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Energy and Cost Savings from Roof Insulation Added to Four Types of Army Buildings: Final Report—ECIP Project Validation Project No. 308 Fort Riley, Kansas

Fred D. Boercker
Howard A. McLain
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ENERGY DIVISION

ENERGY AND COST SAVINGS FROM ROOF INSULATION ADDED TO FOUR TYPES OF ARMY BUILDINGS: FINAL REPORT—ECIP PROJECT VALIDATION

Project No. 308
Fort Riley, Kansas

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Date Published—December 1986

Prepared for the
U.S. ARMY FACILITIES ENGINEERING SUPPORT AGENCY
Fort Belvoir, Virginia 22060-5516

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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ACKNOWLEDGMENTS

This validation project required the cooperation of individuals from many organizations. Only with their help was the study possible.

Staff members from the Energy Office at Fort Riley, Mr. Larry Stillwagon, Mr. Doug Harley, and Ms. Rose Boerner, made important contributions to the design of the project. Their knowledge of the Fort Riley buildings helped in selecting representative ones for metering and modeling. They arranged for installation of the meters and supplied ORNL with weekly reports of meter readings and weather data. Mr. Rob McWilliams, Facility Engineers Office, supplied detailed information regarding building construction of the four modeled buildings.

Mr. Kirt Grahl, Mr. Buck Vannaman, and Mr. Harold Chart of the Kansas City Office, U. S. Army Corps of Engineers, supplied copies of retrofit specifications and project cost data.

Mr. Henry Gignilliat and Mr. Bill Ell, U.S. Army Facilities Engineering Support Agency, provided program guidance and facilitated many crucial operations of the project.

Several ORNL staff members have reviewed preliminary drafts of the report. Messrs. Jeff Christian and Robert Kedl provided helpful suggestions which have been incorporated into this document. Ms. Clara Nichols typed the report, checked on format details, and helped with publication details.

The authors wish to acknowledge and thank each of the above persons and the organizations they represent.

EXECUTIVE SUMMARY

THE VALIDATION STUDY

This document reports findings of a study designed to validate energy savings and cost savings attributed to a roof insulation retrofit project carried out at Fort Riley, Kansas, as part of the U.S. Army Energy Conservation Investment Program (ECIP). The study was conducted by Oak Ridge National Laboratory (ORNL) for the U.S. Army Facilities Engineering Support Agency (USAFESA). The results will be used by the Army to improve the effectiveness of building roof insulation programs and to validate savings achieved through this category of the ECIP program.

This particular ECIP project involved insulating roofs of 16 buildings at Fort Riley, Kansas. All 16 buildings were originally constructed between 1880 and 1920, and all are listed in the National Register of Historic Buildings. The buildings have heavy walls (18 in. of native limestone), and before retrofit, they had no ceiling or roof insulation. The retrofit consisted of adding R-19 batt insulation to the roofs of 15 buildings and placing R-33 insulation on the suspended ceiling of a hangar building. With two exceptions, each of the 16 buildings may be classified into one of four categories: warehouses/storehouses, shops, combination barracks/mess halls, or hangar.

The point of the validation study was to determine energy savings from the retrofit and to calculate cost savings associated with these energy savings. Then, using procedures prescribed in ECIP guidance and project cost data from the District Corps of Engineers, life-cycle cost analyses were to be performed for the overall project and for each of the four building types.

THE VALIDATION METHOD

The study procedure consisted of modeling the space conditioning energy use of four buildings, one selected from each of the four categories. The models (DOE-2.1B) were run for both pre-retrofit and post-retrofit conditions, and energy savings were normalized for a typical meteorological year (TMY) at Fort Riley. This modeling effort was supplemented by three months of pre-retrofit submetered space conditioning fuel use data. These weekly fuel use data were used to adjust the model of each building so that its outputs conformed with the measured energy consumption data. Modeled energy savings for each building type were extrapolated to all buildings of that type within the retrofit group.

Project design and construction costs were obtained from the Kansas City Office, U.S. Army Corps of Engineers. Current fuel costs were obtained from the Energy Office at Fort Riley. The modeled energy savings and fuel cost information were used to calculate annual cost savings. ECIP guidance specified a maximum economic life of 25 years for this type of retrofit and a corresponding Uniform Present Worth Factor of 20.23. All of this

information was used as input to a life-cycle cost analysis. Savings-to-investment ratios (SIRs) were calculated for the overall project and for each of the four building types.

FINDINGS: FOUR BUILDINGS

- Based on heating season data for a 12-week period, three of the four metered buildings showed very high correlations between weekly fuel use and average weekly outside temperature (Rs of -0.91, -0.95, and -0.98). The barracks/mess hall, with large internal loads and small roof/wall ratio, showed little correlation between fuel use and outside temperature (R = -0.38). Balance point temperatures and measured inside temperatures both indicate a wide variation in thermostat settings among these building types.
- The DOE-2.1B model required extensive data input, including hourly weather data, numerous building construction details, HVAC characteristics, and building use patterns. Modeled energy usage for each building tracked metered fuel use closely for each of six test weeks. Differences were less than 13%.
- Modeled energy savings for the four metered buildings showed appreciable fuel (natural gas) savings during the heating season. The barracks were the only air-conditioned buildings, and they showed negligible electricity savings during the summer. Roof insulation saved about one-third of heating energy use for the warehouses, one-fourth for the maintenance shop, less than one-tenth for the hangar, and almost none for this 3-story combination barracks/mess hall. However, because the warehouse is kept at a low temperature (about 55°F), its absolute energy use is low and its absolute energy savings is modest.

FINDINGS EXTRAPOLATED TO 16 BUILDINGS

When the modeled energy savings of the four buildings are extrapolated to all 16 buildings,

- the 6 warehouses/storehouses, which account for 39% of total roof area (and installed insulation), account for 26% of the total annual energy savings;
- the five shops account for 29% of roof area and 56% of energy savings;
- the two barracks/mess halls have 10% of roof area, but supply <1% of energy savings; and
- the hangar, with 12% of roof area, accounts for 9% of energy savings.

The total energy savings, normalized for a typical meteorological year at Fort Riley, is 8,762 MBtu/yr.

- Total costs for this ECIP project were:
  - — Construction (labor and materials)—$233,449
  - — Supervision, inspection, overhead (SIOH), and design—$19,451

  Costs were also available for each building retrofit, permitting SIR calculations to be made by building type.

- Current ECIP guidance allows a maximum economic life of 25 years for shell retrofits and provides a corresponding discount factor of 20.23 for natural gas in Region 7. Fort Riley currently has a relatively low natural gas rate of $3.10/MBtu. Using these factors and the modeled energy savings, the following SIRs result:

  — Entire project (16 buildings)—2.41

  — Warehouses/storehouses (6 buildings)—1.66

  — Shops (5 buildings)—4.35

  — Barracks/mess halls (2 buildings)—0.14

  — Hangar (1 building)—1.84

  If a 15-year economic life, rather than 25 years, had been used, the overall SIR would be reduced to 1.64. If 1982 natural gas prices of $3.82/MBtu had been used, the overall SIR would be 2.02 for a 15-year economic life and 2.97 for a 25-year economic life.

- The SIR from this study may be compared with one estimated by the Corps of Engineers in 1985 using the BLAST modeling program and an economic life of 15 years (SIR—1.97). The originally estimated SIR of a consulting group (updated 1982) was 12.35 based on a 25-year economic life and $3.82/MBtu natural gas costs.

CONCLUSIONS

- For buildings of the type studied in this project, added roof insulation from R=1 to R=20 is very cost effective for maintenance shops, reasonably effective for warehouses maintained at low temperatures, but good for those maintained at moderate temperatures, reasonably effective for hangars, and ineffective for this type of 3-story barracks/mess hall. Savings will vary depending upon climate, building use patterns, and building structural details. (For example, a one-story barracks may show good savings from roof insulation even though this 3-story hybrid did not.)

- Careful modeling, supplemented by some basic metering, is an effective approach to identifying impacts of roof insulation on a variety of building types. Such modeling, however, requires a large amount of input data and skillful use of the data by an experienced professional staff member in a complex modeling procedure. It is time-consuming.

- Adherence to ECIP guidance requiring analysis of discrete portions of the project may save retrofit investment dollars. This project illustrates a situation in which the overall SIR was well above 1.0, but one portion (building type) had an SIR <1.0 and could have been omitted.

- ECIP validation studies are greatly facilitated by

  — prompt installation of the retrofit, as scheduled. Delays add to the cost of the study and impair accuracy of results because building structure and/or building use patterns change with time.

— early involvement and coordination of the working groups: USAFESA, Energy Office of the Army base, District Office of Corps of Engineers, and the study group (ORNL).

ENERGY AND COST SAVINGS FROM ROOF INSULATION ADDED TO FOUR TYPES OF ARMY BUILDINGS

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ABSTRACT

This is the final report of a study designed to validate energy and cost savings attributed to roof insulation retrofits carried out at Fort Riley, Kansas, as part of the U.S. Army Energy Conservation Investment Program (ECIP). The study was conducted by Oak Ridge National Laboratory for the U.S. Army Facilities Engineering Support Agency.

Insulation was added to the roofs of 16 buildings which had no ceiling or roof insulation prior to retrofit. With two exceptions, each of the buildings could be classified into one of four categories: warehouses/storehouses, shops, combined barracks/mess halls, and hangar. The validation study was to provide life-cycle cost analyses for the entire project and for each building category.

The validation procedure consisted of modeling both pre-and post-retrofit energy use of four buildings, selected to represent each of the four building categories. The modeling was supplemented by three months of pre-retrofit submetering of space heating fuel use by the four modeled buildings. These weekly fuel use data were used to adjust the model of each building so that its outputs tracked metered fuel use data.

When the modeled savings of the four buildings were extrapolated to all 16 buildings,

- the six warehouses/storehouses accounted for 26% of annual energy savings,
- the five shops accounted for 56% of savings,
- the two combination barracks/mess halls provided <1% of savings,
- the one hangar accounted for 9% of savings, and
- the remaining two unclassified buildings provided 9% of annual savings.

Based on these energy savings, life-cycle cost analyses were performed resulting in savings-to-investment ratios (SIRs) as follows:

Entire project (16 buildings)	2.41
Warehouses/storehouses (6 buildings)	1.66
Shops (5 buildings)	4.35
Barracks/mess halls (2 buildings)	0.14
Hangar (1 building)	1.84

ECIP guidance requires an SIR of at least 1.0. The overall project at Fort Riley and all but one building category fulfill this requirement.

1. INTRODUCTION

1.1 STATEMENT OF WORK

The original "Statement of Work"[1] for the Energy Conservation Investment Program (ECIP) Project Validation Studies lists tasks that will be performed by Oak Ridge National Laboratory (ORNL) staff for the U.S. Army Facilities Engineering Support Agency (USAFESA) in each of four phases of ECIP validation studies. These tasks are

Phase I	—	Validation planning, evaluation of project documentation, and site assessment;
Phase II	—	Design of the validation study;
Phase III	—	Implementation of the validation study; and
Phase IV	—	Analysis and evaluation of results.

The first three phases of work have now been completed for ECIP Project No. 308 at Fort Riley, Kansas—adding roof or ceiling insulation to 16 buildings. A previously published interim report by ORNL[2] summarized the planning and design phases for this study (Phases I and II), and the planned validation tasks have now been implemented (Phase III). This document reports findings of the study (Phase IV), including a life-cycle cost analysis for each of four building types that were retrofitted with roof insulation.

1.2 PURPOSE OF THE STUDY

Rapid escalation of fuel prices brought on by the oil embargo of 1973–74 impacted all sectors of the United States, including the military. Funds intended for military mission-related tasks were, in part, diverted to paying utility bills. In 1980, the Department of Defense (DOD) established goals for reducing energy use per square foot of building space. Relative to FY 1975, energy consumption was to be reduced 20% by FY 1985 and then reduced an additional 5% each successive five-year period until FY 2000.

A number of funding options were made available to the military bases to help implement the necessary energy-saving building retrofits. ECIP is one of these options. It makes military construction funds available to the Army bases for cost-effective retrofits costing more than $200,000.

Congress has required, however, that a reasonable effort be directed toward validating the benefits realized from ECIP funds. A memorandum from the Office of the Assistant Secretary of Defense providing guidance for the ECIP program states:

> "Clearly, the continued level of Congressional support for this program is dependent on the presentation of a convincing demonstration that the funds spent through the ECIP are being managed prudently. In addition, a rigorous after-the-fact analysis is essential for future project programming in order to

identify those specific projects which are more cost-effective in practice as well as theory, and to identify any real-world savings limiting constraints which may not be apparent to the design engineer."

The purpose of this report is to present the findings of a validation study carried out by ORNL for USAFESA dealing with the installation of roof insulation in selected buildings at Fort Riley. The initial sections of the report will describe this ECIP project, evaluate the documentation of the project, and provide an overview of the validation procedure. The bulk of the report will describe the findings of the study (energy savings and economic analysis) and discuss implications of these findings for similar ECIP projects. These results will provide the Army with a comparison between projected energy and cost savings of the ECIP retrofit (based on engineering calculations) with achieved energy savings (based on a combination of metering and modeling). The validation study had to be carried out within reasonable cost limits, so the number of buildings metered and modeled and the complexity of instrumentation were reduced to a minimum. The focus is to provide an improved estimate of the benefit/cost ratio for this ECIP project, and the findings will be of interest to those involved with energy-saving retrofits of military buildings. The study, however, is not designed as a basic research effort.

2. ECIP PROJECT DESCRIPTION

Fort Riley was established approximately 100 years ago, and the on-post buildings range from modern ones to some of original construction. The 16 buildings of concern for this ECIP project were built between 1880 and 1920, and they are listed on the National Register of Historic Buildings.

The original specifications (1 March 1982) for this project, as stated in the Military Construction Project Data document (DD Form 1391), listed 27 buildings to be retrofitted. However, two cold-storage warehouses were soon removed from the list, leaving 25 units to be insulated. Construction was to start in September 1984 and be completed by September 1985. Before retrofit, the roofs had no insulation; the asphalt shingles, roofing felt, and wood sheathing had a combined R-value slightly over 1, much less than required by DOD 4270.1-M, *The Construction Criteria Manual.* Almost all of the buildings could be classified within four categories: warehouses or storage, maintenance shops, combination barracks/mess halls, and hangars.

The final ECIP retrofit project specifications advertised for bid by the U.S. Army Corps of Engineers, Kansas City District[3] in June 1985, reduced the number of buildings to 20 and required:

> "For batt and blanket insulation, the actual installed thickness shall provide a U value of 0.05 for the completed ceiling and roof construction."

For Building 201 (the hangar):

> "Insulation shall be layed on the suspended ceiling and shall be 0.03."

The insulation was installed in the buildings beginning about February 1986 and extending through July of 1986. Some final changes during this retrofit phase reduced the number of buildings receiving roof insulation from 20 to 16.

3. EVALUATION OF PROJECT DOCUMENTATIONS

A brief description of the proposed ECIP retrofit project and engineering calculations estimating energy savings and project costs are contained in the A-E (Burns and McDonnell) contractor's report submitted to Fort Riley.[4] These calculations projected energy savings of 49,800 × 10^6 Btu/yr and corresponding fuel cost savings of $190,236/yr. Initial capital costs were projected to be $308,823 for installing approximately 300,000 ft^2 of R-19 insulation. The total benefits were projected to be $3,814,232, yielding a discounted benefit/cost ratio of 12. The Burns and McDonnell analysis was carried out in 1980 and assumed an economic life of 25 years for the retrofit, which corresponded to ECIP guidance for that time. During 1985, the Kansas City Corps of Engineers recalculated the discounted benefit/cost ratio for this project. They used the Buildings Loads Analysis and Systems Thermodynamics (BLAST) Program to model the buildings; they used updated natural gas prices; and they used revised ECIP guidance that specified 15-year economic life for the retrofit. The recalculated benefit/cost ratio was 1.97. The remaining parts of this section provide a review and critique of the Burns and McDonnell estimates of energy and cost savings to be obtained by roof insulation of buildings of Fort Riley.

3.1 CONFORMANCE WITH ECIP GUIDANCE

The Statement of Work agreement between ORNL and USAFESA[1] provides that ORNL staff members will evaluate each candidate ECIP project to see if it is in "conformance with ECIP guidance and program criteria." It is important to note, however, that ECIP guidance was published in 1977 and revisions appeared in 1982, 1983, and 1985.[5] Therefore, in evaluating conformance with ECIP guidance, it is necessary to know what guidance was in effect when the document was prepared. The Department of the Army also requires that "the SIR calculation will be performed using the mode of analysis of the National Bureau of Standards (NBS) Handbook 135...." (ref. 6). These guidance documents have been reviewed as they pertain to the building insulation project at Fort Riley.

The original documentation of this ECIP project by the A-E, Burns and McDonnell,[4] was published in 1980 (updated March 1, 1982) and was governed, therefore, by the 1977 ECIP guidance. Total energy savings were estimated by modeling building 129 (a vehicle maintenance shop) and then extrapolating this savings by multiplying by the ratio of the ceiling area of all retrofitted buildings to the ceiling area of building 129. Their modeled results for building 129 indicated an annual energy savings of 1173 × 10^6 Btu or a 58% savings over the uninsulated condition. Since the total ceiling area for all retrofitted buildings would be 42.5 times that of building 129, the total savings were estimated as

$$(42.5)(1173 \times 10^6 \text{ Btu}) = 49{,}800 \times 10^6 \text{ Btu}.$$

Having estimated the annual fuel savings, the Burns and McDonnell staff calculated the net discounted savings (based on a 25-year maximum economic life) as $3,814,232. The initial capital costs were estimated to be $308,823, so the discounted benefit-to-cost ratio was

$$\$3{,}814{,}232/\$308{,}823 = 12.3.$$

These calculations follow ECIP guidance in effect at that time, including 25-year economic life, except for one important exception. ECIP guidance requires that "...overall projects and discrete portions of projects must be life-cycle cost-effective (SIR equal to or greater than 1)." These calculations did not show that each portion of the project (in this case, each general type of building to be retrofitted) had an SIR greater than 1.

3.2 ADEQUACY OF ENGINEERING ANALYSIS

The buildings proposed for retrofit are varied, consisting of a hangar, warehouses/storehouses, maintenance buildings, and barracks/mess hall. Although most have similar construction (heavy native limestone walls erected at the turn of the century), they display a variety of sizes and functions (see Table 3.1). At least one building from each of the four major types should have been selected for analysis.

Table 3.1. Classification of 16 retrofit buildings, Fort Riley

Building type	Number	% of total roof area
Warehouses/storehouses	6	39
Maintenance shops	5	29
Hangar	1	12
Barracks/mess hall	2	10
All other	2	10
Totals	16	100

A second problem with the original engineering analysis involves assumptions regarding interior temperatures of the buildings, or thermostat settings. Extrapolation of energy savings from building 129 to all retrofitted buildings assumes that the assigned interior temperature for building 129, for modeling purposes (68°F), is representative for the entire building group. This temperature is high for the warehouses which comprise the largest group of buildings.

In like manner, these four groups of buildings differ markedly in infiltration rates, internal loads, and in ratios of roof-to-wall areas. All of these factors influence heating energy consumption, and it is not likely that values chosen in modeling building 129 are representative or average for all four groups of buildings.

In summary, these initial calculations probably have overestimated the annual energy savings that might be expected from the Fort Riley ECIP project. Another modeling study of energy consumption in Army buildings[7] did report on energy savings to be expected from adding roof insulation, as did a later modeling study of the Fort Riley buildings by the Kansas City Corps of Engineers. The results of these studies suggest a lesser energy savings than was projected and, therefore, a reduced SIR.

4. SITE AND PHYSICAL CONDITIONS

Staff members from the Energy Division and from the Instrumentation and Controls Division of ORNL have made four visits to Fort Riley over the period of this ECIP validation study. The general purposes of the visits were to inspect buildings, plan metering, collect information, and coordinate activities with the Facility Engineers and Energy Offices at Fort Riley. Mr. Rob McWilliams of the Facility Engineers Office supplied detailed information concerning four buildings chosen for metering and modeling. Mr. Larry Stillwagon, Mr. Doug Harley, and Ms. Rose Boerner of the Energy Office helped arrange for the installation of meters, obtained weekly meter readings, and obtained monthly summaries of daily weather data for Fort Riley.

Findings from the four visits included the following:

1. These buildings are listed on the National Register of Historic Buildings, and, therefore, the energy retrofits must not change the external appearance of the buildings.

2. The buildings are heated by natural gas. Each building has its own boiler or set of unit heaters.

3. The heating systems for buildings in different groups are quite different. Warehouses are heated by a number of wall-mounted gas units; the hangar is heated by a boiler that supplies steam to two heat exchangers, and large blower systems distribute the heated air to the two wings of the hangar; the barracks are heated by steam from two boilers, but they also have large internal loads supplying heat; and the maintenance shops are heated by boilers supplying steam to wall-mounted heat exchangers.

4. The Fort's gas meters record total gas used on the post, but none of the buildings are individually metered.

5. All but two of the buildings to be retrofitted may be classified into one of four groups by use pattern: warehouses/storehouses, maintenance shops, barracks/mess halls, and hangar.

6. Buildings of a given group (say, warehouses) maintain interior temperatures that are markedly different from buildings in another group (say, barracks).

7. The Fort Riley staff members preferred to have USAFESA purchase the meters, but they had their own on-site technicians install the meters.

5. THE VALIDATION PROCEDURE

5.1 OVERVIEW OF VALIDATION PROCEDURE

The validation method for this ECIP project was prepared by ORNL staff members from the Energy Division and the Instrumentation and Controls Division. The plan was reviewed internally at ORNL and then sent to USAFESA and to Fort Riley for additional review. After incorporating suggestions from these sources, the revised plan was approved for implementation by USAFESA.

In a memorandum prepared by the U.S. General Accounting Office (GAO) for the DOD,[8] the GAO suggested that "...alternatives to collecting actual use data over a two-year period should be considered." The method proposed in this section to validate energy and cost savings of the Fort Riley roof/ceiling insulation project essentially follows the GAO suggestion. Energy savings are obtained by modeling the space heating energy use of a sampling of buildings before and after retrofit. This modeling effort is supplemented by a minimal submetering of fuel usage, which data are used to calibrate the model.

The buildings scheduled for retrofit with roof or ceiling insulation were classified into four categories based on use patterns: warehouse, maintenance shop, barracks/mess halls, and hangar. One building from each category was selected for modeling. Natural gas flow meters were installed to submeter energy use for space heating, and watt-hour meters were used to measure total building electrical load. The meters were read manually each week for three months of the pre-retrofit heating season. Each of the four buildings was modeled for the pre-retrofit condition using DOE-2.1B. The model was adjusted so that it would track the weekly pre-retrofit metered fuel use pattern. Added roof insulation was then inserted (mathematically) into the model inputs and the post-retrofit seasonal fuel use for space heating was calculated. The original validation plan specified that these post-retrofit fuel use patterns be checked by post-retrofit metering. Unfortunately, the installation of the retrofit, which was scheduled originally to begin in September 1984, was postponed,and the insulation was not installed until late July 1986. Post-retrofit metering would not have been possible until the winter of 1986-87, but the meters are still in place and a check of the post-retrofit fuel use reported in this document could be carried out.

In addition to fuel savings, calculation of the SIR requires project cost data. These data were supplied by the Kansas City Office of the Corps of Engineers.

5.2 ALTERNATIVE METHODS CONSIDERED

In addition to the validation procedure described above, which relies primarily upon modeling supplemented by minimal measurement, ORNL staff considered a heavily instrumented approach. Again, four sample buildings would be selected, but each would be heavily instrumented:

- thermocouples monitoring inside temperatures,
- heat flux meters to monitor heat flow through roof or ceiling,
- natural gas flow meters in line with heating units, and
- mini weather station to monitor outside temperature, wind speed and direction, and humidity.

These data would be used to determine the change in heat flux caused by the added insulation and the resulting decrease in fuel usage. All data from the sensing apparatus would be recorded hourly by data loggers. From an engineering viewpoint, this direct measurement approach would be preferred to the modeling approach, but it would have been more expensive.

5.3 DETAILS OF THE VALIDATION PROCEDURE

5.3.1 Selection and Instrumentation of Modeled Buildings

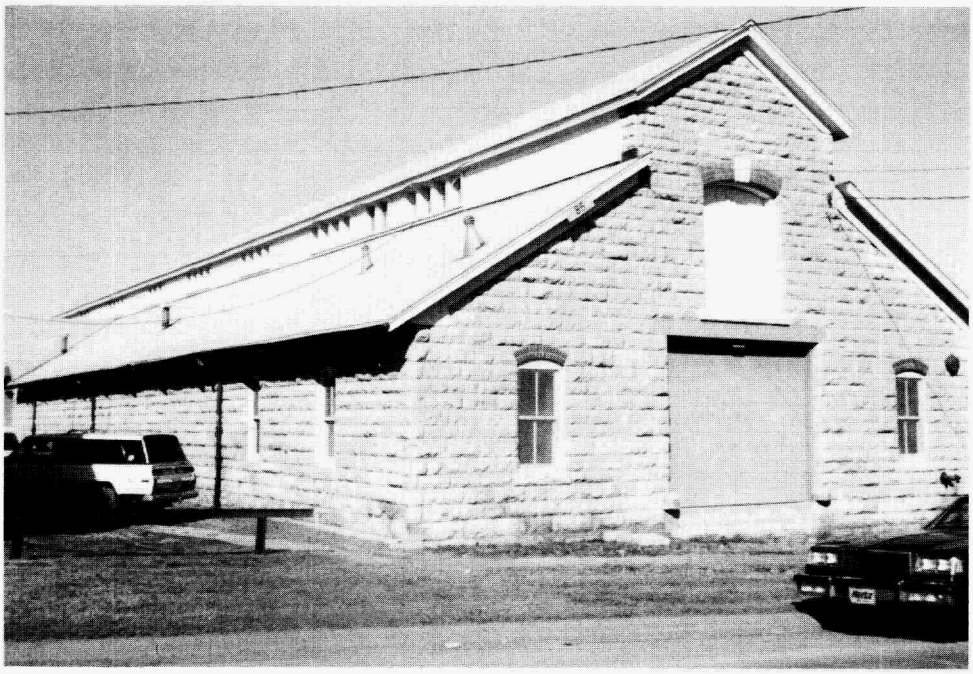
Table 3.1 shows that 6 of the 16 buildings that were scheduled for roof insulation are warehouses or storehouses, and they account for 39% of the total roof area. Five of the 16, accounting for 29% of the area, are maintenance shops; two barracks/mess halls account for 10% of the area; the hangar has 12% of the area; and the two remaining buildings account for 10% of the total roof area. One building from each of the four groups was selected for study. Each of these was submetered for space heating fuel use and for total electrical consumption, and each was modeled using DOE-2.1B. (Figure 5.1 pictures the four buildings, and Fig. 5.2 indicates the instruments installed in each.) The instruments were read weekly by a member of the Fort Riley Energy Office, and the data were mailed to ORNL along with monthly summaries of daily weather data.

The selection of the four sample buildings was accomplished on a visit by ORNL staff members to Fort Riley. The Fort Riley personnel were helpful in weighing factors such as security of instrumentation and physical location of buildings to facilitate surveillance. Building 129 was selected because it was the one modeled by Burns and McDonnell in projecting energy savings. Detailed procurement specifications for the meters and installation drawings for the meters are contained in a previous ORNL report.[2]

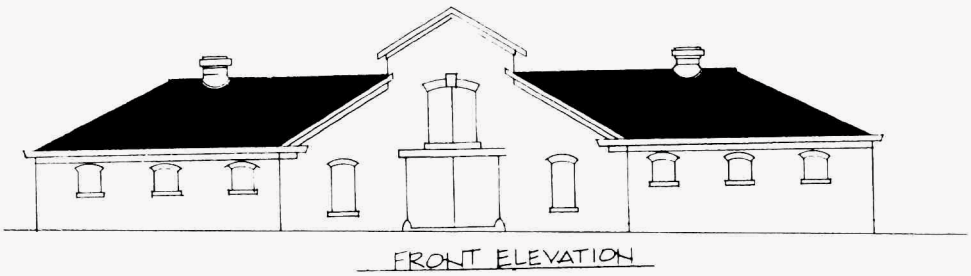
5.3.2 The DOE-2.1B Model and Data Requirements

The DOE-2.1B simulation model was selected to model the heat transfer patterns for each of the four sample buildings. DOE-2.1B was chosen for several reasons.

1. It can do the job required. DOE-2.1B provides a detailed heat balance for the various components of the building. This detail is needed if one is to detect and isolate the effect of adding roof/ceiling insulation to a building as complex in heat flow characteristics as a hangar or a barracks/mess hall. The model does require extensive input data (weather, construction details, heating system details, internal loads, etc.), but such data are available. Site-specific weather data can be easily input into the DOE-2.1B model.



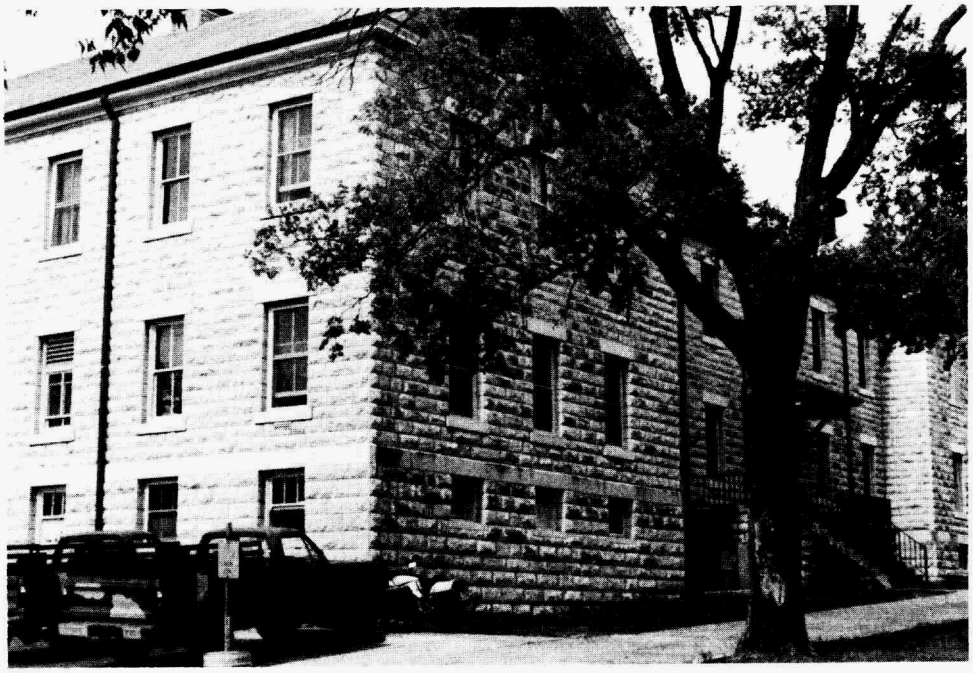
(a) Warehouse Building 86



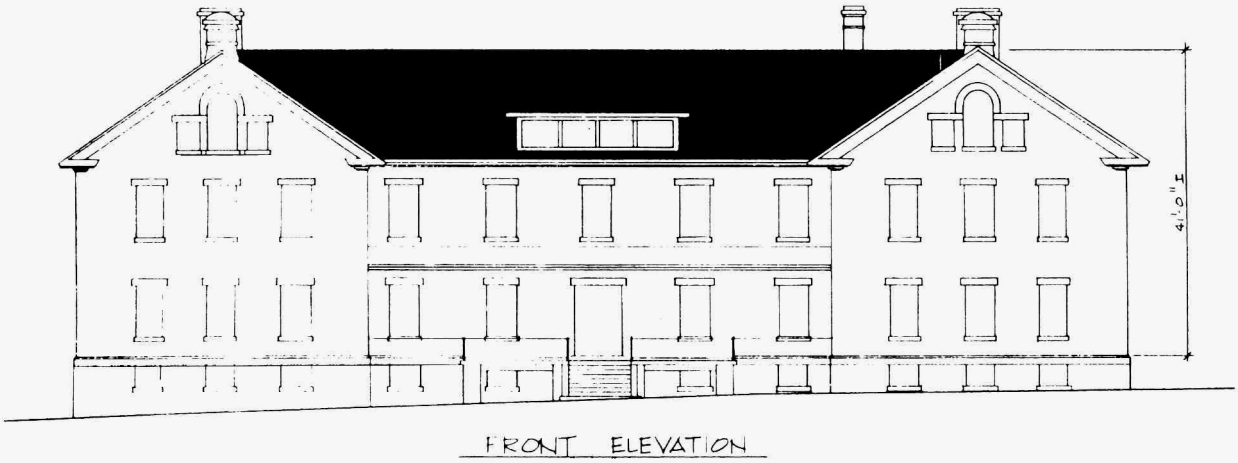
One floor, T-shaped in plan view, 250' × 46' or 100'.
Floor area = 14,000 ft^2; roof area = 18,000 ft^2.

Heated by 7 gas-fired, wall-mounted unit heaters with fans, plus 2 small space heaters.

Fig. 5.1. Pictures of four Fort Riley buildings selected for metering and modeling: (a) warehouse, (b) barracks/mess hall, (c) maintenance shop, and (d) hangar.



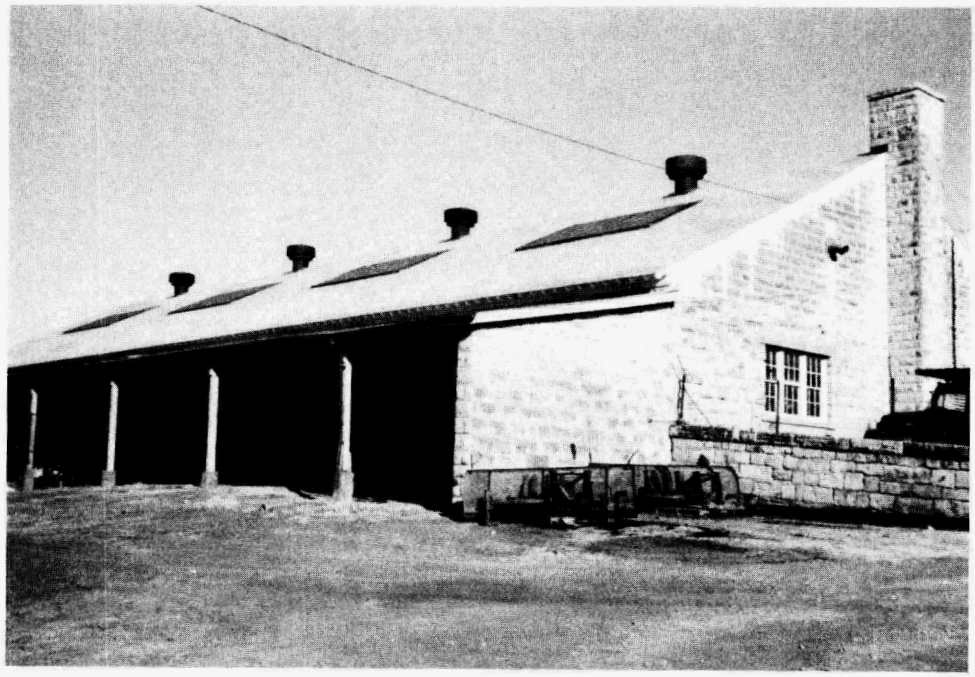
(b) Barracks/Mess Hall Building 94



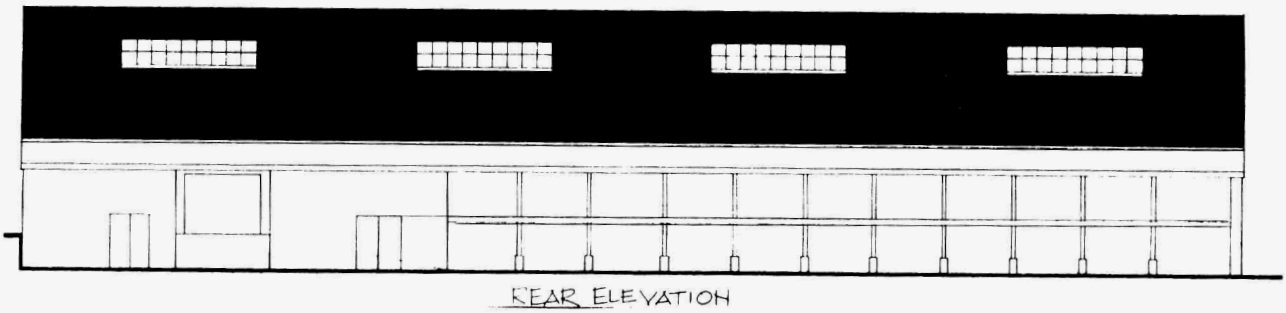
Three floors + attic, C-shaped in plan view, overall 142' × 85'.
Each floor area = 9,100 ft^2; roof area = 11,800 ft^2.

Two gas-fired boilers (one at each end of the building) provide steam for use in space heating and DHW.

Fig. 5.1 (cont.)



(c) Maintenance Shop Building 129

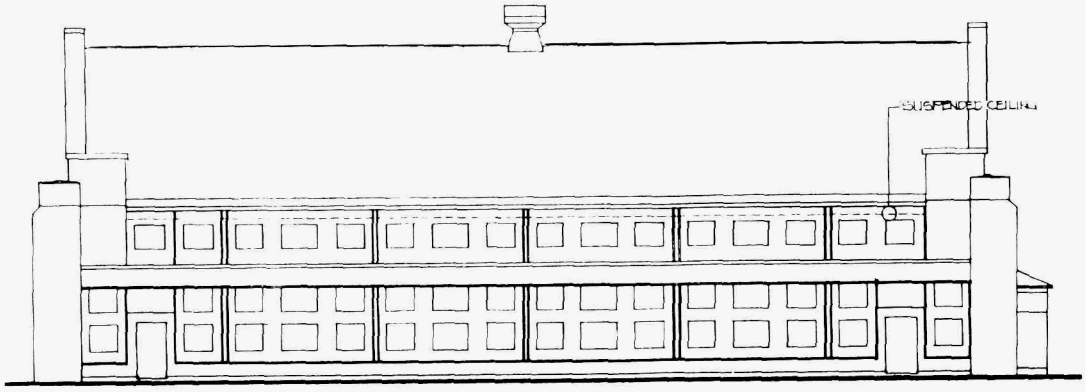


One floor, rectangular in plan view, 163' × 67'.100'.
Floor area = 10,975 ft^2; roof area = 10,400 ft^2
insulated plus 1,150 ft^2 skylight.

Heated with 8 gas-fired, wall-mounted unit heaters with fans.

Fig. 5.1 (cont.)

(d) Hangar Building 201

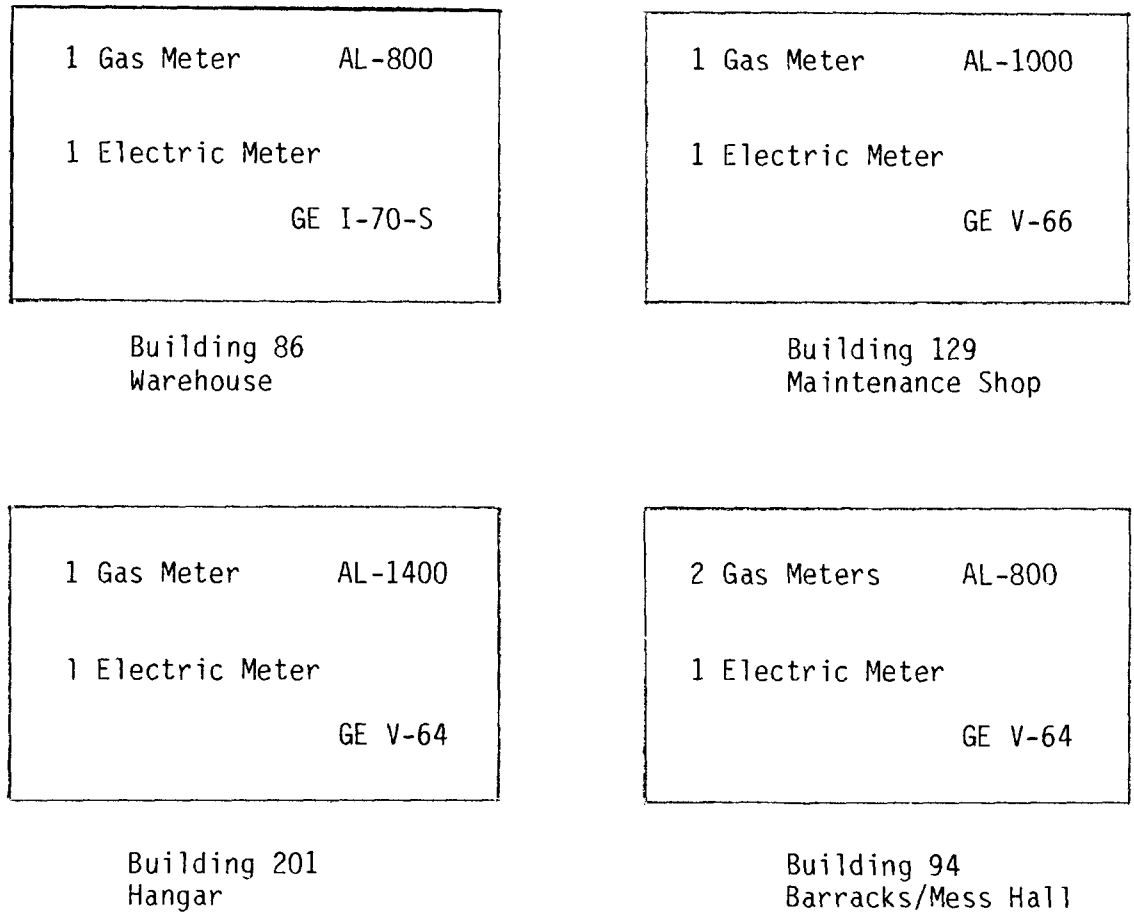


LEFT SIDE ELEVATION

Generally, one floor, but some second-story office spaces, exist in central section of the building. Rectangular in plan view, 120' × 240'. Floor area = 29,000 ft^2; suspended ceiling area = 29,000 ft^2.

Heated by a gas-fired boiler sending steam to 4 heat exchangers/air handling units, each equipped with 3 large air blowers directed into hangar bays.

Fig. 5.1 (cont.)



Note: Building 94 is the only air conditioned building, and the projected electricity savings during the summer from roof insulation was small, so a/c use was not submetered (see Sect. 6.2.3).

Fig. 5.2. Instrumentation installed in four Fort Riley buildings.

2. ORNL staff have used the model and know its strengths and limitations. ORNL staff have used DOE-2.1B and DOE-2.1A to model building heat transfer patterns and have made careful checks of model behavior versus measured thermal behavior of the modeled buildings. Having this experience, the cost of modeling the four sample buildings was minimized. The actual cost of running the computer simulation was small; the major cost was incurred in gathering the necessary input data (see Table 5.1).

3. Its use allowed a more reasonable comparison with results reported by Burns and McDonnell.[3] In projecting the energy savings of the roof/ceiling insulation project for Fort Riley, Burns and McDonnell engineering staff used DOE-1.4, an earlier version of the DOE-2 models.

Table 5.1. General data requirements for use of DOE-2.1B in the Fort Riley ECIP validation

Type of input data needed	Source
Weather data:	Marshall Army Air Field weather station
Outside dry-bulb temperature	
Dewpoint (or) wet-bulb temperature	
Barometric pressure	
Wind speed	
Sky cover	U.S. Weather Bureau, Topeka
Building construction details:	From building plans, checked by on-site inspection
Orientation	
Walls—area, construction	
Windows—area, type, setback	
Roof/ceiling—area, construction	
Floor—rea, construction	
Foundation—construction	
Number of stories, stairwells	
Doors—size, conditions for opening	
Shading, if any	
Building usage:	On-site inspection
Internal heating:	
people	
appliances and lighting	
Hours and type of use, schedule	
Heating system:	On-site inspection
Type of system, performance characteristics	
Distribution system	
Location of thermostat	
Internal temperatures:	Measured
Near (2') each exterior wall	
Near roof/ceiling	
Fuel usage for space heating:	Measured

In order to specify the data inputs required by this rather complex model, it will be useful to describe briefly the general characteristics of DOE-2.1B. This program describes the flow of heat in a building and the associated space conditioning equipment on an hourly basis. The program uses detailed data for the building geometry and construction, for the space conditioning equipment, and for the weather to predict the energy flow in the building. Internal heat loads in the form of people, lights and equipment, as well as any infiltration and ventilation air, are incorporated in the energy flow description. Heat flow through all the internal and external building surfaces is assumed to be one-dimensional. Delay of heat flow through the external surfaces having significant mass is described by the use of time series having constants called *response factors*.

The program uses a sequential approach to calculate the energy use by the heating and air conditioning equipment. It first determines the heating or cooling loads in each zone of the building, assuming that the interior temperature in each zone is fixed. The part of the program where this is done is called LOADS, and the method used in LOADS to account for the time delays for heat transfer from the zone mass to the interior air is the *weighting*

factor method. The weighting factors are constants in the transfer function giving the time response of the zone to a unit pulse of each of the zone heat gains. These fixed temperature loads are then passed on to the next part of the program, called SYSTEMS, where the actual temperatures in the zones and the amount of heat added or extracted by the HVAC system are determined. In SYSTEMS, the weighting factor method, accounting for the time delays in removing or adding heat to the zones by the HVAC equipment, is used again, together with the equipment operating characteristics, to predict these values. The amount of energy required to operate the HVAC system is also calculated in the SYSTEMS part of the program.

Hourly weather data must be preprocessed into a format readable by the program. A weather processor package furnished with the program is capable of converting various weather data into the desired format, (e.g., formats such as TDS 1440 [airport surface observations], TRY [test reference year], and TMY [typical meteorological year]). The data can then be modified, using the EDIT routine incorporated in the weather processor package.

The program is designed to accept detailed input data regarding the building geometry and construction and the HVAC equipment design and performance characteristics. Many of these data do not have to be specified to use the program. In these cases, the program can draw upon its library of default data and routines to fill in the missing input data.

From the preceding description of the DOE-2.1B program, it is obvious that the model requires a large amount of detailed input data. Table 5.1 provides a list of the data requirements and data sources.

5.3.3 Calculations

1. Using weekly submetered natural gas data and average weekly outside temperatures at Fort Riley, regression analyses indicated the correlation coefficients (how well fuel consumption tracked outside temperature). The regression analysis also revealed the "balance point" (BP) temperature for each building. The BP is the outside temperature below which space heating is required.

2. Eventually all energy savings were to be normalized for weather corresponding to a typical meteorological year (TMY). Unfortunately, TMY data are not available for Fort Riley. TMY data tapes are available from the National Climatic Data Center for a limited number of sites in the United States, Topeka being the closest to Fort Riley (50 miles east).* A comparison was made between Fort Riley and Topeka weather for

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*The TMY is defined in the *ASHRAE Handbook, 1985 Fundamentals*, as follows: Typical Meteorological Year (TMY) tapes were prepared by Sandia Laboratories in Albuquerque from U.S. Weather Service 1440 series data tapes for the years 1954 through 1972. A year of 8760 hours for each of 234 stations was prepared. Nine indices (total horizontal radiation: maximum, minimum, and mean of dry-bulb and dew point; and the maximum and mean of wind speed) were identified as critical. They were weighted with the solar index as 50%, and the rest at 50%. Typical months were identified by their closeness to long-term cumulative distribution functions. In the final selection, lengths of hot or cold periods with sunny or cloudy days were used. Discontinuities between months were machine smoothed. The TMY is made up of the typical months selected. Missing and atypical data were not replaced (p. 24.3).

the period January 1, 1985 through April 30, 1985, and it showed very close correspondence for both average outside temperature and heating degree days. Therefore, the use of Topeka TMY data tapes as a substitute for Fort Riley TMY data was warranted.

3. Using the DOE-2.1B model and input data listed in Table 5.1, each of the four sample buildings was modeled for heating and cooling energy use for the pre-retrofit condition. Fort Riley hourly weather was used initially for the model, and weekly modeled fuel use was compared with metered fuel use for corresponding weeks. The model was adjusted so that it tracked the metered pattern reasonably well. The model was then rerun for both pre-retrofit and post-retrofit conditions (without and with the roof insulation). Differences in fuel consumption, normalized to TMY conditions, were taken from these modeled results.

4. Because all buildings of a given type (warehouses, maintenance shops, etc.) have almost identical structure and design, the annual energy savings for each of the four modeled buildings was extrapolated to all buildings of that type by multiplying by a factor based on roof area. For example:

$$\frac{\text{total roof area, all 6 warehouses}}{\text{total roof area, Bldg. 86}} = \text{factor for warehouses.}$$

5. Using local fuel values for natural gas and electricity, obtained from the Fort Riley Energy Office, the annual energy savings for each building type was converted to annual dollar savings.

6. Design and installation costs of the retrofits were obtained from the Corps of Engineers, Kansas City Office.

7. Using ECIP guidance,[5,6,8] along with dollar savings and retrofit costs, SIRs were calculated for each building type and for the entire ECIP project.

5.3.4 Accuracy and Performance Standards

Input data for modeling the four buildings are of good quality (within 5% of true values) with two exceptions (see 5 and 6 below):

1. The building construction details have been taken from building plans obtained from the Fort Riley Facility Engineering Office and verified by ORNL staff. Unresolved questions of details were checked out by the Energy Office staff on site. These input data are within 2–5% of sample values measured by ORNL staff.

2. Temperature data are recorded hourly at the Fort, and the weekly average from these recorded data should be within a few degrees Fahrenheit of weekly average ambient temperatures of the four modeled buildings. The TMY weather data for Topeka differs by about 3% from the Fort Riley weather data, based on a comparison of heating degree days. (See discussion in Sect. 6.2.1.)

3. Internal temperatures near the walls of the four buildings were recorded by an ORNL staff member using a digital readout thermometer that had been calibrated just before use.

4. Metered natural gas consumption and electrical energy use should be within 3% of true values. The meters were new and had been calibrated at the factory. They are rated at ±2%. The weekly readings were taken on the same day each week, but not always at the same hour. However, variations of ±5 hours/week correspond to only ±3% for the readings.

5. Infiltration values for the four modeled buildings are not accurately known. "Tuning" of the model so that its fuel consumption outputs match the metered fuel consumption was primarily a matter of adjusting infiltration values, within reasonable limits. If the infiltration remains essentially constant throughout the pre- and post-retrofit periods, the calculated savings (*difference* between pre- and post-retrofit energy uses) will be influenced by this almost constant factor, but not to a very large extent—perhaps ±5–10%, depending on building type.

6. Internal loads are also difficult to quantify for buildings such as the maintenance shop and the barracks/mess hall. Again, some tuning of the model involved adjusting values for internal loads. If, as with infiltration, these loads remain about constant before and after retrofit, they should have only a small effect on the pre- and post-retrofit difference in energy use.

5.4 IMPLEMENTATION OF THE VALIDATION PLAN

The Phases I and II: ECIP Project Validation Design Plan for this project[2] set forth a validation procedure which was essentially that described in the preceding section. Implementation of this design plan required extensive coordination of activities among four groups: USAFESA, the U.S. Army Corps of Engineers (Kansas City Office), Fort Riley Energy Office, and ORNL.

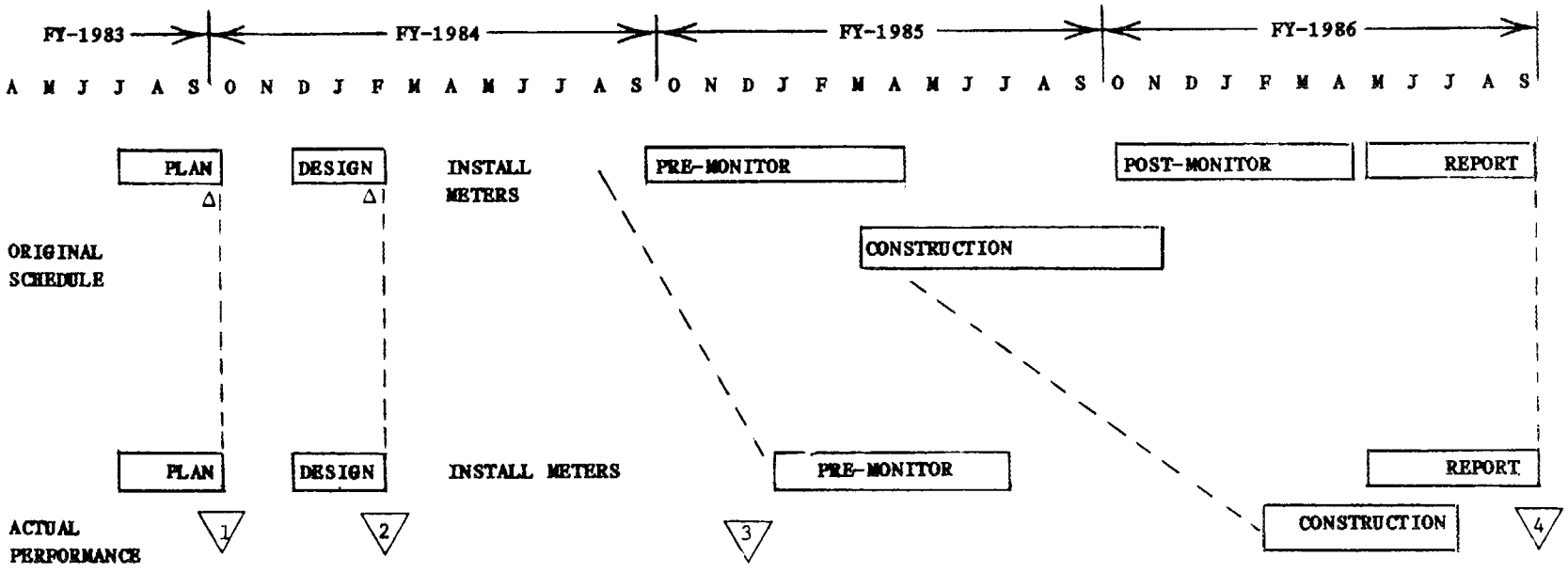
USAFESA authorized implementation of the validation plan as described in the ORNL report, purchased the gas and electric meters for the four Fort Riley buildings, and authorized Fort Riley to install these meters.

The Corps of Engineers drew up specifications for the roof insulation retrofit at Fort Riley,[3] awarded the contract, and provided ORNL with copies of the specifications and with cost information for the retrofit.

The Fort Riley Energy Office arranged for installation of the gas and electric meters, read the meters weekly, and sent these data plus monthly summaries of daily weather data to ORNL.

ORNL designed the validation study, inspected the meter installations, obtained building construction details from the Fort Riley Facilities Engineers Office, assembled metered data, modeled the four Fort Riley buildings, calculated SIRs for each building group and for the entire ECIP project, and wrote the final report of the ECIP validation study.

With so many tasks being performed by four groups that had never worked together before on such a project, it is not surprising that the actual performance schedule slipped somewhat from the schedule in the original plan. (See Fig. 5.3.) Lags in both the meter



1. Issue Phase I Report, Project Validation Plan.
2. Issue Phase II Report, Project Design.
3. Inspect meter installation. Begin Phase III, data collection.
4. Issue Phase IV Report, Project Final Report.

Fig. 5.3. ECIP implementation: original plan vs actual performance schedules.

installation and in the construction phases caused serious disruptions in the validation plan. The original plan had envisioned the modeling of the four buildings (pre- and post-retrofit) and metering of fuel use for both pre- and post-retrofit heating seasons. The modeled fuel savings could then be checked by the metered savings. In practice, the pre-retrofit metering (1984–85) was curtailed by delays in meter installation, and the post-retrofit metering (1985–86) was cancelled by delays in construction. Two options were considered: (1) delay the final report for almost a year in order to accommodate post-retrofit metering in 1986–87, or (2) omit the post-retrofit metering and retain the original report schedule, depending upon the modeling, as tuned to the pre-retrofit metering, to provide dependable estimates of savings. The latter course was selected.

6. TECHNICAL ANALYSIS: ENERGY SAVINGS POTENTIAL

6.1 PRE-RETROFIT METERING OF FOUR BUILDINGS

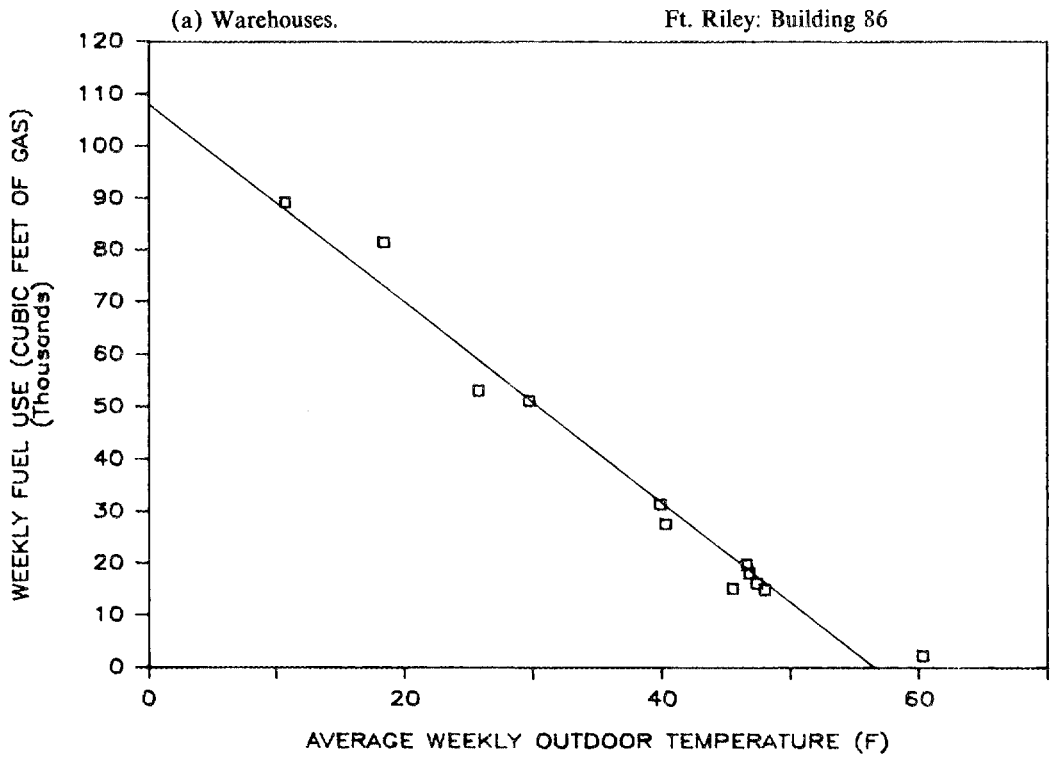
Pre-retrofit metering of the four buildings selected for special study began on January 22, 1985, and the meters were read weekly by Fort Riley Energy Office staff members for the remaining 12 weeks of the heating season until April 16, 1985. Weekly electric meter readings were continued throughout the following summer and fall (until October 30) when they were discontinued in anticipation of installation of the insulation.

Although the data period was not as complete as originally planned, it was adequate for most purposes of the study. Specifically, these data were needed to

1. determine the degree of correlation between average weekly outdoor temperature and measured weekly space heating fuel consumption for each building type,
2. determine the BP temperature and compare the BPs with observed inside temperatures for all four building types, and
3. provide an experimental baseline that could be used to adjust or calibrate the DOE-2.1B model for each of the four buildings.

Figure 6.1 and Table 6.1 show how well outdoor temperature predicts fuel use and how well BP temperatures correspond with observed inside temperatures. For three of the buildings, outdoor temperature is an excellent predictor of space heating fuel use, with correlation coefficients of -0.9 or better. Only building 94 (the combination barracks and mess hall) shows a low correlation. The large internal loads of the building, from the mess hall and from large electrical appliance use, greatly complicate the heating patterns of the building and prevent a simple relation between fuel use and weather as observed in the other buildings. It is not surprising to find that for a given outdoor temperature the fuel requirements are quite varied for the different buildings. At about 10–20°F, the hangar, a large building with high infiltration, uses about 500,000 Btu/week for space heating, but the warehouse uses only about 80,000 to 90,000 Btu/week.

The BP temperature is that outdoor temperature below which space heating is required. Graphically, it is represented by the intercept of the regression line and the temperature axis. (See Fig. 6.1.) Except for building 94, the BP seems to correspond very well with the measured inside temperatures of all buildings. (See Table 6.1.) Overall, the metered space heating fuel consumption patterns of these four buildings appear to be quite reasonable. The data should provide a valid baseline with which to calibrate the DOE-2.1B model.



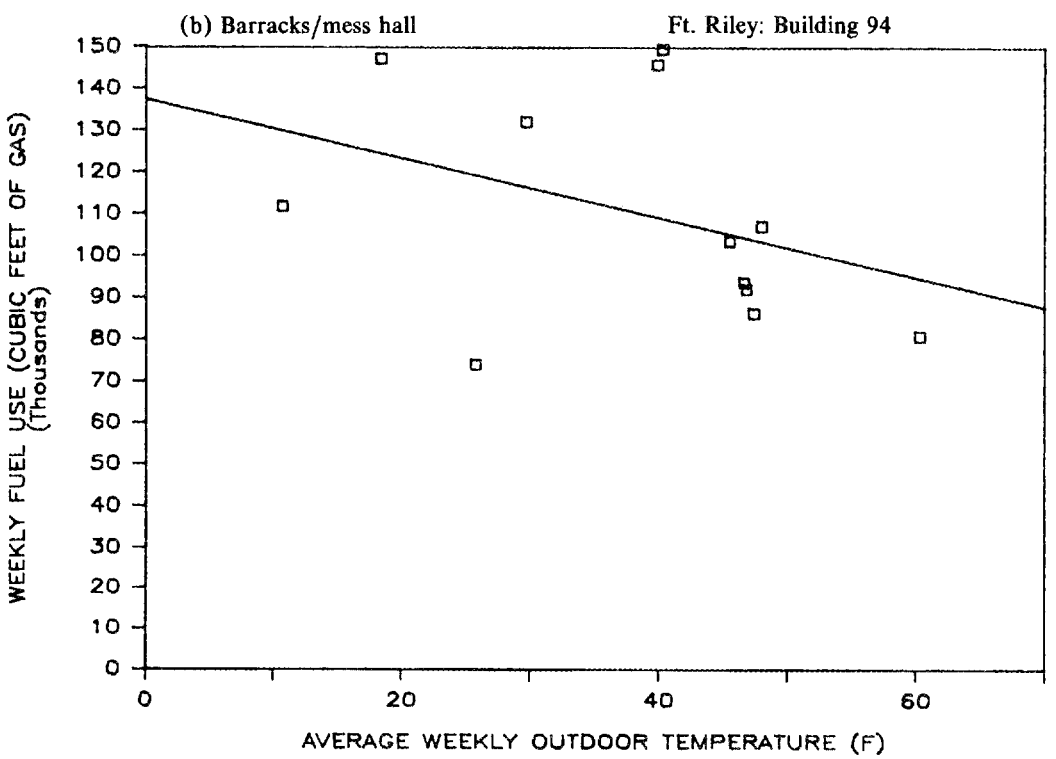
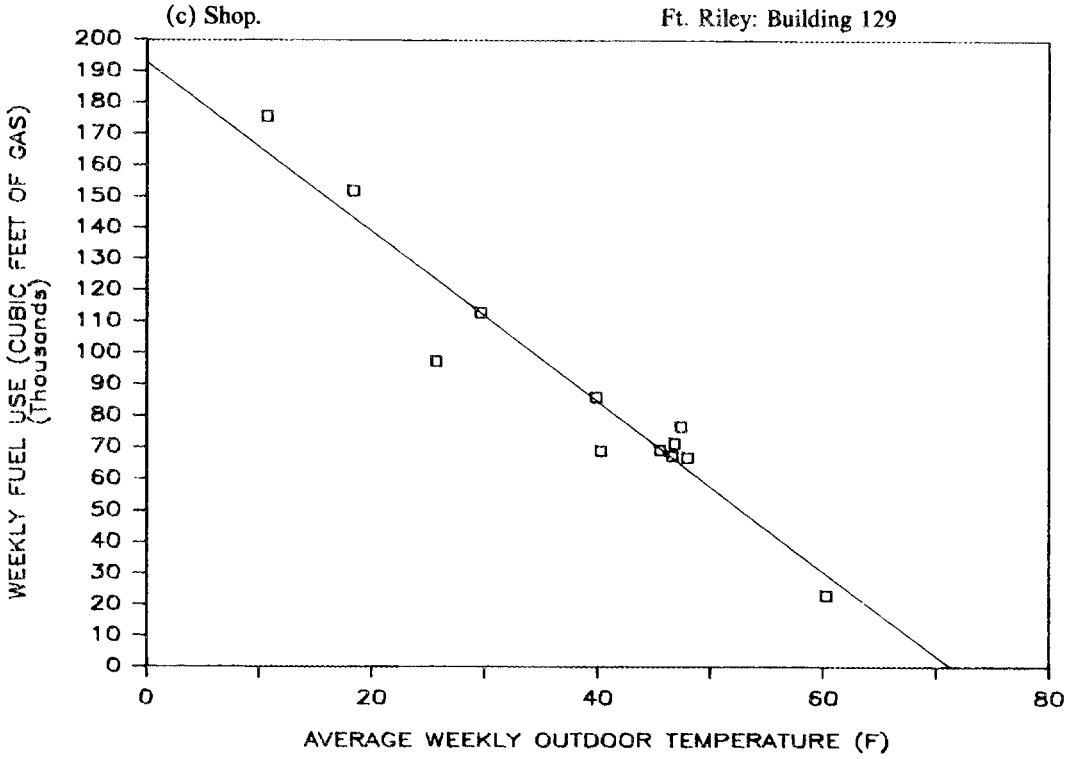


Fig. 6.1. Pre-retrofit weekly fuel consumption (space heating) vs average weekly outdoor temperature, four buildings, Fort Riley, January–April 1985. (a) Warehouses, (b) Barracks/mess hall, (c) Shop, and (d) Hangar.


(c) Shop.
Ft. Riley: Building 129
WEEKLY FUEL USE (CUBIC FEET OF GAS)
(Thousands)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
AVERAGE WEEKLY OUTDOOR TEMPERATURE (F)

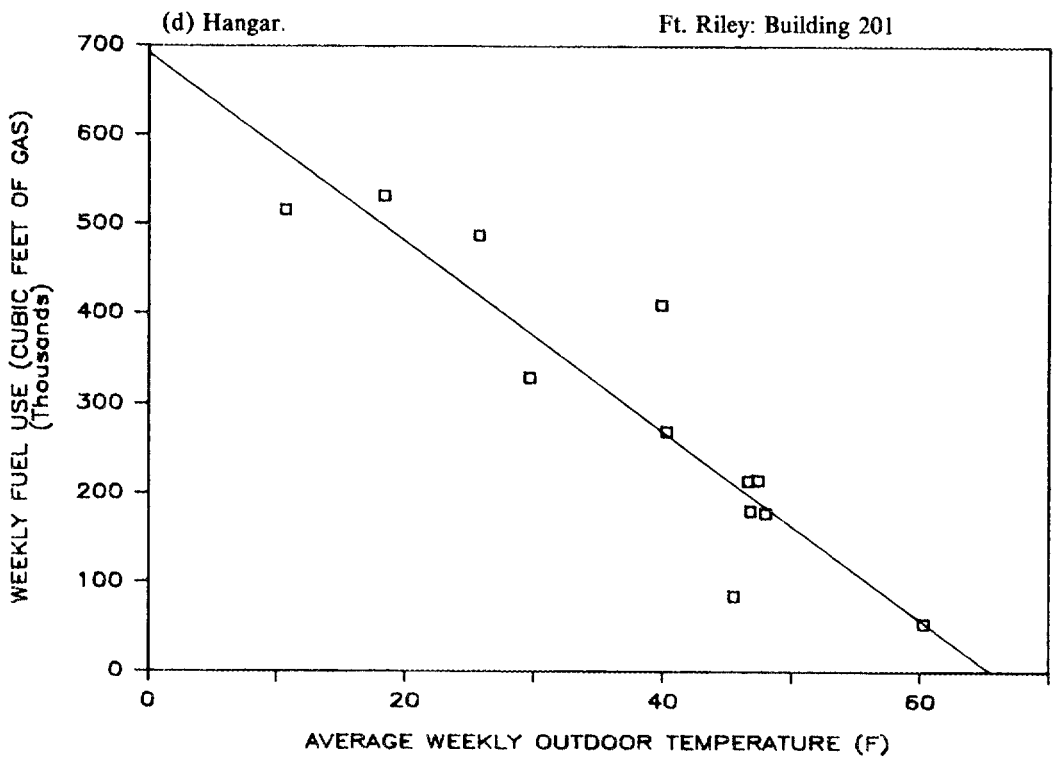

(d) Hangar.
Ft. Riley: Building 201
WEEKLY FUEL USE (CUBIC FEET OF GAS)
(Thousands)
700
600
500
400
300
200
100
0
0
20
40
60
AVERAGE WEEKLY OUTDOOR TEMPERATURE (F)

Fig. 6.1 (cont.)

Table 6.1. Correlation coefficient (fuel use vs outdoor temperature), balance point temperature, and observed inside temperature, four buildings, Fort Riley

Building No.	Correlation coefficient wk. fuel use vs avg. wk. temperature	Balance point temperature (°F)	Observed inside temperature (°F)
86 (warehouse)	-0.98	57	50
94 (barracks/mess)	-0.38	Not well defined	72
129 (shop)	-0.95	71	70
201 (hangar)	-0.91	65	66

6.2 MODELED PRE-RETROFIT AND POST-RETROFIT FUEL USE FOR FOUR BUILDINGS

6.2.1 Weather Data

Section 5.3.2 of this report described some of the complexities of the DOE-2.1B model and listed the array of input data required. Since outdoor temperature is such an important determinant of building fuel use, it is especially important that the weather data inputs be selected with care. It is necessary, also, to distinguish between the weather patterns of a particular year, say the winter of 1985–86, and the long-term average weather patterns for a locality. This latter is generally referred to as TMY. (See Sect. 5.3.3 for a more precise definition.)

The long-term energy savings of a building retrofit are best referred to the TMY for that locality rather than to the savings that occurred during a given year, which could be very atypical. Unfortunately, TMY weather data are available for only a limited number of sites, and Fort Riley is not one. TMY data do exist, however, for Topeka, Kansas, which is only 50 miles east of Fort Riley. Can Topeka TMY data provide a reasonable substitute for Fort Riley TMY data?

Table 6.2 presents two comparisons: (1) it compares monthly temperature and heating degree day weather statistics for Fort Riley and Topeka for the period January through

Table 6.2. Outdoor temperature comparisons, Fort Riley and Topeka, January–April 1985

Site	Year	Average temp. (°F) and HDD_{65}, by month							
		January		February		March		April	
		Avg. temp.	HDD	Avg. temp.	HDD	Avg. temp.	HDD	Avg. temp.	HDD
Fort Riley	1985	22.5	1329	27.0	1106	45.5	612	58.8	241
Topeka	1985	21.5	1349	27.2	1057	48.7	513	58.3	273
Topeka	TMY[a]	25.8	1215	31.7	933	40.3	768	56.8	285

[a]Typical Meteorological Year. See Sect. 5.3.3 for definition.

April 1985, and (2) it compares Topeka weather statistics for 1985 with Topeka TMY statistics. From the first comparison, it appears that Topeka and Fort Riley outdoor temperatures and HDDs are nearly equal, at least for January through April 1985. The greatest difference in average monthly temperatures was 3°F, and the HDD_{65} differed by only 3%. From the second comparison, it is obvious that during January and February, 1985, the average temperatures in Topeka were below the TMY; for March and April, the average temperatures were above those of the TMY. In summary, the Topeka weather data provide a reliable substitute for those of Fort Riley, and Topeka TMY data may be used in place of the non-existent Fort Riley TMY data.

6.2.2 Calibrating the DOE-2.1B Models for Four Buildings

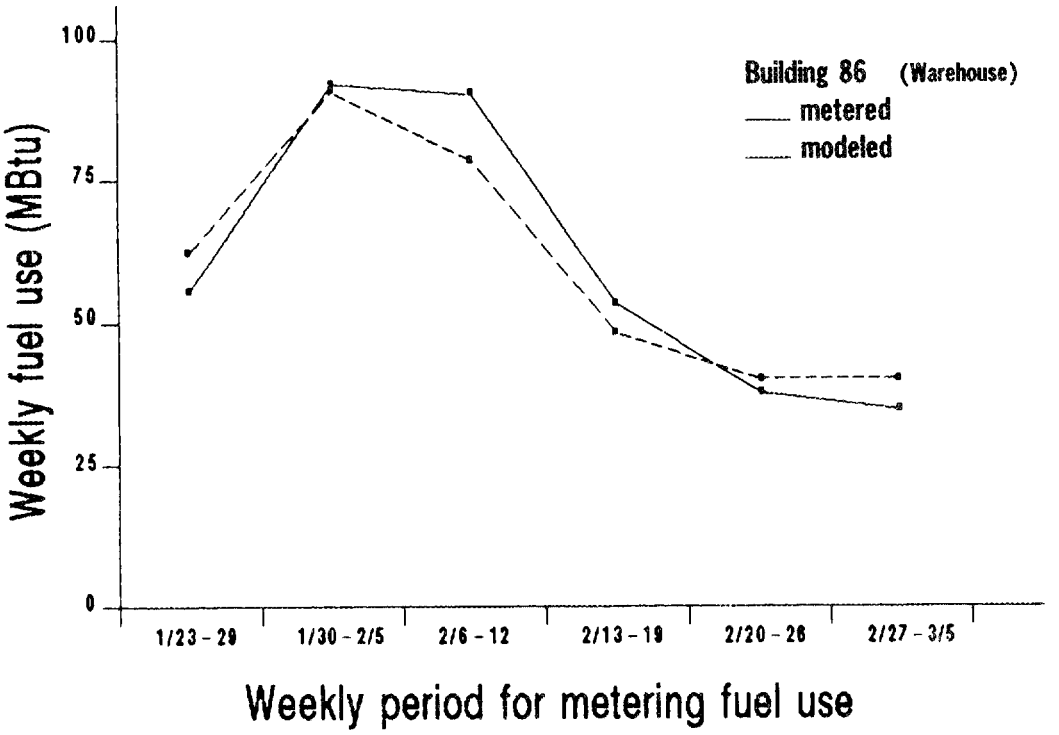
Accurate modeling output requires accurate and complete data input, and DOE-2.1B data input requirements are formidable. Most of the input was available in good accuracy—building dimensions, wall areas, window areas, roof areas, R-values, hourly weather data, heating system details, etc. Internal loads were inferred from electricity consumption data, from information regarding power tools and lighting, and from hours and use schedules. The most difficult parameter to evaluate was infiltration, or the number of air changes per hour (ACH) for the building. The basic approach taken was to insert all the well-known values for the building and then make a first estimate of ACH. The modeled fuel consumption for a given period was then compared with metered fuel consumption for the same period. Only *reasonable* adjustments in ACH were made to bring the modeled results into closer agreement with the metered values.

The accuracy of modeling is, of course, also influenced by the complexity of the building and the activities carried out within the building. The warehouse (building 86) is the least complicated. It has very few internal loads, and it is kept closed most of the time, allowing little infiltration. In contrast, the barracks/mess hall has large internal loads, a steady stream of people pass in and out permitting large infiltration, and the use pattern varies dramatically as troops move in and out or perhaps leave entirely for some time.

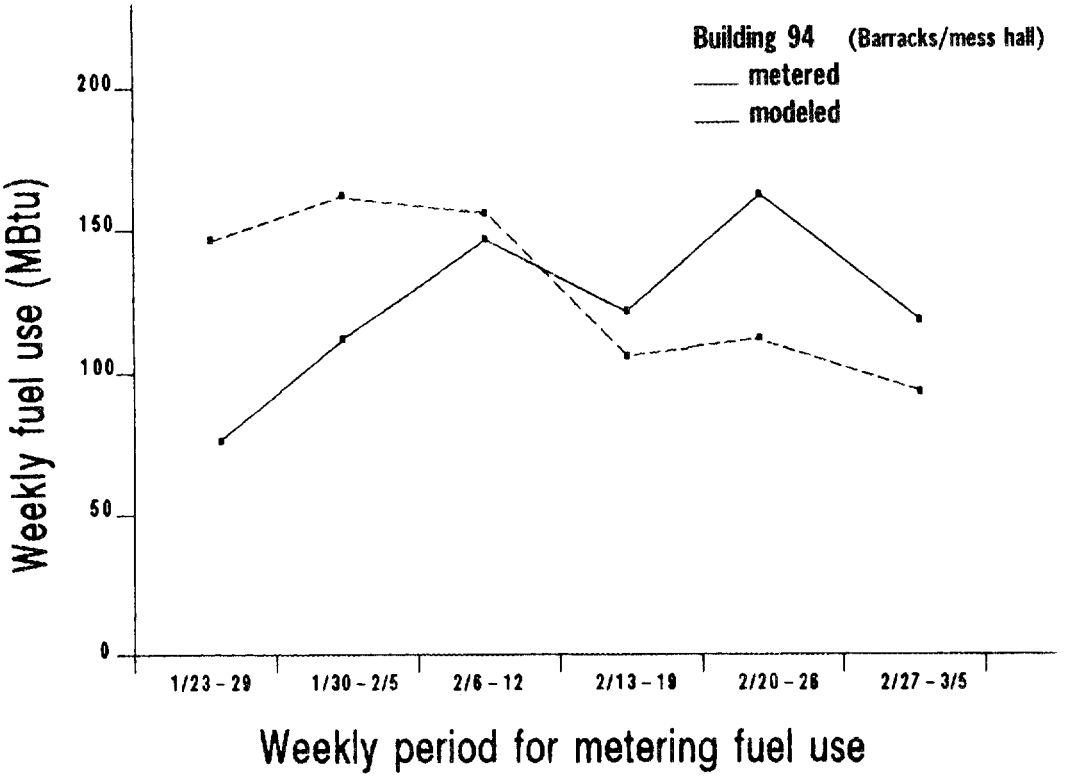
The first task required to tune the DOE-2.1B models to metered results was to take hourly Fort Riley weather data from printed copy and put it on tape. (Neither Fort Riley nor the National Climatic Data Center have these data on tape.) The following Fort Riley weather information was put on tape for the period January 22–March 5, 1985:

- dry-bulb temperature,
- atmospheric pressure,
- dew point,
- wind speed,
- wind direction, and
- sky cover.

Each building DOE-2.1B model was run using the Fort Riley weather tape. The modeled natural gas space heating fuel consumption for each week of the six-week period was recorded and compared with the corresponding metered values. Infiltration was adjusted, within reasonable limits, to bring about a close fit between metered and modeled fuel consumption patterns. Figure 6.2 shows the final results for the four buildings.

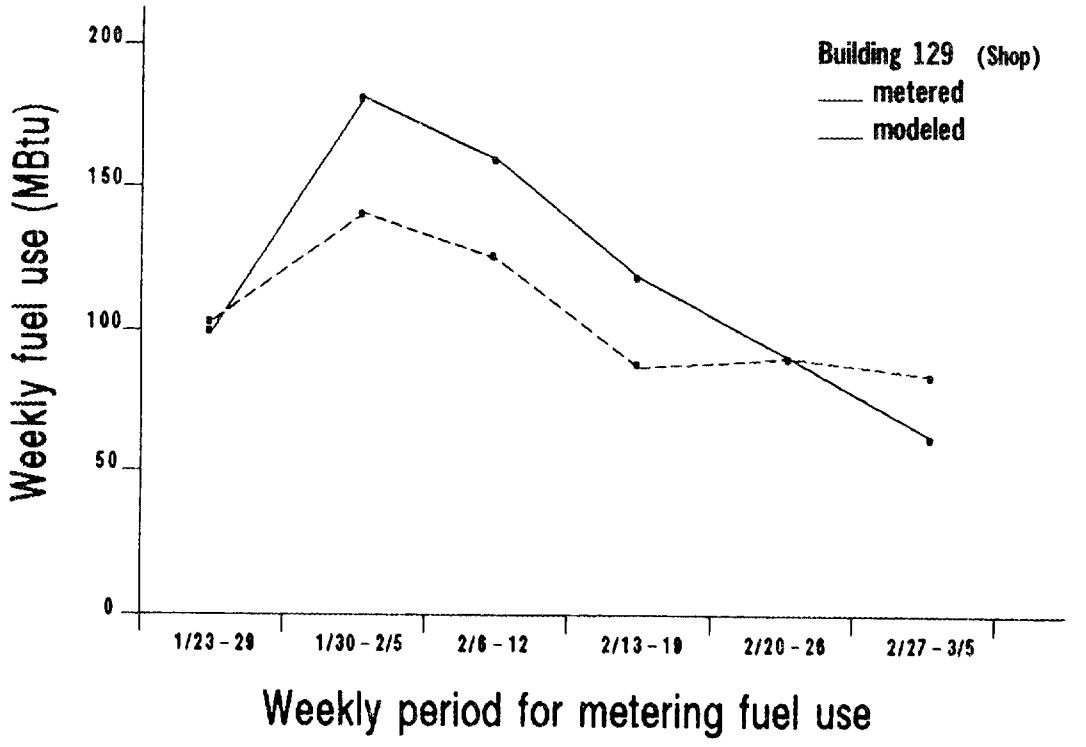


(a) Warehouse. Building 86

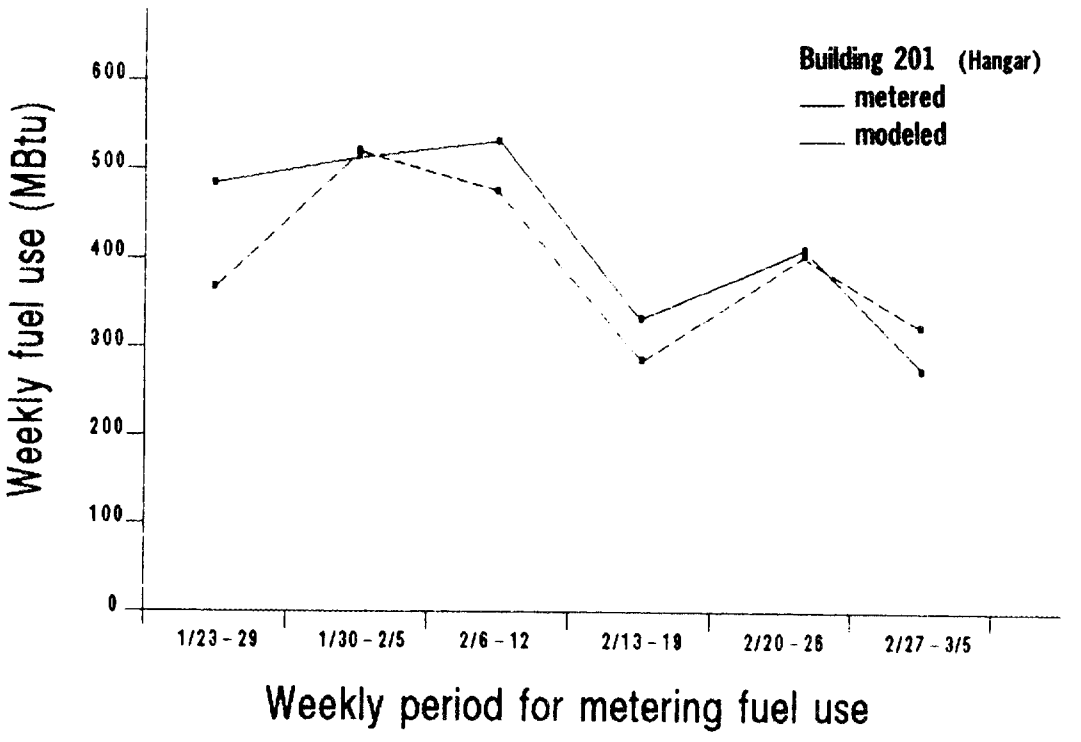


(b) Barracks/mess hall. Building 94

Fig. 6.2. Modeled vs metered comparison, weekly fuel use, six-week period, four buildings, Fort Riley. (a) Warehouse, (b) Barracks/mess hall, (c) Shop, and (d) Hangar.



(c) Shop. Building 129



(d) Hangar. Building 201

Fig. 6.2 (cont.)

Data on building 86 (warehouse) resulted in an almost perfect correspondence between metered and modeled values. Building 201 (hangar) shows a very good fit for five of the six weekly periods, but the modeled value for the first week was much lower than the metered value. The modeled pattern for building 129 (maintenance shop) tracks the metered pattern but is reduced in amplitude. (Perhaps the modeled infiltration should have been increased again, but it was felt added ACH would be unreasonable.) As expected, building 94 was very difficult to model, but the final result was modestly successful. Overall, the modeling patterns track the metered patterns quite well. The modeled fuel use over the six-week period may be compared with the metered fuel use over the same period for the various buildings (see Table 6.3). The differences are 13% or less. To some extent, these differences represent unknowns for which the model has not accounted. When the buildings are modeled for pre-retrofit and post-retrofit conditions and a difference or retrofit savings calculated, these unknowns *may* behave as constants that cancel out to some extent as one modeling result is subtracted from the other.

Table 6.3. Metered vs modeled fuel use for four buildings

Building number	Metered fuel use for six weeks (MBtu)	Modeled fuel use for six weeks (MBtu)	Difference (%)
86 (warehouse)	344	343	<1
94 (barracks/mess)	782	789	1
129 (shop)	714	630	13
201 (hangar)	2635	2354	12

6.2.3 Modeled Retrofit Savings, Four Buildings

Having adjusted the DOE-2.1B models of the four buildings so that they tracked metered fuel use patterns, each building model was rerun using Topeka TMY weather tapes. Space conditioning energy consumptions were modeled for each of the four buildings for both pre-retrofit and post-retrofit conditions and for each month of the TMY. Buildings 86, 129, and 201 are not air conditioned, so their space conditioning energy use is the natural gas consumed during the winter heating season (October 15-April 16). Building 94 (barracks/mess hall) is heated using natural gas and air conditioned using electricity. The modeled electricity savings (difference between pre-retrofit and post-retrofit uses), however, were only 1.5 megawatt-hours for the summer cooling months. This amounts to only a 1.3% savings, or about $100/summer cooling months. *Therefore, since the electricity savings attributed to the retrofit effect on space cooling is negligible in these buildings, all space conditioning energy savings are assumed to take place during the winter heating season. Modeled energy savings for the heating season are treated in this report as equivalent to modeled annual energy savings.* Natural gas consumptions calculated for each building for the official heating season are displayed in Table 6.4.

Building 86 shows the best percentage energy savings for the roof insulation retrofit, but because warehouses are maintained at low temperatures and have low infiltration

Table 6.4. Modeled fuel savings for heating season of typical meteorological year, four buildings, Fort Riley

Building no.	Type of retrofit	Modeled fuel use (MBtu) heating season, TMY		Savings/heating season	
		Pre-retrofit	Post-retrofit	MBtu	%
86	Add R-19 to roof	1,190	763	427	36[a]
94	Add R-19 to roof	4,438	4,414	24	<1
129	Add R-19 to roof	2,702	1,974	728	27
201	Add R-33 to ceiling	11,432	10,606	826	7[b]

[a]Adding R-19 to the roof and R-11 to walls would increase savings to about 50%.
[b]Adding R-33 to the ceiling and cutting infiltration in half would increase savings to about 37%.

rates, the absolute energy use and the absolute energy savings are low. The model was also run to check the effect of adding R-11 wall insulation in addition to the R-19 roof insulation, and the results showed a total energy savings of about 50% for the combined retrofit. Because of the relatively low absolute energy use by this building, adding wall insulation would not be cost effective.

Building 94 will apparently experience the least benefit from roof insulation, and this is reasonable. This was the only building with a low correlation between metered fuel use and outdoor temperature (Table 6.1). Its large internal loads provide considerable heating regardless of outdoor weather, rendering shell retrofits less effective. Also, the configuration of the barracks/mess hall differs from the other buildings. It has a ground-level floor plus two upper floors and a storage attic. Its roof area is small compared with its wall and window area, and this also reduces the effectiveness of roof insulation. These results are similar to ones reported in an earlier study by the U.S. Army Corps of Engineers.[7]

Building 129 shows high absolute and percentage energy savings from roof insulation. Structurally, it closely resembles building 86, but its inside temperature is maintained at about 70°F instead of about 50°F, and it has a higher infiltration rate. Its high percentage savings, applied to a high energy use rate, results in high absolute savings.

Building 201 is the hangar, and the insulation retrofit differed somewhat from that of the other buildings. An R-33 insulating layer was applied (compared to R-19 for the others), and the insulation was placed on the top side of a suspended ceiling (instead of to the underside of the roof). The building is large, about 30,000 ft^2 of floor area, is maintained at about 65°F, and has a high infiltration rate. Its fuel use, therefore, is large. Even though the percentage savings of the retrofit is modest (7%), the absolute energy savings is large. The DOE-2.1B model was also run to check the energy savings that could be attained if, in addition to adding ceiling insulation, the large infiltration rate of this building were cut in half. The energy savings in this case would increase to 37%. It would probably be very cost effective for Fort Riley staff members to consider inexpensive procedural and structural changes to reduce infiltration in this building.

How accurate is the list of savings in Table 6.4? This type of modeled output does not lend itself to statistical measures of standard error, but reasonable assessments of confidence can be made. It is first necessary to point out that the modeled savings assume

- the retrofit installation is well done, and R-19 (or R-33) additional insulation is added uniformly over the entire roof or ceiling; and
- the building use pattern does not change, and there are no marked changes in thermostat settings, internal loads, infiltration, etc.

If these conditions hold true, then the modeled savings for building 86 should be accurate to within a few percent, and actual savings of 30–40% should be realized. The model tracked the metered fuel use pattern perfectly, and fuel use was almost completely determined by outdoor temperature (R = -0.98).

Building 94 results are less reliable. The model had difficulty tracking the metered pattern, and fuel use was little related to weather patterns. It is not likely that the insulation was counterproductive (would cause increased fuel use), and perhaps some positive savings would result (0–10%).

The modeled fuel use and savings for building 129 are probably conservative. The model tracks the metered pattern, but during very cold periods, it seems to underestimate fuel use. Actual savings may be in the range of 25–40%.

Modeled savings for building 201 are reasonably accurate. The model tracked the metered pattern very closely except for the initial week. Actual savings are probably within the range of 5–15% of annual pre-retrofit usage.

6.3 EXTRAPOLATION OF ENERGY SAVINGS TO 16 BUILDINGS

Table 6.3 of the preceding section summarized the modeled annual fuel savings for four buildings. These energy savings must be extrapolated to include the entire set of 16 buildings which were retrofitted. The extrapolating factor will be the ratio of the total roof area of a building category to the roof area of the modeled building of that category.

$$ES_T = \left(ES_{SB}\right)\left(\frac{RA_{BC}}{RA_{SB}}\right) ,$$

where

ES_T = total annual energy savings for all buildings of a given category,

ES_{SB} = annual energy savings for the modeled building of that category,

RA_{BC} = total roof area for all buildings of that building category, and

RA_{SB} = roof area of the modeled building of that category.

The data regarding individual building use pattern and roof area are listed in Table 6.5, and Table 6.6 summarizes this information by building category and type. The projected

Table 6.5. Roof insulation specifications, 16 buildings, Fort Riley

Building number	Building use pattern	R-Value of added insulation	Roof/ceiling area (ft^2)
53	Shop	R-19 Roof	14,000
64	Storehouse	R-19 Roof	9,650
68	Storehouse	R-19 Roof	10,000
80	Storehouse	R-19 Roof	18,000
82	Storehouse	R-19 Roof	18,000
86	Warehouse	R-19 Roof	18,000
88	Storehouse	R-19 Roof	20,500
94	Barracks w/dining	R-19 Roof	11,800
129	Shop	R-19 Roof	10,400
147	Vehicle storage	R-19 Roof	17,850
156	Shop	R-19 Roof	6,600
159	Barracks w/dining	R-19 Roof	11,800
178	Administration	R-19 Roof	6,600
201	Hangar	R-33 Ceiling	29,000
602	Shop	R-19 Roof	12,100
1671	Shop	R-19 Roof	12,400

Sources: ref. 3 and ref. 9.

Table 6.6. Roof areas of retrofitted buildings by building type, Fort Riley

Building type	No. of bldgs.	Total roof/ceiling area insulated (ft^2)	Percent of total roof area	Roof area of modeled building (ft^2)	Modeled bldg. as percent of roof area of building type
Warehouse/ storehouse	6	94,150	39	18,000	19.1
Shop	5	69,850	29	10,400	14.9
Barracks	2	23,600	10	11,800	50.0
Hangar	1	29,000	12	29,000	100.0
Other	2	24,450	10	0	0.0
Totals	16	241,050	100	69,200	28.7

annual energy savings for a given building category, say shops, would be carried out as follows:

$$ES_T = \left(728 \frac{\text{MBtu}}{\text{yr}}\right)\left(\frac{69{,}850\, ft^2}{10{,}400\, ft^2}\right) = 4{,}890\ \text{MBtu/yr} \ .$$

In like manner, the projected annual energy savings may be calculated for warehouses/storehouses, barracks/mess halls, and the hangar. Two buildings (178 and 147) do not fit into any of these four categories, so a savings estimate for this other

category was obtained by multiplying the average annual savings/ft^2 of the four modeled buildings by the total roof area of these two buildings:

$$ES_T = \left[0.0313 \frac{\text{MBtu}}{\text{yr} \cdot ft^2}\right](24{,}450\, ft^2) = 765\ \text{MBtu/yr}\ .$$

The resulting extrapolation of total annual energy savings for each category of building is presented in Table 6.7 and in Fig. 6.3.

Table 6.7. Estimated annual energy savings from roof insulation, 16 buildings, Fort Riley

Building type	No. of buildings	Estimated annual energy savings	
		MBtu/yr	% of total
Warehouse/ storehouse	6	2,233	26
Shop	5	4,890	56
Barracks/ mess hall	2	48	<1
Hangar	1	826	9
Other	2	765	9
Totals	16	8,762	100

Although the five shop buildings account for 29% of the retrofit roof insulation area, they provide over half of the estimated energy savings. The hangar accounts for 12% of roof area and 9% of the annual energy savings. The warehouses/storehouses and the barracks also provide proportionately less energy savings than would be expected from the area of roof insulated. These discrepancies were discussed in Sect. 6.2.

The final goal of this validation study is to establish savings-to-investment ratios (SIRs) for this ECIP project. The annual energy savings by building type,* listed in Table 6.7 will be critically important factors in making these calculations.

*The original validation study plan for this project specified that projected energy savings for the four modeled buildings would be checked by comparing post-retrofit metered energy use with pre-retrofit metered use. Because the retrofit installation was delayed, the planned post-retrofit metering during the 1985-86 winter was cancelled. It is possible, however, to perform this check by metering space conditioning fuel use for the four buildings during the 1986-87 winter and comparing these measurements with the pre-retrofit results. Appendix A contains instructions for carrying out such a project.

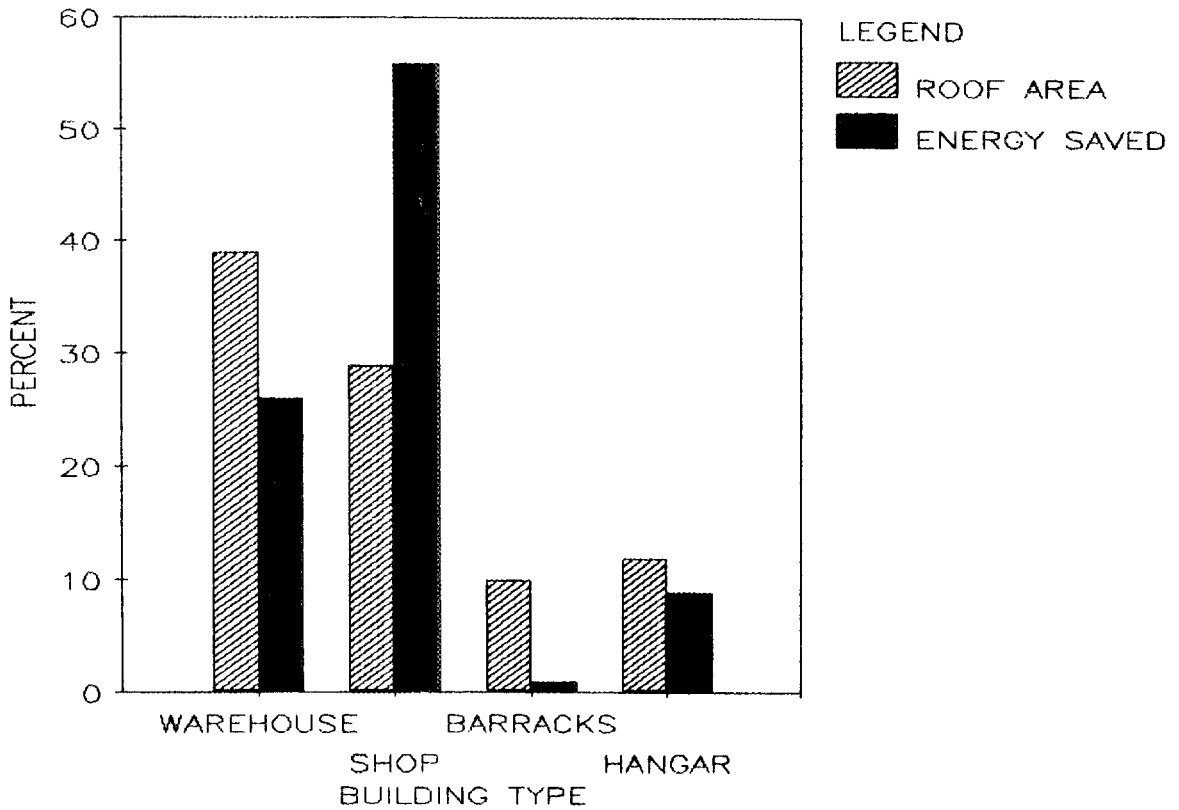


Fig. 6.3. Percent of annual energy savings from roof insulation vs percent of total roof area, four building types, Fort Riley.

7. ECONOMIC ANALYSIS: PROJECTED COST SAVINGS

7.1 RETROFIT COSTS

The denominator of the savings-to-investment ratio is the sum of various investment costs associated with installation of the retrofit. These costs are (1) construction cost or the contracted cost for materials and labor of the retrofit installation, (2) supervision-inspection-overhead (SIOH) costs, and (3) design costs of the retrofit. Mr. Harold Chart of the Kansas City Office, United States Army Corps of Engineers, was able to supply ORNL with cost data for the roof insulation installed in 16 buildings at Fort Riley:

Construction cost	$233,449
SIOH & Design	$19,451

In addition, Mr. Chart was able to supply construction cost information for each of the 16 retrofitted buildings. (See Table 7.1.) The cost data from Table 7.1 may be combined to show construction costs by building type, and the SIOH plus design costs may be

Table 7.1. Construction costs for roof insulation, each of 16 buildings, Fort Riley

Building no.	Building type[a]	Construction costs materials + labor[b] ($)
53	Shop	11,251
64	Storehouse	9,988
68	Storehouse	8,852
80	Storehouse	16,604
82	Storehouse	16,604
86	Warehouse	16,604
88	Storehouse	18,090
94	Barracks/dining	11,113
129	Shop	17,310
147	Vehicle storage	17,112
156	Shop	20,325
159	Barracks/dining	11,134
178	Administration	5,923
201	Hangar	28,949
602	Shop	11,723
1671	Shop	11,867
Totals	16 buildings	233,449

[a]Fort Riley Building Directory, October 1985.
[b]Private communication, Mr. Harold Chart, Kansas City Office, United States Army Corps of Engineers.

distributed among the building types in the same proportion as construction costs. (See Table 7.2.) These cost data, by building type, will permit SIRs to be calculated for each building category as well as for the entire project.

Table 7.2. Total costs for roof insulation, by building type, Fort Riley[a]

Building type	No. of buildings	Construction costs ($)	SIOH + design costs ($)	Total costs ($)
Warehouses/ storehouse	6	86,742	7,227	93,969
Shops	5	72,278	6,022	78,300
Barracks/dining	2	22,247	1,854	24,101
Hangar	1	28,949	2,412	31,361
Other	2	23,233	1,936	25,169
Totals	16	233,449	19,451	252,900

[a]Note: The roof insulation retrofit was being completed as this report was being prepared. A few final costs were still to be determined, so these numbers should be treated as preliminary. Final official construction costs ($235,525) became available as the report was in a final publication stage. This total differs by less than 1% from the $233,449 in this table.

7.2 COST SAVINGS

The cost savings attributed to an ECIP project stem from the annual energy savings brought about by the building retrofit. The annual energy savings for Fort Riley resulting from installation of roof insulation in 16 buildings have been calculated as 8,762 MBtu of natural gas. (See Table 6.6.) These energy savings may, in turn, be converted to first-year dollar savings by multiplying by an energy cost factor. The Energy Office at Fort Riley reports that the Fort pays $3.10/MBtu for natural gas (March 1986). Therefore,

$$\text{first year savings} = (8{,}762\ \text{MBtu})(\$3.10/\text{MBtu}) = \$27{,}162.$$

In order to project the dollar savings to the Fort beyond the first year, assumptions must be made as to the appropriate economic life of the retrofit, the discount rate, and projected escalation rates of energy prices. ECIP guidance supplies values for these factors in the form of Uniform Present Worth (UPW) factors. The most recent ECIP guidance (see Ref. 5, March 4, 1985) lists 25 years as the maximum economic life for weatherization projects, including insulation projects such as that of Fort Riley. The same guidance document provides tables of UPW factors, by geographic region, for each fuel type and for various years of economic life. For Region 7 (including Kansas), the UPW factor for natural gas at 25-year economic life is 20.23. The discounted savings for the Fort Riley project is the product of the first year savings times this UPW factor:

$$\text{discounted savings} = (\$27{,}162)(20.23) = \$549{,}487.$$

The result is the numerator of the SIR calculation.

7.3 SIR CALCULATIONS

ECIP guidance[5] requires a life-cycle cost analysis for each overall project and for each discrete retrofit action included within the project. As applied to the Fort Riley ECIP, this guidance requires an SIR calculation for roof insulation of all 16 buildings and additional calculations of SIRs for roof insulation of each of the four building types (warehouses/storehouses, shops, barracks/mess halls, and hangar). The ECIP guidance also specifies the format for the SIR calculations: Life Cycle Cost Analysis Summary, Energy Conservation Investment Program (ECIP). Figures 7.1–7.5 display the SIR calculations conforming to this ECIP guidance.

Figure 7.6 displays the SIRs for the four building types and for the total project. The overall project has a respectable SIR of 2.41, and SIRs of all but one of the building types are above 1.0. One major cause for differences among these SIRs is the varied effectiveness of roof insulation for energy conservation among the different building types. For reasons discussed in Sect. 6, roof insulation is very effective for these Fort Riley shops, and it is modestly effective for the warehouses/storehouses and the hangar. Roof insulation was ineffective for this particular barracks/dining complex.

The value of the SIR is also influenced by the particular set of ECIP guidelines in effect at the time of analysis. For example, if this Fort Riley ECIP project had been subject to ECIP guidelines of 18 January, 1983, the maximum economic life of the project would have been 15 years, the UPW factor would be 13.72, and the resulting SIR of the overall projected would be reduced to 1.64.

Another important but unstable input to the SIR calculation is the current and site-specific cost of fuel. At the time of this analysis, Fort Riley was paying $3.10/MBtu for natural gas. If the calculation had been carried out in March of 1982, when the cost of natural gas at Fort Riley was $3.82/MBtu, the overall SIR would have been 2.02 (15-year economic life) or 2.97 (25-year economic life). Obviously, the value of an SIR reported for a project must be interpreted with care.

7.4 COMPARISON WITH PREVIOUS SIR ESTIMATES

The Statement of Work for this project[1] specifies that the SIR from the ECIP validation study will be compared with results predicted during the design phase. The first estimate of an SIR for the overall project was made in March 1982 (ref. 4) by a consulting firm. A second estimate was made by the Kansas City Office, Corps of Engineers, during the spring of 1985. This latter estimate was based on a modeling effort using the BLAST program. Neither of the above studies reported SIRs by building type. Table 7.3 compares the results of these two earlier efforts with results from this validation study.

The ORNL estimate of SIR agrees closely with that of the Corps of Engineers. If both had been calculated for 15-year economic life, the Corps' SIR would be 1.97 and ORNL's SIR would be 1.64. The earlier estimate made by the ECIP project A-E was much more optimistic regarding annual and life-cycle savings. Causes for these differences in results stem from failure by the A-E to differentiate the analysis to accommodate differences among the four basic building types.

LIFE CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Fort Riley, Kansas REGION No. 7 PROJECT NUMBER 308
PROJECT TITLE Insulate Roofs FISCAL YEAR 1985
DISCRETE PORTION NAME Total Project (16 buildings)
ANALYSIS DATE 8/5/86 ECONOMIC LIFE 25 YEARS PREPARED BY F. D. Boecker

1. INVESTMENT

A. CONSTRUCTION COST	$ 233,449	
B. SIOH }	$	
C. DESIGN COST }	$ 19,451	
D. ENERGY CREDIT CALC (1A+1B+1C)X.9	$ 227,610	
E. SALVAGE VALUE	−$	
F. TOTAL INVESTMENT (1D-1E)		$ 227,610

2. ENERGY SAVINGS (+) / COST (−)
ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)	
A. ELEC	$		$		$	
B. DIST	$		$		$	
C. RESID	$		$		$	
D. NG	$ 3.10	8,762	$ 27,162	20.23	$ 549,487	
E. COAL	$		$		$	
F. TOTAL		8,762	$ 27,162		>	$

3. NON ENERGY SAVINGS(+) / COST(−)

A. ANNUAL RECURRING (+/−) $
(1) DISCOUNT FACTOR (TABLE A)
(2) DISCOUNTED SAVING/COST (3A X 3A1) $

B. NON RECURRING SAVINGS(+) / COST(−)

ITEM	SAVINGS(+) COST (−)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS (+) COST(−)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$			$

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(−) (3A2+3Bd4) $

D. PROJECT NON ENERGY QUALIFICATION TEST
(1) 25% MAX NON ENERGY CALC (2F5 X .33) $ 181,330
✓ a IF 3D1 IS = OR > 3C GO TO ITEM 4
b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F=
c IF 3D1b IS = > 1 GO TO ITEM 4
d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. AVERAGE ANNUAL DOLLAR SAVINGS 2F3+3A+(3B1d÷YEARS ECONOMIC LIFE) $ 27,162
5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ 549,487
6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY)(SIR)=(5÷1F)= 2.41

Fig. 7.1. SIR calculation for total project.

LIFE CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Fort Riley, Kansas REGION No. 7 PROJECT NUMBER 308
PROJECT TITLE Insulate Roofs FISCAL YEAR 1985
DISCRETE PORTION NAME Warehouses/storehouses (6 buildings)
ANALYSIS DATE 8/5/86 ECONOMIC LIFE 25 YEARS PREPARED BY F.D. Boercker

1. INVESTMENT

A. CONSTRUCTION COST	$ 86,742	
B. SIOH }	$	
C. DESIGN COST }	$ 7,227	
D. ENERGY CREDIT CALC (1A+1B+1C)X.9	$ 84,572	
E. SALVAGE VALUE	−$	
F. TOTAL INVESTMENT (1D-1E)		$ 84,572

2. ENERGY SAVINGS (+) / COST (−)
ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)	
A. ELEC	$		$		$	
B. DIST	$		$		$	
C. RESID	$		$		$	
D. NG	$ 3.10	2,233	$ 6,922	20.23	$ 140,032	
E. COAL	$		$		$	
F. TOTAL		2,233	$ 6,922		>	$ 140,032

3. NON ENERGY SAVINGS(+) / COST(−)

A. ANNUAL RECURRING (+/−) $
(1) DISCOUNT FACTOR (TABLE A)
(2) DISCOUNTED SAVING/COST (3A X 3A1) $

B. NON RECURRING SAVINGS(+) / COST(−)

ITEM	SAVINGS(+) COST (−)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS (+) COST(−)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$			$

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(−) (3A2+3Bd4) $

D. PROJECT NON ENERGY QUALIFICATION TEST
(1) 25% MAX NON ENERGY CALC (2F5 X .33) $ 46,210
✓ a IF 3D1 IS = OR > 3C GO TO ITEM 4
b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F=
c IF 3D1b IS = > 1 GO TO ITEM 4
d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. AVERAGE ANNUAL DOLLAR SAVINGS 2F3+3A+(3B1d÷YEARS ECONOMIC LIFE) $ 6,922
5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ 140,032
6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY)(SIR)=(5÷1F)= 1.66

Fig. 7.2. SIR calculation for warehouses/storehouses (6 buildings).

LIFE CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Fort Riley, Kansas REGION No. 7 PROJECT NUMBER 308
PROJECT TITLE Insulate Roofs FISCAL YEAR 1985
DISCRETE PORTION NAME Shops (5 buildings)
ANALYSIS DATE 8/5/86 ECONOMIC LIFE 25 YEARS PREPARED BY F.D. Boercker

1. INVESTMENT

A. CONSTRUCTION COST	$ 72,278	
B. SIOH }	$	
C. DESIGN COST }	$ 6,022	
D. ENERGY CREDIT CALC (1A+1B+1C)X.9	$ 70,470	
E. SALVAGE VALUE	−$	
F. TOTAL INVESTMENT (1D-1E)		$ 70,470

2. ENERGY SAVINGS (+) / COST (−)
ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)	
A. ELEC	$		$		$	
B. DIST	$		$		$	
C. RESID	$		$		$	
D. NG	$ 3.10	4,890	$ 15,159	20.23	$ 306,667	
E. COAL	$		$		$	
F. TOTAL		4,890	$ 15,159		>	$ 306,667

3. NON ENERGY SAVINGS(+) / COST(−)

A. ANNUAL RECURRING (+/−) $
(1) DISCOUNT FACTOR (TABLE A)
(2) DISCOUNTED SAVING/COST (3A X 3A1) $

B. NON RECURRING SAVINGS(+) / COST(−)

ITEM	SAVINGS(+) COST (−)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS (+) COST(−)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$			$

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(−) (3A2+3Bd4) $

D. PROJECT NON ENERGY QUALIFICATION TEST
(1) 25% MAX NON ENERGY CALC (2F5 X .33) $ 101,200
✓ a IF 3D1 IS = OR > 3C GO TO ITEM 4
b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F=
c IF 3D1b IS = > 1 GO TO ITEM 4
d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. AVERAGE ANNUAL DOLLAR SAVINGS 2F3+3A+(3B1d÷YEARS ECONOMIC LIFE) $ 15,159
5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ 306,667
6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY)(SIR)=(5÷1F)= 4.35

Fig. 7.3. SIR calculation for shops.

LIFE CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Fort Riley, Kansas REGION No. 7 PROJECT NUMBER 308
PROJECT TITLE Insulate Roofs FISCAL YEAR
DISCRETE PORTION NAME Barracks/Dining (2 buildings)
ANALYSIS DATE 8/5/86 ECONOMIC LIFE 25 YEARS PREPARED BY F.D. Boecker

1. INVESTMENT

A. CONSTRUCTION COST	$ 22,247	
B. SIOH	$	
C. DESIGN COST	$ 1,854	
D. ENERGY CREDIT CALC (1A+1B+1C)X.9	$ 21,691	
E. SALVAGE VALUE	−$	
F. TOTAL INVESTMENT (1D-1E)		$ 21,691

2. ENERGY SAVINGS (+) / COST (−)
ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)	
A. ELEC	$		$		$	
B. DIST	$		$		$	
C. RESID	$		$		$	
D. NG	$ 3.10	48	$ 149	20.23	$ 3,014	
E. COAL	$		$		$	
F. TOTAL		48	$ 149		>	$ 3,014

3. NON ENERGY SAVINGS(+) / COST(−)

A. ANNUAL RECURRING (+/−) $
(1) DISCOUNT FACTOR (TABLE A)
(2) DISCOUNTED SAVING/COST (3A X 3A1) $

B. NON RECURRING SAVINGS(+) / COST(−)

ITEM	SAVINGS(+) COST (−)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS (+) COST(−)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$			$

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(−) (3A2+3Bd4) $

D. PROJECT NON ENERGY QUALIFICATION TEST
(1) 25% MAX NON ENERGY CALC (2F5 X .33) $ 995
✓ a IF 3D1 IS = OR > 3C GO TO ITEM 4
b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F=
c IF 3D1b IS = > 1 GO TO ITEM 4
d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. AVERAGE ANNUAL DOLLAR SAVINGS 2F3+3A+(3B1d÷YEARS ECONOMIC LIFE) $ 149
5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ 3,014
6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY)(SIR)=(5÷1F)= 0.14

Fig. 7.4. SIR calculation for barracks/dining.

LIFE CYCLE COST ANALYSIS SUMMARY
ENERGY CONSERVATION INVESTMENT PROGRAM (ECIP)

LOCATION: Fort Riley, Kansas REGION No. 7 PROJECT NUMBER 308
PROJECT TITLE Insulate Roofs FISCAL YEAR 1985
DISCRETE PORTION NAME Hangar (1 building)
ANALYSIS DATE 8/5/86 ECONOMIC LIFE 25 YEARS PREPARED BY F.D. Boercker

1. INVESTMENT

A. CONSTRUCTION COST	$ 28,949	
B. SIOH	$	
C. DESIGN COST	$ 2,412	
D. ENERGY CREDIT CALC (1A+1B+1C)X.9	$ 28,225	
E. SALVAGE VALUE	−$	
F. TOTAL INVESTMENT (1D-1E)		$ 28,225

2. ENERGY SAVINGS (+) / COST (−)
ANALYSIS DATE ANNUAL SAVINGS, UNIT COST & DISCOUNTED SAVINGS

FUEL	COST $/MBTU(1)	SAVINGS MBTU/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)	
A. ELEC	$		$		$	
B. DIST	$		$		$	
C. RESID	$		$		$	
D. NG	$ 3.10	826	$ 2,561	20.23	$ 51,809	
E. COAL	$		$		$	
F. TOTAL		826	$ 2,561		>	$ 51,809

3. NON ENERGY SAVINGS(+) / COST(−)

A. ANNUAL RECURRING (+/−) $
(1) DISCOUNT FACTOR (TABLE A)
(2) DISCOUNTED SAVING/COST (3A X 3A1) $

B. NON RECURRING SAVINGS(+) / COST(−)

ITEM	SAVINGS(+) COST (−)(1)	YEAR OF OCCURRENCE(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS (+) COST(−)(4)
a.	$			$
b.	$			$
c.	$			$
d. TOTAL	$			$

C. TOTAL NON ENERGY DISCOUNTED SAVINGS(+) / COST(−) (3A2+3Bd4) $

D. PROJECT NON ENERGY QUALIFICATION TEST
(1) 25% MAX NON ENERGY CALC (2F5 X .33) $ 17,097
✓a IF 3D1 IS = OR > 3C GO TO ITEM 4
b IF 3D1 IS < 3C CALC SIR = (2F5+3D1)÷1F=
c IF 3D1b IS = > 1 GO TO ITEM 4
d IF 3D1b IS < 1 PROJECT DOES NOT QUALIFY

4. AVERAGE ANNUAL DOLLAR SAVINGS 2F3+3A+(3B1d÷YEARS ECONOMIC LIFE) $ 2,561
5. TOTAL NET DISCOUNTED SAVINGS (2F5+3C) $ 51,809
6. DISCOUNTED SAVINGS RATIO (IF < 1 PROJECT DOES NOT QUALIFY)(SIR)=(5÷1F)= 1.84

Fig. 7.5. SIR calculation for hangar.

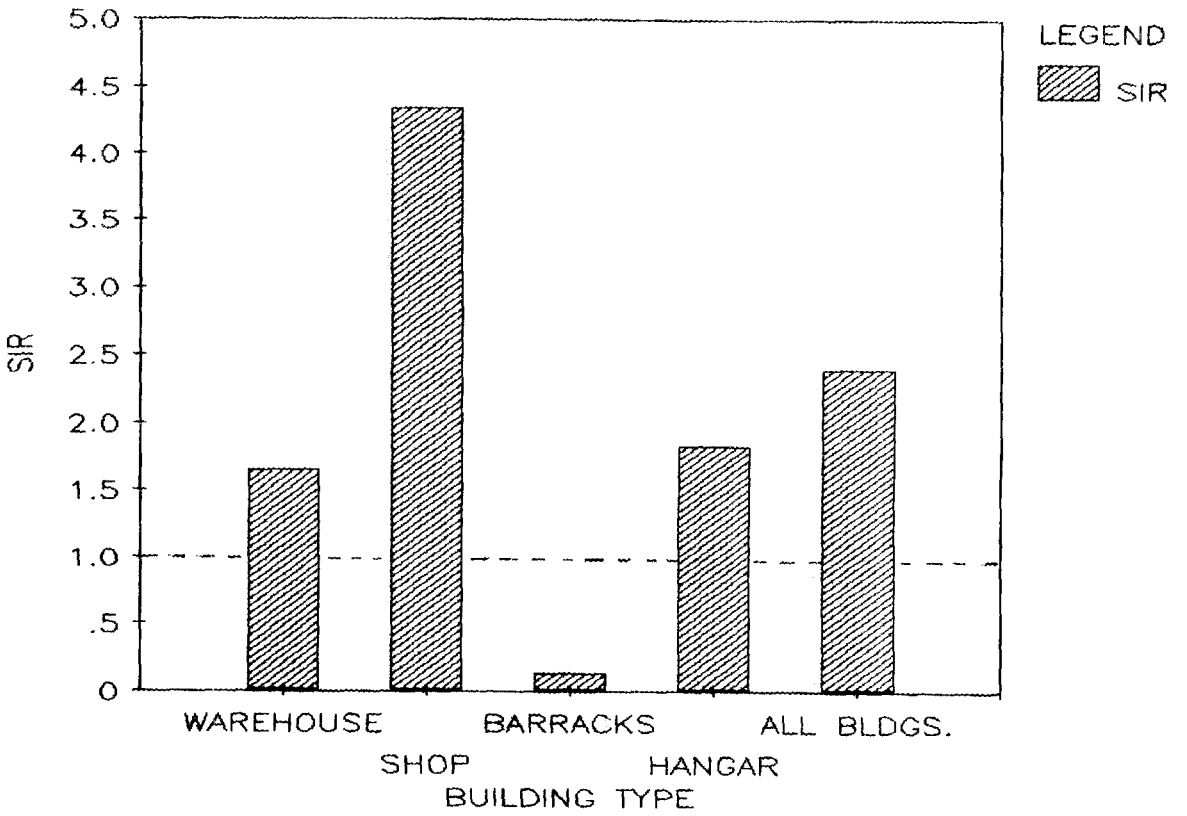


Fig. 7.6. Estimated SIR for roof insulation by building type, Fort Riley.

Table 7.3. Comparison of life-cycle savings estimates for the Fort Riley roof insulation ECIP project

Date of study	Study group	Projected annual savings		Projected life-cycle savings	
		($)	(MBtu)	(SIR)	(MBtu/$1000)
1982	Consulting Group (27 buildings, 25-yr economic life)	190,236	49,800	12.35[a]	169
1985	Corps of Engineers (20 buildings, 15-yr economic life)	25,889	7,954	1.97	31
1986	ORNL Validation (16 buildings, 25-yr economic life)	27,162	8,762	2.41	38

[a]Recent information provided by the Army indicates that this SIR had been recalculated in 1983, and the revised project was submitted to Congress with an SIR of 5.23. Supporting documentation for this revision was not available for the ORNL analysis.

8. SUMMARY AND CONCLUSIONS

8.1 SUMMARY OF FINDINGS

This report contains the findings of an ECIP validation study conducted by ORNL for USAFESA. The study was designed to determine annual energy and cost savings and projected life-cycle savings for ECIP Project No. 308 at Fort Riley, Kansas—adding roof insulation to 16 buildings. The buildings were constructed between 1890 and 1920 and are listed on the National Register of Historic Buildings. They have massive walls (18-in. limestone) which provide large thermal mass but small thermal resistance. Before retrofit, the roofs had no insulation (R ~1); after retrofit, the R-value was 20.

Estimates of energy savings were obtained by modeling the space heating energy use of each of four building types and projecting the modeled savings to all buildings of that type. This modeling effort was supplemented with submetering of fuel use of the four building types. The major findings are

- the overall project has an SIR of 2.4. It does save Army energy, and it is a cost-effective investment;
- SIRs, by building type, are varied, but only one type (barracks/dining hall) has an SIR <1;
- six of the 16 buildings are warehouses or storehouses. The roof insulation saves about one-third of space heating energy, but because such buildings are maintained at low temperatures and have low infiltration rates, the absolute energy use and corresponding energy savings are modest (SIR = 1.7);
- five of the 16 buildings are shops of various sorts. Roof insulation saves about one-fourth of space heating energy, and because inside temperatures are maintained at about 70°F and infiltration rates are high, the absolute energy use and the absolute energy savings are large (SIR = 4.4);
- two of the 16 buildings are multi-story combination barracks and dining halls. Large internal loads from cooking, lighting, and appliances, coupled with small roof/wall ratios, greatly reduce the effectiveness of roof insulation (SIR = 0.1); and
- one building is a hangar with about 30,000 ft^2 of floor area and a very high infiltration rate resulting in large space heating energy use. Ceiling insulation is modestly effective (7% savings), but the absolute energy savings are good (SIR = 1.8). If the infiltration rate of this building could be reduced to half the present rate, the energy use would be decreased by an additional 30%.

8.2 CONCLUSIONS

A number of general conclusions, or lessons learned, may be abstracted from the technical findings of this study and from the experiences of staff members of USAFESA, Corps of Engineers, Fort Riley Energy Office, and ORNL over the course of the project.

1. ECIP guidance is useful and may save retrofit investment dollars. This project's findings illustrated an instance in which an overall SIR was well above 1.0, but one discrete portion (building type) was <1.0.

2. For buildings of the types studied in this project, added roof insulation (R-1 to R-20) is very cost effective for shops, reasonably effective for warehouses maintained at low temperatures, but good for those maintained at moderate temperatures, reasonably effective for hangars, and ineffective for this type of 3-story barracks/mess hall. Savings at other military bases will vary somewhat from those reported in this study, depending upon climate, building use patterns, and building structural details.

3. Careful modeling, supplemented by baseline metering, proved to be an effective way to study energy savings of a variety of buildings retrofitted by roof insulation. The model must have detailed and accurate input—hourly weather data, building plans, mechanical equipment, internal loads, use patterns, etc. The model must be calibrated to agree with a series of metered energy consumption data points. Under these circumstances, the model will estimate insulation retrofit savings that might be difficult or impossible to estimate with good confidence from metered data alone.

4. Careful modeling, as described above, may not be appreciably less expensive than detailed metering.

5. The Army has limited metered data regarding space conditioning energy consumption for specific buildings. This is especially true regarding natural gas. The Army may wish to allow installed meters from ECIP validation studies to remain for use by the Fort's Energy Offices.

6. ECIP validation studies are greatly facilitated by prompt installation of the retrofit as scheduled. Delays in retrofit installation add to the cost of the validation study and seriously impair the accuracy and validity of the findings. Candidate sites for ECIP validation studies should be screened very carefully to select those that can maintain the schedule of retrofit.

7. ECIP validation studies are dependent upon cooperation with the Energy Office personnel at the Fort and with personnel at the District Office of the Corps of Engineers. These persons are essential partners in the validation study from initial planning through final report, and they should be involved with the project as early as possible.

8. USAFESA personnel must interact very frequently with the other groups. They must select the project sites, review interim and final reports, arrange for funding, and make policy decisions regarding the validation studies.

REFERENCES

1. DOE/ORO letter (J. A. Lenhard) to UCC-ND (R. F. Hibbs) dated July 19, 1983, entitled, "ORNL Project, ECIP Project Validation Studies," Interagency agreement DOE #40-1380-83 (with attached MIPR-43106 and "Statement of Work").

2. Boercker, F. D., et al., **Phases I and II: ECIP Project Validation Design Plan, Roof/Ceiling Insulation Added to 25 Buildings**, ORNL/TM-8931, December 1985.

3. U.S. Army Corps of Engineers, Kansas City District, **Specifications for Insulated Roofs**, Solicitation No. DACA 41-85-R-0277, June 1985.

4. Burns and McDonnell, **Integrated Energy Master Plan, Executive Summary for Fort Riley, Kansas**, Contract No. DACA 45-78-C-0106, prepared for the U.S. Army Engineer District, Omaha, Nebraska, 1980.

5. Department of the Army, Office of the Chief of Engineers, "Energy Conservation Investment Program (ECIP) Guidance," DAEN-FEU, November 7, 1977; DAEN-MPO-U, August 10, 1982 (revision to DAEN-FEU); DAEN-ZCF-U, January 18, 1983 (revision to DAEN-MPO-U); DAEN-ZCF-U (revised), March 4, 1985 (revision to DAEN-ZCF-U).

6. National Bureau of Standards, **Life Cycle Cost Manual for the Federal Energy Management Program**, NBS Handbook 135, December 1980.

7. Windingland, L., **Parametric Analysis of Energy Consumption in Army Buildings by the Building Loads Analysis and System Thermodynamics (BLAST) Computer Program**, U.S. Army Construction Engineering Research Laboratory (CERL), Technical Report E-162, August 1980.

8. General Accounting Office, GAO Letter Report, "Findings, Conclusions, and Suggestions," GAO Code No. 003516-OSD Case No. 6203, February 4, 1983.

9. Directorate of Engineering and Housing, Fort Riley, **Fort Riley Building Directory**, October 1985.

APPENDIX

Procedure for Measurement Check on Modeled Fuel Savings Caused by Roof Insulation, Four Buildings, Fort Riley

Procedure for Measurement Check on Modeled Fuel Savings Caused by Roof Insulation, Four Buildings, Fort Riley

The SIR calculations for the overall roof insulation project at Fort Riley and for each building type are presented in Sect. 7.3 of this report. A key input to each calculation is the energy savings attributed to the ECIP project. In this study, these savings have been based on DOE-2.1B modeling results of pre-retrofit vs post-retrofit fuel use. Using the natural gas flow meters that have been installed in the four modeled buildings, it is possible to check these modeled savings by comparing pre-retrofit metered fuel use/HDD with post-retrofit metered fuel use/HDD. Three months of pre-retrofit weekly fuel use data and associated weather data have already been collected and analyzed. This Appendix describes a procedure for making an appropriate comparison with post-retrofit metered data.

1. Check that pre-retrofit and post-retrofit building use patterns and mechanical system patterns are comparable for the four buildings. Check

   - building use category. (Compare Table 7.1.);
   - thermostat setpoint. (Compare Table 6.1.); and
   - check with Facility Engineers that HVAC systems have not been altered.

   If marked changes have been made, useful pre-retrofit/post-retrofit comparisons will not be possible.

2. Check that the roof or ceiling insulation has been installed as described in the Specifications. (See Ref. 3 and Table 6.4.)

3. Arrange for weekly readings of natural gas meters in the four buildings. (See attached data recording form, Fig. A.1.) These readings should be taken during the 1986–87 heating season which begins about mid-October and ends about mid-April.

4. Collect monthly summaries of daily weather data from Fort Riley. (See attached Daily Climatological Data sheet, Fig. A.2.)

5. Using data from 3 and 4 above, make a table for each building to show weekly fuel use vs average weekly outside temperature. Plot weekly fuel use vs average weekly outside temperature and note slope of linear regression line, intercept of regression line with temperature axis, and correlation coefficient. (See Fig. 6.1.) The intercept of the regression line with the temperature axis is the balance point temperature (BP).

6. Comparing these BPs and correlation coefficients with those in Table 6.1 for buildings 86, 129, and 201, expect correlation coefficients of about -0.90 and BP temperatures several degrees lower than those in Table 6.1. For building 94, expect a low correlation coefficient (<-0.50) and an undefined BP.

7. Using the weather data from 4 above, calculate the number of heating degree days for each week of the metered heating season based on the BP temperature of each building (HDD_{BP}).

Fuel Use for Space Heating, 4 Buildings, Fort Riley

*Date meters read: _____

Building number	Current meter reading	Units of reading**
129		
86		
94 meter #1		
94 meter #2		
201		

*Meters should be read weekly during heating season, on the same day of each week.
**cu. ft., or 100 cu. ft., etc.

Fig. A.1. Data recording form.

8. Using data from 3 and 7, make a table for each building to show weekly fuel use vs weekly HDD_{BP}. Plot weekly fuel use vs weekly HDD_{BP} and note the slope of the linear regression line and the standard deviation of the slope. (See attached graphs, Fig. A.3.) The slope of the regression line is the fuel use/HDD_{BP}.

9. Compare pre-retrofit with post-retrofit values for fuel use HDD_{BP}.

Bldg. no.	Fuel use/HDD_{BP}		Percent difference	Confidence level of difference
	Pre-retrofit	Post-retrofit		
86				
94				
129				
201				

10. Compare the percent difference for each building with the modeled percent savings. (See Table 6.4.)

DAILY CLIMATOLOGICAL DATA

MONTH: JAN YEAR: 85 DETACHMENT 8 SQUADRON 5WS

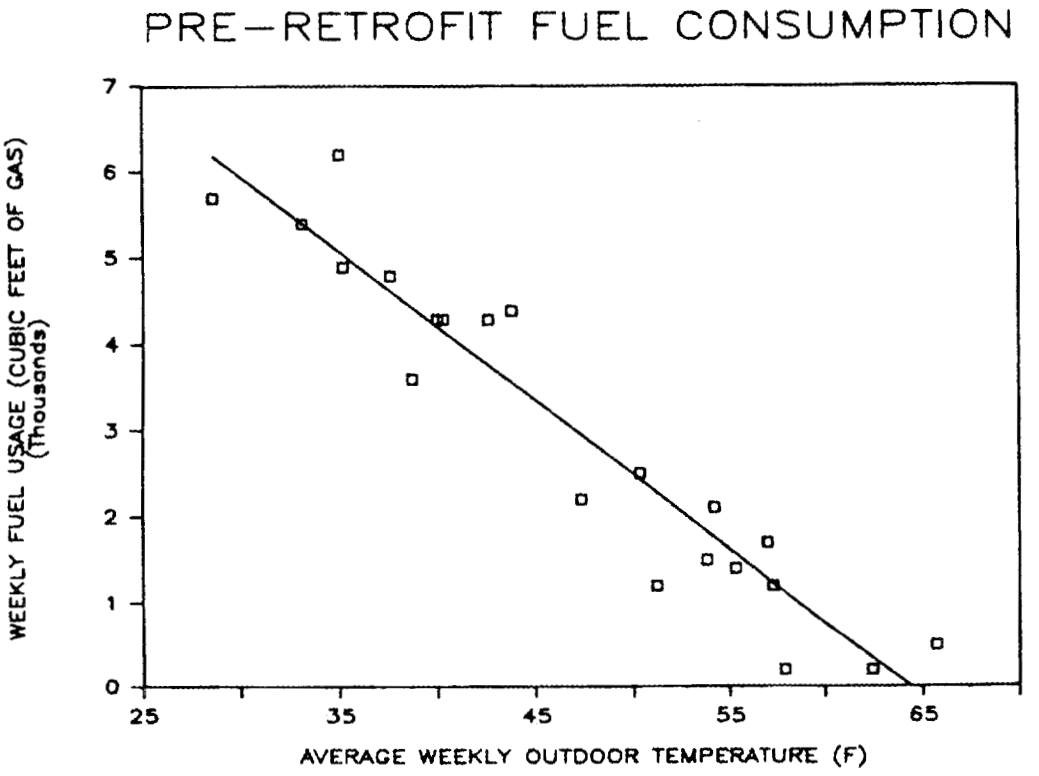
DAY OF THE MONTH	TEMPERATURE MAX	MIN	MEAN	65 DEGREE DAYS HEAT	COOL	PRECIPITATION WATER EQUIV TOTAL	SNOW TOTAL	WIND MEAN DIR	SPEED	MAXIMUM DIR	SPEED	24HR RH	S	RS
1	22	5	16	51		T	T	290	09	350	20	61	5	0
2	32	2	16	48		0	0	290	04	240	11	90	2	0
3	32	9	19	45		0	0	170	02	080	02	84	0	0
4	46	13	30	36		0	0	310	08	350	18	75	0	0
5	47	25	34	29		0	0	210	05	200	09	88	0	0
6	56	32	43	21		0	0	250	06	340	21	74	0	0
7	48	32	38	25		0	0	290	04	290	10	75	0	0
8	34	27	32	35		0	T	020	06	066	14	79	2	0
9	31	26	29	36		51	12	050	08	030	13	94	21	3
10	30	16	25	42		T	T	270	05	360	12	83	9	1
11	19	-5	09	58		T	T	340	06	060	17	70	2	0
12	22	-10	05	59		T	T	240	05	240	19	62	2	0
13	29	14	22	44		0	0	250	06	260	13	75	0	0
14	38	5	24	43		0	0	320	07	350	18	75	0	0
15	31	+3	17	48		0	0	100	05	160	14	70	0	0
16	51	11	22	44		0	0	260	05	320	18	73	2	0
17	38	21	29	36		0	0	250	06	220	10	74	0	0
18	41	25	36	32		0	0	300	07	350	18	67	0	0
19	36	-5	13	50		02	8	340	11	140	24	65	12	1
20	14	-9	03	63		0	0	290	07	280	18	48	0	0
21	26	10	18	47		0	0	280	04	340	14	65	0	0
22	25	5	16	50		T	T	280	04	270	07	70	2	0
23	25	13	19	46		0	0	250	05	270	13	73	1	0
24	39	9	20	41		0	0	210	08	010	28	54	1	1
25	40	21	33	35		0	0	270	06	360	25	68	0	0
26	36	6	23	44		0	0	260	07	210	20	62	0	0
27	36	22	29	36		0	0	340	04	350	08	73	0	0
28	32	14	24	42		0	0	140	04	160	09	76	5	0
29	34	30	32	33		.14	1.5	110	04	180	11	82	15	6
30	33	5	16	46		.05	1.0	070	11	010	24	71	16	3
31	10	-7	2	64		0	0	320	05	350	17	35	0	0
TOTAL	1013	365	694	1329		72	153						97	15
MEAN	33	12	22	43		—		230	06	060	15	71		
EXTREME	56	-10				.51	12							

NUMBER OF DAYS WITH:

1. 90° F or above _____
2. 32° F or below _____
3. 0° F or below _____
4. ≥ 0.01 inches precip. _____
5. ≥ 0.10 inches precip. _____
6. ≥ 0.50 inches snowfall _____
7. ≥ 1.00 inches snowfall _____
8.
9.
10.
11.
12.

5WW FORM MAR 82 4

Fig. A.2. Daily climatological data sheet.



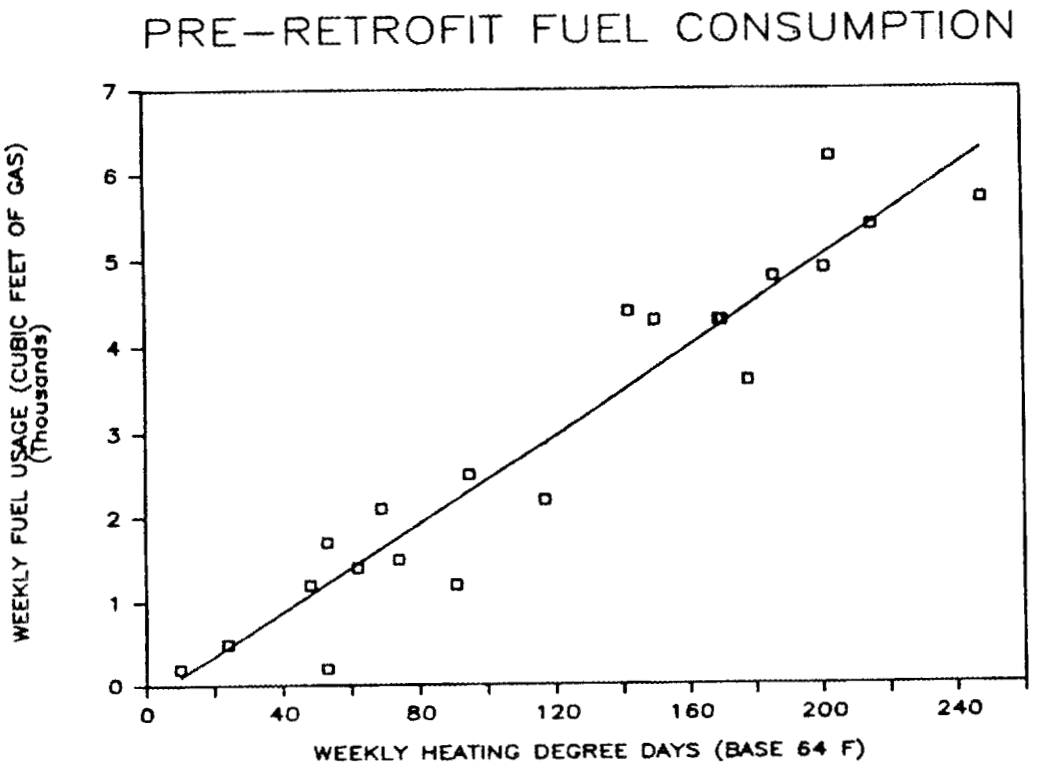


Fig. A.3. Sample graphs for plotting weekly fuel use vs weekly HDD_{BP}.

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