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# Assessment of Weatherization Assistance Program Needs for Improved Residential Measure Selection Techniques

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Prepared for the
Office of State and Local Assistance Programs
Weatherization Assistance Program
U.S.Department of Energy
under contract DE-AC05-84OR21400

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

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Energy Division

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## ABSTRACT

This report documents a study conducted by the Oak Ridge National Laboratory (ORNL) to evaluate the current measure selection techniques and needs of agencies within the Weatherization Assistance Program (WAP). The study precedes initiation of a project to revise and upgrade the current means of selecting energy conservation measures for low-income single- and multi-family housing and includes recommendations for the revision.

Issues relevant to the formation of the revised audit procedures are discussed. Currently available audits are reviewed. No single- or multi-family audit program was found capable of fulfilling the current needs of the WAP.

Recommendations include the separate development of single- and multi-family audits. Addition of specific features to the single-family audit is recommended, including (1) measure ranking unique to each eligible house, (2) heating and cooling equipment measures, (3) cooling envelope measures, (4) means of determining the amount of infiltration work to be performed, (5) potential for customizing and simplifying to meet local needs, and (6) implementation on either a personal computer or as an alternate manual technique. A single-family audit development plan is proposed which includes examination of several existing programs as potential starting points.

Recommendations related to the development of a WAP multi-family audit include examination of several existing private programs for possible use by state WAP agencies expressing the greatest need and further study of the DOE supported programs ASEAM and CIRA as possible starting points for a DOE procedure. Early identification of approved multi-family measures and their applicability to various building stock, equipment types, and fuels is also recommended.

## EXECUTIVE SUMMARY

This report documents a study conducted by the Oak Ridge National Laboratory (ORNL) to evaluate the current measure selection techniques and needs of agencies within the Weatherization Assistance Program (WAP) of the Department of Energy (DOE). The study precedes initiation of a project to revise and upgrade the current means of selecting energy conservation measures for low-income single- and multi-family housing and includes recommendations for the revision.

Changes in the program policies (which increased the number of acceptable measures and the rules of allocating retrofit funds) as well the availability of newer technologies (such as blower door infiltration measurements and the advent of personal computing devices) have dictated the need for revision or replacement of the earlier audit, Project Retrotech. Consequently, in 1988, the WAP initiated a project with ORNL to review information on existing single- and multi-family weatherization programs, review measure selection techniques, survey users needs, and make recommendations for improving the measure selection procedure. Recommendations would then be implemented following DOE approval.

This report contains the findings of this investigation and recommendations for the revision of Project Retrotech. Different information sources, issues, and procedures for single- and multi-family weatherization programs indicate the need to examine and then develop techniques for the two building types separately. The report is arranged accordingly.

### SINGLE-FAMILY PROGRAM STUDY

Information relating to current WAP single-family audit procedures was obtained from personal communications with a majority of the state and regional WAP agencies as well as from a literature search. Characteristics of currently available WAP measure selection techniques are reviewed and several specific areas are discussed, including the basic structure of the proposed technique, implementation of cooling measures, the use of blower doors for infiltration reduction, and the integration of various audit segments.

Thirty-five of the 50 states surveyed reported using Project Retrotech or a modification thereof as their principal measure selection technique. Ten states appear to have computerized techniques of varying complexity. Both priority lists of measures and measure selection techniques computing individual measure savings have potential use. However, because the former have limited and often uncertain applicability, the necessity exists for a primary technique which individually accesses the value of relevant measures under the unique conditions of each eligible house.

One of the factors motivating the development of an upgraded measure selection technique was the need to consider measures applicable in predominately cooling climates. Also, an increase in the expenditure limits within the WAP has permitted many additional measures to be considered, for example, heating equipment replacement.

The upgraded measure selection technique requires a means of establishing how much infiltration work is to be performed. The use of blower-doors not only provides of measure of the need for infiltration reduction, but can also assist in locating the major infiltration paths. Eleven of 19 state agencies responding to questions relating to infiltration reduction indicated use of blower doors in some way within their programs. The major disadvantage to their use cited by the agencies was the

initial cost of purchasing the devices and training personnel in their use. Advantages include increased program cost-effectiveness.

A complex audit which addresses cooling and equipment measures, as well as heating envelope measures, requires implementation on a personal computer to make feasible computation of the measure savings and their interactions unique to each house. An alternate method not requiring a computer should be derived from the primary technique by restricting the applicability or dividing the procedure into independent modules, although some loss of accuracy would result.

Since none of the currently available measure selection techniques sufficiently addresses all the needs presently seen, it is recommended that the Weatherization Assistance Program support the development of an upgraded technique. The technique should:

- allow measure ranking unique to each eligible house;
- include heating and cooling equipment measures and their interactions with other measures fully integrated into the selection technique;
- include the capability of being customized to meet the local needs of agencies;
- provide ranking of cooling envelope measures when appropriate;
- provide means to determine the amount of infiltration work that should be performed on each house;
- provide ranking of measures based on a variety of economic criteria, but specifically include benefit-to-cost estimates over the life of the measures;
- allow implementation on a personal computer and permit development of a manual version.

A proposed single-family audit development plan describes formation of a first phase audit appropriate for testing in a North Carolina field trial already being planned. The work is divided into five tasks, each with estimated completion dates. It includes examination of several existing programs as possible starting points.

## MULTI-FAMILY PROGRAM STUDY

Since no DOE-supported measure selection technique currently addresses multi-family residences, development of such a procedure necessitated a review of available sources of information on multi-family weatherization programs and procedures. Sources are identified which relate to various facets of the multi-family weatherization procedure.

A survey of 21 WAP agencies in the more populous states identified six which have little or no need for a multi-family program. Eleven indicated having no distinct provisions for multi-family buildings even though some retrofit work is performed. Four states use computerized single-family audits into which multi-family measures have been added. No state used a program specifically designed for multi-family buildings.

The multi-family retrofit programs of four private organizations are reviewed to help establish their potential contributions to the development of a WAP multi-family procedure. The Center for Neighborhood Technology of Chicago appears to have the most complete and user-friendly computerized audit for multi-family weatherization, though considerable modification would yet be required to permit its general use in the WAP. However, the program is not public domain. The Minneapolis Energy Office's program uses a multi-family audit designed specifically for the building stock in their area. Fast payback measures are installed on the basis of observed applicability rather than any computed criterion. Considerable research has been performed on the energy savings potential of many of the measures included in their audit, which should benefit development of a WAP procedure.

Four energy analysis computer programs appropriate for application to multi-family buildings are discussed. ASEAM 2 and CIRA were developed under DOE sponsorship and would be available as starting points for a WAP multi-family procedure. However, the first lacks an actual measure selection algorithm and has considerable input requirements. The second was developed primarily for single-family buildings and would, therefore, require enhancements.

Recommendations for the development of a WAP multi-family measure selection technique include:

- independent development from the single-family audit procedure;

- further investigation into the cost-effectiveness of implementing currently available copyrighted multi-family programs where the need exists;

- identification of approved measures and their applicability to various building categories, equipment types, and fuels; and

- examination of the CIRA and ASEAM 2 computer programs to determine the number and difficulty of adaptations required to produce a program appropriate for the WAP program.

# 1. INTRODUCTION

## 1.1 BACKGROUND

Government funded weatherization assistance programs resulted from increased oil prices caused by the 1973 oil embargo. These programs were instituted to reduce U.S. consumption of oil and help low-income families afford the increasing cost of heating their homes. The earliest programs were managed by the Office of Economic Opportunity, later called the Community Services Administration (CSA). Upon enactment of the Energy Conservation in Existing Buildings Act of 1976 and the formation of the Department of Energy (DOE), formal control of the Weatherization Assistance Program (WAP) was placed under DOE, which presently directs the program. Other government programs, however, exist alongside the WAP. The Department of Health and Human Services (HHS) manages the Low-Income Home Energy Assistance Program (LIHEAP). Additional funds for energy conservation in homes are provided by the Petroleum Violation Escrow Fund administered by DOE and the Department of Housing and Urban Development's (HUD) Solar Energy and Energy Conservation Bank (GAO, 1985).

Under the present organization, the Weatherization Assistance Program is administered by the Office of State and Local Assistance Programs (OSLAP) of DOE. Ten regional support offices report to six Operations Offices located throughout the U.S. The operations offices report to the Secretary of Energy in Washington. Each regional office also has assigned a WAP Liaison in Washington which assists in answering specific questions regarding the program.

The regional offices oversee designated state offices, called grantees, which are the actual recipients of the WAP funds. The state offices contract with local agencies, called subgrantees, to perform the weatherization of homes. The subgrantees may be either non-profit, non-government agencies called Community Action Programs (CAPs) or other non-profit or government organizations, such as the Alliance to Save Energy (ASE) and the D.C. Government (Schweitzer, 1987).

With the necessity of weatherizing the low-income housing stock came the need for direction on how best to reduce residential energy consumption. Project Retrotech "evolved from efforts by the Department of Energy to fill a need expressed by various consumer groups. State and local agencies that use Federal and State funds to weatherize the homes of fixed- and low-income people have pointed out a need for a source of technical know-how to improve the effectiveness of their weatherizing measures" (DOE, 1978). Published in 1978, Project Retrotech provided a manual means of determining what energy conservation measures might be implemented in residences to maximize the energy savings per dollar expended in the project.

However, several factors dictate a need for revision or replacement of this earlier audit. Program changes have altered the assumptions upon which the original measure selection technique was based. The number of approved measures and materials allowed by the current program is greatly expanded from that initially considered by Retrotech. Heating system retrofit or replacement is now included in addition to many new building-envelope measures. However, means of evaluating the new measures and their interactions have not been added. The expenditure limit has been increased and the applicability of this limit is allowed on the average rather than per residence, adding further flexibility in implementation. In addition, the needs of residences in cooling climates and multi-family buildings are not sufficiently addressed in present programs, adding to the need for further investigation.

Technological advances have opened new possibilities to increase the effectiveness of measure selection techniques. Blower doors can assist in detecting air leakage locations in a house and establish when sufficient infiltration retrofit work has been performed. Support for use of a blower door in an updated measure selection technique could encourage their use and increase the cost-effectiveness of the entire program.

With the increased complexity presented by the expanded acceptable measures list, the use of a computer to rank applicable energy conservation measures may become advantageous. Many WAP agencies already use personal computers to store records or generate reports and work orders. The availability of a computerized measure selection technique could further facilitate their weatherization programs.

These factors have led many states to initiate their own programs for the purpose of developing updated measure selection techniques. Thus, the absence of a DOE supported updated technique has contributed to considerable duplication of effort which might be further avoided if a common procedure were developed. In many instances, states have contracted the development work to private firms, whose products are then copyrighted and, therefore, not economically transferable to a large number of agencies.

## 1.2 PURPOSE AND APPROACH

The DOE WAP initiated a project with the Oak Ridge National Laboratory (ORNL) in the summer of 1988 to maintain and improve the technical foundation and cost-effectiveness of the WAP. Within the scope of work for this project was the task to upgrade or revise the Project Retrotech. Preliminary to the fulfillment of this task was the need to survey current practices and perceived needs of users at the state and local level in order to (1) verify the need to revise the Retrotech audit and (2) determine the form of the revision and issues to address. Current means of measure selection were to be compiled, identifying weaknesses, strengths, and innovations.

This report has been prepared as a result of an ORNL evaluation of weatherization measure selection techniques for the DOE WAP. The objective of this initial task was to gather information on existing single- and multi-family weatherization programs, review measure selection techniques, determine needs of users, and make recommendations for improving the measure selection procedure for WAP.

The approach used for this task was to (1) review the literature assembled on weatherization measures for single- and multi-family buildings, particularly several associated studies, (2) survey various individuals and organizations active in weatherization to obtain procedures for measure selection and information on various issues relevant to the measure selection process, and (3) evaluate the status and needs of state agencies through contacts with WAP personnel.

As the study progressed, it became clear that most of the information sources, issues, and procedures examined were more related to either single- or multi-family buildings, rather than the two combined. Thus, the majority of this report addresses these two building types separately.

# 2. SINGLE-FAMILY PROGRAM STUDY

## 2.1 CURRENT MEASURE SELECTION TECHNIQUES

A parallel study, also sponsored by the WAP of OSLAP, surveyed the current plans for implementation of the WAP program in the various states (Shaladia, 1988). Information for the report was taken from the 1988 "State Plans" submitted by each state, as required by WAP. Additional information presented here was received by personal contact with various individuals within the state or local agencies as well as other studies not directly surveying for information on the measure selection technique, e.g., the Alliance to Save Energy (ASE) survey of southern states (ASE, 1988). This section of the report will summarize the types of measure selection techniques found, saving discussion of the issues identified for Sect. 2.2.

Precise counts of how many states use a particular measure selection technique are difficult to assess. The Shaladia report partially attempts this, but some discrepancies exist for several reasons. First, there are many variations of a given technique, particularly Retrotech. Whether a modified procedure is still considered Retrotech may be a matter of opinion, not even consistent within a state itself. Second, each state typically contracts work to many subgrantees. The subgrantees within a state may use variations of a technique or even totally different techniques. Thus, the information on the techniques used by any given state may differ depending on who is contacted. Third, the techniques used by the states are constantly changing. A substantial number of states were found in various stages of developing, testing, or implementing new measure selection techniques. Best estimates are given below, but no attempt should be made to resolve any inconsistencies found when comparing with other sources.

Not unexpectedly, the Shaladia report found 35 of 50 states using Project Retrotech or a variation of this technique. For a specified list of potential energy conservation measures, Retrotech specifies calculations estimating total energy savings over the life of each measure, the associated dollar savings, and the cost of implementation. A savings-to-cost ratio is used to rank the measures in an economically justifiable order to insure implementation of the measures with the highest ratio first.

The manual calculations of Retrotech can be time consuming, particularly in light of the repetitions necessary if performed for every house involved in a state's program. However, Retrotech allows states to apply the measure selection technique to "typical" houses representative of the building stock existing in their state to generate generic "priority lists" of measures. These priority lists are then applied to each house belonging to the representative groups.

A variety of applications of Retrotech was found to exist in the states. Five states applied the technique to every house individually. One of these (Kentucky) had simplified the procedure by pre-calculating all parameters applicable to houses with specific characteristics. The data entry form was reduced from five to two pages. Alabama has also simplified its Retrotech entry form. Illinois, on the other hand, has developed a computer version of Retrotech which resulted in a program vastly different from its predecessor.

Other states have examined alternative methods of arriving at fixed priority lists of measures applicable to their building stock. California, Michigan, Massachusetts, and North Carolina have already implemented priority lists based on studies other than Retrotech. Minnesota, Oklahoma, and

Virginia are in the midst of developing new lists, while Delaware and New Mexico are considering doing so. These newer priority lists may be more detailed, including more house-type groupings than earlier procedures. Virginia is developing a technique which will be more house specific, having perhaps as many as 15 representative house groups, yet which can still be implemented without a computer. The project is seen as an interim step toward generating a fully automated audit and measure selection technique.

Some states have adopted comparatively complex measure selection techniques which use personal computers to select measures tailored to each house participating in the program. At least nine states are believed to have some type of computerized measure selection technique and Alabama is funding a utility to generate a computerized audit. These techniques vary greatly in complexity, as determined by both the detail of the input data and the sophistication and number of algorithms computing energy savings and costs.

The Illinois program ranks measures selected by the "assessor" in order of decreasing savings-to-investment ratio. The program has extensive data input (15 computer screens or more) and computes the whole house energy consumption whether or not it is needed for measure evaluation. It includes a mechanical equipment section which evaluates heating system retrofits or replacements. Other measures use the upgraded equipment efficiencies in their energy savings estimates. Infiltration measures are assumed mandatory and not ranked.

New York's program, EA-QUIP, is an adaptation of the CIRA program, developed by the Lawrence Berkeley Laboratory (LBL) (see Sect. 3.3.2). Although the program is also detailed, users generally report it being easy to use. Favorable features consist of user-friendly input including help screens and standard responses; adaptability allowing programmers to add or modify measures; infiltration, heating system, and envelope measures integrated into a single program; solar algorithms which would be necessary for implementation of cooling measures; measure interactions; and a job order form as possible output.

Wisconsin's program is copyrighted by the Wisconsin Energy Conservation Corporation (WECC), though the original version was developed by ORNL and would be available for adaptation. The WECC program contains equipment measures whose benefit-to-cost ratios are computed with the envelope measures. An infiltration procedure is included which accommodates use of a blower door.

Montana's measure selection technique, "Blanket," is not as complex as the Wisconsin or New York techniques. It considers fewer measures but has less required input. Montana experimented with the WECC audit but reverted to a simpler computerized procedure with less detailed input. New Jersey and Connecticut's computerized techniques were developed by utility companies as part of their Residential Conservation Service (RCS) program. They are also copyrighted and not available for reference.

Little is yet known of the computerized measure selection techniques used by Colorado and North Dakota. Idaho and Utah use the copyrighted "Manucomp" procedure, which has input similar to Retrotech. Idaho has apparently computerized the technique, while Utah has not.

## 2.2 ISSUES

In examining the currently available data on WAP measure selection techniques, certain basic issues associated with broad characteristics of a technique present themselves. Any development of an upgraded, DOE-supported measure selection technique must address these areas and choose the approaches to be implemented. The following section discusses these issues in light of information derived from WAP agency interviews and data from accessible reports and studies. The major issues include: (1) possible alternate structures for the upgraded technique, i.e., priority list or computerized selection with results unique to each house, (2) the incorporation of cooling measures into the technique, (3) the use of blower doors in infiltration reduction, (4) mechanical equipment measures, (5) economic criteria, and (6) appropriate weather parameters.

### 2.2.1 Measure Selection Structure

In considering the basic structure of the upgraded measure selection technique, two somewhat opposite approaches appeared most prevalent in the agency survey -- the priority list and individual measure savings calculations determining relative benefit. Many states have adopted fixed priority lists based on more detailed studies, some even finding a single list applicable to the majority of houses. Others have allowed their investigations to lead to detailed analyses which are applied individually to each house. Such methods normally require a computer to perform the calculations rapidly enough to make the technique practical.

In either approach, the primary objective remains the selection of the most cost-effective package of measures allowed within spending allowances. The specific ordering of measures is important only in its contribution to this end. Measures near the margin of acceptability may, or may not, have a large effect on the overall cost-effectiveness of the program.

This section will briefly discuss the application of each approach, their perceived advantages and disadvantages, and the potential of each in satisfying the needs for an updated WAP measure selection technique.

#### 2.2.1.1 Priority Lists

Many factors are involved in establishing when fixed priority lists may be considered an effective measure selection approach. Certainly, a single priority list is applicable to two identical houses located in similar climates and having comparable occupancy, both in number and life style. (Local energy costs may also be a factor if the ranking criterion involves energy cost, not simply energy saved.) However, if any one of these three broad categories of factors differs, potential exists for the same measure to have different rankings in two different houses. For example, the savings from installation of low-flow showerheads depends on occupancy (how many showers are taken) as well as the house's characteristics (the efficiency of the hot water heater). Although other measures may not be as sensitive to such factors, until the sensitivity is established, assumptions could likely lessen the efficiency of the weatherization program. The applicability of a specific priority list to a given house-type can only be established by an energy analysis technique capable of modeling all the relevant features of the measures and houses.

Apart from the question of whether a single list of ranked measures is applicable to two or more different houses, is the question of the correctness of the ordered measures themselves. If the analysis procedure used to establish the rankings is unable to correctly account for the major effects and interactions of the measures, the resulting ranked list may not be sufficiently accurate to be used on even the house for which it was specifically designed.

Nevertheless, under limited circumstances, priority lists may be appropriate. Retrotech recognized this situation in allowing such lists to be generated for representative groups of houses. Some have felt that this option has been abused, leading to reduced program effectiveness in many instances. However, several of the states contacted having extreme climates indicated that they had begun applying Retrotech to every house, but found the list of envelope measures which resulted to be the same most of the time. As the number of acceptable measures grows, the likelihood of a single list being applicable to a significant portion of homes retrofitted becomes less. Utah attempted to apply Retrotech to representative types of houses, only to find that local energy and retrofit costs dictated the need for over a hundred categories.

Fixed priority lists have advantages, if they can be shown applicable to the participating building stock. For instance, with a fixed list of measures, normally less in number than for a broad computerized technique, the building data required should be reduced. Retrofit crews could specialize in efficient installation of the specific measures included on the list. It might also be expected that the expertise of the auditor need not be as great since the measures are pre-selected. (However, the Massachusetts WAP director felt that use of a computerized technique tended to replace the detailed investigation of a well trained auditor.) A Michigan WAP representative felt that a computerized audit was less successful at determining the savings of a specific home than the average savings of a sample, while a good auditor could better evaluate individual houses. One Wisconsin CAP agency employee saw an advantage in having all agencies in the state apply the same measures so that local conditions would not affect the number of measures needing implementation, making uniform quotas more equitable.

#### 2.2.1.2 Individual Measure Savings Calculations

Measure selection methods which compute energy savings for specific measures can be applied individually to each participating house. Their applicability is more apparent than for priority lists. As additional measures are permitted in any particular program, their energy and economic computations are simply added to those of others formerly accepted. In contrast, addition of measures to a priority list may require initiation of an extensive evaluation procedure, depending on the process originally used to develop the list. Also, since development of priority lists requires initial evaluation of individual measure savings, only a technique capable of performing this function may be used to determine a priority list and potentially define its application.

Unfortunately, as the number of accepted measures increases, the complexity of manually computing the individual measure savings becomes cumbersome. If equipment measures are allowed, interactions between them and the envelope measures require added computational effort to insure selection of the most cost-effective measures. For example, with the increased efficiency of a newly installed furnace, less savings is incurred by adding insulation because less energy is required to provide the same heat output. This added complexity makes application of a particular measure selection technique individually to each house both more needed and difficult. With the addition of cooling measures and equipment and their potential interactions, further complexity results.

Nevertheless, there are indications that a degree of this complexity is required if program efficiency is to be obtained. One agency reported that more sophisticated energy determination techniques indicate some of the work traditionally performed on houses in their area is likely ineffectual. An ASE study of current audits indicated that "78% do not define an optimal package of measures or level of investment for individual homes" (Guyant and Hopkins, 1988).

The availability of a measure selection technique that can efficiently deal with this added complexity, yet retain the advantages of individually computing measure savings, prompts considering a computerized technique as the primary tool to be developed for the DOE WAP. The potential exists to create such a procedure in modules, each of which could be applied manually. The separate modules might address groups of similar measures, such as envelope, equipment, and infiltration measures. Thus, agencies without computers could yet benefit from the updated procedures, though the interactions of the various program segments would not be accounted for. Otherwise, as previously mentioned, the tool could be used to established verifiable priority lists for acceptably narrow groupings of houses, which could also be used without a computer.

The states contacted specifically for this study were asked what they felt were the advantages and disadvantages of a computerized audit and measure selection technique. The responses are summarized in Table 2.1. The majority gave the cost of purchasing necessary hardware as the major disadvantage. Yet many agencies are already purchasing computer-based machines to assist in word processing, program cost accounting, etc. Such machines may already be compatible with software allowing implementation of computerized audit procedures. If computerized techniques were available, future hardware purchases could be made with this application in mind. Nevertheless, it should not be assumed that all agencies will immediately have access to computers.

An associated disadvantage is the need to train users of a computerized technique. However, training will always be necessary whether a technique is computerized or not. In addition, with the user friendly systems which can now be developed, including help screens and computer tutorials, part of this task may even become easier, requiring less instructors' time. Several agencies had designated a specific individual or group to input the data, whose specialization permitted greater efficiency.

A disadvantage perceived by some weatherization staff was losing the advantage of an auditor's intuitive ability to discern the measures required or the capability of including less qualitative perceptions in the measure selection criteria. These criticisms may be valid, but their seriousness depends largely on the proficiency of the computer technique considered and the expertness of the auditor, both before and after implementation of the computerized audit.

A last criticism, regarding time to obtain input to a computerized audit, also depends on the form and proficiency of the technique. For instance, the amount of data required as input to a program which computes an annual whole-house energy consumption will undoubtedly be greater when compared with the simpler techniques. Yet, if the savings from an increased efficiency furnace is to be determined, a whole-house heating load must necessarily be computed. Unless the data entry on the auditor's form is logically ordered with required entries easily identified, more time will be spent on obtaining the data than is necessary, whether or not the measure selection technique is computerized. Several complaints were of this nature. The amount of data required also depends on the number of measures the technique considers. Here, elimination of input at the expense of potentially cost-

**Table 2.1. Computerized audit/measure selection technique advantages and disadvantages from State Representatives.**

| Characteristic | Number of State Representatives Holding Opinion |
|---|---|
| Disadvantage | |
| Cost of implementation | 5 |
| Need for training personnel | 3 |
| Loss of flexibility | 2 |
| Increased time to obtain inputs | 2 |
| Need for multiple trips to site or on-site input of data | 1 |
| Advantage | |
| Interface with report generation and cost accounting | 9 |
| Increase data handling capabilities | 5 |
| Cost effectiveness of selected measures | 5 |
| Savings of time and money | 4 |
| Ability to account for measure interaction | 2 |
| Assists in program evaluation | 2 |

effective measures would not be advantageous. A measure selection technique should be developed in which the necessary input is kept to a minimum, perhaps tailored to the climate or building stock applicable. In opposition to this criticism, states already having computerized audits indicate that data collection is not necessarily more time consuming and, in some cases, can even be more streamlined.

In areas of low population, such as in some parts of Utah, where large distances separate the houses retrofitted and the agencies performing the work, only one trip is made to each residence. In such situations, a manual measure selection technique would be required, unless portable personal computers were available.

Advantages given for use of a computerized measure selection technique included (1) the ability to tie into report generating software or program cost accounting and evaluation techniques, (2) high speed handling of large amounts of data, (3) the increased cost-effectiveness of the implemented measures, characteristic of measure lists unique to each house considered, and (4) the ability to handle more complex calculations, such as would be required to determine measure interactions, providing more accurate estimates of energy saved. Provided the disadvantages stated above can be mitigated, these stated advantages provide valid reasons for considering computerization of a measure selection technique in most applications.

#### 2.2.1.3 Summary

Advantages and disadvantages exist for both general forms of measure selection techniques discussed in this report, priority lists and computerized audits applied individually to each home. Also, there are likely applications appropriate to each. Indeed, DOE may find it necessary to make available alternate procedures. The most effective technique may likely be dictated by the climate, building stock, and measures to be considered in a specific location. Advantage is not always gained through increased complexity or expanded candidate measure lists. In some western states where a particular subgrantee may work mostly with adobe structures, many of the detailed energy calculations performed for more traditional houses are of little use. The "best" technique for a specific application will be that one which maximizes the cost-effectiveness of the program with the least degree of effort.

Thus, because priority lists have only limited applicability, which can only be determined by a procedure capable of computing the savings of individual measures in specific houses, it appears necessary to develop a computerized technique capable of addressing the many pertinent factors involved. However, a simplified manual technique should also be formed from the more complete tool which may be used by agencies either not requiring the added detail or who do not have computers. The primary tool may also be developed in modules, each capable of being independently implemented without the need of a computer. However, some accuracy would be forfeited due to the loss of the modules' interactions.

### 2.2.2 Cooling Measures

One of the factors motivating the development of an upgraded measure selection technique was the need to consider measures applicable in predominately cooling climates. None of the techniques discussed in the survey of state WAP programs sufficiently addressed this area. The majority of the following information regarding cooling measures originates from either personal conversations with the state WAP directors, draft comments of a study performed by the Alliance to Save Energy,

"Southern States Survey Results, Weatherization/LIHEAP Program Directors," (ASE, 1988) or an ORNL draft report, "Appropriate Conservation Measures for Single-Family Buildings in Hot Humid Climates," (McLain, 1985).

In order to save energy by implementing cooling measures in a home, that home must have some form of cooling equipment. Many concerns of state directors centered around the health of the occupants, particularly the elderly, in hot climates. Yet, some state WAP representatives indicated that unless cooling equipment existed, there simply was nothing that could be done with respect to cooling. No matter how uncomfortable families were in the summer, no measures could be implemented that would either save energy or help the families pay for their energy needs.

Louisiana personnel expressed direct concern for the effect the lack of cooling measures has on low-income, elderly, and disabled residents. The increased death rate during extremely hot weather has become an issue. Of the 14 southern states contacted and specifically asked about cooling, nine had some form of "crisis" program, however inadequate, to address these concerns. Only five indicated they had little or no concern with regards to implementing cooling programs.

Cooling measures either suggested or presently implemented by states under all programs, not simply WAP, include the following:

Window shading
Reflective films
Radiant barriers
Screens to allow for natural ventilation
Box, window, or ceiling fans
Air conditioning tuneups, repair
Evaporative cooling
Evaporative cooling replacing A/C
Air conditioning
High efficiency air conditioning

Two of these measures, installing evaporative cooling or air conditioning where no cooling equipment had formerly been present, are installed with other than WAP funds, not to save energy, but for the health of the occupants. The ORNL report (McLain, 1985) demonstrates that ceiling and wall insulation and infiltration reduction can also be effective measures in hot and humid climates, although in most instances their benefit during the heating season must also be considered to make their implementation cost-effective.

The difficulty in estimating energy savings for several of the above measures should be noted. Savings from shading devices rely on the amount of sunlight they can block, which is highly dependent on orientation, time of day, and cloud cover. Energy savings from use of natural ventilation induced by the installation of screens depends on the resident choosing to open the windows rather than run an air conditioner. Fans may increase comfort but must also be used in place of air conditioning in order to save any energy. Other difficulties are not hard to envision.

The Louisiana WAP director had concern for the interaction of winter and summer energy conservation measures. Though they add insulation to reduce winter heating needs, they sometimes receive complaints that the houses are harder to cool down at night in the summer. Thus, some basic

questions will have to be addressed in implementing cooling measures, particularly into the WAP program.

### 2.2.3 Implementation of Blower Door Procedures

Blower-doors were developed in the mid-1970s as a means of quantifying the leakiness of a house to air infiltration. The equipment used includes a fan mounted into the envelope of the house to be tested, usually in a door, and instrumentation which allows determination of the pressure differential across the house envelope and the volumetric flow rate of air (e.g., cubic feet per minute) passing through the fan. Since all air passing through the fan must enter or leave the house by other paths, the flow rate of air through the fan is a measure of the leakiness of the house at the pressure differential recorded. Although under normal conditions the house is not subject to the pressure differential created by the fan, approximate correlations or procedures exist to estimate the air infiltration of the house under more natural circumstances.

Studies have indicated that the use of blower doors in a low-income single-family home weatherization program can reduce the overall cost of the program (Gettings, 1988). Blower doors may be used to determine if a house really needs extensive infiltration reduction measures, which are usually labor intensive tasks. If the initial measured leakage rate is already sufficiently low, funds routinely used for infiltration rate reduction may be assigned to more cost effective measures. Measuring the leakage rate with the blower door during infiltration reduction procedures can help weatherization crews know when enough work has been performed, again saving funds which can be applied to other measures (WECC, 1988).

Blower doors can also be used to locate leaks. At the increased pressure differential created by the fan, air passage into or out of a house is more pronounced, allowing easier identification of the leakage paths. Some states are using blower doors to train their retrofit crews in locating leaks, even though the doors are not actually used in retrofitting individual houses.

State WAP directors were asked how, if at all, they use blower doors in their program and what advantages or disadvantages they could see in their use. Table 2.2. summarized their responses. Eight of the 19 state agencies asked and responding to the question did not use blower doors in any way in their program. However, six of the eight not using the devices were southern states, where infiltration is a less serious energy consuming problem. The most common uses for the blower door were in locating leaks and training crews. Other uses cited were to determine when to terminate infiltration reduction efforts and to provide input to energy savings estimates. Most states indicated the advantages of reduced cost for the retrofit through eliminating or reducing the amount of infiltration work performed on houses which are already tight.

Indiana is beginning to use blower doors extensively in conjunction with Project Retrotech. They are discovering that the results of blower door tests are dictating elimination of much caulking, which would normally have been performed under Retrotech without use of a blower door. Utah has mandated that every house undergo a blower door test. "A pre- and post-blower door test is required on all dwelling units... A 30% minimum reduction in the Leakage Ratio is required on all dwelling units after the following items have been addressed: 1. broken glass,..." The state plan indicates that where the above is not possible, it must be documented for review. Wisconsin has implemented use of a blower door into its program and has established definitive criteria for establishing how much infiltration work should be performed (WECC, 1988).

**Table 2.2. Use of blower doors in state WAP programs.**

| Use/Advantage | Number of State Representatives Indicating Use |
|---|---|
| Locating leaks | 9 |
| Training retrofit crews | 7 |
| Increased cost-effectiveness of program | 6 |
| Determine amount of infiltration work to perform | 5 |
| Provide input to energy savings calculations | 2 |
| Provide infiltration rating of home | 1 |
| Not using blower doors for any purpose | 8 |
| Disadvantages | |
| Time required to perform test | 3 |
| Cost of equipment and training | 2 |
| Simpler methods exist to locate leaks | 2 |
| Houses too leaky to measure | 2 |
| Difficulty in contracting work | 2 |
| Disruption to occupants | 1 |
| Unproven savings | 1 |

The major disadvantages to the use of blower doors were the initial cost of the equipment and the need to train crews in their use. One agency indicated that they would have to purchase about eight doors at approximately $1500 each. They preferred using these funds to retrofit houses instead. On the other hand, another agency cited the large number of homes they retrofit and indicated that even a small savings per house resulting from use of the blower door was cost effective.

Other comments included that use of a blower door would "suck up" the house, referring to the poor construction of many of the residences retrofitted. A similar situation is presented by those homes which are so leaky, the blower door cannot establish a pressure differential across the house to allow a measurement. Others indicated that they can often see the cracks in the envelope or use smoke pencils to locate smaller leaks. Another disadvantage cited was that use of the blower door would slow down retrofit crews. Another state, though in favor of their use, stated a concern regarding the disruption to the occupants associated with performing the tests, especially for homes with wood stoves, which must be extinguished for the test.

Massachusetts refers to a 1986 study by the Massachusetts Audubon Society (MAS, 1986) which states, "these findings indicate that infiltration reduction is a poor indicator of fuel savings performance, and that pre-screening to locate houses that will benefit most from house doctoring based upon initial infiltration has minimal value."

Thus, though there may be difficulty verifying the energy saved by some infiltration work, the use of blower doors in weatherization programs normally produces reduced costs and greater consistency of measure implementation. Although some states do not use blower doors, none had made this decision based on previous use.

### 2.2.4 Regional Issues

Several regional issues were identified during the study. Most were anticipated, but several additional issues arose. Resolution of these concerns will not be attempted in this report, but they should be considered during the measure selection development process. Their existence supports the need for a measure selection technique that can be adapted to the specific circumstances found in each agency. This could possibly be accomplished through a "setup" routine executed during the installation of a computerized audit. Regional differences indicate that if priority lists are used, they must yet be developed using a technique which can recognize the peculiar factors inherent in the individual agencies.

Climatic differences among the agencies will always produce varying needs. The most obvious is the need for cooling measures in some states, not applicable to others. In hot, dry climates, evaporative cooling may be a viable option to air conditioning. In milder climates, the present condition of some structures may prohibit blower door testing, or any infiltration related procedures, until basic repair work is performed. One agency reported finding buildings whose roofs were so deteriorated, they could "see sky" through them. Several southern states objected to the WAP funding allocation formula which biases the allocation toward the states with colder climate, i.e., with primary concerns for heating measures.

Construction differences in the states also produce differing needs amongst the agencies. This was demonstrated by one state's need for a "plantation" category in its Retrotech generic building types. Another expressed concern over implementing any electrical consuming measures in many of their

low-income housing stock because the wiring was often so poor that doing so could cause an increased fire hazard.

The availability and cost of fuels may also cause regional differences. Arizona encourages replacement of electric heaters with wood burning stoves on Indian reservations. Other areas may have codes against wood burning stoves, etc. The use of portable, liquid-fueled, room heaters in some areas causes concern that normal tightening of the house could cause a health hazard from the heaters' fumes.

On the other hand, no concerns from the various agencies were expressed regarding the availability of appropriate labor or technical expertise to perform tasks such as blower door measurements, furnace efficiency tests, etc. in single-family buildings. Such may not always be the situation for WAP auditors in multi-family buildings (see Sect. 4.2.1, State Programs).

### 2.2.5 Integration of Audit Segments

The total implications of integrating the mechanical, envelope, and infiltration segments of the audit procedure are not yet fully appreciated. Advantages and disadvantages are seen in both approaches. Performing and ranking heating system measures together with the envelope and infiltration measures appears to allow more accurate ranking of all measures in the least time. However, problems are encountered for several reasons. Many of the measures' effects on energy consumption are dependent on one another. Because of this interaction, the truly economic ordering of the measures depends on exactly which measures are implemented. Thus, an optimum package can be determined only if all possible combinations of two or more measures are evaluated as packages. Yet, it is seldom practical to compute an economic parameter for so many combinations. Some assumptions must be made, compromising the benefit of the measures' integration.

Similar problems are encountered when measures are mutually exclusive, such as the installation of a flue damper into the stack of the original furnace and total replacement of the furnace system when the new system includes a damper. The ranking must then consider an either/or situation.

The data required to perform an accurate ranking of the measures in an integrated manner may be difficult or impossible to obtain. For instance, in order to rank infiltration retrofits with envelope measures, not only is the initial infiltration rate of the house required, but also the reduction in rate attributable to the infiltration retrofits. Such information is seldom known until after the weatherization of the building. Similarly, correct evaluation of heating system measures requires the size and efficiency of the mechanical systems both before and after weatherization.

It is not always possible to perform the audit segments concurrently or in an appropriate order. Agencies may need to contract out the mechanical systems segment of the audit or the infiltration work. It may not be cost-effective to have such crews make multiple visits to the building to first collect the data and then to perform the designated retrofits.

Finally, if an agency does not wish to implement a program containing all segments at a particular time, the existence of distinct envelope, infiltration, and mechanical systems modules permits ease in adopting only the desired segments.

None of the above problems may be insurmountable in developing an integrated audit; some may not even be applicable in all situations. However, they need to be considered in the development of an upgraded measure selection technique. It appears that the upgraded method could accommodate both integrated and modular approaches at the discretion of the user.

### 2.2.6 Other Issues

Particularly in low-income retrofit, where houses tend to be older, equipment retrofits or replacement should be considered. The majority of states addressed this issue in some form or another. Many attempt repair or retrofit of the present system until the cost of doing so becomes a prescribed percentage of the replacement cost, frequently 50%. Illinois has an entirely separate program for "mechanical systems," which includes manuals on implementation and installation. Wisconsin incorporates furnace replacement into its measure selection technique. Hopkins (1988) indicates that proper installation of flame retention burners in oil heat systems is an effective conservation measure for low-income programs and that installing new, high efficiency replacement heating systems accounted for a large portion of the savings for one field test. On the other extreme, a preliminary study performed by the Ohio WAP agency showed heating system retrofits not as cost effective as other commonly installed measures.

The states were asked about the economic criteria used to prioritize measures considered in their program. Since a great many states use the Retrotech Program, their economic criterion was already determined as the benefit-to-cost ratio over the life of the retrofit. This constituted 17 of the 26 states surveyed on this item. Another four, using other forms of measure selection techniques, also had this as their economic criterion. Benefit-to-cost analysis over the life of the measure is specified by DOE (1986) as the prescribed economic procedure, where the savings are assumed to be discounted over the life of the measure. Two agencies said they used simple payback, which does not take into account the savings and cost over the life of the retrofit. The remaining three used savings-to-investment ratio (SIR) (likely the same as benefit-to-cost), discounted payback, or did not know. None were found to use internal-rate-of-return or net-present-value techniques. A key factor in any economic evaluation involving discounted costs and savings is the discount rate chosen. Further study will be required to determine appropriate values for this parameter.

Guyant and Hopkins (1988) recommend using discounted benefit-to-cost over the life of the measure as the economic criterion for establishing measure cost-effectiveness. Whether the costs include maintenance, repair, or replacement costs is not indicated. The ASE is currently funded to investigate economic factors of the measure selection process for WAP. Coordination of efforts will be pursued.

All but one of the selection techniques used simple or adjusted heating degree days as the weather parameter. Degree day calculations have inherent uncertainty involved in their use, as indicated by the number of adjustments necessary. New York's measure selection technique, however, uses a variable base degree day method. Such may be necessary for more accurate estimates of energy savings from measures (Wortman and Christensen, 1985). When cooling measures are considered, cooling degree days appear as a logical choice for incorporating weather effects. However, due to the decreased indoor-outdoor temperature difference in the summer (a 50 degree difference in winter indoor-outdoor temperature would not be unusual, but summer outdoor temperatures seldom reach 120 degrees, assuming a 70 degree indoor temperature) and the important contribution of solar loads, cooling degree days offer even less accurate estimates. Also critical are the limited number of cooling

degree day data available. If shading devices are shown to be a viable cooling measure, appropriate solar parameters will have to be provided to estimate their savings. Additional investigation needs to be conducted in the area of appropriate weather parameters.

## 2.3 ENERGY SAVINGS ESTIMATES AND VERIFICATION

Estimates of energy savings from implementing individual energy conservation measures are necessary for most weatherization programs in order to determine which measures should be installed. For those states performing analysis on every house participating in the program, these estimates are obtained repeatedly throughout program implementation. For those who use priority lists, a general study, including energy saving estimates, is required to generate the priority list. In almost all instances, the determination is made using engineering estimates of savings from theoretical considerations. Insufficient experimental data are available to allow such decisions to be based on actual field data.

This report will not examine the individual algorithms used by the state programs in arriving at energy savings estimates. Most are based on the same general physical principles, yet with countless variations in their implementation.

What is of primary interest, however, are investigations which offer verification of these estimates based on actual installed conditions. Such offer validation of the energy savings assumed to occur from conservation programs. A previous study, performed for the DOE by the Meridian Corporation (Meridian, 1988) compiles many evaluations of this nature. The Meridian report divides the evaluations into those which attempt to establish whole program effectiveness, and those investigating individual measures. The Meridian report summarizes WAP program evaluations in Illinois, Massachusetts, Michigan, Minnesota, New Hampshire, Ohio, Vermont, and Wisconsin. The report also outlines studies on the energy savings from water heater insulation and timers, heat pump modifications, furnace retrofits, flame retention burners, storm windows, infiltration control, and radiant barriers. Additional measures and program studies, specifically related to multi-family buildings, are referenced in Sect. 3.2.2 of this report.

The only single-family building verification analysis uncovered for this current study, not described in the Meridian report, was an attempt made by the California State WAP agency to prioritize its measures on the basis of installed performance. Although some performance data were used in the determinations, the study primarily fell back on engineering calculations due to insufficient definitive field test results. Estimates of program energy savings ranging from 6% to 24% were obtained from a sample of 113 California houses using utility billing data to establish energy savings.

## 2.4 CONCLUSIONS OF THE SINGLE-FAMILY PROGRAM STUDY

The following conclusions are based upon the information obtained through contact with the state WAP directors, examination of the currently available measure selection techniques, together with recommendations from other studies cited in this report.

**None of the currently available measure selection techniques sufficiently addresses all the elements deemed necessary as part of the upgraded technique, though several procedures will likely provide valuable input or form a starting point for the development.**

Although ten state measure selection techniques were found to be computerized, none appeared general enough to allow application by agencies with significantly different weather or housing conditions. Many were proprietary, restricting their use. None of the techniques examined addressed cooling measures sufficiently. Illinois' program is proprietary and likely too complex to be used by many states. CIRA, the parent program of New York's procedure, and the earlier version of the WECC audit are both public domain and offer potential as a starting points for modification. They contain many of the elements perceived as necessary and find substantial user approval. However, the WECC audit and its predecessor are written in Lotus, which makes adaptability difficult. If used, the algorithms would probably be translated into a more friendly computer language. Montana's program could also be considered a possible starting point upon which to build. Considerable upgrading would be required to incorporate the measures desired for the DOE product into Idaho's computerized version of Manucomp.

**The updated measure selection technique should include equipment retrofits and replacement as ranked measures and account for associated interactions with other measures.**

Sufficient data exist to indicate that substantial energy savings can result from equipment measures if installed correctly in those homes that can most benefit. Including such measures into the ranking procedure will help insure their cost-effective implementation. Most states indicated the availability of furnace efficiency tests within their program. Regional differences will likely have to be addressed to properly incorporate equipment measures into the primary selection tool. Guyant and Hopkins (1988) advise that "audits should account for the energy saving interaction that occurs when insulation and heating system measures are mixed." However, the technique should also allow separation of the heating system component if individual agency needs require it.

**Means should exist for adapting the primary measure selection technique to meet local needs.**

All applications of the measure selection technique may not require the completeness or complexity of the primary tool. All agencies should not be required to use all features of the audit on every house. The technique could be developed in modules, each of which might be implemented independently by agencies requiring its specific function. Such modules would likely be capable of being implemented without a computer, though their interaction would be lost. Local conditions may allow proper measure selection from a reduced menu of measures or by a subset of algorithms likewise not requiring a computer for their evaluation. Where data are no longer needed to properly evaluate all applicable measures, it should be deleted from the input form and associated computations eliminated. The primary tool may be the means of producing and validating simpler techniques appropriate to specific regions or applications. Regional issues identified in this report will also have to be considered.

**Cooling measures and their energy savings must be incorporated into the measure selection process.**

Although the need for cooling measures may not exist in all regions, their necessity in others has been demonstrated. Implementation of cooling measures often relate to the health and well-being of the occupants. Local agencies may require guidance in determining funding for such measures when health or comfort are the factors driving implementation. Low-income homes without air conditioning are common in some areas. In such instances, energy cannot be saved by incorporating cooling retrofits, no matter how unbearable the climate. The existence of other local and government funded programs must be considered.

**The upgraded measure selection technique should be based on new infiltration reduction procedures and be able to fully utilize results of blower-door measurements.**

The use of blower-doors within the infiltration reduction procedure has been shown to reduce program costs through helping to locate leaks and determine when work should be terminated. Their application is not yet universal, and may never be, particularly in warmer climates. Thus, different levels of improved infiltration reduction procedures should be identified and provision made to accept several forms of input relating to infiltration. However, full advantage should be made of having blower-door data fully integrated into the selection technique, not only providing the greatest accuracy, but also encouraging its use.

**Measure selection should be based on benefit and cost estimates over the life of the measure.**

Some current techniques use a simple payback criterion, which may minimize first cost but does not necessarily produce the maximum savings over the life of the retrofit. Although such alternate methods may be provided, discounted benefit-to-cost estimates over the life of the measure, as prescribed by DOE (1986), should be the primary means of establishing a measures cost-effectiveness. This conclusion concurs with that of Guyant and Hopkins (1988).

**The primary measure selection technique developed for the Weatherization Assistance Program should allow implementation on a personal computer, though an alternate manual technique should also be formed.**

The increased number and complexity of currently accepted retrofit measures in the WAP warrants availability of a measure selection technique capable of accounting for the various measure savings and interactions possible in order to optimize the process. The addition of equipment and cooling measures into the program creates an even greater need for the increased complexity of calculations to be handled by personal computing devices. In addition, local conditions may require application of the technique on a house-by-house basis, further necessitating implementation on a computer to increase the speed of individual computations. The need is partially attested to by the ten agencies found already implementing such a technique or seeking to develop one. A significant number of other agencies are using PCs for other purposes, representing additional potential users for such a product. This conclusion is consistent with the recommendation of the ASE to "use advanced auditing techniques to select measures" (Guyant and Hopkins, 1988). However, for agencies unable to accommodate use of personal computers, an alternate technique incorporating as many state-of-the-art features as possible should also be made available. **User-friendly attributes must be incorporated into the computerized primary measure selection technique.**

To a large degree, the acceptance of any measure selection technique will depend on its user-friendliness. This is particularly true with a computerized technique. Appropriate attention must be focused on this area of the development project. The auditor's data sheet should be logically arranged and contain only those entries necessary for proper measure selection and program administration. (The form could perhaps be generated by the computer software following initial

setup indicating local preferences and restrictions.) The language in which the computer program is written should allow screen manipulation providing easy data input. Default values should be available (perhaps with the option of user selection during setup) and help screens or appropriate prompts should be incorporated. An ability to input comments specific to an individual home's audit should possibly be available. All reasonable effort should be made to make the use of the program as easy and logical as possible.

**Further investigation will be required to establish appropriate weather parameters to be use in the energy savings calculations.**

Commonly used heating and cooling degree-day calculations may not provide sufficient accuracy in determining the energy savings for the measures. Including shading devices as cooling measures will require a solar related parameter.

# 3. MULTI-FAMILY PROGRAM STUDY

Multi-family retrofit procedures are less well developed than those in single-family programs, in part due to the increased complexity of the multi-family building. While smaller multi-family buildings, in which each unit has its own heating and cooling equipment, may often be adequately addressed by single-family audits, larger buildings and those buildings with central equipment servicing multiple zones need special audits to address the differences from single family buildings. These differences include zones which are often isolated from each other having varying occupancy, exposure, and use characteristics and major differences in equipment measures for centrally heated and cooled buildings. As a building's volume-to-surface area ratio increases, mechanical system measures become increasingly more important compared with envelope measures. The large variety of heating and domestic hot water (DHW) systems used in multi-family housing increases the complexity substantially. Several of the currently used multi-family procedures rely on the uniformity of building stock in a specific locale to limit the factors which must be addressed.

No DOE-supported measure selection technique currently exists that addresses multi-family residences, particularly larger multi-family buildings with central mechanical equipment. Thus, the development of such a procedure necessitated a review of available sources of information on multi-family weatherization programs and procedures. The findings are presented in order of logical steps in the multi-family weatherization process. State WAP and private multi-family retrofit programs are summarized. The most common energy analysis computer programs and energy conservation measures applicable to multi-family programs are presented.

## 3.1 LITERATURE REVIEW

A substantial amount of literature exists relating to energy conservation in multi-family buildings. Literature containing information most applicable to the audit and retrofit procedures was examined for this study. The reports and papers reviewed suggest that the retrofit procedure for multi-family buildings presents the auditor and program manager with a complex process. It is beyond the scope of this work to examine this process in detail. The outline of elements that must eventually be addressed by a program, presented in Table 3.1. is included to provide an appreciation for the entire process and to help categorize the subject material examined in the literature review.

### 3.1.1 Participant Selection and Financial Management

The participant selection method used in a multi-family program differs from that which would be used for a single-family program. Tenants are often not charged directly for their energy use. Thus, their interest in implementing and maintaining energy conserving measures is limited. The initiative must be taken by either the building owner or manager, who may be skeptical of the potential worth of such work. Whether for a single- or multi-family program, participant selection based on previous histories of energy consumption from billing records would undoubtedly increase the effectiveness of the program. The inclusion of public housing into a particular program is also a question to be addressed. The decision may depend on what other programs are operating in a specific locale.

The DOE Office of Conservation and Renewable Energy publication, 10 CFR Part 440, states that "to the maximum extent practicable, the use of weatherization assistance shall be coordinated with

**Table 3.1. Elements of the multi-family weatherization procedure.**

1. Participant solicitation/selection, Program Management
   - Solicitation methods
   - Selection criteria
   - Consideration of public housing

2. Financial considerations
   - Administrative costs
   - Coordination of funds (LIHEAP, Oil overcharge, loan pool)
   - Public/private organization participation
   - Owner participation
   - Labor/Material costs
   - Allocation of funds ($/unit, benefit/cost cutoff, etc.)

3. Audit/Measure selection technique
   - Diagnostic tools
   - Infiltration measurement
   - Mechanical system efficiency/tuneup
   - Mechanical system and control complexity
   - Measure applicability
   - Measure ranking
   - Uniformity of building stock

4. Contractor selection/Crew training

5. Measure installation
   - Techniques
   - Repairs

6. Occupant/manager/owner education

7. Site inspection and quality assurance

8. Savings verification

9. Reporting

10. Overall program evaluation

other Federal, State, local, or privately funded programs..." Combined with the considerations of allocation limits per dwelling, mandated limits on labor versus material costs, and contractor fees, the financial factors in a multi-family program can become complicated.

Additional discussion of participant selection and financial management of programs is found in Freedberg and Schumm (1986), Waterman (1988), Burke (1988), and Sahagian (1988).

### 3.1.2 Audits, Measure Selection, and Installation

Multi-family retrofit procedures are less well developed than those in single-family programs, in part due to the increased complexity of the multi-family building. Table 3.2. lists seven of the major information sources reviewed for this report and the specific areas of the audit/measure selection procedure addressed by each. Brief comments on the references will be given below. Those desiring greater detail should examine the original documents.

Two studies address the relative complexity presented in diagnosing the energy retrofit needs of multi-family buildings. Dutt and Harrje (1988) concentrate primarily on boiler, DHW, and infiltration diagnostics in multi-family buildings. The International Energy Agency publication (IEA, 1987) is more general in scope, giving procedures applicable to many types of buildings, including multi-family. These two sources provide some of the most current data and techniques which should be incorporated into an updated audit procedure. However, neither present recommendations or procedures for implementation into weatherization programs.

Other sources consider building diagnostics, but not with the detail supplied by Dutt or the IEA publication. Yet, they give general procedures for conducting a building audit and obtaining specific information required for their individual evaluations. The McLain report (1984) describes the modifications made to the single-family RCS audit to adapt it for multi-family buildings. However, it does not address centrally heated or cooled buildings. The report includes a description of the audit procedure and methodology, audit forms and questionnaires, and calculational aids. The method was designed for implementation without a computer.

A relatively old publication, the Multi-Family Housing Energy Conservation Workbook, issued by the New York State Energy Office about 1980 (NYSEO, circa 1980), provides a manual, yet considerably detailed, procedure for auditing and retrofitting multi-family buildings. Charts and graphs are used in place of calculations in determining the energy savings. A decision tree methodology is included to help establish the applicability of measures. Its list of measures include maintenance and repair items. This procedure has since been replaced by a computerized technique, yet the information contained within the document could yet prove valuable in developing a new technique.

A procedure similar to New York's manual technique was introduced by the U.S. Department of Housing an Urban Development (HUD) in 1982 (HUD, 1982). The publication has an extensive building survey form and lists 50 energy conservation measures with methods of determining B/C ratios. The measures are then ranked according to descending B/C ratio. The survey form appears lengthy and manual calculations could be time consuming, but the measure savings algorithms should be reviewed for potential applicability in the upgraded technique.

**Table 3.2. Major information sources for the audit/measure selection technique.**

| | Audit | Measure List | Measure Applic. | Install. Proced. | Costs | Energy Calcul. | Measure Ranking |
|---|---|---|---|---|---|---|---|
| Dutt (1988) | X | | | | | | |
| IEA (1987) | X | X | X | | | | |
| McLain (1984) | X | X | X | | | X | |
| New York (1980) | X | X | X | | | X | |
| HUD (1982) | X | X | X | X | | X | X |
| DOE (1984) | | X | X | X | X | | |
| Mills (1987)[1] | | X | | | X | X | X |

[1]This document contains descriptions of computer programs which address these areas.

The 1984 DOE publication, Specification and Cost Manual for Energy Retrofits on Small Commercial and Multifamily Buildings (DOE, 1984), prepared for the Commercial and Apartment Conservation Service includes material specifications, installation guidelines, and labor and material costs for measures appropriate to small commercial and apartment buildings. The estimated hours of labor for installation of measures could be most useful when coupled with local labor rates. Sub-sections on recommendations and maintenance for each measure might also be helpful to an auditor, particularly one whose past experience was more in single- than multi-family buildings.

The last document listed in Table 3.2. DOE-Sponsored Microcomputer Tools for Buildings Energy Analysis: Applicability to Multifamily Retrofit Evaluation (Mills and Ritschard), catalogues 27 microcomputer simplified programs for whole-building energy analysis, listing general information on each. It examines in more detail four DOE-sponsored computer programs which would be available to adapt for multi-family use. The report concludes that "none of the four DOE-sponsored programs assessed in this review fills the needs of the auditors, weatherization program people, or analysts who are making retrofit decisions for multi-family buildings." More detail regarding the programs examined in this study will be given in Sect. 3.2 of this report.

### 3.1.3 Miscellaneous Areas

Other areas, of no less importance to the overall success of a weatherization program, yet of less relevance to this report, include contractor selection, crew training, occupant education, savings verifications, and reporting. Comments on two of these areas are included here.

Several sources have indicated the importance of occupant education in the success of their retrofit program. In the case of multi-family buildings, this needed service must be expanded to the building manager or maintenance personnel as well. Diamond and du Pont (1988) indicate that "the day-to-day decisions made by building managers greatly influence energy use in multi-family buildings, but their role has been underemphasized in energy conservation efforts." A yet unpublished DOE report indicates that programs stressing customer education were more often successful, based on total program cost per MBtu saved, than those not containing this element. Massachusetts has recently increased the emphasis on client education in its program.

Verification of the savings resulting from multi-family weatherization programs is difficult. Much of the research in current multi-family retrofit programs centers around evaluating the energy savings of individual measures or small packages of measures. The Minneapolis Energy Office has conducted numerous studies into the effectiveness of measures including boiler tuneups, steam balancing and venting, steam-to-hot-water conversion, outdoor reset and cutoff controls, and vent dampers (MEO, 1988). Examination of data from the Buildings Energy Use Compilation and Analysis (BECA) database has also provided valuable information on multi-family energy conservation retrofits (Greely and Goldman, 1989). Ability to predict savings from many measures, however, is yet very uncertain.

A study by The Energy Resource Center of St. Paul appears to come the closest to a full program verification. The measured energy savings resulting from a combination of envelope and heating system retrofits in 12 multi-family buildings was found to average 31 percent, compared to a 28 percent savings predicted by the computer program CIRA (Nevitt and Stefanson, 1986).

## 3.2 MULTI-FAMILY PROGRAMS

Government and private agencies were contacted to establish what multi-family weatherization programs may already exist. Individual agencies tend to specialize in various installation techniques or measures. While some approaches use sophisticated computer programs, others rely primarily on the experience of the auditor to decide which retrofits to
install, with no set checklist or procedure for determining their cost effectiveness relative to other measures. The following is a brief description of the information obtained from these contacts.

### 3.2.1 State Programs

Twenty-one state WAP agencies were contacted specifically to determine how they manage multi-family weatherization needs. Among those contacted were those states having the larger cities. Though responses varied, program needs and approaches can generally be placed into those categories shown in Table 3.3.

Six states indicated little or no need for a multi-family low-income weatherization program. Texas was the only state giving this response that might be considered to contain larger metropolitan areas. The second group of 11 states, including California, Michigan, and some agencies in Pennsylvania, use the same audit approach for both single- and multi-family buildings. These agencies may be indicative of those that perform audits only on small multi-family buildings with no central equipment. In such instances, most single-family measures are applicable and fewer measures unique to larger multi-family buildings apply.

The third group constitutes those states indicating that they basically use their single-family audit approach with several additional measures included specifically for multi-family buildings. Massachusetts fell within this third group. New Jersey and Ohio indicated that they use programs similar to the CACS program.

Two states, Wisconsin and some agencies within Pennsylvania, use the WECC computerized measure selection technique. Through several upgrades, this program has been made applicable to multi-family buildings of four or less units. The program allows modeling a building with as many as four separate zones, each with its own heating system. Thus, centralized heating systems are not addressed. A variety of heating system types and fuels provide the remaining flexibility which categorizes the program as applicable to multi-family buildings. Although a version for five or more units per building was to be available in 1988, development has been deferred due to a lack of staff and less than expected need. WECC currently uses a list of short payback, high savings measures which they recommend if applicable in a particular building. Many measures may be coupled with utility rebate programs.

Illinois and New York each have a computerized single-family measure selection technique into which multi-family measures have been incorporated. The Illinois procedure must "fool" the computer to allow modeling of units having ceilings/roofs not exposed to the outside air.

New York's program, EA-QUIP, appeared more complete than others examined. It is an adaption of the CIRA program developed at LBL (see discussion of computer programs in Sect. 3.3.2). Measures appropriate to multi-family buildings listed within the documentation included outdoor reset and cutoff controls, energy management systems, distribution system balancing, door closures, air

**Table 3.3. Multi-family weatherization program needs and approaches. (Twenty-One States Surveyed)**

| Response | Number of State Representatives Giving Response |
|---|---|
| Have little or no need for multi-family program | 6 |
| No distinct provisions for multi-family units | 11 |
| Similar to single-family procedure | 3 |
| Multi-family approach similar to CACS | 2 |
| Computerized technique integral with single-family procedure | 4 |
| Contracted to engineering firm | 1 |
| States mentioning two or more measures unique to multi-family approach | 7 |

leakage through elevator shafts, boiler ventilation air, and general maintenance and repair, e.g., checking steam traps in two pipe systems. Some of these measures are appropriate for buildings with central systems as well as individual unit systems.

The computerized audits used by both New York and Illinois, as well as the WECC audit, are not public domain procedures. They are copyrighted and could not be altered without permission of their originators. Obtaining such permission would most likely involve fees and possible restrictions on the resulting program's distribution. Seven states mentioned that their programs model two or more measures specifically appropriate to multi-family buildings. See the Sect. 3.4 on "Multi-Family Energy Conservation Measures."

### 3.2.2 Programs of Private Organizations

Private organizations--often non-profit subsidiaries of other companies -- have also become involved in energy conservation in multi-family buildings. Some are considered energy service companies (ESCO's) that obtain payment for services from the savings customers realize in their energy bills. Others cater to utilities or local, municipal, or area governmental agencies. Several programs are discussed briefly below. Additional information can be obtained by references to the reports and articles listed.

#### 3.2.2.1 Center For Neighborhood Technology (Chicago)

The Center For Neighborhood Technology (CNT) has been developing a multi-family weatherization program for the city of Chicago and the local utility since 1982. Currently used in Chicago's Energy Savers Fund (CESF), the "Multi-Family Building Audit" addresses envelope, mechanical heating systems, hot water, and lighting measures. Building and heating system characteristics from the auditor's visit are used in a computerized ASHRAE "bin" method calculation to estimate annual energy consumption for the building before and after weatherization. The predicted energy consumption of the building before weatherization is compared with actual consumption from utility bills. Data inputs that were based on estimates rather than measurements are adjusted or refined until the estimated and actual consumptions are within acceptable agreement. Savings and economic parameters are computed for each candidate measure individually, given material cost and measure lifetimes supplied by the user. Only after an auditor has chosen a package of measures from this initial list does the computer program compute interactions of the selected measures and provide a combined savings and economics for the package.

The audit appears to be a tool that could be useful in the WAP. The audit seemed to be easy to use, requiring only several hours in the field and office to complete, yet is one of the most advanced procedures specifically for multi-family buildings. A wide variety of measures are considered by the audit. Uncertainty in the accuracy of the audit's savings estimates remains a limitation, as with all multi-family programs, because so little research has been performed on individual multi-family measures. Another current limitation of the audit is that the auditor selects the package of measures to be recommended for a particular building. Standard procedures for infiltration reduction and hot water measures would also need to be developed and included in the audit if used in the WAP. Further details may be found in Evens (1986). Further development of the program is ongoing. The program is proprietary, but Mr. Scott Bernstein, executive director of CNT, indicated that the program is for sale (Bernstein, 1989).

### 3.2.2.2 Citizens Conservation Corporation (Boston)

The Citizens Conservation Corporation (CCC) of Boston is a non-profit energy service company (ESCO) retrofitting primarily low- and moderate-income multi-family buildings (Waterman, 1988). Their energy audit, developed by their own staff, is a variable-base, degree-day, method. Both mechanical and envelope measures are considered. Diagnostics may involve the use of a blower door or infrared camera. Building characteristics and retrofit costs are used in determining life-cycle economic parameters providing justification for their retrofits. Much of the company's success appears to stem from novel financing schemes and tenant incentive programs.

The company sometimes monitors buildings retrofitted by their program. Specific studies have been performed to establish the cost-effectiveness of individual unit metering and automatic setback thermostats in buildings weatherized by the company's program.

However, as with the CNT audit, CCC's energy analysis techniques are not public domain. Conversation with the vice-president of operations for CCC revealed little detail. Reference was made to the Waterman (1988) article.

### 3.2.2.3 Minneapolis Energy Office

The Minneapolis Energy Office (MEO) has conducted a weatherization program for Minnegasco (the local gas utility) since 1985 that includes both audit and financial services. The program focuses on lower-cost measures with short pay-back periods for two reasons: (1) the intent of the program is to achieve conservation investments, and (2) the buildings' owners must pay for the measures to be installed. Research performed by MEO prior to starting the program allowed the multi-family building stock to be characterized and methods of reducing energy consumption in the buildings to be developed.

Most of the buildings addressed in the program can be classified as three story walk-ups with 5-20 apartments having attic insulation and storm windows already installed. Most of the structures are brick, making the installation of wall insulation expensive. The buildings have primarily single-pipe steam systems with some two-pipe steam or hot water systems. MEO relies heavily upon this relative uniformity in building stock. It was indicated that they know quite well what will be most cost-effective from simply examining a building due to this uniformity and their previous experience.

MEO's standard audit includes a gas bill history study, which breaks consumption into individual components; boiler efficiency tests; hot water heater inspection; and examination of hallways and selected individual units. Their entire audit visit takes one to two hours. MEO's measure selection procedure is less formalized than those of CNT and CCC. It appears to resemble a priority list of measures. If no insulation is present in accessible areas, they will add a prescribed insulation level. Infiltration work will be performed, mostly around windows. Lighting is also addressed. They attempt to focus on the larger items shown in the past to be most cost-effective. These are primarily mechanical system retrofits. Steam distribution balancing is primarily performed in buildings equipped with single-pipe steam systems, although some boiler adjustments are also made. The emphasis in buildings with two-pipe systems is the installation of improved controls and, hopefully in the future, conversion of steam systems to hot water.

MEO uses fixed-price contracting, i.e., contractors have agreed on the cost of installing specific measures. Thus, once the owner reviews the recommended measures list and agrees on those to be installed, MEO personnel can immediately give him the cost of the installation by their approved contractors (Heim, 1989).

Research performed by MEO has resulted in the development and refinement of many conservation techniques for heating systems that could be used in the WAP. Their technical publications list includes reports on boiler tuneups, steam balancing and venting, steam-to-hot-water conversion, outdoor reset and cutoff controls, and vent dampers (MEO, 1988). This information can be used fairly systematically by trained auditors. However, no strict written audit procedures have been developed, and, as mentioned previously, their approach relies heavily on the uniformity of their building stock. An audit developed for the WAP will have to be broader because these similarities will not always exist.

#### 3.2.2.4 Energy Resource Center (St. Paul)

The multi-family energy conservation retrofit program at the Energy Resource Center of St. Paul relies heavily on the studies performed by the MEO. Their program is similar, installing most of the same measures and using fixed-price contracting. They use a fuel billanalysis to estimate the savings attributed to measures installed. They have little need for benefit-to-cost analyses. If prescribed measures are applicable, they will be recommended (Nevitt, 1989).

## 3.3 MULTI-FAMILY BUILDING ENERGY ANALYSES COMPUTER PROGRAMS

In addition to those computer programs discussed in the above sections, other building energy analysis programs applicable to multi-family buildings exist. Those most appropriate for use in a WAP measure selection technique have already been reviewed in a former report (Mills and Ritschard, 1987). A brief synopsis of the findings for the programs rated highest will be presented below.

### 3.3.1 ASEAM 2

Developed by W. S. Fleming and Associates, Inc., under contract to the DOE, ASEAM 2 (A Simplified Energy Analysis Method) "is a highly flexible program...intended primarily for commercial buildings, although in most respects it is suitable for multi-family buildings." However, "the building description procedure requires a substantial amount of information" and "it sacrifices user ease to an extent that may restrict its use by non-engineers" (Mills and Ritschard, 1987). Thus, the program would likely require some modifications to its user interface to permit use by WAP agency auditors. The program is also strictly a building energy analysis tool, not a measure selection technique. Routines for computing the savings of various retrofit options and then prioritizing those options would have to be incorporated.

### 3.3.2 CIRA

CIRA was developed in the early 1980s at LBL under DOE sponsorship. As its name implies, the Computerized Instrumented Residential Audit was designed specifically for single-family residences. Thus, modifications would include addition of multi-family measures and the capability to model multi-zone systems. However, the program has incorporated within it an actual retrofit measure selection technique based on economic parameters. CIRA is flexible and rated easy to use by the

Mills study (Mills and Ritschard, 1987), which also designates it as coming "the closest to the ideal retrofit analysis tool." The program is now marketed as an IBM-compatible PC-based program under the name EEDO by Burt Hill Kosar Rittelmann Associates in Butler, PA. However, the company indicates that because of certain enhancements, this version is no longer in the public domain.

### 3.3.3 Trakload

Written and supported by Morgan Systems of California, Trakload was given first preference in a City of Portland Energy Office study of microcomputer tools for multi-family audits. The program lacks ability to model thermostat radiator valves and DHW systems. The program is not public domain and would have to be purchased for use by individual agencies. Some of the other programs considered in the Portland study include ASEAM 2, CNT's program, CALPAS 4, and PEAR 2.

### 3.3.4 Multi-Family Building Audit (CNT)

The Center For Neighborhood Technology's "Multi-Family Building Audit" (see Sect. 3.2.1.1, "Center for Neighborhood Technology" above) ranked second in the Portland study. Like Trakload, the CNT program is not public domain.

## 3.4 MULTI-FAMILY BUILDING ENERGY CONSERVATION MEASURES

Energy conservation measures appropriate for multi-family buildings are listed in Table 3.4. The table provides a partial listing of those measures found most commonly in the sources cited. The IEA publication (1987) itself lists nearly 200 measures. However, many are operational and maintenance measures and others are applicable to only a narrow range of buildings. Nevertheless, the number of potential measures which must be considered in the development of a multi-family weatherization program is large.

Regional construction practices play a key role in the measures applicable in a particular locale. As was seen in the weatherization programs of some private organizations, considering only those measures common to their building stock can greatly reduce the complexity of a program. A national program, however, must address all typical constructions.

## 3.5 CONCLUSIONS OF MULTI-FAMILY PROGRAM STUDY

Multi-family retrofit procedures are less well developed than those in single-family programs, in part due to the increased complexity of the multi-family building and its systems. Mechanical system measures become increasingly more important compared with envelope measures as the building size increases.

The need for a multi-family weatherization measure selection program is not universal among the WAP agencies, justifying development of separate single- and multi-family programs. Adoption of currently available copyrighted programs for those agencies having such a need may also be warranted.

**Table 3.4. Multi-family energy conservation measures.**

| | References | | | | |
|---|---|---|---|---|---|
| Insulation | 1 | 2 | 3 | 4 | 5 |
| Radiant Barriers | 1 | | 3 | | |
| Multiple Glazings | 1 | 2 | 3 | 4 | 5 |
| Replacement Windows | | | | | 5 |
| Sun Shades | | 2 | | | 5 |
| Thermal Doors | | 2 | 3 | | 5 |
| Construct Vestibule | | | | 4 | 5 |
| Infiltration Reduction | 1 | 2 | 3 | 4 | 5 |
| Wind Screens | | | | 4 | |
| Incand to Fluorescent | 1 | 2 | | 4 | 5 |
| Ext Light Timer/Photocells | | 2 | | 4 | 5 |
| High Efficiency Ballasts | | 2 | | | 5 |
| Daylighting Controls | | 2 | | | 5 |
| Install Tenant Fuel Metering | | | | | 5 |
| Front-End Boilers | 1 | | | | |
| High-Efficiency Furnaces/Boilers | 1 | 2 | 3 | | 5 |
| Burner Replacement | | 2 | 3 | | |
| Turbulators | | 2 | | 4 | 5 |
| Modulating Burners | | | | | 5 |
| Preheat Boiler Air/Water | | | | 4 | |
| Boiler Ignition Systems | | 2 | 3 | | 5 |
| Repair/Replace Burner Nozzles | | 2 | | | 5 |
| Outdoor Reset Thermostat | 1 | | | | |
| Steam-to-Water Conversion | 1 | | | | |
| Vent Dampers | 1 | 2 | 3 | 4 | 5 |
| EMS | 1 | 2 | 3 | | |
| Individual Zone Controls | 1 | 2 | | 4 | 5 |
| Deadband Thermostat | 1 | 2 | | | |
| Clock Thermostat | | | 3 | | |
| Setback Thermostat | | 2 | | 4 | 5 |
| Tamperproof Thermostats | | | | 4 | |
| Steam Traps | | 2 | | 4 | |
| Replace Leaking Air Dampers | | 2 | | 4 | |
| Install Low Resistance Air Filters | | | | 4 | |
| Exhaust Fan Shutoffs | | | | 4 | |
| Add Warmup Cycle To Air Handlers | | | | 4 | 5 |
| Heat Recovery Devices | | 2 | | 4 | |
| Passive Solar Devices | | | | 4 | 5 |
| Air Conditioner Replacement | | | 3 | 4 | 5 |
| Economizer Controls | | | | 4 | |
| DHW Heater Insulation | 1 | | 3 | 4 | 5 |
| Tankless Waterheater | 1 | | | | |
| Summer DHW Heater | | | | 4 | 5 |
| DHW Setback | 1 | | | | |
| Flow Restrictors | | 2 | | 4 | 5 |
| Solar DHW | | 2 | 3 | 4 | 5 |
| DHW Off Peak Controls | | 2 | | | 5 |

Sources

1- (Mills and Ritschard 1987)
2- (IEA 1987)
3- (McLain 1984)
4- (NYSEO circa 1980)
5- (HUD 1982)

The CNT program appears to be the most advanced procedure specifically designed for multi-family buildings. The program is copyrighted and available for sale. Inquiry might be made into permitting DOE to examine the program in greater detail in exchange for a potential recommendation to WAP agencies for its use as an acceptable interim product.

The two sources, Multi-Family Building Energy Diagnostics Technical Reference Manual (Dutt and Harrje, 1988) and IEA's Source Book For Energy Auditors (IEA, 1987) provide some of the most current data and techniques which should be incorporated into an updated audit procedure.

The CIRA and ASEAM 2 public domain energy analysis computer programs appear to offer greatest potential for starting points of a computerized multi-family audit. Each, however, has a major deficiency requiring further study before conclusive decisions could be made.

Many energy conservation measures are currently available for multi-family buildings. A significant step in developing a national multi-family weatherization program for WAP lies in identifying the applicability of these measures in the diverse building stock to be addressed.

Ongoing and future research into the effectiveness and applicability of measures and techniques applicable to multi-family building weatherization program dictates that any measure selection procedure be flexible in permitting incorporation of the results from such studies.

Multi-family WAP auditors are also faced with a substantial number of measurement and testing techniques not encountered in residential audits. Though training of crews will always have an over-riding factor in a program's success, easy to understand printed instructions on applying such techniques would be helpful.

# 4. ADDITIONAL RESEARCH NEEDS

Several specific areas requiring additional research have been identified during this study. Although most will be addressed during the development of the upgraded measure selection technique, many will also undoubtedly be the subjects of ongoing research by other organizations in the coming years.

The effects of some energy conservation measures, especially for cooling climates, are not yet well understood. Field trials are and will be undertaken to obtain a greater ability to predict their effect on the energy consumption of residences (McLain, 1985 and ASE, 1989). For example, the installation of radiant barriers is a relatively new procedure whose effect is yet somewhat debated. Other measures, traditionally installed for reduction of heating loads, also alter the cooling requirements of a home, yet their effect is often overlooked or not understood. Infiltration control and increased insulation levels undoubtedly reduce both heating and cooling loads, but the measures may also prevent a house from benefitting from evening cooling in the summer.

Other measures will require additional study in order to implement them into measure selection techniques or understand their potential role within the WAP. The effect of measures reducing the solar load on a home depends on many factors not traditionally considered in measure selection techniques (e.g., external shading, cloud cover, average insolation, and window orientation). Other measures have effects whose magnitude depends on the occupants, such as natural ventilation or use of fans instead of air conditioning.

A related area for research concerns the appropriate weather parameters to use in the measure selection technique. Traditional cooling degree days (CDD) ignore solar loads, which can be a major factor in hot, dry climates. Bin methods must link the solar load to the outdoor air temperature, an approximation whose error is not well documented. How the chosen weather parameters are used to predict savings of measures specifically designed to reduce solar loads is yet to be determined.

Questions regarding implementation of the audit also exist. All the implications of when infiltration reduction work is performed are not totally appreciated. Introduction of highly packed blown insulation into walls prior to the infiltration work may reduce or even eliminate the leakage through many cracks, yet it is normally advised that attic insulation be installed after air leakage paths between the living space and attic are sealed. Agencies who contract out their infiltration work have additional factors to consider. The performance of furnace/boiler maintenance has similar circumstances. Such routine tuneups, if performed prior to the equipment efficiency tests, may reduce or eliminate the need for further retrofits of replacement.

Two additional areas requiring research involve the interaction of measures in determining savings and the discount rate to be used in economic calculations. For interacting measures, the savings of the combined measures is not equal to the sum of the savings of the individual measures. The question then arises regarding how to apportion the savings among the measures. Ideally, every possible combination of measures would be evaluated, but such is most often impractical. The choice of discount rate in ranking prospective measures can dramatically affect their ordering, particularly between high-cost, high conserving measures and those costing less yet saving less energy. Further literature searches and research need focus on both the appropriate values of discount rate to use and their effect on the economic calculations.

The added complexity of multi-zoned, multi-family buildings, especially with central heating and cooling equipment, introduces further research needs regarding the energy savings of individual measures, their interactions, and implementation. It is beyond the scope of this study to attempt to identify these areas. However, significant work is already being performed (see Sect. 3.2.2) whose results will prove advantageous to the eventual development of a multi-family measure selection technique.

# 5. RECOMMENDATIONS

## 5.1 SINGLE-FAMILY RECOMMENDATIONS

Since none of the currently available single-family measure selection techniques incorporate all of the factors seen as beneficial, it is recommended that the WAP support the development of an upgraded technique which should

- allow measure ranking unique to each eligible house,

- include heating and cooling equipment measures fully integrated into the selection technique, providing for interactions with other measures, and using economic criteria to establish their cost-effectiveness,

- include capability of being customized to meet the local needs of agencies, eliminating data and computational requirements irrelevant to their specific climate or housing stock or provide a basis for developing and validating a simpler technique when appropriate,

- allow development of a manual version, perhaps in the form of independent modules, addressing envelope measures, equipment measures, infiltration, etc. (further definition of this alternate approach will be accomplished in the program definition task of the project),

- provide ranking of cooling envelope measures when appropriate,

- provide means to determine the amount of infiltration work that should be performed on each house (e.g., through the use of blower door data),

- provide ranking of measures based on a variety of economic criteria (e.g., simple payback, discounted payback, etc.), but specifically include benefit-to-cost estimates over the life of the measure, as prescribed by DOE (1986). The approaches should lend themselves to the development of ranked measure lists.

- allow implementation on a personal computer, incorporating user-friendly features, such as help screens, default values, or prompts.

## 5.2 MULTI-FAMILY RECOMMENDATIONS

The following recommendations relate to the development of a multi-family energy conservation measure selection technique for the DOE WAP.

- Any DOE sponsored program for multi-family weatherization should be developed independently from programs for the single-family sector. Although there may be some items applicable to both, the audience, relevant measures, techniques, etc., differ significantly.

- Further investigation should be made into the cost-effectiveness of implementing currently available copyrighted multi-family programs, such as CNT's audit, at those state WAP agencies expressing a need for a multi-family audit tool.

- Initial steps in the development of a DOE multi-family measure selection technique should include identification of approved measures and their applicability to various building stock, equipment types, and fuels.

- Development of a DOE multi-family measure selection technique should proceed by examining the CIRA and ASEAM 2 computer programs to determine the number and difficulty of adaptations required to produce a program appropriate for the WAP program.

- Any multi-family measure selection technique either adopted or developed should be used to determine if a simplified approach could be effectively applied in a specific geographical area for a particular building type.

# 6. PROPOSED AUDIT DEVELOPMENT PLANS

The following plans for the development of upgraded single and multi-family measure selection techniques are discussed separately. As has been indicated within this report, the two procedures differ sufficiently to warrant individual project status. Although the two could be undertaken concurrently, separate funding and project tracking is advised. Also, since the apparent need for the single family audit is greater than for the multi-family audit, priority should be given to the development of the former. In addition, there are elements of the single family development which may offer significant input to the development of the multi-family technique (such as the evaluation of the CIRA program), which also supports this same priority decision.

## 6.1 SINGLE FAMILY

Funding and scheduling considerations have naturally divided the single-family development project into at least two distinct phases. The opportunity to exercise an upgraded single-family audit in North Carolina provides an intermediate evaluation point for a preliminary version of the final product, to be made available to all WAP agencies. Thus, the first phase of the development is to produce an upgraded WAP audit procedure which can be tested in the North Carolina field test. The following plan describes individual tasks necessary to produce this first phase audit. A succeeding phase (or phases) will further enhance the audit for use by all WAP agencies and will likely contain similar tasks. The plan is consistent with the recommendations previously presented in this report.

### Development Plan

The overall structure of the measure selection technique (MST) development plan is shown in Fig. 6.1. The major tasks within the plan are described below.

Task 1 - Evaluation. The objective of this task is to lay the foundation for the entire MST development by providing evaluations in two key areas. First, existing audit and MST programs--such as the CIRA program, the public version of the WECC audit, and the Manucomp audit -- will be evaluated for features that could be adapted for the new DOE MST program. Concurrent with these evaluations lies the need to address several basic questions, including (1) the appropriate weather parameters (e.g., degree-day or bin methods) and (2) the need for computing whole-house energy consumption.

Secondly, issues that affect how a MST could be implemented in actual practice will be evaluated. Such issues include (1) organization of the auditing and measure selection/work order preparation steps, (2) organization of the various work crews for infiltration control, envelope measures, and heating and/or cooling equipment measures, and (3) consequences of using subcontractors versus in-house staff.

Task 2 - Program Definition. The objective of this task is to outline the structure of the new MST program. This would be accomplished by defining the requirements of the new MST (specifically with regards to needs of the North Carolina field test), documenting any known assumptions and restrictions that may apply, and identifying interfaces with other MST and audit programs and techniques that should be explored or included. Specific components of the audit (e.g., input, consumption estimates, savings estimates, measure interactions, measure selection, and output) will

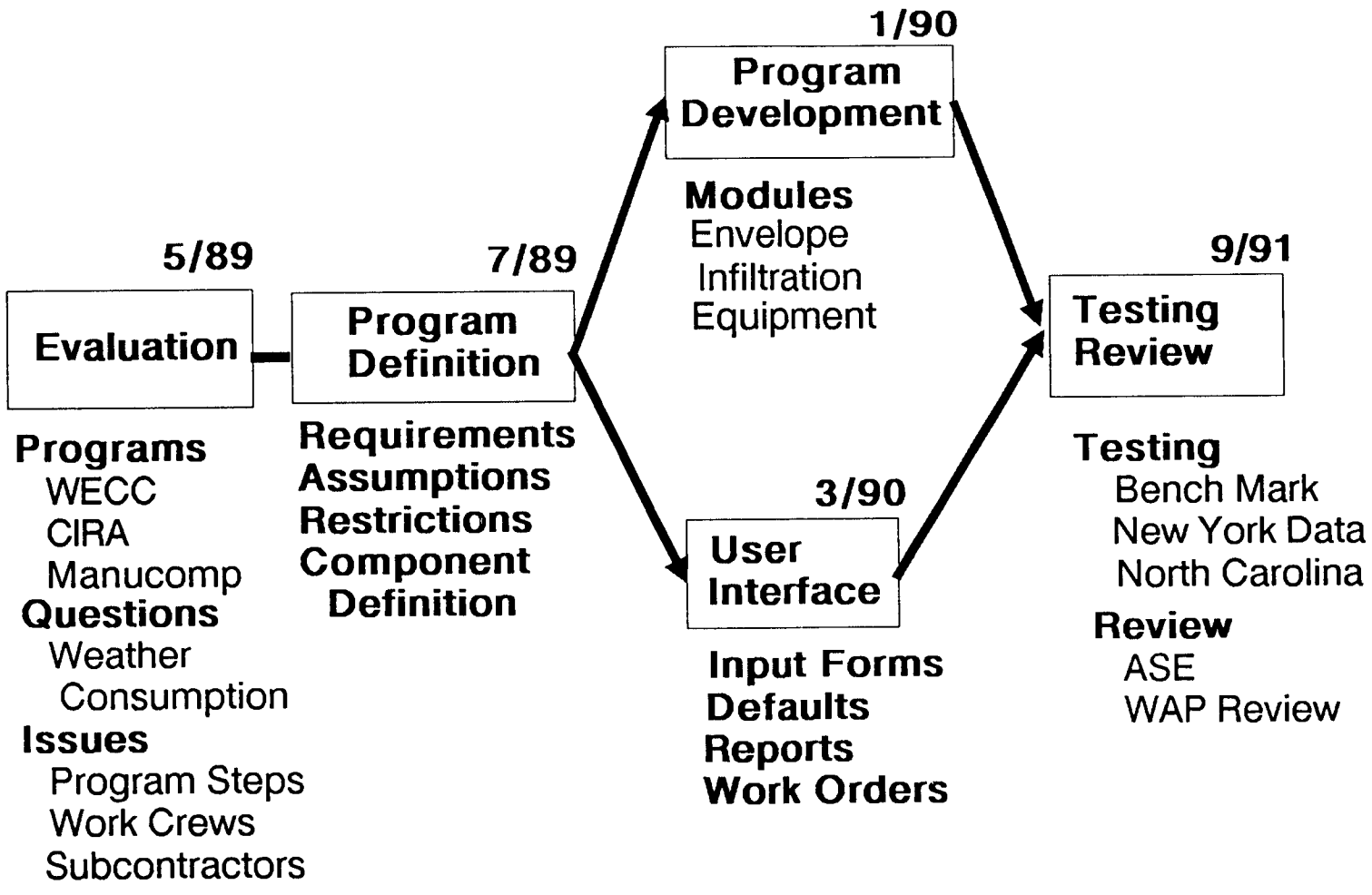


Figure 6.1 Single Family Development Plan

be defined and their inter-dependency considered. The potential of offering a modular approach as an alternative to the fully integrated procedure will be further defined, identifying any additional obstacles or restrictions which may be encountered.

Task 3- Program Development. This task encompasses the core development of the MST. Its objective is to develop the primary structure of a new first phase MST. Development may progress concurrently on several modules of the program, including building envelope measures, infiltration control, heating equipment measures, and cooling equipment measures. Adaptability of the technique for those agencies not prepared to implement all modules or who desire to implement the modules independently will be considered.

Task 4 - User Interface. This task would develop or adapt software for interfacing with users, providing input data forms, default data files, standard reporting formats, and job work order procedures.

Task 5 - Testing and Review. This task would provide testing and review at critical points in the program's development. Benchmark tests would be performed on all new measure algorithms as they are developed. Data from a New York field test may afford a preliminary verification for a portion of program. Application of the audit in the North Carolina Weatherization Project will provide feedback to be incorporated into the program. Reviews may be conducted by the ASE and the DOE/State WAP Review Committee as desired.

### Development Schedule

The development schedule of Fig. 6.1 is consistent with the schedule proposed for the North Carolina Research Project (ASE, 1989). Planning for the extended phases of the project (i.e., extension to all WAP regions, enhanced user interfacing, expanded testing and dissemination) has not yet been fully developed.

## 6.2 MULTI-FAMILY

Additional investigation must be performed before definitive plans for the development or adoption of a DOE-supported multi-family measure selection technique can be drafted. The relatively smaller perceived need for a multi-family audit by the agencies and the additional complexity involved in developing such a technique warrant further study of two alternate approaches.

1. Adapt Private Audit - Examine options for using currently existing private multi-family audits, which might include:

- Use an RFP to locate and improve an existing private audit to meet state needs.
- Develop criteria and tests by which DOE could pre-approve multi-family audits for WAP use.
- Wait for states to request DOE approval of private audits, then provide service.

2. Further Examine Public Domain Programs - Although CIRA and ASEAM each have deficiencies as multi-family measure selection techniques for the WAP, they may provide starting points for the development of an acceptable procedure. Due to the complexity of the problem, further investigation of the programs would yet be necessary to estimate the degree of effort involved in their adaptation and enhancement.

These two approaches must then be compared in order to make recommendations for future development.

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