**DEVELOPMENT OF RESIDENTIAL-CONSERVATION-
SURVEY METHODOLOGY FOR THE U.S. AIR FORCE**

Interim Report -Task Two

November 13, 1981

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DEVELOPMENT OF RESIDENTIAL ENERGY CONSERVATION SURVEY METHODOLOGY
FOR THE U.S. AIR FORCE

INTERIM REPORT: TASK TWO

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Development of Residential Conservation Survey Methodology
For The U.S. Air Force

Interim Report: Task Two

SUMMARY

Task Two compares USAF needs and available data to the inputs, methodology, and outputs of a building energy survey procedure. Initially, it was postulated that the DOE Residential Conservation Service (RCS) model audit procedure might constitute a usable survey procedure. It has been established that RCS, per se, is not suitable to USAF needs. A survey, analysis, and documentation procedure which draws upon RCS is recommended. Modifications must be made with consideration given to data availability, use of a building population sampling technique, USAF requirements, a modified list of energy conservation alternatives, and USAF output requirements.

Significant conclusions from each subtask follow.

2.1 A grouped housing approach can be effectively used to reduce field survey time. Definition of groups, sample size, sample selection, and accuracy limits are discussed. Results of a sensitivity analysis for Tyndall AFB housing are presented.

2.2 AFM 88-29 climatological data is not adequate for analysis of all energy alternatives previously identified. However, the additional data required are available for most bases from other sources. A cross reference of specific data sources and stations is compiled individually for ninety-four bases in the continental U.S.

2.3 With annual energy savings data from the survey methodology to be developed, Energy Conservation Investment Program (ECIP) life cycle costing calculations are straightforward. All required data are available, with the

exception of periodic maintenance costs and salvage value for some alternatives. Project implementation costs are not addressed by RCS or the survey methodology to be developed. They are to be produced for each project by the individual base engineering staffs.

2.4 The list of proposed energy conservation alternatives, submitted as part of the Task One Interim Report, has been developed further. Each item has been ranked according to their usability and value. Analysis techniques and data requirements are delineated.

2.5 A technique is presented for developing average unit energy consumption data from group or area consumption data. Opportunities for several levels of metering and performance evaluation are described.

The work completed as part of Task Two lists energy conservation alternatives and describes the basic analysis techniques to be used in evaluating their thermal performance. With the completion of this effort, SSEC is ready to proceed with the development of the procedures and documentation required to survey USAF housing.

DEVELOPMENT OF RESIDENTIAL ENERGY CONSERVATION SURVEY METHODOLOGY
FOR THE U.S. AIR FORCE

INTERIM REPORT: TASK TWO

INTRODUCTION

This document constitutes an interim report to the Engineering and Services Center (ESC) of SSEC's progress on the project "Development of a Residential Energy Conservation Survey Methodology for the U.S. Air Force." Task Two is now complete. In the course of identifying energy conservation alternatives and defining analysis techniques, an initial step has been made toward the development of modified analysis procedures, as defined in Task 3.1. This work is described as part of the Subtask 2.4 report.

Task Two is composed of five subtasks. The text of each subtask from the statement of work is followed by a description of the work accomplished. This section provides a concise overview of the work; detailed information, and background work is described in the appendices.

Also, a selected reference list is included. Copies of the relevant portions of these references are available separately.

Task Two: Compare USAF needs and available data to RCS procedures and assumptions

2.1 Analyze Data Limitations

"Determine if and how a grouped house approach can be used. Identify how many and what type of houses must be visited individually for data collection, and how much data can be simply assumed or extracted from desk-top data such as drawings and routine reports. Specify the possible limits of accuracy of desk-top data surveys. Identify RCS required data points which can only be obtained by individual building site visits. Determine sensitivity of RCS procedures when applied to individual houses, housing areas, and housing construction types peculiar to military installations."

A grouped housing approach can be used for USAF family housing. A group is defined as an assembly of units with similar energy consumption characteristics. With this definition, the constitution of a group may be expected to vary from base to base as the housing stock varies. Typically, a group will be a subset of the base housing in which all units are built to a particular design. However, in many cases a group will be smaller. If for example, the base housing was laid out on an orthogonal grid system, the orientation may be a significant parameter in the energy consumption and a group would consist of all units built to a particular design having the same orientation. While it is not possible to state group composition definitively, it is possible to develop guidelines to allow the analyst to adequately group the structures. Within each group, 16 percent of the units must be surveyed in order to get a statistically valid sample. The units to be sampled should be chosen at random from all the units in the group. This sample is to be completely surveyed including individual site visits. The results of this study may indicate that particular features need additional audits in order to improve the accuracy of the results. In this case, additional surveys may be conducted for only those features where more data is needed. The overall approach is discussed in Appendix A.

Appendix B lists the data requirements for an energy survey of USAF family housing and indicates which data can be extracted from desk-top data, which must be acquired through a site visit, and which data from the desk-top source must be verified by site visit. Data that is a function of design can be extracted from the plans. Number and size of windows and doors, and wall construction, are examples. Data that is a function of the construction, such as insulation thickness, may be extracted from the plans but must be verified during the audit. Data that is not available on the drawings or that can change with time can only be acquired through a site visit. This includes cracks in walls due to settling, presence and condition of

caulking, and duct taping, and similar items. Occupant-dependent parameters are defined by a questionnaire to all occupants of the housing group being studied. These parameters include thermostat settings and setbacks, hot water consumption, occupancy patterns, and others.

The limitation in accuracy of a survey conducted purely on the basis of desk-top data lies in the data assumed or estimated. The primary items that must be estimated are infiltration and thermostat set points. On Unit A-22 at Tyndall AFB, for example, a 25 percent difference in infiltration causes a 6 percent change in heating energy consumption and a 3.5 percent change in cooling energy consumption. Changing the summer thermostat setting from 75°F to 78°F causes a 10 percent decrease in cooling energy consumption, a 70°F to 68°F change in the winter thermostat setting causes a 5 percent decrease in heating energy consumption. Desk top data, such as drawings or reports, can be reliably used for dimension and area take-offs, building orientation and geometry, design details, and duct and piping dimensions. Yearly energy consumption calculations based purely on the data from reports and drawings are expected to vary by ± 25 percent for the cooling season and ± 15 percent for the heating season, depending on the assumptions. Accuracy limits and other aspects are discussed in Appendix C.

The RCS Model Audit Procedures were designed for application to individual, single-family, detached dwelling units. When applied to military family housing, modifications are needed. A significant portion of the RCS audit procedure is devoted to acquiring data that the Air Force will be able to obtain from desk-top sources. This includes such things as dimensions, areas, orientation, energy sources, and costs. Because of the ECIP requirements for accurate life cycle costing estimates, and documentation of the analysis, changes in the RCS calculation procedure are required. The grouped housing approach alone will require a major revision in the

methodology, as will the inclusion of additional retrofit options to be considered. The RCS model audit will, therefore, provide only a convenient framework around which to structure a new survey methodology for the USAF.

2.2 Compare Climatic Data Required Under RCS to Data Contained in AFM 88-29

"Determine if AFM 88-29 weather data is adequate for an RCS survey. If not, identify additional points required and the impact if not provided."

Climatic data requirements are presented in Appendix D. In general, monthly total or average data are required for the analysis. By appropriate arithmetic treatment of the data contained in AFM 88-29 (see Appendix D), it is possible to generate all the climatic data required by the RCS model audit with the exception of maximum and minimum average temperatures, domestic water supply temperatures, wind data, and solar radiation data. A review of the RCS procedures shows no use for the maximum and minimum temperatures. Since the survey methodology now envisioned does not require temperature extremes data, they are considered extraneous.

The survey methodology will modify infiltration loss and gain as a function of wind data. The RCS model audit provides the necessary wind data for this application. Since wind energy systems are not to be considered, more detailed wind data is not required.

Monthly average ground temperature data provide a good estimate of the cold water temperature used to calculate the domestic hot water heating load. It must be provided to analyze options for solar domestic hot water, hot water heat pumps, water flow restrictors, and water heater thermostat settings. Ground temperature data is also needed for analysis of ground-coupled cooling devices, such as earth cooling tubes.

Solar radiation data are needed for the analysis of all solar technologies including sunspaces, Trombe walls, direct gain, thermosiphon air panels, active solar hot water heaters, passive solar hot water heaters, and active solar heating systems. Monthly average solar radiation data for either a horizontal or vertical surface are required. Lack of these data would prohibit the consideration of solar technologies in the survey.

In addition to the RCS data requirements, the proposed USAF survey methodology requires the full-load hours of cooling and heating equipment operation and heating degree-days at variable temperature bases. The NAHB Research Foundation has tabulated the full-load hour data for cooling equipment for various locations. Additional full-load hour data may be generated using the bin data in AFM 88-29. The full-load hours of heating equipment operation are calculated from heating degree-days by multiplying by 24 (hours per day) and dividing by the winter design temperature difference.

Heating degree-days at variable temperature bases (other than the standard 65°F base) for most areas are tabulated in the Passive Solar Design Handbook, Volume Two, by DOE [1]. Solar data is also available from this reference for the same areas. Ground temperature data may be obtained from the local water utility, or may be estimated using AFM 88-29 (see Appendix D). Additional climatological data services will be useful. Appendix E contains a cross-reference of Air Force bases with the site of the most appropriate solar data (and variable base degree-days), full load hour data, and bin data for each base.

The climatic data contained in AFM 88-29 are inadequate for the proposed survey. However, a portion of the additional information required can be developed from AFM 88-29 data and the remainder is available for most bases from other sources.

2.3 Determine RCS Modifications Needed to Perform Life Cycle Cost Analysis

"Compare life cycle costing method contained in USAF Energy Conservation Investment Program (ECIP) to data contained in RCS. Identify additional data required in RCS to allow ECIP life cycle cost analysis, if any."

The ECIP reference document employed in this study is a memorandum (no date) titled "Energy Conservation Investment Program (ECIP) Guidance" [2] issued by the Deputy Assistant Secretary of Defense, Perry J. Fliakas. A copy was provided by Engineering Services Center (ESC) personnel on August 7, 1981.

The document sets forth certain common economic factors required for all ECIP projects. These are:

- 1) Discount rate
- 2) Fuel cost escalation factors
- 3) Energy conversion factors
- 4) Uniform present worth factors for:
 - Annual fuel savings
 - Other recurring savings
 - Other one-time savings

The first three items are provided in the current ECIP guidance and presumably will be updated periodically by DOE and DOD to reflect changing economic conditions. The uniform present worth factors are standard economic analysis factors based on the discount rate and regional fuel cost escalation estimates. Formulas and tables of values are contained in the ECIP guidance for each of nine DOE regions. An alternate interim procedure allows the use of a factor based on a 7 percent discount rate and a single table of nationally-applicable fuel cost escalation rates.

All of these economic factors are currently available and would require no modification for use in conjunction with an RCS or RCS-derived survey.

In addition to economic factors, the ECIP project evaluation procedure requires inputs on current fuel costs, energy savings, and implementation costs. Specifically, the following data are required for each proposed project:

- 1) Project cost
- 2) Fuel source and unit fuel cost
- 3) Estimated annual energy savings
- 4) Other one-time savings or costs
- 5) Other recurring savings or costs

The RCS documentation does not provide cost data for the various conservation and alternative energy features considered. Rather, the auditor is directed to develop his own cost data specific to his area of operation. Cost estimates arising from the RCS program and other residentially oriented programs would be for specific areas and individual installations. The USAF is faced with conducting housing energy surveys in diverse locations but has the advantage of dealing with a large number of common units in each project.

Rather than attempt to develop standardized costs for each of the conservation and alternative energy projects that might be considered, it is suggested that each base engineering group develop its own cost figures as required. Costs will vary as a function of location, project size, and other factors. The preferred source would be cost estimates from local contractors. Somewhat rougher estimates could be quickly developed using a standard cost guide such as Means Building Construction Cost Data [3].

The fuel source and unit cost data, Item 2, should be provided by each base engineering group using the rate structures currently in effect. In light of the probability of frequent and significant energy cost increases, care must be exercised to use accurate, current costs.

Estimated annual energy savings, Item 3, expressed in Btu/yr per housing unit are to be available as an output from the survey.

Other one-time and recurring costs or savings include: salvage value of replaced equipment, salvage value of installed equipment, savings or costs associated with energy distribution capacity changes, and periodic maintenance. Most projects will not have significant "other costs" or savings associated with them. With the exception of periodic maintenance costs, any "other costs" or savings estimates should be provided by the base engineering group. Estimates or guidelines for periodic maintenance costs associated with active and passive solar energy systems should be provided with the survey procedure. These estimates can be developed with the aid of existing DOE and industry publications; it is anticipated that maintenance would be characterized as a fraction of first cost. RCS provides no specific information on such costs.

In reviewing the ECIP guidance, it appears that only two additional items in the text have a relationship to a potential survey methodology. Item (5.d.1) of the guidance requires the maintenance of "readily auditable supporting documentation for each ECIP project." It is felt that the proposed survey methodology would adequately document the estimated energy savings associated with each project. ESC should verify this based on USAF policy and procedures.

Item (5.f) calls for energy consumption data to be gathered by each service for one project in each representative category of projects funded in each year. The survey methodology, as envisioned, will not include the installation of additional meters. It is assumed that this requirement could be met by utilizing data from those units which already include meters. Alternatively, the ECIP guidance stipulates that metered data could be replaced with engineering estimates of normalized pre- and post-retrofit energy use. ESC should establish whether or not the survey methodology would be adequate for this purpose.

In summary, the survey methodology envisioned does not conflict with the economic evaluation requirements of ECIP. With annual energy savings data being supplied by the survey, all required input data are available.

2.4 Identify Additional Energy Systems for RCS Inclusion

"Reconsider passive solar construction already included in RCS, such as sunspaces, direct gain, thermal storage walls, and thermosyphon air panels to determine how well RCS treatment applies to USAF. In addition, consider other technologies, such as wholehouse fans, heat pumps, passive SDHW units, heat recovery devices, and DHW heat pumps for feasibility of inclusion in a USAF adaption of RCS. It must be recognized that RCS does not include some technologies because they were too difficult to model. (A great deal of experience with both RCS and the technologies in question will be essential to successfully complete this task.) Identify additional data points required for the analysis of each option and identify the technique to be used in weighing these options against other RCS considerations."

SSEC has previously submitted a list of potential options to USAF ESC. This list has been further developed to include proposed analysis methods and data requirements. This information is presented in Appendix F.

Passive solar systems as included in RCS are appropriate for consideration in a USAF survey. The passive solar systems are all intended to supplement heating, and include the following: direct gain, Trombe wall, water wall, sunspace, and thermosyphoning air panel (TAP). All of these residential systems have been proven to be effective when properly applied, and should be considered for USAF bases in heating-dominated climates.

Because of the potential cooling load attributable to passive heating systems during the cooling season, care must be taken when applying them in areas with high cooling loads. Recognizing this concern in earlier work, SSEC studied the heating and cooling loads

for two typical houses, a standard and an energy-conserving house [4]. The ratios of these loads for various locations were plotted on maps. A representative map is shown in Figure One. Maps of this nature were developed for different fuel sources using current cost figures to show how the relative importance of heating or cooling changes with fuel type and cost. Similar maps of the entire country with this information would assist in selecting those bases where passive solar heating should be considered.

The RCS analysis methods for passive solar techniques were found to be outdated because of the recent design and analysis tool development by DOE and Los Alamos National Laboratory (LANL). The Passive Solar Design Handbook, Volume Two [1] with additional sunspace information from LANL and the upcoming Volume Three (currently in draft form) are recommended for the USAF survey. The analysis method is based on correlations of detailed computer model simulations of generic system designs, and is a more highly developed version of the methodology used by RCS.

In addition to the solar and other conservation techniques included in RCS, many additional technologies were evaluated for inclusion in the USAF survey. For the RCS items, the analysis methods were reviewed and modified where required. For the new technologies considered, analysis techniques were developed with similar accuracy and ease of use. The complete list of techniques, analysis methods, and data requirements is in Appendix F.

Fundamental to all analysis of building skin loads and conservation options is the evaluation of yearly energy consumption. Numerous techniques are available for transforming design loads to yearly energy consumption. It has been specified that only manual calculation techniques be considered in this study. Currently available methods include: degree-day methods, bin methods, full-load hour methods, ASHRAE T.C. 4.7 method, and House Energy

HEATING TO COOLING COST RATIO FOR A STANDARD HOUSE
(Electric heat pump, COP=2.6, EER=8.87)

$\frac{\text{ANNUAL HEATING BILL}}{\text{ANNUAL COOLING BILL}}$

FIGURE 1

Analysis Procedure (HEAP) by the National Bureau of Standards [5]. As would be expected, the more complex and time-consuming the analysis method, the higher the anticipated accuracy.

RCS currently uses the degree-day method, which is the quickest and easiest to apply. However, recent comparisons with computer simulation models have brought the accuracy of this method into doubt, particularly the cooling energy predictions [5]. Accuracy of heating calculations is improved by a modification to the standard degree-day method which accounts for the heating effect of internal heat gains (people, lights, appliances). Degree-days are determined using a temperature base which corresponds to the outside temperature below which auxiliary heating (in addition to the internal gains) is required for the specific house in question. This modified degree-day method for heating compares well with computer simulation from a heating standpoint. However, cooling loads do not compare well.

The standard bin method requires calculation of the heating and cooling loads at each of the temperature bins in AFM 88-29. Annual heating and cooling loads are then determined by multiplying the load associated with each bin by the yearly frequency of the bin. Agreement between this method and computer simulation is generally better than the degree-day methods, but still not satisfactory for cooling loads in residences [5]. Furthermore, computational time is excessive.

The full-load hour (FLH) method for cooling calculations was developed in order to determine annual cooling energy requirements in a simple and straightforward manner. Annual cooling energy is a function of the design cooling load, the equivalent full-load hours of operation, and air conditioner efficiency. The full-load hour figures are calculated from bin data using a weighting factor for each bin based on the assumption that the compressor operates at full load at the outdoor design temperature and zero load at the balance

temperature (based on internal gains). The load is linearly proportional to temperatures between these points. Reasonably good agreement has been found between this methodology and detailed computer simulations.

The ASHRAE T.C. 4.7 method was developed for manual calculation of the performance of large non-residential buildings. Loads are calculated using the commercial load methodology for conditions of peak cooling, intermediate cooling, intermediate heating, and peak heating. Bin methods are then used, with the loads for each bin developed by a linear interpolation between the established points. Latent loads are calculated separately for each bin based upon the mean coincident wet bulb. Accuracy of this method is quite good, with results falling within 15 percent of computer simulation. Computational time is excessive, though, requiring approximately one-half man-week per analysis. Each option considered would require a new analysis.

HEAP is based on the concept that energy consumption will be a function of average indoor-outdoor temperature difference. The method is still under development, and so far does not correlate well to computer simulations.

All of the available residential analysis methodologies are plagued by one problem: the effect of the occupants on the building energy loads. Studies have shown that identical occupied houses in the same location may have auxiliary fuel bills that differ by a factor of two. Thus, the interpretation of any building analysis must be tempered with this knowledge.

The method chosen for this program is a combination of the modified degree-day method for heating and the compressor full-load hours method for cooling. The modified degree-day method adjusts for internal heat generation and the thermal integrity of the structure. Good comparison with computer models has been obtained. The

compressor full-load hours method is conceptually similar to the ASHRAE T.C. 4.7 method, but much simpler computationally. The combination of these two methods results in a procedure capable of rapid evaluation of alternatives, with results that will allow an accurate life cycle cost analysis.

The methods described above allow calculation of the annual heating and cooling loads for a building based on the design heating and cooling loads. Design loads described the space conditioning loads at design conditions for equipment sizing. They should be differentiated from annual loads which reflect annual energy consumption. The design load for heating is determined as in the RCS procedure and is based on [6]. The cooling design load is calculated by the simplified residential technique described in Chapter 26 of [6], which accounts for solar heating effects on the building shell and solar gains through the windows. Annual energy consumption loads are developed by considering design loads, equipment efficiency, and modified degree-days (heating) or full load hours (cooling). The RCS method of calculating cooling load is not used because it ignores solar effects. The infiltration loads for heating and cooling are determined as outlined in the RCS manual and account for the various leakage paths, wind effect, terrain factor, and enthalpy content of the air.

The analysis of hot water heating energy use is considerably simpler than the building analysis. A heat balance on the water heating system accounts for the energy supplied to the water plus standby losses. An estimate of hot water consumption is obtained from an occupant questionnaire (see Appendix B). Whereas RCS assumed the tank insulation and standby losses, the proposed methodology accounts for standby losses explicitly.

For analyzing solar domestic hot water, the RCS procedure is too general and over-simplified to account for the wide range of system performance available today. The methodology proposed for this

survey uses the FCHART correlations developed by the University of Wisconsin [7]. The method accounts for the specific solar system performance, hot water load, and weather data.

Many of the analysis techniques use the 1977 ASHRAE Handbook of Fundamentals [6] as a reference source. A new, updated version of this handbook will be widely available soon. This new volume should be reviewed for applicability to the USAF survey.

Appendix F contains a listing of sixty-five items which have been proposed for inclusion in the USAF survey. This listing includes both RCS items and additional items identified by ESC and SSEC. The fundamental thermal analysis methodology chosen utilizes a variable temperature base degree-day method for heating energy consumption and the ASHRAE residential cooling load calculation procedure and full load hours method for cooling energy consumption. Within this general framework, a basic thermal performance evaluation procedure is outlined for each item in the list. Input data requirements are also specified. With this work completed, detailed survey procedures may now be developed.

2.5 Determine the Applicability of Existing Energy Consumption Data to RCS

"Military family housing units are not metered individually, and it is impossible to do so. However, housing as a whole, and in some cases, individual housing areas, are metered separately from the rest of the base. Determine a technique for estimating individual unit consumption based on actual consumption data. Determine the cost effectiveness of collecting unit sample data."

SSEC has developed a technique for estimating the unit energy consumption given the metered aggregate housing energy consumption. It is described in Appendix G and outlined in the following paragraphs.

The metered energy consumption for housing may include loads due to equipment such as street lights and sewage lift stations, as well as transmission losses. These loads and losses are subtracted from the metered energy consumption to give net housing energy consumption. Standard conversion factors are used to convert this figure to British Thermal Units (Btus).

Next, a "Distribution Factor" for each housing area is calculated. This is the fraction of the net housing energy consumption of each group of units. The distribution factor is a function of all the energy flows of the unit: service hot water, appliances, lighting, heat release by occupants, and space conditioning. All of these factors are included in the meter data except occupancy, which is indirectly reflected in the space conditioning loads. The data requirements for the calculation include: floor plans, design heating and cooling loads, average climatic data (bin data), base guidelines for family size per unit, and estimated equipment efficiencies.

For each housing group on a meter, the monthly net housing energy consumption times the monthly distribution factor for that housing group, divided by the number of units in that group will yield monthly unit energy consumption estimates. Yearly consumption data is developed by summing the monthly data.

Individual unit metering is not required for the survey. However, it may be desirable to meter some portion of the base housing to validate the survey methodology and results or to get a better understanding of energy use in base housing.

Residential energy consumption is extremely dependent upon the usage patterns of the occupants. In order to isolate this effect, two options are available: 1) instrument the units thoroughly enough to be able to measure occupant effects, or 2) meter enough units to

be able to account for occupant effects statistically. In either case, the effects of the occupant on unit energy consumption can be accounted for in evaluating the energy flows in the residences.

Instrumentation, installation, data acquisition, and data reduction will cost from \$20,000 to \$100,000+ per unit for monitoring at a level adequate to identify occupant effects. The cost is a function of the number of units, the complexity of the energy usage in the units, and the required degree of accuracy. Comparable studies have been undertaken by SSEC and SERI as part of the Class A and Class B Performance Monitoring Programs [8, 9].

As an alternative to intensive monitoring of a few buildings, a much larger sample size may be utilized with only basic instrumentation, watt-hour meters and thermometers. The accuracy of the estimate is a function of sample size, which cannot be determined until the data is analyzed since it is also a function of the data. An initial estimate of required sample size is 16 percent of the population. Even with simple instrumentation a significant amount of information can be extracted. SSEC's Class C Performance Monitoring Program and Homeowner's Monitoring Program provide examples of such programs [10, 11]. The cost of individual watt-hour meters and installation is estimated to be less than \$600. The cost of periodic data collection and analysis must be added to that figure.

Unit metering may be a viable energy conservation option in itself. Psychological Strategies to Reduce Energy Consumption by the Center for Energy and Environmental Studies, Princeton University, [12], contains several examples of the use of meter readings as a feedback mechanism to reduce energy consumption.

The RCS methodology allows determination of building loads either by regression from fuel consumption and climatic data or by calculation. Appendix G describes a method which has been devised

for obtaining unit data from overall consumption. Individual unit metering does allow a convenient check on calculated values and provides a method of gauging the results of building modifications and occupant effects. However, the cost of individual unit metering is excessive when compared to the potential benefits. For the USAF survey, either calculated building loads or building loads developed using the unit data obtained as described in Appendix G could, in theory, be used. In order to minimize costs and labor requirements and provide the most dependable results, the calculated building load method is recommended.

CONCLUSION

Task Two of a project to develop a USAF Residential Energy Conservation Methodology has been completed. Under this task a comparison has been made of USAF needs and available data to the procedures of the Residential Conservation Service (RCS) program as developed for general use by utility companies serving civilian customers. Attention has been given to the data implications related to group housing, climatic data requirements, life cycle cost analysis, energy saving modifications beyond those covered by RCS, and methods for utilizing existing energy consumption data in approaching the USAF survey program.

Detailed information on each subtask of this part of the work has been provided in the preceding text, with appendices used to document much of the basic information and analysis methods. Key points resulting from the effort may be summarized as follows:

1. A grouped housing approach can be utilized to help reduce the field survey effort. This use of available data and the matter of determining representative samples and accuracy limits are resolved to the extent practical at this stage of the effort. Insight into the accuracy of the basic technique is provided through a sensitivity analysis performed on a unit at Tyndall AFB.
2. AFM 88-29 climatic data is not adequate for analysis of all of the energy alternatives and must be supplemented. However, most of the additional data is readily available from other sources or can be derived in a reasonable manner.
3. Energy Conservation Investment Program (ECIP) life cycle costing calculations are straightforward and it is felt that all of the required data should be readily available with the exception of some alternatives which will require special attention. It appears that cost information for each type of project is best developed by the individual base engineering staffs. This may require further review

concerning the preferred method of documenting the information so that some method of indexing might be used to adjust for inflationary changes if basic data is to be utilized over an extended time interval of decision-making. It should be noted that neither RCS nor the proposed survey methodology directly address the method of cost estimating.

4. An extensive listing of energy conservation alternatives has been developed and the basic method for analysis of the energy savings of each one is presented. The analysis technique selected is based on simple calculations wherever possible. One exception is in the use of FCHART techniques for some of the solar analyses. In this instance, additional work will be required to derive relatively simple graphical or tabular references. An alternative would be to utilize a reference listing of computer-derived performance data, or some equivalent.

It should be noted that the basic analysis technique must be translated into working materials for the actual survey process. This has not been undertaken under this phase of the effort and is intended for Task Three of the project. Appendix F provides detailed information on the analysis method, or equivalent rationale, to be used for a total of 65 individual conservation items. Of course, not all of the items would be considered for every base housing installation and it is recognized that the survey methodology must provide a means to quickly identify those to be considered for a given base housing situation.

5. The matter of assessing average unit energy consumption from group or area data has been examined and an approach derived for treating this problem. No difficulties are anticipated in being able to apply the calculations outlined in Appendix F to determine the energy savings which will result from upgrading. In addition, a number of options exist for different levels of sample metering and follow-up surveys to evaluate performance. This matter is discussed further in Appendix G.

While the RCS procedures are not directly applicable to USAF use, they do provide valuable inputs and a useful base for the development of a suitable survey methodology. The work which has been accomplished, and particularly that under Subtask 2.4 (and Appendix F), provides a firm basis for the next phase of effort to develop the needed methodology. A full range of energy conserving alternatives has been analyzed. Data availability and interface with the ECIP program do not pose any significant problems.

It is recommended that, after appropriate review and inputs from USAF personnel, the effort be continued into the next phase of the project. This will provide a useful and practical tool to meet specific needs related to military base housing, and will provide the basis for substantial energy-related cost reductions and reductions in fossil fuel consumption which are in the national interest.

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NOTE: References are common to both the text and the appendices.

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APPENDICES

- A. DEVELOPMENT OF SAMPLE REQUIREMENTS
- B. DATA REQUIREMENTS
- C. ACCURACY LIMITS AND SENSITIVITY
- D. SURVEY DATA REQUIREMENTS VS. AFM 88-29
- E. USAF BASE DATA SOURCES
- F. PROPOSED ENERGY CONSERVATION MEASURES AND ANALYSIS TECHNIQUES
- G. DEVELOPMENT OF UNITARY CONSUMPTION DATA

NOTE: References (indicated in brackets) are common to both the text and the appendices. Equations (numbered in parentheses), figures, and tables are numbered separately for each appendix with a letter indicating the appendix.

APPENDIX A

DEVELOPMENT OF SAMPLE REQUIREMENTS

RCS was developed to conduct and analyze audits on single houses. In the USAF ESC study there are large populations of identical units, and it is necessary to survey only a sample of these to analyze the alternatives.

First, it should be recognized that not every feature needs the statistical analysis implied by the sampling concept. A significant amount of the data needed for the energy analysis will not vary within one design. These are features that can be extracted from the drawings without a field survey such as window areas, number of glazings, and wall areas.

Other features of the analysis may be expected to vary. For example, blown-in or loose-fill ceiling insulation may be expected to settle with time, and thickness will vary from unit to unit. Analysis of this type of data will be based on statistics derived from a sample of the population.

While this approach is valid and will reduce the number of units to be field surveyed, it raises a number of questions:

- Which houses must be field surveyed?
- How many units must be field surveyed?
- For the various features to be surveyed, should the sample size be uniform?
- What effect will sampling have on life cycle costing considerations?

Selection of Units

The units to be field surveyed should be selected randomly from all the units within a group. A group is defined as an assembly of units with similar energy consumption characteristics. Grouping of units is based on parameters that characterize energy consumption. This will include such things as:

- Unit floor plan
- Ceiling insulation levels
- Orientation
- Wall insulation levels
- Age of unit
- Heating system type and age
- Cooling system type and age

In almost all cases the units in one group will have identical or mirror image floor plans. Decisions as to grouping in smaller number of units will be a semi-subjective decision by the analyst. Consider for example, the heating system. If a few have been replaced, one at a time, then they would not constitute a separate group. If, however, half of the heating systems were replaced at one time, this would constitute a separate group.

There may also be a difference between grouping for the field survey and grouping for the analysis. Consider the earlier example of grouping by design and heating system. For the field survey and for the analysis of heating system, this would represent two groups. For the analysis of ceiling insulation levels, however, it may be possible to analyze this as one group and therefore improve the confidence interval due to the larger sample size.

Exact guidelines for grouping and its application to the field data requirements and analysis will be developed as part of the methodology.

The required sample size is a function of the properties of the sample. Initially however, nothing is known of the sample, and a valid sample size must be selected. The initial assumption is that the values encountered in the survey will vary from zero to the amount shown on the plans. The assumed distribution shape is a right triangle, that is, the highest probability is associated with the values on the drawings, and the probability is a linear function of the difference from the drawings. Allowing a 20 percent error and requiring 95 percent confidence, the sample size is 16 percent of the population. That is, 16 percent of the units in each group must be sampled.

It should be recognized that this is an upper limit on the sample size. Application of the survey methodology will allow a better estimate of the statistical deviation of the units from the drawings. As this data becomes available, the required initial sample size will become better known and is expected to decrease.

Statistics to be Applied to the Sample Data

The acquired field data will have some degree of variation among the samples. The distribution of this data can be characterized by the mean and variance of the sample data.

Since the purpose of the survey is to analyze alternatives for the population, not just the samples, the data from the samples must be used to represent the population. It is assumed that the sample mean and the population mean are the same.

Statistical treatment of the sample data using standard methods will allow determination of the confidence interval of the values of surveyed features. In addition, if too large a confidence interval is obtained for a feature, standard statistical methods will allow an estimate of the number of additional surveys necessary for that feature to bring the confidence interval to within required limits.

Effects on Life Cycle Costing

The statistical analysis envisioned for the survey methodology will allow upper and lower bounds to be established on the data. These upper and lower bounds should be used as the basis for life cycle costing considerations and not the mean.

Many features to be considered as options exhibit a sensitivity to the level of what is already present in the structure. Ceiling insulation is one good example. Suppose the desired insulation level is R-30. However, if the existing level is R-27, it may not be cost effective to add more, while if it

is presently R-10, it probably would be. By providing upper and lower bounds the range of expected existing values can be explored as to the benefits of the alternative considered.

Application of statistical analysis will allow the following to be accomplished:

- Use of statistical analysis methods as recommended in this appendix will allow the analyst to establish confidence intervals for audited measurements.
- In order to provide reasonable confidence in the audit results it may be necessary to vary the number of audits per feature. This will be primarily dependent on the standard deviation of the sample. In this case the method gives an estimate as to the number of additional audits required. In addition, full audits need not be conducted, but rather only those features needing more samples will be audited.
- Providing upper and lower bounds allow the evaluation of the life cycle cost effect of the variation in the feature being evaluated.

APPENDIX B

DATA REQUIREMENTS

In order to calculate the energy performance of a building, whether by the RCS methodology or by the proposed methods for USAF, data are required for the building and the climate. These data can conveniently be broken down into three classifications: 1) available from desk-top sources such as drawings or routine reports, 2) available from desk-top sources, but needing field verification, 3) available only through a field study.

1. Available from desk-top sources:

- Housing energy consumption
- Ancillary equipment consumption on housing meter
- Number of units built to each design
- Climatic data
- Design data
- Base guidelines for housing assignment (number of occupants)

For each design:

- Wall area and construction
- Floor area and construction
- Window area, orientation, and number of glazing layers
- Number of fireplaces
- Heating system energy source and age of system
- Air conditioning system energy source and age of system
- Hot water system energy source and age of system
- Location of HVAC system and hot water heater (conditioned or unconditioned space)

2. Available from desk-top data, but needing field verification:

For each design:

- Any building modifications that affect energy consumption
- Wall insulation thickness and material (only needs field verification if in question)
- Roof/ceiling insulation thickness and material
- Floor/perimeter insulation thickness and material
- Basement/crawl space insulation thickness and material
- Crawl space ventilation, height, and relation to grade
- Attic ventilation
- Thermal integrity of fireplace dampers and doors
- Heating system condition, manufacturer and model, capacity, rated performance
- Cooling system condition, manufacturer and model, capacity, rated performance
- Duct and piping condition and insulation
- Hot water system rating and set point
- Exterior shading device geometry
- Hot water heater surface area and insulation R-value
- Thermostat settings (HVAC system and water heater)
- Presence of window locks and latches (affects infiltration rate)
- Presence of vent dampers
- Major appliance power ratings

3. Available only through field survey

For each design, by inspection:

- Fit of window and door (average crack width)
- Presence and condition of caulking on window and door frames
- Presence and condition of weatherstripping on window and door frames
- Cracks in ceilings, floor, and wall joints and corners
- Presence of leaks around wall, floor, roof, and ceiling penetrations
- Duct taping

- HVAC system filter status
- Air conditioner or heat pump outdoor unit condition
- Undocumented building modifications

For each design, by questionnaire to all occupants:

- Use of thermostats, preferred comfort levels, use of manual setback
- Estimated hot water consumption, based on use of appliances (dishwasher, clothes washer) and bathing
- Use of interior shading devices
- Approximate number of entrances and exits per day
- Occupancy patterns

Field Survey

The field survey is most effectively accomplished with personnel trained specifically for that task, as in the RCS program. The field survey team must have a reasonable understanding of all the factors influencing building energy consumption and must be trained to provide specific data and observations required for the conservation survey. Much of the field survey requires only qualitative observations, but the "eye" of the observer must know what to look for. Ability to work with a tape measure and dimensions is also required.

The field survey should require approximately one and one-half to two man-hours per unit. The occupant questionnaire is a separate item and is not part of the field survey.

Occupant Questionnaire

To obtain a good statistical data base for the occupant questions, a questionnaire should be sent to all residents rather than just those in the field survey. The questionnaire would resemble those used for the DOE Class C Performance Monitoring Program methodology [10] but would be considerably shorter, addressing only those items listed previously.

APPENDIX C

ACCURACY LIMITS AND SENSITIVITY

In order to assess the limits of accuracy of a survey using only desk-top data, an analysis was performed on Unit Type A-22, Capeheart Housing Area, Tyndall AFB, Florida (Figure C-1). This single storey duplex is composed of two units, each having 1192 ft² (gross) of floor area, with two bedrooms. Construction is slab on grade with concrete block walls.

Insight into the impact of errors in significant load-determining parameters is provided through a detailed heating load analysis and cooling load analysis. Both methods are detailed by ASHRAE [6].

FLOOR PLAN - UNIT TYPE A22
TYNDALL AFB, FLORIDA

FIGURE C-1

Base Case Heating Load

The design conditions for this base case analysis are:

Tyndall AFB, Panama City, Florida

Latitude: 30°N

Longitude: 85.7°W

Elevation: 22 ft.

Outside Dry Bulb Temperature: 33°F

Inside Design Temperature: 70°F

ΔT : 37°F

Heat Loss Table

Component	Area (ft ²)	U-Value (Btu/hr. ft. ² F)	ΔT (°F)	Q (Btu/hr.)	% of Total
North Wall	256	.119	37	1,129	5.8
North Door	19.5	.49	37	355	1.8
North Glazing	60	1.10	37	2,442	12.5
South Wall	316	.119	37	1,391	7.1
South Doors	39	.49	37	707	3.6
South Glazing	33	1.10	37	1,343	6.9
East Wall	208	.119	37	918	4.7
West Party Wall	208	-	-	0	0.0
Ceiling	1,118	.083	34	3,155	16.2
Floor	Perim. = 104 ft.	$F_2 = 30$ Btu/hr. ft.		3,120	16.0
Infiltration	ACH = 1.0 ADR = 1.0	.018 Btu/ft. ³ F Vol. = 7,379 ft. ³		4,914	25.4
Total				19,474	100.0

Q = 19,474 Btu/hr.

UA = 526 Btu/hr.F

q = 16.34 Btu/hr. ft.² (gross floor area)

Base Case Cooling Load

The design conditions are:

Tyndall AFB, Panama City, Florida

Latitude: 30°N

Longitude: 85.7°W

Elevation: 22 Ft.

Outside Dry Bulb Temperature: 90°F

Outside Wet Bulb Temperature: 77°F

Mean Daily Range: 14°F

Average Daily Temperature: $90 - 0.5 (14) = 83^{\circ}\text{F}$

Indoor Dry Bulb Temperature: 75°F

Indoor Relative Humidity: 50%

Design Hour: 5 p.m. (solar time)

Cooling Load Nomenclature [6]

- U = overall thermal conductance (Btu/hr sq ft $^{\circ}\text{F}$)
- A = area (sq ft)
- CLTD = cooling load temperature difference ($^{\circ}\text{F}$)
- F_c = factor to account for heat loss to environment
- Q = heat gain (Btu/hr)
- SC = shading coefficient
- SHG = solar heat gain factor (Btu/sq ft hr)
- CLF = cooling load factor
- cfm = infiltration rate (cu ft/min)
- ΔT = temperature difference ($^{\circ}\text{F}$)
- ΔW = humidity ratio difference (lb water/lb dry air)

Cooling Load Table: ASHRAE Residential Calculations

<u>Component</u>	<u>Q (Btu/Hr)</u>	<u>% of Total</u>
Walls	1420	9.8
Doors	482	3.3
Ceiling/Roof	3990	27.5
Floor	0	0
Glazing	2052	14.2
Infiltration	1096	7.6
Appliances	1200	8.3
Occupants	900	6.2
 Sensible Load	 11140	 77.0
Latent Load	3342	23.0
 Total Heat Gain	 14482	 100.0

Cooling Load Table: ASHRAE Commercial-Type Calculations

Hour 17

<u>Component</u>	<u>U</u> (Btu/hr. ft. ² F)	<u>A</u> (ft. ²)	<u>CLTD</u> (F)	<u>F_C</u>	<u>Q</u> (Btu/hr.)	<u>% of</u> <u>Total</u>
Roof	.071	1,118	63	.944	4,720	21.7
N. Wall	.135	268	13.3	.944	453	2.1
E. Wall	.119	208	27.4	.944	640	2.9
S. Wall	.153	348	23.2	.944	1,166	5.4
Floor	-	-	-	-	0	0.0
Glass (cond.)	1.04	108	14	.944	1,484	6.8

<u>Solar Gains</u>	<u>A</u> (ft. ²)	<u>SC</u>	<u>SHG</u> (Btu/hr ft ²)	<u>CLF</u>	<u>F_C</u>		
N. Glass	68	.64	41.3	.78	.944	1,323	6.1
Unshaded S. Glass	37	.64	51.0	.27	.944	308	1.4
Shaded S. Glass	3	.64	41.3	.27	.944	20	0.1

<u>Internal Sources</u>	<u>Heat Output</u> (Btu/hr.)	<u>CLF</u>	<u>F_C</u>		
Lights	3,410	.82	.944	2,640	12.1
Appliances	5,200	.72	.944	3,534	16.2
People (70% Radiant)	1,020	.77	.944	755	3.5

	<u>Factor with Conversions</u>	<u>cfm</u>	<u>ΔT</u>		
Infiltration	1.10	67.9	15	1,120	5.1

<u>Heat Output for Four People</u>					
People (latent)	1,020			1,120	4.7

	<u>Factor with Conversions</u>	<u>cfm</u>	<u>ΔW</u>		
Infiltration (latent)	4,840	67.9	.0079	2,596	11.9
Total Cooling Load (Btu/hr.)				21,779	100.0

Sensitivity Analysis

The preceeding heating load calculation indicates that the analysis will be particularly sensitive to indoor/outdoor temperature differences, infiltration, and ceiling and floor insulation levels. The cooling load calculation indicates large sensitivity to conduction heat gain through the roof and infiltration. In order to better assess the change in loads with variation of parameters, analyses were made with varying orientation, interior shading, overhangs, infiltration, insulation levels, roof color, internal loads, and thermostat set points.

Table C-1 summarizes the results of the sensitivity analysis. The base case is the Type A-22 Capeheart unit facing due south. The effect of parameter variations is illustrated by the change in design loads for each case. Standard ASHRAE design heating load procedures and the ASHRAE residential cooling load methodology were used.

While the ASHRAE commercial-type cooling load calculations might seem to be more accurate for detailed examination of changes, it is not appropriate to this study.

Table C-1 indicates that the cooling design loads are more sensitive to parameter variations than heating loads. In general, this is due to the smaller design temperature differences for cooling. A given change is reflected as a larger fraction of the cooling load than the heating load. However, when considering annual energy consumption, heating loads normally become the dominant influence.

Table C.1 Results of Sensitivity Analysis

Description of Case	Design Heating Load		Design Cooling Load	
	Btu/hr. ft. ² (Based on Gross Floor Area)	% Increase Over Base Case	Btu/hr. ft. ² (Based on Gross Floor Area)	% Increase Over Base Case
Base case	16.34	-	12.15	-
Base case done with commercial calculations	16.34	0.0	18.27	50.4
Base case with the house rotated 90° so that the house axis now runs north-south	16.34	0.0	14.33	17.9
Base case using roller shades rather than venetian blinds for interior shading	16.34	0.0	12.50	2.9
Base case while ignoring overhangs	16.34	0.0	12.50	2.9
Base case with no overhangs & no interior shading	16.34	0.0	13.83	13.8
Base case with low infiltration: Summer ACH = .35 Winter ACH = .75	15.31	-6.3	11.71	-3.6
Base case with high infiltration: Summer ACH = .75 Winter ACH = 1.25	17.37	6.3	12.58	3.5
Base case except with 15% less insulation in the walls and ceiling	16.96	3.8	12.86	5.8

Description of Case	Design Heating Load		Design Cooling Load	
	Btu/hr. ft. ² (Based on Gross Floor Area)	% Increase Over Base Case	Btu/hr. ft. ² (Based on Gross Floor Area)	% Increase Over Base Case
Base case except with 10% more insulation in the walls and ceiling	15.99	-2.1	11.77	-3.1
Base case except with a light colored roof	16.34	0.0	11.34	-6.7
Base case except with internal loads used in cooling analysis 25% less	16.34	0.0	11.58	-4.7
Base case except with internal loads used in cooling analysis 25% more	16.34	0.0	12.72	4.7
Base case except with: Summer T _{in} = 72°F Winter T _{in} = 68°F	15.58	-4.7	13.42	10.5
Base case except with: Summer T _{in} = 78°F Winter T _{in} = 72°F	17.09	4.6	10.88	-10.5

From the standpoint of a desk-top data survey, the results of the analysis are disappointing. The parameters shown to have the largest effect--infiltration, and thermostat settings--are not available from the desk-top survey. Accounting for the potential variability in thermostat settings, infiltration estimates, and insulation levels, the calculated heating load can vary by ± 15 percent, and the cooling load may vary by ± 25 percent.

The study was conducted for a unit at Tyndall AFB and is climate dependent. Both design temperature differences and energy-determining climate parameters (heating degree-days, compressor full load hours) are site dependent. A cooler climate will show more variability in the design cooling load because of the smaller temperature difference. However, the energy consumption error on a yearly basis might be smaller due to a shorter cooling season. If it is assumed, however, that the above limits are representative, and that the climate effects for Tyndall are acceptable, it is estimated that desk-top data should be able to predict actual unit energy consumption to within +40%, -30%.

APPENDIX D

SURVEY DATA REQUIREMENTS VS. AFM 88-29

Data Requirements

Weather data used in the RCS Study is provided in Section E-1 of the RCS Model Audit Manual. Data are available on a monthly basis as follows:

Dry Bulb (°F): (Daily Average)
 (Daily Minimum Average)
 (Daily Maximum Average)
 (Daytime Average)
 (Nighttime Average)

Heating Degree Days (°F-Day, base 65°F)
Cooling Degree Days (°F-Day, base 65°F)
Relative Humidity (Daytime Average, %)
Wind Speed (Daily Average, Mph)
 (Monthly Maximum, Mph)

Mean Daily Solar Radiation (Btu/Sq. Ft.)
Wind Speed Distribution (5 Mph Bins, 0 to 65, %)
Ground Temperatures (°F)
Liu/Jordan Factors

In addition to the RCS data requirements, additional data are needed for the proposed USAF survey methodology:

Full-load hours of cooling equipment operation
Summer and winter design temperatures and mean coincident wet bulb (summer)
Heating degree-days at variable base temperatures (corresponds to building balance points)

Data Available in AFM 88-29

Chapter 1:

Winter Design Data: Dry Bulb 99%
 Dry Bulb 97.5%
 Prevailing Wind Direction
 Mean Wind Speed (Knots)

Heating Degree Days (65°F)
Summer Design Data: Dry Bulb 1% (w/Mean Coincident Wet Bulb (MCWB))
 Dry Bulb 2.5% (w/MCWB, Mean Daily Range, Prevailing
 Wind Direction)
 Dry Bulb 5% (w/MCWB)
 Wet Bulb 1%
 2.5%
 5%

Summer A.C. Criteria: Dry Bulb: Hours $\geq 93^{\circ}\text{F}$
 $\geq 80^{\circ}\text{F}$
Wet Bulb: Hours $\geq 73^{\circ}\text{F}$
 $\geq 67^{\circ}\text{F}$

Chapter 2: Same data for areas outside U.S.

Chapter 3:

Temperature Bins, Hours per month in 5°F dry bulb bins during hours
01-08, 09-16, 17-24 with MCWB for each temperature bin

Chapter 4: Same temperature data as Chapter 3, except outside U.S.

Chapter 5: Cooling Degree Days, Base 65°F

Chapter 6: Same as Chapter 5 except outside U.S.

This appendix presents the treatment necessary to use AFM 88-29 data to meet the requirements of the USAF survey methodology. The method will be presented by example. Lack of adequate data in AFM 88-29 is also indicated.

For this example, January data for Tampa, FL, which is common to both RCS and AFM-88-29, will be used.

Tampa, FL January Bin Data From AFM 88-29

MID BIN Temp	Temp. Range	Annual Observations by Hour Group			Total	MCWB
		<u>01-08</u>	<u>09-016</u>	<u>17-24</u>		
82	80-84		3		3	69
77	75-79		26	4	30	67
72	70-74	1	44	19	64	65
67	65-69	25	47	51	123	62
62	60-64	57	46	59	162	58
57	55-59	55	36	44	135	53
52	50-54	39	24	36	99	48
47	45-49	34	14	21	69	43
42	40-44	22	5	10	37	38
37	35-39	10	3	3	16	33
32	30-34	3	1	1	5	28
27	25-29	1			1	25

The following equations are used:

$$\text{DAILY AVERAGE} = \frac{\sum_{\text{Bins}} \sum_{\text{Time}} (\text{MIDBIN} \times \text{OBSNS})}{\sum_{\text{Bins}} \sum_{\text{Time}} \text{OBSNS}} \quad (\text{D-1})$$

$$\text{DAYTIME AVERAGE} = \frac{\sum_{\text{Bins}} \sum_{\text{09-16}} (\text{MIDBIN} \times \text{OBSNS})}{\sum_{\text{Bins}} \sum_{\text{09-16}} \text{OBSNS}} \quad (\text{D-2})$$

$$\text{NIGHTTIME AVERAGE} = \frac{\sum_{\text{Bins}} \sum_{[\text{Time} - (09-16)]} (\text{MIDBIN} \times \text{OBSNS})}{\sum_{\text{Bins}} \sum_{[\text{Time} - (09-16)]} \text{OBSNS}} \quad (\text{D-3})$$

where: OBSNS = observations

Following is a tabulation of the data required in the numerators:

Weighted Values = MIDBIN x OBSNS

MID BIN Temp.	HOUR GROUPS			TOTAL
	01-08	09-16	17-24	
82		246		
77		2002	308	
72	72	3168	1368	
67	1675	3149	3417	
62	3534	2852	3658	
57	3135	2052	2508	
52	2028	1248	1872	
47	1598	658	987	
42	924	210	420	
37	370	111	111	
32	96	32	32	
27	27			
<hr/>				
TOTAL	13459	15728	14681	43868
OBSNS	247	249	248	744

RESULTS:

	FROM BIN DATA	FROM RCS DATA
DAILY AVERAGE =	59°F	59.6°F
DAYTIME AVERAGE =	63°F	63.0°F
NIGHTTIME AVERAGE =	57°F	56.3°F

To find average RH, calculate average wet bulb, using same methodology as above.

Average W.B. = 54.3°F
Daytime Average Temp = 63.0°F

Yields:

Daytime Average RH = 72%
RCS value = 67%

The bin data in AFM 88-29 represents long term weather statistics in a tabular format. Given this data, it is straightforward to generate reasonable values of the means. The daily minimum and maximum averages cannot be generated from this data since the bin data already represent averages. However, review of the RCS methodology indicates that the daily minimums and maximums are extraneous data and are not required.

Cooling and heating degree days (base 65°F) are required and are provided directly in AFM 88-29 chapters 1 and 5.

Ground temperature data can be obtained from AFM 88-29 indirectly though application of the following formula:

$$T(x, t) = T_m - A_s e^{-x (116.2/a)^{-0.5}} \cos [(t - t_0 - x(29.05/a))/58.1] \quad (D-4)$$

where:

$T(x, t)$ = temperature at depth x , time t

T_m = average annual air temperature + 2.5°

A_s = annual temperature amplitude (Chapter 24, 1977 ASHRAE Handbook of Fundamentals)

x = depth, (feet)

a = thermal diffusivity of soil (ft²/day)

t = day of year

t_0 = day of year with minimum air temperature (generally about day 35)

The average annual air temperature can be obtained in the same manner as daily average, except using the annual bin data.

This formula can be simplified to the form:

$$T(x, t) = T_M - A_S f(x, a, t) \quad (D-5)$$

The function $f(x, a, t)$ can be supplied in a pre-tabulated form for various depth (x), soil types (a), and each month of the year (t).

Windspeed data are required by RCS to evaluate wind energy devices. Since these devices are not considered in the proposed USAF survey, wind data is not required. Wind information is used indirectly to derive the annual infiltration load, but the RCS data can be extrapolated for this purpose.

Additional Data

The only data that must be provided, in addition to AFM 88-29, to meet the RCS Model Audit requirements are solar radiation data consisting of monthly mean total daily radiation on a horizontal or vertical surface. For the proposed USAF survey, full-load hours of cooling equipment operation and heating degree-days at variable base temperatures must also be provided. Appendix E addresses sources for this information.

APPENDIX E

USAF BASE DATA SOURCES

The following table contains the location and appropriate source site of bin data, cooling data (full load hours), and solar radiation data (and variable temperature base degree-days) for 94 USAF bases throughout the United States. The base listing corresponds to those found in the Automatic Voice Network (AUTOVON) Directory. Additional USAF facilities may be added to this listing, as required. Bin data sites are from AFM 88-29 [13], cooling full load hours from Insulation Manual, Homes and Apartments [14], and solar radiation data and variable base degree-days from the Passive Solar Design Handbook [1].

In general, the data assigned to the bases corresponds to that from the nearest geographic location where data are available. Adjustments were made for features that may affect the local climatic such as mountain ranges and seashores. In such cases, an assignment was made that more closely represents the climate of the base.

Additional data are available from the National Climatic Center (NCC), National Oceanic and Atmospheric Administration, Asheville, North Carolina. The NCC tabulates and analyzes the weather data from over 250 stations throughout the United States. Of particular interest are "Local Climatological Data," published monthly by city [15]; "Climatological Data," published monthly by state [16]; and "Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days," by state [17].

LIST OF USAF BASES

State	Air Force Base Name	City Location	Lat. (°N)	Long. (°W)
Alabama	Gunter	Montgomery	32.30	86.40
"	Maxwell	Montgomery	32.38	86.37
Alaska	Eielson	Fairbanks	64.67	147.10
"	Elmendorf	Anchorage	61.25	149.80
Arizona	Davis-Monthan	Tucson	32.18	110.90
"	Luke	Glendale	33.55	112.37
"	Williams	Chandler	33.50	111.67
Arkansas	Blytheville	Blytheville	35.95	89.95
"	Little Rock	Little Rock	34.92	92.15
Calif.	Beale	Marysville	39.12	121.43
"	Castle	Merced	37.38	120.57
"	Edwards	Edwards AFB	34.90	117.87
"	George	Victorville	34.58	117.38
"	March	Riverside	33.88	117.25
"	Mather	Sacramento	38.57	121.30
"	McClellan	Sacramento	38.67	121.40
"	Norton	San Bernardino	34.10	117.23
"	Travis	Fairfield	38.27	121.93
"	Vandenberg	Lompoc	34.72	120.57
Colorado	Peterson	Colo. Springs	38.83	104.78
"	Lowry	Denver	39.72	104.88
Delaware	Dover	Dover	39.13	75.47
Florida	Eglin	Valparaiso	30.48	86.52

State	Air Force Base Name	City Location	Lat. (°N)	Long. (°W)
"	Homestead	Homestead	25.48	80.40
"	MacDill	Tampa	27.85	82.50
"	Patrick	Cocoa Beach	28.23	80.60
"	Tyndall	Panama City	30.07	85.58
Georgia	Dobbins	Marietta	33.92	84.52
"	Moody	Valdosta	30.97	83.20
"	Robins	Warner Robins	32.63	83.60
Hawaii	Bellows	Honolulu	21.37	157.72
"	Hickman	Honolulu	21.33	157.92
"	Wheeler	Honolulu	21.48	158.03
Idaho	Mountain Home	Mountain Home	43.03	115.90
Illinois	Chanute	Rantoul	40.30	88.13
"	Scott	Belleville	38.55	89.85
Indiana	Grissom	Bunker Hill	40.65	86.15
Kansas	McConnell	Wichita	37.63	97.13
Lousiana	Barksdale	Shreveport	32.50	93.67
"	England	Alexandria	31.33	92.55
Maine	Dow	Bangor	44.80	69.83
"	Loring	Limestone	46.95	67.88
Maryland	Andrews	Wash., D.C.	38.82	76.87
Mass.	Otis	Falmouth	41.65	70.52
"	Westover	Chicopee	42.20	72.53

State	Air Force Base Name	City Location	Lat. (°N)	Long. (°W)
Mich.	KI Sawyer	Gwinn	46.35	87.40
"	Wurtsmith	Oscoda	44.45	83.40
Miss.	Columbus	Columbus	33.65	88.45
"	Keesler	Biloxi	30.42	88.92
Missouri	Richards-Gebaur	Grandview	38.85	94.55
"	Whiteman	Knobnoster	38.82	93.55
Montana	Malmstrom	Great Falls	47.50	111.18
Nebraska	Offutt	Omaha	41.12	95.92
Nevada	Nellis	Las Vegas	36.25	115.03
N. H.	Pease	Portsmouth	43.07	70.82
N. J.	McGuire	Wrightstown	40.02	74.60
New Mex.	Cannon	Clovis	34.28	103.22
"	Holloman	Alamogordo	32.85	106.10
"	Kirtland	Albuquerque	35.05	106.62
N. York	Griffiss	Rome	43.23	75.42
"	Plattsburg	Plattsburg	44.65	73.47
"	Stewart	Newburgh	41.50	74.00
N. Car.	Pope	Fayetteville	35.17	79.02
"	Seymour-Johnson	Goldsboro	35.33	77.97
N. Dak.	Grand Forks	Emerado	47.95	97.40
"	Minot	Minot	48.42	101.35
Ohio	Rickenbacker	Columbus	39.82	82.93
"	Wright-Patterson	Dayton	39.82	84.05

State	Air Force Base Name	City Location	Lat. (°N)	Long. (°W)
Oklahoma	Altus	Altus	34.65	99.27
"	Tinker	Oklahoma City	35.42	97.38
"	Vance	Enid	36.55	97.92
S. Car.	Charleston	Charleston	32.90	80.03
"	Myrtle Beach	Myrtle Beach	33.68	78.93
"	Shaw	Sumter	33.97	80.47
S. Dak.	Ellsworth	Rapid City	44.13	103.10
Tenn.	Arnold	Tullahoma	35.50	86.10
Texas	Bergstorm	Austin	30.20	97.67
"	Brooks	San Antonio	29.35	98.45
"	Carswell	Fort Worth	32.78	97.43
"	Dyess	Abilene	32.42	99.85
"	Ellington	Houston	29.62	95.17
"	Goodfellow	San Angelo	31.43	100.40
"	Kelly	San Antonio	29.38	98.58
"	Lackland	San Antonio	29.38	98.62
"	Laredo	Laredo	27.53	99.45
"	Laughlin	Del Rio	29.37	100.78
"	Randolf	San Antonio	29.53	98.20
"	Reese	Lubbock	33.60	102.05
"	Sheppard	Wichita Falls	33.98	98.50

State	Air Force Base Name	City Location	Lat. (°N)	Long. (°W)
Utah	Hill	Ogden	42.12	111.97
Virginia	Langley	Hampton	37.08	76.35
Washington	Fairchild	Spokane	47.62	117.63
"	McChord	Tacoma	47.15	122.48
Wyoming	F. E. Warren	Cheyenne	41.15	104.83

LOCATION OF APPROPRIATE DATA SITES

State	Air Force Base Name	Bin Data Site	Cooling Data Site	Solar Data Site
Alabama	Gunter	Maxwell AFB	Montgomery	Montgomery
"	Maxwell	Maxwell AFB	Montgomery	Montgomery
Alaska	Eielson	Eielson AFB	Fairbanks	(No Data)
"	Elmendorf	Elmendorf AFB	Anchorage	(No Data)
Arizona	Davis-Monthan	Davis-Mon. AFB	Tucson	Tucson
"	Luke	Luke AFB	Phoenix	Phoenix
"	Williams	Luke AFB	Phoenix	Phoenix
Arkansas	Blytheville	Blytheville	Memphis, TN	Memphis, TN
"	Little Rock	Little Rock AFB	Little Rock	Little Rock
Calif.	Beale	Beale AFB	Marysville	Sacramento
"	Castle	Castle AFB	Merced	Fresno
"	Edwards	Edward AFB	Los Angeles	Los Angeles
"	George	Edwards AFB	Los Angeles	Los Angeles
"	March	Los Angeles	Los Angeles	Los Angeles
"	Mather	McClellan AFB	Sacramento	Sacramento
"	McClellan	McClellan AFB	Sacramento	Sacramento
"	Norton	Norton	Los Angeles	Los Angeles
"	Travis	Travis AFB	Sacramento	Sacramento
"	Vandenberg	Vandenberg AFB	Santa Maria	Santa Maria
Colorado	Peterson	Colo. Springs	Colo. Springs	Colo. Springs
"	Lowry	Buckley ANGB	Denver	Denver
Delaware	Dover	Dover AFB	Dover	Dover
Florida	Eglin	Eglin AFB	Pensacola	Mobile, AL

State	Air Force Base Name	Bin Data Site	Cooling Data Site	Solar Data Site
"	Homestead	Homestead AFB	Miami	Miami
"	MacDill	McDill AFB	Tampa	Tampa
"	Patrick	Patrick AFB	Melbourne	Daytona Beach
"	Tyndall	Tyndall AFB	Panama City	Apalachicola
Georgia	Dobbins	Atlanta	Marietta	Atlanta
"	Moody	Moody AFB	Valdosta	Tallahassee, FL
"	Robins	Robins AFB	Warner Robins	Macon
Hawaii	Bellows	Barbers Pt.	Honolulu	(No Data)
"	Hickman	Barbers Pt.	Honolulu	(No Data)
"	Wheeler	Barbers Pt.	Honolulu	(No Data)
Idaho	Mountain Home	Mtn. Home AFB	Mtn. Home	Boise
Illinois	Chanute	Springfield	Urbana	Springfield
"	Scott	Scott AFB	Belleville	St. Louis, MO
Indiana	Grisson	Grisson AFB	Kokomo	Fort Wayne
Kansas	McConnell	McConnell AFB	Wichita	Wichita
Lousiana	Barksdale	Barksdale AFB	Shreveport	Shreveport
"	England	England AFB	Alexandria	Shreveport
Maine	Dow	Bangor/Dow AFB	Bangor	Portland
"	Loring	Loring AFB	Caribou	Caribou
Maryland	Andrews	Andrews AFB	Wash., D.C.	Wash., D.C.
Mass.	Otis	Otis AFB	New Bedford	Providence, RI
"	Westover	Westover AFB	Boston	Boston

State	Air Force Base Name	Bin Data Site	Cooling Data Site	Solar Data Site
Mich.	KI Sawyer	KI Sawyer AFB	Marquette	Sault Ste. Marie
"	Wurtsmith	Wurtsmith AFB	Alpena	Alpena
Miss.	Columbus	Columbus AFB	Columbus	Birmingham, AL
"	Keesler	Keesler AFB	Biloxi	Mobile, AL
Missouri	Richards-Gebaur	Richards-G. AFB	Kansas City	Kansas City
"	Whiteman	Richards-G. AFB	Kansas City	Kansas City
Montana	Malmstrom	Malmstrom AFB	Great Falls	Great Falls
Nebraska	Offutt	Offutt AFB	Omaha	North Omaha
Nevada	Nellis	Nellis AFB	Las Vegas	Las Vegas
N. H.	Pease	Pease AFB	Portsmouth	Concord
N. J.	McGuire	McGuire AFB	Trenton	Philadelphia, PA
New Mex.	Cannon	Cannon AFB	Clovis	Tucomcari
"	Holloman	Holloman AFB	Alamogordo	Truth or Conseq.
"	Kirtland	Albuquerque	Albuquerque	Albuquerque
N. York	Griffiss	Griffiss AFB	Utica	Syracuse
"	Plattsburg	Plattsburg AFB	Burlngtn, VT	Burlngtn, VT
"	Stewart	Newburgh	Poughkeepsie	New York City
N. Car.	Pope	Fort Bragg	Fayetteville	Raleigh
"	Seymour-Johnson	Sey-Johnson AFB	Kinston	Raleigh
N. Dak.	Grand Forks	Grand Forks AFB	Grand Forks	Minot
"	Minot	Minot AFB	Minot	Minot
Ohio	Rickenbacker	Wright-Patt. AFB	Columbus	Columbus
"	Wright-Patterson	Wright-Patt. AFB	Dayton	Dayton

State	Air Force Base Name	Bin Data Site	Cooling Data Site	Solar Data Site
Oklahoma	Altus	Altus AFB	Altus	Amarillo, TX
"	Tinker	Tinker AFB	Oklahoma City	Oklah. City
"	Vance	Vance AFB	Ponca City	Tulsa
S. Car.	Charleston	Charleston AFB	Charleston	Charleston
"	Myrtle Beach	Myrtle B. AFB	Myrtle B.	Charleston
"	Shaw	Shaw AFB	Columbia	Columbia
S. Dak.	Ellsworth	Ellsworth AFB	Rapid City	Rapid City
Tenn.	Arnold	Stewart AFB	Chattanooga	Chattanooga
Texas	Bergstorm	Bergstorm AFB	Austin	Austin
"	Brooks	Kelly AFB	San Antonio	San Antonio
"	Carswell	Carswell AFB	Fort Worth	Fort Worth
"	Dyess	Dyess AFB	Abilene	Abilene
"	Ellington	Ellington	Houston	Houston
"	Goodfellow	Dyess AFB	San Angelo	San Angelo
"	Kelly	Kelly AFB	San Antonio	San Antonio
"	Lackland	Kelly AFB	San Antonio	San Antonio
"	Laredo	Laughlin AFB	San Antonio	Del Rio
"	Laughlin	Laughlin AFB	San Antonio	Del Rio
"	Randolf	Kelly AFB	San Antonio	San Antonio
"	Reese	Webb AFB	Lubbock	Lubbock
"	Sheppard	Carswell AFB	Wichita Falls	Wichita Falls

State	Air Force Base Name	Bin Data Site	Cooling Data Site	Solar Data Site
Utah	Hill	Hill AFB	Salt Lake City	Salt Lake City
Virginia	Langley	Langley AFB	Norfolk	Norfolk
Washington	Fairchild	Fairchild AFB	Spokane	Spokane
"	McChord	McChord AFB	Seattle	Seattle
Wyoming	F. E. Warren	Cheyenne	Cheyenne	Cheyenne

APPENDIX F

PROPOSED ENERGY CONSERVATION MEASURES AND ANALYSIS TECHNIQUES

Listed below are the items described in Section 2.4 to be considered by ESC for inclusion in the USAF Residential Conservation Survey Methodology. For each item a thermal analysis technique is outlined. The input data points required to make the computations are identified. This work begins the process of developing the complete survey methodology as outlined in Task 3.1. Special procedures and documentation for data collection and calculation must be developed.

The list of items has been divided into four categories and prioritized based on cost-effectiveness, practicality, and suitability to USAF requirements. The ranking relates to the inclusion of the items in the survey methodology and is not intended to be an evaluation of the items for specific applications.

The categories used are:

- A - Highly recommended for consideration at all sites
- B - Recommended for consideration at all sites
- C - Recommended for consideration in certain areas or situations
- D - Not recommended

The rankings appear to the right of the name of each item. Categories A, B, and D are self explanatory. Category C includes those items whose technical or economic value may be limited to particular climates, geographic areas, or economic environments. For such items, an overall technical and economic analysis is suggested. This would reduce the survey and calculation burden on individual bases where certain alternatives are not viable. For many technically acceptable items in Category C, such an evaluation would provide fuel price thresholds for future economic consideration. Passive solar systems are examples.

Some of the proposed conservation strategies may not be applicable since they may be considered maintenance items by USAF, for example, duct taping or condensor cleaning. The potential exists to improve the cost-effectiveness of certain measures by incorporating them into the periodic refurbishment of the housing units. Applicable measures include lowering the water heater thermostat setting, applying gaskets to lights and switches, caulking, weatherstripping, condensor cleaning, and duct taping.

The analysis techniques outlined were selected on the basis of accuracy and ease of use. The general criteria is to choose the most accurate analysis methodology that meets the constraint of keeping the calculation time reasonable. Per ESC instructions, all calculations are designed to be made with a four-function calculator.

The RCS procedures were first reviewed for each item, where applicable. All RCS measures are addressed except load management, pool heating, and wind energy devices, as directed by USAF ESC. In many cases, the RCS procedures were adequate. Some required minor modifications; while in other cases, more current and appropriate techniques were available and recommended. For those items not covered under RCS, similar analysis techniques were developed. The primary reference was the 1977 ASHRAE Handbook of Fundamentals [6], which is required for the analysis.

The measures are grouped by the following headings: envelope changes (Items 1-18), sun control (Items 19-23), mechanical system (Items 24-42), domestic hot water (Items 43-47), solar (Items 48-56), and low-cost measures (Items 57-65).

Table F-1, at the end of this appendix, summarizes the recommendation.

Envelope Changes

2.4.1 Wall Cavity Insulation

C

Loose fill or foamed-in-place insulation for stud walls or cavity masonry walls. Reduces conduction heat loss/gain. This technique is applicable to those cavity walls that have no existing insulation. Any foam materials must meet health, safety, and fire requirements; formaldehyde compounds are a particular concern.

Analysis Method

Changes in exterior insulation levels are all analyzed in the same manner, which is based on [6]. The RCS methodology is very similar but is presented in nomogram form rather than a simple, algebraic relation.

The fundamental relationship is:

$$E_h = (1/\eta) (\Delta U) (A) (24) (\text{HDD}) \quad (\text{heating}) \quad (\text{F-1a})$$

$$E_c = (1/\eta) (\Delta U) (A) (\text{DETD}) (\text{FLH}) \quad (\text{cooling}) \quad (\text{F-1b})$$

where:

E_h, E_c = annual energy savings for heating and cooling, respectively (Btu/yr)

η = annual HVAC system operating efficiency in decimal form:
SPF (Seasonal Performance Factor) for heat pumps
SEER (Seasonal Energy Efficiency Ratio)/3.413 for air conditioners

ΔU = difference in effective U-value between the existing and retrofit cases (Btu/hr sq ft $^{\circ}\text{F}$)

A = surface area of the component (sq ft)

HDD = heating degree days ($^{\circ}\text{F day}$)

DETD = design equivalent temperature difference for cooling ($^{\circ}\text{F}$)

FLH = equivalent full-load hours of cooling equipment operation (hr)

Data Required

Existing wall construction (cross-section), retrofit insulation material and thickness, total surface area of the retrofitted section, heating degree-days, DETD and FLH tables, HVAC system seasonal efficiency.

2.4.2 Interior Wall Insulation

C

Rigid insulation with gypsum board, as one example, applied to interior of walls to provide additional R-value. Good for brick or block walls where cavity insulation is not applicable. Reduces heat loss/gain due to conduction.

Analysis Method

Analyzed in the same manner as 2.4.1.

Data Required

Same as 2.4.1.

2.4.3 Exterior Wall Insulation

C

Rigid insulation plus exterior weatherproof finish. Provides additional R-value without decreasing net floor area. Similar applications as for interior wall insulation.

Analysis Method

Analyzed in the same manner as 2.4.1.

Data Required

Same as 2.4.1.

2.4.4 Floor Insulation

A

Batts applied between floor joists to minimize heat loss through basement or crawl space.

Analysis Method

Floor insulation is handled slightly differently than wall insulation because the temperature in the basement or crawl space is usually different from the ambient temperature. The ASHRAE Handbook of Fundamentals [6] has a method to predict the temperature of the unconditioned space under design conditions [page 24.2, equation (F-1)]. However, this method is not straight-forward in the case of a basement crawl space or foundation which exchanges heat with the ground. Based on our experience, three factors are proposed to adjust for the unconditioned space temperature. For basements, a factor of 0.5 is applied to equation (F-1). For unvented crawl spaces, a factor of 0.75 is applied. For vented crawl spaces, a factor of 1.00 is appropriate.

For the cooling calculations, the floor is only considered if it is over an unconditioned room or a vented crawl space.

Data Required

Existing floor construction, retrofit insulation material and thickness, total retrofit floor area, heating degree-days, FLH tables, HVAC system seasonal efficiency, ventilation of crawl space.

2.4.5 Slab Perimeter Insulation

B

Exterior insulation applied vertically along the perimeter to minimize heat loss in slab-on-grade construction, recommended only if no slab insulation exists. Some excavation is required to retrofit this item.

Analysis Method

Heat loss from floor slabs is correlated to the perimeter or exposed edge length rather than the floor area. The analysis method is outlined in the ASHRAE GRP 158 Cooling and Heating Load Calculation Manual [18] and uses a table of heat loss per foot of exposed perimeter based on insulation and design temperature. To determine an equivalent UA-value difference to utilize in equation (F-1), the heat loss per foot is determined for both the existing and retrofit conditions. The difference is multiplied by the perimeter length and then divided by the design temperature difference. This value is then used in equation (F-1) in place of $(\Delta U_e)(A)$.

For the cooling season, the slab is assumed to provide zero net effect on the load due to the tempering effect of the earth.

Data Required

Retrofit insulation material and thickness, exposed perimeter length, heat-load factor table, heating design temperature, heating degree-days, heating system seasonal efficiency, ASHRAE GRP 158 Cooling and Heating Load Calculation Manual [18].

2.4.6

Foundation Insulation

B

Insulation on the inside of crawl space walls to minimize heat loss through floors and reduce risk of freezing pipes in crawl space. A vapor barrier should also be placed on the ground to prevent moisture seepage from the ground. The insulation will only be effective if all significant air leaks are sealed. If a combustion device is in the crawl space, combustion air must be ducted to it.

Analysis Method

The foundation wall insulation reduces the heat loss from the floor of the house and therefore, an effective U-value is needed. The method from [6] mentioned under floor insulation [equation (F-1), page 24.2] is used to determine the temperature of the crawl space

with the retrofit insulation. An air change rate of 1 per hour should be assumed for the retrofit case. The foundation wall U-value is determined by the methodology outlined under basement wall insulation, Section 2.4.7. The effective U-value of the floor is:

$$U_e = U (T_h - T_{cs}) / (T_h - T_d) \quad (F-2)$$

where:

U_e = effective U-value of floor (Btu/hr sq ft $^{\circ}$ F)

U = actual U-value of floor (Btu/hr sq ft $^{\circ}$ F)

T_h = design interior temperature ($^{\circ}$ F)

T_{cs} = design crawl space temperature ($^{\circ}$ F)

T_d = design ambient winter temperature ($^{\circ}$ F)

For the existing crawl space, the effective U-value is assumed to be 0.75 and 1.00 times the actual U-value for unvented and vented crawl spaces, respectively (see floor insulation). The energy savings from the effective U-value difference is calculated with equation (F-1).

No cooling effect is considered if the crawl space is unvented due to the tempering effect of the earth.

Data Required

Crawl space wall area, height, and depth below grade; retrofit insulation material and thickness; floor construction and insulation; interior and ambient winter design temperatures; heating degree-days; heating system efficiency.

2.4.7

Basement Wall Insulation

B

Insulation on the inside of basement walls to minimize basement/floor heat loss. Suitable where basement is used as a conditioned space.

Analysis Method

The below-grade portion of basement walls is handled differently than above-grade walls. Heat transfer is with the ground rather than the ambient air, a very complex interaction. The ASHRAE [6] techniques used account for the ground effect by determining heat loss coefficients based on the depth of the wall section below-grade and on the additional insulation thickness (Table 1, p. 24.4). The basement wall is divided into sections based on the depth and a total U-value calculated, both for the existing and retrofit cases. The U-value difference is used in equation (F-1) to determine energy savings.

No cooling effect is considered because the basement does not generally have a cooling load due to the earth-tempering effect.

Data Required

Basement wall area and depth below-grade, retrofit insulation material and thickness, heating degree-days, heating system efficiency.

2.4.8

Ceiling Insulation (below unconditioned attics)

A

Poured in place, loose fill, or batt insulation in the ceiling to lower heat gain/loss from the attic space.

Analysis Method

The effectiveness of the ceiling insulation is very dependent on the existing attic ventilation. In general, higher ventilation rates reduce the solar gain effect and improve the insulation effectiveness in summer and reduce it in winter. The analysis methods are from ASHRAE Handbook of Fundamentals [6], (page 22.6 and

24.2). Ventilation is accounted for in the procedure by determining an effective U-value which also accounts for the roof construction and ceiling insulation. The effective U-value is calculated for the existing and retrofit cases and used in equation (F-1) to determine the seasonal energy savings. A separate U-value is calculated for summer gains and another for winter gains. The summer calculation (page 22.6) accounts for solar gains and typical summer ventilation rates, resulting in a higher effective U-value than in the winter.

Data Required

Ceiling area, existing insulation material and thickness, retrofit insulation material and thickness, roof construction and area. HVAC system seasonal efficiency, heating degree-days, FLH tables, existing attic ventilation.

2.4.9 Roof Insulation

B

Batt or rigid insulation applied to roof to lower heat gain/loss to attic space or to conditioned space (no attic).

Analysis Method

The analysis is similar to that used for ceiling insulation, but ventilation is usually not present. Therefore, additional roof insulation is handled in the same manner as additional wall insulation, item 2.4.1.

Data Required

Roof area, existing insulation material and thickness, retrofit insulation material and thickness, HVAC equipment seasonal efficiency, heating degree-days, DETD tables, FLH tables, HVAC system seasonal efficiency.

2.4.10 Storm Doors

A

Lightweight exterior door, normally glazed, added to the outside of an existing door. Adds insulation value and reduces infiltration.

Analysis Method

The change in U-value resulting from a storm door is calculated from manufacturer's data or from generic data in Table 9, p. 22.25 [6]. Savings through conduction are determined by equation (F-1). Infiltration savings are determined by manufacturer's data or by estimates of the change in air leakage. Air leakage rates of common doors are tabulated on page 21.6 [6] and are based on the average crack width between the door and frame and the door area. An effective UA-value is determined from the following relation:

$$UA_e = CFM (1.08) \quad (F-3)$$

where:

UA_e = effective change in UA-value due to infiltration (Btu/hr °F)

CFM = air leakage for 15 mph wind (cu. ft./min.)

1.08 = factor to account for air density and heat capacity.

The reduction in air leakage is calculated assuming that the leakage of the existing door is reduced by 50 percent when retrofitted with a storm door.

Data Required

Existing door construction, area, and average crack size; storm door construction and weatherstripping, heating degree-days, FLH tables, HVAC system seasonal efficiency.

2.4.11 Storm Windows

A

External or internal removable glazing added to existing windows to increase insulation and reduce infiltration.

Analysis Method

Similar to storm doors; generic data is in Table 8, p. 22.24 and Tables 2 and 4, Chapter 21 [6]. Infiltration savings are determined by the change in leakage as with storm doors.

Data Required

Existing window construction, area, and apparent crack size; storm window construction and weatherstripping, heating degree days, FLH tables, HVAC system seasonal efficiency.

2.4.12 Double or Triple Glazed Windows

C

Multiple glazing layers separated by dead air space to decrease heat loss, would replace existing window glazing. This technique would be warranted if the window is in very poor condition or is to be changed for any reason.

Analysis Method

Similar to storm windows and doors. The change in U-value would be calculated from manufacturer's data or from generic data in Table 8, p. 22.24 [6]. Air leakage changes are handled using manufacturer's data or generic data in Tables 2 and 4, Ch. 21 [6]. Savings are determined with equation (F-1).

Data Required

Existing glazing type and area, multiple glazing type, heating degree days, FLH tables, HVAC system seasonal efficiency.

2.4.13 Movable Insulation

C

Insulating curtains, drapes, or shutters to reduce nighttime heat loss from windows.

Analysis Method

Analyzed as outlined in Movable Insulation, Appendix I [19], from a heating standpoint. No credit is given for cooling savings since windows are generally left uncovered during the day for lighting. The relationship is:

$$E = (1/\eta) (A) (F_a) (U) (HDD) (R) (24 \text{ hr/day}) (0.84) \quad (F-4)$$

where:

E = annual energy savings (Btu)

η = annual heating system efficiency in decimal form

A = gross window area (sq ft)

F_a = sash area factor

= 1 for aluminum

= 0.9 for wood

U = U-value of the existing window (Btu/hr sq. ft. °F)

HDD = heating degree days (°F - day)

R = reduction in U-value with movable insulation (Table A11-1)

0.84 = factor to account for the portion of the HDD during which auxiliary heating fuel is used

Movable insulation on south facing windows is addressed in Section 2.4.49 on direct gain.

Data Required

Existing number of window glazings and gross area, movable insulation R-value, heating degree days, operating schedule Table A11-1, [19].

2.4.14 Forced Attic Venting

D

Attic fans or blowers used to increase the ventilation in the attic and thus decrease summer attic temperatures and heat gain. This technique is only advantageous where a low level of attic insulation exists.

Analysis Method

The technique benefits only the cooling energy usage. Attic ventilation effect is calculated using manufacturer's flow rate data and estimating the effect on design cooling load through the ceiling, as outlined on p. 22.6 [6] and in Section 2.4.8. The analysis procedure is identical to the procedure for ceiling insulation in the cooling season, section 2.4.8. The effect is greatly dependent on the insulation level in the ceiling with the ventilation benefit decreasing as insulation level increases. The difference in effective U-value between retrofit and existing is used in equation (F-1b) to determine annual energy savings.

Data Required

Ceiling area, ceiling insulation material and thickness, roof area and construction, existing attic ventilation, forced ventilator flow rate, FLH tables, cooling system efficiency.

2.4.15 Natural Attic Venting

B

Increased ventilation of the attic space by the use of gable vents, ridge vents, or soffit vents. Lowers attic temperatures and reduces the ceiling cooling load. The value of natural attic venting is reduced by high levels of ceiling insulation.

Analysis Method

Similar to forced attic venting. The flow rate due to natural ventilation is derived from natural ventilation component manufacturer's data or by using the default values in Table 6, p. 22-23 [6].

Data Required

Ceiling area, ceiling insulation type and thickness, roof area and construction, existing attic ventilation, natural ventilation flow rate, FLH tables, cooling system efficiency.

2.4.16 Interior Thermal Mass

D

Additional interior mass such as masonry may have an impact on energy consumption due to mean radiant temperature effects and decreased cycling of HVAC equipment. Interior mass will also be important in the future when utilities implement time-of-day rate schedules. However, unless combined with solar heating, additional interior mass is presently not practical or cost-effective. Furthermore, no simplified analysis techniques for calculating the effect of interior thermal mass in residences have been found except combined with solar heating. Even the techniques used for solar heating do not adequately address the thermal mass effect. Therefore, thermal mass is only considered as part of a solar heating system, see Section 2.4.48.

2.4.17 Skylights

D

Glazing panels installed on the roof to introduce daylight and reduce lighting energy consumption. Daylighting is very complex to analyze and also to control. Residences do not often have a significant lighting load in the day like offices and businesses. Therefore, it is not recommended for consideration.

2.4.18 Landscaping

B

Addition of shrubs and trees to block summer sun and provide wind breaks. Reduces solar heat gains and cooling loads and also reduces air infiltration due to wind effects.

Analysis Method

The analysis requires qualitative estimates of the effect of landscaping on air infiltration and on shading. Air infiltration reduction can be estimated based on various field studies, such as the Twin Rivers study by Princeton University [20]. Infiltration effects on heating and cooling loads would be estimated by determining the effective UA-difference, equation (F-3), and then using equation (F-1).

With an estimate of typical summer shade patterns on the building from the landscaping, the shading effect on design equivalent temperature difference (DETD) and summer heat gain can be calculated as follows. For each building component in shade, the reduced design cooling load is calculated by the following relation:

$$\Delta L_c = U (A) (F_{sh}) (DETD - DETDS) (FLH) \quad (F-5)$$

where:

ΔL_c = reduction in design cooling load for a given component (Btu/hr)

U = overall U-value of the component (Btu/hr sq. ft. °F)

A = surface area (sq ft)

F_{sh} = the typical fraction of the component shaded on August 21

DETD = the DETD for the unshaded component, Table 35 [6] (°F)

DETDS = the design temperature difference for the shaded component (°F)
 = DETD for partitions if considering walls (°F)
 = the design temperature difference between inside and outside air if considering roofs (°F)

FLH = full-load hours of air conditioner operation (hr)

Data Required

Existing site plan; proposed landscaping type, location, and size; estimated shade patterns of landscaping on building; areas and U-values of the shaded building components; DETD tables; cooling design temperature; FLH tables.

Sun Control

2.4.19 Surface Colors

B

Wall and roof colors may have a significant impact on heating and cooling loads depending upon climate and construction. However, the effect is highly dependent on many factors: overall U-value of the component, thermal capacitance, orientation, and climate. A study was performed by Los Alamos National Laboratory for the Navy on heating effects of differently colored masonry walls [21]. A surface color change would only be recommended for wall or roof components that are expensive to insulate and/or ventilate.

2.4.20 Solar Control Films

C

Reflective or heat absorbing film on windows. These can be retrofitted to significantly decrease solar heat gains and window cooling loads.

Analysis Method

The effect of window films on cooling loads is determined by comparing the shading coefficients (SC) with and without the film, using manufacturer's data or generic data from Ch. 26 [6]. Cooling load reduction is determined from the following equation:

$$E = (3.413/SEER) (\Delta SC) (A) [SHGCF - (U) (DTD)] (FLH) \quad (F-6)$$

where:

E = annual cooling energy savings (Btu)

SEER = seasonal energy-efficiency ratio of the air conditioning equipment

ΔSC = the change in shading coefficient between existing and retrofit (from manufacturer or Ch. 26)

A = area of the glazing (sq ft)

SHGCF = solar heat gain and conduction factor, from Table 36 [6], based on design temperature, glazing type and orientation (Btu/hr sq ft)

U = U-value of the window (Btu/hr sq ft $^{\circ}F$)

DTD = cooling design temperature difference ($^{\circ}F$)

FLH = full load hours of cooling equipment operation (hr)

Heating effect is much more complex and the film would increase the heating requirement by reducing solar gains. An estimate of the heating effect for south-facing windows is made by comparing the auxiliary energy requirements for the existing glazing and for a reduction in effective solar aperture estimated directly from the SC values. This collector area effect is analyzed as a direct gain system, see Section 2.4.48. A change in effective aperture area of less than 10 percent may be neglected.

Data Required

Existing glazing type, area, and orientation; existing shading devices; solar film shading coefficient; FLH tables; cooling system efficiency.

2.4.21 Overhangs

B

Horizontal projections over windows to provide shading. Proper overhang design can be used to expose south-facing windows fully to winter sun, yet provide full shade in the summer to minimize heat gain. Horizontal overhangs are only applicable to south-facing windows (within 30° east or west).

Analysis Method

Overhangs affect window loads in a complex manner and are difficult to analyze precisely. With proper overhang design, interference with winter heat gains can be ignored. A check of the shading on December 21 should be made to insure proper design (no shading on December 21). The cooling effect is estimated by determining the fractional shading of the aperture on August 21 at solar noon. Solar position and related angle charts, specifically the profile angle, are used to determine the fractional shading [Table 2, Ch. 26, Reference 6]. Then the annual cooling load reduction for the aperture is determined as follows:

$$E = (3.413)/(SEER) (A) (SHGCF_e - SHGCF_a) (F_s) (FLH) \quad (F-7)$$

where:

E = annual cooling energy savings (Btu)

$SEER$ = seasonal energy-efficiency ratio of the air-conditioning equipment

A = area of the glazing (sq ft)

$SHGCF_e$ = solar heat gain and conduction factor for existing window, Table 36 [6] (Btu/hr sq ft)

$SHGCF_a$ = solar heat gain and conduction factor for a window with an awning, Table 36 [6] (Btu/hr sq ft)

F_s = fraction of window shaded on August 21

FLH = full load hours of cooling equipment operation (hr)

Data Required

Existing glazing type, area, and orientation; overhang geometry and dimension details; FLH tables; cooling system efficiency.

2.4.22 Louvers

B

This includes vertical fins, movable louvers, and trellises. Proper design can shield windows from summer heat gain, yet expose them to winter sun.

Analysis Method

These components affect the shading coefficient (SC) of the window in a similar manner to solar films. SC values for louvers are determined from manufacturer's data or from generic data in Table 40 [6]. Calculations are performed for noon on August 21. For trellises, no generic data exists and manufacturer's data would have to be relied on. If trellises are site-built, an estimate of the shading on August 21 should be made using solar angle data and geometry. Vertical fins require analysis of the average shading for a representative month. August is appropriate, and the average daily SC is calculated from data in Table 3.29 [6], which gives shadow widths per foot of vertical side projection for various latitudes, window orientations, and months of the year. The SCs are used in equation (F-6) to determine the annual energy savings.

Data Required

Existing number of window glazings, area, and orientation; louver SC; FLH tables; cooling system efficiency.

2.4.23 Awnings

B

Canvas, metal, or other material designed to provide summer solar gain control. Some designs are removable to allow winter heat gain. Awnings are effective for non-south-facing windows which are difficult to shade with fixed overhangs and are especially effective for east-west-facing windows. If applied to south windows, the awnings should be movable to allow winter solar gains. Awnings should be designed and installed to avoid trapping hot air against windows.

Analysis Method

Awnings will have little effect on heating load if removable on south-facing windows. Any effect on heating performance may be estimated as in 2.4.20. Therefore, only cooling effects are normally calculated. Air conditioning energy savings are determined in a manner similar to overhangs, Section 2.4.21. Equation (F-7) is used directly with $F_s = 1$ to account for the full shading effect of the awning.

Data Required

Existing glazing type, area, and orientation; awning details; FLH tables; cooling system efficiency.

Mechanical System

2.4.24 Duct Taping and Insulation

A

Control of heat leakage from ducts to decrease heat loss/gain from exposed ductwork in unconditioned spaces. Duct taping is recommended and analyzed only if obvious leakage paths are noticed during the survey.

Analysis Method

Duct taping is analyzed by assuming the net effect to be a 5 percent reduction in heating and cooling load. No data on actual duct leakages has been found, but normal equipment sizing procedure assumes a total duct loss of 10 percent. Therefore, an assumption of 5 percent due to air leakage is reasonable. This is a gross estimate of the reduction and the savings can be much larger. The relatively low cost for duct taping warrants its use if obvious leaks are noticed.

For duct insulation, the energy savings are calculated by the following relation:

$$E = (1/\eta) (\Delta U) (A) (\Delta T) (FLH) \quad (F-8)$$

where:

E = annual energy savings (Btu)

η = annual HVAC system efficiency in decimal form

ΔU = change in U-value between existing and retrofit (Btu/hr sq ft °F)

A = surface area of the duct (sq ft)

ΔT = typical temperature difference between air in duct and its environment (°F)

FLH = equivalent full-load hours (FLH) of operation for cooling and for heating (hr).

The full-load hours for heating are determined by multiplying the degree-days by 24 (hours/day) and dividing by the design temperature difference.

Data Required

Duct surface area and existing insulation; retrofit insulation material and thickness; FLH tables; typical unconditioned space temperature; HVAC system efficiency; existing annual heating and cooling load; heating degree-days and design temperature difference.

2.4.25 Replacement HVAC System

B

Replacement of old HVAC systems with new high-efficiency units.

Analysis Method

Using manufacturer's data, the seasonal efficiency of the new and existing equipment is determined. If manufacturer's data is not available, seasonal efficiencies are estimated using the

RCS data (pages E5-1 through E5-4, [22]). The following equation is then used to determine the savings:

$$E = [(\eta_r - \eta_e) / (\eta_r \eta_e)] (L) (FLH) \quad (F-9)$$

where:

E = annual energy savings (Btu)

η_r = seasonal efficiency of retrofit unit

η_e = seasonal efficiency of existing unit

L = design heating or cooling load (Btu/hr)

FLH = full-load hours of equipment operation for heating or cooling (hr)

If the replacement system uses a different fuel type than the existing, a separate fuel usage and cost must be calculated for each fuel type.

Data Required

Manufacturer's data on seasonal efficiency for existing and retrofit equipment or estimate based on climate and steady state efficiency, building design heating and cooling load, full-load hours of equipment operation.

2.4.26 Oil Burner Replacement

B

Replacement of the burner of an oil furnace to increase combustion and heating efficiency. Not warranted if the heating unit already has a retention head or rotary cup burner, or if it is a boiler of the wet base type, as recommended by RCS.

Analysis Method

The large range of oil burner efficiency makes specific analysis difficult. The only accurate method is to perform a flue gas analysis and measure the combustion efficiency directly. This reading is then compared with the manufacturer's ratings of the candidate replacement burners. The seasonal efficiencies for existing and retrofit are determined using the RCS table (page E5-1, [22]) which accounts for severity of the heating season, furnace type, and combustion efficiency.

In lieu of flue gas measurement, the steady-state efficiency is estimated using the RCS data (page E5-2, [22]) for various boiler and furnace types. Typical improvement with burner replacement ranges from 4 percent to 16 percent.

Annual heating energy savings are determined using the seasonal efficiencies in equation (F-9).

Data Required

Flue gas measurement (optional), manufacturer's efficiency rating of replacement burner (default values on page E5-2, [22]), design heating load, full-load hours of heating unit operation.

2.4.27 Add-on-Heat Pumps

B

Retrofitting of a heat pump with the existing gas or oil furnace used as a backup instead of electric strip heat. This is most effective if the existing furnace is in reasonably good condition.

Analysis Method

This requires the development of nomograms to estimate the amount of time the heating system operates in the back-up mode, basically involving the heat pump resistance heating temperature point and temperature bin data (site-specific). Knowing the fraction of time in the heat pumping mode and the seasonal efficiency, annual fuel

savings are determined as in 2.4.25. The savings would only have to be figured for the time in the heat pumping mode because the back-up mode and fuel usage (during that time) would be the same before and after.

Data Required

Manufacturer's data on seasonal efficiency and resistance heating setpoint, building design heating and cooling loads, existing HVAC system seasonal efficiency, and full-load hours of equipment operation.

2.4.28 Ceiling Fans

D

Low speed paddle fans suspended from ceiling to induce air movement so that the same comfort level may be reached in the cooling season with increased thermostat settings and reduced a/c usage. Though an analysis technique is presented, there is no guarantee that the occupants would raise their thermostat settings due to the presence of fans. Therefore, this measure is not recommended.

Analysis Method

Using Figure 17D [6], the effect of air movement on comfortable air temperature is determined. Air velocities are determined from manufacturer's data or estimates. Using the higher comfortable air temperature, the retrofit design cooling load is determined along with the full load hours of operation for the retrofit design temperatures.

The energy savings is then determined by the relation:

$$E_C = (\Delta L_C) (\Delta FLH) (3.413/SEER) \quad (F-10)$$

where:

$$E_L = \text{cooling energy savings (Btu)}$$

$$\Delta L_C = \text{change in design cooling load (Btu/hr)}$$

Δ FLH = change in full-load hours of operation (hr)

SEER = seasonal energy efficiency ratio of the cooling system

Data Required

Design cooling load calculations, fan equivalent air velocity, HVAC equipment seasonal efficiency, FLH tables, bin data.

2.4.29 Roof Spray Cooling Systems

C

Water sprayed on the roof surface to evaporatively cool the surface and reduce the cooling load through the ceiling. Roof spraying lowers the roof temperature nearly to the wet-bulb temperature and essentially eliminates solar heat gains through the roof. Issues associated with water availability and cost, mineral deposits on roofing and other concerns may preclude the use of those systems at certain bases.

Analysis Method

The effect on cooling load is estimated by comparing the existing roof design cooling load to the design cooling load based on the roof surface temperature being the mean coincident wet bulb temperature at design conditions. The annual energy savings are determined from equation (F-10) using the actual full load hours in place of FLH. Water consumption is estimated from manufacturer's literature and its cost is debited to the roof spray system. As with attic ventilation, the benefit of roof spraying decreases with increasing ceiling insulation levels.

Data Required

Ceiling area, insulation type, and thickness; roof area and construction; existing attic or roof ventilation; FLH tables; cooling system efficiency.

2.4.30 Evaporative Coolers

C

Use of water evaporation to provide sensible cooling, applicable only in arid climates.

Analysis Method

Requires knowledge of the seasonal efficiency of the evaporative cooler, including water consumption. This can be determined from manufacturer's data. Knowing this, the energy savings are calculated as outlined in 2.4.25, with an additional debit being the water consumption.

Data Required

Evaporative cooler seasonal efficiency and water consumption, same as 2.4.25.

2.4.31 Spray Cooling of A/C

C

Involves spraying water on the air conditioner condensor coil to lower the operating temperature and improve efficiency. Though an analysis technique is presented, other considerations must be addressed before this item is implemented. Corrosion effects must be investigated as well as water usage and the effect on local humidity levels.

Analysis Method

Spraying of the condensor would effectively lower the air temperature to the ambient wet-bulb. The seasonal effect on air conditioner efficiency is estimated by comparing the manufacturer's SEER based on condensor air temperature. Using the 2-1/2 percent design dry-bulb and mean coincident wet-bulb temperature as the two air temperatures at the condensor, the difference in SEER is determined. Then, the typical annual energy savings are determined by:

$$E_c = 13.413 (SEER_r - SEER_e) / (SEER_r SEER_e) \quad (F-11)$$

where:

E_c = cooling energy savings (Btu)

$SEER_r$ = seasonal efficiency of retrofit unit

$SEER_e$ = seasonal efficiency of existing unit

L_c = design cooling load (Btu/hr)

FLH = equivalent full-load hours of air conditioner operation (hr)

Data Required

Manufacturer's data on EER vs. condenser temperature, design dry and wet-bulb temperatures, design cooling load, cooling full load hours.

2.4.32 Setback Thermostats

A

Based on time of day, adjust thermostat set point to reduce heating or cooling load.

Analysis Method

Graphic aids would be developed showing the relationship of heating degree-days and cooling full-load hours to thermostat setting. The degree-days (or FLH) at the set and setback temperature would be algebraically combined based on the fractional time at each setting to arrive at the modified degree-days (or FLH) for the setback case. Annual energy savings are determined by:

$$E = (\Delta DD) (UA_h) (1/\eta) (24) \quad (\text{heating}) \quad (F-12a)$$

$$E = (\Delta FLH) (L_c) (3.413/SEER) \quad (\text{cooling}) \quad (F-12b)$$

where:

E = annual energy savings (Btu)

ΔDD = degree day difference between existing and retrofit
(F-day)

ΔFLH = cooling full-load hour difference between existing and retrofit (hr)

UA_h = design heat loss coefficient (Btu/hr $^{\circ}F$)

L_c = design cooling load (Btu/hr)

η = heating system efficiency

SEER = seasonal energy efficiency ratio

Data Required

Original thermostat setpoint, thermostat setback schedule, design heat loss coefficient and design cooling load, degree days and full-load hours for various temperature bases, HVAC system efficiencies.

2.4.33 Furnace Flue Dampers

A

Automatic damper to close furnace flue if combustion air is taken from a conditioned space. Reduces infiltration losses when furnace is not in use. A flue damper can only be implemented if the furnace has a pilotless ignition.

Analysis Method

The RCS method assumes that the installation of a flue damper saves 7 to 10 percent on heating cost. As a first effort, this method could be used, but other sources of information have been identified and should be investigated. A similar effect in the cooling season is assumed.

Data Required

Annual heating and cooling load.

2.4.34 Pilotless Ignition

B

Electric spark ignition to replace furnace pilot light and eliminate pilot energy consumption.

Analysis Method

A pilotless ignition is analyzed using the RCS method, which relies on a graph of energy savings versus heating degree days. Net savings go down as the degree-days go up, because furnace run time increases, and some of the pilot light heat is useful in meeting the space heating load. Maximum savings is 7 MMBtu per year.

Data Required

Number of pilot lights, heating degree-days.

2.4.35 Outside Combustion Air

B

Provides a source of outside air to combustion appliances located in conditioned spaces. Reduces heating and cooling load by replacing conditioned air for combustion with ambient air. If no flue damper is present, this technique will also reduce the effect of uncontrolled exfiltration up the flue. The mechanical room should be weatherstripped and sealed from the conditioned space to minimize infiltration.

Analysis Method

Using outside combustion air saves what a furnace flue damper would (see section 2.4.33) plus the amount of air used for combustion when the equipment is on. This incremental savings is determined by using manufacturer's data on combustion air requirements, the design heating load, and full-load hours of operation for heating. Combustion air requirements may also be obtained from an energy balance using the gas consumption rate from the manufacturer.

Data Required

Furnace combustion air requirement, design heating load, FLH tables for heating.

2.4.36 Fireplace Inserts

D

A variety of devices to insert into a standard fireplace to improve the overall efficiency. These are not recommended due to high cost and the unsettled issues of wood supply and air pollution.

Analysis Method

The energy savings from a fireplace insert are based on manufacturer's performance data and an estimate of annual wood consumption. Assuming that a similar amount (weight) of wood would be burned post-retrofit, the annual reduction in purchased heating energy may be calculated. Furthermore, many devices tend to reduce air infiltration. If this is the case, the infiltration reduction (heating and cooling) is estimated from a chart similar to D-4 in the RCS Model Audit Manual [22]. Then, equation (F-3) is applied to find the infiltration energy savings.

Data Required

Wood consumption, existing fireplace construction and efficiency estimate, retrofit device performance data (heating efficiency and infiltration).

2.4.37 Glass Doors on Fireplaces

B

Replacement of metal screens with airtight glass doors. Reduces uncontrolled flow of house air into the fireplace and is often combined with an outside combustion air source.

Analysis Method

The analysis would be based on manufacturer's data or an estimate of the infiltration reduction from the RCS procedure, D-4 [22]. Annual energy savings due to infiltration reduction are calculated with equation (F-3).

Data Required

Wood consumption, existing fireplace construction, glass door performance, heating degree-days, and cooling full load hours.

2.4.38 Economizer Cycle

C

An economizer as used here refers to a device which saves air conditioning energy by utilizing outside air for cooling whenever the outside air enthalpy is lower than the inside air.

Analysis Method

The cooling energy savings may be estimated by determining the difference in full load hours (FLH) of operation. Normal FLH are calculated from bin data using a house balance temperature which is based on internal gains and the overall loss coefficient of the building. Thus, if the cooling thermostat is set at 75°F, the house may actually need cooling whenever the outside temperature is above about 68°F. To account for economizer operation in the outside temperature range 68-75°F, a new value for FLH is determined from the bin data using a balance temperature equal to the thermostat setting. Annual energy savings are determined using the difference in FLH and equation (F-10).

Data Required

Bin data, FLH tables, cooling system efficiency, and design cooling load.

2.4.39 Vent Dampers

B

Dampers on vents to reduce infiltration, for example, bathroom and kitchen vents.

Analysis Method

The effect on infiltration would be determined using the Infiltration Chart on page D-4 [22] which accounts for the various contributors to infiltration. Energy savings from the reduced infiltration heat loss/gain are determined using equation (F-1).

Data Required

Infiltration Chart on page D-4 [22], number of vents, total floor area, winter wind factor, terrain factor, and heat loss factor.

2.4.40 Earth Cooling Tubes

D

Buried pipes which allow use of the earth as a heat sink. SSEC has conducted an investigation of earth cooling tubes. While there is definitely a cooling benefit available from the earth, the low cooling capacity and high costs usually result in poor cost-effectiveness. Therefore, earth cooling tubes are not recommended for consideration.

Analysis Method

Our research has resulted in a published analysis method for earth cooling tubes [23]. The method relies primarily on data on soil conductivity, thermal capacitance, and temperature for accurate analysis. Unfortunately, these parameters can exhibit large variations and are affected by short-term climate influences like rainfall. However, assumptions are possible and a reasonable estimate made of annual performance.

Data Required

Thermal conductivity, diffusivity, and temperature of the earth; fluid mass flow rate in the tubes; tube length, wall conductivity and wall thickness; air temperature; cooling load data.

2.4.41 Condenser Cleaning

A

Periodic cleaning of the outdoor coil for an air conditioner to improve the heat exchanger effectiveness and seasonal equipment efficiency.

Analysis Method

The effect of fouling or dirt on the condensor is usually determined by the manufacturer. Using the manufacturer's data on the SEER under normal operation and for a clean heat exchanger, the annual energy savings are estimated with equation (F-11).

Data Required

Manufacturer's data on SEER with and without a clean heat exchanger, design cooling load, FLH tables.

- 2.4.42 High Efficiency Appliances B
Replacement of major appliances with higher efficiency units.
Reduces energy consumption and cooling loads.

Analysis Method

The DOE appliance labeling program requires all new appliances to indicate the typical annual energy consumption. For existing appliances, nameplate power figures would be used with the corresponding DOE usage schedules to determine their annual energy consumption. The direct electrical (or gas) savings are then subtractively calculated. The reduced cooling load is calculated by adjusting the design cooling load based on the lowered internal gain rate. High efficiency appliances will also reduce the internal gains during the heating season, resulting in an increased heating load. The annual net energy savings must include the direct electrical savings as well as cooling savings and heating load increase (a debit).

Data Required

Existing and retrofit appliance types and amperages, design heat loss coefficient, HVAC seasonal efficiency, existing internal gain rate, heating degree days, FLH tables.

Domestic Hot Water

- 2.4.43 Insulation Jackets for Tanks A
Additional insulation to DHW tank to reduce standby losses. Only effective if the water heater is in an unconditioned space or if it is in a conditioned space and the site has a large cooling load.

Analysis Method

Knowing the hot water thermostat setpoint, existing tank insulation (from manufacturer or measurements) and average space temperature, the standby losses may be calculated as follows:

$$E = (UA) (\Delta T) (1/\eta) (8760 \text{ hr/yr}) \quad (F-13)$$

where:

E = annual water heating standby losses (Btu)

UA = effective UA-value of water tank (Btu/hr^{°F})

ΔT = temperature difference between the water heater thermostat setting and average annual temperature of the tank environment (°F)

η = hot water heater efficiency

The standby losses before and after retrofit are calculated with this equation and the appropriate UA-value. The UA-value must account for heat loss through the water and drain lines connected to the tank, as well as losses through the insulation.

If the tank is in a conditioned space, the effect of the reduced tank loss on heating and cooling load must be examined. Using an estimate of the fraction of time of the year in the heating and cooling mode, the increase in heating load and decrease in cooling load may be estimated directly from the decreased internal gain. The seasonal HVAC efficiencies are applied to the loads and all the terms are added to determine the net annual savings (increase in space heating load is a debit).

Data Required

Existing tank insulation and area, thermostat setting, temperature of space where tank is located, retrofit insulation type and thickness, hot water heater efficiency, HVAC system efficiency, FLH tables.

2.4.44 Dedicated Heat Pumps

C

Air source heat pump that supplies heat to the domestic hot water system. Normally used only in mild climates where a unit located in an unconditioned space is not exposed to freezing conditions.

Analysis Method

Water heating savings are calculated by first determining the existing water heating energy requirement (without heater efficiency).

The annual water heating load is:

(F-14)

$$E = (Q) (\Delta T) (3044) (1/\eta) + (\text{Standby losses from equation 13})$$

where:

E = annual water heating load (Btu)

Q = daily water consumption (gal/day)

ΔT = average water temperature rise which is equivalent to the water heater thermostat setting minus the annual average ground water temperature ($^{\circ}\text{F}$)

η = water heater efficiency

A nomogram would be used which accounts for water consumption, delta-T, and standby losses. The savings with a heat pump are then equal to the water heating load divided by the difference in seasonal operating efficiency between the heat pump and the existing water heater. There can be some cooling benefit from a dedicated heat pump, but they are generally too noisy to put in the conditioned space. Hence, the cooling energy is usually wasted in an unconditioned space.

Data Required

Tank insulation and area, thermostat setting, temperature of space, average annual cold water temperature, typical daily water consumption, existing and retrofit seasonal water heater (or heat pump) efficiencies.

2.4.45 Tankless Heaters

B

Also known as "instantaneous heaters" or "point of use heaters," they eliminate standby losses since there is no storage tank. Most applicable where water heater replacement is required.

Analysis Method

Procedure is similar to 2.4.42 with the retrofit UA-value equal to zero, and the fuel types and/or seasonal efficiencies different as required. For different fuels and/or efficiencies, the annual water heating energy use must be calculated for each fuel. Corresponding fuel costs are applied to annual fuel usage, and then the savings are determined.

Data Required

Tank insulation and area, thermostat setting, temperature of space, average annual cold water temperature, typical daily water consumption, existing and retrofit seasonal water heater (or heat pump) efficiencies.

- 2.4.46 Timers D
Operation of heating element on DHW tank on a fixed time schedule.
Reduces standby losses. May provide additional savings in the
future due to time-of-day pricing.

Analysis Method

The savings associated with water heater timers are strongly dependent upon the occupants' hot water use schedule. An analytical evaluation approach alone is not adequate. It will be necessary to examine field studies of energy savings resulting from timer use to develop a methodology.

The occupants of a unit utilizing a water heater timer will notice a difference in the availability of hot water during the off cycles. For this reason, ESC may elect to eliminate water heater timers from consideration.

Data Required

Same as 2.4.43, plus the timer schedule.

- 2.4.47 Heat Recovery From A/C Compressors C
Use of heat from a/c system condenser to heat domestic water supply.

Analysis Method

Water heating contribution is estimated from manufacturer's specifications for the heat recovery unit and full load hours of operation of the cooling equipment.

Data Required

HRU specifications - water heating rate at full load, FLH tables.

Solar

2.4.48

Sunspaces

D

Addition of an unconditioned space to the south wall designed for large solar gains. Excess heat is then supplied to the home, usually through doors, windows, or large vents. A sunspace is usually more expensive than the other passive solar heating techniques because it adds additional floor space to the house.

Analysis Method

The passive solar techniques in Section 2.4.48-51 are analyzed from a heating standpoint using the Load Collector Ratio (LCR) method which was developed by Los Alamos National Laboratory (LANL) [1]. SSEC has further developed the procedure to the form of one-page graphical design aids for a given location, see Figure F-1. For a given location, the two major parameters that enter the analysis are the building heat loss coefficient and the aperture area. The effect of night insulation is handled explicitly by the method. Other factors, such as thermal mass, orientation, number of glazings and solar absorptances are addressed in sensitivity curves which may be extrapolated to a specific location to obtain a rough estimate of the effect.

The cooling impact is estimated by determining the design cooling load for the solar component and comparing it with the existing wall. For example, if the addition of windows to a south wall is being considered, the design cooling load for the windows must be compared to the design cooling load for the walls. Any shading must be accounted for. The increase in cooling energy (a debit to the system) is determined from the full load hours and cooling system efficiency.

APALACHICOLA, FL

DG-DIRECT GAIN
 DGNI-DIRECT GAIN with NIGHT INSULATION
 TW-TROMBE WALL
 TWNI-TROMBE WALL with NIGHT INSULATION
 WW-WATER WALL
 WWNI-WATER WALL with NIGHT INSULATION
 SSA-SUNSPACE Type "A"
 SSAIE-SUNSPACE Type "A" with INSULATED ENDWALLS
 SSB-SUNSPACE Type "B"
 SSBIE-SUNSPACE Type "B" with INSULATED ENDWALLS

Degree Days (Base: 65°F) = 1361

SOLAR SAVINGS FRACTION VS. LOAD COLLECTOR RATIO

FIGURE F-1

Data Required

Building heat loss coefficient, sunspace type and projected vertical glazing area, orientation, thermal mass type and amount, movable insulation details, appropriate LANL Climatic and Load Collector Ratio Tables [1], FLH tables, cooling system efficiency.

2.4.49 Direct Gain

C

Modification of existing windows, or addition of properly oriented windows to provide winter heat gain. Direct gain can be the most cost-effective approach to solar heating, especially if no additional thermal mass is required by the building to prevent overheating. Housing with slab-on-grade floors is attractive for this technique due to existing mass in the floor. There is an upper limit to the amount of glazing that can be added because of the difficulty of controlling unwanted solar gains through the glazing.

Analysis Method

The methodology is similar to 2.4.48, and is based on the LANL Load Collector Ratio Methodology.

Data Required

Overall building loss coefficient, direct gain area and orientation, number of glazings, amount and type of existing thermal mass, proposed movable insulation R-value, existing wall construction and insulation, appropriate LANL Climatic and Load Collector Tables [1], FLH tables, cooling system efficiency.

2.4.50 Trombe Wall

C

Addition of glazing, and possibly vents, to existing masonry exterior walls to provide winter heat gain. The use of an existing masonry wall reduces the cost of materials and improves the cost-effectiveness of the technique in many applications. The existing masonry wall construction must be reviewed to assure compatibility.

Analysis Method

The methodology is similar to 2.4.48, and again relies on the LANL Load Collector Ratio Methodology.

Data Required

Overall building loss coefficient, Trombe wall glazing area and number, orientation, wall construction details, appropriate LANL Climatic and Load Collector Ratio Tables [1], FLH tables, cooling system efficiency.

2.4.51 Water Wall

C

A water wall involves the placement of water containers behind glazing in a south-facing wall. Water containers of various shapes and sizes are commercially available; some conveniently fit into the stud cavity and others stand on the floor. A water wall can be an effective modular method of increasing the solar aperture and thermal mass. The cost-effectiveness is generally not as good as retrofit direct gain or a Trombe wall because of the cost of the water containers. The weight and positioning of the water containers must be analyzed from a structural standpoint to insure safety.

Analysis Method

The methodology is similar to 2.4.48 and is based on LANL Load Collector Ratio Methodology.

Data Required

Overall building loss coefficient, water wall glazing area and number, orientation, water container dimensions and placement, appropriate LANL Climatic and Load Collector Ratio Tables [1], FLH tables, cooling system efficiency.

2.4.52 Thermosiphon Air Panels (TAPs)

B

Thermosiphon air panels are similar in appearance to active flat plate collectors. A TAP system has one or more glazings, an airspace, an absorber, another airspace, and (often) an insulated

backing. Air flows naturally through the TAP and enters the structure through a vent at the top, returning through a vent at the bottom. Their effective use is during the day, since they have no storage. Material selection and summer venting or shading are important to prevent degradation due to overheating. TAPs can be very cost-effective if built on-site with inexpensive materials.

Analysis Method

The performance of TAPs is similar to active air-heating collectors and can be analyzed using FCHART for air systems with the minimum storage mass. FCHART is a design and analysis tool developed by the University of Wisconsin [7]. While FCHART itself is too complex to be utilized directly, a simplified graphical version could be developed for the USAF survey. A rule-of-thumb for maximum TAPs array size based on building size and existing mass would insure that the proposed TAPs would not overheat the building and that the model would apply. Unlike the other passive systems, a TAP will usually not impact the cooling load because the vents are closed and an insulated wall separates the TAP from the space.

Data Required

TAP efficiency curve and area, overall building loss coefficient, building square footage, existing thermal mass type and amount, monthly solar data, average monthly ambient temperature.

2.4.53 Active Domestic Hot Water

B

A solar system incorporating collectors, a storage tank, and forced circulation to provide heat to the domestic hot water system. This device is only considered if there is an adequate area for placement of the components.

Analysis Method

The RCS methodology relies on generic performance data for active solar systems. However, the range of possible performance of the multitude of manufacturers leads to a great deal of uncertainty

about the method. To be more specific and accurate, a simplified form of the FCHART methodology is recommended for this effort. Performance and cost information would be gathered from the various manufacturers that would be considered. The FCHART-based method is applied to the various systems to develop typical annual system performance for several solar system sizes using the specific loads and weather data for the site.

Data Required

Domestic hot water heater load by month (from 2.4.44), solar collector area and efficiency, monthly solar data, average monthly ambient temperature.

2.4.54 Active Space Heating

B

An active solar heating system (collectors, storage, and circulation loop) is connected to the existing space heating and hot water systems. More collector area and storage capacity is required than in a solar DHW system, and a heat exchanger is usually necessary to transfer heat from the active loop to the storage system. Because of the high equipment costs, active is generally less cost-effective than passive.

Analysis Method

The performance is analyzed similarly to active domestic water heating, except that the building load is now the major load. For certain systems, domestic water is heated also, and the monthly water load is combined with the building load.

Data Required

Overall building loss coefficient, monthly domestic hot water load, solar collector area and efficiency, monthly solar data, average monthly ambient temperature.

2.4.55 "Breadbox" Hot Water Heaters

B

A breadbox combines the collector and storage tank into one unit which is exposed to solar radiation. The solar heat gain occurs on the storage tank itself. These are generally used as a preheater for the domestic hot water supply.

Analysis Method

Because a breadbox water heater transfers heat continuously with the environment, its performance is most dependent on the water demand profile and ambient temperature. Active systems are not quite so dependent because of the isolated thermal energy storage. No simple analysis or design tool has been identified, but some initial work has been performed by Lawrence Berkeley Laboratory (LBL) [24]. A comprehensive analysis method could be developed using the LBL work as a basis. In cold climates, those months with average ambient temperatures below 40°F would not be considered because the breadbox would generally be drained to prevent freezing.

Data Required

Domestic hot water heater load by month, breadbox collector area and number of glazings, monthly solar data, average monthly ambient temperature.

2.4.56 Thermosiphon Domestic Hot Water Heater

B

Domestic hot water systems in which fluid circulation is provided by thermally induced density gradients in the fluid; no pump or control is needed for circulation.

Analysis Method

Because of the similarity to active solar water heaters, the analysis is similar to 2.4.53 and will involve the FCHART correlations.

Data Required

Same as 2.4.53.

Low Cost Measures

2.4.57 Dryer Vents

B

Use of dryer exhaust heat in home during heating season.

Analysis Method

Based on typical dryer energy usage from reference [25], the monthly savings from venting dryer heat inside is determined. To calculate annual energy savings, the number of months in which the dryer heat would be useful is determined based on the house balance temperature and the severity of the heating load. Purchased energy savings are determined by dividing the dryer heat contribution by the seasonal efficiency of the heating system. The application of this measure is limited by local humidity levels and overheating during mild weather.

Data Required

Dryer energy usage per capita, number of occupants, average monthly ambient temperature, house balance temperature.

2.4.58 Flow Controllers

A

Flow restrictors on shower heads and lavatories to limit flow rate of hot water.

Analysis Method

The amount of energy consumed for hot water, less stand-by losses, is directly proportional to hot water consumption. Based on annual hot water consumption and on manufacturer's data on the flow reduction from the orifice, the reduction in overall hot water consumption is determined. If manufacturer's data is not available, flow rates of the various taps can be measured before and after installing the orifice. The fractional reduction is directly applied to the hot water energy consumption less standby losses, equation (F-14).

Data Required

Hot water energy, volume consumption, and standby loss; flow reduction from orifice.

2.4.59 Manual Ignition Devices

B

Replacement of pilot light on gas range and oven with a hand-held igniter.

Analysis Method

The typical gas stove pilot lights for the burners and oven consume about 1.9 MMBtu of gas a year [25]. A solid-state or manual ignitor saves this amount of gas directly. Elimination of the pilot lights also decreases the internal gain rate, and this must be accounted for as in 2.4.42.

Data Required

Number of gas pilot lights per unit, design heat loss coefficient, HVAC system efficiency, existing internal gain rate, heating degree-days, FLH tables.

2.4.60 Thermostat Limit

A

Reduction of water heater thermostat temperature to reduce hot water loads.

Analysis Method

The lower thermostat setting reduces both standby losses and the energy required to heat the water. In general, the lower thermostat setting would not affect the volume consumption of most appliances. Slightly more hot water would be consumed for showers and baths. An estimate of increase in water consumption can be made using typical water consumption data by end-use. Then, assuming a bathing temperature and equivalent energy content (before and after reducing the hot water temperature), the increase in water consumption can be estimated. The as-built and retrofit energy consumptions are calculated as outlined in 2.4.44.

Data Required

Tank insulation and area, thermostat setting, temperature of space, average cold main temperature, typical water consumption, existing and retrofit seasonal water heater (or heat pump) efficiencies.

2.4.61

Outlet Seals

A

Flexible gaskets applied to electric outlets and switches on exterior walls. Reduces infiltration significantly, studies by Texas Power and Light indicated that outlets account for about 20 percent of total house leakage [26].

Analysis Method

The analysis method for outlet gaskets is based on empirical measurements and statistics because of the difficulty of predicting the actual effect. Reference [26] tested many houses and found the retrofitting of outlet gaskets to reduce the overall leakage by 7 percent. This factor is used directly with the maximum infiltration savings from the RCS procedure to determine savings using equation (F-1).

Data Required

Maximum infiltration savings, heating degree-days, FLH tables, HVAC system efficiency.

2.4.62

Caulking

A

Caulking applied to all potential leakage areas around windows, doors, and other envelope penetrations. This item is highly recommended for uncaulked buildings or those with poor existing caulking.

Analysis Method

Analysis is difficult due to the wide variance in construction details and finishing. The RCS estimate of 20 percent savings on total maximum infiltration seems to be somewhat high based on

reference [26]. A savings of 15 percent seems to be more reasonable and is recommended for this survey. Energy savings from the infiltration reduction are determined with equation (F-1).

Data Required

Net infiltration heat loss and gain, heating degree-days, FLH tables.

2.4.63 Weatherstripping A

Any of a number of flexible sealing materials applied around exterior doors and operable windows. Significantly reduces the air infiltration of poorly fitting doors and windows.

Analysis Method

Analysis presents similar difficulties, as with caulking, due to the wide variance in window and door fit. The RCS methodology assumes that weatherstripping of all doors and windows accounts for 10 percent of the maximum infiltration savings as determined on pages D-4 and D-5 [22]. This estimate is reasonable and is recommended for this analysis. Annual energy savings for heating and cooling are calculated using equation (F-1).

Data Required

Net infiltration heat loss and gain, heating degree-days, FLH tables, HVAC system efficiency.

2.4.64 Vapor Barrier C

Paints designed to form a vapor barrier on the inside of an exterior wall. This would only be recommended if there is some evidence of moisture accumulation in the wall. This technique is not recommended solely as an energy saving alternative.

2.4.65 Relamping B

This involves a change from incandescent to fluorescent lights where feasible. Energy is saved both for direct lighting costs and for cooling costs.

Analysis Method

Lighting usage can vary significantly from unit to unit, and therefore, statistical usage patterns must be used for the survey. There are several sources of this information, and they could be reduced to a table of typical annual lighting energy consumption per square foot of floor area. A house with fluorescent lights typically consumes about 50 percent of the power used by standard incandescent lighting [25]. High frequency fluorescent lights consume only about 25 percent of the power used by incandescents. Therefore, the direct electrical savings are 50 to 75 percent of the annual lighting energy based on the floor area of the house. The cooling savings are determined by lowering the design cooling load by the lighting savings and then applying the FLH and SEER to determine annual savings. The increase in heating energy consumption must also be accounted for by reducing the internal gains and debiting the heating increase to the net savings.

Data Required

Typical lighting energy consumption per square foot of floor area, heating degree-days, FLH tables, HVAC system efficiency.

TABLE F-1

SUMMARY OF RECOMMENDATIONS FOR PROPOSED ENERGY CONSERVATION MEASURES

A: STRONGLY RECOMMENDED FOR CONSIDERATION
 B: RECOMMENDED FOR CONSIDERATION
 C: RECOMMENDED UNDER CERTAIN CIRCUMSTANCES
 D: NOT RECOMMENDED

TABLE F-1

Envelope Changes

<u>Number</u>	<u>Name</u>	<u>Ranking</u>	<u>Comments</u>
2.4.1	Wall Cavity Insulation	C	Recommended if no wall insulation exists
2.4.2	Interior Wall Insulation	C	Recommended if no wall insulation exists
2.4.3	Exterior Wall Insulation	C	Recommended if no wall insulation exists
2.4.4	Floor Insulation	A	
2.4.5	Slab Perimeter Insulation	B	
2.4.6	Foundation Insulation	B	
2.4.7	Basement Wall Insulation	B	
2.4.8	Ceiling Insulation	A	
2.4.9	Roof Insulation	B	
2.4.10	Storm Doors	A	
2.4.11	Storm Windows	A	
2.4.12	Double or Triple Glazed Windows	C	Recommended only if windows require replacement
2.4.13	Movable Insulation	C	Requires occupant interaction
2.4.14	Forced Attic Ventilation	D	Has not proven cost-effective
2.4.15	Natural Attic Ventilation	B	

<u>Number</u>	<u>Name</u>	<u>Ranking</u>	<u>Comments</u>
2.4.16	Interior Thermal Mass	D	Not cost-effective unless used with solar heating
2.4.17	Skylights	D	Rarely cost-effective in residences
2.4.18	Landscaping	B	
2.4.19	Surface Colors	B	
2.4.20	Solar Control Films	C	Only for areas with major cooling loads
2.4.21	Overhangs	B	
2.4.22	Louvers	B	
2.4.23	Awnings	B	

Mechanical Systems

<u>Number</u>	<u>Name</u>	<u>Ranking</u>	<u>Comments</u>
2.4.24	Duct Taping & Insulation	A	
2.4.25	Replacement HVAC System	B	
2.4.26	Replacement Oil Burner	B	
2.4.27	Add-on Heat Pump	B	
2.4.28	Ceiling Fans	D	Usage and effect are difficult to quantify; requires occupant interaction
2.4.29	Roof Spray Cooling System	C	Only for areas with major cooling loads
2.4.30	Evaporative Coolers	C	
2.4.31	Spray Cooling of A/C	C	Corrosion and water usage must be evaluated
2.4.32	Setback Thermostats	A	
2.4.33	Furnace Flue Dampers	A	
2.4.34	Pilotless Ignition	B	
2.4.35	Outside Combustion Air	B	

<u>Number</u>	<u>Name</u>	<u>Ranking</u>	<u>Comments</u>
2.4.36	Fireplace Inserts	D	High initial cost; requires major occupant participation; wood supply is problem
2.4.37	Glass Door on Fireplace	B	
2.4.38	Economizer Cycle	C	For mild cooling climates or area with high diurnal swing
2.4.39	Vent Dampers	B	
2.4.40	Earth Cooling Tubes	D	Poor cost-effectiveness
2.4.41	Condensor Cleaning	A	
2.4.42	High Efficiency Appliances	B	

Domestic Hot Water

<u>Number</u>	<u>Name</u>	<u>Ranking</u>	<u>Comments</u>
2.4.43	Insulation Jacket for Tank	A	
2.4.44	Dedicated Heat Pump	C	Restricted to mild climates
2.4.45	Tankless Heaters	B	
2.4.46	Timers	D	Reduces "quality of life"
2.4.47	Heat Recovery from A/C Compressor	C	Limited to areas with high cooling loads

Solar

<u>Number</u>	<u>Name</u>	<u>Ranking</u>	<u>Comments</u>
2.4.48	Sunspaces	D	Expensive unless extra floor area needed
2.4.49	Direct Gain	C	Limited to areas with appropriate climate and high fuel costs
2.4.50	Trombe Wall	C	
2.4.51	Water Wall	C	
2.4.52	Thermosiphon Air Panels	B	
2.4.53	Active Domestic Hot Water	B	
2.4.54	Active Space Heating	B	
2.4.55	Breadbox Hot Water Heaters	B	Must be freeze protected or drained in most climates
2.4.56	Thermosiphon Hot Water Heater	B	Must be freeze protected or drained in most climates

Low Cost Measures

<u>Number</u>	<u>Name</u>	<u>Ranking</u>	<u>Comments</u>
2.4.57	Dryer Vents	B	
2.4.58	Flow Controllers	A	
2.4.59	Manual Ignition Devices	B	
2.4.60	Thermostat Limit	A	
2.4.61	Outlet Seals	A	
2.4.62	Caulking	A	
2.4.63	Weatherstripping	A	
2.4.64	Vapor Barrier Paint	C	Only if moisture problem exists; minimal energy savings
2.4.65	Relamping	B	

APPENDIX G

DEVELOPMENT OF UNITARY CONSUMPTION DATA

According to USAF ESC, base housing is on a single meter, or in some cases, different housing areas may be on submeters. In either case, to be of utility, the data should be reduced to per-unit consumption.

The worst situation expected is where all billing data available is for "base housing" as a single item. This data includes non-housing consumption such as street lights and sewage lift stations, transmission losses, and the housing energy consumption. To arrive at per-unit energy consumption, the effects of non-housing consumption and transmission losses must be removed by summing these loads, available from the base civil engineer, and subtracting them from the metered consumption. The remaining consumption is allocated among the various groups in the survey by the distribution factor. Figure G-1 outlines the calculation process.

The distribution factor for a group may be defined as the energy consumption of that group relative to all the groups. This distribution is expected to change from season to season as the importance of the various energy flows changes. For example, heating may be insignificant in April, and internal loads may dominate. In January, heating may dominate internal loads. These changes influence the relative energy consumption of the various groups. In order to handle this problem, distribution factors and per-unit energy consumption are analyzed on a monthly basis.

From a gross load viewpoint, building energy consumption may be divided into two large categories: weather-dependent and weather-independent loads. The weather-dependent loads are principally due to space conditioning requirements, and building design loads will be used as the weather-dependent load parameter.

The weather-independent loads include service hot water, appliances, lighting, and heat release by occupants. The following values (from Quantified Occupant Use Factors Affecting Energy Consumption in Residences [27]) are assumed:

DEVELOPMENT OF UNITARY ENERGY CONSUMPTION ESTIMATES

FIGURE G-1

Service Hot Water = 167 (temperature difference) (number of occupants)
Btu/day

Appliances	=	67×10^3 Btu/day	gas and electric
		47×10^3 Btu/day	all electric
Lighting	=	12.3×10^3 Btu/day	winter
		11.9×10^3 Btu/day	summer
Heat Release by Occupant	=	11.1×10^3 Btu/day	2 adults, both working
		20.2×10^3 Btu/day	2 adults, both retired
		32.5×10^3 Btu/day	family of 5, 2 preschool
		25.1×10^3 Btu/day	family of 5, 3 in school

Inspection of the above indicates that the number of occupants is a significant parameter. It is anticipated that each base will have established guidelines as to family size versus the number of bedrooms. This can then be fitted to:

$$\text{Occupants} = (N_{Br} - 1) C + 2$$

where:

N_{Br} = number of bedrooms

C = number of children per bedroom

Using this concept the service hot water energy consumption becomes:

$$E_{shw} = \frac{167[(N_{Br} - 1) C + 2]}{24 (N_{shw})} (T_{set} - T_g) \quad (G-1)$$

where:

E_{shw} = normalized service hot water energy consumption (Btu/hr per unit)

N_{shw} = efficiency of hot water heater (default values can be provided)

T_{set} = hot water set point ($^{\circ}F$)

T_g = ground temperature used to estimate water main temperature ($^{\circ}F$)

The heat release from occupants must be normalized in the same fashion. The average heat release per child may be approximated by averaging the two values for a family of five, subtracting the heat release due to two adults, and dividing by the number of children (yielding 6.07×10^3 Btu/day - child). Multiplying this value by the number of children, adding in the effects of adults, and averaging over a day gives:

$$E_{occ} = 253 (N_{Br} - 1) C + 463 \quad (G-2)$$

where:

E_{occ} = normalized heat release by occupants (Btu/hr - unit)

Appliance and lighting energy consumption are relatively independent of the number of occupants. These are normalized by dividing by 24.

E_a = 2792 gas and electric
1958 all electric

E_l = 512 winter
495 summer

where:

E_a = normalized appliance energy consumption (Btu/hr - unit)

E_l = normalized lighting energy consumption (Btu/hr - unit)

The overall concept for determining the distribution factor consists of taking a ratio of the energy balances on the groups. The heat balance is conducted on a reference unit for each group using normalized energy terms. When the total reference energy flow into the unit is multiplied by the number of units in the group, a reference group energy consumption is obtained. The comparison of this reference energy consumption to the total reference energy consumption of all the groups is the distribution factor.

For the cooling season then, an energy balance on the unit will give:

$$E_{ts} = E_{shw} + E_a + E_l + E_{ac} \quad (G-3)$$

where:

E_{ts} = normalized total energy load in summer (Btu/ hr - unit)

E_{ac} = normalized air conditioning energy consumption (Btu/hr - unit). Calculated as the design load divided by the efficiency (default values for efficiency available from RCS Model Audit Manual, [22], p. E5-4), and multiplied by a month factor, F_m .

The month factor (F_m) accounts for the fact that the space conditioning equipment is not always running at full load.

$$F_m = (T_1 - T_2) / \text{Design Temperature Difference} \quad (G-4)$$

where:

F_m = month factor

T_1 = inside reference temperature in the winter, outside mean temperature in the summer

T_2 = monthly average outdoor air temperature in the winter, inside reference temperature in the cooling season

The design temperature difference is calculated from winter or summer design data. The reference temperatures are the set point minus 8°F in summer, 5 F in winter, in order to approximately account for the effect of internal loads.

The normalized total energy consumption, E_{ts} , must be calculated for each group of units.

The distribution factor for group i during the cooling season is calculated by comparing the energy consumption of group i to all groups:

$$D_s(i) = \frac{N_i E_{TS}(i)}{\sum_i N_i E_{TS}(i)} \quad (G-5)$$

where:

$D_s(i)$ = distribution factor for group i

N_i = number of units in group i

$E_{ts}(i)$ = normalized summer energy load of group i

During the winter, the design load for heating does not adequately characterize the space conditioning energy consumption, since a fraction of the other energy flows into the the unit offset some of the heating requirements. The following percentages of the diversified loads offset heating (Solar Availability in Cities and Towns, [28]):

Service hot water - 50 %

Appliances - 85 %

Lighting - 100 %

Occupants - 100%

Application of these percentages in the energy balance yields:

$$E_{tw} = 0.5 E_{shw} + 0.15 E_a - E_{occ} + E_h \quad (G-6)$$

where:

E_{tw} = normalized total energy load in winter (Btu/hr - unit)

E_h = normalized heating energy consumption (Btu/hr - unit) calculated as the design load divided by efficiency (default efficiency values from RCS Model Audit Manual [22] pp. E5-1 to E5-3) and multiplied by the month factor F_m .

The distribution factor for heating months is then:

$$D_w(i) = \frac{N_i E_{tw}(i)}{\sum_i N_i E_{tw}(i)} \quad (G-7)$$

where:

$D_w(i)$ = winter distribution factor for group i

$E_{tw}(i)$ = normalized winter energy load for group i

Since the summer and winter energy balances are different, the dividing point between summer and winter needs to be defined and a procedure developed to account for spring and fall loads. The solution to this problem lies in the definition of F_m , the month factor and E_{tw} , the winter total energy consumption. Neither of these factors can be negative, as that would imply a unit that produced energy. If equation F-6 yields a negative result, then that implies that the heating energy (E_h) is very small and summer calculations should be used. If F_m calculated for the winter values becomes negative, the same implication holds. In that case, use cooling season calculations. If F_m is still negative, set it equal to zero and continue.

The distribution factor for group i times the total housing metered energy consumption divided by the number of units in group i will yield the average unit energy consumption.

The method is best illustrated by an example. While Tyndall data could be used, the example is for a fictional base in Atlanta, since Atlanta climatic data is more representative of seasonal variations around the country.

The required climatic data is presented below:

BIN OBSERVATION - ATLANTA, GA.

SOURCE: AFM 88-29

<u>BIN</u>	<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>	<u>JUN</u>	<u>JUL</u>	<u>AUG</u>	<u>SEPT</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>
100							1					
95						5	6	7	2			
90					5	39	40	39	11	1		
85				2	46	77	91	105	42	4		
80			1	24	81	114	142	137	91	20	1	
75		2	13	58	106	143	171	165	118	57	6	
70	5	11	27	79	141	185	234	211	186	94	25	3
65	18	28	56	113	176	121	55	68	143	135	54	19
60	47	52	84	143	100	28	6	11	86	149	92	47
55	69	82	117	121	52	7		0	30	123	111	61
50	89	97	122	81	25	1			8	87	113	86
45	106	106	115	54	9	0			1	43	117	114
40	117	108	99	31	3					20	94	136
35	123	87	61	11						8	60	121
30	91	53	37	2						2	31	87
25	46	26	9								12	41
20	17	11	2								3	18
15	9	6	1								2	5
10	4	2	0									3
5												

GROUND TEMPERATURES

<u>Month</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Jun</u>	<u>Jul</u>	<u>Aug</u>	<u>Sep</u>	<u>Oct</u>	<u>Nov</u>	<u>Dec</u>
$T_g(^{\circ}\text{F})$	56	56	59	59	59	72	72	72	69	69	69	55

Next, we assume a heating load exists whenever the outdoor air temperature is below 65°F, and a cooling load exists when the outdoor temperature is above 70°F. Tabulated below are monthly means from bin data and calculated temperature differences from the inside reference point.

<u>Month</u>	<u>Mean</u>	<u>(65-Mean)</u>	<u>(Mean-70)</u>
JAN	43	22	-
FEB	47	18	-
MAR	51	14	-
APRIL	61	4	-
MAY	70	-	0
JUN	76	-	6
JUL	78	-	8
AUG	78	-	8
SEPT	72	-	2
OCT	62	3	-
NOV	51	14	-
DEC	44	21	-

The Atlanta design condition gives a 14° temperature difference in summer and a 45° temperature difference in winter. Using these values, F_m is calculated using equation F-4. The results are tabulated below.

<u>Month</u>	<u>F_m (Winter)</u>	<u>F_m(Summer)</u>
JAN	.48	-
FEB	.39	-
MAR	.30	-
APR	.09	-
MAY	-	0
JUN	-	.42
JUL	-	.57
AUG	-	.57
SEP	-	.14
OCT	.06	-
NOV	.30	-
DEC	.45	-

The fictional base housing consists of 4 different types of units, each type of which constitutes a group.

Description of Fictional Base Housing

<u>Description</u>	<u># of Units</u>	<u>Cooling Load KBtu/hr</u>	<u>Heating Load KBtu/Hr</u>	<u># of Children</u>
2 Bdr. Duplex	100	24	21	1
2 Bdr. Detached	50	28	25	2
2 Bdr. Duplex	80	35	30	3
2 Bdr. Detached	20	40	35	4

Unit: 2 Bdr. Duplex

Design Cooling Load = 24,000 Btu/hr

Design Heating Load = 21,000 Btu/hr

$N_{Br} = 2$ $C = 1$

$(N_{Br}-1)C = 1$

$E_1 = 496$ Btu/hr (Summer)

$E_1 = 512$ Btu/hr (Winter)

$E_{occ} = 716$ Btu/hr

$E_a = 2,792$ Btu/hr:

A/C C.O.P. = 1.9

Furnace Efficiency or C.O.P. = 61%

Service Hot Water (SHW) Heater Efficiency = 65%

Supply Energy: Gas and Electricity

<u>Month</u>	<u>T_g(°F)</u>	<u>F_m(W)</u>	<u>F_m(S)</u>	<u>Energy Requirements (Btu/hr)</u>				
				<u>Components</u>			<u>Totals</u>	
				<u>E_{shw}</u>	<u>E_{ac}</u>	<u>E_h</u>	<u>E_{ts}</u>	<u>E_{tw}</u>
Jan	56	.48	-	2.70	-	16.52	-	17.58
Feb	56	.39	-	2.70	-	13.43	-	14.48
Mar	59	.30	-	2.60	-	10.33	-	11.33
Apr	59	.09	-	2.60	-	3.10	-	4.10
May	59	-	-	2.60	-	-	5.89	-
Jun	72	-	.42	2.18	5.31	-	10.78	-
Jul	72	-	.57	2.18	7.20	-	12.67	-
Aug	72	-	.57	2.18	7.20	-	12.67	-
Sep	69	-	.14	2.28	1.77	-	7.34	-
Oct	69	.06	-	2.28	-	2.07	-	2.91
Nov	69	.30	-	2.28	-	10.33	-	11.17
Dec	56	.45	-	2.70	-	15.49	-	16.55

Unit: 2 Bdr. Detached

Design Cooling Load = 28,000 Btu/hr

Design Heating Load = 25,000 Btu/hr

$N_{Br} = 2$ $C = 2$

$(N_{Br} - 1)C = 2$

$E_1 = 496$ Btu/hr (Summer)

$E_1 = 512$ Btu/hr (Winter)

$E_{occ} = 969$ Btu/hr

$E_a = 2,792$ Btu/hr:

A/C C.O.P. = 1.9

Furnace Efficiency or C.O.P. = 61%

Service Hot Water (SHW) Heater Efficiency = 65%

Supply Energy: Gas and Electricity

Month	$T_g(^{\circ}F)$	$F_m(W)$	$F_m(S)$	Energy Requirements (kBtu/hr)				
				Components			Totals	
				E_{shw}	E_{ac}	E_h	E_{ts}	E_{tw}
Jan	56	.48	-	3.60	-	19.67	-	20.92
Feb	56	.39	-	3.60	-	15.98	-	17.23
Mar	59	.30	-	3.47	-	12.30	-	13.48
Apr	59	.09	-	3.47	-	3.69	-	4.88
May	59	-	.00	3.47	0.0	-	5.76	-
Jun	72	-	.42	2.91	6.19	-	12.39	-
Jul	72	-	.57	2.91	8.40	-	14.60	-
Aug	72	-	.57	2.91	8.40	-	8.39	-
Sep	69	-	.14	3.04	2.06	-	14.60	-
Oct	69	.06	-	3.04	-	2.46	-	3.43
Nov	69	.30	-	3.04	-	12.30	-	13.27
Dec	56	.45	-	3.60	-	18.44	-	19.69

Unit: 3 Bdr. Duplex

Design Cooling Load = 35,000 Btu/hr

Design Heating Load = 30,000 Btu/hr

$N_{Br} = 3$ $C = 1.5$

$(N_{Br}-1)C = 3$

$E_1 = 496$ Btu/hr (Summer)

$E_1 = 512$ Btu/hr (Winter)

$E_{occ} = 1,222$ Btu/hr

$E_a = 2,792$ Btu/hr:

A/C C.O.P. = 1.9

Furnace Efficiency or C.O.P. = 61%

Service Hot Water (SHW) Heater Efficiency = 65%

Supply Energy: Gas and Electricity

Month	$T_g(^{\circ}F)$	$F_m(W)$	$F_m(S)$	Energy Requirements (Btu/hr)				
				Components			Totals	
				E_{shw}	E_{ac}	E_h	E_{ts}	E_{tw}
Jan	56	.48	-	4.50	-	23.61	-	25.05
Feb	56	.39	-	4.50	-	19.18	-	20.63
Mar	59	.30	-	3.34	-	14.75	-	16.12
Apr	59	.09	-	4.34	-	4.43	-	5.79
May	59	-	.00	4.34	0.0	-	7.63	-
Jun	72	-	.42	3.64	7.74	-	14.67	-
Jul	72	-	.57	3.64	10.50	-	17.43	-
Aug	72	-	.57	3.64	10.50	-	17.43	-
Sep	69	-	.14	3.80	2.58	-	9.67	-
Oct	69	.06	-	3.80	-	2.95	-	4.05
Nov	69	.30	-	3.80	-	14.75	-	15.85
Dec	56	.45	-	4.50	-	22.13	-	23.58

Unit: 3 Bdr. Detached

Design Cooling Load = 40,000 Btu/hr

Design Heating Load = 35,000 Btu/hr

$N_{Br} = 3 \quad C = 2$

$(N_{Br}-1)C = 4$

$E_l = 496 \text{ Btu/hr (Summer)}$

$E_l = 512 \text{ Btu/hr (Winter)}$

$E_{occ} = 1,475 \text{ Btu/hr}$

$E_a = 2,792 \text{ Btu/hr:}$

A/C C.O.P. = 1.9

Furnace Efficiency or C.O.P. = 61%

Service Hot Water (SHW) Heater Efficiency = 65%

Supply Energy: Gas and Electricity

Month	$T_g(^{\circ}\text{F})$	$F_m(W)$	$F_m(S)$	Energy Requirements (Btu/hr)				
				Components			Totals	
				E_{shw}	E_{ac}	E_h	E_{ts}	E_{tw}
Jan	56	.48	-	5.40	-	27.54	-	29.19
Feb	56	.39	-	5.40	-	22.38	-	24.02
Mar	59	.30	-	5.21	-	17.21	-	18.76
Apr	59	.09	-	5.21	-	5.16	-	6.71
May	59	-	-	5.21	-	-	8.49	-
Jun	72	-	.42	4.37	8.84	-	16.50	-
Jul	72	-	.57	4.37	12.00	-	19.66	-
Aug	72	-	.57	4.37	12.00	-	19.66	-
Sep	69	-	.14	4.56	2.95	-	10.80	-
Oct	69	.06	-	4.56	-	3.44	-	4.67
Nov	69	.30	-	4.56	-	17.21	-	18.44
Dec	56	.45	-	5.40	-	25.82	-	27.47

Monthly Energy Requirements (kBtu/hr)

<u>Month</u>	<u>2 Bdr. Dup.</u>	<u>2 Bdr. Det.</u>	<u>3 Bdr. Dup.</u>	<u>3 Bdr. Det.</u>	<u>$\sum_i N_i E_{Ti}$</u>
Jan	17.58	20.92	25.05	29.19	5,391.80
Feb	14.48	17.23	20.63	24.02	4,440.30
Mar	11.33	13.48	16.12	18.76	3,471.80
Apr	4.10	4.88	5.79	6.71	1,251.40
May	5.89	6.76	7.63	8.49	1,707.20
Jun	10.78	12.39	14.67	16.50	3,201.10
Jul	12.67	14.60	17.43	19.66	3,784.60
Aug	12.67	14.60	17.43	19.66	3,784.60
Sep	7.34	8.39	9.67	10.80	2,143.10
Oct	2.91	3.43	4.05	4.67	879.90
Nov	11.17	13.27	15.85	18.44	3,417.30
Dec	16.55	19.69	23.58	27.47	5,075.30
Yearly Totals	127.47	149.64	177.90	204.37	38,548.40
No. of Units	100	50	80	20	

$$\sum_i N_i E_T = 100(E_{2 \text{ Bdr Dup.}}) + 50(E_{2 \text{ Bdr Det.}}) + 80(E_{3 \text{ Bdr Dup.}}) + 20(E_{3 \text{ Bdr Det.}})$$

(for each Month.)

The Distribution Factor is:

Monthly Distribution Factors

(Example Calculation)

<u>Month</u>	<u>2 Bdr. Dup.</u>	<u>2 Bdr. Det.</u>	<u>3 Bdr. Dup.</u>	<u>3 Bdr. Det.</u>
Jan	.326	.194	.372	.108
Feb	.326	.194	.372	.108
Mar	.326	.194	.372	.108
Apr	.328	.195	.370	.107
May	.345	.198	.358	.099
Jun	.337	.194	.367	.103
Jul	.335	.193	.368	.104
Aug	.335	.193	.368	.104
Sep	.342	.196	.361	.101
Oct	.331	.195	.368	.106
Nov	.327	.194	.371	.108
Dec	.326	.194	.372	.108

Assume that the base housing energy consumption, after subtracting auxillary equipment, is 2×10^9 Btu in January. Then the energy consumption, per unit, figures are:

2 Bdr Duplex	=	6.52×10^6 Btu/unit
2 Bdr Detached	=	7.76×10^6 Btu/unit
3 Bdr Duplex	=	9.3×10^6 Btu/unit
3 Bdr Detached	=	10.8×10^6 Btu/unit

The calculation is carried out for each month of the year and summed to yield yearly energy consumption.

The method presented is an estimate of energy consumption. As an estimate, many features are ignored. Service hot water energy consumption, for example, only considers delivered energy; standby losses are ignored. In addition, the method only considers energy use, not fuel use. Electricity and fossil fuels are only treated as so many Btus and cannot be estimated independently.

The RCS methodology uses billing data to determine heating and cooling energy use rates. It assumes that the energy consumption is a function of a climatic dependent term, and a climatic independent consumption. These values are found through linear regression of the billing data and the heating and cooling degree-days that actually occurred during the billing period [22]:

$$\text{Heating Energy} = H_1 (\text{HDD}) + H_2 \quad (\text{G-8})$$

$$\text{Cooling Energy} = C_1 (\text{CDD}) + C_2 \quad (\text{G-9})$$

where: H_1 and C_1 are weather dependent parameters
 H_2 and C_2 are weather independent parameters
HDD and CDD are actual heating and cooling degree-days

The weather dependent parameters developed through this analysis are used in developing the savings analysis of many options investigated by RCS.

A similar analysis could be used on the unitary consumption data developed for base housing. This, however, is not recommended. The performance of the various options under consideration are calculated based on standard engineering analysis techniques. The basis for the life cycle costing is the existing cost of energy used in the units. For a valid comparison to be made, the current performance and the change in performance due to options in the survey should be calculated using the same methodology.

Further, the unit consumption figures obtained by use of the methods of this appendix are estimates. Their calculation depends upon estimating the relative consumption of one type of unit versus all other units. Implicit to this analysis is an assumption as to the relative magnitude of weather-dependent versus independent parameters. Since RCS derives these parameters from the billing data, the method assumes part of the solution.

The method is useful, however, in examining the groups to be surveyed. Application of the method will indicate which groups are currently the largest energy consumers, and therefore, which groups should have priority in retrofitting.