# A DESIGN GUIDE FOR ENERGY-EFFICIENT MILITARY FAMILY HOUSING

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## ABSTRACT

*The United States military is upgrading its existing family housing through a process of revitalization, replacement, and additional new construction aimed at meeting its future housing needs and providing housing quality comparable to that found in the private sector. This paper summarizes energy deficiencies and design flaws found in military family housing that typically have not been corrected during past projects, and presents a description of a design guide prepared for use by designers to help ensure that energy efficiency is properly addressed in future projects.*

*Energy performance design and construction flaws that should be corrected during revitalization include poorly defined building thermal boundaries, lack of insulation, and significant duct leakage. Inspection forms guide field personnel through a process that is performed on a sample of housing units to be revitalized. In-depth diagnostic inspections are performed when major portions of the existing units are to be retained. A graphic-based analysis method is used to determine if the existing level of efficiency of each element of the housing unit should be increased or, in the case of replacement, the level of efficiency that should be installed. Specifications to properly perform work on infiltration, windows and doors, heating and cooling equipment, and air distribution systems are provided as a supplement to or in lieu of standard military specifications.*

## INTRODUCTION

The United States military is upgrading its existing family housing through a process of revitalization, replacement, and additional new construction aimed at meeting its future housing needs and providing housing quality comparable to that found in the private sector. These programs offer unique opportunities to economically improve energy efficiency and help meet reductions in energy consumption mandated by the Energy Policy Act of 1992. It is important that energy efficiency be thoroughly addressed during the design process because comparable opportunities to positively impact energy performance will not exist for many years. Therefore, a guide to the energy-efficient design of these projects was developed.

This paper focuses on the methodology developed to guide decision making during the design of revitalization projects. Because revitalization projects retain significant portions of the previous dwelling, selecting cost-effective energy-efficiency options is not as straightforward as in new construction.

Revitalization typically involves a major overhaul of the building structure and systems. It can include reconstruction of the interior, additions to increase floor area, improvements to exterior siding and windows, and installation of new equipment. Some of the unique opportunities to address energy efficiency during a revitalization project, compared to an energy-efficiency improvement (weatherization) project, include

- whole system replacements if needed,
- fuel conversion when economical, and most important,
- incremental cost increases associated with energy-efficiency improvements are more easily offset by potential energy savings.

The design guide was prepared for use by the firms commissioned by the U.S. Air Force and Army to develop the design and specification of military housing construction and revitalization projects. It provides necessary information and analytical tools to enable the designer to make prudent and cost-effective decisions regarding the type and extent of energy-efficiency measures to be implemented as part of the revitalization process.

Detailed diagnostic inspection procedures for existing housing are provided; these identify the adequacy of current energy-impacting conditions. The guide addresses typical energy-related "problem areas" that have been found in many military housing units. It provides sample forms to walk the designer through the process of inspection and covers each of the potential areas of revitalization that have an impact on energy performance. The inspection forms are used to collect and organize field data from the inspection of a sampling of each type of housing unit to be revitalized.

Step-by-step procedures are provided for analyzing and selecting among the various energy-efficiency actions available. This section is organized by topic to permit access to only those items under consideration in each particular revitalization project. Analysis forms are

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used in conjunction with energy impact charts (both provided in the guide), fuel cost data (provided by the installation), and estimated construction cost data (provided by the designer) to determine which of the potential energy-efficiency measures are cost effective.

Specifications are provided for performing selected measures or installing selected material and equipment. These address various energy-efficiency measures that, historically, have not been successfully implemented.

## NEED FOR A GUIDE

The need for a guide may be questioned when professional design firms develop the detailed plans and specifications and when prescriptive standards for new construction can be applied to parts of revitalization projects. However, site inspections (Levins and Ternes 1994; Ternes and Scully 1992) have found that the current approach has been insufficient to correct many of the energy deficiencies found in military family housing. To ensure that past mistakes are not repeated, comprehensive diagnostics are needed to identify house-specific energy-related issues, and life-cycle cost-effective energy solutions are necessary to resolve them.

Comprehensive inspections of representative types of revitalized and nonrevitalized housing at several military installations in the United States were performed during the development of the design guide. The inspections of each housing unit included examination of the building shell and attic, determination of insulation levels, measurement of the airtightness of the unit, and inspection of the space heating and cooling systems. These inspections evaluated the energy performance of existing housing to develop cost-effective recommendations for the family housing revitalization process.

The inspections identified energy performance design and construction flaws that should be addressed during revitalization. These flaws include the following:

- Air leakage between the conditioned and nonconditioned spaces (primarily to the attic) around unsealed openings (Figure 1).
- Poorly defined building thermal boundary, resulting in incomplete insulation coverage (Figure 2).
- Lack of insulation at second floor overhangs, underwindow openings, in basements and crawlspaces, and around air distribution ductwork.
- Highly varied attic insulation depth caused by maintenance personnel working in the attic and wind scouring at the eaves.
- Inadequate or blocked attic ventilation, resulting in potential moisture-related problems.
- Disconnected and deteriorated air distribution ductwork (Figure 3) and poor system design (Figure 4), resulting in significant air leakage from and to the system.
- Imbalance of pressure within the conditioned space due to inappropriate air distribution system design, resulting in increased air infiltration.
- Recent installation of HVAC equipment with a higher efficiency rating than is cost effective based on the local climate and fuel costs
- Older appliances and HVAC equipment, which offer the opportunity for replacement with more energy-efficient units.

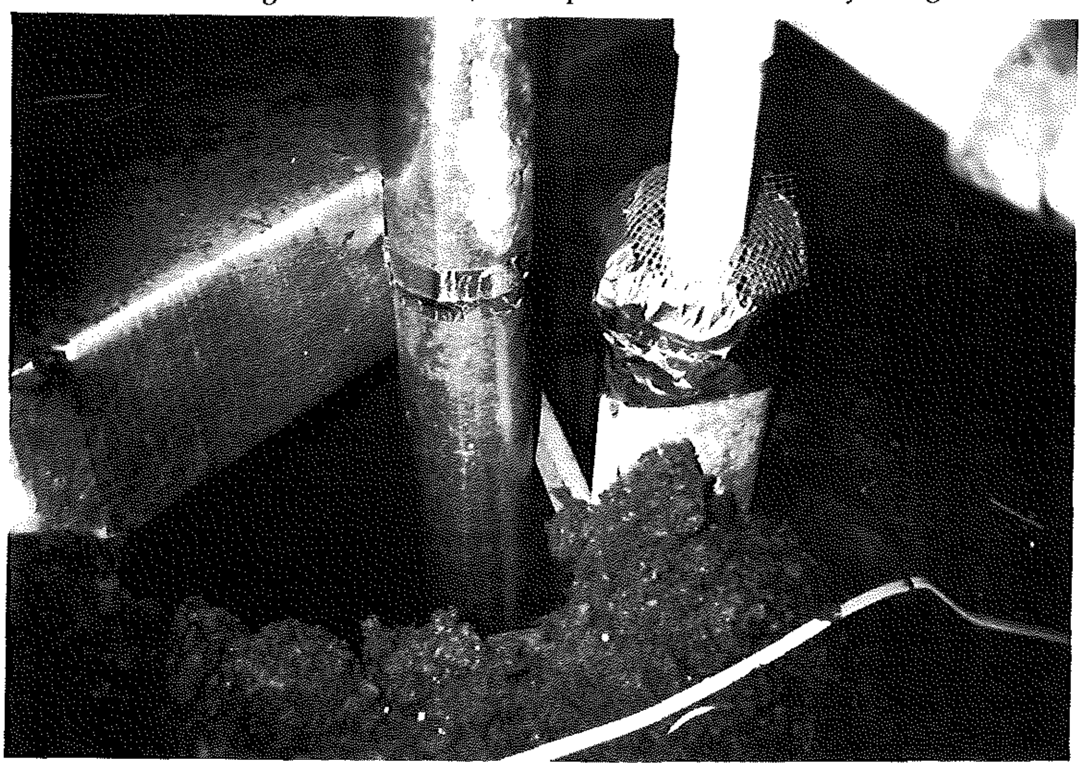


*Figure 1 An "attic bypass" formed from a flue pipe chaseway in this two-story housing unit provides an easy path for conditioned air to exfiltrate into the attic.*

Some recently revitalized units contained many of the same types of flaws as the units awaiting revitalization because the flaws were not corrected during revitalization or the flaws actually were introduced during revitalization construction. The fact that optimized energy designs were not achieved by

*Figure 2* A main distribution supply trunk runs from the basement (which contains a supply register) into a ventilated (nonconditioned) crawlspace. An adequate thermal boundary for this housing unit has not been defined considering the free air movement allowed by the hole in the wall separating the conditioned basement from the ventilated crawlspace, and the lack of floor and duct insulation in the ventilated crawlspace.

*Figure 3* An air distribution supply line is disconnected from the main supply trunk allowing conditioned air to be lost directly to the unconditioned attic.

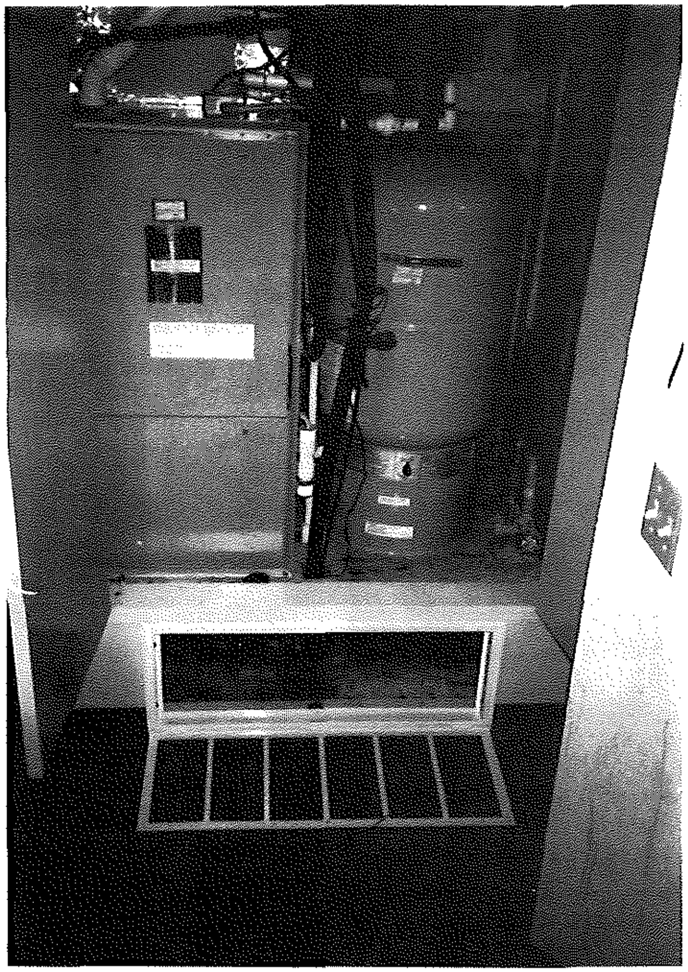
previous revitalization efforts confirmed the need for this guide.

## INSPECTION OF EXISTING CONDITIONS

This section of the guide provides the information required for architects and engineers (A/E) to appropriately inspect existing housing units from an energy-efficiency viewpoint. 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 correction before building efficiency improvements are made.

The elements of the full inspection process are included on the inspection forms found in an appendix of the guide. The forms (Figure 5) are designed to guide field personnel knowledgeable in building construction and terminology but untrained in energy efficiency through the inspection process. They also document the findings of the inspection for use by those who will analyze the existing condition, select appropriate efficiency options, and prepare the revitalization project plans and specifications. The guide recommends that an appropriate sample of each housing type being revitalized must be inspected to adequately define the areas to be addressed during revitalization.

A reduced level of energy-related inspection is justified for some items. Items defined by the military in the revitalization project's scope of work as "to be retained" or "to be replaced" do not require a detailed energy-related inspection. Examples include previously installed replacement windows in good condition that will be retained and air-conditioning systems with no remaining useful life that will be replaced. However, it will be a)



b)

***Figure 4*** *A return plenum was built below this heating system by constructing a 1 ft raised floor in an existing closet (Figure 4a). An inside view of the return plenum (Figure 4b) shows unsealed interior walls and plumbing lines that allow return air to be drawn from the attic and the outside. The unsealed interior walls also connected a supply plenum built above the heating system (not visible in the figure) to the return plenum, allowing conditioned air to recirculate through the unit.*

necessary to obtain a limited amount of field data to estimate the current energy performance of these items, which is an element in the analysis phase of the project. Field inspection also may be required to integrate these items into the overall revitalization project.

When major portions of the existing units are to be retained, the guide prescribes an in-depth diagnostic inspection of a sampling of existing structures and equipment to evaluate their pre-revitalization energy efficiency and identify areas requiring improvement. Conversely, many revitalization projects involve a wall-to-wall "gutting" of the housing unit, leaving little of the existing unit beyond the walls, roof, and floor. In these cases, blower door testing and other detailed diagnostics are of little benefit because most of the existing energy deficiencies will be replaced with "new" construction. For units with less extensive modification, a sampling of unit performance with blower door and heating and cooling equipment diagnostic evaluation is appropriate. The guide acknowledges that these supplemental diagnostic procedures will most likely be performed by professionals in the field because the A/E inspectors lack the necessary equipment and training. Specifications are included in the guide for the acquisition of qualified professional assistance for blower door and duct leakage testing.

Areas of potential revitalization that are inspected include the building envelope, heating and cooling systems, exhaust systems, major appliances, domestic water heating, lighting, and site improvements. Areas of the inspection process prescribed in the guide that are more comprehensive than many home audits and weatherization programs include thermal boundary definition, infiltration, and heating and cooling distribution systems.

## Thermal Boundary Definition

This part of the inspection process clearly delineates the thermal boundary between conditioned and unconditioned areas of the dwelling. The procedure includes sketching both the

Housing unit ID: ______

EXTERIOR WALLS

| Wall location (keyed to floor plans) | Wall type | Wall exposure | Exterior finish | Gross wall area (ft²) | Existing insulated sheathing | Existing cavity insulation type | Thickness (in.) | Vapor barrier present (Y,N) |
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Shared walls found in duplexes and row houses 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

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 wood batt, RB-rigid board or foam, X-other, N-none

*Figure 5 Inspection form used to document existing wall characteristics.*

plan and sections of the unit to locate the boundary in three dimensions. This process calls attention to those areas of the envelope that frequently are overlooked or missed in the process of installing insulation, such as stairwells to unconditioned attics or basements, interior walls between conditioned spaces and garages, upper-floor overhangs, and various attic and roof areas. The sketches also provide a "route map" to follow when checking for the existence and extent of insulation in the dwelling. Many existing units that were inspected had significant gaps in their thermal boundary.

## Infiltration

An infiltration or air leakage inspection is accomplished on those units retaining much of their existing structure and layout. It is performed by trained professionals using a blower door in accordance with prescribed procedures contained in the guide. It provides a detailed understanding of the overall infiltration rate of the unit, and identifies the specific locations of air leakage. Because most military housing units of a particular type are similar in construction and performance, a sampling of several units will identify the typical deficiencies to be corrected during revitalization. These deficiencies include air leaks to: the attic at plumbing walls, internal chaseways, and pocket doors; unconditioned basements and garages at floor or wall penetrations; and the outside through second-story overhangs and exterior wall penetrations. Such air leaks were common in the military family housing units inspected.

## Heating and Cooling Distribution Systems

The initial ductwork inspection is visual to determine if the existing system is adequate for retention with regard to size, condition, and location. If retained, the system is subjected to duct leakage measurements using a blower door. The procedure for accomplishing this testing is detailed in the guide. In addition to leaks to and from fabricated ducts, this testing identifies problems associated with ducts and plenums constructed using the house structure: "short circuiting" between supply and return plenums and potential interconnects of ducts and plenums to unconditioned spaces. Loss of conditioned air in supply and return systems was identified as a major source of energy loss in the inspected housing units.

# ANALYSIS AND SELECTION OF REVITALIZATION OPTIONS

This section of the guide provides information to assist the designer in selecting the most cost-effective revitalization options. Each element of the housing unit that impacts energy consumption is examined to determine if the existing level of efficiency should be increased or, in the case of replacement, the level of efficiency that should be installed.

The analysis method is accomplished by the designer without the use of a computer program. This approach was selected to reduce "nonproductive" learning time often required to use the various available programs. It also focuses the time allocated by the designer(s) on making specific decisions within the limits imposed by the revitalization project. This approach requires some compromises of "accuracy" to obtain "ease of use." A graphic-based analysis was developed for most options.

The designer needs to know the annual heating and cooling degree-days for the project's location to evaluate the energy savings for most of the options presented with this approach. The analysis method used assumes that housing units are single-family (detached or attached) or "townhouse" multifamily structures (units side by side, not above or below). The analysis also assumes that heating and cooling systems are not shared between units. The simplified graphic-based analysis does not consider the interaction between measures (i.e., the total energy savings of two measures installed together may be less than the sum of the savings if installed individually). However, this is not felt to produce any significant errors because energy savings were conservatively estimated for each measure assuming that the thermal efficiency of the remaining housing units met minimum standards. For example, savings for higher efficiency furnaces were estimated assuming exterior walls were insulated with R-13, ceilings insulated to R-38, etc.

The areas of potential revitalization to be analyzed based on information from the inspection include the building envelope, heating and cooling system, exhaust systems, major appliances, domestic water heating, lighting, and site improvements.

The energy savings graphs for the thermal envelope and heating and cooling system options were developed using a computerized residential building simulation tool designed to select a package of energy-efficiency measures for weatherization programs (Krigger et al. 1993). This simulation tool was used to estimate energy savings of the various efficiency options for single-family and townhouse building units in 16 selected military installations that represent a broad range of heating and cooling climates. Energy savings were normalized to appropriate building areas and regressed vs. heating or cooling degree-days to establish general trends. Cooling degree-days rather than degree or enthalpy hours were used because this is the climatic variable included in the military's climatic reference manual (Departments of the Air Force, the Army, and the Navy 1978).

The analysis method was prepared to select only those measures that are cost effective, rather than those that maximize energy efficiency. A number of assumptions are needed to calculate cost effectiveness, such as discount rates, fuel escalation rates, and measured lifetimes. Values for these were selected to be reasonable, based on literature recommendations, but with discretion used to promote energy efficiency.

The designer needs to know the current cost of energy to convert energy savings into dollar values that can be compared with installation cost estimates (provided by the designer) of the energy-efficiency features under consideration. Estimating installation costs and comparing them to discounted savings values is the responsibility of the project's designer because of the variety of 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 interior finish (drywall, paneling, plaster) is being removed for other reasons (such as repair of termite damage or rewiring) than if it remains. Accessible stud cavities can be insulated with batts, while enclosed cavities require a more expensive blown insulation process. However, the energy-savings estimates are about the same in both cases.

Because the cost of energy impacts option selection, it is important to determine both the current energy cost and that projected for the future. If significant (> 25% above inflation) energy cost increases at the installation where revitalization will occur are projected within the next five years, these increases must be factored into the decision-making process.

## Example Analysis—Wall Insulation

New portions of the thermal envelope added during revitalization (such as new walls, foundations, and ceilings installed to expand the size of a housing unit) should be insulated to the current standards for new construction applicable to each specific branch of the military.

Various portions of the existing building thermal envelope may be underinsulated, causing increased energy loss. The designer should determine existing insulation levels by referring to the information recorded during the site inspection. The following analysis provides a procedure to determine the cost-effective level of insulation (if any) to install during revitalization for 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). 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 achieve an insulation level of R-13. 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:

- it can be installed when the interior wall finish (drywall or plaster) is removed as part of the revitalization (primarily batts or wet sprayed cellulose);
- 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 in the exterior wall finish after the existing siding is removed or before new siding is installed.

Insulation added to the outside of the wall is provided by rigid boards that must be covered by an exterior finish for protection. This usually can achieve an insulation level of R-5. This approach can be considered when new siding is being installed. A combination of stud cavity and exterior wall insulation would yield an overall insulation level of R-18, 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 during revitalization can be determined using Figures 6, 7, and 8.

1. The annual space-heating energy savings per unit of wall area is obtained from Figure 6a (stud cavity) or Figure 6b (exterior) using the heating degree-days for the installation.
2. The annual space-cooling electricity savings per unit of wall area is obtained from Figure 7a (stud cavity) or Figure 7b (exterior) using the cooling degree-days for the installation.

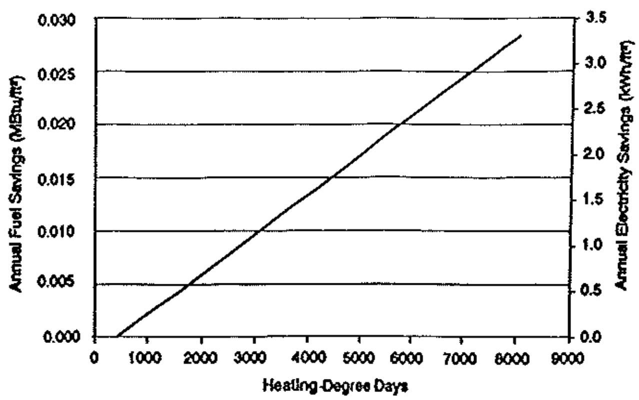


*Figure 6a* Annual space-heating energy savings per square foot of wall area from installing R-13 insulation in the stud cavity of an uninsulated wood-frame wall.

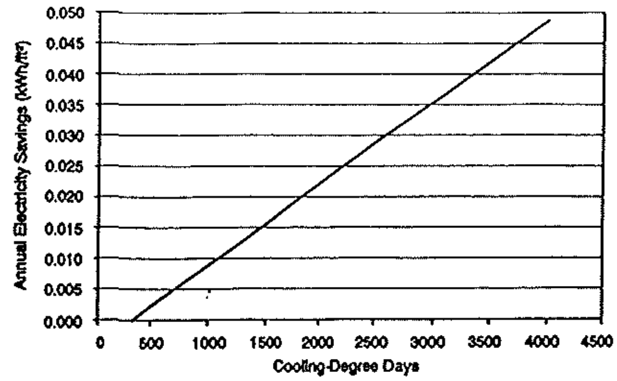


*Figure 7b* Annual space-cooling energy savings per square foot of wall area from installing R-13 insulation in the stud cavity of an uninsulated wood-frame wall.

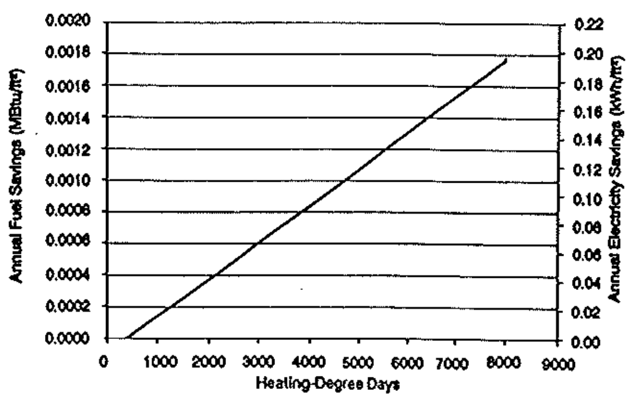


*Figure 6b* Annual space-heating energy savings per square foot of wall area from installing R-5 insulation on the exterior of a wood-frame wall with R-13 stud-cavity insulation.

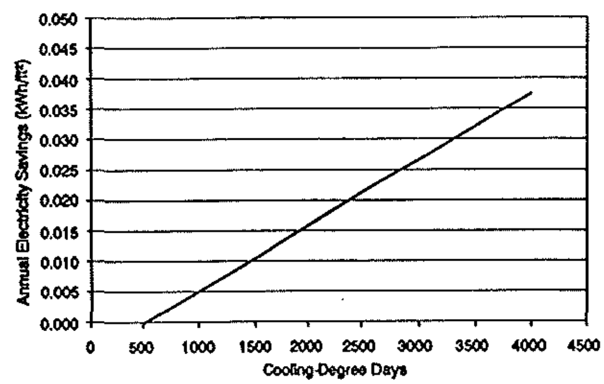


*Figure 7c* Annual space-cooling energy savings per square foot of wall area from installing R-5 insulation on the exterior of a wood-frame wall with R-13 stud-cavity insulation.

3. The present values of the space-heating and space-cooling energy savings are calculated as outlined in Figure 8 using the installation's costs for fuel and the 25-year uniform present worth (UPW) factors indicated in the figure. These values are summed to obtain the total present value of the wall insulation savings.
4. The designer must determine the total cost of installing the wall insulation per unit 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 replacement as part of the revitalization. An important factor for the designer to consider for cavity insulation is whether the interior or exterior finishes will be removed during revitalization, providing ready and low-cost access to the wall cavity.
5. The stud cavity or exterior wall insulation is cost-effective if the net present value (NPV) of the investment is greater than zero. Install insulation in both locations if both are cost effective.

## SPECIFICATION OF SELECTED EFFICIENCY OPTIONS

Specifications for use in revitalization projects as a supplement to, or, in some cases, in lieu of standard military specifications are provided to the designer on infiltration, windows and doors, HVAC equipment, and air distribution systems. Specifications for infiltration concentrate on materials and procedures to correct infiltration deficiencies in the building envelope, as identified by an infiltration specialist. A primary focus of the heating and cooling equipment specifications is the commissioning and tune-up of furnaces, boilers, air conditioners, and heat pumps. Installation procedures for new ductwork are provided to prevent introduction of deficiencies during construction. Repair procedures for existing duct sys-

Wood-frame wall insulation

| | Annual energy savings[a] (MBtu/ft$^2$ or kWh/ft$^2$) | Fuel cost ($/MBtu or $/KWh) | Uniform present worth factor[b] | Present value of the energy savings ($/ft$^2$) | Insulation Installation cost[c] ($/ft$^2$) | Net present value of the investment[d] ($/ft$^2$) |
|---|---|---|---|---|---|---|
| | A | B | C | D = A·B·C | E | F = D − E |
| Stud cavity: | | | | | | |
| Heating | | | | | | |
| Cooling | | | | | | |
| Total | | | | | | |
| Exterior: | | | | | | |
| Heating | | | | | | |
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| Total | | | | | | |

[a] Annual energy savings are determined from Figs. 6 and 7 and are per square foot of wall area.
[b] The uniform present worth factor is based on a 25-year life. The factor is 20.98 for natural gas, 19.84 for fuel oil, and 17.57 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 is cost effective if the net present value of the investment is greater than zero. Insulation should be installed in both locations if both are cost effective.

***Figure 8*** *Analysis form used to determine the cost-effective level of wall insulation resulting from revitalization.*

tems are provided to correct deficiencies found by an infiltration specialist.

## CONCLUSIONS

Recent military family housing projects have not achieved the desired level of energy efficiency. Recurring design and construction flaws have contributed to this deficient performance. This design guide will provide the knowledge and analytic tools needed by project designers to achieve the highest cost-effective level of energy efficiency in their projects. It will enable the military to improve the energy efficiency of both existing housing (through revitalization) and new dwellings added to its housing stock. These more efficient units will assist in achieving the mandated energy-use reduction prescribed by the Energy Policy Act of 1992.

With the increased emphasis on improved military housing announced by President Clinton in late 1994, it is expected that this guide will influence design decisions relating to the revitalization and construction of thousands of units over the next few years.

## ACKNOWLEDGMENTS

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