPACES

Type	Space status	Floor area (ft^2)	Floor insulation thickness (inches)	Perimeter		Wall height		Existing wall insulation	
				Length (ft)	Percent exposed	Total (ft)	Percent above ground	Type	Thickness (inches)

Floor area - Area of floor between foundation space and intentionally conditioned space above it. For slab-on-grade, the area of the intentionally conditioned slab floor.
Perimeter length - Do not include perimeter bordering another foundation space.
Percent exposed - For basements and crawlspaces, the percent of band joist length that is exposed to the outside and not insulated.
Total wall height - Height of basement or crawlspace wall; an estimated average if the height is not uniform.

Foundation type	
B	basement
C	crawlspace
US	uninsulated slab
IS	insulated slab

Foundation space status	
NH	not heated
IH	intentionally heated
UH	unintentionally heated

Existing wall insulation type	
BC	blown cellulose
BF	blown fiberglass
FB	fiberglass batt
RB	rigid board or foam
BRW	blown rock wool
RWB	rock wool batt
X	other
N	none

DOMESTIC WATER-HEATING SYSTEM

Fuel: _______ (NG-natural gas, P-propane, O-oil, K-kerosene, E-electricity, X-other, N-None)
Type: _______ (SA-stand alone system, T-tankless [integrated with space-heating system], X-other, N-None)
Is an external blanket insulation used? _______ (Y,N,NA)
Location: _______ (NH - non-heated space, IH - intentionally heated space, UH - unintentionally heated space)

House ID: _______

APPLIANCES

Appliance	Fuel	Location
Cooking range		
Conventional oven		
Microwave oven		
Refrigerator		
Deep freezer		
Dishwasher		
Clothes washer		
Clothes dryer		
Whole house fan		
Attic ventilation fan		
Other: __________		

Fuel	
NG	natural gas
P	propane
O	oil
K	kerosene
E	electricity
X	other

Location	
NH	non-heated space
IH	intentionally heated space
UH	unintentionally heated space

AIR CONDITIONERS

Unit type	Nameplate information						Age (years)
	Input (watts)	Voltage (volts)	Current (amps)	Efficiency		Output (Btu/h)	
				EER	SEER		

Unit type	
CAC	central air conditioner
CHP	central heat pump
WAC	window air conditioner
WHP	window heat pump
EC	evaporative cooler
X	other

House ID: ______

SPACE-HEATING SYSTEMS

PRIMARY OIL-FIRED SYSTEM	
System type (see next page)	
System age (years)	
Original fuel if converted system (see next page or NA)	
Location (see next page)	
Nameplate input rating (value and units)	
Nameplate output capacity (value and units)	
Nameplate efficiency (%)	
Actual installed nozzle size (value and units)	
Intermittent (electronic) ignition device present (Y,N)	
Vent damper present (Y,N)	
Flame retention head burner present (Y,N)	
Regular thermostat present (Y,N)	
Smart thermostat present (Y,N)	
Combustion products vented outdoors (Y,N)	
For boilers, outdoor temperature reset present (Y,N,NA)	

AUXILIARY SYSTEMS	
Type (see next page)	Fuel

The primary oil-fired system is the system metered under the field test.
Units for the input rating and output capacity will likely be Btu/h or GPM.

House ID: _______

Fuel	
NG	natural gas
P	propane
O	oil
K	kerosene
E	electricity
W	wood
C	coal
X	other

Location	
NH	non-heated space
IH	intentionally heated space
UH	unintentionally heated space

HEATING SYSTEM TYPES

Central systems	
1	forced air furnace
2	gravity furnace
3	steam boiler
4	hot water boiler with radiators/convectors
5	hot water boiler for slab heating
6	heat pump
Other	
21	wood or coal stove
22	fireplace
23	cooking range or oven
24	other

In-space heaters	
Fossil fueled:	
7	room heater
8	forced air wall furnace
9	gravity wall furnace
10	forced air floor furnace
11	gravity floor furnace
12	vaporizing pot heater (oil and kerosene)
13	portable kerosene
Electric:	
14	wall
15	floor
16	baseboard
17	ceiling imbedded cable
18	wall or floor imbedded cable
19	portable (cord-connected)
20	window heat pump

AIR-LEAKAGE MEASUREMENT TEST PROCEDURE

OBJECTIVE

The objectives of this procedure are to

1. provide the necessary measurements to calculate, for single-family houses, the air flow rate with the house depressurized 50Pa below ambient, the equivalent or effective leakage area[1], and air exchange rate[1] (if the number of conditioned stories is known);

2. examine the air tightness of the house as constructed, including all intentional and non-intentional openings in the envelope; and

3. ensure comparability of measurements performed by different contractors using different brands of blower doors.

Although this procedure does not fully comply with ASTM Standard E779-87[2] especially regarding pressurized measurements, it generally follows the principles contained in the standard.

This procedure was developed under the assumption that the blower door to be used in making the measurements meets the criteria for pressure-measuring devices and air flow or velocity-measurement systems listed in ASTM Standard E779-87, or has been individually calibrated by an independent laboratory to these criteria. In addition to other calibration standards and procedures, the following guidelines should be followed while performing the calibrations:

1. test pressure differences or pressure stations (indoor - outdoor pressure differences) identified in this procedure must be used for the calibration;

2. the calibration must be performed following the methods described in this procedure;

3. the calibration must be performed separately for all orifices and plates provided with the blower door; and

4. the calibration report must identify the actual air flow rate in cfm at each pressure difference and for each orifice and plate, and the absolute error in cfm from the air flow rate provided by the blower-door manufacturer's calibration.

---

[1]Handbook of Fundamentals, American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1989.

[2]Standard Test Method for Determining Air Leakage Rate by Fan Pressurization, The American Society for Testing and Materials, 1987.

PRE-TEST PROCEDURE

House Preparation

The house should be prepared for measurement as follows:

1. Close all fireplace and wood stove dampers, glass doors, and other flue openings. Have occupant extinguish all fires. Place wet cloths or newspapers over cold ashes.

2. Turn off exhaust fans, space-heating systems, water-heating systems, gas-stoves, and all pilot lights.

3. Close all windows and exterior doors, including doors to garages and other such buffer spaces that are not heated. A heated space is defined to be a space with permanent space-heating equipment and/or distribution outlets designed to maintain a desired temperature in the space. A space (such as a basement) that is heated primarily from equipment jacket and/or distribution losses (there is little control over the resulting temperature) is not a heated space.

4. Open all interior doors (except for closets) so that all interior heated space is connected, including heated basements (if only portions of the basement are heated, open all doors necessary to connect these heated basement areas with other heated areas). If a space was designed to be a heated space but is maintained by the occupant in an unheated condition, the space should still be considered a heated space.

5. Record on the Blower-Door Test Data Sheet the exclusion/inclusion of buffer spaces, zoned rooms, and basements in order that the post-weatherization test can be performed on the same heated space of the house.

Equipment Set-Up

All equipment should be kept at as close to 70°F as possible while in transit and brought into the house immediately upon arrival. Equipment should be set-up as specified below.

1. Deploy a thermometer outside away from the door in a shaded area, and one inside in the <u>same room</u> as the blower door.

2. Install the fan on an exterior door for depressurizing the house. The chosen door must be free of obstructions for at least 4 ft upstream of the fan. Blow and suck on the gauge hoses or taps to drive the gauge needles over their full range 6-8 times. Tape the free end of the hose measuring the outside pressure to the outside wall at a level parallel with the center of the fan and out of line of the blower-door fan. Multiple outside hoses or pressure equalizing boxes must not be used. Set up the gauges inside the house and out of the direct flow of air through the blower-door fan (if a hose is used to measure the inside pressure, ensure that it is out of the direct flow of air as well). Check all hose fittings for tightness and trim or tighten as necessary. Connect all hoses. Check for leaks around the fan and door.

3. Gauges are zeroed to remove the natural pressure difference that may exist between the inside and outside of the house due to thermal or wind effects. Cover the fan opening (using the "shower cap" provided by the manufacturer, plugging or taping all holes with the orifice plate on, or some other equivalent technique). Zero the gauges. Remove the fan opening cover. Re-zero the gauges in this manner each time a new run is started.

4. Briefly walk through the house while maintaining a negative pressure difference across the house of 20-40 Pa to check for previously undetected operable openings in the envelope (i.e. open windows, attic hatches, dampers) and other significant sources of air leakage. Identify on the Blower-Door Test Data Sheet any unusual sources of air leakage. Also, look for indications of weak areas (ceilings, windows) that could be damaged with increased negative pressures.

9. Establish a negative pressure difference across the house of 50 Pa for 15 seconds. Do not pressurize the house after this step.

TEST PROCEDURE

Starting the Test

1. Record the indoor and outdoor temperatures, and barometric pressure.

2. Record the average wind speed and maximum wind gust. The measuring device should be deployed three to five building heights away from buildings and other major obstructions and be faced into the wind. Average wind speed should generally not exceed 10 mph; greater speeds and gusty wind conditions can cause difficulty in obtaining quality air-leakage measurements.

3. Record the local shielding class.

Pressure Station Measurements

A test entails making measurements at all pressure stations identified on the Blower-Door Test Data Sheet unless the maximum pressure generated by the fan is insufficient. In this case, make measurements at as many of the assigned pressure stations as possible. Make measurements starting at the lowest pressure station and proceeding in ascending order.

Orifice Plates

For blower doors with orifice plates, at least one (and possibly two) changes in orifice plates should be expected during any particular test. The number and size of orifice plates used must be recorded with each pressure station.

1. The initial orifice plate should be the smallest allowed by the blower-door manufacturer. Using this plate, attempt to make a measurement at the first pressure station. If this is not possible, move to the next larger orifice until the measurement can be made.

2. As measurements are made at higher pressure stations, change to the next largest orifice plate only when it is no longer possible to reach 5 Pa above the desired pressure station.

Gauge Reading Procedures

1. To make a measurement at each pressure station, first raise the house to about 5 Pa above the desired pressure. Then slowly reduce the pressure until the desired pressure is reached. If the pressure is undershot, raise the pressure again to 5 Pa over the desired pressure and repeat the process.

2. Tap the gauges continuously while adjusting the pressure down to the desired station as the stored spring energy will cause the gauge needles to jump slightly.

3. Set the gauge needle on the indicated pressure stations, within +/- 2 Pa.

4. Wait 30 seconds for the blower-door readings to stabilize. Record the actual house pressure reading, the fan pressure or flow rate reading, and the orifice configuration on the Blower-Door Test Data Sheet. When lining the gauge needle up with the marks on the gauge, read the gauge from directly in front to avoid parallax. Always take readings off of the gauge with the lowest range possible. For example, when measuring a flow pressure of less than 125 Pa, read from a gauge with a range of 0-125 Pa rather than from one with a range of 0-750 Pa. Note the reason for any alternate pressure station readings.

Acceptable Error Level

Input the data collected at eight of the nine pressure stations into the blower-door computer: do not use the 10 Pa data if a 60 Pa reading was made. The test must be repeated if the percent error in the flow data at each pressure station is more than 5%, the correlation coefficient is less than 0.99, or the flow exponent (n) is less than 0.5 or greater than 1.0. These errors and numbers appear on the blower-door tape. Before re-doing a test, examine all hoses and fittings for leakage and carefully re-zero the gauges as these could be the cause of excessive error.

Completing the Test

1. Record the indoor temperature.

2. Return ventilation controls, vents, and thermostats to their original settings. Re-light pilot lights. Make sure all space- and water-heating systems are operating correctly. Close interior doors to restore the house to it's original state.

3. The final printout from each test must be included with the Blower-Door Test Data Sheet.

4. Extreme care must be taken in recording all data points as tests with unacceptable levels of accuracy must be repeated.

Technician: ____________________
Date: ____________________

BLOWER-DOOR TEST DATA SHEET: INFILTEC BLOWER DOOR

House ID: ____________ Subgrantee name: ______________________________

Occupant name: ______________________________ Phone number: ______________

Occupant address: ____

Type of test: pre-weatherization ______________ post-weatherization______________

Procedures to prepare house for test: Basement door ______________ (closed or open)

____

Unusual sources of leakage: ____

Indoor temperature (°F)		Outdoor temperature (°F)	Barometric pressure (inches Hg)	Average wind speed (MPH)	Maximum wind gust (MPH)	Local shielding class
Start	Finish					

Pressure station			Flow rate (cfm)	Orifice
Goal		Actual		
(Pa)	(inches of water)			
10	0.04			
15	0.06			
20	0.08			
25	0.10			
30	0.12			
35	0.14			
40	0.16			
50	0.20			
60	0.24			

Local shielding classes	
1	No obstructions or local shielding
2	Light local shielding; few obstructions, a few trees, or small shed
3	Moderate local shielding; some obstructions within two house heights, thick hedge, solid fence, or one neighboring house
4	Heavy shielding; obstructions around most of perimeter, building or trees within 30 ft in most directions; typical suburban shielding
5	Very heavy shielding; large obstructions surrounding perimeter within two house heights; typical downtown shielding

Notes:

____

____

APPENDIX D
On-Site Occupant Survey

version 9W
6/10/91

Interviewer____________________

Date of Interview________________

Time Started___________________

SINGLE-FAMILY STUDY OCCUPANT QUESTIONNAIRE
WEATHERIZED HOME

A. Identification

INTERVIEWER INSTRUCTIONS:

Complete Questions A1, A2, and A4 using data from the local weatherization agency before starting the interview.

A1. Household Identifier ______________________________________

A2. Name of WAP Applicant ______________________________________

SCREENER:

ASK TO SPEAK TO THE APPLICANT NAMED IN QUESTION A2. IF AVAILABLE, READ THE FOLLOWING AND GO TO QUESTION A3.

> Your home was weatherized as a participant in the Weatherization Assistance Program. As a follow up to that we would like to conduct an interview to learn more about how that weatherization may have affected your energy use and ask your opinions regarding the value of weatherization.

IF THE APPLICANT NAMED IN QUESTION A2 IS NOT AVAILABLE, READ THE FOLLOWING AND THEN ASK QUESTION 1:

> Your home was weatherized as a participant in the Weatherization Assistance Program. As a follow up to that we would like to conduct an interview to learn more about how that weatherization may have affected your energy use and ask your opinions regarding the value of weatherization.

1. I'd like to speak to a person over eighteen years of age who is knowledgeable about paying the energy bills. Is that person available? (IN ORDER TO QUALIFY, THE RESPONDENT DOES NOT HAVE TO PAY THE CHECK. AS LONG AS THE RESPONDENT IS KNOWLEDGEABLE ABOUT THE ENERGY USE AND/OR BILLS, HE OR SHE QUALIFIES.)

1. YES, THE PERSON YOU ARE SPEAKING TO IS THE RESPONDENT.	CONTINUE WITH QUESTION A3.
2. YES, RESPONDENT IS ANOTHER PERSON. . .	ONCE A RESPONDENT IS PRESENT, RETURN TO THE INTRODUCTION AND CONFIRM THAT THE RESPONDENT IS OVER 18 AND IS KNOWLEDGEABLE ABOUT PAYING THE ENERGY BILLS. IF THE RESPONDENT QUALIFIES, CONTINUE WITH QUESTION A3.
3. NO, RESPONDENT IS NOT AVAILABLE.	(NAMES: ________________) IDENTIFY NAMES OF SEVERAL PEOPLE WHO MIGHT BE SUITABLE RESPONDENTS. INFORM THE CURRENT RESPONDENT THAT WE WILL CONDUCT THE INTERVIEW OVER THE TELEPHONE AT A LATER DATE. LEAVE A COPY OF THE EXHIBITS AT THE HOUSE. DO NOT PROCEED WITH THE INTERVIEW.

INTERVIEWER INSTRUCTIONS:

IF RESPONDENT NEEDS INFO: The survey is a part of the Weatherization Assistance Program.

IF RESPONDENT IS HESITANT: Your answers to these questions will provide valuable information to the Department of Energy. The interview will take approximately 30 minutes.

A3. Name of respondent____

Relation to WAP applicant____

[ ] RESPONDENT IS SAME AS WAP APPLICANT

A4. Dates of WAP weatherization work____

A5. I want to confirm that the weatherization work done by the Weatherization Assistance Program took place on (READ DATES FROM QUESTION A4). (RECORD DATES BELOW IF RESPONDENT GIVES DIFFERENT DATES.)

DATES ____________________

[ ] RESPONDENT CONFIRMS THAT WEATHERIZATION TOOK PLACE ON THE SAME DATES AS QUESTION A4.

[ ] DON'T REMEMBER

INTERVIEWER INSTRUCTIONS:

If respondent has trouble remembering the dates in Questions A6, A7, and A8, probe for:

- Season
- Major life event
- Major news story or political event happening at that time

Then, ask for year (and month) again.

A6. In what year was this home built? Just your estimate.*

[ ] Before 1900	[ ] 1940-1949	[ ] 1985
[ ] 1900-1909	[ ] 1950-1959	[ ] 1986
[ ] 1910-1919	[ ] 1960-1969	[ ] 1987
[ ] 1920-1929	[ ] 1970-1979	[ ] 1988
[ ] 1930-1939	[ ] 1980-1984	[ ] 1989
		[ ] 1990

A7. In what year did your family move into this home?*

[ ] Before 1900	[ ] 1940-1949	[ ] 1985
[ ] 1900-1909	[ ] 1950-1959	[ ] 1986
[ ] 1910-1919	[ ] 1960-1969	[ ] 1987
[ ] 1920-1929	[ ] 1970-1979	[ ] 1988
[ ] 1930-1939	[ ] 1980-1984	[ ] 1989
		[ ] 1990

IF "1987" OR LATER ON QUESTION A7, ASK:

A8. In which month did you move in?*

[ ] January	[ ] May	[ ] September
[ ] February	[ ] June	[ ] October
[ ] March	[ ] July	[ ] November
[ ] April	[ ] August	[ ] December

B. Major Heating Fuel

Next, I will ask some questions about the fuels you used to heat your home during the winter before and after weatherization on (READ DATES FROM QUESTION A4). *Throughout the survey, when I ask about the winter* ***before*** *weatherization, I mean October, November, and December of 1988, and January and February of 1989.*

INTERVIEWER INSTRUCTIONS:

If two or more heating fuels are used, the **main heating fuel** is the one that provides most of the heat for the home. The main heating fuel may not necessarily be the one used for the central heating system.

(HAND RESPONDENT EXHIBIT BOOKLET)

B1. Please look at Exhibit B1. What was the **one main heating fuel** used for heating your home during the winter **before** weatherization?*

	B1 Main Fuel (Mark only one)	B2 (Mark all other fuels that apply)
Gas from underground pipes serving the neighborhood.	[ ]	[ ]
Bottled gas (LPG or Propane).	[ ]	[ ]
Fuel oil.	[ ]	[ ]
Kerosene or coal oil.	[ ]	[ ]
Electricity.	[ ]	[ ]
Coal or coke.	[ ]	[ ]
Wood.	[ ]	[ ]
Solar collectors.	[ ]	[ ]
Other (specify)________________	[ ]	[ ]
NO FUELS USED.	[ ]	[ ]
DON'T KNOW.	[ ]	[ ]

B2. Please look at Exhibit B1 again. You mentioned that your **main heating fuel** used during the winter **before** weatherization was (FUEL FROM QUESTION B1). What **other** fuels were used to heat your home during the winter before weatherization -- including those used to provide heat just occasionally? Don't forget to include fuels that ran portable heaters if you used them. (MARK ALL THAT APPLY IN COLUMN B2. IF NONE, MARK "NO FUELS USED")*

IF ADDITIONAL FUELS ARE IDENTIFIED FROM QUESTION B2, ASK:

B3. Going back to your **main heating fuel** used during the winter **before** weatherization--(FUEL FROM QUESTION B1) -- did this fuel provide all or almost all of the heat for your home, about three-fourths, or closer to half of the heat for your home?*

[ ] All or almost all (95% or more)
[ ] About three-fourths (67-94%)
[ ] Closer to half (66% or less)
[ ] DON'T KNOW/REMEMBER

*Now, I will ask similar questions about the fuels you used during the winter **after** weatherization. The winter after weatherization includes October, November, and December of 1990, and January and February of 1991.*

B4. Please look at Exhibit B1 again. What was the **one main heating fuel** used for heating your home during the winter **after** weatherization?*

	B4 Main Fuel (Mark only one)	B5 (Mark all other fuels that apply)
Gas from underground pipes serving the neighborhood.	[ ]	[ ]
Bottled gas (LPG or Propane).	[ ]	[ ]
Fuel oil.	[ ]	[ ]
Kerosene or coal oil.	[ ]	[ ]
Electricity.	[ ]	[ ]
Coal or coke.	[ ]	[ ]
Wood.	[ ]	[ ]
Solar collectors.	[ ]	[ ]
Other (specify)________________	[ ]	[ ]
NO FUELS USED.	[ ]	[ ]
DON'T KNOW.	[ ]	[ ]

B5. Please look at Exhibit B1 again. You mentioned that your **main heating fuel** used during the winter **after** weatherization, was (FUEL FROM QUESTION B4). What **other** fuels were used to heat your home during the winter after weatherization -- including those used to provide heat just occasionally? Don't forget to include fuels that ran portable heaters if you used them. (MARK ALL THAT APPLY IN COLUMN B5. IF NONE, MARK "NO FUELS USED")*

IF ADDITIONAL FUELS ARE IDENTIFIED FROM QUESTION B5, ASK:

B6. Going back to your **main heating fuel** used during the winter **after** weatherization --(FUEL FROM QUESTION B4) -- did this fuel provide all or almost all of the heat for your home, about three-fourths, or closer to half of the heat for your home?*

[ ] All or almost all (95% or more)
[ ] About three-fourths (67-94%)
[ ] Closer to half (66% or less)
[ ] DON'T KNOW/REMEMBER

B7a. Please look at Exhibit B7. During the winter **before** the weatherization work was done, did you use any of the following to **help** heat your home? (USE COLUMN B7a TO CHECK AS MANY AS WERE USED.)

(B7a) BEFORE		(B7b) AFTER
[ ]	Wood/coal stove.	[ ]
[ ]	Fireplace.	[ ]
[ ]	Cooking stove/range/oven.	[ ]
[ ]	Non-portable room heater burning gas, oil, or kerosene.	[ ]
[ ]	Portable kerosene heater.	[ ]
[ ]	Non-portable electric heater	[ ]
[ ]	Electric portable heater (cord-connected).	[ ]
[ ]	Other (specify):________________________________. . .	[ ]
[ ]	NONE.	[ ]

B7b. Please look at Exhibit B7 again. During the winter **after** the weatherization work was done, did you use any of the following to **help** heat your home? (USE COLUMN B7b TO CHECK AS MANY AS WERE USED.)

INTERVIEWER INSTRUCTIONS:

Confirm that responses to B7a do not contradict responses to B1 and B2. Confirm that responses to B7b do not contradict responses to B4 and B5. Probe the respondent if the responses contradict.

ASK QUESTION B8 ONLY FOR EACH ITEM IN QUESTION B7 USED BOTH BEFORE AND AFTER WEATHERIZATION:

B8. Please turn to Exhibit B8. Please tell me how often you used the following to help heat your home during the winter **after** the weatherization work was done, as compared to the winter **before** the weatherization work was done. Did you use it less, about the same, or more **after** weatherization as compared to **before** weatherization? (CIRCLE ONE NUMBER IN EACH LINE ASKED.)

	Used Less After	Used About The Same	Used More After
1. Wood/coal stove	1	2	3
2. Fireplace	1	2	3
3. Cooking stove/range/oven	1	2	3
4. Non-portable room heater burning gas, oil, or kerosene	1	2	3
5. Portable kerosene heater	1	2	3
6. Non-portable electric heater	1	2	3
7. Electric portable heater (cord-connected)	1	2	3
8. Other (________________)	1	2	3

C. Demographics

Now I have some questions about the people who live here and about your housing costs.

C1. Please tell me how many people living in your home during the winter **before** weatherization were . . . (READ EACH ITEM).

Under the age of 5 ____________

Between 5 and 17 years old ____________

Between 18 and 64 years old ____________

65 years old or older ____________

TALLY -- so that is (READ NUMBER) in total? ____________
ENTER CORRECT TOTAL HERE

C2. You have told me that there were (READ TOTAL NUMBER FROM QUESTION C1) people living in your home during the winter **before** weatherization. How many people were living in your home during the winter **after** weatherization?

____
NUMBER OF RESIDENTS

[ ] SAME NUMBER AFTER WEATHERIZATION AS BEFORE WEATHERIZATION

C3. Were any of the people living in your home during the winter **before** weatherization handicapped? By handicapped, I mean a permanent condition. I do not mean a temporary condition, such as a short-term illness. (EYEGLASSES ARE NOT CONSIDERED A HANDICAP). (IF YES, ASK HOW MANY.)

____
NUMBER HANDICAPPED

C4. Do you or members of your household own your home, or rent?*

[ ] Own (buying)
[ ] Rent
[ ] Occupied without payment of rent (SKIP TO SECTION D)

FROM QUESTION C4, IF HOUSEHOLD OWNS OR PAYS RENT, ASK:

C5. Please tell me which category best describes the monthly rent or mortgage payment the household pays for your home. Is it . . .? Stop me when I reach the category. (READ CATEGORIES.)

[ ] less than $200 per month
[ ] $201 - 300 per month
[ ] $301 - 400 per month
[ ] $401 - 500 per month
[ ] $501 - 600 per month
[ ] $601 - 700 per month
[ ] $701 - 800 per month
[ ] $801 - 900 per month
[ ] more than $900 per month
[ ] OWNED, MORTGAGE PAID OFF (SKIP TO SECTION D)
[ ] DON'T KNOW

C6. Does this payment include: (READ ITEMS AND PROBE FOR "YES" OR "NO".)

	Yes	No	DON'T KNOW
1. electricity.	[ ]	[ ]	[ ]
2. natural gas.	[ ]	[ ]	[ ]
3. fuel oil.	[ ]	[ ]	[ ]
4. property tax.	[ ]	[ ]	[ ]
5. insurance (house or renter's).	[ ]	[ ]	[ ]
6. water.	[ ]	[ ]	[ ]
7. garbage.	[ ]	[ ]	[ ]
8. other (specify):____________.	[ ]	[ ]	[ ]

D. Conditioned Living Space

My next question is about the number of different types of rooms in your home. Remember that when I ask about the winter **before** weatherization, I mean October, November, and December of 1988, and January and February of 1989. When I ask about the winter **after** weatherization, I mean October, November, and December of 1990, and January and February of 1991. Weatherization work was done to your home on (READ DATES FROM QUESTION A4).

INTERVIEWER INSTRUCTIONS:

For one-bedroom efficiency or studio apartment, record "0 bedrooms" and number of bathrooms and other rooms.

Full Bathroom -- sink with running water **and** flush toilet **and** bathtub or shower.

Half Bathroom -- toilet **or** bathtub **or** shower

D1. How many of each of the following rooms does this home have? (ASK EACH ITEM AND RECORD NUMBER FOR EACH.)*

	D1 Total Number	D2A Number heated during the winter **before** weatherization	D2B Number heated during the winter **after** weatherization
Bedroomsʔ.	______	______	______
Full bathrooms?.	______	______	______
Half bathrooms?.	______	______	______
All other rooms:. . . . . (Do not count laundry rooms, foyers or unfinished storage space. Only count porches if they are enclosed and used year-round.)	______	______	______

D2. (FOR EACH TYPE OF ROOM THE RESPONDENT HAS IN THE HOME, ASK D2A, THEN D2B. A HEATED ROOM IS ONE THAT IS WARM ENOUGH TO BE USED.)

D2a. Of the (READ NUMBER OF ROOMS AND TYPE OF ROOM), how many were heated during the winter **before** weatherization (RECORD ABOVE ON COLUMN D2A.)

D2b. And how many (READ TYPE OF ROOM) were heated during the winter **after** weatherization? (RECORD ABOVE ON COLUMN D2B.)

E. Thermostat Management

I would now like to ask you some questions about the temperature at which you kept your home.

INTERVIEWER INSTRUCTIONS:

Remember, we are interested in the respondent's perceptions. Ask the respondent for their opinion; avoid checking the thermostat for the actual settings.

If respondent keeps different sections of the home at different temperatures, we want to know the temperature in the part of the house where the people are. If, for example, the heat is turned off upstairs during the day because the family is downstairs, we want the downstairs temperature.

We would like to know the actual temperature of the home. If the respondent doesn't know the temperature, but does know the thermostat setting, record the thermostat setting. Otherwise, probe for best estimate.

E1a. During the winter **before** weatherization, did you keep your home at the same temperature at all times of the day, or did you change the temperature?

[ ] Kept home at same temperature (ASK QUESTION E1B)
[ ] Changed the temperature (GO TO QUESTION E1C)

IF KEPT HOME AT SAME TEMPERATURE ON QUESTION E1A, ASK:

E1b. **Before** weatherization, at what temperature did you **usually** keep your home?

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

(GO TO QUESTION E2A)

IF CHANGED THE TEMPERATURE ON QUESTION E1A, ASK:

E1c. **Before** weatherization, at what temperature did you **usually** keep your home during the day **when someone was at home**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E1d. **Before** weatherization, at what temperature did you **usually** keep your home during the day **when no one was at home**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E1e. **Before** weatherization, at what temperature did you **usually** keep your home **during sleeping hours**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

(ASK EVERYONE:)

E2a. During the winter **after** weatherization, did you keep your home at the same temperature at all times of the day, or did you change the temperature?

[ ] Kept home at same temperature (ASK QUESTION E2B)
[ ] Changed the temperature (GO TO QUESTION E2C)

IF KEPT HOME AT SAME TEMPERATURE ON QUESTION E2A, ASK:

E2b. **After** weatherization, at what temperature did you **usually** keep your home?

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

(GO TO SECTION F)

IF CHANGED THE TEMPERATURE ON QUESTION E2A, ASK:

E2c. **After** weatherization, at what temperature did you **usually** keep your home during the day **when someone was at home**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E2d. **After** weatherization, at what temperature did you **usually** keep your home during the day **when no one was at home**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

E2e. **After** weatherization, at what temperature did you **usually** keep your home **during sleeping hours**?*

Degrees Fahrenheit: ________
[ ] HEAT TURNED OFF

F. Events Affecting Energy Use

The next questions are about events which may have affected your energy use during the winter. (REMIND RESPONDENT IF NECESSARY): *Remember that when I ask about the winter **before** weatherization, I mean October, November, and December of 1988, and January and February of 1989. When I ask about the winter **after** weatherization, I mean October, November, and December of 1990, and January and February of 1991. Weatherization work was done to your home on* (READ DATES FROM QUESTION A4).

F1a. During the winter **before** your home was weatherized, was there ever a time when you wanted to use your main source of heat, but could not, for one or more of the following reasons?

	Yes	No
Your heating system was **broken**?	[ ]	[ ]
The utility company **discontinued** . . . . your gas or electric service?	[ ]	[ ]

IF "YES" TO EITHER PART OF QUESTION F1A, ASK:

F1b. Thinking about these times that you went without heat, during the winter **before** weatherization, how many <u>separate</u> times were there?

Total times: __________

F1c. Altogether, how many hours or days were you without heat?

Total hours without heat: __________

OR

Total days without heat: __________

F2a. During the winter **after** your home was weatherized was there ever a time when you wanted to use your main source of heat, but could not, for one or more of the following reasons?

	Yes	No
Your heating system was **broken**?	[ ]	[ ]
The utility company **discontinued** your gas or electric service?	[ ]	[ ]

IF "YES" TO ANY PART OF QUESTION F2A, ASK:

F2b. Thinking about these times that you went without heat, during the winter **after** weatherization, how many separate times were there?

Total times: __________

F2c. Altogether, how many hours or days were you without heat?

Total hours without heat: __________

OR

Total days without heat: __________

F3. Except for the weatherization of your home on (READ DATES FROM QUESTION A4), was any home repair or major house renovation that would affect energy use done on your home by yourself or other organization between January 1987 and April 1991?

[ ] Yes
[ ] No
[ ] DON'T KNOW

IF YES ON QUESTION F3, ASK:

F4. Please describe the home repair or renovation. (RECORD VERBATIM BELOW.)

		MONTH/YEAR
(1)	____________________	__________
	____________________	__________
(2)	____________________	__________
	____________________	__________
(3)	____________________	__________
	____________________	__________
(4)	____________________	__________
	____________________	__________

F5. In which month/year was the work done? (RECORD UNDER COLUMN FOR MONTH/YEAR ABOVE.)

G. Impacts on Health, Safety, Comfort, Affordability

My next questions ask for your opinion about how weatherization affected the health, safety, comfort, and value of your home.

G1a. Please look at Scale G1. Using a scale of 1 to 7, where 1 is too cold, 4 is comfortable, and 7 is too hot, how would you rate the temperature in your home during the winter **before** weatherization?

BEFORE

1	2	3	4	5	6	7	8
too cold			comfortable			too hot	DON'T REMEMBER

IF 1-3 OR 5-7 ON QUESTION G1A, ASK:

G1b. Why couldn't you keep your home the temperature you preferred during the winter **before** weatherization? (DO NOT READ ANSWER CATEGORIES.) (CHECK ALL THAT APPLY.)*

[ ] Heating system problem
[ ] Landlord controls the temperature
[ ] Difference of opinion in household
[ ] Fuel shortage
[ ] High cost of fuel
[ ] Construction problem, such as broken windows, or holes in walls
[ ] Other (please specify)________________________________

____

[ ] NOT SURE

G1c. Using the same scale (REPEAT SCALE IF NECESSARY) how would you rate the temperature in your home during the winter **after** weatherization?

AFTER

1	2	3	4	5	6	7	8
too cold			comfortable			too hot	DON'T REMEMBER

IF 1-3 OR 5-7 ON QUESTION G1C, ASK:

G1d. Why couldn't you keep your home the temperature you preferred during the winter **after** weatherization? (DO NOT READ ANSWER CATEGORIES.) (CHECK ALL THAT APPLY.)*

[ ] Heating system problem
[ ] Landlord controls the temperature
[ ] Difference of opinion in household
[ ] Fuel shortage
[ ] High cost of fuel
[ ] Construction problem such as broken windows, or holes in walls
[ ] Other (please specify)________________________________

____

[ ] NOT SURE

G2. Please look at Scale G2. Using a scale of 1 to 7, where 1 is very drafty, 4 is somewhat drafty, and 7 is not at all drafty, how would you rate the draftiness of your home during the winter **before** weatherization?

BEFORE

1	2	3	4	5	6	7	8
very drafty			somewhat drafty			not at all drafty	DON'T REMEMBER

Using the same scale (REPEAT SCALE IF NECESSARY), how would you rate the draftiness in your home during the winter **after** weatherization?

AFTER

1	2	3	4	5	6	7	8
very drafty			somewhat drafty			not at all drafty	DON'T REMEMBER

G3. Please look at Scale G3. Using a scale of 1 to 7, where 1 is very poor, 4 is acceptable, and 7 is very healthy, how would you rate the health of household members during the winter **before** weatherization? By health I mean illnesses such as colds, flus, allergies, frequent headaches, frequent nausea, or arthritis.

BEFORE

1	2	3	4	5	6	7	8
very poor			acceptable			very healthy	DON'T REMEMBER

Using the same scale (REPEAT SCALE IS NECESSARY), how would you rate the health of household members during the winter **after** weatherization?

AFTER

1	2	3	4	5	6	7	8
very poor			acceptable			very healthy	DON'T REMEMBER

G4. Please look at Scale G4. Using a scale of 1 to 7, where 1 is very unsafe, 4 is acceptable, and 7 is very safe, how would you rate the safety of your home during the winter **before** weatherization? By safety, I mean absence of hazards. Some examples of hazards in the home are faulty electrical, heating, or plumbing systems; combustible materials or other fire hazards; unstable porches or broken doors; or the absence of safety precautions such as bolt locks or smoke detectors.

BEFORE

1	2	3	4	5	6	7	8
very unsafe			acceptable			very safe	DON'T REMEMBER

Using the same scale (REPEAT SCALE IF NECESSARY), how would you rate the safety of your home during the winter **after** weatherization?

AFTER

1	2	3	4	5	6	7	8
very unsafe			acceptable			very safe	DON'T REMEMBER

G5. Please look at Scale G5. Using a scale of 1 to 7, where 1 is very expensive, 4 is acceptable, and 7 is very <u>in</u>expensive, how would you rate the cost of your heating bills during the winter **before** weatherization?

BEFORE

1	2	3	4	5	6	7	8
very expensive			acceptable			very inexpensive	DON'T REMEMBER

Using the same scale (REPEAT SCALE IF NECESSARY), how would you rate the cost of your heating bills during the winter **after** weatherization?

AFTER

1	2	3	4	5	6	7	8
very expensive			acceptable			very inexpensive	DON'T REMEMBER

G6. Please look at Scale G6. Using a scale of 1 to 7, where 1 is very much lower, 4 is about the same, and 7 is very much higher, how would you rate the property value of your home **after** weatherization as compared to **before** weatherization? By property value, I mean the dollar value of the home if sold.

1	2	3	4	5	6	7	8
very much lower			about the same			very much higher	DON'T REMEMBER

END

On behalf on the U.S. Department of Energy, I would like to thank you for your time and patience today. The information that you have shared with us will be helpful in our study.

*These items are modified versions of questions taken from the 1990 Residential Energy Consumption Survey (RECS) conducted by the Energy Information Administration.

INTERVIEWER INSTRUCTIONS:

Check to make sure each question has been answered and that verbatim responses are clear and legible.

TIME ENDED:____________________

EXHIBIT B1

GAS FROM UNDERGROUND PIPES SERVING THE NEIGHBORHOOD

BOTTLED GAS (LPG OR PROPANE)

FUEL OIL

KEROSENE OR COAL OIL

ELECTRICITY

COAL OR COKE

WOOD

SOLAR COLLECTORS

OTHER

EXHIBIT B7

WOOD/COAL STOVE

FIREPLACE

COOKING STOVE/RANGE/OVEN

NON-PORTABLE ROOM HEATER BURNING GAS, OIL, OR KEROSENE

PORTABLE KEROSENE HEATER

NON-PORTABLE ELECTRIC HEATER

ELECTRIC PORTABLE HEATER (CORD-CONNECTED)

OTHER

EXHIBIT B8

USED LESS AFTER WEATHERIZATION

USED ABOUT THE SAME AFTER WEATHERIZATION

USED MORE AFTER WEATHERIZATION

SCALE G1

1	2	3	4	5	6	7
too cold			comfortable			too hot

SCALE G2

1	2	3	4	5	6	7
very drafty			somewhat drafty			not at all drafty

SCALE G3

1	2	3	4	5	6	7
very poor			acceptable			very healthy

SCALE G4

1	2	3	4	5	6	7
very unsafe			acceptable			very safe

SCALE G5

1	2	3	4	5	6	7
very expensive			acceptable			very <u>in</u>expensive

SCALE G6

1	2	3	4	5	6	7
very much lower			about the same			very much higher

APPENDIX E
Data Collection Forms on Costs and Energy Conservation Measures

NATIONAL WEATHERIZATION EVALUATION

AGENCY INFORMATION FORM

Agency id #, contact, address, and telephone number:

When you finish filling out this form, the dwelling-specific forms, and the waiting list forms, please estimate the amount of staff time it took to complete them.

__________ **hours**

AGENCY INFORMATION FORM

A. Please provide the name(s) and telephone numbers of staff member(s) completing these forms, just in case we have any questions about the answers.

Name:____

Phone #:____

B. COST DEFINITIONS AND INSTRUCTIONS

There are two types of forms included in this package: this form (the Agency Information Form) and a Dwelling-Specific Form for each dwelling in the random sample.

Figure 1 on page 2 provides background information for completing questions E1 to E3 of the Dwelling-Specific Form and for completing the information on installation-related overhead and program management costs on pages 3 and 4 of this form.

The total cost of a program can be divided into **installation costs** and **program management costs** (Fig.1). Total installation costs include the costs of materials, direct labor and overhead expenses that are directly related to the installation process, such as the costs of vehicles, travel, equipment, insurance, field supervision, and training. When contractors deliver services, these installation overhead expenses are included, along with a profit, in the charges made for a job. When agency crews do the work, some of the installation overhead expenses may not be tracked directly on a per-house basis. As a result, there are separate questions for crew vs. contractor installation costs on both of the forms.

If a job is crew-based, supply the materials costs (Question E1 of the Dwelling-Specific Form) and calculate the direct labor costs (Question E2 of the Dwelling-Specific Form). If a job is contractor-based, supply the materials costs (Question E1) and the total installed costs (Question E3). If both crews and contractors worked on a house, complete all three questions (Questions E1, E2, and E3 of the Dwelling-Specific Form).

Both crew-based and contractor-based programs should estimate an average program management cost per house weatherized (Question C1 on this Agency Information Form). The program management cost should be calculated by subtracting the total installation costs (labor + materials + installation-related overhead) for all houses weatherized in PY 1989 from the total agency budget (in PY 1989). The total program management cost should then be divided by the number of houses weatherized (in PY 1989) to produce an average per-house program management cost (Question C1). This estimate only needs to be recorded on the Agency Information Form because it will be the same for all houses.

If your agency has any crew-based jobs, the average per-house cost of installation-related overhead expenses should be estimated (Question C3 on this Agency Information Form). To do this estimate, your agency's costs for vehicles, equipment, liability insurance, training, travel time, field supervision and any other installation-related expenses in the 1989 program year (PY) should be summed and then divided by the number of homes weatherized in the 1989 program year. You only need to record your estimate of the average per-house cost of installation-related overhead expenses once on the Agency Information Form because it will be the same for all houses.

We realize that different agencies track costs in different ways. Please just use your best judgement in estimating the average installation-related overhead and the average program management expenses. The dwelling-specific records of materials costs, crew-based labor hours, and contractor's total installed costs that are in your files should be coded onto a Dwelling-Specific Form for each house in the sample.

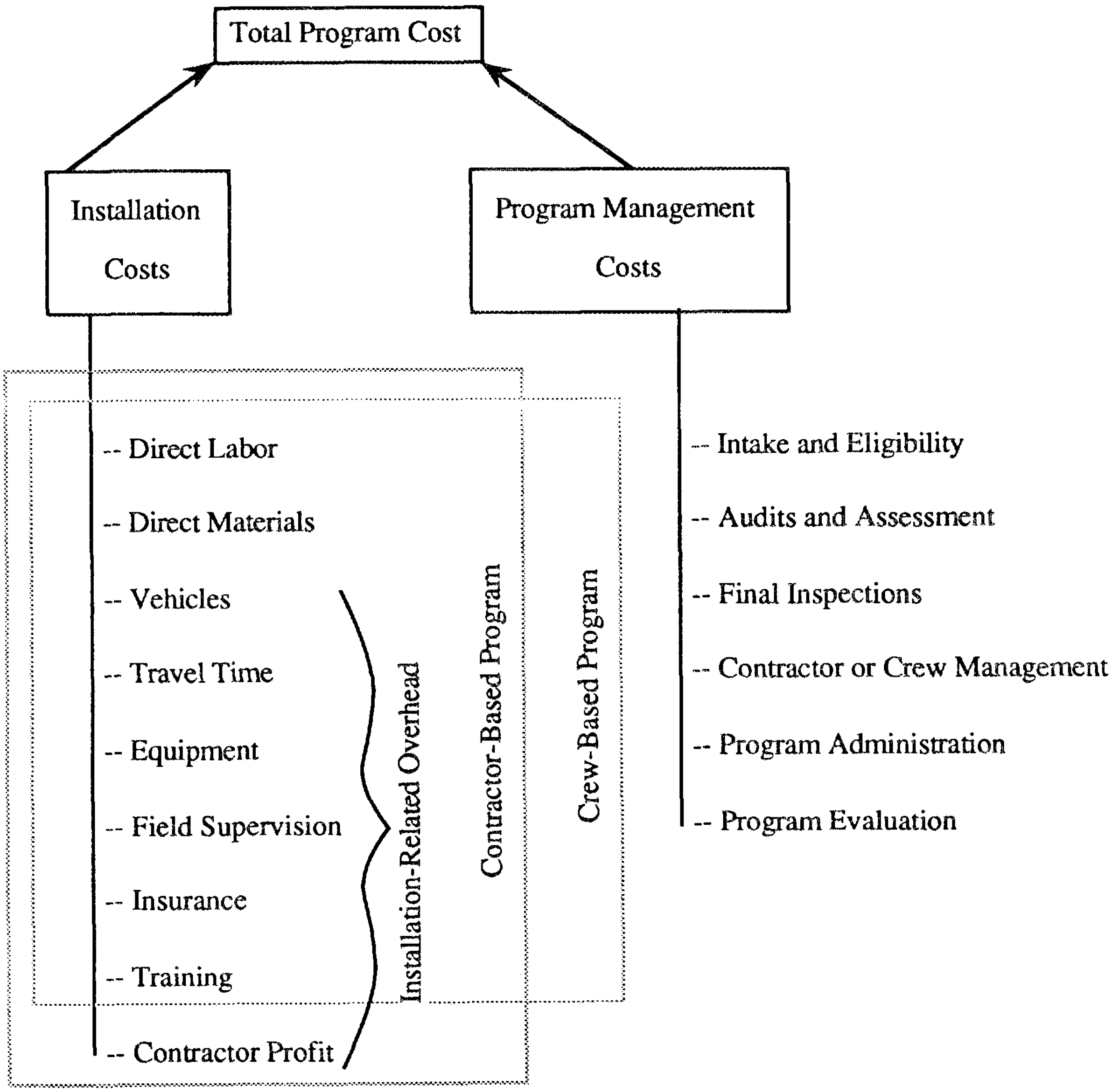


Figure 1. Cost Categories

C. AVERAGE AGENCY PROGRAM MANAGEMENT COSTS AND INSTALLATION-RELATED OVERHEAD

C1. AVERAGE PROGRAM MANAGEMENT COSTS

Total Program Costs for PY 1989 $__________

– Total Installation Costs* for All Houses Weatherized in PY 1989 $__________

*Add all direct materials costs, labor costs, and installation-related overhead together to obtain this cost figure.

Total Program Management Costs → $__________

-- Intake and Eligibility

-- Audits and Assessment

-- Final Inspections

-- Contractor or Crew Management

-- Program Administration

-- Program Evaluation

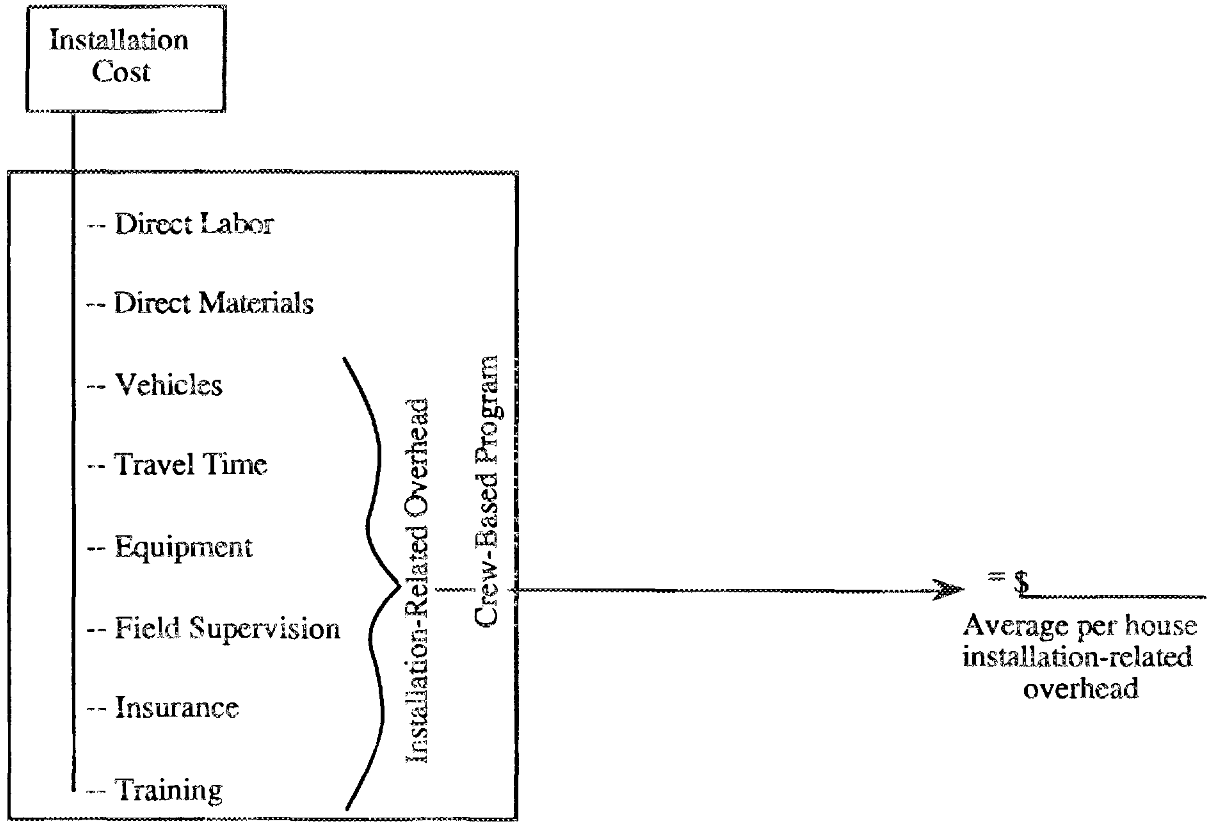
Average per house** program management cost $__________

**Divide the total program management costs for PY 1989 by the number of houses weatherized in PY 1989.

C2. Some program management costs (such as client intake and eligibility checks, or office space and expenses) may be absorbed by other programs or agencies (e.g., LIHEAP, Councils on Aging). What percentage of your program management costs would you estimate are absorbed by other programs or agencies?

____________%

C3. CREW-BASED INSTALLATION-RELATED OVERHEAD



D. HOUSING TYPE DEFINITIONS

Definitions of single-family and small multifamily housing units for Question A2 on page 1 of the Dwelling-Specific Form:

[A] single-family housing unit [is] a structure that provides living space for one household or family. The structure may be detached, attached on one side (semidetached), or attached on two sides. Attached houses are considered single-family houses as long as the house itself is not divided into more than one housing unit and has an independent outside entrance. A single-family house is contained within walls that go from the basement (or ground floor, if there is no basement) to the roof.

[A] house or building with two to four housing units is a structure that is divided into living quarters for two, three, or four families or households. This category also includes houses originally intended for occupancy by one family (or for some other use) that have since been converted to separate dwellings for two to four families. Typical arrangements in these types of living quarters are separate apartments downstairs and upstairs, or one apartment on each of three or four floors.

NATIONAL WEATHERIZATION EVALUATION

AGENCY INFORMATION FORM

Agency id #, contact, address, and telephone number:

When you finish filling out this form, the dwelling-specific forms, and the waiting list forms, please estimate the amount of staff time it took to complete them.

__________ **hours**

A. DWELLING CHARACTERISTICS AND EQUIPMENT

A1. When was the weatherization completed on this dwelling?

Month______________ (CIRCLE YEAR) 1989 1990*

*If this house was not weatherized between April 1, 1989 and March 31, 1990, it should not be in the sample and no further information is needed. Please return this form along with the others.

A2. Is this dwelling a. . . ?** (MARK ONE)

[ ] Mobile/manufactured home
[ ] Single-family detached
[ ] Single-family attached (townhouse or rowhouse)
[ ] Small multifamily (2-4 units)
[ ] Large multifamily (5 or more units)***

**Our definitions of single-family and small (2-4 unit) multifamily dwelling units are the same as those used by DOE's Residential Energy Consumption Survey (RECS). The RECS definitions are given on the accompanying agency information form.

***If this dwelling is part of a large multifamily building, it should not be in the sample and no further information is needed. Please return this form along with the others.

A3. At the time of weatherization, what was the conditioned (heated or cooled) square footage of this dwelling? (include the basement only if it is conditioned)

______________________ conditioned square feet

A4. At the time of weatherization, did members of this household own this home or did they rent? (MARK ONE)

[ ] Own (buying)
[ ] Rent
[ ] Occupied without payment

A5. At the time of weatherization, what was the **one main heating fuel** used for heating this home? (MARK ONLY ONE FUEL IN COLUMN A5)

A6. What **supplemental** fuels were used to heat the home -- including those used to provide heat just occasionally? Include fuels that ran portable heaters if they were used. MARK ALL THAT APPLY (If none, mark "No supplemental fuels used" in Column "A6" below.)

	A5 Main Fuel (MARK ONLY ONE)	A6 Supplemental Fuels (MARK ALL THAT APPLY)
Gas from underground pipes serving the neighborhood.	[ ]	[ ]
Bottled gas (LPG or Propane).	[ ]	[ ]
Fuel oil.	[ ]	[ ]
Kerosene or coal oil.	[ ]	[ ]
Electricity.	[ ]	[ ]
Coal or coke.	[ ]	[ ]
Wood.	[ ]	[ ]
Solar collectors.	[ ]	[ ]
Other (specify)____________ ____________________.	[ ]	[ ]
No supplemental fuels used.		[ ]
Don't know.	[ ]	[ ]

A7. If this household's main fuel is gas or electricity, please provide the name of the gas (if any) and electric utility companies that provide service to this dwelling and the household's utility account numbers.

______________________ Electric Utility	______________________ Account Number
______________________ Gas Utility	______________________ Account Number

A8. Which heating system types were used in this home? (MARK ALL THAT APPLY)

[ ] Central systems (e.g., forced air furnace, central gravity furnace, steam boiler, hot water boiler, heat pump)
[ ] Fossil fueled in-space heaters (e.g., wall furnaces, floor funaces, wood, coal, kerosene or gas stoves)
[ ] Electric in-space heaters (e.g., wall, floor, baseboard, imbedded cable, portable [cord connected])
[ ] Both central and in-space
[ ] Other (specify) ______________________________
[ ] Don't know

A9. About when was this dwelling originally built? (MARK ONE)

[ ] Before 1900
[ ] 1900-1909
[ ] 1910-1919
[ ] 1920-1929
[ ] 1930-1939
[ ] 1940-1949
[ ] 1950-1959
[ ] 1960-1969
[ ] 1970-1979
[ ] 1980-1984
[ ] 1985 or later

A10. Does this dwelling have central air conditioning equipment ? (MARK ONE)

[ ] Yes
[ ] No
[ ] Don't know

A11. How many wall or window unit air conditioners does it have? (MARK ONE)

[ ] None
[ ] 1
[ ] 2
[ ] 3
[ ] 4 or more
[ ] Don't know

B. OCCUPANT CHARACTERISTICS

B1. Please indicate the total number of persons living in this house at the time of weatherization and the number who were elderly or handicapped.

Total number: ______________________

Number of elderly: ______________________

Number of handicapped: ______________________

B2. What was the household's income on the application form at the time when its eligibility was verified for the services it received in the 1989 program year?

$______________

C. WEATHERIZATION MEASURES INSTALLED

Please check any of the measures listed that were installed in this dwelling. Indicate whether they were installed by in-house crew or contractor. If measures that are not listed were installed, please describe them in the appropriate "Other" category.

	Installed by: In-house crew	Installed by: Contractor
C1. Insulation		
Attic Insulation (installed for the first time).	[ ]	[ ]
Attic Insulation (added to existing insulation).	[ ]	[ ]
*Wall Insulation (normal technique).	[ ]	[ ]
*Wall Insulation (high-density technique).	[ ]	[ ]
Floor Insulation.	[ ]	[ ]
Rim or Band Joist Insulation.	[ ]	[ ]
Other Envelope Insulation.	[ ]	[ ]

(Specify: ______________________________

______________________________________)

*The "normal technique" for installing wall insulation is characterized by blowing cellulose or fiberglass insulation into exterior wall cavitites to average densities using a two-hole, gravity-blow installation method. The "high-density technique" is characterized by blowing cellulose insulation into exterior wall cavities to high densities using a one-hole, tube-fill installation method. Under the "high-density technique," special attention is focused on sealing air leakage sites while insulating the walls; air bypasses are identified during the installation process and sealed by plugging the air-leakage pathways with cellulose.

	In-house crew	Contractor
C2. Air Leakage Control		
General Caulking and Weatherstripping. . . . . (door and window)	[ ]	[ ]
Air Sealing, emphasizing bypasses with . . . . blower door testing	[ ]	[ ]
Air Sealing, emphasizing bypasses without . . . . blower door testing	[ ]	[ ]
Distribution System.	[ ]	[ ]
Other Infiltration Reduction.	[ ]	[ ]

(Specify: ______________________________

______________________________________)

	Installed by: In-house crew	Contractor
C3. Water Heating System		
Water Heater Tank Insulation.	[ ]	[ ]
Entire Water Heating System Replacement.	[ ]	[ ]
Pipe Insulation.	[ ]	[ ]
Low Flow Shower Heads.	[ ]	[ ]
Temperature Reduction.	[ ]	[ ]
Other Water Heater Measures.	[ ]	[ ]

(Specify: ______________________________

______________________________________)

	In-house crew	Contractor
C4. Structural Repairs (full or partial)		
Attic Ventilation.	[ ]	[ ]
Roof.	[ ]	[ ]
Doors.	[ ]	[ ]
Replacement of Doors.	[ ]	[ ]
Windows/Glazing.	[ ]	[ ]
Replacement of Windows.	[ ]	[ ]
Walls.	[ ]	[ ]
Floor.	[ ]	[ ]
Other Structural Repairs.	[ ]	[ ]

(Specify: ______________________________

______________________________________)

	In-house crew	Contractor
C5. Windows and Doors		
Storm Windows (How many? ________).	[ ]	[ ]
Storm Doors.	[ ]	[ ]
Window Films or Shades.	[ ]	[ ]
Other Window or Door Treatments.	[ ]	[ ]

(Specify: ______________________________

______________________________________)

	In-house crew	Contractor
C6. Mobile Home Measures		
Vapor Barrier.	[ ]	[ ]
Underpinning/Skirting.	[ ]	[ ]
Cool Seal (on roof).	[ ]	[ ]
Other.	[ ]	[ ]

(Specify: ________________________________

____)

	Installed by: In-house crew	Installed by: Contractor
C7. Space Heating System		
Clean and Tune-up.	[ ]	[ ]
Entire Heating System Replacement.	[ ]	[ ]
Set-back Thermostat.	[ ]	[ ]
Heating System Component Retrofits.	[ ]	[ ]
(Specify: ______________________________)		
Safety Problem Fixed.	[ ]	[ ]
(Specify: ______________________________)		
Repairs.	[ ]	[ ]
(Specify: ______________________________)		
Other Heating System Modifications.	[ ]	[ ]
(Specify: ______________________________ ______________________________________)		
C8. Space Cooling System		
Tune-up. . . . . (e.g., cleaning, controls adjustment, filter replaced)	[ ]	[ ]
Entire Air-conditioning System Replacement	[ ]	[ ]
Fans Installed or Replaced.	[ ]	[ ]
Set-back Thermostat.	[ ]	[ ]
Other Cooling System Modifications.	[ ]	[ ]
(Specify: ______________________________ ______________________________________)		
C9. Other Health and Safety Repairs or Improvements		
Smoke Detectors.	[ ]	[ ]
Radon Testing.	[ ]	[ ]
Carbon Monoxide Testing.	[ ]	[ ]
Other.	[ ]	[ ]
(Specify: ______________________________ ______________________________________)		

D. SERVICE DELIVERY PROCEDURES

Selection of Measures

D1. Please check the type of procedure that was used to select the measures that were installed in this dwelling in the 1989 program year. (CHECK ALL THAT APPLY)

[ ] Envelope measures were selected using a priority or prescribed list of measures
[ ] Envelope measures were selected using a decision approach or scoring (calculation) developed for each house
[ ] Envelope measures were selected based on an analysis of energy savings per $ invested
[ ] Space-heating system measures were selected based on physical characteristics or a standard approach
[ ] Space-heating system measures were selected using a decision approach or scoring (calculations) based on operating performance
[ ] Space-heating system measures were selected based on an analysis of energy savings per $ invested
[ ] Selection of envelope and space-heating system measures was made simultaneously under one approach rather than separately using two distinct procedures.
[ ] Other measure selection procedures. Specify:____________________________

____

Use of Diagnostics

D2. Please check the type of diagnostic procedures that were used in this dwelling in the 1989 program year. (CHECK ALL THAT APPLY)

[ ] Blower door testing was used to find leakage areas for sealing
[ ] Blower door testing to measure air leakage rates
[ ] Blower door testing was used to determine when to stop work using cost-effectiveness guidelines (not minimum ventilation guidelines)
[ ] Distribution system diagnostics were used to find leakage areas for sealing
[ ] Distribution system diagnostics were used to determine system balancing
[ ] Infrared scanning was used
[ ] Indoor air quality testing was used
[ ] Heating system efficiency testing was used
[ ] A heating system safety inspection was conducted
[ ] Other diagnostic procedures. Specify: ____________________________

____

Quality Control

D3. Please indicate the type of quality control inspection this house received in the 1989 program year. (CHECK ALL THAT APPLY)

[ ] A visual quality control inspection after weatherization for envelope measures
[ ] A quality control inspection after weatherization for envelope measures that used blower door testing as a diagnostic tool
[ ] A quality control inspection after weatherization for envelope measures that used infrared scanning as a diagnostic tool
[ ] A visual quality control inspection after weatherization for heating system measures
[ ] A quality control inspection after weatherization for heating system measures that used diagnostic tools such as combustion efficiency testing
[ ] Other quality control procedures. Specify: ____________________________

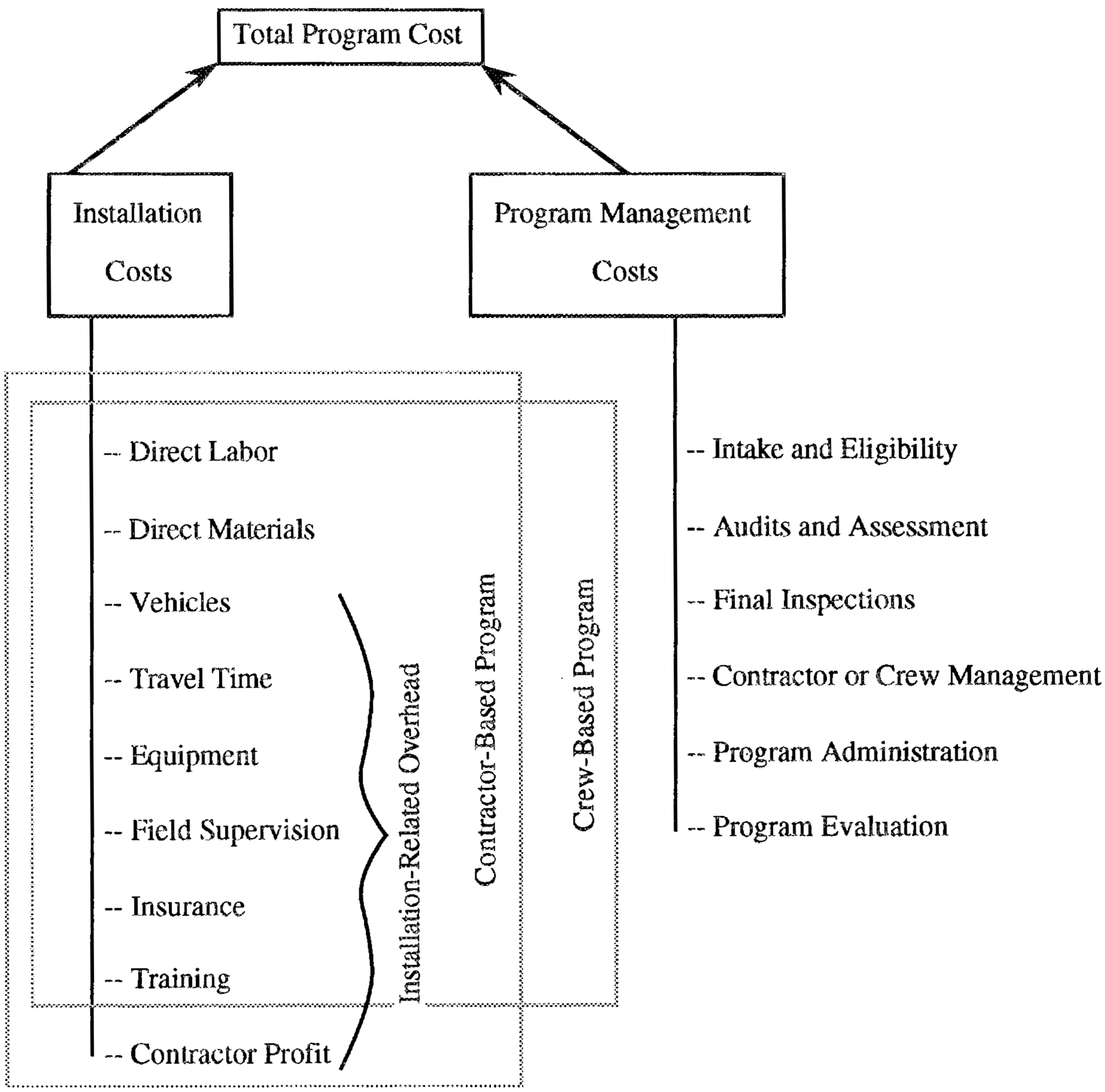
____

E. COSTS: MATERIALS, LABOR, INSTALLATION OVERHEAD AND PROGRAM MANAGEMENT

<u>Definitions and Instructions</u>

If a job is crew-based, supply the materials costs (Question E1) and calculate the direct labor costs (Question E2). If a job is contractor-based, supply the materials costs (Question E1) and the total installed costs (Question E3). If both crews and contractors worked on a house, complete all three questions (Questions E1, E2, and E3). If you need further instructions, please see the instructions in the agency information form.

Figure 1. Program Cost Categories



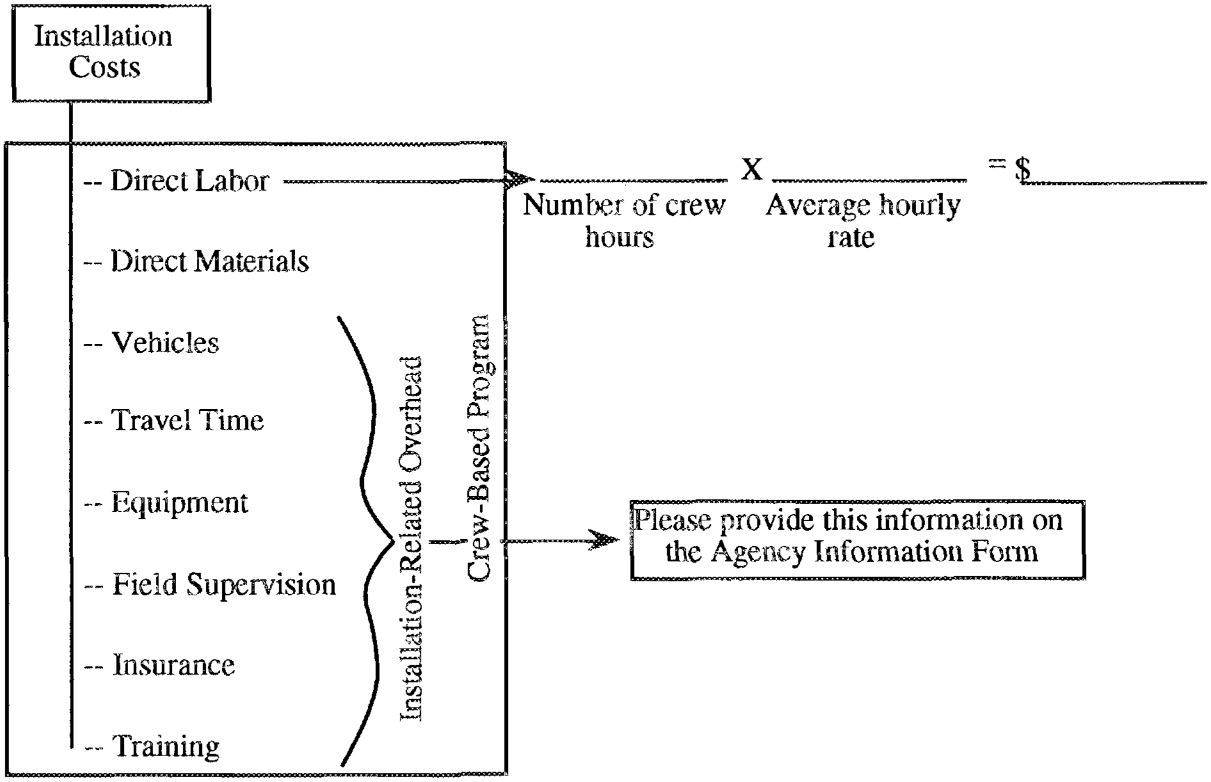
E1: BREAKDOWN OF MATERIALS COSTS

In the chart below please fill in the crew-based and/or contractor-based materials cost of the measures that were installed in this dwelling in the 1989 program year. Do not include labor, administrative or program support costs here. Do include costs covered by all sources of funding (i.e., PVE, LIHEAP, or utilities). If you cannot provide the costs by measure, just enter the total materials cost in the box at the bottom.

	Crew-Based Materials Costs	Contractor-Based Materials Costs
Insulation		
attic	$	$
wall	$	$
other	$	$
Air Leakage Control	$	$
Water Heating System Measures	$	$
Structural Repairs	$	$
Windows and Doors	$	$
Space Heating System		
retrofit	$	$
replacement	$	$
Space Cooling System		
retrofit	$	$
replacement	$	$
Other	$	$
	$	$
	Crew-Based Total Materials Costs	Contractor-Based Total Materials Costs

E2: CREW-BASED INSTALLATION COSTS

Directions: Please fill in the number of crew hours for <u>this house</u> from information in your files. Provide your best estimate of the average hourly rate for your crew and multiply this by the number of hours to produce an estimate of the direct labor costs.



E3: CONTRACTOR-BASED INSTALLATION COSTS

Directions: Please fill in the total installation costs* billed by contractors for <u>this house</u>. This should include all the cost categories listed above <u>plus the contractor's profit</u>.

Total Installed Cost $____________________

*Include the materials costs (reported on p.9) in this total, as well as labor costs and installation-related overhead.

F. FUNDING SOURCES

F1. What percentage of the funds spent on this house were funds from DOE's WAP?

____________%

F2. If funds from non-DOE sources were used, were they all used according to DOE guidelines?

[ ] Yes
[ ] No

*U.S. GOVERNMENT PRINTING OFFICE: 1991-548-134/40025

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