DESIGN GUIDE

Military Family Housing

Energy-Efficient Revitalization and New Construction

July 1996

Prepared for:

United States Air Force
United States Department of Energy

Prepared by:

Oak Ridge National Laboratory
National Association of Home Builders Research Center

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Design Guide for Military Family Housing:
Energy-Efficient Revitalization
and New Construction

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ACRONYMS

ACCA	Air-Conditioning Contractors of America
ACH	air chanages per hour
A/E	architect/engineer
AFUE	annual fuel utilization efficiency
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CAPS	Computerized, Automated Point System
CCT	correlated color temperature
COSTSAFR	Conservation Optimization Standard for Savings in Federal Residences
CRI	color rendition index
DHW	domestic hot water
DOD	Department of Defense
DUERS	Defense Utility Energy Reporting System
ECM	energy conservation measure
EUB	energy use budget
gpm	gallons per minute
HIR	halogen incandescent with an infrared-reflective coating
HSPF	heating seasonal performance factor
HVAC	heating, ventilating, and air conditioning
IID	intermittent ignition device
LP	liquid petroleum
LPW	lumens per watt
MBtus	millions of Btus
NPV	net present value
Pa	pascal
SC	shading coefficient
SEER	seasonal energy efficiency ratio
SIR	savings-to-investment ratio
SPP	simple payback period
UL	Underwriter’s Laboratory

Chapter 1

INTRODUCTION

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1.1 Need for This Guide

PURPOSE

This design guide has been prepared for use by the architect/engineering (A/E) firms commissioned by the Air Force to develop the design and specification of military family housing revitalization and new construction projects. It provides the necessary information and analytical tools for the A/Es to make prudent and cost-effective decisions regarding the type and extent of energy conservation measures to be provided during the new construction or revitalization process. A companion retrofit guide has been prepared to identify and implement energy-efficiency improvements in dwellings that are not scheduled for revitalization within the next 10 years.

The design guide includes

- step-by-step procedures for analyzing and selecting energy conservation measures in new and revitalized housing;
- detailed diagnostic inspection procedures that will identify energy-efficiency problem areas in existing housing; and
- selected specifications for material and equipment installation.

The program manager for a revitalization or new construction project will initiate the use of this design guide by (a) specifying adherence to this design guide in the Request for Proposal or Statement of Work with the A/E (general A/E responsibilities are outlined in Chap. 2, "Responsibilities of the Architect/Engineer"), and (b) providing the A/E with energy-related information as discussed in Sect. 1.4, "Preparation of Instructions to the Architect/Engineer."

The A/E will provide the program manager with documentation of energy analyses performed and identification of energy-efficiency measures and efficiency levels that are cost effective for the project (see Sect. 3.2, "Selection of ECMs Using COSTSAFR," and Sect. 4.2.20, "Documentation of Analysis Process"). The A/E will also provide the program manager with specifications regarding the installation of recommended efficiency measures as outlined in Chap. 5, "Specification of Selected Energy-Efficiency Options."

The program manager or designee will review the energy analyses submitted using a commissioning guide that is a companion to this design guide. The program manager will include in the Request for Proposal or Statement of Work for construction projects the energy-efficiency measures and efficiency levels identified by the A/E as being cost effective, as well as any installation specifications developed by the A/E.

BACKGROUND

The Air Force family housing revitalization program brings existing dwellings into compliance with current military construction standards, extending their useful life for another 20 years. Likewise, new military family housing construction continues throughout the Air Force to meet changing installation needs and missions. These programs offer unique opportunities to economically improve energy efficiency and help meet mandated reductions in energy consumption. It is important that energy efficiency be thoroughly addressed during new construction and revitalization because no other comparable opportunity will exist for many years.

Prescriptive standards have been developed for new construction and can apply to revitalization, but by themselves they are insufficient to correct the energy deficiencies of current Air Force housing and ensure that past mistakes will not be repeated. Comprehensive diagnostics are needed to identify house-specific energy-related issues in existing housing, and life-cycle cost-effective energy solutions are necessary to resolve them. The fact that previous revitalization efforts have not achieved optimized energy designs confirms the need for this guide.

Representative examples of various types of revitalized and nonrevitalized housing at the following Air Force bases were inspected during the development of the design guide: Shaw Air Force Base, Malmstrom Air Force Base, and Altus Air Force Base. The inspection of each housing unit generally included examining the building shell and attic, determining insulation levels, measuring the air tightness of the unit, and inspecting the space-heating and space-cooling systems. The purpose of these inspections was to evaluate the energy performance of existing housing in order to develop cost-effective recommendations to be implemented as part of the new construction and revitalization process for family housing.

The inspections identified design and construction flaws that adversely affect the housing energy performance and that must be corrected during revitalization and prevented during new construction. Some recently revitalized units contained many of the same types of flaws as the units awaiting revitalization. These flaws include the following:

- Disconnects and deterioration of the air distribution duct work and poor system design cause leakage in the system resulting in a significant increase in energy consumption.
- Air leaks occur between the conditioned and unconditioned space (primarily to the attic) around unsealed openings.
- Inappropriate design of the air distribution system creates unbalanced pressure within the conditioned space resulting in increased infiltration and exfiltration.
- Poorly defined building thermal boundaries result in incomplete insulation coverage.
- Insulation is lacking at second-floor overhangs, under window openings, in basements, and in crawl spaces.
- Attic insulation depth is highly varied because of disruption by maintenance personnel working in the attic and wind scouring at the eaves.
- Inadequate or blocked attic ventilation results in potential moisture-related problems.
- Recently installed heating, ventilating, and air conditioning (HVAC) equipment has a higher efficiency rating than may be cost effective.
- Temperature settings (150ÉF) on water heaters are excessive.
- No low-flow (2.5 gpm) shower heads have been installed.
- Little or no energy-efficient lighting is in use.

1.2 Opportunities and Challenges

OPPORTUNITIES

New construction offers the opportunity to build housing that provides a comfortable living environment without excessive ongoing expenditures for energy. Some unique opportunities to address energy efficiency are also available when existing housing undergoes revitalization. These opportunities include:

- The house is vacant for an extended period.
- The scope of the project is large enough to allow economies of scale (in both design and construction).
- Replacement of whole systems is possible if needed.
- Fuel conversion is possible and encouraged when economical.
- Energy-efficiency measures can be installed more easily and less expensively.

CHALLENGES

Several challenges in new construction and revitalization programs can influence design. These challenges include the following:

- The occupants do not pay for utilities consumed.
- Energy efficiency competes for budgeted funds with other housing requirements such as the amount and quality of space provided.
- Local energy managers may have limited incentive and opportunity to run an effective conservation program.
- The actual energy consumption of existing houses is not accurately known because houses lack individual meters. Faulty design, construction, or operation is not apparent because there is not enough feedback to determine when one house type has an energy problem. Additionally, it is difficult to measure the payback from an upgrade and verify its benefits.

It is important to note that the comfort of occupants drives their conservation actions. Houses with uninsulated slab-on-grade foundations without carpet are cold. Drafty houses and houses with uneven heating and cooling are not comfortable, and oversized air conditioning units will not control humidity, causing summer discomfort. Residents compensate for these discomforts by changing thermostat settings—the primary control they have over their environment. Because these residents do not pay utility costs (which would moderate their actions), it is especially important that proper equipment and materials be selected for new or revitalized military houses. Marginally effective materials or high-maintenance equipment that is prone to breakdown or inefficient operation should be avoided.

1.3 Use of This Guide

The organization of this guide follows the normal process used in developing new construction and revitalization projects.

Chapter 2, “Responsibilities of the Architect/Engineer,” defines what A/Es are expected to accomplish relative to energy conservation as part of their commission to prepare plans and specifications for Air Force family housing projects (both new construction and revitalization).

Chapter 3, “Design, Analysis, and Selection of Options for New Housing,” provides the information and methodology needed to select the appropriate energy-efficiency options needed to obtain the cost-effective energy budget defined by the Conservation Optimization Standard for Savings in Federal Residences (COSTSAFR) program. The chapter highlights areas that the A/E is to consider during the design process and references other portions of the Guide regarding typical deficiencies to be avoided in new construction and selected specifications needed to accomplish the work in a satisfactory manner.

Chapter 4, “Inspection, Analysis, and Selection of Options for Revitalized Housing,” defines the field inspection process to be used in determining the adequacy of existing energy impacting conditions. This chapter points out typical energy-related “problem areas” that have been found in many Air Force housing units and provides the information and methodology needed to select among the various energy-efficiency actions available. This chapter does not address the inspection of housing relative to the other criteria and issues related to revitalization.

Chapter 5, “Specification of Selected Energy-Efficiency Options,” provides suggested specifications to be used to implement selected energy-efficiency measures.

The “Inspection, Analysis, and Selection of Options for Revitalized Units” and “Specification of Selected Energy-Efficiency Options,” chapters of the guide are organized so that persons from individual design disciplines (architectural, mechanical, and electrical) can access information specifically applicable to their area of expertise. Individual topics are listed in the table of contents, permitting direct access to those topics of interest to each discipline.

1.4 Preparation of Instructions to the Architect/Engineer

The program manager or initiator of an Air Force family housing construction or revitalization project is responsible for providing the A/E with output from the COSTSAFR and Computerized, Automated Point System (CAPS) programs. This output defines the energy budget and design parameters for each housing type to be addressed in the project. The COSTSAFR and CAPS programs will be run by the Air Force Civil Engineer Support Agency (HQAFCESA/CES) at Tyndall Air Force Base, Florida, at the request of the Major Commands.

The program manager will need to provide personnel at the Civil Engineer Support Agency the following information for the overall project:

- Proposed occupancy year
- Project location
- Fuel costs
  - — Oil ($/gal)
  - — Liquid petroleum (LP) gas ($/gal)
  - — Natural gas ($/therm)
  - — Electricity ($/kWh)

The program manager will also need to provide the following for each unique building type:

- Foundation type
  - — Slab-on-grade
  - — Crawl space
  - — Basement

- Building type
  - — Single-story ranch
  - — Split-level
  - — Townhouse
  - — Two story
  - — Apartment
  - — Single-section manufactured
  - — Multisection manufactured

- Planned heating equipment
  - — Furnace (preferred fuel: oil, natural gas, LP gas)
  - — Heat pump (electric)

- Planned air conditioning?
  - — Yes
  - — No

- Planned domestic hot water fuel
  - — Electric
  - — Gas

For new construction, this information describes acceptable options for housing units. Therefore, more than one foundation type, building type, heating equipment, and domestic hot water fuel can be approved. For revitalization, because this information describes an existing unit, only one foundation type and building type can be specified. However, a specific selection for heating equipment and domestic hot water fuel does not need to be made.

The instructions provided to the A/E in the Request for Proposal or Statement of Work should include the following:

- a copy of the output of the COSTSAFR and CAPS programs for each unique housing type,
- a copy of this guide, and
- copies of, or references to, all applicable Air Force codes and standards.

Chapter 2

RESPONSIBILITIES OF THE ARCHITECT/ENGINEER

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2.1 Purpose

The purpose of this chapter is to define the A/E's responsibilities in producing plans and specifications for new and revitalized Air Force family housing projects that will result in cost-effective, energy-efficient dwelling units. The A/E's responsibilities with regard to the design of energy-efficient housing will be fulfilled in accordance with this guide through the accomplishment of the following tasks:

- design, analysis, selection, and documentation of cost-effective energy-efficiency options for new housing units, or
- inspection, analysis, selection, and documentation of cost-effective energy-efficiency options for revitalization units, and
- specification of the cost-effective energy-efficiency options identified and building envelope and equipment performance verification testing requirements.

For new construction, energy efficiency will be partially achieved by complying with various prescriptive standards referenced in this guide and the requirements set by the COSTSAFR program for each distinct housing type (see Sect. 3.2, "Selection of ECMs Using COSTSAFR"). COSTSAFR identifies the cost-effective level of energy efficiency for each new housing type at the project's location. To fully achieve the intended level of energy efficiency, quality materials and equipment and their proper installation must be specified, as well as verification testing to ensure that everything is functioning properly (Chap. 5, "Specification of Selected Energy-Efficiency Options").

For revitalization of existing housing, the use of prescriptive standards is less appropriate because existing conditions and deficiencies can limit the cost-effective application of efficiency measures. This guide provides a methodology (see Chap. 4, "Inspection, Analysis, and Selection of Options for Revitalized Housing") for making cost-effective energy-efficiency decisions in an environment when such limits must be taken into account. As with new construction, the specification of materials and equipment, commissioning, and verification testing is required.

2.2 Design, Analysis, and Selection of Options for New Housing

Chapter 3, "Design, Analysis, and Selection of Options for New Housing," will assist the A/E in selecting the appropriate types and levels of energy-efficiency options for new housing units. The design process must avoid reproducing flaws typically found in existing housing as described in Sect. 1.1, "Need for This Guide," and throughout Sect. 4.2, "Analysis and Selection."

AREAS TO BE ANALYZED

The following elements impact the energy efficiency of Air Force family housing and shall be addressed by the A/E in the analysis phase of the design process:

Building Envelope

The entire envelope will be analyzed, thermal boundaries will be defined, and insulation levels for the entire boundary will be determined and specified for the specific climate and fuel cost. Air-leakage locations and bypasses in the building thermal envelope that allow conditioned air to move directly out of the house will be avoided or sealed. Appropriate quality, energy-efficient windows and doors will be specified.

Heating and Cooling System

The proper heating and cooling equipment will be determined for the climate, fuel type and cost, and house load. A life-cycle cost approach will be used to select the appropriate level of efficiency. Equipment must be properly sized. Insulation levels for ducts located outside the thermal boundary (in attics, crawl spaces, or unheated basements) must be determined and specified.

Domestic Water Heating System

The life-cycle cost impact of alternative fuels (electric and natural gas) will be evaluated and the least costly selected. The efficiency difference among available equipment will be evaluated on a life-cycle cost basis. Water conservation opportunities will be identified and included in the project to the extent that they are cost effective.

Major Appliances

The life-cycle cost impact of alternative fuels (electric and natural gas) will be evaluated and the least costly selected. The efficiency difference among appliances will be evaluated on a life-cycle cost basis and the one with the least life-cycle cost selected.

Lighting

The lighting system will be based on a cost-effective energy-efficient lighting design.

Site Improvements

Site improvements (landscape and pavement) will be evaluated as to their potential impact on the energy performance of the dwelling units. Designs that minimize energy consumption will be used whenever cost effective.

DOCUMENTATION OF ANALYSIS

A summary of the analysis process shall be accomplished for each housing type in the project and be submitted to the program manager for review and approval. Instructions for completing specific forms for this purpose are included in Chap. 3, "Design, Analysis, and Selection of Options for New Housing."

STANDARDS FOR NEW WORK

The following manuals are the Air Force standards that govern design of new family housing: *Air Force Instruction 32-6002* dated May 12, 1994, and *Air Force Family Housing Guide for Planning, Programming, Design, and Construction* dated December 1995. The prescriptive standards and criteria that are listed in these manuals are applicable to construction of all new buildings.

RESOLUTION OF CONFLICTING CRITERIA

Conflicting criteria will be resolved in the following order: (a) adhering to the project's Statement of Work, (b) adhering to the appropriate Air Force standards manuals previously cited, and (c) selecting the criteria that are shown to be most cost effective as applied to the specifics of the project.

2.3 Inspection, Analysis, and Selection of Options for Revitalized Housing

In conjunction with the detailed house inspection required by other parts of the A/E's contract, inspectors shall investigate existing conditions that have the potential to significantly impact the energy consumption of the units being revitalized.

Before inspections begin, current energy consumption data will be examined to determine the current performance and the extent of existing problems. A methodology of assessing existing consumption is described in Sect. 4.1.1, "Energy Use Review."

The inspection by the A/E will consist of visual observation of energy systems and components as described in Sect. 4.1, "Inspection," and the completion of the inspection report forms included in Appendix A. It is anticipated that a qualified inspector—one who has a technical background and is familiar with energy-efficiency techniques and tools (but is not necessarily an energy specialist)—can complete approximately two inspections per day. For units in which the retention of the existing air distribution duct system and/or a major portion of the interior is anticipated, a detailed evaluation by an inspector qualified in the use of a blower door is required. The procedures to follow and detailed inspection forms are provided in Appendixes C, D, E, and F of this guide.

An inspection of existing housing units for each type being revitalized is required to adequately define the areas to be addressed during revitalization. Table 2.1 shows how many buildings must be inspected in relation to the number of buildings to be revitalized. The data from the inspection reports will form the basis of decisions made during the analysis and selection of revitalization options. The inspection process identifies current efficiency levels and flaws and barriers preventing further efficiency improvements.

Section 4.2, "Analysis and Selection," will help the A/E select the appropriate kinds and levels of energy efficiency for each type of unit in the project. This section guides the A/E in determining whether and to what extent efficiency levels should be improved, the efficiency measures to consider, and the means of achieving improvements.

AREAS TO BE ANALYZED

The following elements impact the energy efficiency of Air Force family housing and shall be addressed by the A/E in the analysis phase of the process.

Building Envelope

The entire existing envelope and any additions will be analyzed, thermal boundaries will be defined, and insulation levels for the entire boundary will be determined and specified for the specific climate and fuel cost. Air-leakage locations and bypasses in the

Table 2.1. Inspection sampling requirements

Number of buildings of a specific type	Number of buildings to be inspected
1	1
2–50	2
51–75	3
76–100	4
101–125	5
126–150	6
151–175	7
>175	8

building envelope that allow conditioned air to move directly out of the house, often associated with “holes” in the envelope, will be identified for sealing. Appropriate quality energy-efficient replacement windows and doors will be identified and specified when replacement units are called for in the revitalization project or if economically justified.

Heating and Cooling System

The proper heating and cooling equipment will be determined for the climate, fuel type and cost, and house load if replacement units are called for in the revitalization project or if economically justified. A life-cycle cost approach will be used to decide whether to replace equipment and what new equipment to select. Insulation levels for uninsulated ducts that are located outside the thermal boundary (in attics, crawl spaces, or unheated basements) will be identified, and leaking ducts will be identified for repair or replacement.

Domestic Water Heating System

Water heating equipment not identified for replacement as part of the revitalization will be evaluated for replacement during revitalization based on its energy efficiency. The life-cycle cost impact of alternative fuels (electric and natural gas) will be evaluated and the least costly selected. The efficiency differences among available equipment will be evaluated on a life-cycle cost basis. Water conservation opportunities will be identified and included in the revitalization to the extent that they are cost effective.

Major Appliances

Appliances not identified for replacement in the revitalization project will be evaluated to determine if replacement based on improved energy efficiency is economically justified. The life-cycle cost impact of alternative fuels (electric and natural gas) will be evaluated and the least costly selected. The efficiency differences among appliances will be evaluated on a life-cycle cost basis and the one with the least life-cycle cost selected.

Lighting

Replacing old lighting systems will usually be part of a revitalization. However, when replacing the existing lighting system is not part of the revitalization, an energy-efficient lighting strategy will be evaluated to determine if partial or complete system replacement is economically justified.

Site Improvements

Existing and future site improvements (landscape and pavement) will be evaluated for their potential impact on the energy performance of the dwelling units. Designs that minimize energy consumption will be specified whenever cost effective.

DOCUMENTATION OF ANALYSIS

The analysis process (Forms G.1 to G.17, Appendix G) will be completed and provided to the program manager for review and approval.

STANDARDS FOR REVITALIZATION

The following manuals are Air Force standards that govern the design of new family housing: *Air Force Instruction 32-6002*, dated May 12, 1994, and *Air Force Family Housing Guide for Planning, Programming, Design, and Construction* dated December 1995. The prescriptive standards and criteria listed in these manuals are applicable to “all buildings of new construction or substantially altered building envelopes.” They shall be consulted in those portions of revitalization projects in which

- new construction replaces or adds to the existing building envelope (e.g., building additions),
- access is provided (for other than energy-efficiency reasons) to normally inaccessible portions of the existing

building envelope, allowing the changes to meet prescriptive standards and to be made cost effectively (e.g., removal of the interior or exterior finish of a wall because of deteriorated conditions or electrical upgrade, permitting increased levels of wall insulation), or
- the total cost of modifying the existing envelope (demolition, modification, and restoration) to prescriptive standards can be shown to be cost effective based on energy savings alone.

The U.S. Department of Commerce annually updates the present worth factors to be used in military life-cycle cost analyses. Annual figures are published in *Present Worth Factors for Life-Cycle Cost Studies in the Department of Defense* (S. R. Peterson, NISTIR 4942-2). Factors presented in this Guide are for 1995. Revised factors must be obtained for future years from the reference.

BASIS OF SELECTION

Three different bases for selecting efficiency options are likely to be encountered in revitalization projects and are as follows:

1. A revitalization option is selected for other than energy-efficiency reasons. These reasons could include deterioration of building components (e.g., new double-pane windows to replace worn out windows), equipment that has reached the end of its useful life [e.g., a new 80% annual fuel utilization efficiency (AFUE) furnace to replace an existing 20-year-old unit], or other aesthetic or functional reasons (e.g., upgrading space to conform to current private-sector practices).
2. The incremental cost of a higher efficiency replacement option compared with the standard replacement option is cost effective. An example is replacing a worn-out furnace with a high-efficiency (92% AFUE) furnace rather than a minimum efficiency (80% AFUE) unit because the incremental cost increase provides benefits that are cost effective over the life of the furnace.
3. A revitalization measure is selected on the basis of energy conservation potential and is cost effective. Examples are adding insulation to an uninsulated wall, converting an existing electric water heater in good condition to a new gas heater, or installing a new high-efficiency furnace even though the existing unit has remaining life.

For purposes of this guide, the total project energy savings does not depend on which basis is used to determine to replace a component. For example, the savings of new windows is the same whether the windows were replaced because they were worn out or because they were inappropriate for the climate. The total savings generated will be related only to the design of the new windows compared with the windows that were replaced.

The cost of installation and the energy savings to be used for life-cycle analysis, however, will depend on which basis is used to determine to replace a component. For example, if the windows need replacement because of the condition of the old windows, then the cost and energy comparisons should be based only on the incremental cost and energy savings of a new efficient window over a new basic window. However, if the existing windows are in good shape but should be replaced for energy reasons, the total energy savings should be used and the cost of an upgraded window should include the cost of the new window, demolition and disposal of the old window, and installation of the new one.

This guide contains the information needed to make cost-effective revitalization decisions based on climate, fuel cost, and the A/E’s estimate of installation cost. The procedures are detailed in Sect. 4.2, “Analysis and Selection.”

RESOLUTION OF CONFLICTING CRITERIA

Conflicting criteria will be resolved in the following order: (a) adhering to the project's Statement of Work, (b) adhering to the appropriate Air Force standards manuals previously cited, and (c) selecting the criteria that are shown to be most cost effective as applied to the specifics of the project.

2.4 Specification of Energy-Efficiency Options

Use existing commercial/industry standards and specifications as identified in the Statement of Work and applicable Air Force standards manuals cited in Sects. 2.2 and 2.3 for routine equipment and materials such as furnaces, air conditioners, water heaters, insulation, etc. These are examples of components that are routinely available in the marketplace and for which existing specifications are referenced.

Use the following additional or supplemental specifications from this guide (provided in Chap. 5, “Specification of Selected Energy-Efficiency Options”) for areas not appropriately covered in existing specifications: infiltration reduction, windows and doors, heating and cooling equipment, and air distribution systems.

Chapter 3

DESIGN, ANALYSIS, AND SELECTION OF OPTIONS FOR NEW HOUSING

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3.1 Overview

This chapter provides information to the A/E about energy-saving considerations that shall be included as an integral part of the design effort for new construction. The energy-efficiency measures identified in this guide are conventional in approach in that they use proven, cost-effective, off-the-shelf materials and hardware that will produce significant energy savings. Production of an energy-efficient home does not require exceptional materials or construction skills. However, attention to detail and emphasis on quality building practices are essential to the project's success and will have a major influence on its energy consumption and costs.

This chapter outlines a two-part process for the design of an energy-efficient housing unit. The first part involves the selection of energy conservation measures (ECMs) and features for the unit. This selection will be based partly on efficiency levels selected using a point system work sheet established by the COSTSAFR program as outlined in Sect. 3.2, "Selection of ECMs Using COSTSAFR." ECMs for elements of the housing unit not addressed by COSTSAFR are selected as outlined in Sect. 3.5, "Design Considerations."

The second part of the design process for new construction involves the proper specification of all ECMs to ensure correct installation. Specifications are discussed in Sect. 3.5, "Design Considerations," and provided in Chap. 5, "Specification of Selected Energy-Efficiency Options."

3.2 Selection of ECMs Using COSTSAFR

The analysis and selection of ECMs for new or replacement Air Force family housing units using COSTSAFR should follow the following six steps.

STEP ONE: REVIEW POINT SYSTEM WORK SHEETS PROVIDED

The point system work sheet established by the COSTSAFR program is unique for each housing type being considered. A work sheet for each housing type to be designed will be provided to the A/E as part of the Request for Proposal or Statement of Work for the project. The work sheet provides three important items for use in the design of each new housing type:

- the minimum number of points a housing design must meet to ensure that it is energy efficient,
- the means to calculate the points for a proposed housing design, and
- "optimum" cost-effective energy-efficiency levels for that particular housing type.

The term "points" relates inversely to energy consumption, that is, the higher the points, the lower the expected energy consumption of the housing unit.

Select ECMs that earn credit in the point system. ECMs include insulation levels, window type and area, infiltration levels, heating and cooling equipment types and efficiencies, and water-heating type and efficiency. The cumulative points from all ECMs must equal or exceed the minimum point total provided on the last page of the work sheet.

The optimum efficiency levels identified in the work sheets are calculated by COSTSAFR based on program inputs. These levels may be altered (above or below) as needed to obtain an appropriate design as long as the total energy package has a total number of points that equals or exceeds the specified minimum.

The optimum efficiency levels and minimum points for a specified size of housing unit are summarized on one page by the CAPS program. CAPS also estimates the energy intensity of the optimized design in units of thousands of Btus per square foot.

STEP TWO: VERIFY MANDATORY ENERGY REQUIREMENTS

Air Force energy-efficiency standards identified in Sect. 2.2, "Design, Analysis, and Selection of Options for New Housing," and pertaining to the various energy-related housing elements addressed by COSTSAFR will already be integrated into the point system work sheets by the personnel running the COSTSAFR program (see Sect. 1.4, "Preparation of Instructions to the Architect/Engineer"). Additionally, personnel running COSTSAFR will integrate unique project requirements affecting energy use into the work sheets to the extent possible. Some project requirements, such as fuel choice, may have to be factored into the design by the A/E as subsequently outlined.

STEP THREE: DESIGN PROTOTYPES

Develop a conceptual energy design package keeping in mind the minimum points and optimum efficiency levels identified in the work sheets, project specifications that have not already been integrated into the work sheets, and the energy conservation measures described in Sect. 3.5, "Design Considerations," and Sect. 4.2, "Analysis and Selection." Choose the combination of energy-saving techniques that are most compatible with the project design approach and cost goals. Cost effectiveness should be the major consideration when choosing the mix of energy-saving features.

STEP FOUR: COMPLETE POINT SYSTEM WORK SHEETS

Once a conceptual energy design package for each unit type has been developed, complete the point system work sheet for that unit to calculate the total energy points for the design. A work sheet must be completed for each unit type. Instructions for preparing the point system work sheet are described in Sect. 3.3, "Details of the Point System Work Sheet."

STEP FIVE: COMPARE TOTAL ENERGY POINTS WITH THE MINIMUM REQUIRED POINT TOTAL

The total energy points of each unit type must be compared to the minimum required point total for that unit type. If the design does not meet the minimum required point total, return to Step Three and develop a new design prototype by changing some of the ECM levels after identifying what elements of the unit design are causing poor performance. If the design equals or exceeds the minimum required point total, then proceed to Step Six. Higher point totals that exceed the minimum required point total are acceptable if the improved level of energy efficiency is cost justified or results from architectural considerations. For example, vinyl rather than aluminum windows may be installed to maintain the architectural appearance of the housing unit even though aluminum windows with a thermal break are a more economic choice.

STEP SIX: COMPLETE DOCUMENTATION

When the energy performance requirements of each unit type have been satisfied, compile the point system work sheet for each housing unit, and submit the final package to the program manager for review and approval. The point system work sheet for each housing type is to be completed to show compliance with the minimum required point total developed specifically for the unit.

3.3 Details of the Point System Work Sheet

This section provides detailed information on the procedure to determine compliance with the minimum required point total established by the COSTSAFR program for each housing type being considered. An example of the point system work sheet is provided in Sect. 3.4, "Example of Point System Work Sheet." The point system work sheet used to determine compliance will hereafter be referred to as the "point system."

DEFINITION OF POINTS

Points are proportional to dollars of life-cycle energy savings and are relative to the worst (least energy-efficient) level for each ECM. For example, a point total of 53 indicates that the prototype being considered generates a life-cycle cost savings of $5,300 in current-year dollars over the same prototype with the COSTSAFR minimum-level ECMs. The absolute value of the points for any ECM must be taken in relative, marginal context. For example, the points awarded to foundation measures tend to be much higher than the points awarded to ceiling and wall insulation because floor measures are compared to the very inefficient minimum level of R-0 (no insulation). In contrast, the minimum level for ceiling and wall insulation is R-11.

Negative numbers are possible for some ECMs. For example, heat-absorbing glass (Sect. F on the work sheet) and reflective glass (Sect. G) can have negative points for heating because they negate the potential solar-heating benefits of clear glass.

STRUCTURE OF POINT SYSTEM

The ECMs in the point system can be thought of as two independent groups. The principal group includes heating and cooling ECMs. This group contains space-conditioning measures (work sheet Sects. A through N) and heating, ventilation, and air conditioning (HVAC) equipment measures (work sheet Sect. O). The space-conditioning ECMs consist of the envelope or building-shell measures and are modified in the HVAC section to account for HVAC efficiency. Therefore, a change in points for any envelope ECM does not directly translate to an equal change in total points. The secondary group of ECMs includes domestic hot water (DHW) and refrigerators. Work sheet Sects. A, B, C, D, and E must always be completed, together with work sheet Sect. O and the DHW group. Work sheet Sects. F through N are optional, unless otherwise specified.

POINT SYSTEM INSTRUCTIONS

The point system begins with the ceiling, wall, and floor insulation levels (work sheet Sects. A, B, and C, respectively). Circle the specific ECMs incorporated in the design, and copy the points assigned to these levels into the appropriate space on the work sheet. In work sheet Sect. B, select either the wood-frame wall or the thermal-mass wall measure. The points for the thermal-mass wall ECM depend on the R-value of the insulation, the heat capacity of the heavyweight material, and the location of the insulation.

Work sheet Sect. D covers infiltration (leakage of air into the building), which is based on average, tight, or very tight construction. Table 3.1 provides an infiltration point work sheet that must be used to determine infiltration levels.

Work sheet Sect. E covers the window points and is based on three factors: window area, glazing layers, and sash type. The window area is the percentage of window area as a fraction of the total conditioned floor area. For example, a house with 1000 ft^2 that is conditioned and 120 ft^2 of window area has a 12% window area. The sash type can be either aluminum, with or without a thermal break, or

Table 3.1. Infiltration point work sheet

Put a check by the required measures to indicate that they will be included. Circle points for selected optional measures. Add the points and attach this table to the compliance forms. The total points determine the infiltration level.

Required construction measures	Check
All doors and windows caulked and weather- stripped.	____
Cover, caulk, seal, or weather-strip all envelope joints around windows, between wall panels, and between floor/wall and wall/ceiling surfaces.	____
Cover, caulk, seal, or weather-strip all envelope penetrations for plumbing, space conditioning ducts, electricity, telephone, and utility services.	____
Provide backdraft or automatic dampers on all exhaust systems.	____
<u>Optional Construction Measures</u>	<u>Points</u>
Select no more than one of the following three measures:	
a) Continuous air infiltration barrier installed on exterior side of exterior walls, with all joints in the barrier and all penetrations through the barrier sealed; barrier must cover all joints in the building envelope, from sill to top plate, and must act as a gasket or be sealed to all window and door frames.	13
b) Continuous vapor retarder sheet (e.g., polyethylene sheeting) installed on heated-in-winter side of exterior walls, sealed at all penetrations (electrical outlets, window and door frames); retarder must be continuous over all envelope joints and junctions (corners, band joist, interior partition meeting exterior wall, etc.) and must be lapped and sealed with acoustical sealant at all retarder joints; electrical outlets and switches in exterior wall must be gasketed with foam inserts, or of a proven airtight design.	13
c) Air infiltration barrier (item a above) plus a vapor retarder sheet (item b above).	20

Optional construction measures	Points
All electrical outlets and switches in exterior walls gasketed with foam inserts (0 points if credit taken for an air infiltration barrier or continuous vapor retarder).	1
Interior partitions, duct drops, and cabinet soffits framed after installation of continuous vapor barriers (e.g., polyethylene sheeting) and continuous drywall on ceiling.	4
No recessed lighting fixtures installed in ceilings between conditioned or unconditioned spaces, or specification of “IC” (insulated ceiling) recessed light fixtures.	3
Windows and doors certified to have infiltration rates equal to or less than 0.25 cfm per foot of crack (windows) or per square foot (doors).	3
Windows and doors certified to have infiltration rates from 0.26 to 0.34 cfm per foot of crack (windows) or per square foot (doors).	2
Windows and doors certified to have infiltration rates from 0.35 to 0.5 cfm per foot of crack (windows) or per square foot (doors).	1
Storm doors and windows provided.	1
Specification of nonducted space conditioning system (e.g., electric baseboard, hydronic), or location of all ductwork within conditioned space.	10
Sealed and taped ductwork specified for all supply and return air ducts located in unconditioned space, if a duct system is used.	5
Specification of noncombustion heating equipment (electric furnace or heat pump) or sealed combustion furnace (for gas or oil heating systems), or location of combustion furnace in unconditioned space.	2
TOTAL POINTS =	____

Circle applicable infiltration level

Average:	less than 16 points
Tight:	16 to 35 points
Very Tight:	35 points plus heat exchanger

wood/vinyl (vinyl is considered to be equivalent to wood).

Work sheet Sects. F through L cover various window measures that can then be used to modify the absolute contribution of the windows to the point total. Window area, glazing layers, and sash type in these sections must be consistent with those selected in work sheet Sect. E. The sun-tempered measure in Sect. I accounts for window orientations more favorable than the default, which assumes that windows are equally distributed. Work sheet Sects. J, K, and L represent points for movable night insulation for windows. Work sheet Sect. M is for sun spaces, and work sheet Sect. N is for light-colored roofs. Work sheet Sect. I should be used infrequently because housing units of the same type have multiple orientations when built, and work sheet Sects. J, K, L, and M should be used infrequently because moveable insulation and sun spaces are not usually practical for military family housing. A roof (or its shingle) must have a rated reflectance value of 0.3 or greater to be classified as a light-colored roof. This can typically be met only by light-colored metal roofs and white-shingle roofs in an area not subject to mildew growth.

In work sheet Sect. I, the points are determined for sun-tempered designs by completing three equations for both heating and cooling. Note that this section is completed only if the window orientation is not divided evenly among the four cardinal directions. In Equation A of work sheet Sect. I, the area of each orientation is entered as a fraction of the total window area. For example, if 20% of the windows are on the north side, then the entry above “N” is 0.20. In Equation B of Sect. I, the quantity “X”, calculated in Equation A, is multiplied by the total window area percentage and the shading coefficient. The total window area percentage is entered as a fraction of one. For example, if the total window area is 10% of the heated floor area, then the entry above “%AREA” is 0.10. If actual shading coefficients are not available, use the data in Table 3.2. Equation C of work sheet Sect. I uses the quantity “Z” from Equation B in two different locations. By using this equation, the heating and cooling points for the sun-tempered section are determined.

Work sheet Sect. O uses the heating and cooling total points from work sheet Sects. A through N, *Space Conditioning Total*, in equations for the HVAC equipment to determine the *Total Heating and Cooling Points*. The heating and cooling points from Sects. A though N of the work sheet are added and entered at the middle of page 5 of the work sheet to get a separate total for heating and cooling. In work sheet Sect. O, first enter the appropriate space-conditioning total in the parentheses in step A (heating) and step C (cooling). Complete the equations in steps A and C, and insert the results in the parentheses above the letters “X” and “Y” in steps B and D, respectively. You must also enter the efficiency

Table 3.2. Window shading coefficients

	Layers		
Glass type	Single	Double	Triple
Clear	1.00	0.88	0.79
Heat absorbing	0.77	0.64	0.56
Reflective	0.40	0.31	0.30
Low-E	—	0.78	0.70

of the heating and cooling equipment in steps B and D. Use the AFUE, HSPF, and SEER values from the Federal Energy Label, which is required for all residential furnaces and air conditioners, for the proposed equipment.

The A/E may choose any of the different types of heating equipment listed in step B. It is recommended that all allowable equipment be tried and the heating points compared. Equipment with higher fuel costs will often make it extremely difficult to meet the minimum required point total.

The numbers obtained from steps B and D for both heating and cooling in work sheet Sect. O are the *Total Heating and Cooling Points* and are rewritten at the bottom of page 5 of the work sheet. The *Total Heating and Cooling Points* on the bottom of page 5 of the work sheet are the only points from work sheet Sect. O.

The DHW and REFRIGERATOR/ FREEZERS point systems on page 6 of the work sheet are independent of all other ECMs. The equations for the DHW heaters are based on the number of bedrooms in each unit. Enter the energy factor from the Federal Energy Label of the proposed water heater in the blank above "EF" on the appropriate line, and perform the necessary calculation to determine the points for the DHW heater. Enter the rated annual energy consumption from the Federal Energy Label of the proposed refrigerator/freezer in the blank above "kWh/year," and perform the necessary calculation to determine the points for the refrigerator/freezer. Add both points to determine the "Total DHW Heater and Refrigerator/Freezer Points."

To determine the *Total Points* on page 7 of the work sheet, copy the heating point total and the cooling point total from the bottom of page 5 into the appropriate blanks. Also, copy the *Total DHW/RFR* from page 6. Calculate the *Total Points* by adding the three values. The *Total Points* must be equal to or greater than the *Minimum Required Point Total* shown just beneath the *Total Points*. Note that the required points vary with the number of bedrooms because of varying hot water usage.

The *Estimated Unit Energy Cost* over 25 years is calculated and appears at the bottom of page 7. Enter the conditioned floor area in square feet. The *Estimated Unit Energy Cost* is shown in hundreds of dollars.

INTERPOLATING BETWEEN ENERGY CONSERVATION MEASURES

ECMs that fall between levels in the point system can be awarded points through standard interpolation techniques. For example, an R-16 wall is the average of the point values for R-13 and R-19.

3.4 Example of Point System Work Sheet

An example of the COSTSAFR point system work sheet to be provided to and used by the A/E is provided on the following pages. The one page summary output obtained from CAPS is also provided at the end. This example is for a single-story ranch-style house located at Tyndall AFB, Florida. The values on the work sheets provided to the A/E will vary from this example because of differences in climate, fuel cost, fuel selection, construction cost, housing type, foundation type, and heating and cooling equipment.

Tyndall AFB, FL		Single Story Ranch Houses3 Bedrooms		
BUILDING CATEGORY		SELECTED LEVELHEATINGCOOLING		
A: Ceiling Insulation			R-19 2.2 1.6	
B: Wall Insulation			R-11 0.0 0.0	
Wood Frame				
Thermal Mass				
C: Floor Type/Insul			Slab on Grade R-5_2FT	
D: Infiltration			TIGHT 5.4 1.9	
E: Window Area/Type			12% ALUMINUM DOUBLE	
F,G,H: Tinted or Low-E			0.0 0.0	
I: Sun Tempered			25%N 25%E 25%S 25%W	
J,K,L: Moveable Insul			0.0	
M: Sunspaces			0.0	
N: Dark Roof Color			0.0	
O: HVAC Equipment			NatGas 0.75 SEER=10.00	
DHW Equipment			Gas Energy Factor=0.621	
Refrig/Freezer			kWh/yr=800.5	

---Complies--

	DWH/RFR	HEATING	COOLINGPROPOSAL	REQUIRED
YEARLY KBTU/SQFT:	29.9	+	15.7+ 9.9=55.5-----	
TOTAL POINTS:		7.3	+37.5+35.9=80.7	79.0

Estimated life-cycle energy cost for 1200 square foot house is $10139

Providing an energy-efficient home includes appropriately addressing four key areas in the design process: building envelope, heating and cooling system, hot water system, and other energy-consuming devices. Meeting the minimum required total points using the point system work sheets addresses only the selection of some elements of each of these areas. Other elements must also be properly selected in each area, and all elements must be properly specified to ensure quality installation.

BUILDING ENVELOPE

The heating and cooling energy consumption of a home is significantly affected by the thermal performance of the building envelope. An energy-efficient building envelope includes the following characteristics.

A Tight Building Envelope

Infiltration and exfiltration through a poorly constructed building envelope can account for a significant portion of a home's heating and cooling energy consumption.

All detached housing units must meet the air-leakage performance criteria specified in Sect. 4.2.6, "Infiltration." Although the means of meeting the air-leakage criteria are left to the contractor, infiltration-reduction characteristics assumed for the housing unit design and used in the point system work sheet (Table 3.1) must be specified for installation. Common air-leakage problems as described in Appendix D must be avoided, and careful sealing of building envelope penetrations must be specified following the techniques described in Sect. 5.2, "Infiltration Repair Specifications and Construction Tips." Compliance with the air-leakage criteria shall be verified through performance testing of a randomly selected sample of housing units, as provided in Sect. 5.3, "Infiltration Performance Testing of Housing Units," and the testing procedure specified in Appendix C.

Air-leakage performance criteria for attached housing cannot be specified because air-leakage criteria and test procedures for this type of housing have not been generally developed or accepted. Infiltration-reduction characteristics assumed for the housing unit design and used in the point system work sheet (Table 3.1) must be specified for installation. Common air-leakage problems as described in Appendix D, as well as air leakage between attached units, must be avoided in the design. Careful sealing of building envelope penetrations must also be specified following the techniques described in Sect. 5.2, "Infiltration Repair Specifications and Construction Tips."

Proper Insulation

Insulation types and thicknesses were selected using the point system to meet energy goals. Specify careful installation of insulation to ensure complete, unbroken coverage of the full building envelope. See Sect. 4.1.4, "Thermal Boundary Identification," and Sect. 4.2.2, "Thermal Boundary," for a discussion of the definition of the thermal boundary and common gaps found in Air Force family housing.

Energy-Efficient Windows and Doors

Energy-efficient windows that minimize heat loss and infiltration were selected under the point system. For additional information on the selection of proper windows, see Sect. 4.2.8, "Windows." Sect. 5.4, "Windows and Doors," provides a recommended specification for windows and glass exterior doors. Exterior doors must conform with Air Force standards (see Sect. 4.2.9, "Doors"), have low infiltration ratings, and be of solid wood or metal with an insulated foam core.

Appropriate Use of Passive Solar Applications and Natural Ventilation

Passive solar applications allow solar radiation to enter the building's thermal envelope in the winter and exclude it in the summer. Applications include site planning, window shading, and landscaping as described in Sect. 4.2.19, "Site Improvements." Natural ventilation, including whole-house fans, also merits consideration for energy-efficient design in moderate climates.

HEATING AND COOLING SYSTEM

Heating and cooling systems directly consume 30 to 45% of the overall energy consumption of a home. An energy-efficient system includes proper selection and installation of heating, cooling, and air distribution systems. Cost-effective selections of fuel type, heating and cooling system types, and system efficiencies were performed using the point system. Properly sized equipment must be specified by performing load calculations as discussed in Sect. 4.2.13, "Heating and Cooling Equipment Sizing and Location." This section also discusses system location criteria that must be considered and addressed in the design. In addition, Sect. 5.5, "HVAC Equipment," provides information for the specification and commissioning of heating and cooling equipment.

Air distribution systems shall be designed following the new ductwork procedures specified in Sect. 5.6, "Air Distribution System Repair and Construction Specifications," and must meet the air-leakage performance criteria specified in Sect. 4.2.15, "Air Distribution System." Common duct problems as described in Appendix F must be avoided in the design. Careful sealing of ducts must be specified following the techniques described in Sect. 5.6. Compliance with the air-leakage criteria shall be verified through performance testing of a randomly selected sample of housing units as provided in Sect. 5.7, "Air Distribution System Performance Testing," and the testing procedure specified in Appendix E.

DOMESTIC HOT WATER SYSTEM

The DHW system directly consumes 20 to 30% of the overall energy consumption of a home. Cost-effective selections of fuel type and system efficiency were performed using the point system. The fuel type selected by the point system should be consistent with the cost-effective fuel as described in Sect. 4.2.16, "Domestic Water Heating System." Specifications concerning insulation and installation to minimize the DHW energy usage as described in this section must also be followed. In addition, flow-limiting shower heads must be specified.

OTHER ENERGY-CONSUMING DEVICES

The remaining 30 to 40% of home energy consumption is attributable to numerous devices found throughout the home. Major appliances and lighting consume the bulk of this energy and are included in new construction projects. Appliances include both government-furnished and occupant-furnished items. Refrigerators and ranges are provided by the Air Force and are major energy consumers. Dryers, washers, color televisions, and other appliances are typically occupant furnished and are beyond the scope of this guide.

Cost-effective selection of the refrigerator was performed using the point system. In addition to the cost-effective fuel selection for ranges, all other major appliances installed by the project should be selected in accordance with Sect. 4.2.17, "Exhaust Systems and Appliances," based on their certified appliance efficiency standards labels. Similarly, energy-efficient lighting should be specified when consistent with project cost and energy objectives. See Sect. 4.2.18, "Lighting," for lighting recommendations.

Chapter 4

INSPECTION, ANALYSIS, AND SELECTION OF OPTIONS FOR REVITALIZED HOUSING

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4.1 Inspection

Section 4.1 provides the information required to appropriately inspect existing housing units from an energy-efficiency viewpoint using the forms provided in Appendix A. Refer to Sect. 2.3, “Inspection, Analysis, and Selection of Options for Revitalized Housing,” to determine the number of individual housing units that need to be inspected.

Section 4.1 identifies both what to look for and how to note the findings for later use with Sect. 4.2, “Analysis and Selection.” It is intended to supplement, not replace, other revitalization inspection procedures that evaluate the unit’s condition, adequacy, and conformance to applicable regulations. These other inspections should include identification of moisture damage, moisture leaks, pest problems, and other elements that need to be corrected before building energy efficiency improvements are made.

4.1.1 Energy Use Review

An important step in inspecting family housing to be renovated is comparing the current energy consumption of the housing units with the "energy budget" calculated by the CAPS program. A one-page summary sheet of output by CAPS (see Sect. 3.2, "Selection of ECMs Using COSTSAFR") will be provided to the A/E as part of the Request for Proposal or Statement of Work for the project. The energy budget is provided in thousands of Btus per square foot of living area per year and reflects optimum energy consumption for a comparable, newly built unit.

Data that will be used by the A/E to estimate the current energy consumption intensity of the housing units to be revitalized can be inaccurate. Additionally, the actual consumption data include energy use for base-load activities such as cooking and lighting that are not included in CAPS values. Therefore, the comparison between current energy use and the CAPS energy budget serves only as a guide to help foresee the magnitude of energy deficiencies that may exist in the units. Feedback obtained during the inspection itself will ultimately determine the degree of energy deficiencies.

Housing units that are 50% over the CAPS energy budget or that have higher than normal (or expected) energy consumption are likely to have significant efficiency problems that need to be identified during inspection and addressed during renovation. Inspectors should be concerned if inspection of these housing units does not reveal efficiency problems sufficient to explain the high consumption. Higher than normal energy consumption can be based on comparisons with other installation energy consumptions as provided by the Defense Utility Energy Reporting System (DUERS) or on comparisons with private sector housing in the same climate.

Actual energy consumption by occupants who do not pay utility bills can be about 20% higher than those with a monetary incentive to conserve. Therefore, consumption that is 20% over the CAPS energy budget could still occur in an energy-efficient dwelling that requires little retrofit.

The CAPS energy budget combines into a single value the annual end-use energy consumption of all fuels (e.g., natural gas, oil, and electricity) consumed by the housing unit for heating, cooling, domestic water heating, and refrigeration. The conversion factor of 3413 Btu per kWh is used to convert electricity consumption.

Ideally, the annual site energy consumption data for just the housing units to be revitalized should be used to calculate energy consumption intensity; however, consumption data are usually available only for *all* family housing at an installation, rather than for individual units or small groups of housing. The energy officer at an installation can usually provide consumption data (usually called DUERS data) and housing unit floor areas needed to calculate an energy consumption intensity. Contacts with the installation's engineering office, mechanical and civil engineering chiefs, and others may also be needed.

The accuracy of the energy consumption and floor area data should be verified when the data are obtained or at the start of the field inspection. Uncertainty in the accuracy of current energy consumption and floor area data should be factored into the comparison to the energy use budget before final conclusions are reached. Conclusions drawn from comparing inaccurate data with energy use budgets will not provide useful information about the present energy efficiency of the housing units.

The accuracy of the energy consumption and floor area data should be evaluated by performing the following four steps.

1. INSPECT THE METERING SYSTEM

Identify the presence of master meters for family housing, and, if present, verify their use to track family housing energy consumption. Inspect the meters to verify their location and operating status and that they are an appropriate type. Determine and verify in the field the calibration schedule of the meters by inspecting calibration tags. Review and field verify the schematics of gas and electricity distribution systems to determine if nonfamily housing loads such as hospitals, day cares, etc., are monitored by the “family housing” meter.

2. EVALUATE THE ALLOCATION FORMULA

Determine the use of an allocation formula to estimate family housing energy use from metered data. Installations without master meters on the family housing use allocation formulae with total installation metered energy consumption to estimate family housing energy use. Even at installations that have master meters to monitor energy consumption of all family housing, nonfamily housing users (e.g., hospitals) are sometimes connected to the family housing meter, requiring an allocation formula to estimate family housing energy use. If a formula is used, the formula should be obtained and evaluated. The evaluation shall consider the engineering (physical) basis for the formula, availability of supporting documentation for the formula, the date the formula was developed, assumptions used in developing the formula, and the additions or deletions of loads since the formula was developed.

3. REVIEW THE SQUARE FOOTAGE AMOUNTS

Determine the family housing square footage value used to normalize the energy use data before entry into DUERS. Evaluate the accuracy of this value by researching the last time the value was updated, the method used to calculate the value, the recent history of housing construction and demolition at the installation, and whether basement, carport, and internal/external storage areas are included in the value.

4. REVIEW DATA ENTRY PROCEDURES

Review the process used to accumulate and input data to DUERS. This includes determining how necessary information is collected, calculations are performed, and final values are reported and inputted.

4.1.2 Inspection Process

The elements of the full inspection process are included on the inspection forms found in Appendix A. The forms are designed to guide field personnel through the inspection process. The forms also document the findings of the inspection for use by those who will analyze the existing condition and prepare the revitalization project plans and specifications.

Some information may be determined either before or during the inspection from “as-built” record drawings of the units. Drawings, sketches, or housing office records that are not certified to be as-built should be avoided unless confirmed during the inspection.

A reduced level of energy-related inspection is justified for some items. Items defined by the military in the revitalization project scope of work as “to be replaced,” “to be retained,” or “no change” do not require a detailed energy-related inspection. Examples include roofs, doors, furnaces, or air conditioning systems with no remaining useful life; a recently replaced roof, furnace, or air conditioning system with significant remaining useful life; and previously installed replacement windows in good condition. It will, however, be necessary to obtain a limited amount of field data for these items to be able to estimate their current energy performance, which is an element in the analysis phase of the project. Field inspection may be required to integrate these items into the overall revitalization project.

4.1.3 General Information

Identify the installation at which the unit is located. Assign a unique identification number to the housing unit and include it on each subsequent form. Document the address of the inspected unit, inspector, affiliation of the inspector, and inspection date.

Identify the type of housing unit inspected and the presence of shared heating or cooling systems. Units should be single-family attached or detached since the analysis methods used in this guide are not applicable to multifamily units. If a unit is single-family attached, indicate how many housing units are attached.

Calculate the total gross floor areas and gross floor areas that are intentionally heated and air conditioned for each floor of the housing unit. (A definition of an intentionally conditioned space is provided on the form.) Calculate the total volume of the house interior using average ceiling heights and living areas for each floor. Also, determine the number of intentionally conditioned stories.

4.1.4 Thermal Boundary Identification

A critical task to be performed during the inspection of the building envelope is determining where the thermal boundary of the building structure is currently and where it should be following revitalization. The thermal efficiency of the boundary can be inspected once this determination is made using the guidelines in the following sections. Although simple in concept, identification of the thermal boundary may require some investigative effort in practice.

The thermal boundary separates the comfort-conditioned (heated and/or cooled) areas of the living unit from the outside or from nonconditioned spaces such as attics, garages, basements, and crawl spaces. The boundary reduces the flow of heat between conditioned and nonconditioned spaces from conduction, radiation, and convection (including air infiltration). The thermal boundary must be continuous (the entire conditioned volume enclosed) to be appropriately defined.

A systematic method of identifying the current and proper locations of the thermal boundary is to sketch the living unit's plan and section(s) as shown in Fig. 4.1. The thermal boundary of the existing unit should then be identified on the sketches. Discontinuities in the boundary or areas where the boundary is uncertain should become evident in preparing this sketch. Building elements (e.g., walls, ceilings, and foundations) that make up the thermal boundary will need to be inspected to determine their current levels of thermal efficiency.

Windows, skylights, exterior walls, exterior doors, and ceilings that separate living areas from the attic or roof (cathedral ceilings) are readily identified as part of the thermal boundary. Components that often are overlooked as part of the thermal boundary include the following:

- floors of second-story overhangs;
- knee walls, roof rafters, and truss cords (collar beam) in finished attics;
- "interior" walls used to form a chaseway for plumbing and ducts that are open to nonconditioned spaces; and
- "interior" walls separating attached nonconditioned storage rooms or garages from the living areas.

Identifying the location of the thermal boundary in foundations can be less clear because the thermal boundary can sometimes be appropriately placed in several different locations. This is especially true with crawl spaces or basements that are not comfort conditioned.

The thermal boundary for a crawl space is typically either the floor separating the crawl space from the living area of the housing unit or the walls of the crawl space plus the crawl space floor.

The thermal boundary of a basement is similar to that of a crawl space, although factors such as use of the basement (e.g., the presence of washers and dryers and water pipes, coupled with an extremely cold climate) must be factored into the determination. For example, the floor separating the basement from the living area may not be the thermal boundary if heat loss to the basement is required to prevent pipes from freezing. In this case, the appropriate thermal boundary for the housing unit is the basement walls and floor.

For slab foundations, the slab itself (including the slab edge) is typically the thermal boundary.

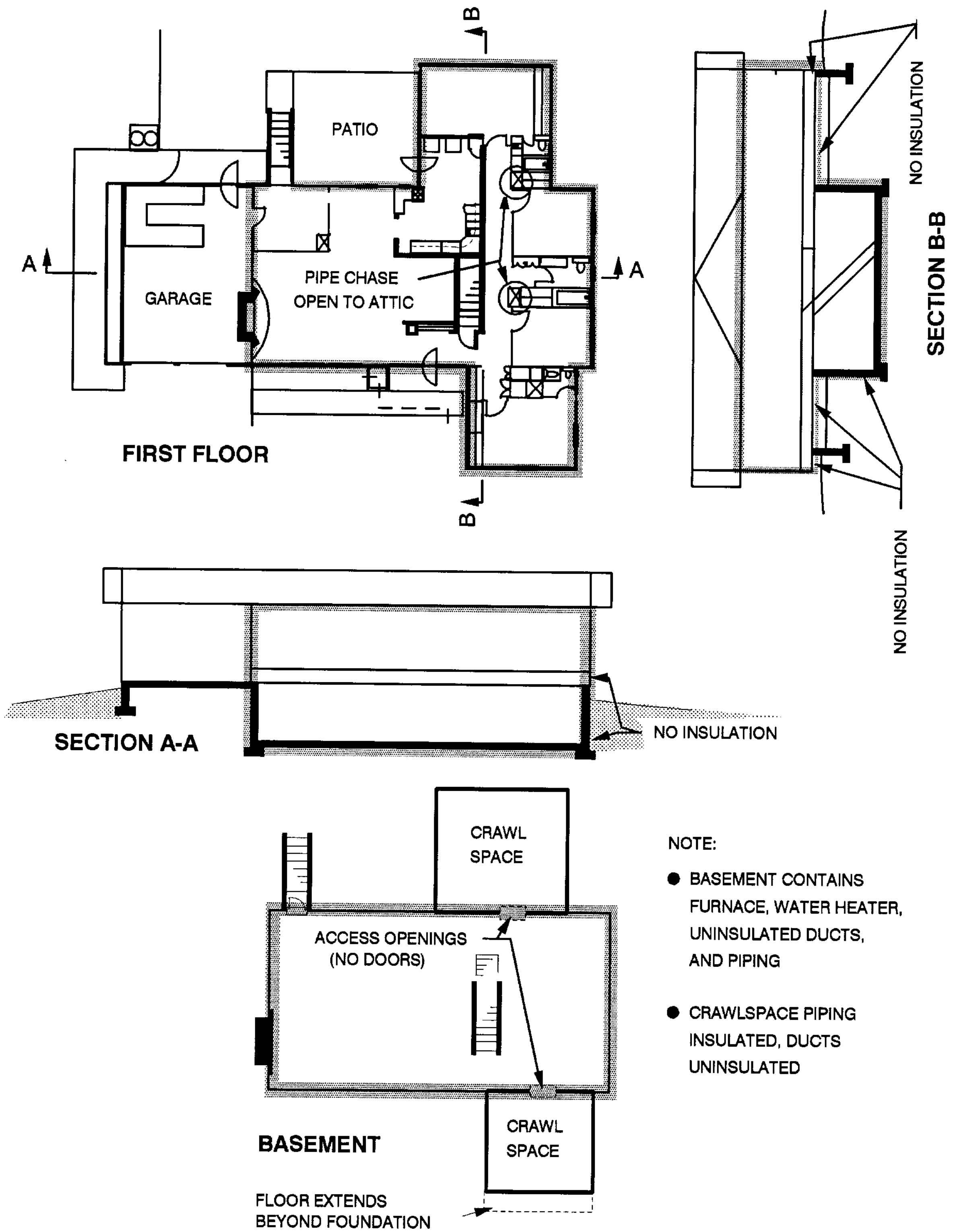

Fig. 4.1. Sample sketch showing how to identify the thermal boundary for a housing unit using house plans and sections.

4.1.5 Insulation

WALLS

Note the type of wall (type of load-bearing structure), wall exposure, and type of exterior siding for each of the exterior wall sections making up the thermal boundary. Shared walls between duplexes, quad-plexes, and multifamily structures are not exterior walls. Floors of second-story overhangs are of particular importance because they are often overlooked. They should be documented with other walls on this form. Calculate the gross wall area of each wall section. Document the type and thickness of existing wall insulation, including whether insulated sheathing is present under the siding (especially if vinyl or metal siding has been added). If possible, determine whether vapor or infiltration retarders are present.

An efficient procedure for collecting wall and subsequent window and door information is to note appropriate information as a scaled sketch of the walls is developed. Each wall segment should be numbered or lettered (wall location) so that wall information entered on the form can be referenced to the sketch and so that windows and doors can be identified by wall segment.

FOUNDATION

Identify the foundation type(s) as either basement, crawl space, or slab. More than one type may be found in a single housing unit.

Crawl Space

Identify the space conditioning status of the crawl space, the joist area separating the crawl space from the floor above (i.e., the “ceiling” area of the crawl space), the perimeter length of the crawl space, the height of the crawl space walls, and the percentage of this height that is aboveground.

Determine the amount of joist insulation (if any), the percentage of the band (rim) joist that is insulated, and the type and thickness of any insulation used to insulate the walls of the crawl space. Also, determine if a vapor retarder is present on the floor of the crawl space (covering the ground).

Basement

Identify the space conditioning status of the basement, the area of the ceiling separating the basement from the floor above, the perimeter length of the basement, the height of the basement walls, and the percentage of this height that is aboveground.

Determine the amount of joist insulation present (if any), the percentage of the band (rim) joist that is insulated, and the type and thickness of any insulation (interior or exterior) used for the walls of the basement.

Slab-On-Grade

Determine the area and perimeter length of slabs. Identify the type and thickness of existing perimeter insulation.

CEILINGS OR ATTICS

Determine the attic type, area, type and amount of existing insulation, and presence of a radiant barrier for all attic areas adjacent to conditioned spaces. This includes knee walls, collar beams, and other envelope areas created by finished attic areas. Also, note whether a vapor barrier is present.

Check the entrances to the attic areas for insulation and weather stripping.

Check the attic for adequate blocking (3-in. clearance) of insulation around soffit vents and possible fire hazards such as recessed lighting, flues, and chimneys. Comment on any nonuniformity of insulation depth caused by poor installation, wind scouring, etc.

Check the attic for ventilation.

4.1.6 Infiltration

For units that will retain a significant portion of the exterior envelope and current interior configuration, an inspection shall be performed by a qualified inspector equipped with a blower door to

- measure the amount of total infiltration flow before revitalization (detached housing only),
- measure the amount of air leakage in the air distribution system (if present), and
- identify envelope-leakage locations (e.g., attic bypasses and unblocked partition walls) that must be sealed during revitalization.

The qualified inspector's report will provide the basic information for deciding where the envelope of the existing housing unit should be repaired or modified to eliminate infiltration deficiencies. As discussed in Sect. 4.1.9, "Air Distribution System," a detailed visual inspection will be performed by the qualified blower-door inspector to identify air distribution leaks if the air distribution system is to be retained, and a cursory inspection will be performed by the A/E auditor if the system is to be replaced.

The contractor selection guide (Appendix B) is provided to aid the A/E in hiring the services of a qualified blower-door inspector by specifying the qualifications of this inspection service. The blower-door inspector shall measure the total infiltration flow of detached housing units following the procedure in Appendix C and perform a detailed visual inspection of the envelope in all housing units following the procedure in Appendix D.

Dwelling units that will be "gutted" throughout (including door and window replacement) require only a cursory visual inspection by the A/E field personnel. The purpose of this cursory inspection is to determine the impact of infiltration deficiencies on the existing energy performance of the dwelling as described in Sect. 4.2.6, "Infiltration." The background material presented in Appendix D presents basic air-leakage concepts to support this inspection. The cursory inspection is to include

- identification of large gaps around floor penetrations to basements and around ceiling penetrations to attics; and
- evaluation of the overall condition of the building envelope [basement/crawl space, main floor(s), and attic] as an infiltration barrier.

Findings from the cursory inspection are documented on the infiltration form in Appendix A.

4.1.7 Windows and Doors

WINDOWS

For each window, determine the following primary data: number of window glazings; frame type; type and condition of storm window; height and width of window; and condition of weather stripping (i.e., adequate or needs replacement). Identify the frame material by inspecting the outside and inside of the sashes to determine if the sash is wood, metal (steel or aluminum), or vinyl. If it is metal, identify (if possible) if it contains thermal breaks.

Reference windows to the wall segment on which they are located, using the wall location code. Identical windows on a wall segment can be listed easily by entering the primary data once, identifying the number of identical windows, and calculating the combined (total) area of all the identical windows.

List all sliding glass doors, french patio doors, and windows in exterior doors as windows in this section.

DOORS

For each exterior door, identify the type of door, height, width, and presence of a storm door. Determine whether the condition of the storm door, existing weather stripping, and threshold are adequate or should be replaced. Reference doors to the wall segment on which they are located using the wall location code.

4.1.8 Heating and Cooling Equipment

Inspections of the space-heating and space-cooling equipment are designed to determine whether the existing equipment needs to be replaced, retained with modification, or retained with no change based on energy considerations. It is assumed that other inspections performed by the A/E as part of the revitalization effort address safety, repair, and code issues such as

- electrical cutoff switches,
- secured wiring,
- asbestos insulation,
- adequacy of combustion air,
- fuel and gas leaks,
- fuel and gas filters and shutoff valves,
- chimney and flue clearances,
- structural and operating conditions of chimneys and flues,
- heat exchanger condition (e.g., cracks), and
- the barometric damper on fuel-oil systems.

A tune-up/commissioning procedure will be specified for all equipment as part of the revitalization to ensure efficient operation (see Sect. 5.5, "HVAC Equipment"). This procedure may be performed by inspection personnel or by a hired contractor on a sample of housing units as part of the inspection process, either to provide additional information needed to make the replacement or modification decisions or to estimate the amount of tune-up work that will have to be performed.

HEATING EQUIPMENT

Collect information on system type, fuel type, and system age (estimated if the actual age cannot be obtained from facility personnel) of the primary space-heating system. Equipment will be replaced automatically if the equipment is older than the following median service lifetimes:

- 15 years for heat pumps,
- 18 years for gas- or oil-fired furnaces, and
- 25 years for gas- or oil-fired boilers.

Equipment will also be automatically replaced if the military has dictated replacement or if the A/E's other inspections have revealed the equipment to be nonoperational, unsafe, or at the end of its useful service life.

Collect additional information, as follows, on the primary space-heating system if it will not be automatically replaced. Identify the location of the system. Collect the following nameplate information: manufacturer, model, input rating, output rating, and rated efficiency.

Note the presence of a pilot light and its condition (on or off) during the summer for gas-fired systems, and note the presence of efficiency measures (e.g., vent dampers, intermittent ignition devices, gas power burners, flame-retention oil burners, outdoor temperature resets) for gas- and oil-fired systems.

Record the type, fuel, and number of any auxiliary space-heating systems.

COOLING EQUIPMENT

Collect information on system type and age (estimated if actual ages cannot be obtained from facility personnel) for the space-cooling systems. Equipment will automatically be replaced if it is more than 15 years old. Equipment will also automatically be replaced if the Air Force has dictated replacement or the A/E's other inspections have revealed the equipment to be nonoperational, unsafe, or at the end of its useful life.

Collect the following nameplate information on the space-cooling systems if they will not be automatically replaced: manufacturer, model, input, output, and rated efficiency. Inspect the outdoor coil section of central systems to determine if there is sufficient clear area to prevent recirculation. Note the presence of landscaping that could contribute to clogging of the coil (e.g., bushes, pollen, or leaves).

CONTROLS

Verify the operation of all thermostats. Note the presence of a “setback” thermostat and whether it is a type with automatic switchover between heating and cooling. Identify the location of the thermostat. Inspect the wall the thermostat is mounted on to see if the wall cavity is open to the attic or basement/crawl space, which would allow unconditioned air to circulate behind the thermostat and lead to incorrect indoor temperature readings.

4.1.9 Air Distribution System

The air distribution system may be retained with or without modifications or be totally replaced during the revitalization process. Total replacement will most likely be needed if a significant portion of the current interior configuration is being modified (a “gut” rehabilitation), and/or if the space-heating and space-cooling equipment are being relocated, requiring significant new ductwork. Total replacement will also be needed if the existing system is damaged, deteriorated, or nonfunctioning and cannot be economically repaired.

Perform a cursory visual inspection of the air distribution system to ascertain the existing conditions. The purpose of this inspection is to allow the impact of the system on the existing energy performance of the dwelling to be estimated in Sect. 4.2.15, “Air Distribution System.” If total replacement is not needed because of a gut rehabilitation or equipment relocation, then the cursory inspection will also allow the A/E field inspector to decide if a total replacement is needed because of the existing condition of the system. Evaluate the condition of the joint seals, structural integrity, and insulation in the system (good, fair, or deteriorated), and record observations on the air distribution system form in Appendix A. The background material presented in Appendix F presents basic duct leakage concepts to support this inspection.

When retention of the existing air distribution system is being considered, an inspection shall be performed by a qualified inspector equipped with airflow measuring equipment to measure the amount of air leakage in the air distribution system, identify duct leakage locations that must be repaired and/or sealed during revitalization, identify insulation levels on the ducts and evaluate its condition, and confirm that continued use of the existing duct system is warranted.

The contractor selection guide (Appendix B) is provided to aid the A/E in hiring the services of a qualified air distribution system inspector by specifying the qualifications of this inspection service. The inspector shall measure the air-leakage rate of the distribution system following the procedure in Appendix E and perform a detailed visual inspection of the duct system following the procedure in Appendix F.

4.1.10 Domestic Water Heating System

Inspection of the domestic water system focuses primarily on heating water from the hot-water tank to faucets and shower heads. Water conservation opportunities are addressed to a limited extent. It is assumed that other inspections performed by the A/E as part of the revitalization effort address safety, repair, and code issues such as the following:

- pressure relief valves,
- flue condition,
- adequacy of combustion air,
- fuel and gas leaks,
- secured wiring,
- shutoff valves,
- leaks in the hot-water tank and water lines, and
- vulnerability to freezing.

Collect information on system type, fuel type, and age. If an actual age cannot be obtained from facility personnel, then an estimate can be made from the date of manufacture listed on the water heater nameplate (e.g., 1285 is a manufacture date of December 1985). The water heater will automatically be replaced if it is older than

- 12 years for natural gas or
- 18 years for electric.

A water heater will also be replaced automatically if the Air Force has dictated replacement, or if the A/E's other inspections have revealed the system to be nonoperational, unsafe, or at the end of its useful service life. Mineral and rust deposits around the fittings are one suggestion that the tank is approaching the end of its service life.

Collect additional information, as follows, on the water-heating system if it will not be automatically replaced. Collect the following nameplate information: manufacturer, model, heating rates, and capacity. Identify the location of the water heater and the R-value of any insulation wrap, if present. Check that the hot and cold water plumbing lines are connected to the proper fitting on the water tank. Check for heat traps on both the hot and cold water plumbing lines. Identify the amount of insulation, if any, on the hot water plumbing line and the length of piping insulated.

Measure the maximum (full) flow rate of all shower heads. Inspect all sink faucets to determine if aerators are present. Determine if water plumbing lines are located outside the conditioned space of the housing unit. If so, identify those lines that are not insulated or lined with heat tape for protection against freezing. Pay careful attention to water lines located in utility rooms that are vented to the outdoors for combustion air.

4.1.11 Other Inspections

EXHAUST SYSTEMS

Verify that all exhaust systems (e.g., range hood, bathroom fans, dryer vent, and plumbing vents) vent directly to the outside rather than to the attic or crawl space. Determine whether the bathroom fans, dryer, and range hood have dampered vents; whether the dampers are free moving; and whether they provide a positive seal when the exhaust system is off. Check for leaks at the fan and in the ducts for these systems.

MAJOR APPLIANCES

The determination to replace or retain appliances other than ranges will be for “other than energy reasons” based on other inspections performed by the A/E. Only two energy-related inspections need to be performed:

- determine the availability of gas for the range, and
- verify that the space allocated in the kitchen for the refrigerator allows adequate airflow around the condenser coils.

LIGHTING

This inspection will determine whether the existing lighting fixtures will be replaced or retained in service. If the A/E’s contract specifically calls for replacing all light fixtures (common in revitalizations), the inspection likely does not need to be performed.

Assess existing lighting by identifying the mounting location of the fixture, lamp type, number of lamps, and total fixture wattage. Identify the type of control. Additional comments should be noted concerning the size of windows, existing skylights, clerestory windows (skylights with vertical glazing), and other factors that affect daylighting.

SITE IMPROVEMENTS

Landscaping

Note existing mature landscape materials (e.g., trees and large shrubs), when the plants offer (or will offer) shade to the south and west facades or roofs of the dwelling, or when they can buffer the dwelling from cold winter winds. Provide exact locations for these plants when they occur within the construction boundaries of a dwelling undergoing revitalization so that site designs can be modified if necessary to accommodate them and so that they can be protected appropriately during construction.

Note existing landscape material located in proximity to current or planned exterior air conditioning units (for removal) if its presence might restrict airflow around the unit in the future or contribute to clogging of the outdoor coil. Note for retention in the final site design any trees that shade planned air conditioning unit locations, without restricting airflow.

Pavement

Carefully evaluate the pavement in close proximity (approximately 5 ft) to the comfort-conditioned portions of the dwelling as to its condition and usefulness when it occurs on the southern and western exposures of the structure and can reflect significant solar heat onto the structure. Consider removing or relocating such pavement in the revitalization process. Projects at Air Force bases with little or no summer air conditioning requirements need not perform this step.

4.2 Analysis and Selection

This section provides information to help A/E personnel select the most cost-effective options to reduce energy consumption in revitalized Air Force family housing. Each element of the housing unit that affects energy consumption is examined to determine whether the existing level of efficiency should be increased or, in the case of replacement, the level of efficiency that should be installed. Form G.17 (found in Appendix G) will be completed to document the analysis process for each housing unit type to be revitalized, and to indicate the efficiency improvement expected from revitalization.

The A/E will need to know the annual heating- and cooling-degree days for the project location as identified in *Engineering Weather Data* (AFM 88-29, TM5-785, and NAVFAC P-89). Heating- and cooling-degree days for most major Air Force bases in the United States are tabulated in Appendix H. The A/E will also need to know the current cost of fuels used in Air Force housing to convert energy savings into dollar values that can be compared with cost estimates of energy-efficiency measures.

Estimating installation costs of energy-efficient measures is the responsibility of the A/E because of the varied situations that can occur in the revitalization process. For example, the cost to install wall insulation in an existing stud wall would be much lower if the drywall were being removed for other reasons (such as repair of termite damage or rewiring). Accessible stud cavities can easily be insulated with batts; however, enclosed cavities require more expensive blown insulation.

The analysis methods used in this guide assume that housing units are single-family detached or attached structures. Attached structures can be duplexes or townhouse-type units (units are side by side rather than above and below) with separate ground-level entrances. The methods also assume that heating and cooling systems are not shared between units.

In general, using the analysis methods, the A/E calculates the annual cost savings for a given efficiency measure by multiplying annual energy saving estimates [millions of Btu (MBtu) or kWh] by the installation's cost for fuel ($/MBtu for natural gas and oil or $/kWh for electricity). The A/E then determines the cost to install the measure and calculates two economic indicators: the savings-to-investment ratio (SIR) and simple payback period (SPP).

The SIR is equal to the present value of the energy savings (annual cost savings multiplied by a present worth factor) divided by the total installation cost. The SPP is equal to the total installation cost divided by the annual cost savings. The SIR must be greater than 1.25 and the SPP less than 10 for the measure to meet military cost-effective criteria.

The net present value (NPV) of the investment is calculated to select one efficiency level for a measure when more than one efficiency level passes the military cost-effective criteria. The NPV is equal to the total installed cost subtracted from the present value of the energy savings. The efficiency level with the greatest NPV is selected. Forms for performing these analyses are found in Appendix G.

The present worth factors presented in this guide are averaged for the United States and are appropriate for 1995. The factors are presented regionally and are updated annually by the U.S. Department of Commerce in *Present Worth Factors for Life-Cycle Cost Studies in the Department of Defense* (S. R. Peterson, NISTIR 4942-2). Updated factors must be used in future years and must be obtained from this reference. The factors are fuel-specific because they consider fuel escalation, which varies by fuel. Present worth factors vary among measures because the estimated lifetimes of the measures vary.

It is important to determine current fuel costs since fuel costs impact option selection. If significant increases in fuel cost (25% above inflation) or decreases (in response to utility restructuring) are projected within five years at the installation undergoing revitalization, the increases must be factored into the decision process.

4.2.1 General Information

Complete the analysis forms provided in Appendix G of this guide for each housing unit type to be revitalized. If two or more housing units of a given type were inspected, the inspection results should be synthesized by the person completing the forms to develop general recommendations for all housing units of that type. Identify the installation at which the housing type is located. Assign a unique identification number to the housing unit type being analyzed, and include it on each subsequent form. Document the name and the affiliation of the person completing the forms.

4.2.2 Thermal Boundary

The building thermal envelope is the protective shell separating conditioned space from unconditioned space and the outside environment. The desired location of the thermal boundary at the completion of revitalization must be clearly defined before building envelope options are selected. The existing boundary identified during the site inspection should be reviewed and modified as needed to correct deficiencies. Alterations during revitalization that impact the boundary must also be addressed. Typical alterations that could affect the location of the thermal boundary include the following:

- room additions,
- conversion of basements from nonconditioned to conditioned space, and
- sealing chaseways for plumbing and ductwork that penetrate the thermal boundary.

Use Form G.2 and the method of identifying the location of the thermal boundary on house sketches described in Sect. 4.1.4 to develop final decisions.

Principal structural elements of the building usually define the thermal boundary. These include windows, exterior doors, exterior walls, and ceilings that separate living areas from the attic or roof (cathedral ceilings). Floors of second-story overhangs and knee walls, roof rafters, and truss chords (collar beams) present in finished attics are thermal boundaries that must not be overlooked.

Define the thermal boundary so that otherwise “interior” walls used to form a chaseway for plumbing and ducts are not part of it. This can be done by sealing and insulating the chaseway where it opens onto nonconditioned spaces.

“Interior” walls separating attached storage rooms or garages from living areas usually are the location of the thermal boundary; defining the boundary as the exterior walls of these areas effectively includes them within the comfort-conditioned portion of the unit.

For slab foundations, the slab itself (including the edge) is the thermal boundary. The thermal boundary for crawl spaces is the floor separating the crawl space from the living area of the housing unit (conventional approach) unless special reasons exist for defining it as the walls and earthen floor of the crawl space.

The thermal boundary of basements generally is the floor separating the basement from the living space. This location will produce the smallest, and least costly to operate, comfort-conditioned space. However, when the basement is used as a laundry or other normally occupied space (e.g., recreation room) or when severe winter climates would place water pipes and other building equipment in jeopardy of freezing, the thermal boundary extends down the walls and across the floor of the basement.

Once the thermal boundary is defined, assess the efficiency of each element comprising the boundary. Specific recommendations for assessing each element are contained in the sections that follow.

4.2.3 Wall Insulation

New walls added during revitalization should be insulated to the current standards for new construction applicable to the Air Force.

Existing walls may be underinsulated, causing increased energy loss. Determine existing insulation levels by referring to the observations recorded during the site inspection.

EXISTING WOOD-FRAME WALLS

Existing wood-frame exterior walls can be insulated by installing insulation in the stud cavities (if none is present) and/or by adding it outside the studs (under the exterior siding) if none is present. Insulation installed in the stud cavity can be fiberglass (batts or blown), blown cellulose, or plastic foams. Fiberglass and cellulose installed in the stud cavity of a 2×4 wall achieves an insulation level of R-11 to R-15. Higher R-values (R-16) can be obtained using plastic foams. These foams are in the developmental phase but may be market-ready in the near future.

Insulation can be installed in the stud cavities in one of the following ways:

- insulation can be installed when the interior wall finish (drywall or plaster) is removed as part of the revitalization (primarily batt insulation or wet-sprayed cellulose insulations);
- loose-fill insulation can be blown through holes drilled in the interior wall finish, with the installation holes patched in the drywall or plaster; or
- loose-fill insulation can be blown through holes drilled from the outside, either through the exterior wall finish followed by patching, after sections of the exterior siding are removed followed by reinstallation, or before new siding is installed.

Insulation added to the outside of the wall is usually rigid boards that must be covered by an exterior finish for protection. An insulation level of R-5 usually can be achieved with this method. This approach is usually considered when new siding is being installed and after stud cavity insulation is installed. A combination of stud cavity and exterior wall insulation would yield an overall insulation level of R-19, which is comparable to that required for new construction.

The cost effectiveness of adding wall insulation to the stud cavity and/or to the exterior (when the stud cavity is already insulated) under revitalization is determined using Figs. 4.2 through 4.5 and Form G.3.

1. The annual space-heating energy savings per square foot of wall area is obtained from Fig. 4.2 (stud cavity) or Fig. 4.3 (exterior) using the heating-degree days for the installation.
2. The annual space-cooling electricity savings per square foot of wall area is obtained from Fig. 4.4 (stud cavity) or Fig. 4.5 (exterior) using the cooling-degree days for the installation.
3. The annual cost savings of the heating and cooling energy savings are calculated in Form G.3 using the installation’s costs for fuel, and the present value of the energy savings are calculated using 25-year present worth factors. These values are summed to obtain the total annual cost savings and total present value of the wall insulation savings, respectively.
4. The A/E must determine the total cost of installing the wall insulation per square foot of wall area. The cost must include all expenses associated with the improvement, although some expenses may appropriately be assigned to other renovation work. For example, the total cost of installing exterior insulation is limited to materials and the direct installation cost of the insulation alone if existing siding is slated for

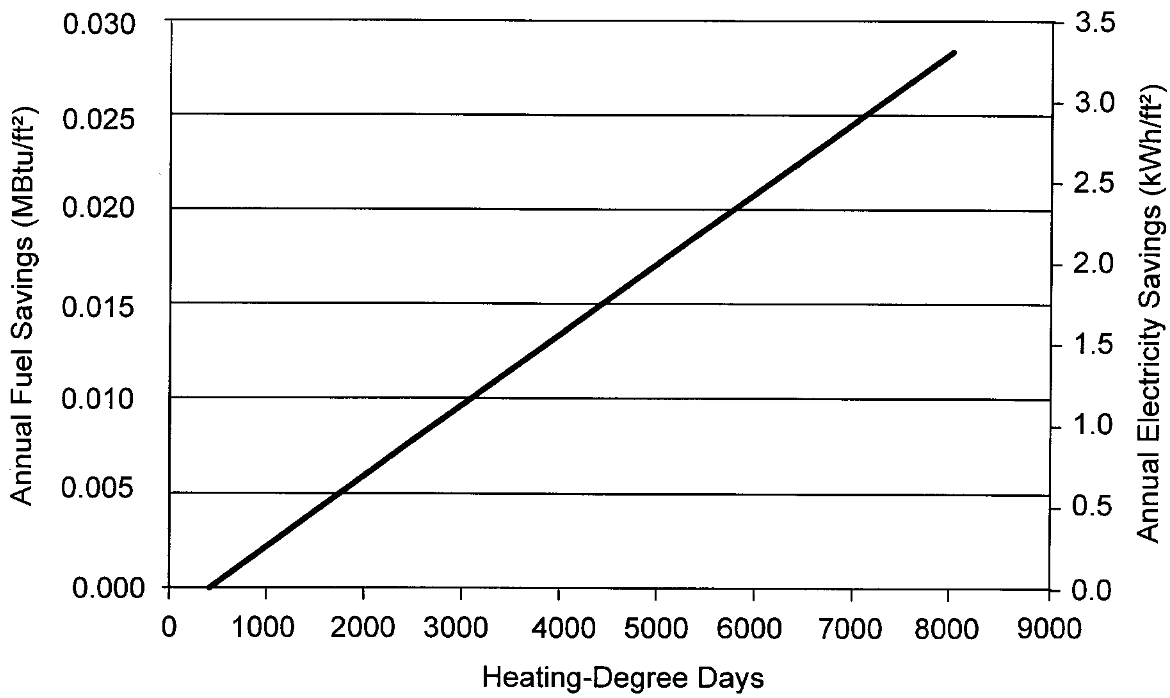

Fig. 4.2. Annual space-heating energy savings per square foot of wall area from installing R-13 insulation in the stud cavity of an uninsulated wood-frame wall.

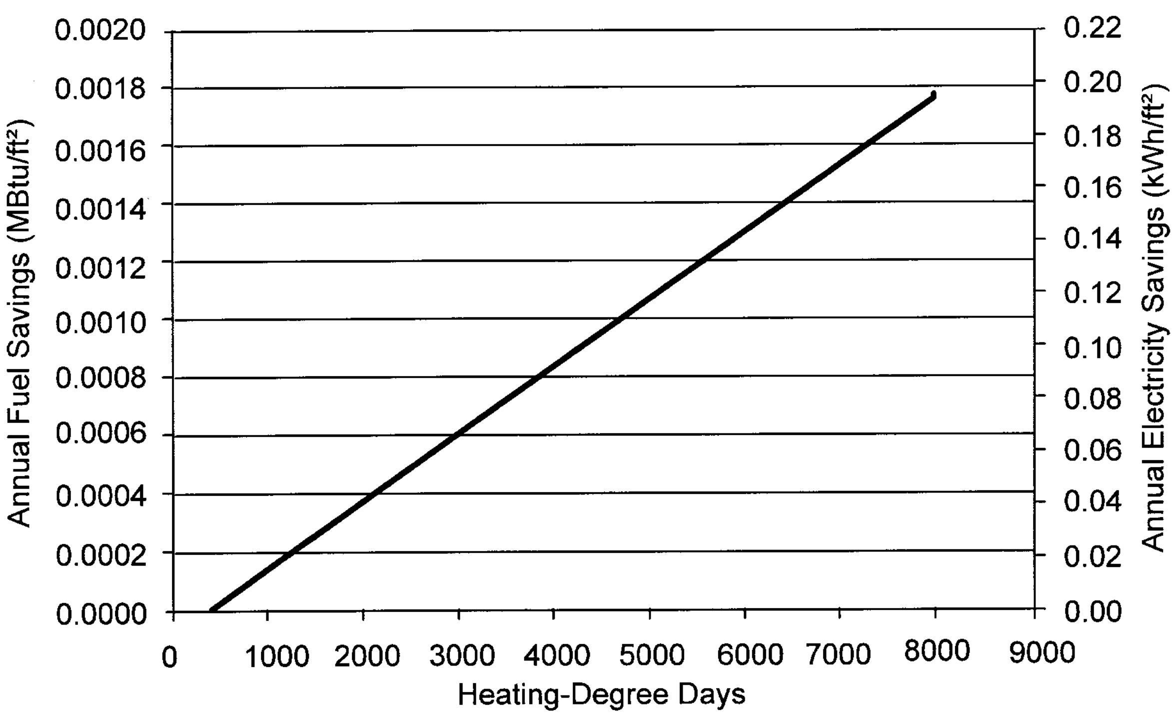

Fig. 4.3. Annual space-heating energy savings per square foot of wall area from installing R-5 insulation on the exterior of a wood-frame wall with R-13 insulation already installed in the stud cavity.

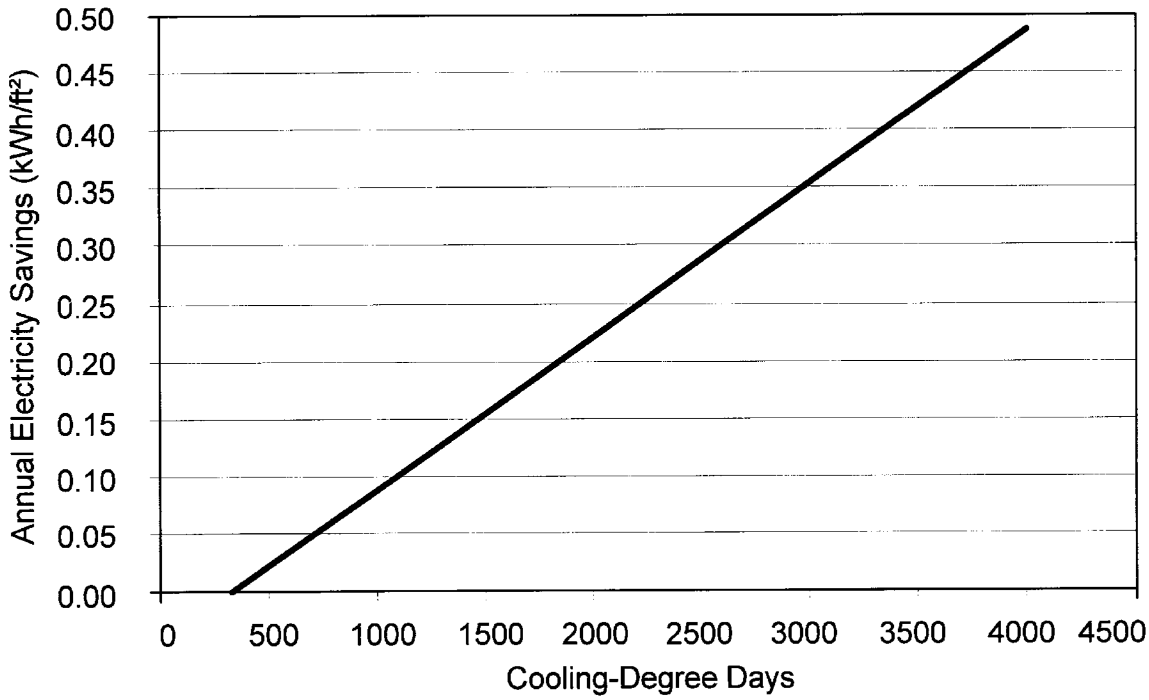

Fig. 4.4. Annual space-cooling electricity savings per square foot of wall area from installing R-13 insulation in the stud cavity of an uninsulated wood-frame wall.

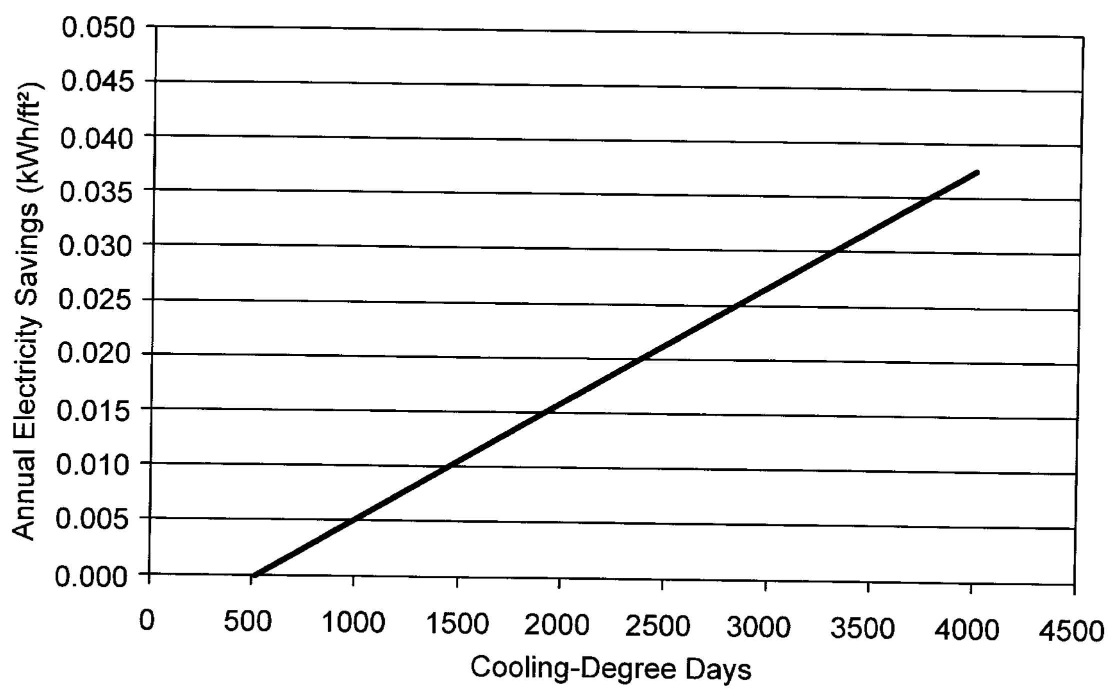

Fig. 4.5. Annual space-cooling electricity savings per square foot of wall area from installing R-5 insulation on the exterior of a wood-frame wall with R-13 insulation already installed in the stud cavity.

replacement as part of the revitalization. An important factor for the A/E to consider for cavity insulation is whether the interior or exterior finishes will be removed during revitalization, providing ready access to the wall cavity.

5. The stud cavity or exterior wall insulation meets military cost-effective criteria if the SIR is greater than or equal to 1.25 and the SPP is less than or equal to 10. Install insulation in both locations if both meet the cost-effective criteria.

Enter the level of insulation found in the wall and that to be obtained following revitalization on Form G.17. Calculate the total annual energy savings (space heating combined with space cooling), if any, by multiplying the values obtained from steps 1 and 2 by the total wall area to be insulated, multiplying electricity savings (kWh) by 0.003413 to convert to MBtu, and summing. Enter the total annual energy savings on Form G.17.

EXISTING MASONRY WALLS

Existing masonry walls can be insulated by furring out the wall interior and adding batt (R-10 to R-15) or rigid insulation (R-5). Space loss and cost are the factors influencing the choice between the two types. For above-grade walls with exposed concrete block on the exterior or face brick in poor condition, installing rigid insulation (R-5 or R-10) on the exterior may be an attractive option. A variety of new exterior finishes are available to complete the installation and protect the insulation.

The cost-effectiveness of adding wall insulation to either the interior or exterior of an uninsulated masonry wall is determined using Figs. 4.6 and 4.7, Form G.4, and the same procedure outlined for wood-frame walls. Again, the total installation cost must include all expenses associated with the improvement, although some expenses may be appropriately assigned to other renovation work. For example, the total cost of installing exterior insulation is limited to materials and direct installation cost of the insulation alone if a new exterior (stucco) is to be installed as part of the revitalization. Install the measure with the highest NPV if more than one measure meets the cost-effective criteria.

Enter the level of insulation found in the wall and that to be obtained following revitalization on Form G.17. Calculate the total annual energy savings (space heating combined with space cooling), if any, by multiplying the values obtained from Figs. 4.6 and 4.7 by the total wall area to be insulated, multiplying electricity savings (kWh) by 0.003413 to convert to MBtu, and summing. Enter the total annual energy savings on Form G.17.

FLOORS OF SECOND-STORY OVERHANGS

An effective insulating technique for second-story overhangs is to blow cellulose insulation into the overhang cavity through holes drilled in the exposed soffit until it is packed tight. This not only insulates the floor but also effectively seals a major air-leakage site.

Floors of second-story overhangs should always be insulated in this manner if they are not already insulated because of the dual benefits obtained (insulation and air-leakage mitigation). Use the technique even if the floor is already insulated if it is warranted for air-leakage mitigation (see Sect. 4.2.6).

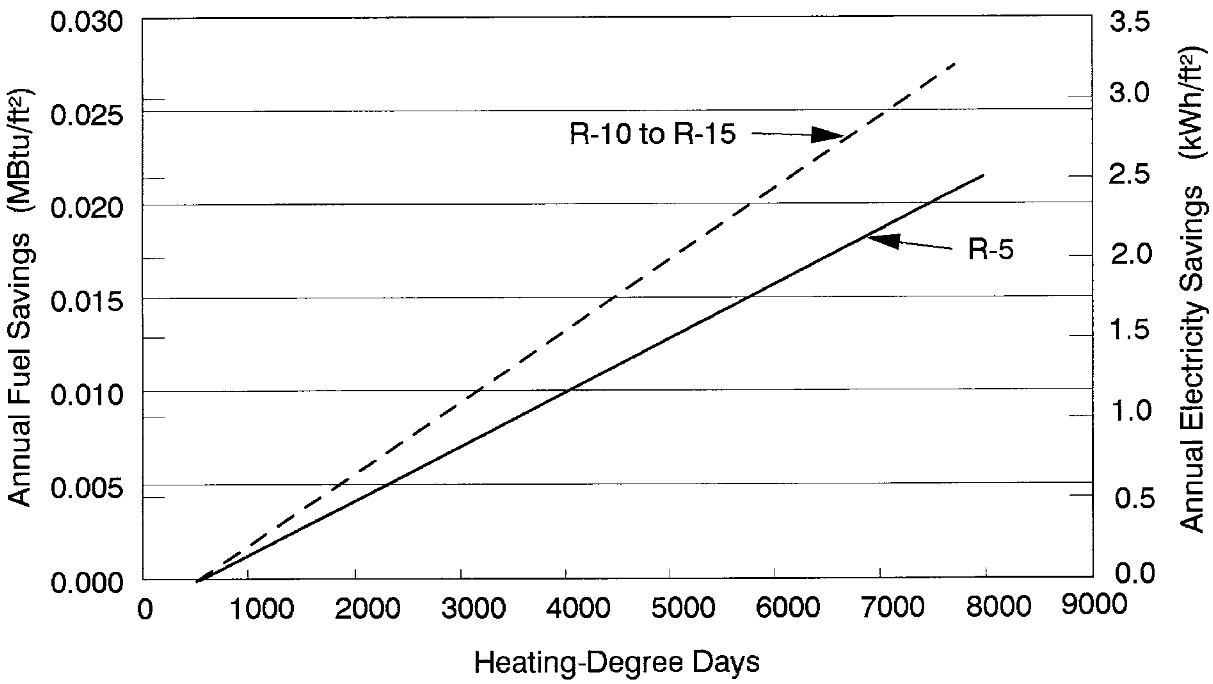

Fig. 4.6. Annual space-heating energy savings per square foot of wall area from installing insulation on the exterior or interior of an uninsulated masonry wall.

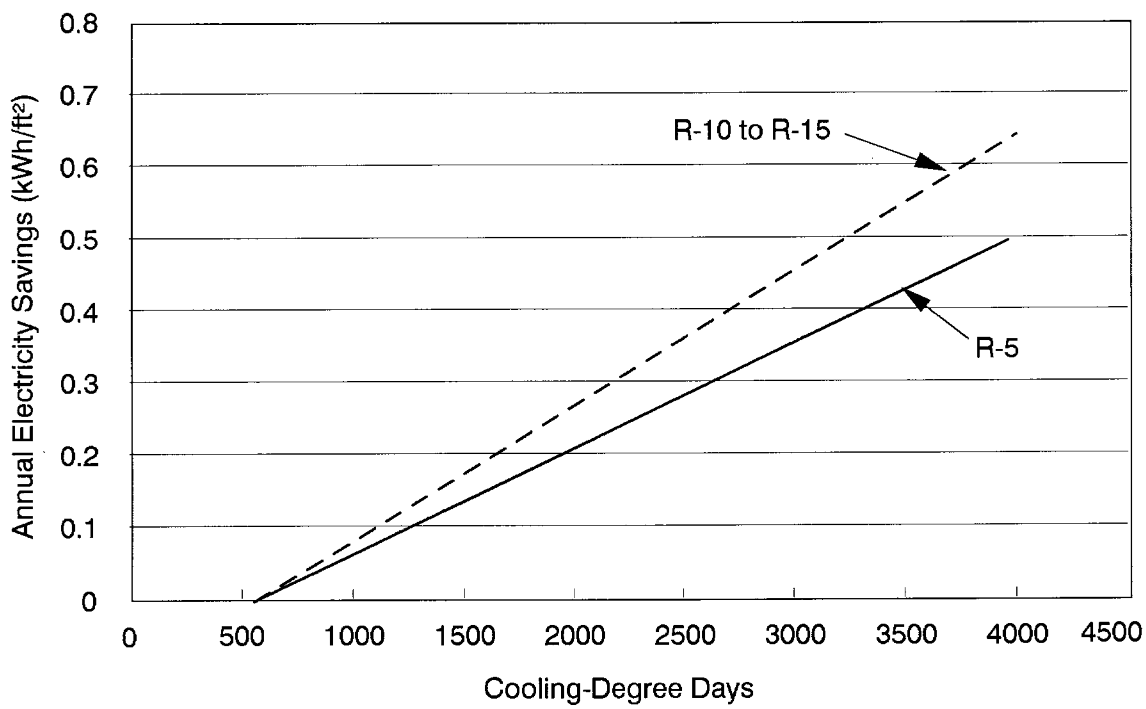

Fig. 4.7. Annual space-cooling electricity savings per square foot of wall area from installing insulation on the exterior or interior of an uninsulated masonry wall.

4.2.4 Foundation Insulation

New foundations added during revitalization should be insulated to the current standards for new construction applicable to the Air Force.

Existing foundations may be underinsulated, causing increased energy loss. Determine existing insulation levels by referring to the observations recorded during the site inspection.

Energy losses from uninsulated foundations can account for 20 to 30% of the space-heating and space-cooling energy used by an average military house. Houses built with uninsulated slab-on-grade foundations are common on Air Force bases. Basements, which are less common, increase the heat loss if the basement walls or ceilings are uninsulated. Crawl spaces are also used in Air Force housing; they are typically uninsulated, increasing energy use.

SLAB-ON-GRADE

Polyurethane insulation and extruded polystyrene insulation treated with a pest- and water-resistant coating are the recommended materials for insulating slab-on-grade perimeters. If the slab perimeter is insulated, no additional insulation will be cost effective. If no slab edge insulation exists, the cost-effectiveness of adding R-5 perimeter slab insulation (assumed to cover the 4–6 in. exposed slab edge and extending down 1.5 ft into the ground) is determined using Figs. 4.8 and 4.9 and Form G.5.

1. The annual space-heating and space-cooling energy savings per linear foot of perimeter length are obtained from Figs. 4.8 and 4.9, using the heating-degree and cooling-degree days for the installation. Note that the cooling savings in Fig. 4.9 are negative. This is because insulation reduces the ability of the slab to “lose heat” to the ground in the summer, increasing the air conditioning requirements.
2. The annual cost savings of the heating and cooling energy savings are calculated using the installation’s costs for fuel, and the present value of the energy savings is calculated using 25-year present worth factors. These values are summed to obtain the total annual cost savings and total present value of the slab insulation savings, respectively.
3. The A/E must determine the total cost of installing the slab insulation per linear foot of perimeter. This cost must include all expenses associated with the improvement, although some expenses may be appropriately assigned to other renovation work. For example, the total cost for slab insulation would be limited to materials and direct installation cost of the insulation alone if excavation around the perimeter is needed as part of the revitalization to fix moisture problems.
4. The slab insulation meets military cost-effective criteria if the SIR is greater than or equal to 1.25 and the SPP is less than or equal to 10.

Enter the level of insulation found in the slab and that to be obtained following revitalization on Form G.17. Calculate the total annual energy savings (space heating combined with space cooling), if any, by multiplying the values obtained from step 1 by the perimeter length to be insulated, multiplying electricity savings (kWh) by 0.003413 to convert to MBtu, and summing. Enter the total annual energy savings on Form G.17.

Seal or caulk the joint between the sill and the slab before applying insulation. Seal any cracks or openings in the slab edge before installation.

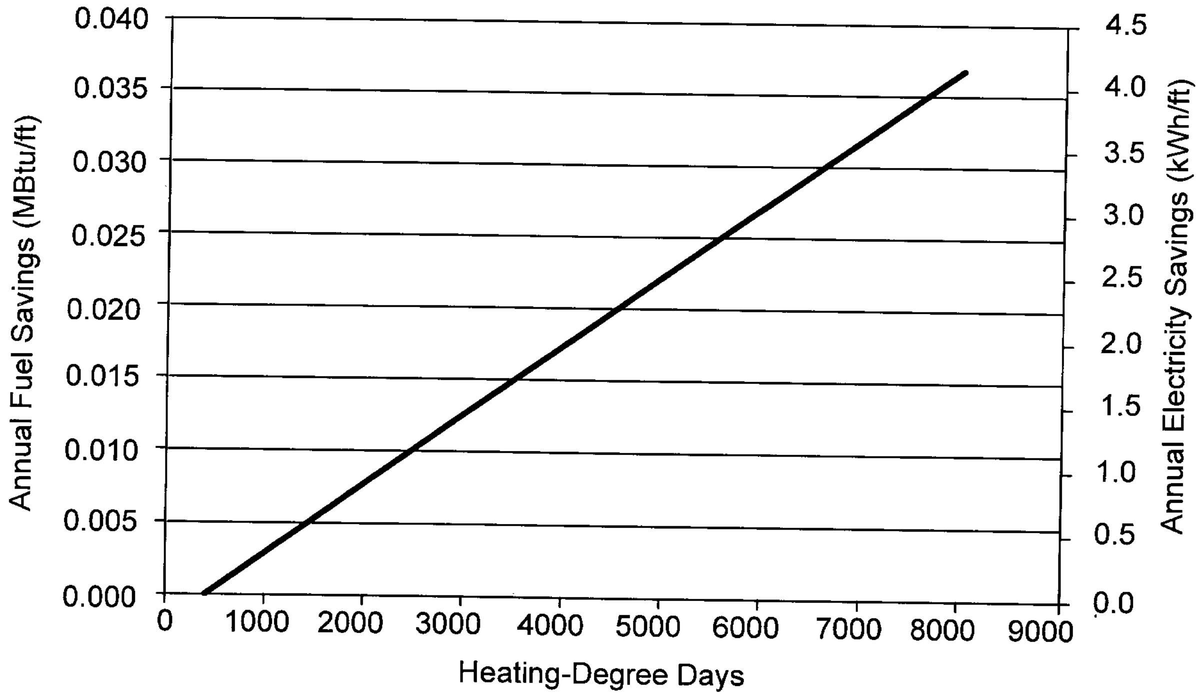

Fig. 4.8. Annual space-heating energy savings per linear foot of perimeter length from installing R-5 insulation on the perimeter of an uninsulated slab foundation.

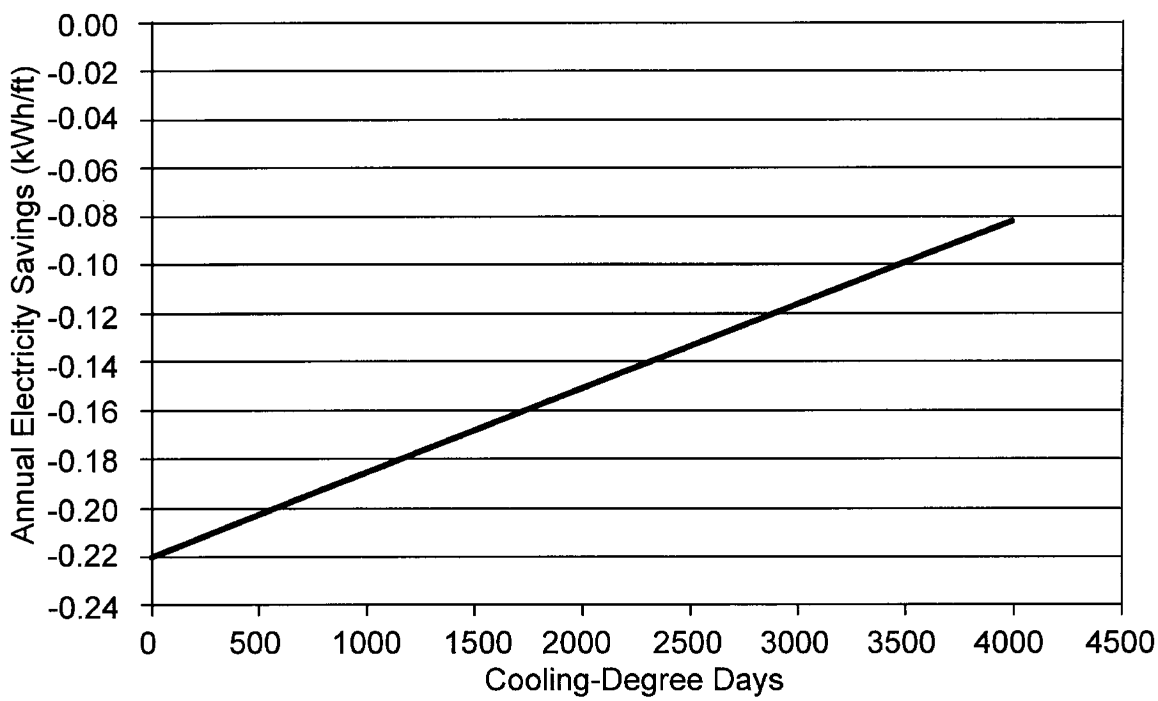

Fig. 4.9. Annual space-cooling electricity savings per linear foot of perimeter length from installing R-5 insulation on the perimeter of an uninsulated slab foundation.

CRAWL SPACE

Crawl space insulation can be located either in the floor joist cavities separating the crawl space from the living area above it or on the crawl space walls.

When the floor over the crawl space (the crawl space ceiling) is to be insulated, batt insulation is recommended because of the low cost, the relative ease of application, and the availability of kraft-paper vapor retarder facing. Insulation levels of R-11, R-19, and R-30 are typical. Install batt insulation with the kraft paper against the subfloor. The insulation is held in place by a friction fit and is further supported with wire hangers. Placing insulation in this location could subject uninsulated water pipes located in the crawl space to freezing and increase the energy loss from uninsulated air distribution ducts located in the crawl space. These problems must be addressed if this application is selected.

An alternative method is to insulate the crawl space walls. The advantage of this approach is that pipes and air distribution ducts located in the crawl space are included within the building thermal envelope, reducing energy loss and freezing potential. The crawl space walls can be insulated on the interior or exterior. Batt insulation, rather than expanded or extruded polystyrene insulation, is recommended for insulation installed on interior crawl space walls because of its lower cost and relative ease of application. The insulation can be attached to the wall using fasteners designed for the type of wall material encountered. Rigid insulation board should be used for exterior insulation. Extruded polystyrene is recommended because of its high R-value, high strength, and relative ease of application in this location.

A vapor barrier must be placed over the ground when the crawl space walls are insulated to reduce the moisture level in the space. A vapor barrier should also be installed on the ground when the crawl space ceiling is insulated as a preventive measure.

Specify insulation levels called for in current Air Force standards and a vapor barrier on the ground for new construction or if the crawl space is currently not insulated in either manner. The A/E selects the insulation approach to be used.

Do not install any additional crawl space insulation if the crawl space walls are already insulated. Also, do not install crawl space wall insulation if the crawl space ceiling is already insulated. Perform the following steps using Figs. 4.10 and 4.11, together with Form G.6, to determine if additional crawl space ceiling insulation is justified when ceiling insulation is already installed.

1. Annual space-heating and space-cooling energy savings (compared with a crawl space with no insulation) for three standard levels of crawl space ceiling insulation (R-11, R-19, and R-30) are provided in Figs. 4.10 and 4.11. The first three steps are to determine the annual cost savings and present value of the *incremental* energy savings from adding crawl space ceiling insulation to bring the existing level to the standard levels. The annual heating savings per square foot of ceiling area is obtained from Fig. 4.10 using the heating-degree days for the installation. Calculate the incremental heating savings of insulation levels above the existing level by subtracting the savings of the existing insulation from the savings for the higher insulation levels.
2. The annual space-cooling electricity savings per square foot of ceiling area is obtained from Fig. 4.11 using the cooling-degree days for the installation. Determine the incremental cooling savings of insulation levels above the existing level using the method described in step 1. Note that the savings on Fig. 4.11 are negative because the insulation reduces the ability of the floor to lose heat to the ground in the summer, increasing the air conditioning requirements.
3. The annual cost savings of the incremental heating and cooling energy savings are

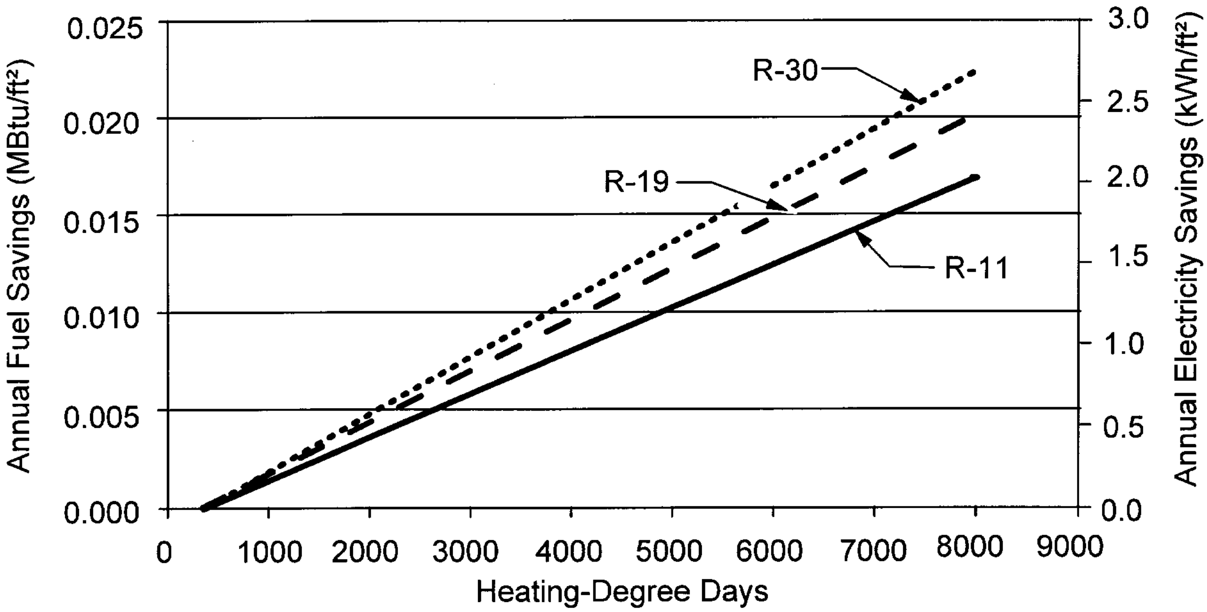

Fig. 4.10. Annual space-heating energy savings per square foot of crawl space ceiling area from installing insulation on the ceiling of an uninsulated crawl space.

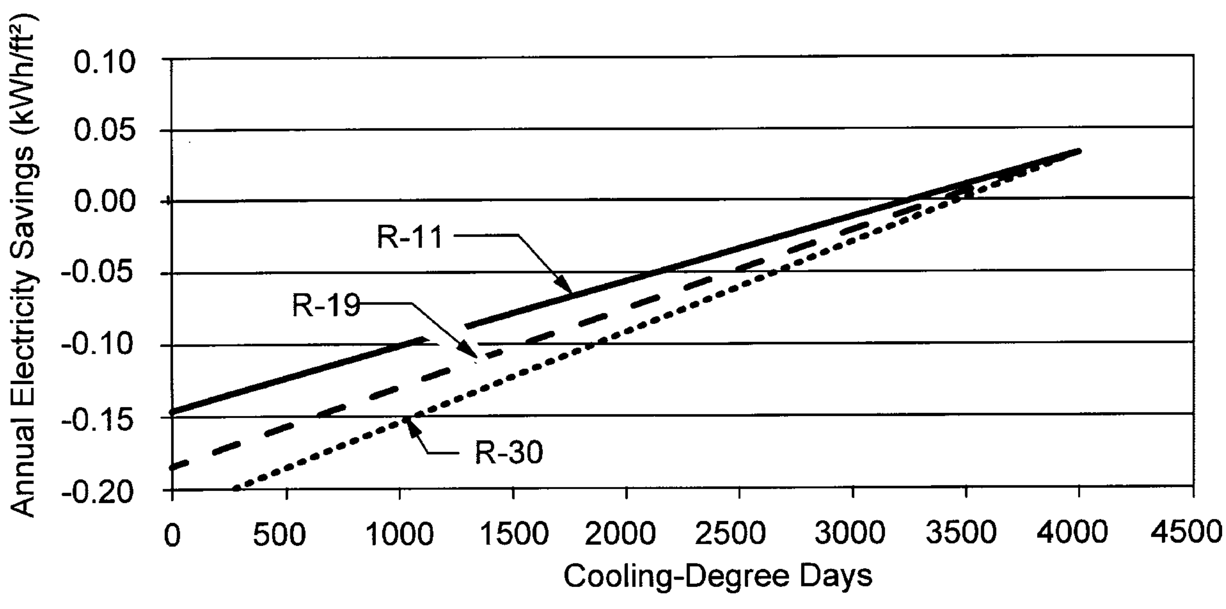

Fig. 4.11. Annual space-cooling electricity savings per square foot of crawl space ceiling area from installing insulation on the ceiling of an uninsulated crawl space.

calculated in Form G.6 using the installation's costs for fuel, and the present value of the energy savings is calculated using 25-year present worth factors. These values are summed to obtain the total annual cost savings and total present value for each insulation level, respectively.

4. The A/E must determine the total cost of installing the incremental amounts of crawl space ceiling insulation per square foot of ceiling area to upgrade to the higher insulation levels. For example, the A/E would determine the cost to add R-8 insulation to achieve a total of R-19 if the current level is R-11. This cost must include all expenses associated with the improvement.
5. An incremental amount of insulation meets military cost-effective criteria if the SIR is greater than or equal to 1.25 and the SPP is equal to or less than 10. If more than one level of insulation meets the cost-effective criteria, select the level with the highest NPV.

Enter the level of insulation existing in the crawl space and that to be obtained by revitalization on Form G.17. If additional crawl space ceiling insulation is added, calculate the total annual energy savings (space heating combined with space cooling) by multiplying the values obtained from steps 1 and 2 by the crawl space ceiling area to be insulated, multiplying electricity savings (kWh) by 0.003413 to convert to MBtu, and summing. If the crawl space is not already insulated, estimate annual energy savings from ceiling insulation using values obtained through the methods outlined in steps 1 and 2 and using Figs. 4.10 and 4.11. Estimate the savings for wall insulation following step 1 and Fig. 4.10 only and still using ceiling areas. Enter the total annual energy savings on Form G.17.

BASEMENT

Basement insulation can be located either in the floor joist cavities separating the basement from the living area above the basement or on the basement walls.

The floor over the basement (the basement ceiling) is the best location if the basement is to be an unconditioned space (with no registers or radiators). Batt insulation is recommended for this application because of its low cost, relative ease of application, and the availability of kraft-paper vapor retarder facing. Insulation levels of R-11, R-19, and R-30 are typical. Install batt insulation with the kraft paper against the subfloor. The insulation is held in place by a friction fit and is further supported by wire hangers or another bridging system. Placing insulation in this location could subject uninsulated water pipes and laundry equipment located in the basement to freezing and increase the energy loss from uninsulated air distribution ducts located in the basement. These problems must be addressed if this approach is selected.

An alternative insulating method is to insulate the basement walls. The advantage of this approach is that pipes and air distribution ducts located in the basement are included within the building thermal envelope, reducing their energy loss and freezing potential. One way to insulate interior basement walls when the basement is a conditioned space is to furr out the walls and create a finished interior wall. The easiest approach is to install batt insulation in the cavities created by 2×4 studs and finish the wall with 1/2-in. gypsum drywall. An alternative is to furr out the walls with 1-in. furring strips, insulate with expanded or extruded polystyrene using a construction adhesive or special wall fasteners, and then apply a fire-rated covering such as 1/2-in. gypsum drywall. Before insulation is installed on the walls of a full basement, cracks or openings along the walls must be sealed. Installation of exterior basement wall insulation as a retrofit is not a cost-effective option.

Specify the insulation levels called for in current Air Force standards for new construction if the basement is not already insulated in either manner. The A/E selects the insulation approach to be used depending on the intended use of the basement.

Do not install any additional basement insulation if the basement walls are already insulated. Also, do not install basement wall insulation if the basement ceiling is already insulated. Perform the five steps outlined for the crawl space ceiling using Figs. 4.12 and 4.13, together with Form G.6, to determine if additional basement ceiling insulation is justified when ceiling insulation is already installed in this location.

Enter the level of insulation found in the basement and that to be obtained from revitalization on Form G.17. If additional basement ceiling insulation is being added, calculate the total annual energy savings (space heating combined with space cooling) by multiplying the values obtained from Figs. 4.12 and 4.13 by the basement ceiling area to be insulated, multiplying electricity savings (kWh) by 0.003413 to convert to MBtu, and summing. If the basement is not already insulated, estimate annual energy savings from ceiling insulation using values obtained from using Figs. 4.12 and 4.13. Estimate the savings for wall insulation using Fig. 4.12 only and still using ceiling areas. Enter the total annual energy savings on Form G.17.

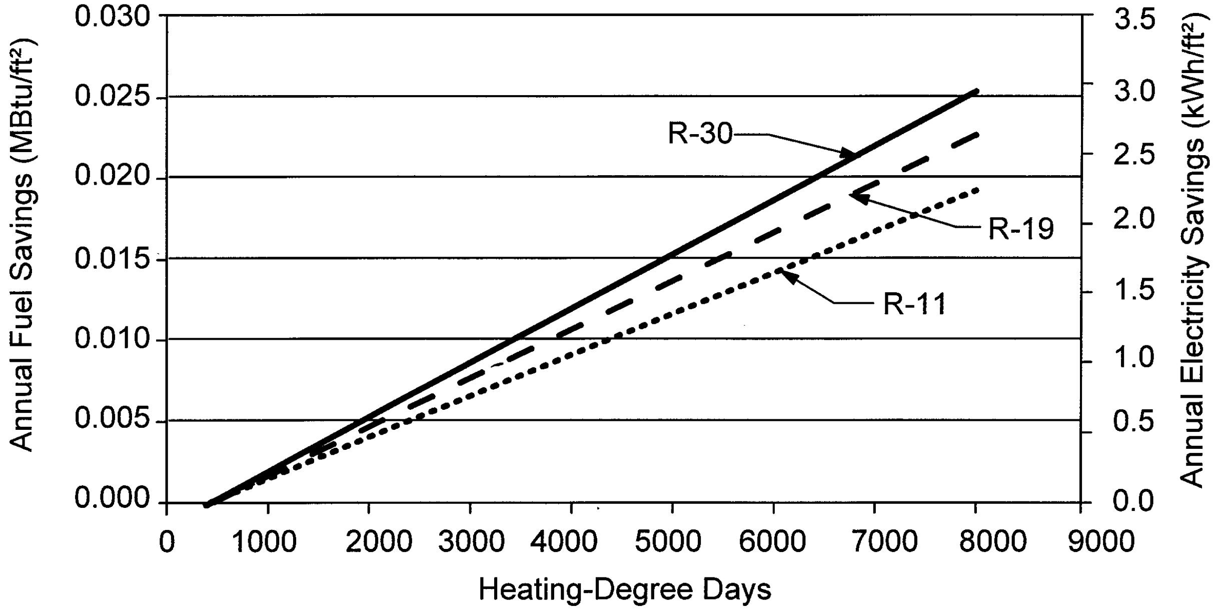

Fig. 4.12. Annual space-heating energy savings per square foot of basement ceiling area from installing insulation on the ceiling of an uninsulated basement.

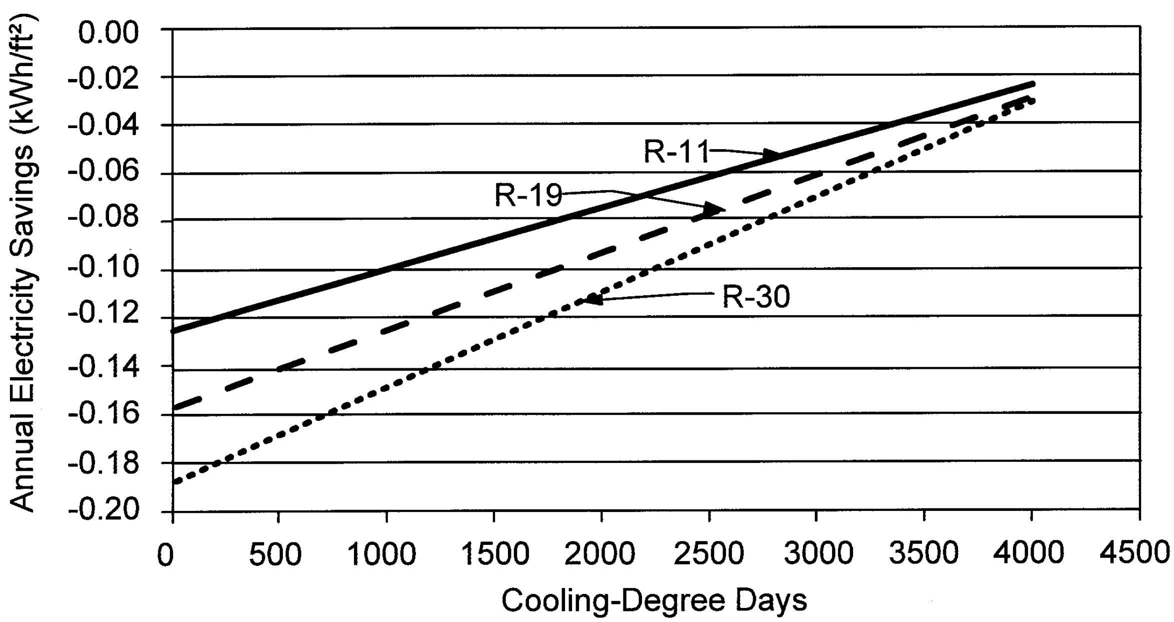

Fig. 4.13. Annual space-cooling electricity savings per square foot of basement ceiling area from installing insulation on the ceiling of an uninsulated basement.

4.2.5 Ceiling or Attic Insulation

New ceilings or attics added during revitalization should be insulated to the current standards for new construction applicable to the Air Force.

Existing ceilings or attics may be underinsulated, causing increased energy loss. Determine existing insulation levels by referring to the observations recorded during the site inspection. Most attic areas in Air Force housing have some level of insulation.

If the existing insulation is in good condition and is uniformly distributed, retain it unless other factors in the revitalization project dictate its removal.

If there is no insulation, or if the requirements of the revitalization project dictate its removal, install attic insulation to levels (R-value) that conform to the current Air Force standard for new construction.

If the attic is an unconditioned space and the attic floor is unfinished, it is usually easiest to add insulation by blowing in additional fiberglass or cellulose. If the attic is an unconditioned space and the attic floor is finished, it is usually easiest to insulate by drilling holes into the finished floor and blowing fiberglass or cellulose into the cavities.

Perform the following steps using Figs. 4.14 and 4.15 with Form G.7 to determine if additional insulation should be added to the existing levels.

1. Annual space-heating and space-cooling energy savings (compared with an attic with no insulation) for five standard levels of attic insulation (R-11, R-19, R-30, R-38, and R-49) are provided in Figs. 4.14 and 4.15. The first three steps are to determine the annual cost savings and present value of the *incremental* energy savings from adding attic insulation to bring the existing level to the standard levels. The annual heating savings per square foot of attic area is obtained from Fig. 4.14 using the heating-degree days for the installation. Calculate the incremental heating savings of insulation levels above the existing level by subtracting the savings of the existing insulation from savings for the higher insulation levels.
2. The annual space-cooling electricity savings per square foot of ceiling area is obtained from Fig. 4.15 using the cooling-degree days for the installation. Determine the incremental cooling savings of insulation levels above the existing level in the manner described in step 1.
3. The annual cost savings of the incremental heating and cooling energy savings are calculated in Form G.7 using the installation's costs for fuel, and the present value of the energy savings is calculated using 25-year present worth factors. These values are summed to obtain the total annual cost savings and total present value for each insulation level, respectively.
4. The A/E must determine the total cost of installing the incremental amounts of attic insulation per square foot of attic area to upgrade to the higher insulation levels. For example, the A/E would determine the cost to add R-8 insulation to achieve a total of R-19 if the current level is R-11. This cost must include all expenses associated with the improvement, such as increased attic ventilation, baffles (soffit dams), and access hatches.
5. An incremental amount of insulation meets military cost-effective criteria if the SIR is greater than or equal to 1.25 and the SPP is less than or equal to 10. If more than one level of insulation meets the cost-effective criteria, select the level with the highest NPV.

Enter the level of existing insulation and of that to be obtained from revitalization on Form G.17. If additional attic insulation is being

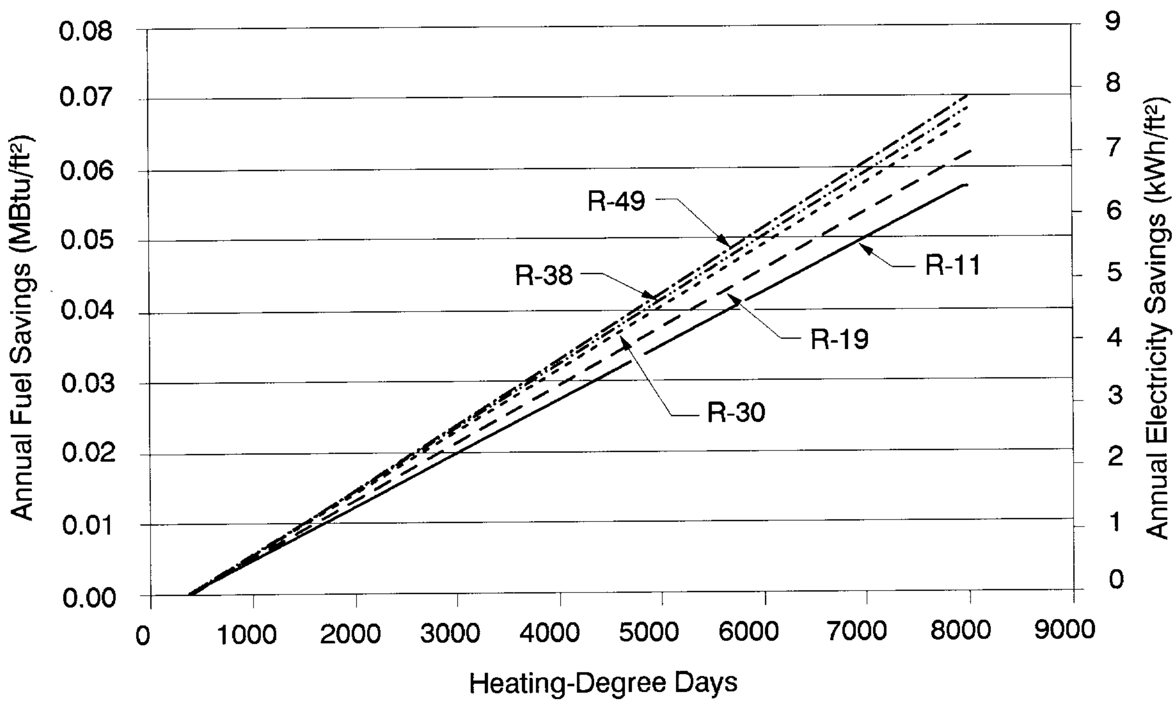

Fig. 4.14. Annual space-heating energy savings per square foot of attic floor area from installing insulation on the floor of an uninsulated attic.

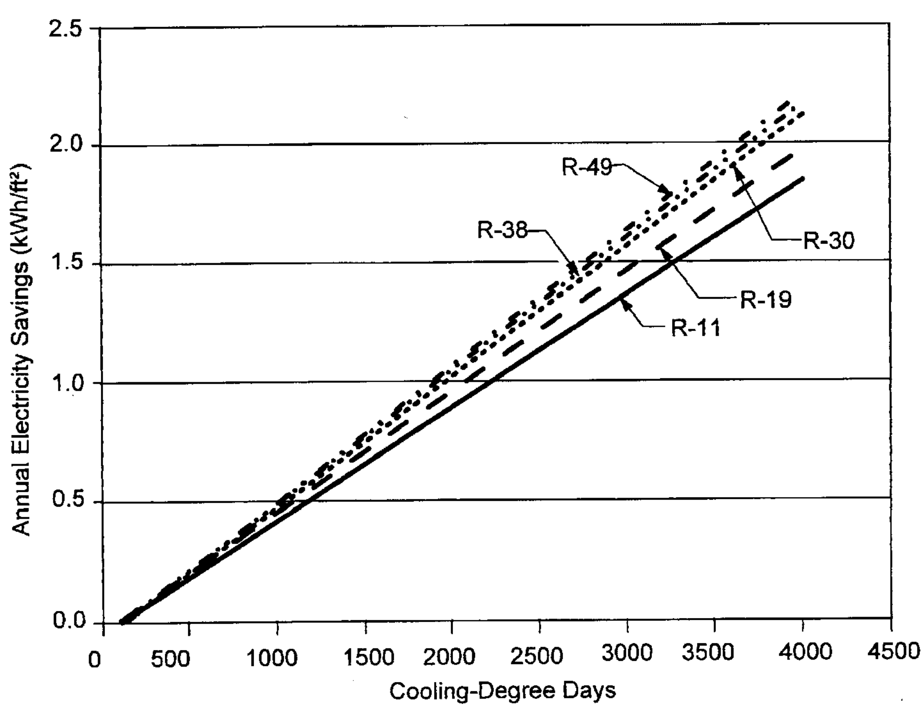

Fig. 4.15. Annual space-cooling electricity savings per square foot of attic floor area from installing insulation on the floor of an uninsulated attic.

installed, calculate the total annual energy savings (space heating combined with space cooling) by multiplying the values obtained from steps 1 and 2 by the attic area to be insulated, multiplying electricity savings (kWh) by 0.003413 to convert to MBtu, and summing. If the attic is not insulated, estimate annual energy savings from new attic insulation using values obtained from following the methods outlined in steps 1 and 2, and using Figs. 4.14 and 4.15. Enter the total annual energy savings on Form G.17.

Perform air-leakage reduction work (e.g., sealing attic bypasses and interior partition walls) and air distribution system repairs in the attic (see Sects. 4.2.6 and 4.2.15) before adding insulation. Be sure that new or existing insulation does not block soffit vents by installing ventilation baffles (soffit dams) before adding insulation as necessary. Also, ensure that attics are adequately ventilated, especially when housing units are air conditioned. Ventilation guidelines are provided in Chapter 2 of the 1993 *American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Handbook—Fundamentals*.

4.2.6 Infiltration

Detached dwelling units for which revitalization entails “gutting” throughout must meet prescriptive air-leakage performance criteria. The air-leakage performance of these housing units following revitalization must fall within a prescribed range of air changes per hour (ACH) for the conditioned volume of the unit.

The minimum ACH value for a detached housing unit is a function of its number of bedrooms and conditioned floor area and can be found from Table 4.1. The value is based on the minimum ventilation required to provide adequate fresh air to remove indoor pollutants and moisture from typical residences as specified in ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality*. ASHRAE recommends an average ventilation airflow rate from natural infiltration and forced ventilation (exhaust fans) of 15 cfm per occupant, or a minimum air change rate of 0.35 per hour.

The maximum value for a detached housing unit is either the value obtained from Table 4.2 or the minimum value plus 0.3 ACH, whichever is greater. The value obtained from Table 4.2 is a function of the local climate and is found after determining the infiltration degree-days for the housing location using Appendix H (Table H.2). The value obtained from Table 4.2 is based on reducing the air infiltration load on the housing unit as specified in ASHRAE Standard 119-1988, *Air Leakage Performance for Detached Single-Family Residential Buildings*. The use of a value 0.3 ACH greater than the minimum value is needed to provide a reasonable range that reflects the limits of

Table 4.1. Minimum air changes per hour

Housing unit conditioned floor area (ft^2)	Number of bedrooms			
	2	3	4	5
600	0.75	0.94	1.13	1.31
700	0.64	0.80	0.96	1.13
800	0.56	0.70	0.84	0.98
900	0.50	0.63	0.75	0.88
1000	0.45	0.56	0.68	0.79
1100	0.41	0.51	0.61	0.72
1200	0.38	0.47	0.56	0.66
1300	0.35	0.43	0.52	0.61
1400	0.35	0.40	0.48	0.56
1500	0.35	0.38	0.45	0.53
1600	0.35	0.35	0.42	0.49
1700	0.35	0.35	0.40	0.46
1800	0.35	0.35	0.38	0.44
1900	0.35	0.35	0.36	0.41
2000	0.35	0.35	0.35	0.39
2100	0.35	0.35	0.35	0.38
2200	0.35	0.35	0.35	0.36
2300 and above	0.35	0.35	0.35	0.35

Table 4.2. Maximum air changes	
Infiltration degree-days (°F-day)	Maximum air changes per hour
<2250	1.60
2250–3182	1.60
3183–4500	1.13
4501–6364	0.80
>6365	0.65

construction practices in closely controlling building infiltration.

Compliance with this criteria shall be verified through performance testing of a randomly selected sample of housing units. A compliance testing procedure is provided in Sect. 5.3, "Infiltration Performance Testing of Housing Units," and shall be specified in the construction design package by the A/E. This procedure relies on the measurement procedure specified in Appendix C. Although the means of meeting the air-leakage criteria are left to the construction contractor, infiltration-reduction concepts used in new construction (Table 3.1) are applicable and should be included in the construction design package by the A/E. Additionally, common air-leakage problems as described in Appendix D must be avoided, and techniques needed to seal building envelope penetrations as described in Sect. 5.2, "Infiltration Repair Specifications and Construction Tips," will be needed and should also be included in the construction design package by the A/E.

Criteria for attached dwelling units that will be gutted throughout cannot be specified because air-leakage criteria and test procedures for this type housing are not generally developed or accepted. Infiltration-reduction concepts used in new construction (Table 3.1) are applicable and should be conveyed in the design package by the A/E. Additionally, common air-leakage problems as described in Appendix D must be avoided, and techniques needed to seal building envelope penetrations as described in Sect. 5.2, "Infiltration Repair Specifications and Construction Tips," will be needed and should also be included in the construction design package by the A/E.

Housing units (detached or attached) in which a significant portion of the exterior envelope and current interior configuration will be retained during revitalization must have the major air-leakage deficiencies identified by the blower-door inspection repaired and sealed. The natural infiltration rate for detached housing units was estimated as part of the blower-door inspection. Little air-sealing work will be specified if the current infiltration rate is close to the minimum values identified in Table 4.1 to avoid overtightening the housing unit. Repair specifications for air-leakage reduction options are provided in Sect. 5.2, "Infiltration Repair Specifications and Construction Tips."

To document the air-leakage analysis for all revitalized housing, enter the initial leakage rate (in units of cfm50) obtained from the blower-door inspection of the housing unit on Form G.17. If a blower-door inspection was not performed, enter a leakage rate of 1800 cfm50 if a minimal number of major infiltration leakage areas were visible during the field inspection or a rate of 2500 cfm50 otherwise. For the purpose of completing Form G.17, calculate the potential energy savings for this measure as follows:

1. Determine the space-heating energy savings from Fig. 4.16 using the heating-degree

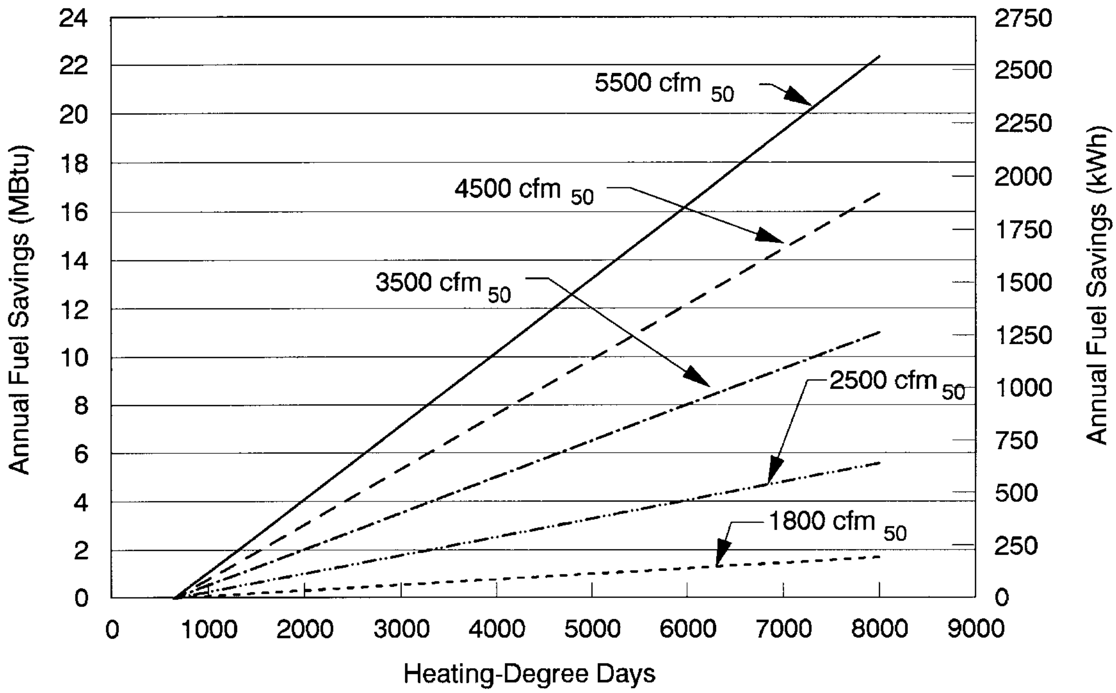

Fig. 4.16. Potential annual space-heating energy savings from air-leakage mitigation.

days for the installation and the initial leakage rate of the housing unit.

2. Determine the space-cooling energy savings from Fig. 4.17 using the cooling-degree days for the installation and the initial leakage rate of the housing unit. Convert this value to MBtu by multiplying by 0.003413.
3. Sum and enter the energy savings from steps 1 and 2 on Form G.17.

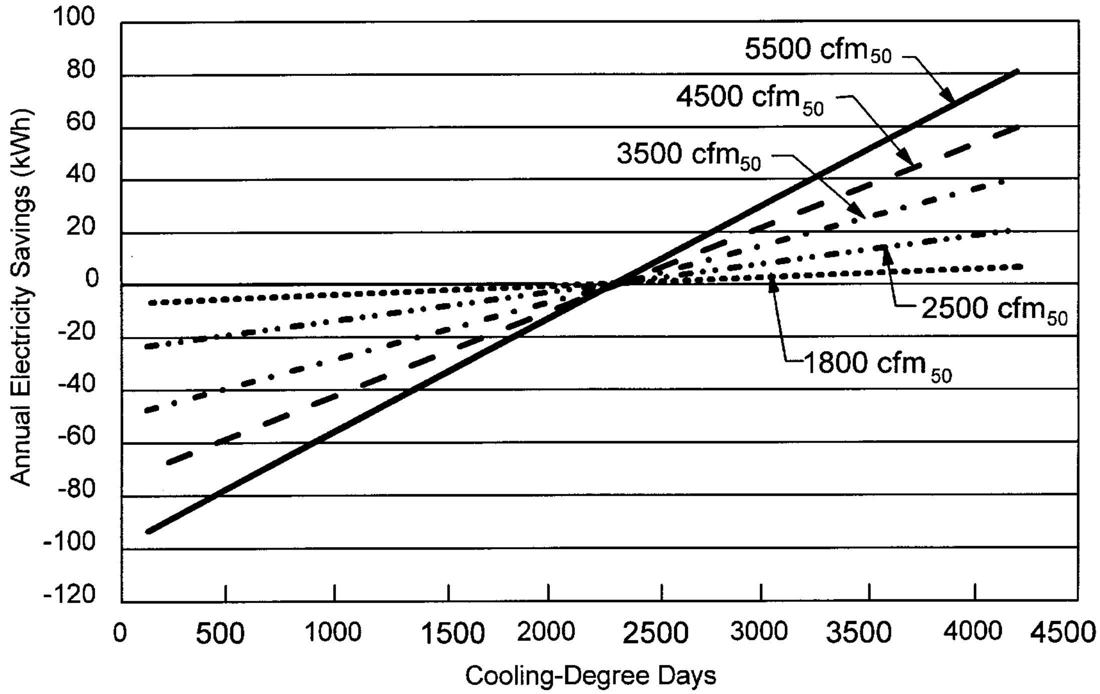

Fig. 4.17. Potential annual space-cooling electricity savings from air-leakage mitigation.

4.2.7 Roofing

The replacement of roofing as part of revitalization offers the opportunity to change the characteristics of the new roof. Changing from a low- to a high-reflectivity roof can lower cooling energy consumption on structures with low levels of attic insulation. In heating-dominated climates however, this increased reflectivity can increase heat energy consumption, offsetting any cooling savings.

The attic insulation levels achieved in revitalizing Air Force housing will be well above the level at which increased reflectivity significantly reduces cooling energy consumption. Standard shingle colors, despite their visual differences, do not have a significant difference in reflectance. To obtain the increase in reflectivity required to markedly reduce energy consumption, it would be necessary to coat the new or existing roof with a reflective material. This process is still under development and evaluation and is not currently cost effective.

A roof (or its shingle) with a rated reflectance value of 0.3 or greater can be classified as a light-colored roof and may reduce cooling energy consumption to a small degree. This can typically be met only by light-colored metal roofs and white shingle roofs in an area not subject to mildew growth.

When ducts are located in the attics of housing units in cooling-dominated climates (see locations where heat pumps are generally allowed in Fig. 4.18 as an indication of a cooling-dominated climate), it is desirable to reduce the attic air temperature. This can be accomplished by proper ventilation and use of light-colored roofs as previously described. This no-cost change may reduce the potential energy loss through the duct system.

Although reducing attic temperature can reduce the potential energy loss through ducts, the key factors in duct performance are that they be well sealed and appropriately insulated (see Sect. 4.2.15).

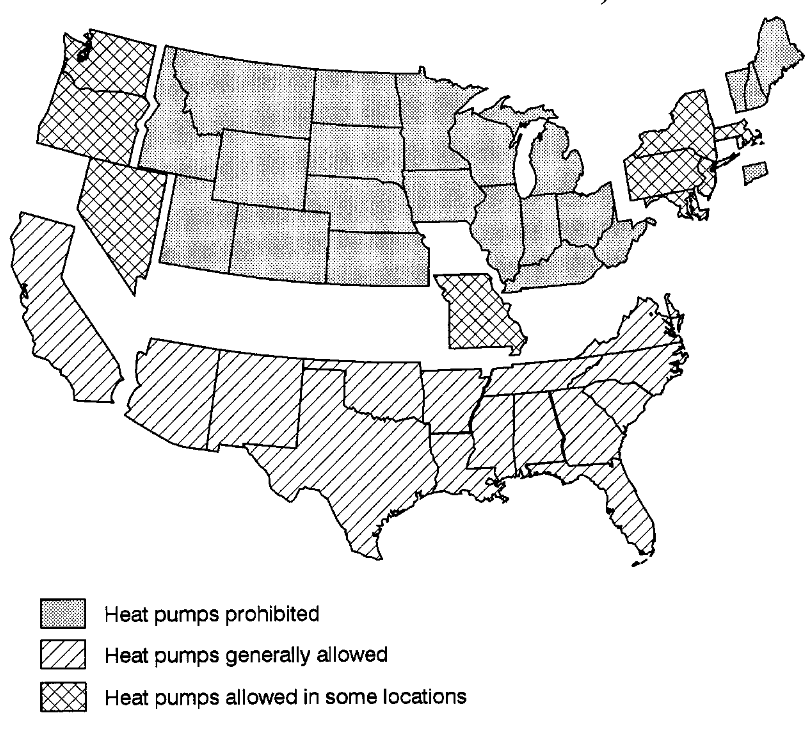

Fig. 4.18. Guidelines on use of heat pumps.

4.2.8 Windows

SPECIFICATION OF NEW WINDOWS

Although windows can be a major cause of energy loss in homes, they should not automatically be replaced during a revitalization project. In fact, the need for new windows must be warranted by the A/E based on architectural considerations rather than on energy savings because energy savings are insufficient to justify the cost of window replacement (removal of the existing window plus buying and installing the new window).

Architectural considerations that warrant window replacement include the following:

- existing windows are no longer functional (have no remaining life),
- existing windows no longer fit the architectural style of the renovated housing unit, or
- wall renovation requires additional windows or windows of a different size.

Keep in mind that many of the original windows in older Air Force family housing have already been replaced with energy-efficient units and may have additional useful life. Other inspections of the housing unit performed by the A/E as part of the revitalization effort, rather than the inspection outlined in this document, are relied on to determine the need for new windows based on architectural considerations.

In determining the functionality of existing wood windows, especially ones in marginal condition, keep in mind that wood windows can usually be repaired. Consider evaluating the long-term maintenance costs before doing so. There are essentially three types of repair:

1. A wood replacement sash can be installed if the sash is rotted or the joints are loose or broken. Although a replacement sash can cost as much as a new window, it will save a great deal of labor compared with removing the entire existing window and installing a replacement. Installing a replacement sash requires 2 to 4 hours. Follow the procedure outlined in this section under “Selection of Replacement Window Options” to select the proper window type.
2. A cabinetmaker or finish carpenter can usually rebuild the window in about 4 hours if the window is hard to open, is loose (it rattles when locked), or doesn’t lock properly but the wood in the sash, jambs, and sill is still in good condition. This rebuilding will be less expensive than replacing the sash or the entire window.
3. Repairs can be made by a competent painter if the paint on the sash is peeling or the glass is loose but the window opens, closes, and locks easily. Old paint can be stripped, loose glazing reset, and the sash repainted to extend the useful life of the window.

While multipane glazing is a primary component of an energy-efficient window, single-pane glazing in the existing window alone is not an appropriate reason to specify replacement. Storm windows are available to economically enhance the energy efficiency of existing single-pane windows, especially in very cold climates. Existing windows that are single glazed but otherwise functional should be retained unless other reasons warrant replacement such as excessive condensation or icing on the interior surfaces (although the solution may be to correct the excessive moisture problem rather than the window). The addition of storm windows to single-glazed windows should be evaluated as described later in this section.

Vinyl, fiberglass, and wood are all nonmetallic and relatively nonconductive materials that are well suited to making energy-efficient windows. Vinyl- and fiberglass-framed windows have lower maintenance characteristics than wood windows, although many wooden windows are clad with aluminum or vinyl to reduce maintenance. Steel and aluminum (metallic materials) are excellent conductors and therefore intrinsically poor choices for the frame material of energy-efficient windows. Some metallic windows have a thermal break (outer and inner sections connected by an insulator) that reduces this problem. Take care during the inspection process that an aluminum-clad wooden window is not mistaken for an all-aluminum window. Although new windows should not be specified because existing windows are inefficiently framed, consider the presence of inefficient framing in determining the functionality and remaining useful life of the existing window. This includes considering condensation and icing problems caused by the framing.

SELECTION OF REPLACEMENT-WINDOW OPTIONS

When new windows are needed or existing windows need to be replaced because of architectural considerations, specify a double-glazed low-E window with either a vinyl or fiberglass frame, or wood frame clad with aluminum or vinyl to be consistent with U.S. Air Force standards for new construction. The low-E coating must have an emissivity value less than 0.40.

Enter the type of window already installed and the type to be installed during revitalization on Form G.17. To determine the heating and cooling savings from the new windows, perform the following steps using Figs. 4.19 and 4.20 and Form G.8.

1. Annual space-heating energy savings per square foot of window area for various types of windows (compared with a single-glazed window with a metal frame) are provided in Fig. 4.19. The annual heating savings per square foot of window area is obtained from Fig. 4.19 using the heating-degree days for the installation. Calculate the heating savings of the new window by subtracting the savings of the existing window from those for the new window.
2. The annual space-cooling electricity savings per square foot of window area is obtained from Fig. 4.20 using the cooling-degree days for the installation. Determine the cooling savings of the new window in the manner described in step 1.
3. Calculate the total annual energy savings by multiplying the combined space-heating and space-cooling savings (after converting space-cooling savings from kWh to MBtu by multiplying by 0.003413) by the new window area to be installed. Enter the total annual energy savings on Form G.17.

STORM WINDOWS

Although the popularity of storm windows has declined as primary windows have improved, storm windows still provide a relatively inexpensive means to improve the energy efficiency of single-glazed windows and reduce condensation and icing problems. Like primary windows, storm windows tend to wear out over time. Storm windows that are no longer functional (poorly fitting or damaged) should be replaced automatically.

Unlike prime windows, storm windows are easy to install. It takes no more than half an hour to install a storm window, and generally a high-quality storm window costs less than 25% of the cost of a new energy-efficient window. Therefore, it may be economical to install storm windows on existing single-glazed windows when it is not economical to replace them with new windows.

The cost-effectiveness of installing storm windows can be determined by using Fig. 4.21 and Form G.9.

1. Figure 4.21 provides the annual space-heating energy savings per square foot of window area for storm windows installed on single-glazed windows with metal frames (with no thermal break) and single-glazed

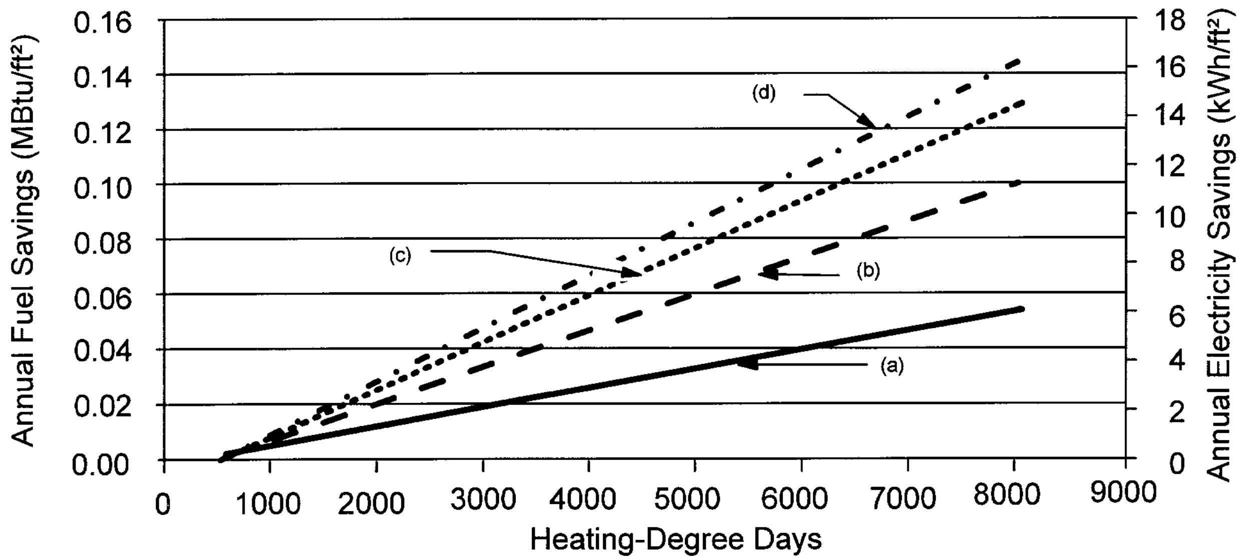

Fig. 4.19. Annual space-heating energy savings per square foot of window area from installing higher-efficiency windows compared with a single-glazed window with a metal frame. Savings are for windows that are (*a*) double-glazed with a metal frame or single-glazed with a nonmetallic frame; (*b*) double-glazed with a thermally broken metal frame; (*c*) triple-glazed with a thermally broken metal frame, double-glazed with a nonmetallic frame, or double-glazed with a thermally broken metal frame and low-E coating; and (*d*) triple-glazed with a nonmetallic frame or double-glazed with a nonmetallic frame and low-E coating.

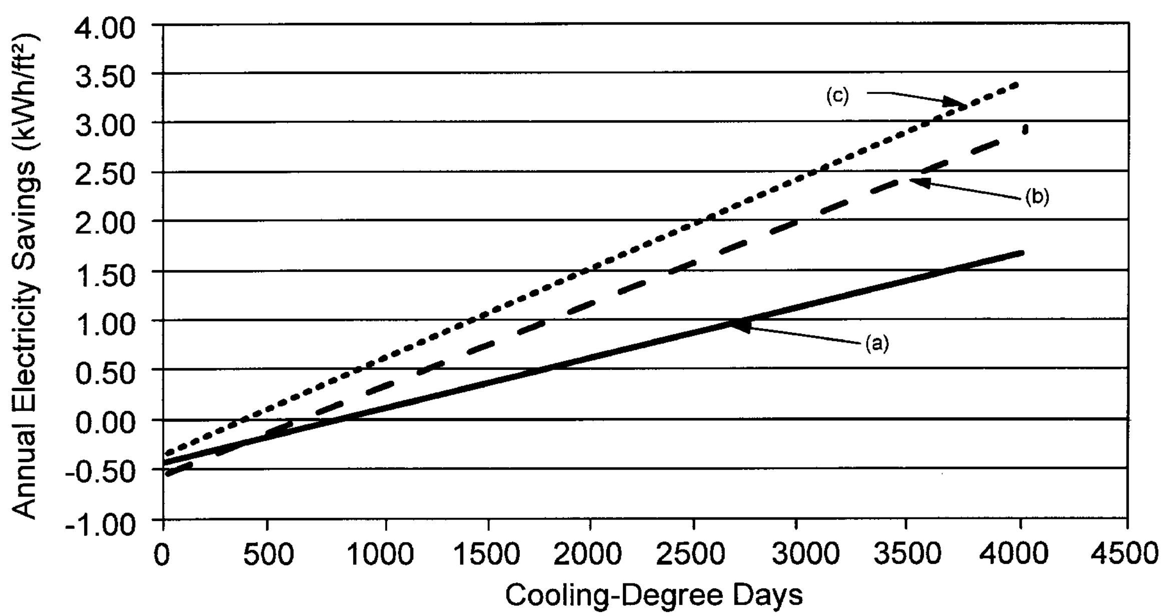

Fig. 4.20. Annual space-cooling electricity savings per square foot of window area from installing higher-efficiency windows compared with a single-glazed window with a metal frame. Savings are for windows with nonmetallic frames or metal frames with a thermal break and that are (*a*) double-glazed, (*b*) triple-glazed, and (*c*) double-glazed with a low-E coating.

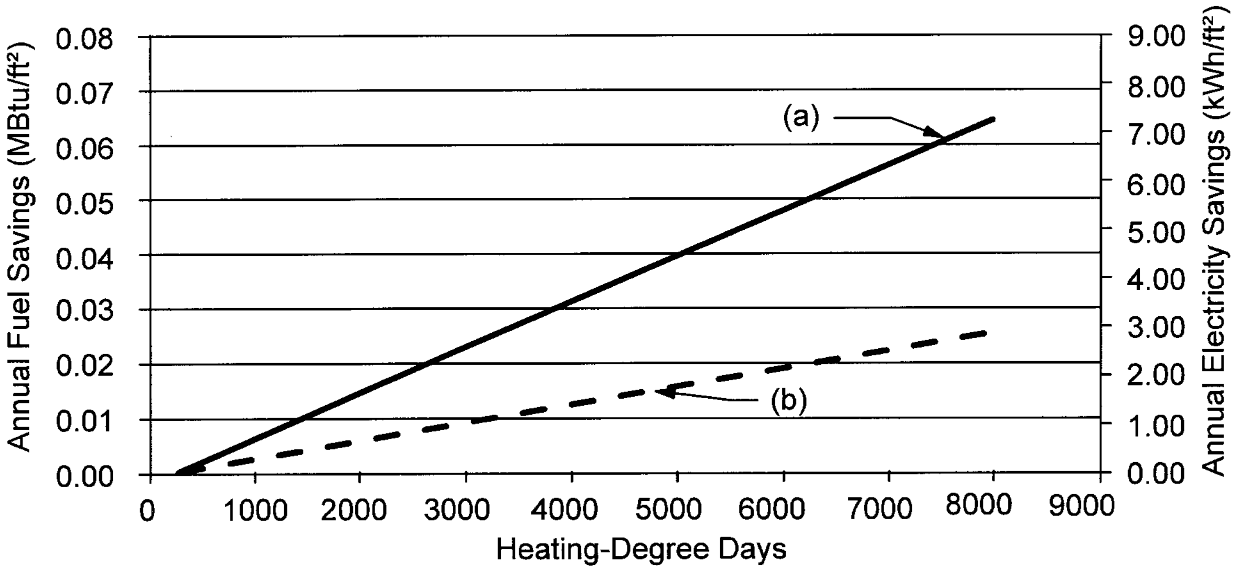

Fig. 4.21. Annual space-heating energy savings per square foot of window area from installing storm windows on single-glazed windows with (*a*) metal frames without a thermal break and (*b*) nonmetallic frames and metal frames with a thermal break.

windows with nonmetallic frames or those with thermal breaks.

2. The annual space-cooling energy savings per square foot of window area is obtained from curve (a) of Fig. 4.20.
3. The annual cost savings of the heating and cooling energy savings is calculated in Form G.9 using the installation's costs for fuel, and the present value of the energy savings is calculated using a 25-year present worth factor.
4. The A/E must estimate the total cost to purchase and install the storm window per square foot of window area.
5. The storm window meets military cost-effective criteria if the SIR is greater than or equal to 1.25 and the SPP is less than or equal to 10.

Note the presence of a storm window on Form G.17, as well as whether a storm window will be installed during revitalization. Calculate the annual space-heating energy savings by multiplying the savings obtained from step 1 by the window area to receive storm windows. Enter this savings on Form G.17.

4.2.9 Doors

OPAQUE EXTERIOR DOORS

It is not cost effective to replace existing opaque exterior doors that are in adequate condition on the basis of potential energy savings. However, weather stripping and thresholds should be replaced if they are determined to be worn or near the end of their service life during the site inspections.

When revitalization requires replacing the exterior doors, a U.S. Air Force standard 1 3/4-in.-thick insulated metal door with a thermal break or a solid-core wood door will provide satisfactory thermal performance. Ensure that all replacement doors are thoroughly weather-stripped and have an appropriate threshold to reduce infiltration.

Screen and self-storing storm doors are required on all exterior hinged doors. An existing storm door in adequate condition (including weather stripping) may be retained. Replace storm doors in deficient condition with new storm doors conforming to current military service standards for new construction.

GLASS EXTERIOR DOORS

New or replacement glass exterior doors (sliding or French) must be warranted for architectural reasons similar to those discussed for windows. As with windows, specify a double-glazed glass door with low-E glass, with either a vinyl or fiberglass frame or wood frame clad with aluminum or vinyl, when a new glass exterior door is needed.

Enter the type of glass exterior door already installed in the housing unit and the type to be installed during revitalization on Form G.17. Determine the total annual energy savings using Form G.10 and the same procedure discussed in Sect. 4.2.8, "Windows."

Replace weather stripping if it is worn or near the end of its service life in all cases.

4.2.10 Heating and Cooling Equipment Replacement Options

Space-heating and space-cooling equipment may be replaced as part of revitalization because resulting energy savings can be obtained cost effectively or because replacement is needed for reasons not related to energy. The first step is to determine the types of equipment most appropriate for the installation and housing unit, although replacement systems will generally be of the same type and use the same fuel as the original equipment.

There are no restrictions on the use of gas- and oil-fired furnaces and boilers.

Air conditioning is provided primarily by central-type systems, although evaporative coolers are used. For Air Force bases, air conditioning is restricted to locations where ambient temperatures during the six warmest months are greater than one of the following:

- 67°F wet-bulb for more than 800 hours,
- 80°F dry-bulb for more than 350 hours, or
- 93°F dry-bulb for more than 155 hours.

Air Force guidelines prohibit the use of air conditioning in Maine, Vermont, New Hampshire, and Alaska but allow its use at some bases in all remaining states (see Fig. 4.22). The necessity for air conditioning should not be assumed if these guidelines are met. Rather, in borderline locations (especially installations in the northernmost and westernmost states), mechanical or natural ventilation should be provided when analysis shows that comfort can be maintained without air conditioning.

Design considerations should be carefully reviewed to eliminate the need for mechanical air conditioning wherever possible, especially in borderline locations. Design considerations include locating carports on southwest and west sides of units, reducing the window area on west and southwest exposures, using reflective or tinted glazings if they are cost effective, using trees and plantings, and using shading devices. Orientation considerations are difficult to implement because generic housing types at installations face random directions, so universal designs cannot be developed. Attics of housing units with air conditioners should be ventilated adequately. Ventilation guidelines are provided in Chapter 2 of the 1993 *ASHRAE Handbook—Fundamentals*.

Use of heat pumps is restricted to locations with heating design temperatures (97.5% basis) greater than 12°F and with less than 5000 heating-degree days. Heat pumps are generally applicable in all southern states (except in some high-altitude locations) and can be used in selected parts of some western and eastern states as indicated in Fig. 4.18; heat pump use is prohibited in most northern states.

Ground-source heat pumps are gaining popularity as efficient space-conditioning systems, but they remain a relatively new technology and have not yet received extensive application. Therefore, ground-source heat pumps are not addressed in this guide and should not be installed unless part of a technology demonstration program.

Electric resistance space heating (except supplemental heating required for heat pumps) should be avoided except where special circumstances dictate.

Conversion to alternate fuels should be seriously considered to reduce heating costs and to standardize the type of fuel used for space heating and for other purposes in the house and at the installation. This decision must be based on life-cycle cost analysis and must be made at the base rather than the house level because of the variety of issues involved, such as utility infrastructure and environmental concerns. Switching from electricity or oil to natural gas is generally the more common conversion.

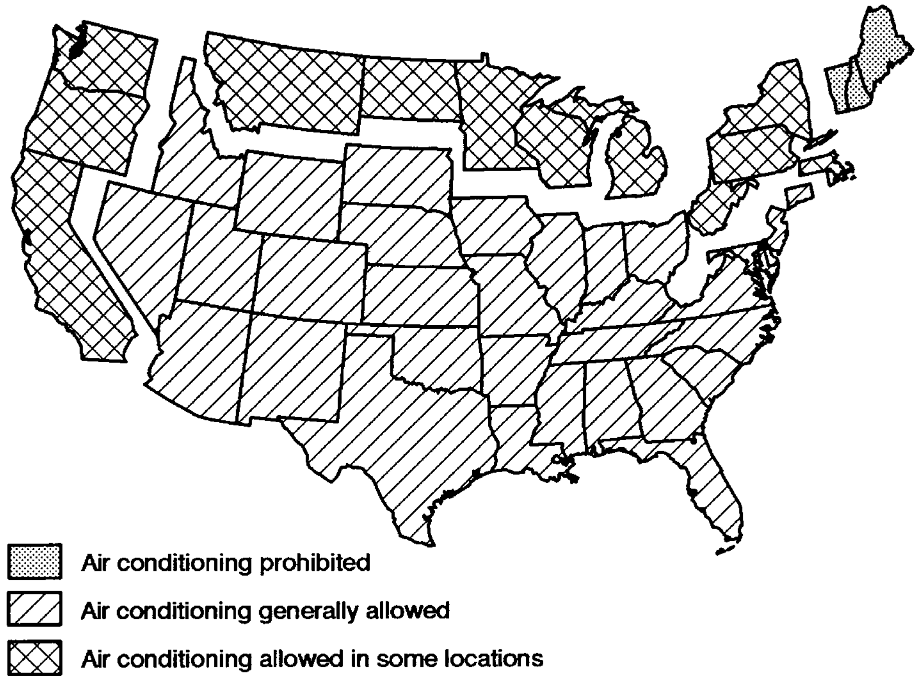

Fig. 4.22. Air Force guidelines on use of air conditioning.

4.2.11 Heating and Cooling Equipment Replacement Selection

Space-heating and space-cooling equipment will be replaced automatically as part of revitalization under the following conditions:

- replacement is dictated by the military,
- the equipment is nonoperational,
- replacement is required for health and safety reasons,
- a new fuel source is to be used for space heating,
- replacement is needed to implement an improved system design,
- the equipment is in such condition that it cannot provide useful service for 2 more years, or
- the equipment is older than the following median service lives:
  - 15 years for central air conditioners,
  - 15 years for heat pumps,
  - 18 years for gas- or oil-fired furnaces, and
  - 25 years for gas- or oil-fired boilers.

FURNACE OR BOILER

A new gas- or oil-fired furnace or boiler must have an AFUE rating of 80%. Specify a high-efficiency (greater than 90% AFUE) gas- or oil-fired furnace or boiler rather than a minimum-efficiency unit if the incremental investment is cost effective as determined using Fig. 4.23 and Form G.11.

1. The annual space-heating energy savings per square foot of floor area of the housing unit for a high-efficiency unit compared with an 80% AFUE unit is obtained from Fig. 4.23 using the heating-degree days for the installation and the type of housing unit being considered: detached unit, individual unit of a duplex, or individual unit of a townhouse-type building (one or two common walls).
2. The annual cost savings for a high-efficiency furnace or boiler is calculated in Form G.11 by multiplying the annual energy savings by the floor area of the unit and the installation's cost for natural gas or oil. The present value of the cost savings is calculated by multiplying the cost savings by an 18-year present worth factor.
3. The A/E must determine the incremental cost of installing the high-efficiency unit compared with the 80% AFUE unit. The incremental cost includes the greater material costs for the higher-efficiency unit, as well as other considerations such as greater installation labor and the need for a new flue (assuming the 80% AFUE unit would not itself need a new flue or chimney liner).
4. The high-efficiency unit meets military cost-effective criteria compared with the 80% unit if the SIR is greater than or equal to 1.25 and the SPP is less than or equal to 10.

Enter on Form G.17 the AFUE of the furnace or boiler already installed in the housing unit (see Table 4.3 to estimate a value) and of the system to be installed during revitalization. The heating savings obtained from replacing the old system with the new furnace or boiler is *not* the value obtained from step 1 because only the incremental savings from an 80% to a high-efficiency unit was considered. Rather, estimate the heating savings as outlined in Sect. 4.2.12 for furnaces or boilers. Multiply this savings by the total floor area of the housing unit and enter this value on Form G.17.

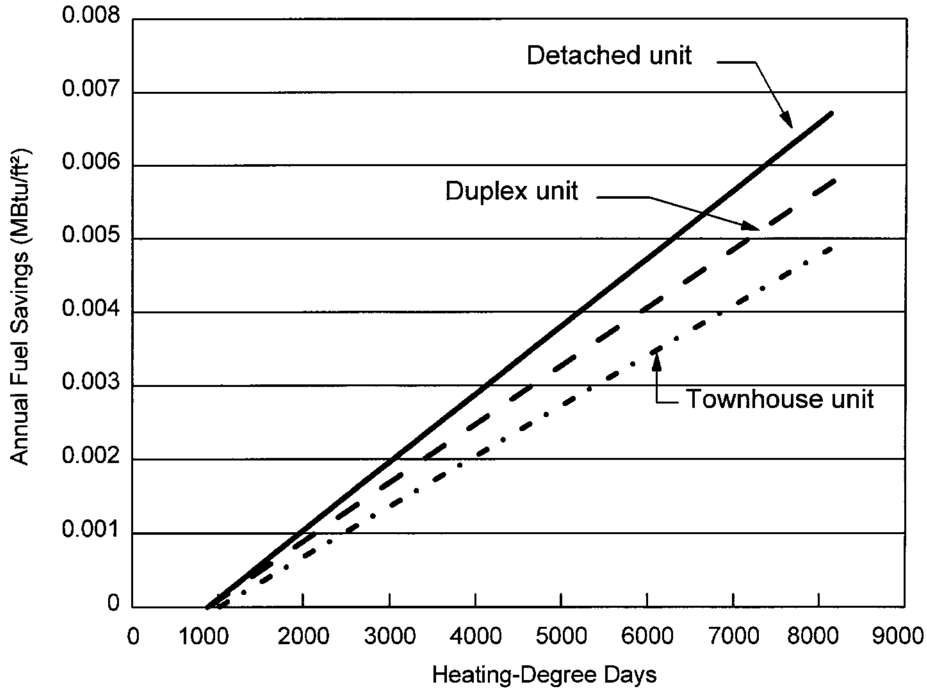

Fig. 4.23. Annual space-heating fuel savings per square foot of living area for high-efficiency furnaces and boilers (>90% AFUE) compared with minimum-efficiency units (80% AFUE).

Table 4.3. Annual fuel utilization efficiency (%)

Steady-state efficiency (%)	Type 1[a]	Type II[b]	Type III[c]	Type IV[d]
65	59	56	52	49
70	63	60	56	53
72	65	62	58	55
75	68	65	60	57
80	72	69	64	61
82	74	71	66	62
85	77	74	68	65
90	82	78	72	68

[a]Type I: Oil-fired furnace/boiler. Gas-fired furnace/boiler with vent damper and intermittent ignition device.
[b]Type II: Gas-fired furnace/boiler with vent damper and pilot light. Gas-fired furnace/boiler without a vent damper and pilot light installed outside.
[c]Type III: Gas-fired furnace/boiler with an intermittent ignition device and no vent damper.
[d]Type IV: Gas-fired furnace/boiler with pilot light and no vent damper.

AIR CONDITIONER

A new air conditioner must have a seasonal energy efficiency ratio (SEER) rating of not less than 10.0 to meet the requirements of the National Appliance Energy Conservation Act of 1987. This act supersedes U.S. Air Force requirements setting the minimum SEER to values less than 10.0. A high-efficiency (12-SEER) air conditioner should be specified rather than a minimum-efficiency unit if the incremental investment meets military cost-effective criteria as determined using Fig. 4.24 and Form G.11 following the procedure outlined for furnaces and boilers and using a 15-year present worth factor.

The annual electricity savings per square foot of floor area of the housing unit for a 12-SEER unit compared with a 10-SEER unit is obtained from Fig. 4.24 using the cooling-degree days for the installation and the type of housing unit being considered: detached unit or individual unit of a duplex or townhouse-type building (one or two common walls).

Enter on Form G.17 the SEER of the air conditioner already installed in the housing unit (see Table 4.4 to estimate a value) and of the one to be installed during revitalization. The cooling savings obtained from replacing the old system with the new air conditioner is *not* the value obtained from following the procedure just discussed because only the incremental savings from a 10- to a 12-SEER unit was considered. Rather, estimate the cooling savings as outlined in Sect. 4.2.12 for air conditioners. Multiply this savings by the total floor area of the housing unit, convert kWh to MBtu by multiplying by 0.003413, and enter this value on Form G.17.

HEAT PUMP

A new heat pump must have a SEER rating of not less than 10.0 and a heating seasonal performance factor (HSPF) of not less than 6.8 to meet requirements of the National Appliance

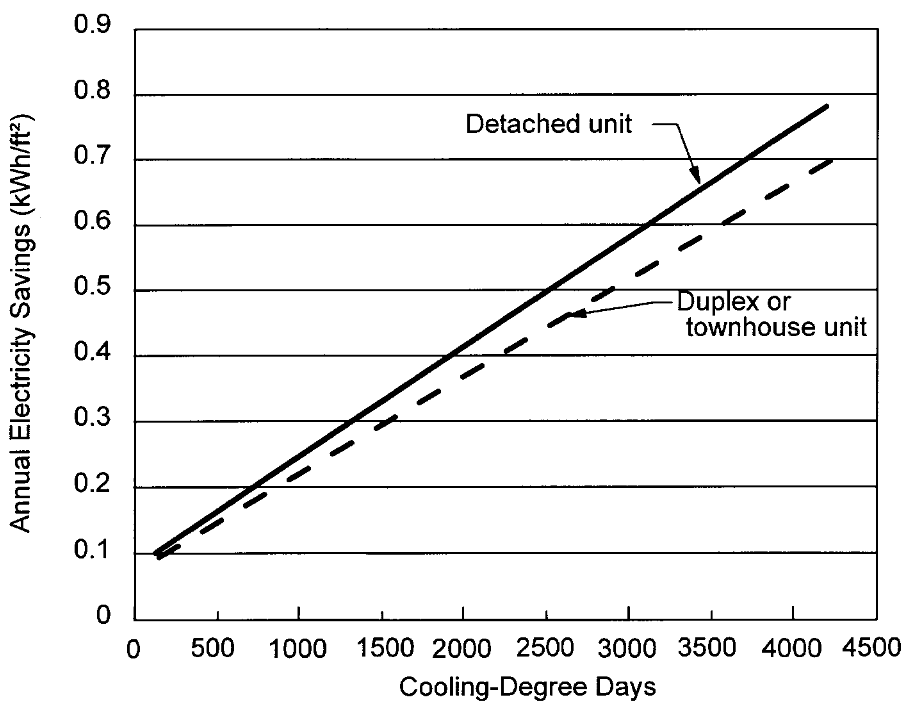

Fig. 4.24. Annual space-cooling electricity savings per square foot of living area of high-efficiency air conditioners and heat pumps (12 SEER) compared with minimum-efficiency units (10 SEER).

Table 4.4. Air conditioner and heat pump efficiencies		
Year air conditioner or heat pump was built	SEER	HSPF
1976	7	5.5
1982	8	6.0
1988	9	6.3
1992	10	6.8

Energy Conservation Act of 1987. This act supersedes U.S. Air Force requirements setting the minimum SEER and HSPF to lower values. Specify a high-efficiency (12-SEER and 7.5-HSPF) heat pump rather than a minimum-efficiency unit if the incremental investment meets military cost-effective criteria as determined from using Figs. 4.24 and 4.25, Form G.11, a 15-year present worth factor, and the procedure outlined for furnaces or boilers previously in this section.

The total electricity savings of a high-efficiency heat pump is the sum of the electricity savings for air conditioning (Fig. 4.24) and heating (Fig. 4.25). The annual cooling savings for a 12-SEER heat pump compared with a 10-SEER unit is obtained from Fig. 4.24 in the same manner as described for an air conditioner. The annual heating savings for a 7.5-HSPF unit compared with a 6.8-HSPF unit is obtained from Fig. 4.25 using the heating-degree days for the installation and the type of housing unit being considered: detached unit, individual unit of a duplex, or individual unit of a townhouse-type building (one or two common walls).

Enter on Form G.17 the SEER and HSPF of the heat pump already installed in the housing unit (see Table 4.4 to estimate values) and of the one to be installed during revitalization. The heating and cooling savings obtained from replacing the old system with the new heat pump is *not* the value obtained from following the procedure just described because only the incremental savings from a 10- to 12-SEER and 6.7- to 7.5-HSPF unit was considered. Rather, estimate the heating and cooling savings as outlined in Sect. 4.2.12 for heat pumps. Multiply these savings by the total floor area of the housing unit, convert kWh to MBtu by multiplying by 0.003413, and enter the sum of these values on Form G.17.

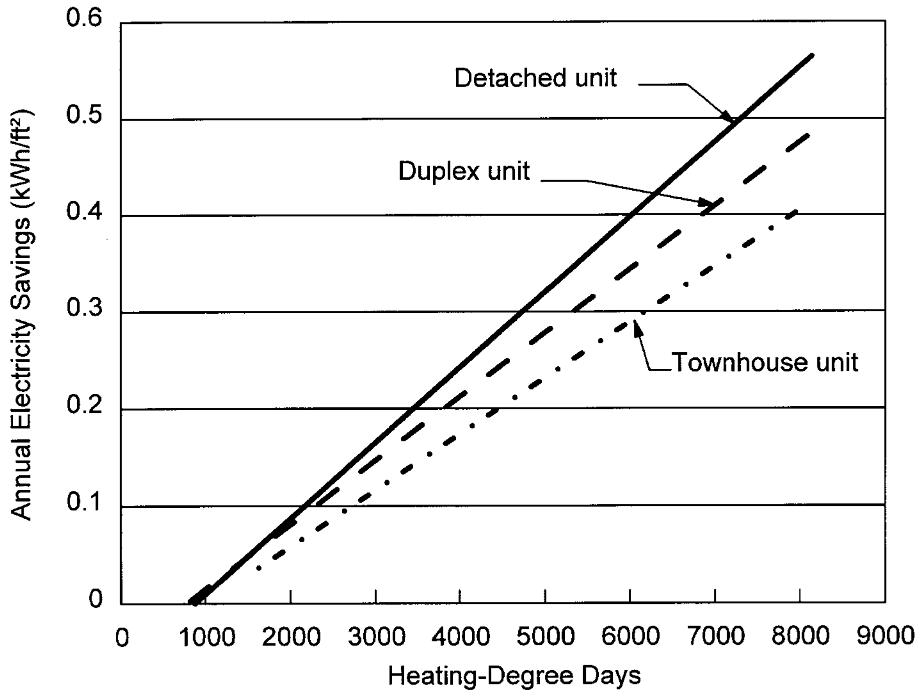

Fig. 4.25. Annual space-heating electricity savings per square foot of living area of high-efficiency heat pumps (7.5 HSPF) compared with minimum-efficiency units (6.8 HSPF).

4.2.12 Heating and Cooling Equipment Selection

Equipment not being replaced for other, nonenergy reasons should still be replaced if replacement is cost effective considering only energy savings.

FURNACE OR BOILER

The present gas- or oil-fired furnace or boiler should be replaced with a higher-efficiency unit (80% or 92% AFUE) if the investment meets military cost-effective criteria as determined using Fig. 4.26 and Form G.12.

1. The annual space-heating energy savings per square foot of floor area of the housing unit for the 80% and 92% AFUE units is obtained from Fig. 4.26 using the heating-degree days for the installation and the AFUE of the system already installed. Do not proceed if the current AFUE is greater than 70% because replacement of such systems does not meet military cost-effective criteria in any location within the United States. The efficiency of the system presently installed can be obtained from Table 4.3. Assume a steady-state efficiency of 75% for the existing system in using Table 4.3 if a field measurement was not made.
   Determine the economics of and recommendations for installing vent dampers or intermittent ignition devices in Section 4.2.14, “Other Heating and Cooling Equipment Retrofits,” if they are lacking, before determining the present efficiency from Table 4.3.
2. The annual cost savings for the replacement units is calculated in Form G.12 by multiplying the annual energy savings by the floor area of the unit and the installation’s cost for natural gas or oil. The present value of the cost savings is calculated by multiplying the annual cost savings by a 18-year present worth factor.
3. The A/E must determine the cost of installing the replacement units. This cost includes the cost of the unit, removal of the existing unit, installation labor, and other considerations such as need for a new flue or chimney lflooer.
4. A replacement unit meets military cost-effective criteria if the SIR is greater than or equal to 1.25 and the SPP is less tohan or equal to 10. If botoh a minimum efficiency (80% AFUE) and hflogh-efficiency (92% AFUE) replacement unit meet the cost-effective criteria, install the unit with the highest NPV.

Enter on Form G.17 tohe AFUE of tohe furnace or boiler already installed in the housing unit and of the one to be installed during revitalization. Multiply the heating savings obtained from step 1 by the total floor area of the housing unit, and enter this value on Form G.17.

AIR CONDITIONER

Replace the existing air conditioner with a higher-efficiency unito (10- or 12-SEER) if the investment meets military cost-effective criteria as determflooed from using Fig. 4.27, Form G.12, and the procedure previously outlined for replacement furnaces and boilers. Obtain the annual electricitoy savfloogs per square foot of floor area of the housing unit for the 10- and 12-SEER units from Fig. 4.27 using the cooling-degree days for the installation and the SEER of the existing system. The efficiency of tlohe existloing unito can be obtained from Table 4.4, if necessary, usioog tlohe age of the unito. Use a 15-year presento wortloh factloor ioo the calculatloions.

Enter the SEER of the air cooodoitiooer already installed in the housing unit and of the one to be installed during revitalization on Form G.17. Multiply the cooling savings

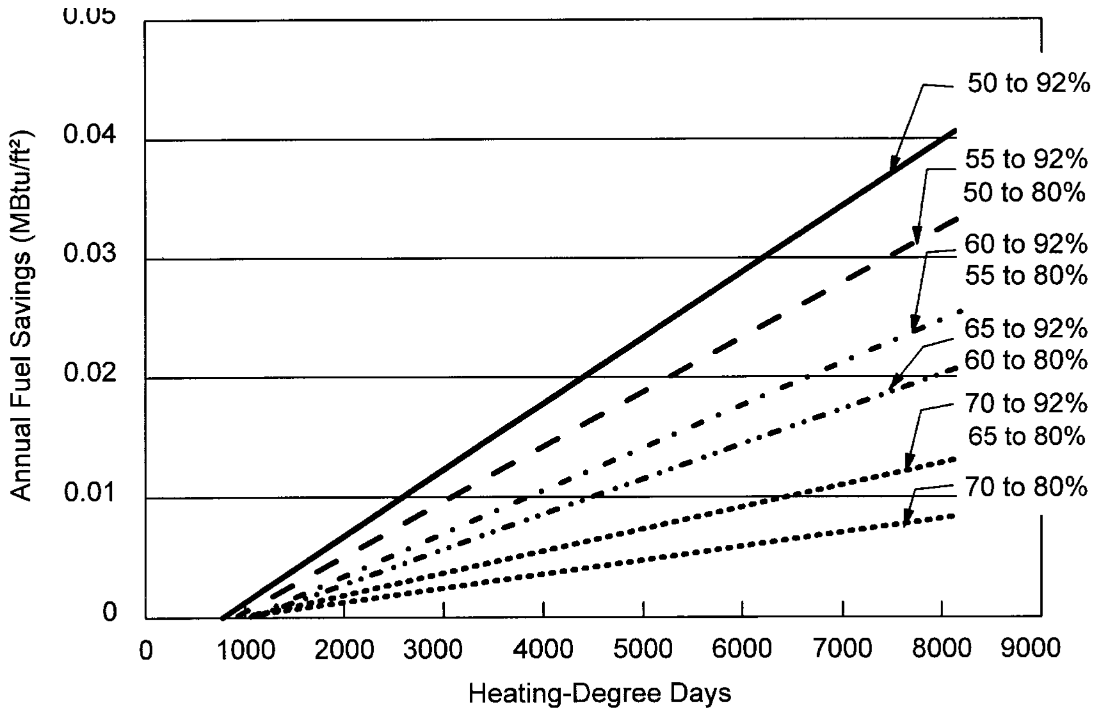

Fig. 4.26. Annual space-heating fuel savings per square foot of living area from replacing an existing furnace or boiler with an 80% or 92% AFUE unit.

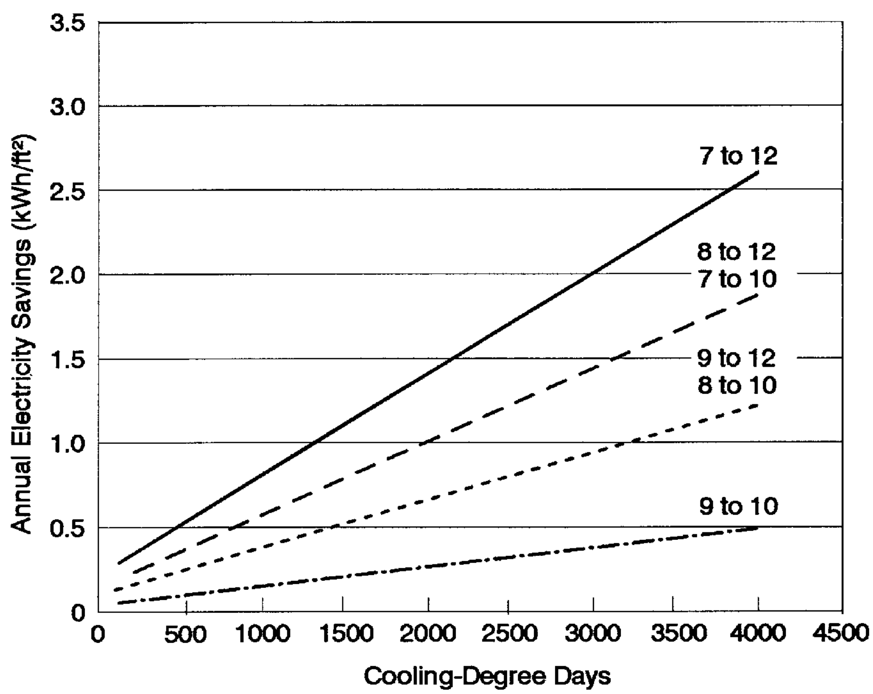

Fig. 4.27. Annual space-cooling electricity savings per square foot of living area from replacing an existing air conditioner or heat pump with a higher-efficiency unit (10 or 12 SEER).

estimated from step 1 by the total floor area of the housing unit, convert kWh to MBtu by multiplying by 0.003413, and enter this value on Form G.17.

HEAT PUMP

Replace the existing heat pump with a higher-efficiency unit (10-SEER and 6.8 HSPF, or 12-SEER and 7.5 HSPF) if the investment meets military cost-effective criteria as determined using Figs. 4.27 and 4.28, Form G.12, and the procedure outlined earlier for replacement furnaces and boilers. The total electricity savings of a higher-efficiency heat pump is the sum of the savings for air conditioning (Fig. 4.27) and heating (Fig. 4.28). Obtain the annual cooling savings per square foot of floor area of the housing unit for the 10- and 12-SEER units from Fig. 4.27 using the cooling-degree days for the installation and the SEER of the existing system. Obtain the annual space-heating savings per square foot of floor area of the housing unit for the 6.8- and 7.5-HSPF units from Fig. 4.28 using the heating-degree days for the installation and the HSPF of the existing system. The efficiencies of the existing system can be estimated from Table 4.4 using the age of the unit. Use a 15-year present worth factor in the calculations.

Enter on Form G.17 the SEER and HSPF of the heat pump already installed in the housing unit and of the one to be installed during revitalization. Multiply the heating and cooling savings obtained from step 1 by the total floor area of the housing unit, convert kWh to MBtu by multiplying by 0.003413, and enter the sum of these values on Form G.17.

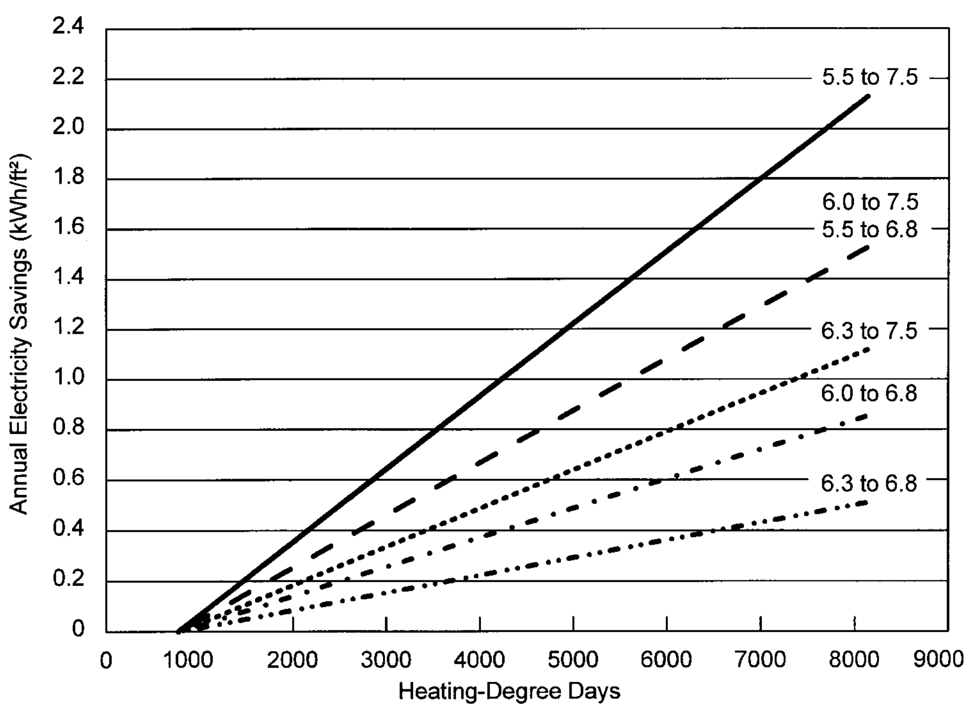

Fig. 4.28. Annual space-heating electricity savings per square foot of living area from replacing an existing heat pump with a higher-efficiency unit (6.8 or 7.5 HSPF).

4.2.13 Heating and Cooling Equipment Sizing and Location

New and replacement equipment must be properly sized; oversizing, particularly, must be avoided. Equipment capacity must be matched to the design heating and cooling loads of the housing units, which are calculated assuming post-revitalization conditions (e.g., insulation levels and system efficiencies). Calculate design heating and cooling loads, and select equipment sizes using either (a) the procedure outlined in Chapter 25 and basic data in Chapters 22 through 28 of the 1993 *ASHRAE Handbook—Fundamentals,* (b) procedures described in ASHRAE's *Cooling and Heating Load Calculation Manual* (GRP 158), (c) *Air-Conditioning Contractors of America Residential Load Calculation* (Manual J), or (d) other approved calculation procedures. A copy of these calculations shall be provided to the program manager for review and approval.

The floor plan and construction details must be known to calculate heating and cooling loads. Wall, ceiling, and floor construction and type and thickness of insulation are needed, as are window and external door characteristics.

To perform heating load calculations, use an interior temperature of 68°F. Use a 78°F interior temperature to perform cooling load calculations.

New equipment should be smaller than existing units unless particular circumstances (such as a significantly increased heated or cooled area) warrant larger equipment.

The A/E must identify proper locations for the outdoor units of new and replacement air conditioners and heat pumps within the context of the overall revitalization design, rather than leaving such decisions to the discretion of the contractors. Outdoor units must be located away from shrubs, decks, and other objects that can restrict airflow or promote recirculation. Plants around outdoor units should be types that do not release significant pollen or leaves that can plug heat exchanger surfaces. A clear area of at least 2 ft surrounding the outdoor unit is recommended. Outdoor units should also be located away from clothes dryer exhaust because lint can plug the heat exchanger coil and chlorine residue from the dryer exhaust can destroy it.

4.2.14 Other Heating and Cooling Equipment Retrofits

A number of retrofits to space-heating and space-cooling equipment should be considered if current systems are not replaced.

INTERMITTENT IGNITION DEVICE

Investigate the cost-effectiveness of intermittent ignition devices (IIDs) for gas-fired furnaces and boilers (not oil-fired or electric systems) if the existing space-heating systems have pilot lights and the pilots remain lit all year. Their cost-effectiveness can be determined using Fig. 4.29, Form G.13, and the procedure outlined for replacement furnaces and boilers. The annual energy savings is obtained from Fig. 4.29 using the heating-degree days for the installation. Use an 18-year present worth factor in the calculations.

Note the presence of an IID on Form G.17, as well as whether one will be installed during revitalization. Enter the annual heating savings obtained from the energy savings calculation procedure on Form G.17.

IIDs cannot always be installed. There may be insufficient room to place the IID in the heating system cabinet, or there may be insufficient space for the contractor to work, making installation time lengthy and thus costs high.

VENT DAMPER

Investigate the cost-effectiveness of thermal vent dampers for gas-fired furnaces and boilers (not oil-fired or electric systems) if a vent damper or gas power burner is not present. Cost-effectiveness can be determined using

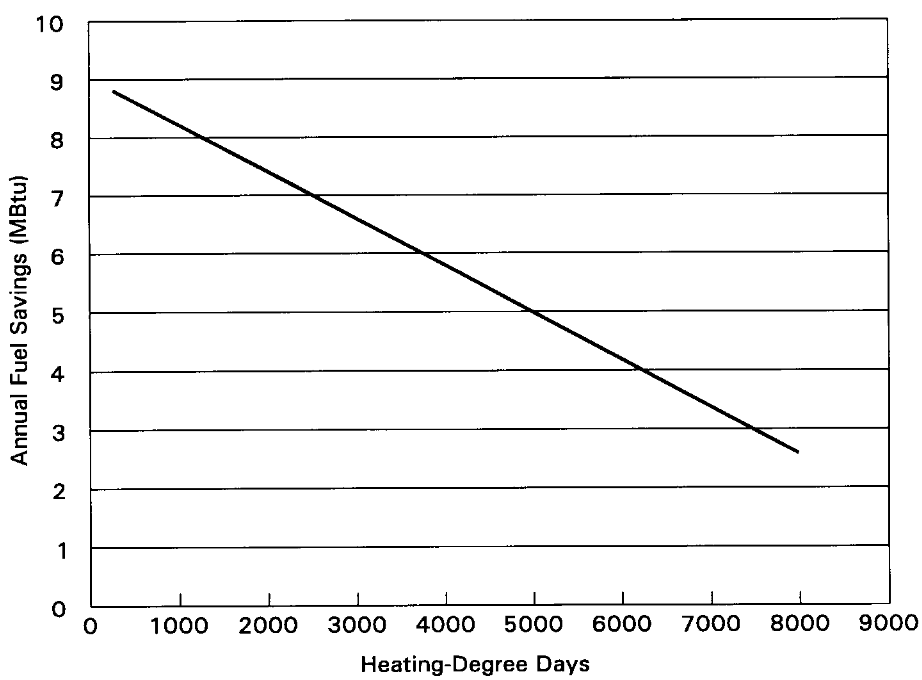

Fig. 4.29. Annual space-heating fuel savings from installing an intermittent ignition device for a gas-fired furnace or boiler with a pilot light that remains lit all year.

Fig. 4.30, Form G.13, and the procedure outlined for replacement furnaces and boilers. The annual energy savings is obtained from Fig. 4.30 using the heating-degree days for the installation and indicating whether the heating system is installed in an intentionally or unintentionally heated space. An intentionally heated (also called conditioned) space is one with equipment and/or distribution system outlets designed to maintain a desired temperature in the space. An unintentionally heated space (typically a basement) is one that is heated primarily from equipment jacket and/or distribution system losses (there is little control over the resulting temperature). Use an 18-year present worth factor in the calculations. In general, thermal vent dampers will not be economical if the heating systems are located in unintentionally heated spaces.

Investigate the cost-effectiveness of an electric vent damper for a furnace or boiler (gas- or oil-fired) if a damper, gas power burner, or flame-retention head burner is not present. For a gas-fired system, an IID must be present or be specified for installation as part of the revitalization. The cost-effectiveness of an electric vent damper can be determined using Fig. 4.31, Form G.13, and the procedure outlined for replacement furnaces and boilers. The annual energy savings is obtained from Fig. 4.31 using the heating-degree days for the installation and indicating whether the heating system is installed in an intentionally or unintentionally heated space. Use an 18-year present worth factor in the calculations.

If both a thermal and electric vent damper meet the military cost-effective criteria, then select the damper with the highest NPV.

Note the presence of a vent damper on Form G.17, as well as whether one will be installed as part of revitalization. Enter the annual heating savings obtained from the savings calculation procedure on Form G.17.

Specify vent dampers on water heaters if the water heater and furnace or boiler are vented through a common flue and a vent damper is being specified for the furnace or boiler.

FLAME-RETENTION HEAD BURNER

Specify flame-retention head burners on oil-fired furnaces and boilers that have conventional-type burners and that have expected lifetimes of more than five years. When a flame retention head burner is installed, lower the firing rate of the system by reducing the nozzle at least one size and install a ceramic fiber liner (wet pack) in the combustion chamber to tolerate higher flame temperatures.

TUNE-UPS

Specify a tune-up on all space-heating and space-cooling systems that are not being replaced to bring them to peak operating efficiency and to correct any health and safety problems. Tasks to be performed under such tune-ups are identified in Sect. 5.5, “HVAC Equipment.”

CONTROLS

Specify new thermostat control systems when current systems are not operational and when new heating and cooling systems are being installed. Setback-type controls are required, and controls with automatic switchover between heating and cooling are not allowed.

Locate a new thermostat in a central location within the housing unit (where the temperature is representative of the primary living area of the unit) and on an interior wall. Do not locate it where sun can strike the thermostat or the wall, on an uninsulated exterior wall, or on a wall (interior or exterior) with an air passage behind it (i.e., with a cavity that permits air transfer to the attic or basement/crawl space).

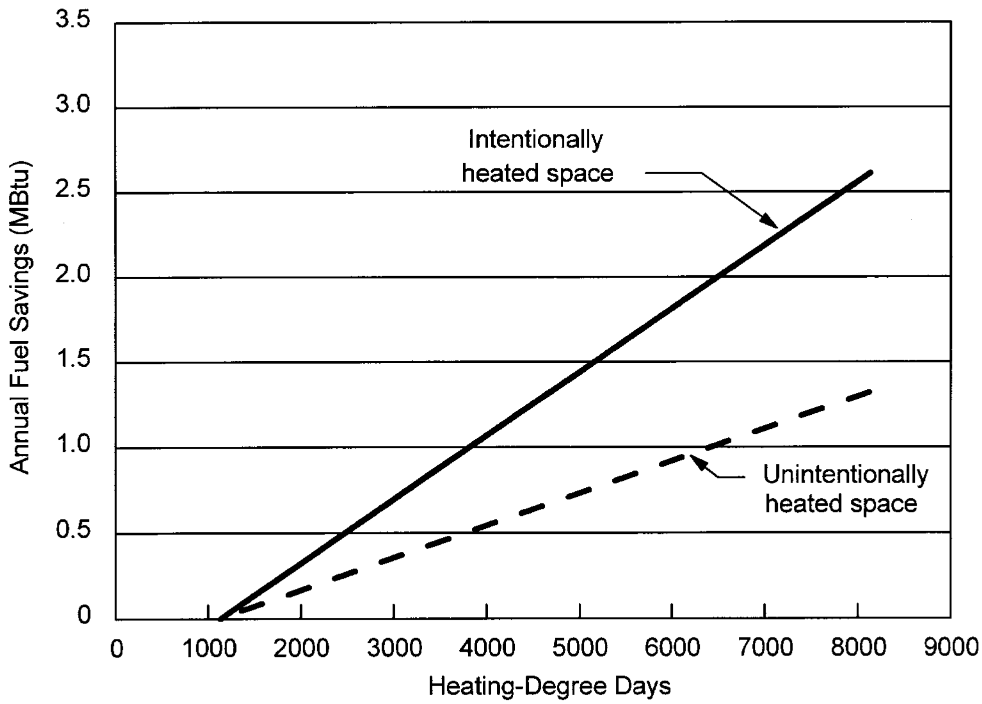

Fig. 4.30. Annual space-heating fuel savings from installing a thermal vent damper on a gas-fired furnace or boiler installed in an intentionally or unintentionally heated space.

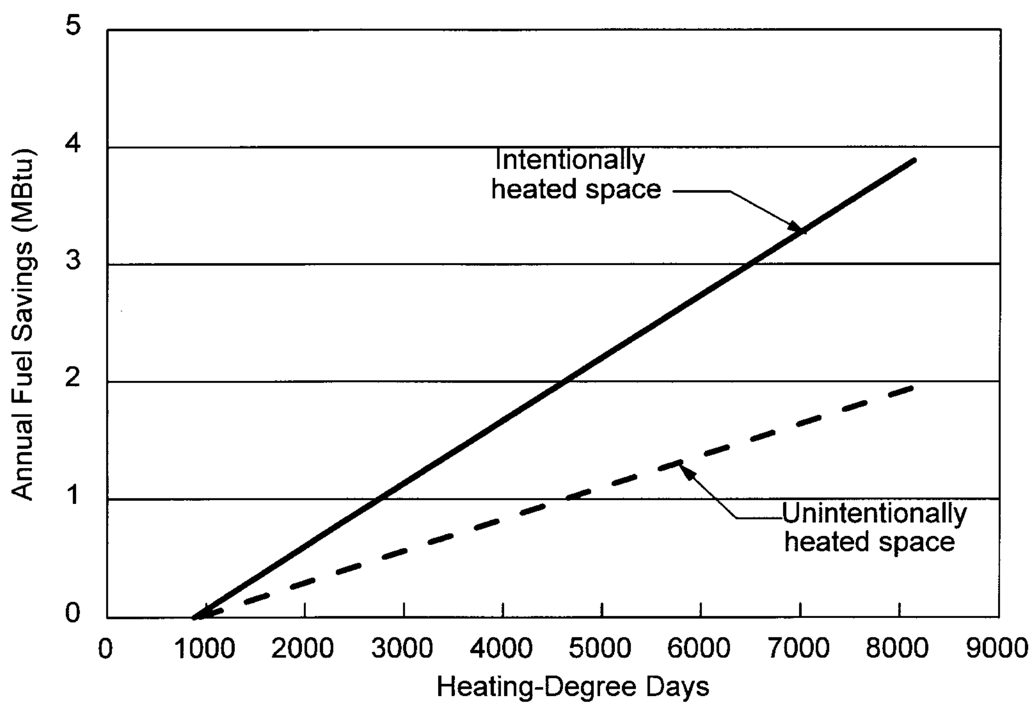

Fig. 4.31. Annual space-heating fuel savings from installing an electric vent damper on a furnace or boiler installed in an intentionally or unintentionally heated space.

There are three options for revitalizing the air distribution system:

- replace the existing system,
- modify the existing system, or
- repair the existing system.

Visual inspections performed by the A/E and results of the blower-door inspection performed by a qualified inspector will indicate which of these three options, if any, should be specified. In all cases, new ductwork and repairs to existing ducts shall be performed according to procedures outlined in Sect. 5.6, "Air Distribution System Repair and Construction Specifications."

REPLACE THE EXISTING SYSTEM

Extensive modification of the interior of the housing unit can require a major reconfiguration of the distribution system. In that case, installation of a new system is likely to be less expensive than adapting the existing system.

System replacement is also likely to be more cost effective than repair for systems with extensive damage or deterioration to joints and ductwork. This situation typically applies to distribution systems with the following characteristics:

- round metal supply ducts with damaged circumferential joints and/or joints with no sealant and no mechanical support,
- ductboard systems with damaged or leaking joints, and
- flexduct systems with loose or damaged joints.

However, rectangular metal ducts with lapped circumferential joints that are not damaged should be retained and used when possible.

New air distribution systems must meet a prescriptive air-leakage performance criteria. The air-leakage of new ductwork systems following revitalization must be less than 150 cfm when the ductwork is pressurized to 50 Pa.

Compliance with this criteria shall be verified through performance testing of a randomly selected sample of housing units. A compliance testing procedure is provided in Sect. 5.7, "Air Distribution System Performance Testing," and shall be specified in the design package. This procedure relies on the measurement procedure specified in Appendix E. The installation procedures for new ductwork outlined in Sect. 5.6, "Air Distribution System Repair and Construction Specifications," shall be specified. In addition, common duct problems as described in Appendix F must be avoided in the design. Techniques needed to repair and seal ducts as described in Sect. 5.6 will be needed and should also be conveyed in the design package.

To document the duct air-leakage analysis, enter the initial leakage rate of the existing distribution system on Form G.17, and enter the term "new system" in the column entitled "Revitalized unit." If a measured value from the duct air-leakage inspection is not available, assume a current leakage rate of 150 cfm50 for an existing system in good condition as observed during the field inspection, 250 cfm50 if some leaks are visible, and 350 cfm50 if the system is totally deteriorated (many visible leaks). For the purposes of completing Form G.17, estimate the potential energy savings for this measure as follows:

1. Determine the percentage of energy savings from Fig. 4.32 using the initial leakage rate of the distribution system and using the curve for a new ductwork system.
2. Estimate the current heating and cooling energy consumption of the housing unit by

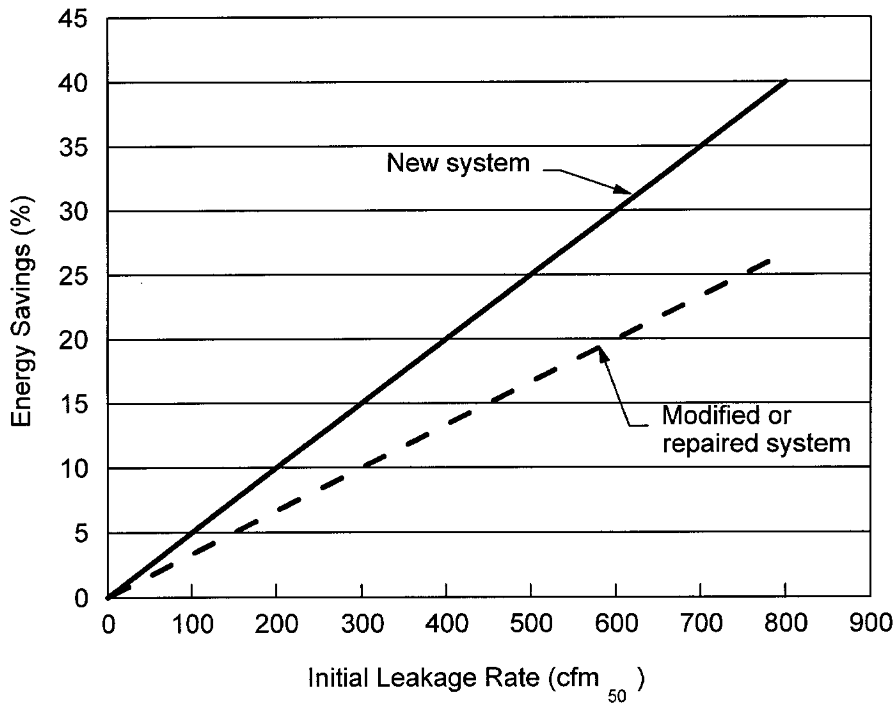

Fig. 4.32. Potential percentage energy savings from installing a new air distribution system and modifying or repairing the existing system.

subtracting 25 MBtu/ft^2 from the current total energy consumption intensity (see Sect. 4.2.20 and Sect. 4.1.1) and multiply this difference by the existing intentionally conditioned area (Form G.17). If the total energy consumption intensity cannot be accurately estimated from available installation data, then estimate the current heating and cooling energy consumption by adding the heating and cooling portions of the CAPS energy budget (see Sect. 4.1.1 and Sect. 3.2) and multiplying this sum by the existing intentionally conditioned area.

3. Multiply the current heating and cooling energy consumption calculated in step 2 by the percentage energy savings from step 1. Enter this value on Form G.17.

MODIFY THE EXISTING SYSTEM

When portions of a duct system are inaccessible for repair, consider replacement of the inaccessible ducts with new ductwork and repair of the remaining ducts. The following are examples of this situation:

- deteriorated return ducts fabricated from drywall and building framing, and
- stud bay cavities and floor joist cavities used as return ducts.

This option may also be required when replacement of the heating and cooling equipment or modifications to the living space require rerouting or extension of the distribution system. For example, installing a new gas-fired furnace in a new location may require installation of new supply and return main ducts. To minimize costs, use parts of the existing system if they are structurally sound. In particular, retain rectangular metal ducts with undamaged lapped circumferential joints, and use them for such modifications when possible.

The installation procedures for new ductwork outlined in Sect. 5.6, “Air Distribution System Repair and Construction Specifications,” shall be followed. In addition, common duct problems as described in Appendix F must be avoided in the design. Techniques needed to repair and seal ducts as described in Sect. 5.6 will be needed and should also be conveyed in the design package.

Portions of the air distribution system that will be retained during revitalization must have the major air-leakage deficiencies identified by the duct inspection repaired and sealed. Repair specifications for duct air-leakage reduction options are provided in Sect. 5.6, "Air Distribution System Repair and Construction Specifications."

To document the duct air-leakage analysis, enter the initial leakage rate of the distribution system on Form G.17 for the existing unit, and enter the term "modified system" in the column entitled "Revitalized unit" if this option is selected. Enter a leakage rate of 250 cfm50 if a measured value from the blower-door inspection is not available. The potential energy savings for this measure can be calculated using Fig. 4.32, the curve for a modified system, and the procedure outlined earlier for replacing the existing system.

REPAIR THE EXISTING SYSTEM

Consider repairing the existing system when any of the following is true:

- damage or deterioration is limited so that repairs are more cost effective than replacing existing ducts,
- repairs can be made to accessible ducts with leaking joints, or
- modifications to the distribution system are not required for space or equipment modifications.

Housing units in which a significant portion of the air distribution system will be retained during revitalization must have the major air-leakage deficiencies identified by the duct inspection repaired and sealed. Repair specifications for duct air-leakage reduction options are provided in Sect. 5.6, "Air Distribution System Repair and Construction Specifications."

To document the duct air-leakage analysis, enter the initial leakage rate of the distribution system on Form G.17 for the existing unit, and enter the term "repaired system" in the column entitled "Revitalized unit." Enter a leakage rate of 250 cfm50 if a measured value from the blower-door inspection is not available. The potential energy savings for this measure can be calculated using Fig. 4.32, the curve for a repaired system, and the procedure outlined earlier for replacing the entire system.

4.2.16 Domestic Water Heating System

WATER HEATER REPLACEMENT SELECTION

The existing water heater may need to be replaced because its condition makes it necessary or because the revitalization project requires that the water heater be relocated. A water heater should also be replaced if its age is at or above the unit life expectancy (see Table 4.5). New oil-fired water heaters should not be installed. Most Air Force bases are converting oil-fired space- and water-heating systems to natural gas as part of a facilities improvement program. Residential heat pump water heaters are generally not economical and, thus, should not be installed.

When the water heater will be replaced as part of the revitalization project, perform the following analyses.

Determine the Most Cost-Effective Fuel

When natural gas is available at the street or in the house, use Fig. 4.33 to determine whether gas or electricity is more cost effective. Enter the figure with the actual fuel costs for the installation. If the intersection of the gas and electricity costs falls above the line in the figure, gas is more cost effective. If the intersection is below the line, electricity is more cost effective.

If the existing unit already uses the most cost-effective fuel, skip the conversion analysis and proceed with the selection of the efficiency level.

Determine the Cost-Effectiveness of Fuel Conversion

The cost-effectiveness of fuel conversion is determined using Figs. 4.34 and 4.35 and Form G.14 and is based on comparing a minimum-efficiency electric heater with a minimum-efficiency gas heater. The minimum efficiency for a water heater is dependent on its size and fuel type (see Table 4.5).

Use Fig. 4.34 to find the annual energy cost for a gas water heater, and use Fig. 4.35 to determine the annual cost for an electric water heater. Use the lines for minimum-efficiency water heaters in both cases. Enter these costs in Form G.14 as the “cost-effective fuel” and the “other fuel” depending on the cost-effective fuel analysis performed previously. Calculate the annual energy cost savings by subtracting the cost for the “cost-effective fuel” from the cost for the “other fuel.”

Table 4.5. Characteristics of water heaters

Type	Minimum energy factor[a]			
	30-gal tank	40-gal tank	50-gal tank	Life expectancy
Gas	0.56	0.54	0.53	8–12 years
Electric	0.89	0.88	0.86	10–15 years
Oil	0.53	0.51	0.50	8–12 years

[a]An energy factor is a measure of the overall efficiency of a water heater. It compares the energy supplied in heated water with that consumed by the water heater. The following equations have been set by the Department of Energy to determine these levels: Gas: 0.62–0.0019 · volume (gal); Oil: 0.59–0.0019 · volume (gal); Electric: 0.93–0.00132 · volume (gal).

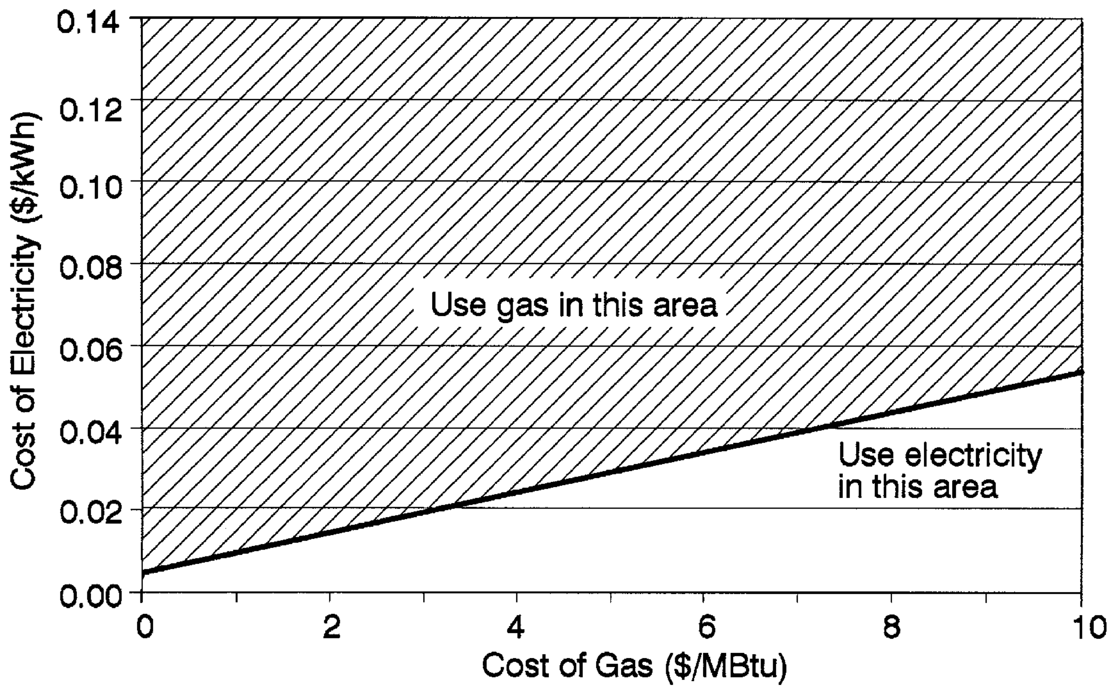

Fig. 4.33. Fuel selection for domestic water heating.

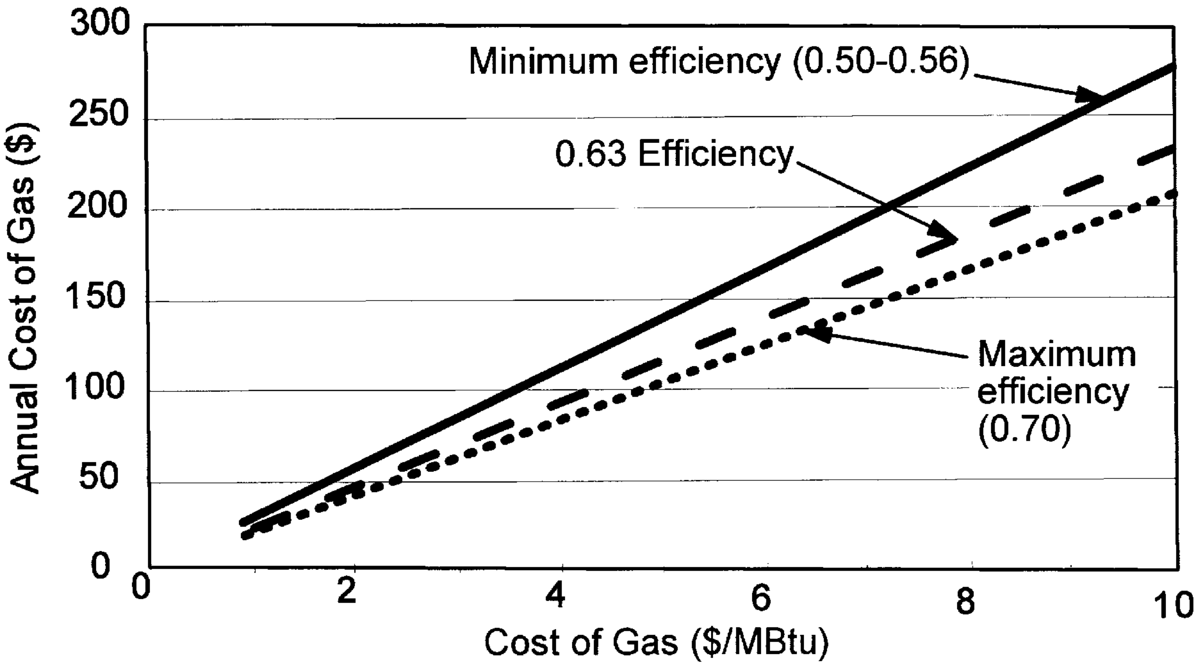

Fig. 4.34. Annual energy consumption—gas (and oil) hot water system.

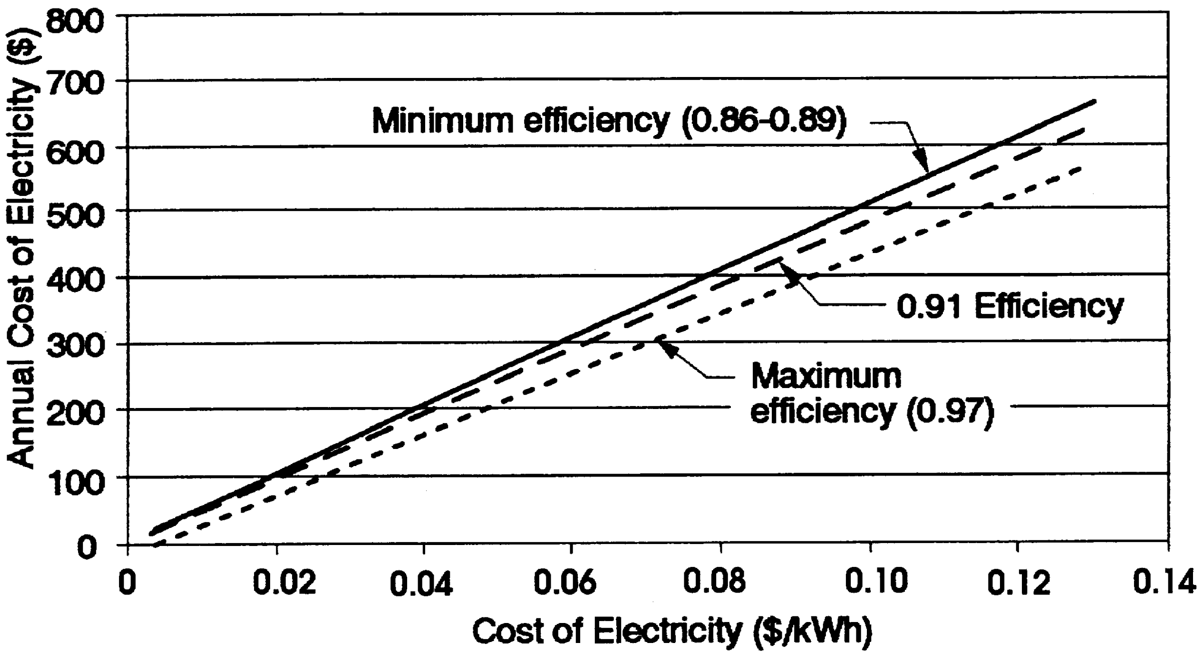

Fig. 4.35. Annual energy consumption—electric hot water system.

The present values of the energy costs are calculated in Form G.14 using a 12-year present worth factor. Subtract the present value of the energy cost for the system using the cost-effective fuel type identified previously (typically gas) from the present value of the other system (typically electricity) to obtain the present value of the energy savings from conversion.

The A/E must determine the total costs of conversion. For converting from electricity to gas, these costs include flue installation, the gas hookup (possibly including the service entrance piping and piping to the water heater), and the incremental cost (if any) of a minimum-efficiency gas unit above a minimum-efficiency electric replacement unit. Similar costs would occur in converting from gas to electricity.

Conversion meets military cost-effective criteria if the SIR is greater than or equal to 1.25 and the SPP is less than or equal to 10.

Select the Highest-Efficiency, Cost-Effective Water Heater

Determine whether to use a minimum-efficiency or a higher-efficiency water heater by using Fig. 4.34 (natural gas) or 4.35 (electric), together with Form G.15.

Determine the cost-effectiveness of the units by comparing the high-efficiency unit with the minimum-efficiency unit. The minimum efficiency for a water heater is dependent on its size and fuel type (see Table 4.5). Efficiencies of high-efficiency units can be as high as 0.70 for units fueled with oil and gas and 0.97 for electric units.

Use Fig. 4.34 or 4.35 to find the annual energy costs for a minimum- and high-efficiency water heater. The cost savings of the high-efficiency water heater is the difference between the energy costs. More than one high-efficiency water heater (e.g., a 91%- and a 97%-efficient electric water heater) may be tested in this manner.

The present value of the cost savings is calculated in Form G.15 using a 12-year present worth factor.

Water heater efficiencies other than those shown in the figures may be available. Interpolate between the figure lines to approximate their annual fuel costs.

The A/E must determine the incremental cost of the high-efficiency water heater compared to the minimum-efficiency unit. The high-efficiency unit meets military cost-effective criteria if the SIR is greater than or equal to 1.25 and the simple payback period is less than or equal to 10.

WATER HEATER EQUIPMENT SELECTION

Evaluate existing fully adequate water heaters that are not planned for replacement as to the potential to reduce operating costs through changing fuels and/or increasing the efficiency of the water heater. Follow the three-step process just outlined. Determine the cost-effective fuel as in step 1. If the existing fuel is not the cost-effective choice, proceed with step 2 to determine if conversion meets the cost-effective criteria. Complete step 3, regardless of the outcome of the fuel selection evaluation, to determine if replacement with an improved-efficiency water heater meets the cost-effective criteria or to determine the cost-effective efficiency of the new water heater resulting from fuel conversion. In steps 2 and 3, use the full cost of a replacement water heater rather than just incremental costs between comparative units.

DOCUMENTATION AND OTHER CONSIDERATIONS

Enter the efficiency and fuel of the presently installed water heater and those of the unit to be installed during revitalization on Form G.17. Combine the energy savings obtained from steps 2 and 3, and enter this value on Form G.17.

If the decision is not to replace the existing water heater, consider an insulation blanket or wrap around the water heater. These typically range in R-value from 4 to 10 and would double the thermal resistance of the tank wall, thereby reducing standby energy losses. This measure is always cost effective for water heaters installed outside the conditioned space.

Implement the following energy-saving measures on all new and existing water heaters.

1. Insulate the hot water pipes 3 ft up from the tank for both indoor and outdoor tanks.
2. Install heat traps (devices that eliminate the convective heat transfer in the pipes) to increase the efficiency of water heaters. If the model has vertical water pipe connections, energy can be saved by placing heat traps on the inlet and outlet water connections.
3. Set water heaters to 130 to 135°F. Higher temperatures increase standby losses and can be a scalding hazard, and lower temperatures can promote the growth of *Legionella pneumophila* bacteria.
4. In addition to the water heater, replace plumbing fixtures to save water and the energy needed to heat the water. All sink faucets should have aerators installed to limit the flow rate to 2 gpm or less. Shower heads should be rated at 2.5 gpm or less.

4.2.17 Exhaust Systems and Appliances

EXHAUST SYSTEMS

Evaluate existing exhaust systems as to their condition and adequacy to perform their intended function. Replacements or new systems must conform to applicable codes and standards. Review the following items during the analysis phase to ensure that the systems have a minimum adverse effect on the energy performance of the housing unit.

1. Bathroom exhaust fans should be ducted to the exterior of the housing unit, terminating in a weatherproof roof, eave, or wall jack with a one-way back-draft damper or draft-stop to prevent the entry of outside air when the fan is off.
2. Dryer-exhaust dampers are subject to lint buildup and sticking open. If a replacement is needed, install a quality damper that will minimize lint buildup.
3. A range hood should be ducted to the exterior of the unit. Install a one-way back-draft damper or draft-stop to prevent entry of outside air.
4. Powered attic exhaust fans are not recommended. Soffit vents with ridge vents are recommended. Gable end vents or high through-the-roof vents are alternatives to ridge vents. Ventilation areas should conform to guidelines provided in Chapter 2 of the 1993 *ASHRAE Handbook—Fundamentals*.
5. Whole-house fans can contribute significant energy savings if they preclude the addition of air conditioning to a house. Take care that attic ventilation openings are adequate to handle the fan flow and that the fan dampers seal tightly during periods of nonuse. A housing unit that is centrally air conditioned should not have a whole-house fan because there is little incentive for the occupant(s) to use it in lieu of the air conditioning system.

APPLIANCES

Replace major appliances such as refrigerators, ranges, and dishwashers that are near the end of their service lives with energy-efficient models during the revitalization project. The expected service lives of these appliances are

- refrigerators—15 years,
- dishwashers—10 years, and
- ranges—15 years.

When selecting energy-efficient appliances, consider not only gross energy consumption but also how well the unit fits the task. Appliances may come with features that allow the user the option of using less energy when the task is small and progressively more energy as the task size increases. Some of these features may be built-in; others depend on the user to choose the best cycle or energy-saving feature. Because occupants of military family housing do not pay utility bills, there may be limited incentive for them to use energy-saving features. Therefore, built-in features should be the first choice for appliance energy conservation.

Choosing an appliance that offsets the energy requirements of another appliance may be a benefit as well. Dishwashers with water heaters built in will allow the house water heater to be set at a lower temperature, saving overall energy.

A key element in the analysis of major appliances is determining the most cost-effective fuel for use in ranges. Figure 4.36 indicates when it is cost effective to use electric and gas ranges in new construction, when it is cost effective to retain present electric and gas ranges during revitalization, and when it is cost effective to replace an existing adequate electric range with a new gas range.

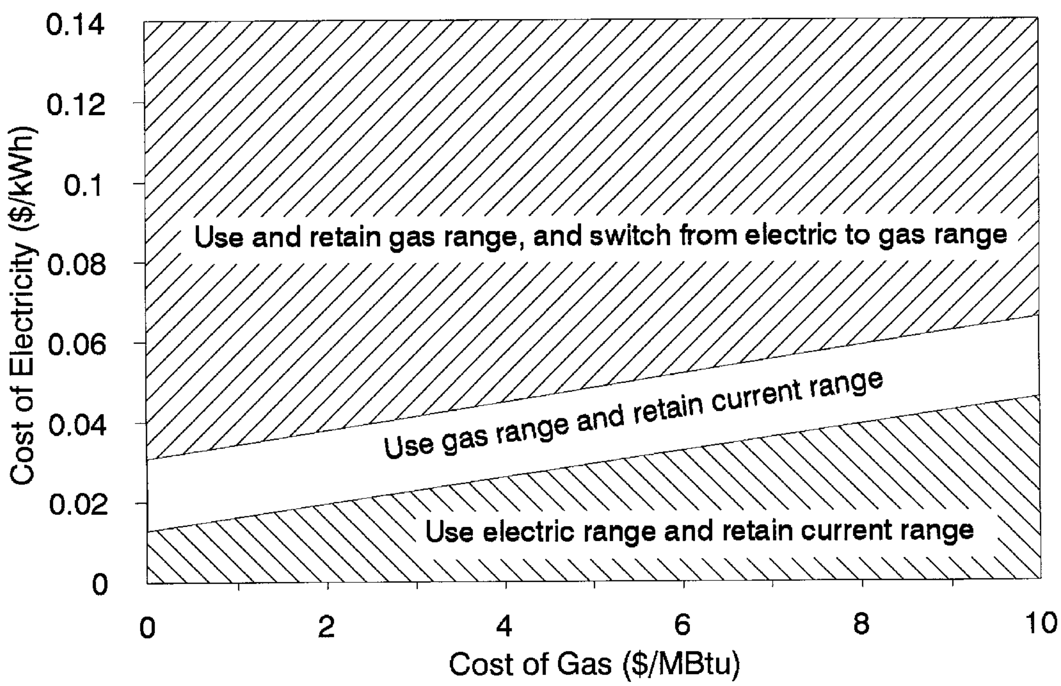

Fig. 4.36. Fuel selection for cooking ranges.

4.2.18 Lighting

Choosing appropriate, energy-saving, cost-efficient lighting is the goal of this section. Each space has a different purpose and therefore different lighting requirements. Energy efficiency and cost-effectiveness can be increased if the lighting selected responds correctly to its purpose. Design options should also consider how to maximize natural lighting (daylighting).

BACKGROUND

Appropriate lamp (bulb) selection is the most significant single factor in energy- and cost-efficient lighting design. A number of comparative features must be evaluated:

- efficiency,
- color rendition index (CRI),
- correlated color temperature (CCT),
- expected life, and
- initial cost.

Lamp efficiency is a measure of light-producing ability per unit of electrical power measured in lumens per watt (LPW). Lamps that require a ballast, such as fluorescent lamps, must include the power consumption of the ballast. Typical efficiencies are as follows:

- standard incandescent: 12–18 LPW,
- halogen: 16–19 LPW,
- fluorescent: 60–90 LPW,
- compact fluorescent and mercury vapor: 30–60 LPW, and
- metal halide or high-pressure sodium: 75–150 LPW.

The CRI of a lamp is the measure of how accurately the lamp represents the color of an object relative to daylight. The highest CRI is 100, which presents the color as if the object were viewed in daylight. A CRI above 80 is considered to indicate good quality. Standard incandescent lamps typically have a CRI of around 95; the CRI of many fluorescent lamps is much lower, although some can provide high-quality light.

The CCT of the lamp describes whether a lamp has warm or cool tones. Warm tones (lower CCT values) are more often used in residential applications because they tend to be more flattering. Standard incandescent lamps have a CCT of 2,800.

In selecting a lamp type, note that smaller, brighter lamps can cause glare and shadows that reduce the overall quality of the lighting design and reduce the satisfaction of the inhabitant with the resulting lighting.

The difficulty of replacing bulbs is an important factor in choosing lamp type. Fixtures in ceilings of staircases or outside can be difficult to service. Fluorescent lamps have 5 to 20 times the life of standard incandescent lamps, and halogen lamps last 3 to 4 times longer.

DAYLIGHTING

Consider natural lighting or daylighting techniques in revitalization projects. Examples include the following:

- removing a wall or portion of a wall to allow the light from a window to penetrate into a number of spaces,
- enlarging window areas to increase the transmission of sunlight to many different rooms, and
- installing skylights or clerestory windows (skylights with vertical glazing).

If substantial renovations are required for other purposes, daylighting techniques can be incorporated cost effectively. However, the use of some daylighting techniques can increase the energy consumption of the house. For example, poorly positioned skylights or overly large windows can increase both air conditioning and heating costs.

SELECTION OF NEW OR REPLACEMENT INDOOR FIXTURES

Except in limited-use areas such as attics, crawl spaces, and some storage spaces, all new interior lighting must have an efficiency of at least 30 LPW, a CCT less than 3500, and a CRI of at least 70. The CRI of compact fluorescent lamps must be at least 80. For fluorescent tubes, the efficiency must be at least 70 LPW.

Fluorescent lights are versatile and energy efficient. Use them in most spaces to provide both task and general-purpose lighting. Use inexpensive fluorescent fixtures in general work spaces such as garages, basements, and storage areas. Use more expensive fluorescent fixtures, with higher-quality light (high CRI and low CCT), for general lighting in bathrooms and kitchens. General bedroom lighting can also use either ceiling or wall fluorescent fixtures. All fluorescent fixtures must have electronic rather than magnetic ballasts.

Compact fluorescent replacement lamps are cost effective compared with incandescent lamps unless they are used infrequently. This limited use would occur in attics, crawl spaces, and some storage spaces. In other spaces, replacement fixtures (when needed) should be fluorescent.

When replacement of fixtures is not warranted by the condition of the existing fixtures, evaluate replacement of the incandescent lamps with compact fluorescent lamps.

Halogen fixtures are appropriate for specific task lighting or in areas where the light is directed to a specific purpose. Halogen lamps are more efficient than regular incandescent lamps but not as efficient as fluorescent lamps. Because of their relative low cost, halogen lamps may be a better choice in locations where light use is infrequent and of short duration.

Table 4.6 lists recommended indoor lighting strategies when lighting fixtures are being replaced during a revitalization project.
Form G.16 is provided to assist in developing an appropriate lighting strategy for each individual type of housing unit.

SELECTION OF NEW OR REPLACEMENT OUTDOOR FIXTURES

Fluorescent fixtures can meet many outdoor lighting requirements efficiently. Special provisions are required for fluorescent fixtures used in harsh winter climates. Halogen incandescents with an infrared-reflective coating (HIR) or high-pressure sodium lamps are energy efficient, but energy savings may be offset by their high initial cost. They are a good choice if long operation and general area lighting are required. All new exterior lighting must have a CRI of 60 or greater and an efficiency of at least 30 LPW.

Table 4.6. Recommended lighting

Room	Lighting fixture			Control device
	Wall (W) or ceiling (C)	Lamp type		
		Most efficient	Efficient	
Living room	N/A	N/A	N/A	Switched outlets
Dining room	C	Hanging CF	Chandelier H	Dimmer on chandelier
Family room	C	Ceiling Fl	Lamps CF	3-way switches
Hall	C or W	CF ceiling	CF wall	3-way switches
Bath	W	FL[1]	CF	Switch
Kitchen	C & W	FL	CF	Switch(es)
Utility room	C	FL	CF	Switch
Storage	C or W	FL	CF	Pull chain
Stairs	C or W	CF	FL indirect wall	3-way switches
Hall upstairs	C or W	CF ceiling	CF wall	3-way switches
Bedrooms	C and/or wall	CF, hidden FL wall[1]	Lamps CF, CF wall	Switch(es)
Basement, unfinished	C	FL	H	Switch(es) pull chains
Attic	C	H	I	Pull chain switch
Outdoor	W	CF[2]	H	Switch
Outdoor storage	C	H	I	Pull chain switch
Garage	C	CF[2]	H	Switch pull chain

FL = fluorescent, CF = compact fluorescent, H = halogen, I = incandescent.
[1]T8 48 in. 32 watt.
[2]If the temperature does not fall below 0°F and the lamp is enclosed by the light fixture, use a 20-watt screwbase compact fluorescent with electronic ballast.

4.2.19 Site Improvements

LANDSCAPING

Landscape material can be used in two ways to reduce energy consumption for space conditioning in a dwelling: (1) to shade the structure in the cooling season and (2) to reduce ambient wind velocities around the structure in the heating season.

Evaluate existing plant material noted in the inspection phase as to how it can contribute to the overall landscape of the site. Retain mature, healthy trees and large shrubs that provide shade to the south and west sides of the structure or adjacent pavement during the cooling season. Similarly, retain plant material, particularly evergreens, located on the windward side (typically northwest, north, or northeast) of the structure as it provides a wind break. This retention of plant material could require some modification of otherwise standard site designs to accommodate this material.

Revitalization projects that include funding for installing additional landscape materials should develop designs that implement energy conservation opportunities as well as meet aesthetic and other landscape objectives.

The use of deciduous trees and shrubs to shade south and west facing walls, particularly those that form the thermal envelope and contain windows, is strongly recommended. Trees that shade the roof of residences can markedly reduce attic temperatures. However, energy benefits are less with attics that are well insulated (which is usually the case). In climates where solar gain in the winter is a benefit, use care to select tree species without dense structures that cast significant shade even when not in leaf. This shading would reduce the benefits of solar gain in the heating season.

PAVEMENT

If practical, avoid significant amounts of pavement (e.g., parking aprons and patios) on the south and west sides of dwelling units with significant air conditioning requirements. Heat reflected from pavement within 10 ft of the structure can markedly increase heat gain through the windows and walls of conditioned space (if they are poorly insulated).

If it is impractical to remove or relocate pavement from these locations, attempt to shade these areas with deciduous trees.

4.2.20 Documentation of Analysis Process

Documentation is a two-step process. The first step summarizes the analysis process from Forms G.1–G.16 on Form G.17. The second step compares the performance of the revitalized unit with an optimum newly constructed unit. Details of these steps follow.

ANALYSIS SUMMARY

Enter the installation name, housing unit ID, and intentionally conditioned floor area of the existing unit on Form G.17. Also, enter the CAPS energy budget for an optimum, newly constructed unit of the same size, type, and location, as well as the estimated energy consumption intensity calculated for the current unit during the site inspection (see Sect. 4.1.1, “Energy Use Review”). The CAPS information is provided in the project’s Request for Proposal or Statement of Work and is explained in Sect. 3.2, “Selection of ECMs Using COSTSAFR.”

Summarize the impact of the individual component analyses performed following the procedures outlined in Sect. 4.2, “Analysis and Selection,” on Form G.17. This includes identifying envelope and equipment specifications for the housing unit both as it currently exists and as it will exist after revitalization and entering the energy savings from revitalization. Only the major revitalization activities that significantly affect energy consumption or for which energy savings projections can be made are included on Form G.17. This form will provide an indication of the impact of the cost-effective energy-efficiency improvements achieved by revitalization. Submit all forms to the program manager for review and approval.

COSTSAFR COMPARISON

In addition to completion of Forms G.1 to G.17, the designer shall complete the six-page COSTSAFR analysis forms (see Chap. 3, “Design, Analysis, and Selection of Options for New Housing,” for detailed methodology) provided in the project’s Statement of Work using the options determined to be cost-effective based on the criteria contained in this chapter. This task will provide a comparison of the energy performance of the revitalized unit to that of an optimum, newly constructed unit of the same size, type, and location. This comparison shall be submitted to the program manager for review and approval.

The point system used in the COSTSAFR analysis was developed to be applicable to new construction. It is unrealistic to expect revitalization to achieve energy-efficiency levels comparable in all cases to the COSTSAFR minimum required point total because of the limitations in dealing with existing building structures. Efficiency levels that can be achieved cost effectively in building a new structure may not be achievable cost effectively in revitalization because of added costs to remove equipment, expose areas for insulation, restore the building to finished condition, etc. An obvious example is wall insulation, which is cost effective to install during construction but may be prohibitively expensive under revitalization because of interior and exterior wall characteristics.

Nevertheless, the A/E should ensure that all possible energy-efficiency measures are considered and properly evaluated if the projected point total of the revitalized unit is less than 75% of the minimum point total of a comparable “new” unit. A first step would be to ensure that current efficiency levels and energy deficiencies were properly identified during the site inspections.

Chapter 5

SPECIFICATION OF SELECTED ENERGY-EFFICIENCY OPTIONS

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5.1 Overview

This chapter provides the A/E with the text of specifications for use in revitalization and new construction projects as a supplement to specifications cited in the project's Request for Proposal or Statement of Work and applicable military standards manuals identified in Sect. 2.2, "Design, Analysis, and Selection of Options for New Housing,"and Sect. 2.3, "Design, Analysis, and Selection of Options for Revitalized Housing."

5.2 Infiltration Repair Specifications and Construction Tips

Use the following materials and procedures to correct identified infiltration deficiencies in the building envelope.

MATERIALS

Apply sealants after thoroughly removing moisture, dust, dirt, oil, grease, or other substances which may diminish the bond of the sealant material.

Mastic and Fiberglass Tape (Fiberglass Mesh)

Mastic sealants are available in water-based form for sealing penetrations and repairing holes in walls and ceilings. Water-based mastics are preferable to petroleum-based mastics because of shorter curing times, easier cleanup, and more "forgiving" application characteristics. When used with fiberglass tape, mastic can seal and provide strength to repairs of practically any configuration. Mastic should generally be applied over the entire joint between mated surfaces and must not be diluted.

Mastic sealants shall conform to the following safety requirements of Underwriters Laboratory (UL) Standard 181, Class 1:

- a flame spread rating of less than 25 and
- a smoke development rating of less than 50 in the dry, final state.

In addition, the mastic sealants shall conform to these characteristics:

- a solids content greater than 50% to reduce shrinkage on drying;
- the capability to adhere to many surfaces—sheet metal, drywall, fiberboard, concrete, wood, and plastic; and
- a temperature range that includes the highest and lowest temperatures likely to be encountered.

Urethane Foam

This material shall have the same safety requirements as mastic sealant and shall be UL rated.

Caulking

Long-lasting (20 years or more) silicone caulking materials are required for sealing leaks in building envelopes. A treated variety must be used if the caulking will be painted. This material shall have the same safety requirements as mastic sealant and shall be UL rated.

Blocking Materials

For large voids that cannot be sealed with fiberglass tape and mastic, rigid fiberglass or fiberboard of 0.5 in. or more in thickness shall be cut to shape and sealed in the void space with mastic, urethane foam, or caulk. The following alternative materials may be used when approved by the military inspector on the project: corrugated cardboard, plywood, and plastic bags filled with fiberglass insulation. Large voids typically occur at electrical and plumbing penetrations and in attic bypasses such as unblocked walls.

Flashing

Metal flashing cut to shape must be used to close gaps around flues and chimneys to avoid placing combustible material next to those hot surfaces.

PROCEDURES

Seal penetrations, gaps between materials, and holes in walls using the materials described previously and using the following procedures:

Penetrations

Use urethane foam for sealing around electrical and plumbing penetrations because it expands to fill the void totally as it cures. Mastic and fiberglass tape may be used for this application if urethane foam is unavailable. Use metal flashing and fireplace mortar to seal around flues and chimneys, as combustible material must not be placed adjacent to those hot surfaces.

Holes and Gaps in Walls and Ceilings

Mastic and fiberglass tape shall be used in most cases to seal these types of leaks. For larger holes (2-in. diameter), use fiberboard to fill the hole or gap, and use mastic or caulk to seal around the filler.

Attic Bypasses and Voids Around Plumbing Chases

These usually larger voids require a fiberboard filler to be cut to fit the shape of the void. Seal these with mastic, caulk, or urethane foam.

Sill Plate to Band Joist Seal

Apply urethane foam to fill all gaps and voids between the sill plate and band joist.

5.3 Infiltration Performance Testing of Housing Units

BLOWER-DOOR TESTING

Randomly selected new and/or revitalized housing units shall be tested to determine the compliance of the unit with the allowable air-leakage rate specified for the building envelope. Units shall be selected by the program manager. Testing shall be performed by a firm qualified to perform inspections using blower doors in accordance with procedures specified in Appendix C for building envelope testing. The testing firm shall be independent of the installing contractors or equipment suppliers for this project. The specifications provided in Appendix B can be used to hire a qualified firm.

PERFORMANCE REQUIREMENTS

Building envelope air leakage shall be greater than or equal to (*enter minimum value determined from Sect. 4.2.6*) but no more than (*enter maximum value determined from Sect. 4.2.6*) natural air changes per hour.

NUMBER OF TESTS REQUIRED

Infiltration testing shall initially be performed on 10% of the housing units (e.g., 10 of 100 housing units). If 90% of the tested units pass the stated performance requirements (e.g., nine of the ten tested units), no additional testing will be required. If less than 90% of the initial sample pass (e.g., fewer than nine units), then the failed units shall receive corrective action and be retested, and an additional 10% of the housing units (e.g., ten additional units) shall be tested. If 90% of the tested units pass (e.g., 18 of the 20 tested units), no additional testing will be required. This testing procedure shall continue in groups of 10% throughout the new and/or revitalized housing units until at least 90% of the tested units comply with the stated performance requirements.

Infiltration testing may be performed after completion of all housing units being constructed or revitalized under the project. However, testing the building envelope on an ongoing basis is recommended to avoid replicating the same deficiencies in units yet to be constructed or revitalized. In this case, for example, a 100-housing-unit project could be divided into five groups of 20 units. Testing would be performed on 2 of the first 20 housing units completed. If both units pass, no additional testing would be required for the first group of 20 housing units. After the second group of 20 housing units are completed, 2 of these 20 units would be tested to determine if the second group of housing units passes. Testing by group would continue until all housing units were completed.

CORRECTION OF AIR-LEAKAGE DEFICIENCIES

The contractor shall supply all labor and material required to make the leakage of all tested units conform to the stated performance requirements. Units initially failing to meet the stated performance requirements shall be retested to verify their conformance after corrective actions have been accomplished.

Windows and glass exterior doors (doors whose surface is 50% or more glazed) shall meet the following standards and must be certified by an independent test laboratory. Windows that slide (double-hung, single-hung, and horizontal sliding) and glass exterior doors shall meet the standards for "hung" windows that follow. Standards for casement windows shall refer to all hinged or fixed windows. Jalousie windows, greenhouse windows, and other unspecified types of windows may not be used unless they are tested and conform to the standards for hung windows.

Windows shall meet the following design pressure standards as designated by the National Fenestration Rating Council:

- hung: DP25 (corresponds roughly to former Grade 40), and
- casement: DP40 (corresponds roughly to former Grade 60).

The following specific tests and minimum standards are required to achieve these design pressure standards.

- Operating force: The force necessary to unlatch and open the window shall not exceed 30 lb for hung and 35 lb for casement.
- Air infiltration: Using ASTM E 283, "Standard Test Method for Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors," the rate shall not exceed 0.25 cfm/ft^2 for hung and 0.15 cfm/ft^2 for casement at a test pressure of 1.57 psf.
- Water penetration: Using ASTM E 547, "Standard Test Method for Water Penetration of Exterior Windows, Curtain Walls, and Doors by Cyclic Static Air Pressure Differential," there shall be no water penetration at 3.75 psf in three 5-minute cycles with a 1-minute rest between cycles for hung, and at 6.00 psf for casement.
- Structural testing—Using ASTM E 330, "Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference," there shall be no glass breakage, damage to hardware, or permanent deformation that would cause any malfunction or impair the operation of the unit. Residual deflection of any member shall not exceed 0.4% of its span. Windows shall be subjected to pressures of 37.5 psf for hung and 60 psf for casement.
- The maximum U-value for the whole window shall not exceed the following:

  — hung: 0.50 U-value (not less than R-2), and

  — casement: 0.40 U-value (not less than R-2.5).

The U-value shall be calculated using ASTM E 1423, "Standard Practice for Determining the Steady State Thermal Transmittance of Fenestration Systems," and\or the National Fenestration Ratings Council's NFRC 100-91, "Procedure for Determining Fenestration Product Thermal Properties."

Double-glazed units shall have a nominal air space of at least 3/8 in. but not more than 1 in. The low-E coating, if present, must have an emissivity value less than 0.40.

The manufacturer of the window must present a copy of a letter from an independent testing laboratory certifying the performance of the window supplied by the manufacturer. This letter must state that a window comparable to the one being used has been tested and meets or exceeds the standards outlined.

Manufacturers of wood or wood-clad windows must present a written statement declaring that the wood is preservative-treated in accordance with the latest version of

NWWDA Industry Standard I.S.4, “Water Repellent Preservative Treatment for Millwork.”

It is the installer’s responsibility to obtain the installation specifications from the manufacturer of the window being installed and to install, insulate, and finish (paint) the window according to those specifications.

FURNACES AND BOILERS

The AFUE rating of all new furnaces and boilers—as determined in Sect. 4.2.11, "Heating and Cooling Equipment Replacement Selection," or 4.2.12, "Heating and Cooling Equipment Selection"—shall be specified for newly purchased units. All new gas-fired units shall have intermittent ignition devices (IIDs). A new condensing furnace that will be installed inside the housing unit shall be a sealed-combustion unit that uses 100% outside air for combustion. A new flue or chimney liner shall be specified with the installation of a new furnace or boiler if it is required to meet building codes, to maintain a proper draft, or to ensure material compatibility with the new flue gas conditions. A new flue or chimney liner shall be specified for the hot water system if a new condensing system is installed.

The commissioning procedure outlined in this section shall be specified for all new furnaces and boilers to ensure correct installation and operation of the unit.

AIR CONDITIONERS

The SEER rating as determined in Sect. 4.2.11, "Heating and Cooling Equipment Replacement Selection," or Sect. 4.2.12, "Heating and Cooling Equipment Selection," shall be specified for newly purchased units. Specify condensing (outside) units to be equipped with a housing that protects the fins (units shall not have exposed plate-type fins). Specify the location of the outdoor unit so that there are no restrictions around it (such as shrubs and decks) that block airflow or promote recirculation. Specify a clear area around the outdoor unit of at least 2 ft. Specify the outdoor unit location to be greater than 6 ft from the exhaust of the clothes dryer.

The commissioning procedure outlined in this section shall be specified for all new air conditioners to ensure correct operation of the unit.

HEAT PUMPS

Specifications for new heat pumps are the same as for air conditioners with one addition. Specify that heat pumps with resistance heaters shall have an outdoor thermostat to prevent the resistance heaters from turning on at ambient temperatures above 45°F or other preselected temperature.

The commissioning procedure outlined in this section shall be specified for all new heat pumps to ensure correct operation of the unit.

INTERMITTENT IGNITION DEVICES

Field-installed IIDs shall be certified by the American Gas Association (see the association's *Directory of Certified Appliances and Accessories*, "Automatic Intermittent Pilot Ignition Systems for Field Installation").

COMMISSIONING AND TUNE-UP OF FURNACES AND BOILERS

The contractor shall commission all newly installed fossil-fuel-fired heating systems and tune up all existing systems by completing the following tasks.

1. Perform a visual inspection of gas- and oil-fired systems to ensure safe operation. Check for the presence of an electrical cutoff switch, proper grounding, insecure wiring, or combustible materials near the flue. Verify the adequacy of combustion air. Inspect the furnace heat exchanger for cracks and any evidence of flame roll-out. Inspect the flue and chimney for structural decay, leaks, accumulation of deposits, and the presence of a flue liner. For fuel-oil systems, verify the presence of a filter and a shutoff valve in the fuel supply line and the

presence and functional condition of a barometric damper in the flue connection. Inspect the fuel supply line and storage tank for leaks. Correct all deficiencies found.

2. For furnaces, set circulation fan “off” limit switches at 90–95°F and high-limit switches at 200–250°F, or set the switches in accordance with manufacturer specifications if they differ. Circulation fan “on” limit switch settings for furnaces are system dependent. Choose the lowest possible temperature setting that avoids “rocking on” or cycling of the fan after the burner has shut off, generally from 120°F to 160°F. For boilers, set system operating temperatures and high-limit switch settings to standard recommended values of the manufacturer.

3. Adjust each burner under the guidance of combustion analysis to maximize its steady-state efficiency. Measure the percentage oxygen reading and net stack temperature to calculate the steady-state efficiency. Adjust this efficiency for smoke number for oil-fired systems. For existing oil-fired systems, targets are to achieve at least a steady-state efficiency of 80% with a flue gas containing 7% oxygen and a smoke number 1.

4. Measure the carbon monoxide level in each burner after the burner has run continuously for 5 minutes. Adjust the burner if carbon monoxide readings greater than 250 ppm occur. Adjustments include cleaning burners and eliminating heat exchanger obstructions. Also, make carbon monoxide measurements 5 ft from the space-heating system and in the living area of the housing unit. Readings greater than 5 ppm indicate leakage from the furnace or flue. Identify and correct the source of the carbon monoxide leakage in these areas.

5. Use at least one of several methods to ensure that heat exchangers are not cracked in furnaces. Measure the percentage oxygen reading in the flue immediately before and after the fan turns on. A change in the reading indicates a cracked heat exchanger. Additionally, observe the burner flame to see if it changes when the fan turns on. Again, a change indicates a cracked heat exchanger.

6. Limit the temperature rise across the heat exchanger of a furnace to 80°F and the exit temperature of supply air to 160°F by maintaining adequate airflow. Try to keep the temperature rise across the heat exchanger within the upper half of the range specified by the manufacturer for new equipment. Current airflow can be measured at return grills using a hand anemometer, measuring the area of the return opening and accounting for the area of the grill if it remained in place while the velocity measurements were taken.

7. Perform draft measurements to ensure that adequate draft is present and that spillage is minimized. Measure the draft with the system off first. After turning the system on, record the draft at 1-minute intervals for 3 to 5 minutes, as well as the time needed to stop spillage. Spillage can best be observed using chemical smoke. Drafts of 0.02 to 0.06 in. water shall be obtained. Spillage shall stop within 30 seconds.

8. For the condensing system, verify the correct installation of the exhaust and air intake pipes. The exhaust pipe must be pitched at least 1/4 in. per foot so that condensate can drain back to the furnace. Supports must be adequate so that the exhaust pipe does not sag between supports. The exhaust pipe must be sized following manufacturer instructions. The air intake pipe (if present) must be located away from dryer vents and power-vented water heaters so that it does not draw in contaminated air. Exhaust and

air intake pipes must be run out the same side of the housing unit and be located above anticipated snow levels.

9. Verify the correct operation of the thermostat by checking the anticipator setting (if present) and the cut-on and cutoff temperatures relative to the set point.

10. Other tasks to be performed include checking and adjusting the manifold pressure of gas-fired systems, adjusting belt tensions, checking the condition and operation of the circulation fan of furnaces, checking the condition and operation of circulating pumps of boilers, checking the operation of zone valves of boiler systems, and using a gas detector to identify the presence of gas leaks.

11. Document the commissioning/tune-up results by providing the military inspector for the project with the following information:

- initial and final steady-state efficiencies,
- net stack temperature,
- oxygen concentration,
- smoke number (oil only),
- circulation fan “on” and “off” limit temperatures,
- high-limit temperature,
- carbon monoxide levels,
- temperature rise across heat exchanger,
- draft readings, and
- deficiencies found and corrective actions taken.

COMMISSIONING AND TUNE-UP OF AIR CONDITIONERS AND HEAT PUMPS

The following tasks shall be accomplished in commissioning new or tuning up existing equipment.

1. Measure the airflow rate across the indoor coil. The rate must be 350 to 450 cfm per ton of cooling capacity for efficient operation. This rate must be established before the system can be correctly charged.

2. For new systems that are not precharged, charge the system by weighing in the proper amount of refrigerant according to nameplate or manufacturer instructions after accounting for the length of refrigerant lines.

3. For all systems, check and adjust the refrigerant charge based on superheat and subcooling measurements made with the system operating in the cooling mode. These measurements give the most reliable results when the ambient temperature is greater than 80°F. For heat pumps that must be tuned up in the winter, check and adjust the refrigerant charge based on the hot gas temperature method. Use this method only when conditions prevent the use of the superheat and subcooling method. The charge shall not be adjusted based on performance curves or noninstrumented approaches.

4. Ensure that the air temperature difference across the indoor coil is 15 to 20°F when the system is operating in the cooling mode.

5. Perform a visual inspection to ensure safe operation of the system. Inspect the fused disconnect, wiring, contactors, relays, pressure controls, and other electrical safety circuits. Tighten electrical connections as needed and correct any deficiencies found.

6. Verify the correct operation of the thermostat by checking the anticipator setting (if present) and the cut-on and cutoff temperatures relative to the set point. For heat pumps, check the operation of resistance heaters to ensure that they are wired correctly to their control circuits (they cycle correctly, are staged correctly, and are not on all the time). Also, test the defrost operation of heat pumps.

7. Other tasks to be performed include checking the voltage and amperage to all motors, cleaning the indoor fan if dirt has built up (especially if the airflow across the indoor coil is less than 350 cfm per ton of cooling capacity), checking bearings, lubricating all moving parts as required, checking and adjusting belt tension, inspecting and cleaning the condensate drain if necessary, and cleaning the outdoor and indoor coils if necessary. As an option, perform a meggar test of hermetically sealed compressors to check the condition of electrical insulation.

8. Document the commissioning/tune-up results by providing the military inspector for the project with the following information:

- airflow rate across the indoor coil and the capacity of the unit;
- initial and final measurements used to charge or check the charge of the system;
- temperature difference across the indoor coil; and
- deficiencies found and corrective actions taken.

5.6 Air Distribution System Repair and Construction Specifications

Use the following materials and procedures to install new ductwork and to correct identified infiltration deficiencies in existing ductwork.

DUCT MATERIALS

New duct systems or replacement ducts shall be fabricated from sheet metal, rigid fiberglass, or fiberboard using the following guidelines. Systems constructed entirely of flexduct are not permitted. However, flexducts may be used as branch connections to supply registers in only those cases where space limitations and short distance runs make installation of metal or fiberboard ducts prohibitively costly or difficult.

Mechanical fasteners shall be used to secure all joints between sections of duct, especially between sections of air ducts and plenums, ducts and terminal fittings, connections at the air handler equipment, connections of branch ducts to main trunk ducts, and duct sections constructed of different materials. Materials intended to seal against air leaks— such as mastics, caulks, and fiberglass tape—shall not be used to fasten sections of duct together.

Metal Ducts

Install metal ducts according to *Duct Construction Standard—Metal and Flexible* (SMACNA 1985, first edition). Seal joints and connections in metal ductwork in accordance with Table 5.1. Fasten transverse joints that are friction-fitted with at least three metal screws equally spaced around the joint. Insulate metal ducts in unconditioned spaces (e.g., attics, crawl spaces, garages) to an insulation value of at least R-6. Wrap the outside of ducts with foil-faced fiberglass batts that are attached with metal-faced duct tape.

Rigid Fiberglass (Fiberboard) Ducts

Fabricate fiberboard ducts from ductboard with metal facing on the outside surface. Fiberboard ducts shall be either round (preformed off site) or rectangular (formed on site from precut, standard-size sections). Install fiberboard ducts according to *Fibrous Glass Duct Construction Standards* (SMACNA 1992, sixth edition). Fiberboard duct sections shall be fastened together using clinching staples. Fiberboard shall provide an insulation value of at least R-6. Lap and seal on-site joints with a combination of fiberglass mesh and mastic (see Table 5.1).

Flexible Ducts (Flexducts)

Prefabricated, round ducts with 2- to 12-in. diameters shall each have an inner, flexible, nonporous core of plastic supported by a metal coil for strength. An outer liner shall enclose fiberglass insulation between the core and the outer liner to provide an insulation level of at least R-6. Acceptable flexduct shall be air-duct rated by National Fire Protection Association 90B, "Warm Air Heating and Air Conditioning Systems," 1989, and shall meet the testing requirements of Standard UL-181 for factory-made air ducts and air connectors.

Install flexduct according to *Duct Construction Standard—Metal and Flexible* (SMACNA 1985, first edition). Seal joints between flexducts and metal collars and register boots at the inner core with approved mastic or joint sealant as directed in Table 5.1. Install flexducts so that their length is minimized. Flexduct bends shall not exceed 90 degrees and must have a radius greater than one diameter. Flexducts shall be mechanically fastened to all metal ducts and metal fittings using drawbands that are preferably metal. Flexducts must be fastened to fiberboard ducts using twist-in

Table 5.1. Sealing requirements for duct systems		
Duct joint or connection	System replacement and/or extension	System repair
Transverse joints in round metal ducts, consecutive lengths	Screw metal joint, mastic and fiberglass tape[a] seal	Screw metal joint, mastic and fiberglass tape[a] seal
Snap-lock joints in round or rectangular metal ducts	None	None
Metal collar to metal or fiberboard duct or junction box	Mastic	Mastic
Metal elbow swivel joints	None	None
Joints in fiberboard ducts	Mastic plus fiberglass tape	Mastic plus fiberglass tape
Return main connection to return grill	Secure with screws and caulk gaps	Add blocking material as necessary, caulk gaps
Return duct joints	Rectangular metal—no joint seal Sheetrock—not allowed	Rectangular metal—no joint seal Sheetrock—mastic joints
Air handler return platform	Sheetrock to framing, caulk or mastic joints	Sheetrock or ductboard to framing, caulk or mastic joints
Building return cavities	Rectangular metal duct	Mastic or caulk joints
Flexduct to metal collars at connections or duct boots	Seal inner liner to collar with mastic, minimum 1-in. overlap; use band around outer liner.[b]	Seal inner liner to collar with mastic, minimum 1-in. overlap; use band around outer liner.[b]
Plenums to air handler	Mastic or caulk	Mastic or caulk
Air handler penetrations	Metal-faced tape	Metal-faced tape
Panned floor joist returns	Not allowed	Remove metal pan and caulk all joints; replace metal pan and caulk joints.
Floor truss cavity or stud bay cavity returns	Remove when possible; replace with rectangular metal ductwork.	Remove when possible; replace with rectangular metal ductwork.
Floor cavity returns	Mastic or caulk joints and penetrations	Mastic or caulk joints and penetrations

[a]Use for gaps more than 1/8–1/4 in. wide.
[b]Metal or nylon bands are required in attics with temperatures above 120°F.

(screw attachment) bend-tabs or screw-tabs and flanges.

JOINT SEALANTS

Apply the following sealants as specified in Table 5.1 after thoroughly removing moisture, dust, dirt, oil, grease, or other substances that may diminish the bond of the sealant material.

Mastics and Fiberglass Tape (Fiberglass Mesh)

Use water-based mastics with fiberglass tape to seal and provide strength to all joints. Water-based mastics are preferable to petroleum-based mastics because of shorter curing times, easier cleanup, and more "forgiving" application characteristics. When used with fiberglass tape, mastic can seal and provide strength to repairs of practically any configuration. Mastic should generally be applied over the entire joint between mated surfaces and must not be diluted. Use fiberglass mesh when gaps are larger than 1/8 in.

Mastic sealants shall conform to the following safety requirements of UL Standard 181, Class 1:

- a flame spread rating of less than 25, and
- a smoke development rating of less than 50 in the dry, final state.

In addition, the sealants shall conform to these characteristics:

- a solids content greater than 50% to reduce shrinkage on drying;
- the capability to adhere to many surfaces—sheet metal, drywall, fiberboard, concrete, wood, and plastic; and
- a temperature range that includes the highest and lowest temperatures likely to be encountered.

Caulking

Long-lasting (20 years or more) silicone caulking materials are required for sealing leaks in duct systems. This material shall have the same safety requirements as mastic sealant and shall be UL rated.

Gasketing

Joints can be sealed using gasketing material placed between the surfaces to be mated and fastened with sufficient force to compress the gasketing material. All voids and cracks at the joint must be filled by the gasketing material.

Duct Tape

Metal-faced pressure sensitive or heat-activated tapes that meet UL Standard 181 shall be used only for sealing penetrations and joints on equipment where access for maintenance is required. Fabric duct tape or tape with rubber-based adhesives is prohibited as a sealing material except as a temporary material to support a joint during fabrication. Remove all fabric tape before the completion of the installation. Pressure-sensitive tape must be applied using a squeegee (rather than by hand), and to surfaces that are at the proper temperature as prescribed by industry standards.

INSTALLATION PROCEDURES FOR NEW DUCTWORK

Size duct systems according to the Air-Conditioning Contractors of America (ACCA) Manual J, and design duct systems according to the ACCA's Manual D. Submit design forms to the contracting officer. Follow the previously outlined material specifications for ducts and joint sealants, the requirements in Table 5.1, and the procedures outlined below.

Return Ducts

Return ducts shall be constructed with the following additional requirements:

1. Locate return ducts in the conditioned space whenever practical to minimize exchange with unconditioned air.

2. Use of building cavities, building framing, floor truss cavities, and panned floor joists for return ducts is prohibited.

3. Enclose raised floor platforms and other return plenums for furnaces and air handlers with drywall and seal all penetrations and joints with mastic or caulk.

4. Provide a separate return duct for each level of a multilevel unit.

5. Attach and seal return ducts to the wall at return grills to isolate building cavity air from the return duct.

Supply Ducts

Supply ducts shall be constructed with the following additional requirements:

1. Locate supply ducts within the conditioned space whenever practical.

2. Extend duct boots at supply registers through the wall, ceiling, or floor material with registers tightly fitted to duct boots to prevent loss of conditioned air to the building cavity.

Air Handler

Use the following procedures to eliminate air leaks at the air handler:

1. Seal penetrations, seams, and gaps in the air handler cabinet with metal-faced duct tape or “tape applied mastics” (foil tapes with 15 mil or thicker butyl adhesive).

2. Seal joints between the air handler cabinet and the main supply and return ducts or plenums with mastic or caulk.

Supports

Support ductwork at intervals of no more than 5 ft. Fiberboard ducts and flexducts in attics may require additional support when elevated above floor joists. Supports shall be metal hangers or other materials that will not penetrate the duct surface.

REPAIR PROCEDURES

Follow the material specifications for ducts and joint sealants outlined previously. When insulation on sheet-metal ductwork is either damaged or nonexistent, attach foil-faced fiberglass batts rated at R-6 or more with metal-faced duct tape. Follow the sealing requirements for “system repair” specified in Table 5.1 to repair existing ductwork. Pull back or remove insulation to expose joints. Remove all fabric duct tape encountered.

Supply Ducts

Use the following procedures to repair existing supply ducts:

1. Seal gaps between supply boots and supply registers with fiberglass tape, mastic, and blocking material to prevent loss of conditioned air.

2. Fasten joints in round metal ducts that leak from lack of sealant (i.e., that are fastened with fabric tape only) with sheet metal screws and seal with mastic and fiberglass tape.

Return Ducts

Use the following procedures to repair existing return ducts:

1. Seal gaps between return ducts, return grills, and the wall at return grills to isolate building cavity air from the return duct.

2. Seal the joints in return ducts made of drywall with mastic where they are accessible.

3. Interior walls under a raised floor furnace or air handler platform shall have drywall or ductboard securely attached to the framing.

Seal all penetrations and joints with mastic or caulk.

4. Replace panned floor joist returns with new ductwork or seal all interior and exterior joints with caulk or mastic. Block off any connections to building cavities.

Air Handler

Use the following procedures to repair air leaks at the air handler:

1. Seal penetrations in the air handler cabinet with metal-faced duct tape or “tape applied mastics” (foil tapes with 15 mil or thicker butyl adhesive).

2. Seal joints between the air handler cabinet and the main supply and return ducts or plenums with mastic or caulk.

5.7 Air Distribution System Performance Testing

DIAGNOSTIC TESTING

Randomly selected new and/or revitalized housing units shall be tested to determine the compliance of the unit with the allowable air-leakage rate specified for the air distribution system. Units shall be selected by the program manager. Testing shall be performed by a firm qualified to perform inspections using blower doors in accordance with procedures specified in Appendix E for air distribution system testing. The testing firm shall be independent of the installing contractors or equipment suppliers for this project. The specifications provided in Appendix B can be used to hire a qualified firm.

PERFORMANCE REQUIREMENTS

Air distribution system air leakage shall be less than or equal to 150 cfm when the system is pressurized at 50 Pa.

Appendix A

ENERGY INSPECTION FORMS FOR MILITARY FAMILY HOUSING UNITS

MILITARY FAMILY HOUSING:
ENERGY INSPECTION FORMS

IDENTIFICATION

Installation name: ____
Housing unit ID: ____
Housing unit address: ____
Inspector:____
Affiliation:____
Inspection date: ____

GENERAL

Type:___________

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

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

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

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

Are the following systems shared with other housing units:

space-heating system_____(Y, N)
space-cooling system_____(Y, N)
water-heating system_____(Y, N)

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

If MFS or MFL, number of housing units: Beside_____
Above_____
Below_____

Housing unit ID:________

FLOOR AREAS AND VOLUMES

Floor	Total area[a] (ft^2)	Intentionally heated area[a,b] (ft^2)	Intentionally air-conditioned[a,b] area (ft^2)	Average ceiling height[c] (ft)	Volume (ft^3)
Basement					
First floor					
Second floor					
All other floors					
Totals					

[a]Areas are gross areas that include internal storage closets, etc. rather than net areas as defined by the military.

[b]An intentionally conditioned space is one with equipment and/or distribution outlets designed to maintain a desired temperature in the space. An unintentionally conditioned space is one that is conditioned primarily from equipment jacket and/or distribution losses (there is little control over the resulting temperature). A space is not conditioned if there is no source to alter the natural temperature of the space. For example, a basement heated primarily from equipment jacket and/or distribution system losses is an unintentionally conditioned space rather than an intentionally heated space. A window air conditioner cools only the room the unit is installed in, not adjacent rooms. If a space was designed to be intentionally conditioned but is maintained by the occupant in an unconditioned state (by closing registers and doors, for example), the space should still be considered a conditioned space.

[c]Floor heights used to calculate volume are floor to floor, except for the top floor, which is floor to ceiling. For cathedral ceilings, use average of maximum and minimum heights.

Number of intentionally heated stories:________(1, 1.5, 2, 2.5, etc.)

Number of intentionally cooled stories:________(1, 1.5, 2, 2.5, etc.)

Housing unit ID:________

THERMAL BOUNDARY

Provide a sketch of the floor plan(s) and the sections of the unit being revitalized indicating the location of the thermal boundary. Identify insulated and uninsulated areas along the boundary.

Housing unit ID:________

EXTERIOR WALLS

Wall location (keyed to floor plans)	Wall type	Wall exposure	Exterior finish	Gross wall area (ft^2)	Existing insulated sheathing	Existing cavity insulation		Vapor barrier present (Y,N)
						Type	Thickness (inches)	

Shared walls found in duplexes, quad-plexes, and multifamily structures are not exterior walls.

Wall type (type of load-bearing structure):
FR—frame, BL—block, ST—stone or masonry, X—other

Wall exposure:
O—outside, N—nonconditioned attic space, B—buffered space (garage, etc.)

Exterior finish:
WO—wood or masonite, AL—aluminum, steel, or vinyl, ST—stucco, BR—brick or stone, AS—asphalt shingle, X—other, N—none

Insulated sheathing:
Y—yes (present), N—not present, U—unknown

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

Housing unit ID:________

FOUNDATION SPACES

Type	Space status	Joist		Perimeter		Wall			
		Area[a] (ft^2)	Insulation thickness (inches)	Length[b] (ft)	Percent[c] insulated	Height[d] (ft)	Percent above ground	Existing insulation type	Thickness (inches)
IS									
US									

[a]For slab-on-grade, the area of the intentionally conditioned slab floor.
[b]Do not include perimeter bordering another foundation space.
[c]The percentage of band (rim) joist length that is exposed to the outside and insulated.
[d]Height of basement or crawlspace wall; an estimated average if the height is not uniform.

Type:
B—basement, C—crawl space, IS—insulated slab, US—uninsulated slab

Space status:
NC—nonconditioned space, IC—intentionally conditioned space, UC—unintentionally conditioned space

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

Vapor retarder present on crawl space floor?________(Y, N, NA)

Housing unit ID:________

ATTICS

UNFINISHED ATTIC AREAS					
		Existing insulation			
Attic type	Floor area[a] (ft^2)	Type	Depth (inches)	Radiant barrier present (Y, N)	Vapor barrier present (Y, N)

FINISHED ATTIC AREAS						
			Existing insulation			
Location	Attic type	Area[a] (ft^2)	Type	Depth (inches)	Radiant barrier present (Y, N)	Vapor barrier present (Y, N)
Outer joist						
Collar beam						
Kneewall						
Roof rafter						

[a]Areas must be adjacent to intentionally or unintentionally conditioned spaces only. For example, the area above an unconditioned garage should not be included.

Attic type:
F—floored, U—unfloored, C—cathedral, F—flat roof

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

Attic access hatches insulated?_____ (Y, N, NA)

Attic access hatches weatherstripped?_____(Y, N, NA)

Comments concerning blocking, uniformity of insulation depth, and attic ventilation: _____________

____

Housing unit ID:________

INFILTRATION

BASEMENT/CRAWL SPACE		
Inspection point	Infiltration problem	Evaluation of conditions
Floor penetrations—electrical service	Gaps around conduits	
Floor penetrations—plumbing service	Gaps around piping	
Floor penetrations—air ducts	Gaps around ducts	
Floor penetrations—general	Holes for air leakage	
Sill plate	No seal at sill plate	
MAIN FLOOR(s)		
Exterior wall penetrations under sinks and appliances	Holes and gaps	
Exterior walls	Holes and gaps	
ATTIC		
Ceiling penetrations—electrical service	Gaps around conduits	
Ceiling penetrations—plumbing service	Gaps around piping	
Ceiling penetrations—air ducts	Gaps around ducts	
Ceiling penetrations—general	Holes for air leakage — at top of interior or exterior walls — at dropped ceilings — other	
Plumbing and duct chaseways	Attic bypasses	
Attic hatch	Poor seal	

Housing unit ID:________

WINDOWS AND GLASS DOORS

Wall code	Glazing type	Frame type	Storm window type	Storm window condition	Height (inches)	Width (inches)	Weather-stripping	Number of windows	Total area (ft^2)

Glazing type:
SP—single pane, DP—double pane, TP—triple pane, GB—glass block, TE—temporary (cardboard, plastic, etc.), X—other

Frame type:
W—wood, M—metal, MTH—metal with thermal breaks, V—vinyl, X—other, N—none

Storm window type:
W—wood, M—metal, X—other, N—none

Storm window condition:
A—adequate, R—needs replacement

Weather stripping:
A—adequate, R—needs replacement

Housing unit ID:________

EXTERNAL DOORS

Wall code	Door type	Height (inches)	Width (inches)	Storm door (Y, N)	Condition		
					Storm door	Weatherstripping	Threshold

Door type:

H—hollow core wood, S—solid core wood, P—paneled wood, M—metal,
MTH—metal with thermal break, X—other

Condition:

A—adequate, R—needs replacement

Housing unit ID:________

SPACE-HEATING SYSTEM

Primary System	
System type	
Fuel type	
System age	years
Location in housing unit	
Manufacturer	
Model	
Input rating	
Output rating	
Efficiency (rated)	%
Pilot light (Y,N,NA)	
Pilot light on over summer (Y,N,NA)	
Other efficiency measures	

Auxiliary Systems		
Type	Fuel	Number

Space-heating system types:

Central systems:
1—forced air furnace, 2—gravity furnace, 3—steam boiler, 4—hot water boiler with radiators/convectors, 5—hot water boiler for slab heating, 6—heat pump

Fossil fueled in-space heaters:
7—room heater, 8—forced-air wall furnace, 9—gravity wall furnace, 10—forced air floor furnace, 11—gravity floor furnace, 12—vaporizing pot heater (oil and kerosene), 13—portable kerosene

Electric in-space heaters:
14—wall, 15—floor, 16—baseboard, 17—ceiling radiant (imbedded cable), 18—wall or floor radiant (imbedded cable), 19—portable (cord-connected), 20—window heat pump

Fuel:
NG—natural gas, P—propane, O—oil, E—electricity, X—other

Location:
NC—nonconditioned space, IC—intentionally conditioned space, UC—unintentionally conditioned space

Other efficiency measures:
V—vent damper, I—intermittent ignition device, F—flame retention burner, O—outdoor temperature reset (boilers only), G—gas power burner, X—other, N—none

Housing unit ID:________

AIR CONDITIONER OR HEAT PUMP

System type	Manufacturer	Model	Age (years)	Input (watts)	Output (Btu/h)	Efficiency

System type:

CACS—central A/C split unit
CHPS—central heat pump split unit
WAC—window A/C
EC—evaporative cooler
X—other
CACP—central A/C package unit
CHPP—central heat pump package unit
WHP—window heat pump
GP—gas pack

Are there problems of air recirculation at the outdoor coil? ________(Y, N, NA)

If yes, describe:____
____
____

Is there plant material next to the outdoor coil that could contribute to clogging of the coil? ________ (Y, N, NA)

HEATING AND COOLING SYSTEM CONTROLS

Thermostats operating correctly?________(Y, N, NA)

Setback thermostat installed?________(Y, N)

If yes, does it have automatic switchover between heating and cooling?_____(Y, N)

Is the thermostat located in a central part of the housing unit, where the temperature would be representative of the primary living area of the unit?________(Y, N)

Is the thermostat located on an interior wall?________(Y, N)

Does the wall cavity behind the thermostat allow air to circulate from the attic or basement/crawl space?________(Y, N)

Housing unit ID:________

AIR DISTRIBUTION SYSTEM

Duct function[a]	Duct type[b]	Location[c]	Joint seal condition[d]	Structural integrity[e]	Insulation condition[f]	Comments

[a]Duct function: SP—supply plenum; ST—supply trunk; SB—supply branch; RP—return plunum; RD—return duct.

[b]Duct types: DB—duct board, SM—sheet metal, FD—flexduct, PFJ—panned floor joists, SBC—stud bay cavities, X—other

[c]Location: A—attic, CB—conditioned basement, UB—unconditioned basement, H—hallway ceiling, C—crawl space, G—garage

[d]Joint condition: G—good; F—fair, minor leakage; D—deteriorated, needs replacement

[e]Structural integrity: G—good, F—fair, minor leakage; D—deteriorated, needs replacement

[f]Insulation condition: G—good; F—fair, minor repairs, D—degraded, replace, N—none.

Housing unit ID:__________

DOMESTIC WATER-HEATING SYSTEM

Type (SA—stand alone, T—tankless, X—other)	
Fuel (NG—natural gas, O—oil, E—electricity, X—other)	
Age	years
Manufacturer	
Model	
Upper heating rate (kW, Btu/h)	
Lower heating rate (electric systems only)	kW
Capacity	gallons
Location (NC—nonconditioned, IC—intentionally conditioned, UC—unintentionally conditioned)	
External insulation wrap (R-values or inches)	
Are hot and cold water lines connected to proper fittings? (Y, N)	
Is a heat trap installed on the cold water line? (Y, N)	
Is a heat trap installed on the hot water line? (Y, N)	
Hot water pipes insulation (R-value or thickness)	
Length of hot water line insulated (feet)	

DOMESTIC WATER DISTRIBUTION

Cold water flow at showerhead number 1	gpm
Cold water flow at showerhead number 2 (or NA)	gpm
Aerators present on all sink faucets (Y, N)	
Are water lines located outside the conditioned area? (Y, N)	
If yes, are lines insulated or protected using heating tapes? (Y, N) If no, identify uninsulated or unprotected lines:	

Housing unit ID:________

EXHAUST SYSTEMS

Do all exhaust systems (e.g., range hood, bathroom fans, dryer vent, plumbing vents) vent directly to the outside?________(Y,N)

If no, describe:____

Do the bathroom exhausts, dryer, and range hood have:

	Bathroom exhaust			Dryer	Range hood
	Bath 1	Bath 2	Bath 3		
Dampered vents? (Y,N)	_______	_________	_________	_________	______________
Free moving dampers? (Y,N)	_______	_________	_________	_________	______________
Positive seal? (Y,N)	_______	_________	_________	_________	______________
Fan/duct leaks? (Y,N)	_______	_________	_________	_________	______________

APPLIANCES

Is there a gas line currently running to the house? (Y, N)________

If yes, is there a gas line currently running to the kitchen? (Y, N)________

Does the kitchen space allocated for the refrigerator allow air to circulate freely around the condensor coils? (Y, N)________

Housing unit ID:________

LIGHTING

Room	Location: wall (W) ceiling (C)	Lamp type	Number of lamps	Total watts	Control device	Condition and Comments
Living room						
Dining room						
Family room						
Den						
Hall (down)						
Hall (up)						
Bath 1						
Bath 2						
Bath 3						
Kitchen						
Utility room						
Storage room						
Stairs						
Bedroom 1						
Bedroom 2						
Bedroom 3						
Bedroom 4						
Bedroom 5						
Basement						
Attic						
Front entry (exterior)						
Rear entry (exterior)						
Porch (exterior)						
Outdoor area lights						
Outdoor storage						
Garage						

Lamp type:
CF—compact fluorescent; FL—fluorescent; H—halogen; I—incandescent.

Control device:
S—switched outlet; TWS—three-way switch; D—dimmer; PC—pull chain.

Housing unit ID:________

SITE IMPROVEMENTS

Provide a sketch of the typical site(s) for each type of unit being revitalized showing

- vegetation that should be retained and protected during construction;
- vegetation that should be removed or pruned because of its proximity to heat pumps, air conditioners, etc.; and
- pavement that is unneeded and could be removed, or is in poor condition and could be relocated during revitalization (at installations with significant summer air conditioning requirements).

Appendix B

BLOWER-DOOR INSPECTOR SELECTION GUIDE

Blower-Door Inspector Selection Guide

PURPOSE OF TESTING

Inspections of new and existing housing units using a blower door will be performed to measure the air-leakage rate of the housing unit and air distribution system (if present). Envelope leakage locations that contribute significantly to infiltration will be identified in existing housing units that will retain most of the exterior envelope and current interior configuration following revitalization. Air distribution systems (if present) will be evaluated if the system is to be retained following revitalization. This evaluation will identify the location and type of major duct leaks that must be repaired during revitalization.

REQUIRED EXPERIENCE

The contractor must be proficient in blower-door testing and inspections of envelope and air distribution system air leakage and must have performed blower-door-guided evaluations of envelope and duct leakage in at least 20 single-family and/or multifamily residential buildings during the past year to be considered for this contract. The contractor shall demonstrate proficiency and experience in all facets of blower-door testing (measuring envelope and duct leakage and identifying envelope and duct-leakage sites) by providing a summary of its relevant experience in blower-door testing of residential buildings over the last three years. The types of programs blower-door testing was performed for shall be described. For each program, the number of units inspected by the contractor shall be listed, the type of testing and inspections performed by the contractor shall be described, testing protocols and data forms followed by the contractor in performing the work shall be provided, and reports prepared by the contractor summarizing the inspection results shall be provided (if they are not confidential). The contractor shall also provide the name, address, and phone number of the most recent five customers or purchasing agents.

Personnel who will perform the work under this proposal must be identified. Their involvement in the blower-door testing performed by the contractor previously described and other relevant blower-door inspection experience must be clearly described. Relevant training received by each personnel shall also be listed.

REQUIRED AND OPTIONAL EQUIPMENT

The contractor must verify that it will provide, as a minimum, the following equipment required for blower-door testing:

- a calibrated blower door that can provide a flow rate of at least 3,000 cfm against 50 pascals (Pa) of back pressure and with a fan orifice and pressure gauge system calibrated to 10% accuracy;
- a calibrated airflow measurement system capable of testing the airtightness of just the air distribution system in a housing unit, that can provide a flow rate of at least 750 cfm against 50 Pa of back pressure, and that has a fan orifice and pressure gauge system calibrated to 10% accuracy;
- a calculator/computer with appropriate software to perform least-squares and error analyses of blower-door data and to calculate a flow rate at 25 and 50 Pa, the effective leakage area, and the exponential coefficient "n" and coefficient of determination (R^2) of the regression; and
- synthetic smoke generators for tracing airflow through leakage sites in air distribution systems and building envelopes.

The contractor should also indicate the availability of the following optional, but desirable, equipment:

- a digital pressure gauge with at least a 60-Pa range and self-zeroing capability and
- a pressure pan(s) to allow measurement of individual duct pressures with the housing unit depressurized.

Appendix C

SPECIFICATION FOR MEASURING HOUSING UNIT INFILTRATION RATE

Specification for Measuring Housing Unit Infiltration Rate

The total infiltration rate of a new single-family detached housing unit will be measured with a blower door to determine its natural air changes per hour following construction. Similarly, the total infiltration rate will be measured in an existing single-family detached housing unit either before revitalization, if a significant portion of the exterior envelope and current interior configuration will be retained, or following extensive “gut” rehabilitation. An infiltration rate for attached housing units cannot be measured using this procedure.

PREPARATION FOR TESTING

Identify on the *Housing Unit Air-Leakage Measurement Form* the installation at which the unit is located. Assign a unique identification number to the housing unit, or use the identification number previously assigned to the housing unit if an energy inspection was performed by the A/E. Document the address of the inspected unit, inspector, and inspection date.

Prepare the house as follows for blower-door inspection testing:

- Close all windows and outside doors.
- Fill plumbing traps with water (especially floor drains or other seldom-used traps).
- Close the damper and outside air supply to the fireplace (if present).
- Close and secure the attic access hatch.
- Turn off all air handler and exhaust fans.
- Open all supply and return registers (if present).
- Remove filters from the air distribution system (if present).
- Turn off all combustion appliances.
- Close doors to unconditioned utility closets or other unconditioned spaces such as unconditioned basements.
- Open all interior doors (except for closets) so that all interior conditioned space is connected, including conditioned basements. If only portions of the basement are conditioned, open all doors necessary to connect these conditioned basement areas with other conditioned areas.

Record on the *Housing Unit Air-Leakage Measurement Form* that the housing unit was prepared for testing. Note the exclusion/ inclusion of the basement (if present) as conditioned space and any other special or unusual situations encountered in preparing the unit for testing.

Identify the climate zone for the housing unit from Fig. C.1, the height of the housing unit (number of stories), and local shielding class. Assign correction factors for each of these categories as indicated on the *Housing Unit Air-Leakage Measurement Form*. Calculate the interior volume of the intentionally conditioned space of the housing unit, or obtain it from the A/E if the unit has already been audited.

Keep all equipment at a temperature as close to 70°F as possible while in transit, and bring it into the house immediately upon arrival. Set up the equipment following the manufacturer’s instructions and as specified in the following:

- Deploy one thermometer outside away from the door in a shaded area and one inside in the same room as the blower door.
- Install the fan on an exterior door for depressurizing the house. The chosen door must be free of wind interference and obstructions for at least 4 ft upstream of the fan and should be centrally located.
- Check for leaks around the fan and door.
- Install the hose measuring the outside pressure out of the direct flow of air through the blower-door fan. Multiple outside hoses

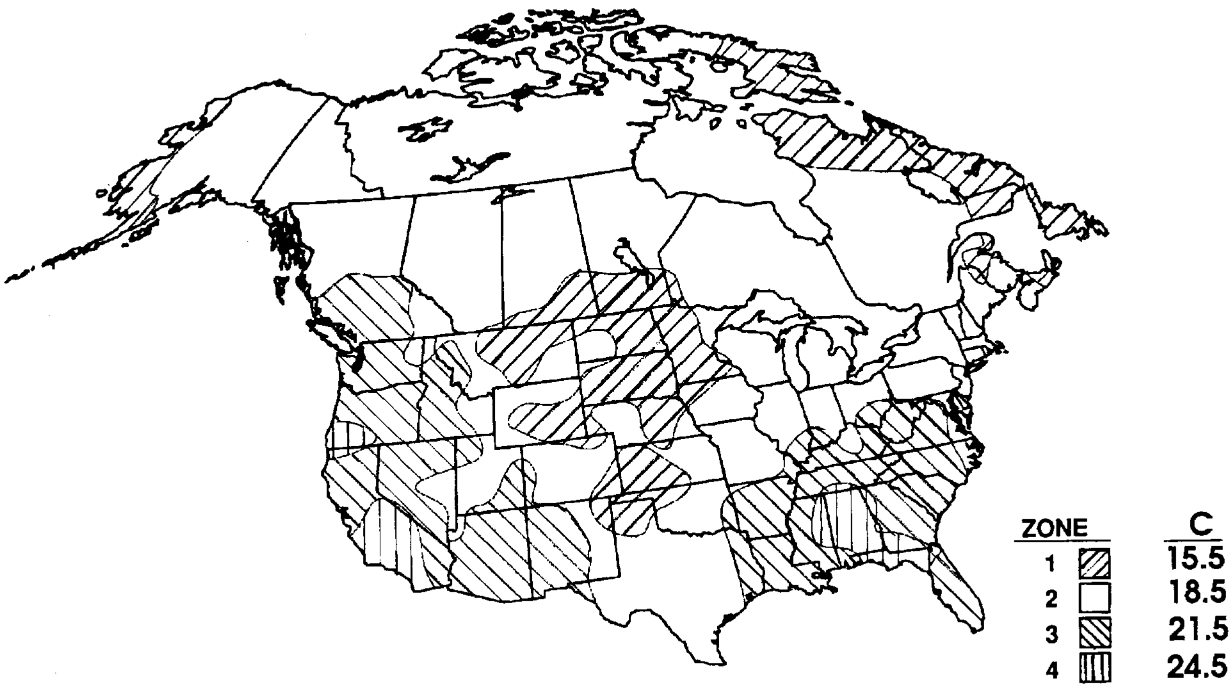

Fig. C.1. Climate correction factor, "C," for calculating average infiltration rates in North America.

or pressure equalizing boxes must not be used.

- Set up and level the gauges inside the house and out of the direct flow of air through the blower-door fan. Zero the gauge to be used to measure airflow through the fan after removing all hoses from the gauge so that both pressure taps are exposed to room air.
- Connect all hoses making sure all hose fittings are tight and that hoses are not pinched or obstructed. Trim or tighten hoses as necessary. If a hose is used to measure the inside pressure, ensure that it is out of the direct flow of air through the blower-door fan.
- Cover the fan opening as recommended by the manufacturer (using a "shower cap" provided by the manufacturer, plugging or taping all holes with the orifice plate on, or some other equivalent technique).
- Zero the gauge used to measure pressure difference across the house envelope to remove the natural pressure difference that may exist between the inside and the outside of the house because of thermal or wind effects.
- Remove the fan opening cover.

Briefly walk through the house while maintaining a negative pressure difference across the house of 20-30 Pa to check for previously undetected operable openings in the envelope (i.e., open windows, attic hatches, dampers) and other significant sources of air leakage. Identify on the *Housing Unit Air-Leakage Measurement Form* any unusual sources of air leakage. In addition, look for indications of weak areas (e.g., loose plaster, suspended ceilings, or windows) that could be damaged with increased negative pressures.

TEST PROCEDURE

Record the following information on the *Housing Unit Air-Leakage Measurement Form*:

- Indoor and outdoor temperatures.
- The average wind speed and maximum wind gust. Deploy the measuring device three to five building heights away from buildings and other major obstructions, and face it into the wind. Average wind speed generally should not exceed 10 mph; greater speeds and gusty wind conditions can cause difficulty in obtaining quality air-leakage measurements.

A test entails making measurements at the five pressure stations identified on the *Housing Unit Air-Leakage Measurement Form*. The pressure stations refer to putting the housing unit in a depressurized mode. If the maximum pressure stations cannot be achieved, then make measurements at as many of the assigned pressure stations as possible. Substitute an intermediate pressure station for every listed pressure station that cannot achieved. For example, if the 60 Pa pressure station cannot be achieved, add an intermediate pressure station of 35 or 45 Pa to the test procedure. Make measurements starting at the highest pressure station and proceeding in descending order.

For blower doors with orifice plates or other means of reducing the size of the fan opening (plugging holes in a cover plate, etc.) to obtain greater accuracy at low flows, at least one (and possibly two) changes in fan opening size should be expected during any particular test. The initial fan opening size should be the largest allowed by the blower-door manufacturer. With the fan in this configuration, attempt to make a measurement at the highest pressure station. If the measured flow is less than the range recommended by the manufacturer for the installed configuration, reduce the size of the fan opening until the measurement can be made. As measurements are made at lower pressure stations, change to the next smallest fan opening size when measured flows are less than the range recommended by the manufacturer for the opening size.

Make measurements at each pressure station in the following manner:

- Lower the house to about 5 Pa *below* the desired pressure. Then *slowly* increase the pressure until the desired pressure is reached. If the pressure is overshot, lower the pressure again to 5 Pa below the desired pressure and repeat the process.
- Tap the gauges continuously while adjusting the pressure up to the desired station, as the stored spring energy will cause the gauge needles to jump slightly.
- Set the gauge needle on the indicated pressure stations, within 2 Pa.
- After waiting 30 seconds for the blower-door readings to stabilize, record the actual house pressure reading, the fan pressure and/or flow rate reading, and fan opening configuration on the *Housing Unit Air-Leakage Measurement Form*. When lining up the gauge needle with the marks on the gauge, read the gauge from directly in front of it to avoid parallax. Always take readings off the gauge with the lowest range possible. For example, when measuring a flow pressure of less than 125 Pa, read from a gauge with a range of 0–125 Pa rather than one with a range of 0–750 Pa. Take extreme care in recording all data points, as tests with unacceptable levels of accuracy must be repeated (see "Analyses" section in this appendix).
- Record the indoor temperature after measurements have been made at all pressure stations.

ANALYSES

Perform a linear regression of the data collected at the five pressure stations after correcting the measured airflow rates for differences in air density using the following model:

$$Q = C(\Delta P)^n \; .$$

The linear regressions must be performed consistently with the analysis procedure and equations outlined in Appendix C of Standard CAN/CGSB-149.10-M86 of the Canadian

General Standards Board, and the airflow rate corrections for air density must be performed in accordance with Appendix D of this same standard. These analyses are usually performed by the computer program provided by the blower-door manufacturer.

The series of measurements must be repeated if the flow exponent (n) is less than 0.5 or greater than 1.0, the correlation coefficient (r) is less than 0.990, the percentage error in the flow data at each pressure station is more than 5%, the relative standard error of the estimated flow at 10 Pa is greater than 7%, or the relative standard error of the estimated flow at 4 Pa is greater than 10%. These numbers are usually calculated and output by the computer program provided by the blower-door manufacturer. Before redoing a test, examine all hoses and fittings for leakage and carefully re-zero the gauges, as these could be the cause of excessive error.

If the test is acceptable, list the airflow rate at 50 Pa as calculated using the regression results on the *Housing Unit Air-Leakage Measurement Form*. This number is usually calculated and output by the computer program provided by the blower-door manufacturer. Calculate the natural infiltration rate in air changes per hour as indicated on the form. Include the printout from each test with the *Housing Unit Air-Leakage Measurement Form*.

COMPLETION OF TESTING

Return ventilation controls, vents, and thermostats to their original settings. Make sure all space-heating, space-cooling, and water-heating systems are operating correctly. Make sure all pilot lights are lighted. Close interior doors to restore the house to its original state.

MILITARY FAMILY HOUSING:
HOUSING UNIT AIR-LEAKAGE MEASUREMENT FORM

IDENTIFICATION

Installation name: ____
Housing unit ID: ____
Housing unit address: ____
Inspector: ____
Inspection date: ____

HOUSING UNIT PREPARATION

Housing unit prepared for testing? _____ (Y,N)
Basement door: ______ (open, closed, NA)
Preparation comments: ____
____
Unusual sources of air leakage: ____________________________________

HOUSE DATA

	Climate zone	Height	Wind shielding	Intentionally conditioned house volume (ft^3)
Description				
Correction factor	C =	H =	S =	

Climate zone: See Fig. C.1 for zone identification. Zone 1 (C=15.5), zone 2 (C=18.5), zone 3 (C-21.5), and zone 4 (C-24.5).
Height: one story (H=1.0), one-and-a-half story (H=0.9), two stories (H=0.8), and three stories (H=0.7).
Wind shielding:

- Well shielded (S=1.2): Urban areas with high buildings or sheltered areas. Buildings surrounded by trees, bermed earth, or higher terrain.
- Normal (S=1.0): Buildings in a residential neighborhood or subdivision setting, with yard space between buildings (80-90% of houses fall into this category).
- Exposed (S=0.9) Buildings in an open setting with few buildings or trees around. Buildings on top of a high hill or ocean front, exposed to winds.

Intentionally conditioned house volume: An intentionally conditioned space is one with equipment and/or distribution outlets designed to maintain a desired temperature in the space. Gross interior floor area (includes internal storage closets, etc.) are used to calculate volumes rather than net areas as defined by the military. Floor heights used to calculate volume are floor to floor, except for the top floor, which is floor to ceiling. Use an average height for cathedral ceilings.

MEASUREMENT DATA

Indoor temperature (°F)		Outdoor temperature (°F)	Wind condition	High wind gusts? (Yes, No)
Start	End			

Wind condition: calm (0-5 mph), moderate (5-10 mph), or higher (greater than 10 mph).

Pressure station		Fan pressure (Pa)	Fan opening configuration	Airflow rate (cfm)
Goal (Pa)	Actual (Pa)			
60				
50				
40				
30				
20				
intermediate				
intermediate				

ANALYSES

Airflow rate at 50 Pa: _____ CFM50 (from regression)

Natural air changes per hour: _____ ACH = (CFM50 × 60)/(Volume × C × H × S)

Appendix D

SPECIFICATION FOR VISUAL INSPECTION OF ENVELOPE AIR LEAKAGE

Specification for Visual Inspection of Envelope Air Leakage

Visual inspection of envelope air leakage will be performed in existing single-family housing units (detached or attached) that will retain a significant portion of the exterior envelope and current interior configuration. The purpose of this visual inspection is to identify major air-leakage locations such as attic bypasses and unblocked partition walls that need to be sealed during revitalization.

BACKGROUND

Infiltration control is based on minimizing the loss of conditioned air through the building envelope (floors, walls, and ceilings). Infiltration (and corresponding exfiltrations) is caused by two weather-related phenomena—wind pressure and the stack effect from the temperature difference between indoors and outdoors. Leaks in building envelopes contribute differently to infiltration depending on their location and the cause of airflow through the building.

Wind pressure acts primarily on walls, windows, doors, sill plates, and band joists. Examples of typical and recurring wall deficiencies are shown in Fig. D.1.

The stack effect acts mainly on fireplaces; penetrations in basements, crawl spaces, and attics (plumbing, electrical service, and other unsealed ceiling penetrations such as canned light fixtures and air distribution ducts); and “attic bypasses.” Attic bypasses are paths for convective air flow through interior and exterior walls (see Fig. D.2). Preventing air leakage into the lowest level of the building and out of the highest level is the best method for eliminating stack-driven infiltration.

Floor cavities of second-story overhangs and second-story floors over porches contribute significantly to infiltration because they connect the interior of the housing unit to the outside and because they are affected by wind pressure and stack effect.

The stack effect typically contributes more significantly to building air leakage than the wind effect. Although sealing small cracks in walls and around windows is necessary to reduce infiltration, caulking small cracks does not significantly reduce stack-driven infiltration and is very labor intensive.

Other penetrations in building envelopes contribute little to naturally caused infiltration but respond primarily to occupant activities and HVAC equipment operation. These penetrations include exhaust vents (kitchen and bath) and air distribution system leaks. Inspection of air distribution systems is covered under Sect. 4.1.9, “Air Distribution System.”

INSPECTION PROCEDURE

Identify on the *Infiltration Inspection Checklist* the installation at which the unit is located. Assign a unique identification number to the housing unit, or use the identification number previously assigned to the housing unit if an energy inspection was performed by the A/E or if the air-leakage rate was measured. Document the address of the inspected unit, inspector, and inspection date.

This procedure starts with the lowest level of the building (basement or crawl space) and proceeds to the attic. Use a blower door to depressurize the unit to 20-30 Pa and a synthetic “smoke” source to promote leakage detection inside the housing unit. Pressurize the unit to 20-30 Pa to help identify leakage sites in the basement and attic. Observations from the inspection shall be recorded on the *Infiltration Inspection Checklist* to document the type and location of the problems that need to be sealed during revitalization. Leakage locations that need to be sealed must be documented with sufficient accuracy and detail so that a sealing

(*a*)

(*b*)

Fig. D.1. Wall penetrations under sinks (*a*) and behind appliances (*b*) open the interior of the housing unit to the outside, attic, crawl space, or basement through exterior and interior walls.

(***a***) (***b***)

(***c***) (***d***)

Fig. D.2. Attic bypasses connect the interior of the housing unit to the attic but are usually not visible from within the house. Chaseways for ducts, flues, and plumbing (*a*); unblocked interior partition walls that often exist between bathrooms and often have plumbing pipes through them (*b*); empty spaces built around and above closets that open up to the attic (*c*); and pocket doors (*d*) are typical and recur frequently in family housing.

contractor can locate the sites at a later date. The information recorded on the *Infiltration Inspection Checklist* should be supplemented with additional material (such as pictures, sketches, house layouts) as needed to provide this accuracy and detail.

Basement or Crawl Space

Air movement by the stack effect flows from low, cool locations such as basements and crawl spaces up through floor penetrations and around the sill plate. Therefore, infiltration inspection in the basement and crawl space focuses on identifying the leakage sites in and around the floor separating the basement or crawl space from the main living area to the house (the basement or crawl space ceiling) that must be repaired and eliminated by revitalization.

Main Floors

Inspection of the main floors between the basement, crawl space, or slab floor and the attic focuses on penetrations in the building envelope and interior walls that can allow air movement from wind and stack effects. For multilevel buildings, all levels should be inspected for conditions that can contribute to infiltration and exfiltration. Multilevel housing units can have substantial leakage areas where the second story floor opens into the exterior wall.

Attic

Inspection in the attic focuses on the top floor ceiling that forms the attic floor, because this surface is the final barrier for exfiltration of air from the stack effect. Check especially for attic bypasses such as open partition walls, plumbing chaseways, around electrical openings, and open floor joists in kneewall attics.

INFILTRATION INSPECTION CHECKLIST Housing unit ID:_______		
Installation:	Unit Address:	
Date:	Inspectors:	
Inspection point	Infiltration problem	Location
BASEMENT/CRAWL SPACE		
Floor penetrations—electrical service		
Floor penetrations—plumbing service		
Floor penetrations—air ducts		
Sill plate		
Floor penetration—general		
MAIN FLOOR		
Wall penetrations under sinks and appliances		
Exterior doors		
Interior walls		
Exterior walls		
Ceiling penetrations above recessed lighting fixtures		
Attic hatch		
Whole-house fan		
ATTIC		
Ceiling penetrations—electrical service		
Ceiling penetrations—plumbing service		
Ceiling penetrations—air ducts		
Canned light fixtures		
Ceiling penetrations—general		
Unblocked interior partition walls		
Unblocked exterior walls		
Plumbing and duct chaseways		

Appendix E

SPECIFICATION FOR MEASURING DUCT AIR-LEAKAGE RATE

Specification for Measuring Duct Air-Leakage Rate

The air-leakage rate of the air distribution system in a new housing unit will be measured to determine its airtightness following construction. Similarly, in an existing unit, the air-leakage rate of the existing duct system will be measured before revitalization if the system will be retained, or the air-leakage rate of a new duct system will be measured after revitalization.

PREPARATION FOR TESTING

Identify on the *Duct Air-Leakage Measurement Form* the installation at which the unit is located. Assign a unique identification number to the housing unit, or use the identification number previously assigned to the housing unit if an energy inspection was performed by the A/E or if a blower-door inspection of the house was performed. Document the address of the inspected unit, inspector, and inspection date.

Prepare the duct system as follows for inspection testing:

- Turn off all air handler and exhaust fans.
- Open all supply and return registers.
- Turn off exhaust fans, dryers, and room air conditioners in the housing unit.
- Open all interior doors.
- Remove filters from the air distribution system.

Record on the *Duct Air-Leakage Measurement Form* that the housing unit was prepared for testing. Note any other special or unusual situations encountered in preparing the system for testing.

Keep all equipment at a temperature as close to 70°F as possible while in transit and bring it into the house immediately upon arrival. Set up the equipment following the manufacturer's instructions and as specified below:

- Install the fan at the largest return or supply register closest to the air handler, or at the air handler cabinet itself. Check for leaks around the fan.
- Seal off all return and supply registers in the system, as well as other intentional openings such as combustion or ventilation inlets.
- Open an exterior door or window.
- Open vents, access panels, or doors to crawl spaces, attics, and garages containing ducts.
- Install the hose measuring the duct pressure in a duct far removed from the fan, out of the direct flow of air through the fan. If the fan is installed in a supply register, install the hose in the return system. If the fan is installed in a return register, install the hose in the supply system.
- Set up the gauges inside the house and out of the direct flow of air through the fan.
- Connect all hoses making sure all hose fittings are tight. Trim or tighten hoses as necessary.
- Cover the fan opening as recommended by the manufacturer (using a "shower cap" provided by the manufacturer, plugging or taping all holes with the orifice plate on, or some other equivalent technique).
- Zero all the gauges.
- Remove the fan opening cover.

Briefly walk through the house while maintaining a positive pressure in the duct system of 15–20 Pa to check for previously undetected operable openings in the ducts and to ensure that the register seals are tight.

TEST PROCEDURE

A test entails measuring the air-flow rate required to pressurize the duct system to 50 Pa. If a pressure of 50 Pa cannot be achieved, then the airflow rate needed to pressurize the ducts to 25 Pa must be measured.

For measuring systems with orifice plates or other means of reducing the size of the fan opening (plugging holes in a cover plate, etc.), the configuration that provides the greatest accuracy and is within the range recommended by the manufacturer must be used.

Make the measurement at 50 Pa (or 25 Pa) in the following manner:

- Raise the duct pressure to about 5 Pa *above* the desired pressure.
- Lower the duct pressure to about 5 Pa *below* the desired pressure. Then *slowly* increase the pressure until the desired pressure is reached. If the pressure is overshot, lower the pressure again to 5 Pa below the desired pressure and repeat the process.
- Tap the gauges continuously while adjusting the pressure up to the desired station, as the stored spring energy will cause the gauge needles to jump slightly.
- Set the gauge needle on the indicated pressure stations, within 0.5 Pa.
- After waiting 30 seconds for the readings to stabilize, record the actual duct pressure reading, fan pressure, fan opening configuration, and fan flow rate reading on the *Duct Air-Leakage Measurement Form*. When lining the gauge needle up with the marks on the gauge, read the gauge from directly in front to avoid parallax. Always take readings off the gauge with the lowest range possible. For example, when measuring a flow pressure of less than 125 Pa, read from a gauge with a range of 0–125 Pa rather than one with a range of 0–750 Pa.

COMPLETION OF TESTING

Return ventilation controls, vents, and thermostats to their original settings. Make sure all space-heating and space-cooling systems are operating correctly. Make sure all pilot lights are lighted. Close interior and exterior doors and/or exterior windows to restore the house to its original state.

MILITARY FAMILY HOUSING:
DUCT AIR-LEAKAGE MEASURMENT FORM

IDENTIFICATION
Installation name: ____
Housing unit ID: ____
Housing unit address: ____
Inspector: ____
Inspection date: ____

DUCT SYSTEM PREPARATION
Duct system prepared for testing? _____(Y,N)
Preparation comments: ____
____

MEASUREMENT DATA

Duct pressure		Fan pressure (Pa)	Fan opening configuration	Airflow rate (cfm)
Goal (Pa)	Actual (Pa)			
50				
25 (optional)				

Appendix F

SPECIFICATION FOR INSPECTION OF DUCT AIR LEAKAGE

Specification for Inspection of Duct Air Leakage

A detailed inspection of the existing air distribution system will be performed in existing housing units that will retain the system. The purpose of this inspection is to evaluate the condition of the system relative to continued long-term use (verify that it is economical to retain the current system) and to identify the location and type of major duct leaks that need to be sealed during revitalization.

The purposes of a visual inspection of the air distribution system are as follows:

- to evaluate the need to replace all or parts of the system because of general deterioration of the system;
- to determine whether the localized damage that is responsible for excessive duct leakage can be repaired;
- to determine whether improper materials or supports are present; and
- to evaluate whether duct insulation is adequate for continued use of the system.

Inspection for leaks is based on visual observation enhanced by depressurizing the housing unit with a blower door (or pressurizing the ducts with a fan) to allow detection of leaks through observation of airflow with a synthetic “smoke” source.

BACKGROUND

Supply System

Leaks in the supply ducts of the air distribution system are important because conditioned air is directly lost through them before it can be delivered to the house. Also, dominant supply leakage can result in depressurization of a house, increasing the infiltration rate of the house whenever the system operates.

Main supply ducts are often fabricated from sheet metal or ductboard, with branches to individual registers fabricated from the same or a different material, such as flexduct. Leaks are often caused by circumferential joints that are unsealed or that are initially sealed with only fabric duct tape, which deteriorates (see Fig. F.1). Joints also may be poorly sealed or unsealed at the junction between the heating and cooling system and the supply trunk.

Junction boxes are fabricated of sheet metal or ductboard to divide supply air into two separate branch flows at the end of a supply trunk. Leaks at junction boxes can occur at the seams of the box if duct tape is the only sealant. Also, duct connections to the box can leak if they are unsealed or sealed only with fabric duct tape.

Connections at supply registers often leak because of a poor seal between the branch ductwork and the connecting “boot.” Poor seals between the connecting boot and the register itself also contribute to leaks. Figure F.2 shows a leak that occurs when a connecting metal boot is incorrectly installed to the supply register.

Lack of a mechanical fastener often contributes to the formation of joint leaks. A mechanical fastener is especially needed to connect flexduct to supply registers to ensure a long-lasting seal. Plastic ties, especially if used in a hot attic, can become loose and slip off the boot connection.

Connecting boots fabricated from ductboard may have poor seals where they slip over the supply register.

Return System

Leaks in return ducts are often more common than leaks in supply ducts. Return leaks are important because they pull hot or cold air and pollutants into a house from attics and other unconditioned locations. Also, dominant return leakage can result in pressurization of a house, increasing the loss of conditioned air through leaks in the building envelope.

(***a***)

(***b***)

(***c***)

(***d***)

Fig. F.1. Circumferential joints in ductwork often deteriorate and leak if they lack mechanical fasteners and were initially unsealed or sealed only with fabric tape.

Fig.F.2. A sheet metal boot in a newly installed duct system is improperly installed, creating a 1/2-in. gap between the boot and the supply register.

The importance of return leakage was not recognized in the past, general thinking being that return leaks were a way to provide "fresh" air to a house. Therefore, it has been common practice to downplay the importance of constructing airtight return systems. Unsealed cavities in the building structure—walls, floor joists, stud bays—have often been used as parts of the return "ductwork."

Return grills are common leak locations when gaps are left between the grill and the wall, ceiling, or floor to which it is mounted. Air can be sucked into the return from the outside, attic, or other unconditioned spaces through the wall, ceiling, or floor cavity. Figure F.3 shows a leak to a wall cavity behind a wall-mounted grill.

Return ducts that connect the return grill to the heating and cooling system are usually constructed from duct materials such as sheet metal and ductboard, or building cavities are often used. Return ducts constructed from traditional duct materials are prone to the same leaks described for supply ducts. A common problem is the connection of a return duct to the heating or cooling system or a junction box at the unit (see Fig. F.4).

Building cavities used as part of the return system are often leaky and are inappropriate substitutes for dedicated ducts. Examples include panned floor joist cavities formed by attaching sheet metal between floor joists, stud bay cavities formed by wall studs and drywall, and floor truss cavities formed within floor trusses. Joints and penetrations in these cavities are typically not sealed, allowing unconditioned air to be drawn into the return from all parts of the housing unit and the outside. These leaks can also allow return air to be drawn from

(***a***)

(***b***)

Fig. F.3. A leak to a wall cavity located behind a wall-mounted grill (*a*). The joints in the ductwork behind the grill are also deteriorated and leaking (*b*).

Fig. F.4. Use of duct tape rather than mechanical fasteners to secure the connection of a return duct to a junction box at an attic-mounted evaporator allowed the joint to fail, forming a significant return leak.

adjacent townhouse units, which increases the infiltration rate in the adjacent housing unit. Connections between ducts and these building cavities frequently are not sealed, and their failure creates large leakage areas (see Fig.F.5).

Heating and cooling units located in a garage are frequently mounted on a plywood box that is a return plenum. Units that are installed in an interior closet often use the entire closet as a return plenum or sit upon a return plenum built using a raised floor and the closet walls. These plenums and closets are often not sealed, allowing nonconditioned air to be drawn into the return system. Figure F.6 shows a return plenum built in a closet with unfaced interior walls and penetrations for plumbing and electrical lines that allow air to be drawn from the outside and attic.

Return plenums are frequently built behind the return grill, formed by spaces between floors or under stairwells. Again, unsealed walls and penetrations serve as leakage sites, allowing air to be drawn into the return from all connected spaces in the house and outside.

Air Handlers

Leaks at air handlers are important because the positive (supply) and negative (return) pressures at this location are the highest in the system. Incorrectly matched equipment sections and poor installation (frequently caused by tight quarters) can produce large leakage sites (see Fig. F.7). Even small leakage areas such as “knockouts” for wiring and equipment lines and cracks between panels can represent significant leakage paths (see Fig. F.8).

Supports for Ductwork

Ductwork can be hung from floor joists in crawl spaces and basements, and from roof trusses in attics. Metal straps or bands are used to provide support for ductwork. If the supports

Fig. F.5. The joint between a return duct and a building cavity used as a return duct was not sealed and mechanically fastened and, following failure, created a large leakage area.

Fig. F.6. Unfaced interior walls and unsealed penetrations for plumbing and electrical lines in this return plenum allow unconditioned air to be drawn into the return from the attic or the outside.

Fig. F.7. An evaporator that is physically too large for and poorly mounted to the furnace created a large supply leak. Metal-faced duct tape used to seal the leak had deteriorated.

are inadequate or fail, the duct can drop and open a leak at joints adjacent to the failure location.

Duct Insulation

All supply and return ductwork in unconditioned spaces should be insulated or have insulation equivalent to current duct insulation standards, nominally a level of at least R-6. Older metal duct systems often were installed without any insulation, even when located in unconditioned spaces such as attics, crawl spaces, and unheated basements.

INSPECTION PROCEDURE

Identify on the *Duct Inspection Checklist* the installation at which the unit is located. Assign a unique identification number to the housing unit, or use the identification number previously assigned to the housing unit if an

Fig. F.8. An unsealed "knockout" for wiring and refrigerator lines and a poorly fitting panel on this attic-mounted evaporator allow attic air to be drawn into the return system.

energy inspection was performed by the A/E, a blower-door inspection of the house was performed, or the tightness of the ducts were measured. Document the address of the inspected unit, inspector, and inspection date.

Prepare a schematic plan of the air distribution system relative to the floor plan of the unit. The plan shall indicate the following major features: (1) location of the heating and cooling equipment; (2) location of supply ducts and junction boxes; (3) location of return plenums and return ducts; and (4) location and type of building cavities used in the duct system. The plan shall include attic, basement, and living-level schematics as needed. The plan shall be used to indicate the location of any repairable leaks found during the inspection.

The following diagnostics shall be performed to identify the location of repairable duct leaks:

1. Prepare the house as follows for blower-door testing:

   - Close all windows and outside doors.
   - Close the damper and outside air supply to the fireplace (if present).
   - Close and secure the attic access hatch.
   - Turn off all air handler and exhaust fans.
   - Open all supply and return registers (if present).
   - Remove filters from the air distribution system (if present).
   - Turn off all combustion appliances.
   - Close doors to unconditioned utility closets or other unconditioned spaces.
   - Open all interior doors (except for closets) so that all interior conditioned space is connected, including conditioned basements.

2. Install a blower door on the house following the manufacturer's recommendations.
3. Depressurize the housing unit to 50 Pa.
4. Working on one register at a time, create a temporary airtight barrier across the register opening by placing a "pressure pan" over the register or using temporary (masking or painter's) tape applied over the face of the grill.
5. Place a pressure gauge near the register to be tested, and level and zero the gauge.
6. Measure the pressure difference across the cover (the difference in pressure inside the duct relative to the house) by connecting the gauge to the pressure pan or inserting a small probe through the duct cover. Record the pressure difference on the *Duct Inspection Checklist.*
7. Remove the temporary barrier across the register, and leave the register open.
8. Repeat steps 4-7 for each register in the house. Move in a clockwise rotation in each room if more than one register is present.
9. Depressurize the house to 25–30 Pa.
10. Visually inspect the duct system for leakage using a source of synthetic "smoke" to aid in detecting leaks. Document the location of repairable duct leaks on the *Duct Inspection Checklist* and the duct schematics. Indicate the magnitude of the duct leak on the duct schematic using the following key: X—small leak, XX—medium leak, and XXX—large leak.
11. Turn off the blower door and return the house to its original condition.

The airtightness of the duct system should have been previously measured following a separate procedure. If the leakage rate of the ducts is less than 150 cfm at 50 Pa, then few repairable duct leaks should be expected. The pressure readings made in Step 6 help guide the visual inspection to identify the primary locations for duct leakage by identifying the leakiest ducts. The higher the pressure difference, the greater the amount of duct leakage expected in that leg of the duct system. Pressure differences of less than 2 Pa indicate little duct leakage.

The following points shall be considered in determining if a duct leak should be identified as repairable:

- Leaks closest to the air handler are important as the pressure driving forces are greatest at the air handler.
- Leaks in return ducts located in the same zone as combustion equipment should almost always be sealed to prevent possible backdrafting of combustion appliances.

MILITARY FAMILY HOUSING: DUCT INSPECTION CHECKLIST				
Housing unit ID: __________				
Installation:			Unit address:	
Date:			Inspectors:	
		Duct pressure (Pa)[a]		
Room	Floor[b]	Supply[c]	Return[c]	Comments
Foyer				
Living				
Dining				
Kitchen				
Family				
Bath No. 1				
Master Bdrm.				
Bath No. 2				
Brdm. No. 2				
Bdrm No. 3				
Bdrm. No. 4				
Bath No. 3				
Hallway No. 1				
Hallway No. 2				
Utility				

[a]With unit depressurized to 50 Pa and duct sealed.
[b]Main, 2nd, 3rd, basement.
[c]If more than one register, list data in clockwise rotation from main entrance to room.

DUCT INSPECTION CHECKLIST — SUPPLY LEAKS **House ID:____________**

Duct function[a]	Duct type[b]	Duct location[c]	Joint seal/ reinforcement[d]	Number of leaks	Leak locations	Leak size[e]	Comments and recommendations[f]

[a]ST—supply trunk; SB—supply branch; JB—junction box; SR—supply register; HU—HVAC unit.
[b]Duct types: DB—ductboard, SM—sheet metal, FD—flexduct, X—other.
[c]Location: A—attic, B—basement, C—crawl space, G—garage, X—other.
[d]Joint sealant/reinforcement for circumferential joints: M—mastic; MT—metal-faced tape; FT—fabric tape; MS—metal screws; MB—metal band; PB—plastic band; N—none.
[e]Leak size: width and length of gap, inches.
[f]Cause of leak—damaged duct, deteriorated seal, unsealed penetration, other. Repair recommendation—replace duct, repair joints or penetrations.

DUCT INSPECTION CHECKLIST — RETURN LEAKS **House ID:____________**

Duct function[a]	Duct type[b]	Duct location[c]	Joint seal/ reinforcement[d]	Number of leaks	Leak locations	Leak size[e]	Comments and recommendations[f]

[a]RG—return grill; RD—return duct; RP—return plenum.
[b]Duct types: DB—ductboard, SM—sheet metal, FD—flexduct, SR—sheetrock, X—other.
[c]Location: A—attic, B—basement, H—hallway, C—crawl space, G—garage, X—other.
[d]Joint sealant/reinforcement for circumferential joints: M—mastic; MT—metal-faced tape; FT—fabric tape; MS—metal screws; MB—metal band; PB—plastic band; N—none.
[e]Leak size: width and length of gap, inches.
[f]Cause of leak—damaged duct, deteriorated seal, unsealed penetration, other. Repair recommendation—replace duct, repair joints.

DUCT INSPECTION CHECKLIST — BUILDING CAVITIES **House ID:____________**

Duct function[a]	Cavity type[b]	Duct location[c]	Joint seal[d]	Number of leaks	Leak locations	Leak size[e]	Comments and recommendations[f]

[a]RD—return duct; RP—return plenum.
[b]Cavity types: SB—stud bay, FT—floor truss, PFT—panned floor truss, F—floor.
[c]Location: IW—interior wall, EW—exterior wall, B—basement, C—crawl space, G—garage, X—other.
[d]Joint sealant: M—mastic; MT—metal-faced tape; FT—fabric tape; N—none.
[e]Leak size: width and length of gap, inches.
[f]Cause of leak—damaged duct, deteriorated seal, unsealed penetration, other. Repair recommendation—replace duct, repair joints.

DUCT INSPECTION CHECKLIST — INSULATION AND SUPPORTS **House ID:____________**

Duct function[a]	Duct type[b]	Duct location[c]	Insulation type[d]	Insulation condition[e]	Duct support[f]	Support failure[g]	Comments

[a]ST—supply trunk, SB—supply branch, RD—return duct, RP—return plenum, JB—junction box.
[b]Duct types: DB—ductboard, SM—sheet metal, FD—flexduct, X—other.
[c]Location: A—attic, CB—conditioned basement, UB—unconditioned basement, C—crawl space, G—garage, H—hallway, X—other.
[d]Batt, R=___; Blanket, R=___; Ductboard, R=___; Flexduct, R=___; Other, R=___; Other, R=___; None.
[e]Good—no repair; Fair—minor repairs; Degraded—replace.
[f]A—adequate support, I—inadequate support (>10 ft span).
[g]L—loose attachment, B—broken support, N—none.

Appendix G

ENERGY ANALYSIS FORMS FOR REVITALIZED HOUSING UNITS

Form G.1. General information

Installation name: ____

Housing unit type ID: ____

Person completing forms: ____

Affiliation: ____

Form G.2. Thermal boundary **Housing Unit Type ID:________**

Provide a sketch of the floor plan(s) and the sections of the unit being revitalized, indicating the location of the thermal boundary to be achieved following revitalization.

Form G.3. Wood-frame wall insulation **Housing Unit Type ID: ________**

	Annual energy savings[a] (MBtu/ft^2 or kWh/ft^2)	Fuel cost ($/MBtu or $/kWh)	Annual cost savings $/ft^2	Uniform present worth factor[b]	Present value of the energy savings ($/ft^2)	Insulation installation cost[c] ($/ft^2)	Savings-to investment ratio[d]	Simple payback periodd (years)
	A	B	C = A · B	D	E = C · D	F	G = E/F	H = F/C
Stud cavity:								
Heating								
Cooling			+		+			
Total								
Exterior:								
Heating								
Cooling			+		+			
Total								

[a]Annual energy savings are determined from Figs. 4.2 through 4.5 and are per square foot of wall area.

[b]The uniform present worth factor is based on a 25-year life. The factor for the U.S. average in 1995 is 23.83 for natural gas, 23.00 for fuel oil, and 18.69 for electricity.

[c]The A/E must determine the total cost of installing the wall insulation per square foot of wall area. This cost must include all expenses associated with the improvement, although some expenses may be appropriately assigned to other renovation work. For example, the total cost associated with installing exterior insulation is limited to materials and direct installation cost of the insulation alone if existing siding is already to be replaced as part of the revitalization. An important factor for the A/E to consider for cavity insulation is whether the interior or exterior finishes will already be removed as part of the revitalization, providing ready and low-cost access to the wall cavity.

[d]The stud cavity or exterior wall insulation meets military cost-effective criteria if the savings-to-investment ratio is greater than or equal to 1.25 and the simple payback period is less than or equal to 10. Insulation should be installed in both locations if both meet the cost-effective criteria.

Form G.4. Masonry wall insulation **Housing Unit Type ID: ________**

	Annual energy savings[a] (MBtu/ft^2 or kWh/ft^2)	Fuel cost ($/MBtu or $/kWh)	Annual cost savings ($/ft^2)	Uniform present worth factor[b]	Present value of the energy savings ($/ft^2)	Insulation installation cost[c] ($/ft^2)	Savings-to-investment ratio[d]	Simple payback period[d] (years)	Net present value[d] ($/ft^2)
	A	B	C = A · B	D	E = C · D	F	G = E/F	H = F/C	I = E – F
R-5 interior insulation:									
Heating									
Cooling			+		+				
Total									
R-11 to R-15 interior insulation:									
Heating									
Cooling			+		+				
Total									
R-5 exterior insulation:									
Heating									
Cooling			+		+				
Total									
R-10 exterior insulation:									
Heating									
Cooling			+		+				
Total									

[a]Annual energy savings are determined from Figs. 4.6 and 4.7 and are per square foot of wall area.

[b]The uniform present worth factor is based on a 25-year life. The factor for the U.S. average in 1995 is 23.83 for natural gas, 23.00 for fuel oil, and 18.69 for electricity.

[c]The A/E must determine the total cost of installing the wall insulation per square foot of wall area. This cost must include all expenses associated with the improvement, lthough some expenses may be appropriately assigned to other renovation work. For example, the total cost associated with installing exterior insulation is limited to materials and direct installation cost of the insulation if a new exterior (stucco) is already to be installed as part of the revitalization.

[d]The wall insulation measures meet military cost-effective criteria if the savings-to-investment ratios are greater than or equal to 1.25 and the simple payback periods are less than or equal to 10. The measure with the highest net present value should be installed if more than one measure meets the cost-effective criteria.

Form G.5. Slab-on-grade perimeter insulation **Housing Unit Type ID: ________**

	Annual energy savings[a] (MBtu/ft or kWh/ft)	Fuel cost ($/MBtu or $/kWh)	Annual cost savings ($/ft)	Uniform present worth factor[b]	Present value of the energy savings ($/ft)	Insulation installation cost[c] ($/ft)	Savings-to-investment ratio[d]	Simple payback period[d] (years)
	A	B	C = A · B	D	E = C · D	F	G = E/F	H = F/C
Heating								
Cooling			+		+			
Total								

[a]Annual energy savings are determined from Figs. 4.8 and 4.9 and are per foot of perimeter.

[b]The uniform present worth factor is based on a 25-year life. The factor for the U.S. average in 1995 is 23.83 for natural gas, 23.00 for fuel oil, and 18.69 for electricity.

[c]The A/E must determine the total cost of installing the slab insulation per linear foot of perimeter. This cost must include all expenses associated with the improvement, although some expenses may be appropriately assigned to other renovation work. For example, the total cost for slab insulation would be limited to materials and direct installation cost of the insulation if excavation around the perimeter is needed as part of the revitalization to fix moisture problems.

[d]The slab insulation is cost effective if the savings-to-investment ratio is greater than or equal to 1.25 and the simple payback period is less than or equal to 10.

Form G.6. Crawl space and basement ceiling insulation **Housing Unit Type ID: ________**

Standard insulation levels	Annual energy savings of current insulation levels[a] (MBtu/ft² or kWh/ft²)	Annual energy savings of standard insulation levels[a] (MBtu/ft² or kWh/ft²)	Annual incremental energy savings[a] (MBtu/ft² or kWh/ft²)	Fuel cost ($/MBtu or $/kWh)	Annual cost savings ($/ft²)	Uniform present worth factor[b]	Present value of the energy savings ($/ft²)	Insulation installation cost[c] ($/ft²)	Savings-to-investment ratio[d]	Simple payback period[d] (years)	Net present value[d] ($/ft²)
	A	B	C = B – A	D	E = C · D	F	G = E · F	H	I = G/H	J = H/E	K = G – H
R-11:											
Heating											
Cooling					+		+				
Total											
R-19:											
Heating											
Cooling					+		+				
Total											
R-30:											
Heating											
Cooling					+		+				
Total											

[a]Annual energy savings are determined from Figs. 4.10 and 4.11 for crawl space and Figs. 4.12 and 4.13 for basements. These savings are per square foot of ceiling area.

[b]The uniform present worth factor is based on a 25-year life. The factor for the U.S. average in 1995 is 23.83 for natural gas, 23.00 for fuel oil, and 18.69 for electricity.

[c]The A/E must determine the total cost of installing the incremental amounts of ceiling insulation per square foot of ceiling area to upgrade to the standard insulation levels. For example, the A/E must determine the cost to add R-8 insulation to achieve a total of R-19 if the current level is R-11, or the cost to add R-11 to achieve an R-30 if the current level is R-94. Ths cost st inle(al)7(l)-6r exss ss(o)-11c id w ith the ioement

Form G.7. Attic insulation **Housing Unit Type ID: ________**

Standard insulation levels	Annual energy savings of current insulation levels[a]	Annual energy savings of standard insulation levels[a]	Annual incremental energy savings[a]	Fuel cost ($/MBtu or $/kWh)	Annual cost savings ($/ft^2)	Uniform present worth factor[b]	Present value of the energy savings ($/ft^2)	Insulation installation cost[c] ($/ft^2)	Savings-to investment ratio[d]	Simple payback period[d] (years)	Net present value[d] ($/ft^2)
	A	B	C = B – A	D	E = C · D	F	G = E · F	H	I = G/H	J = H/E	K = G - H
R-11:											
Heating											
Cooling					+		+				
Total											
R-19:											
Heating											
Cooling					+		+				
Total											
R-30:											
Heating											
Cooling					+		+				
Total											
R-38:											
Heating											
Cooling					+		+				
Total											
R-49:											
Heating											
Cooling					+		+				
Total											

[a] Annual energy savings are determined from Figs. 4.14 and 4.15. They are expressed in MBtu/ft^2 or kWh/ft^2 and are per square foot of attic area.

[b] The uniform present worth factor is based on a 25-year life. The factor for the U.S. average in 1995 is 23.83 for natural gas, 23.00 for fuel oil, and 18.69 for electricity.

[c] The A/E must determine the total cost of installing the incremental amounts of attic insulation per square foot of attic area to upgrade to the standard insulation levels. For example, the A/E must determine the cost to add R-8 insulation to achieve a total of R-19 if the current level is R-11. This cost must include all costs associated with the improvement, such as attic ventilation improvement, soffit dams, and access hatches.

[d] The incremental amounts of insulation meet military cost-effective criteria if the savings-to-investment ratio is greater than or equal to 1.25 and the simple payback period is less than or equal to 10. If more than one level of insulation meets the cost-effective criteria, the level with the highest net present value should be selected.

Form G.8. Windows **Housing Unit Type ID: _______**

	Annual energy savings of the existing window[a] (MBtu/ft^2 or kWh/ft^2)	Annual energy savings of the new window type[a] (MBtu/ft^2 or kWh/ft^2)	Annual energy savings (MBtu/ft^2 or kWh/ft^2)	Annual energy savings (MBtu/ft^2)[b]	New window area (ft^2)	Total annual energy savings (MBtu)
	A	B	C = B – A	D	E	F = D · E
Heating						
Cooling				+		+
Total						

[a]Annual energy savings are determined from Figs. 4.19 and 4.20 and are per square foot of window area.
[b]Convert space-cooling savings from kWh to MBtu by multiplying by 0.003413.

Form G.9. Storm window **Housing Unit Type ID: _________**

Heating and cooling costs	Annual energy savings[a] (MBtu/ft^2 or kWh/ft^2)	Fuel cost ($/MBtu or $/kWh)	Annual cost savings ($/ft^2)	Uniform present worth factor[b]	Present value of the energy savings ($/ft^2)	Storm window installation cost[c] ($/ft^2)	Savings-to-investment ratio[d]	Simple payback period[d] (years)
	A	B	C = A · B	D	E = C · D	F	G = E/F	H = F/C
Heating								
Cooling			+		+			
Total								

[a]Annual energy savings are determined from Figs. 4.20 and 4.21 and are per square foot of window area.
[b]The uniform present worth factor is based on a 25-year life. The factor for the U.S. average in 1995 is 23.83 for natural gas, 23.00 for fuel oil, and 18.69 for electricity.
[c]The A/E must determine the cost to purchase and install the storm windows per square foot of window area.
[d]A storm window meets military cost-effective criteria if the savings-to-investment ratio is greater than or equal to 1.25 and the simple payback period is less than or equal to 10.

Form G.10. Glass exterior doors **Housing Unit Type ID: ________**

	Annual energy savings of current door[a] (MBtu/ft^2 or kWh/ft^2)	Annual energy savings of the new door type[a] (MBtu/ft^2 or kWh/ft^2)	Annual energy savings (MBtu/ft^2 or kWh/ft^2)	Annual energy savings (MBtu/ft^2)[b]	New door area (ft^2)	Total annual energy savings (MBtu)
	A	B	C = B – A	D	E	F = D · E
Heating						
Cooling				+		+
Total						

[a]Annual energy savings are determined from Figs. 4.19 and 4.20 and are per square foot of window area.
[b]Convert space-cooling savings from kWh to MBtu by multiplying by 0.003413.

Form G.11. New high-efficiency equipment **Housing Unit Type ID: ________**

System	Incremental annual energy savings[a] (MBtu/ft^2 or kWh/ft^2)	Floor area (ft^2)	Fuel cost ($/MBtu or $/kWh)	Annual cost savings ($)	Uniform present worth factor[b]	Present value of the energy savings ($)	Incremental cost[c] ($)	Savings-to-investment ratio[d]	Simple payback period[d] (years)
	A	B	C	D = A · B · C	E	F = D · E	G	H = F/G	I = G/D
Furnace or boiler									
Air conditioner									
Heat pump									

[a]Energy savings are obtained from Figs. 4.23 through 4.25 and are per square foot of floor area of the housing unit.
The total electricity savings of a high-efficiency heat pump is the sum of the electricity savings for air conditioning (Fig. 4.24) and heating (Fig. 4.25):

Space-cooling electricity savings: _____________________ kWh/ft^2

Space-heating electricity savings: _____________________ kWh/ft^2

[b]The 18-year uniform present worth factor for the U.S. average in 1995 is 17.53 for natural gas and 17.06 for fuel oil. The 15-year factor for electricity is 12.43.

[c]The A/E must determine the incremental cost of installing the high-efficiency units compared with the minimum-efficiency units. The incremental cost includes the greater material costs for the higher-efficiency unit, as well as other considerations such as greater installation labor or need for a new flue (assuming an 80% AFUE unit would not itself need a new flue or chimney liner).

[d]The high-efficiency unit meets military cost-effective criteria compared with the minimum-efficiency unit if the savings-to-investment ratio is greater than or equal to 1.25 and the simple payback period is less than or equal to 10.

Form G.12. Heating and cooling system replacements based on potential for energy savings **Housing Unit Type ID: ________**

System	Annual energy savings[a] (MBtu/ft^2 or kWh/ft^2)	Floor area (ft^2)	Fuel cost ($/MBtu or $/kWh)	Annual cost savings ($)	Uniform present worth factor[b]	Present value of the energy savings ($)	Installation cost[c] ($)	Savings-to-investment ratio[d]	Simple payback period[d] (years)	Net present value[d] ($)
	A	B	C	D = A · B · C	E	F = D · E	G	H = F/G	I = G/D	J = F – G
Furnace and Boiler										
80% AFUE										
92% AFUE										
Air Conditioner										
10 SEER										
12 SEER										
Heat Pump										
10 SEER 6.8 HSPF										
12 SEER 7.5 HSPF										

[a]Energy savings are obtained from Figs. 4.26 through 4.28 and are per square foot of floor area of the housing unit. The total unit total electricity savings of a high-efficiency heat pump is the sum of the electricity savings for air conditioning (Fig. 4.27) and heating (Fig. 4.28):

Space-cooling electricity savings: __________________________ kWh/ft^2

Space-heating electricity savings: __________________________ kWh/ft^2

[b]The 18-year uniform present worth factor for the U.S. average in 1995 is 17.53 for natural gas and 17.00 for fuel oil. The 15-year factor for electricity is 12.43.

[c]The A/E must determine the cost of installing the replacement units. This cost includes the cost of the unit, removal of the existing unit, installation labor, and other considerations such as need for a new flue or chimney liner.

[d]The replacement units meet military cost-effective criteria if the savings-to-investment ratio is greater than or equal to 1.25 and the simple payback period is less than or equal to 10. If both a minimum-efficiency and a high-efficiency replacement unit meet the cost-effective criteria, the unit with the highest net present value should be installed.

Form G.13. Intermittent ignition device and vent damper **Housing Unit Type ID: ________**

System	Annual energy savings[a] (MBtu)	Fuel cost ($/MBtu)	Annual cost savings ($)	Uniform present worth factor[b]	Present value of the energy savings ($)	Installation cost[c] ($)	Savings-to-investment ratio[d]	Simple payback period (years)	Net present value of the investment[d] ($)
	A	B	C = A · B	D	E = C · D	F	G = E/F	H = F/C	I = E – F
Intermittent ignition device									
Thermal vent damper									
Electric vent damper									

[a]Energy savings are obtained from Figs. 4.29 through 4.31.

[b]The 18-year uniform present worth factor for the U.S. average in 1995 is 17.53 for natural gas and 17.06 for fuel oil.

[c]The A/E must determine the cost of installing the retrofit measures. This cost includes material and installation costs.

[d]The retrofit measures meet military cost-effective criteria if the savings-to-investment ratios are greater than or equal to 1.25 and the simple payback period is less than or equal to 10. If both a thermal and an electric vent damper are economical, then select the damper with the highest net present value.

Form G.14. Water heater fuel conversion **Housing Unit Type ID: ________**

	Annual energy cost[a] ($)	Uniform present worth factor[b]	Present value of the energy cost ($)	Conversion cost[c] ($)	Savings-to-investment ratio[d]	Simple payback period[d] (years)
	A	B	C = A · B	D	E = C/D	F = D/A
Other fuel: ________						
Cost-effective fuel[e]: _________	–		–			
Difference						

[a]Annual energy cost is determined from Figs. 4.34 and 4.35.

[b]The uniform present worth factor is based on a 12-year life. The factor for the U.S. average in 1995 is 11.81 for natural gas and 10.24 for electricity.

[c]The A/E must determine the total cost of conversion. This cost includes flue installation or removal, the gas hookup (possibly including the service entrance piping and piping to the water heater) or disconnect, and the incremental cost (if any) between minimum-efficiency gas and electric units.

[d]Conversion to a different hot water heater meets military cost-effective criteria if the savings-to-investment ratio is greater than or equal to 1.25 and the simple payback period is less than or equal to 10.

[e]Cost-effective fuel is determined from Fig. 4.33.

Form G.15. High-efficiency water heater selection **Housing Unit Type ID: ________**

	Annual energy cost[a] ($)	Uniform present worth factor[b]	Present value of the energy consumption ($)	Installation cost[c] ($)	Savings-to investment ratio[d]	Simple payback period[d] (years)
	A	B	C = A · B	D	E = C/D	F = D/A
Minimum-efficiency unit						
High-efficiency unit	–		–			
Difference						

[a]Annual energy cost is determined from Figs. 4.34 and 4.35.

[b]The uniform present worth factor is based on a 12-year life. The factor for the U.S. average in 1995 is 11.81 for natural gas, 11.56 for fuel oil, and 10.24 for electricity.

[d]The A/E must determine the incremental cost associated with the high-efficiency water heater compared with the minimum-efficiency unit.

[e]The high-efficiency water heater meets military cost-effective criteria if the savings-to-investment ratio is greater than or equal to 1.25 and the simple payback period is less than or equal to 10.

Form G.16. Lighting strategy **Housing Unit Type ID: ________**

Space	Purpose	Daily use (hours)	Location	Fixture type	Lamp type	Control

Form G.17. Summary of revitalization impact on housing unit energy performance **Housing Unit Type ID: _______**

Installation name:		CAPS energy budget:	kBtu/ft^2
Existing intentionally conditioned area: ft^2		Estimated current energy consumption intensity:	kBtu/ft^2
Impact item	Envelope and equipment specification		Estimated annual energy savings from revitalization[a] (MBtu)
	Existing unit	Revitalized unit	
Insulation			
Wall	R:	R:	
Foundation	R:	R:	
Attic or ceiling	R:	R:	
Infiltration	cfm50		
Windows and doors			
Windows			
Storm windows			
Exterior glass doors			
Heating and cooling system			
Heating equipment	AFUE: _______________ HSPF: _______________	AFUE: _______________ HSPF: _______________	
Cooling equipment	SEER:	SEER:	
Intermittent ignition device			
Vent damper			
Distribution system	cfm50		
Domestic water heating	Eff.: _______________ Fuel: _______________	Eff.: _______________ Fuel: _______________	
Total			

[a]Multiply electricity savings (kWh) by 0.003413 to convert to MBtu.

Appendix H

DESIGN WEATHER DATA FOR INSTALLATIONS IN THE UNITED STATES

Table H.1. Weather data for U.S. Air Force bases

State	Base	City	Heating-degree days	Cooling-degree days
Alabama	Gunter	Gunter	2153	2487
	Maxwell	Montgomery	2153	2489
Arizona	Davis-Monthan	Tuscon	1574	2985
	Luke	Glendale	1410	3601
	Williams	Chandler	1535	3503
Arkansas	Baker	Blythville	3760	1789
	Little Rock	Little Rock	3354	2034
California	Beale	Marysville	2835	1525
	Castle	Merced	2590	1566
	Edwards	Lancaster	3077	1829
	George	Victorville	2885	1877
	Los Angeles	Los Angeles	1819	985
	March	Riverside	2162	1343
	Mather	Sacramento	2600	1303
	McClellan	Sacramento	2566	1406
	Norton	San Bernardino	1978	1499
	Travis	Fairfield	2725	831
	Vandenberg	Lompoc	3451	66
Colorado	Lowry	Denver	5978	625
	Peterson	Colorado Springs	6473	481
	USAF Acadamy	Colorado Springs	6973	100
Delaware	Dover	Dover	4756	1115
Florida	Eglin	Valparaiso	1658	2620
	Homestead	Homestead	218	3906
	Hurlburt	Ft. Walton Beach	1782	2370
	MacDill	Tampa	560	3493
	Patrick	Cocoa Beach	452	3405
	Tyndall	Panama City	1413	2737
Georgia	Moody	Valdosta	1549	2716
	Robins	Macon	2244	2276
Hawaii	Hickam	Honolulu	0	4221
	Wheeler		8	2821
Idaho	Mountain Home	Mountain Home	5732	907

Table H.1 (continued)

State	Base	City	Heating-degree days	Cooling-degree days
Illinois	Chanute	Rantoul	5966	1052
	Scott	Belleville	4855	1421
Indiana	Grissom	Bunker Hill	6278	837
Kansas	McConnell	Wichita	4695	1406
Louisiana	Barksdale	Bassier City	2337	2451
	England	Alexandria	1964	2606
Maine	Loring	Limestone	9500	152
Maryland	Andrews	Camp Springs	4551	1237
Massachusetts	Hanscom	Bedford	6474	591
Michigan	K. I. Sawyer	Marquette	9498	198
	Wurtsmith	Oscoda	7929	363
Minnesota	Duluth	Duluth	9757	176
Mississippi	Columbus	Columbus	2890	2039
	Keesler	Biloxi	1549	2793
Missouri	Whiteman	Knob Noster	5012	1410
Montana	Malmstrom	Great Falls	7671	370
Nebraska	Offutt	Omaha	6213	1157
Nevada	Nellis	Las Vegas	2377	3089
New Hampshire	Pease	Portsmouth	6846	481
New Jersey	McGuire	Wrightson	5139	983
New Mexico	Cannon	Clovis	4046	1297
	Holloman	Alamogordo	3223	1870
	Kirtland	Albuquerque	4337	1394
New York	Griffiss	Rome	7331	472
	Plattsburgh	Plattsburgh	8044	461
North Carolina	Pope	Fayetville	3122	1828
	Seymour Johnson	Goldsboro	3124	1769
North Dakota	Grand Forks	Grand Forks	9963	400
	Minot	Minot	9625	398
Ohio	Wright-Patterson	Dayton	5455	1036
Oklahoma	Altus	Altus	3346	2347
	Tinker	Oklahoma City	3588	2068
	Vance	Enid	3971	2088

Table H.1 (continued)

State	Base	City	Heating-degree days	Cooling-degree days
South Carolina	Charleston	Charleston	2146	2078
	Myrtle Beach	Myrtle Beach	2696	1823
	Shaw	Sumter	2453	2160
South Dakota	Ellsworth	Rapid City	7049	738
Tennessee	Arnold	Tullahoma	3883	1212
Texas	Bergstrom	Austin	1712	3078
	Brooks	San Antonio	1272	3339
	Carswell	Ft. Worth	2301	2858
	Dyess	Abilene	2682	2500
	Goodfellow	San Angelo	2240	2702
	Kelly	San Antonio	1520	3190
	Lackland	San Antonio	1520	3190
	Laughlin	Del Rio	1542	3281
	Randolph	San Antonio	1713	2995
	Reese	Lubbock	3453	1738
	Sheppard	Wichita Falls	2904	2606
Utah	Hill	Ogden	6081	920
Virginia	Langley	Hampton	3623	1539
Washington	Fairchild	Spokane	6790	416
	McChord	Tacoma	5287	94
Washington, D.C.	Bolling	Washington, D.C.	4153	1517
Wyoming	F. E. Warren	Cheyenne	7255	327

Table H.2. Infiltration degree-days for U.S. cities	
City and state	Infiltration degree-days (°F-days)
Annette, AK	8369
Bethel, AK	19,861
Big Delta, AK	19,263
Fairbanks, AK	16,609
Gulkana, AK	15,483
Homer, AK	10,382
Juneau, AK	10,175
King Salmon, AK	15,233
McGrath, AK	16,740
Nome, AK	18,364
Yakutat, AK	10,038
Birmingham, AL	4468
Mobile, AL	4480
Montgomery, AL	4463
Fort Smith, AR	6008
Little Rock, AR	6023
Phoenix, AZ	3305
Tuscon, AZ	3093
Winslow, AZ	5443
Yuma, AZ	4264
Bakersfield, CA	2600
Fresno, CA	3103
Los Angeles, CA	1698
Mount Shasta, CA	5801
Oakland, CA	2943
Red Bluff, CA	3795
San Diego, CA	1128
San Francisco, CA	3692
Santa Maria, CA	2801
Colorado Spring, CO	7793
Denver, CO	6806
Grand Junction, CO	6073
Pueblo, CO	6229
Hartford, CT	7881
Wilmington, DE	6884

Table H.2 (continued)	
City and State	Infiltration degree-days (°F-days)
Apalachicola, FL	4670
Daytona, FL	4266
Jacksonville, FL	4501
Miami, FL	5906
Orlando, FL	4593
Tallahassee, FL	3633
Tampa, FL	4629
W. Palm Beach, FL	5910
Augusta, GA	4618
Atlanta, GA	4906
Macon, GA	4453
Savannah, GA	4387
Hilo, HI	1767
Honolulu, HI	3626
Lihue, HI	3200
Des Moines, IA	9149
Sioux City, IA	10,560
Boise, ID	6746
Lewiston, ID	5643
Chicago, IL	8781
Moline, IL	8634
Springfield, IL	8382
Evansville, IN	6326
Fort Wayne, IN	8427
Indianapolis, IN	7913
South Bend, IN	8257
Dodge City, KS	9025
Goodland, KS	9366
Topeka, KS	8214
Lexington, KY	6493
Louisville, KY	6574
Baton Rouge, LA	4692
Lake Charles, LA	5324
New Orleans, LA	4652
Shreveport, LA	5347
Boston, MA	8472
Baltimore, MD	6570

Table H.2 (continued)	
City and State	Infiltration degree-days (°F-days)
Caribou, ME	12,550
Portland, ME	8585
Alpena, MI	8805
Detroit, MI	8624
Flint, MI	8936
Grand Rapids, MI	8793
Sault Ste. Marie, MI	11,313
Duluth, MN	12,515
International Falls, MN	13,266
Minneapolis, MN	10,860
Rochester, MN	11,663
Columbia, MO	7507
Kansas City, MO	7481
Springfield, MO	7539
St. Louis, MO	7793
Jackson, MS	4896
Meridian, MS	4399
Billings, MT	10,376
Glasgow, MT	11,597
Great Falls, MT	10,878
Helena, MT	8915
Miles City, MT	9959
Missoula, MT	7577
Asheville, NC	5421
Cape Hatteras, NC	5525
Charlotte, NC	4539
Greensboro, NC	4990
Raleigh, NC	5103
Bismarck, ND	12,419
Fargo, ND	13,896
Grand Island, NE	10,175
North Platte, NE	9200
Omaha, NE	8950
Scottsbluff, NE	9374
Concord, NH	8240
Newark, NJ	6799

Table H.2 (continued)	
City and State	Infiltration degree-days (°F-days)
Albuquerque, NM	4854
Clayton, NM	7206
Roswell, NM	4989
Elko, NV	7147
Ely, NV	9432
Las Vegas, NV	3524
Reno, NV	5929
Winnemucca, NV	6901
Albany, NY	8185
Buffalo, NY	9840
New York, NY	7518
Rochester, NY	9437
Syracuse, NY	9047
Akron, OH	8118
Cincinnatti, OH	6756
Cleveland, OH	8579
Columbus, OH	7328
Dayton, OH	7681
Toledo, OH	8570
Youngstown, OH	8688
Oklahoma City, OK	7761
Tulsa, OK	7665
Astoria, OR	5025
Medford, OR	4721
Portland, OR	4860
Salem, OR	5027
Allentown, PA	7841
Avoca, PA	7680
Erie, PA	8843
Harrisburg, PA	6470
Philadelphia, PA	6917
Pittsburgh, PA	7462
Providence, RI	7679
Charleston, SC	5072
Columbia, SC	4635
Huron, SD	12,605
Rapid City, SD	10,143
Sioux Falls, SD	11,326

Table H.2 (continued)	
City and State	Infiltration degree-days (°F-days)
Chattanooga, TN	5102
Knoxville, TN	5042
Memphis, TN	5931
Nashville, TN	5607
Abilene, TX	6655
Amarillo, TX	7274
Austin, TX	5652
Brownsville, TX	8193
Corpus Christi, TX	8128
Del Rio, TX	5524
El Paso, TX	3633
Fort Worth, TX	6383
Houston, TX	6189
Lubbock, TX	6150
Midland Odessa, TX	4957
Port Authur, TX	5449
San Angelo, TX	5084
San Antonio, TX	5138
Waco, TX	6916
Witchita Falls, TX	7358
Salt Lake City, UT	6632
Norfolk, VA	5829
Richmond, VA	5119
Roanoke, VA	5552
Burlington, VT	9319
Olympia, WA	5299
Seattle, WA	5811
Spokane, WA	7823
Takima, WA	5997
Green Bay, WI	10,434
La Crosse, WI	9220
Madison, WI	9785
Milwaukee, WI	9855
Charleston, WV	5294