Impacts of Alternative Residential Energy Standards— Rural Housing Amendments Study, Phase I

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ENERGY STANDARDS--RURAL HOUSING
AMENDMENTS STUDY, PHASE 1

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FOREWORD

A companion volume, Impacts of Alternative Residential Standards--Rural Housing Amendments Study, Interim Report: Executive Summary (PNL-5694 Ex. Sum.), has also been printed by Pacific Northwest Laboratory. It contains an overview of the research and a summary of the major findings of this study.

SUMMARY

In the Rural Housing Amendments of 1983 (hereafter referred to as the "Act"), Congress recognized the importance of manufactured housing in meeting the housing needs of many families across the nation, particularly those with lower incomes. The Act permitted the U.S. Department of Agriculture (DOA), through the Farmer's Home Administration (FmHA), to extend its Title V subsidized loan program to buyers of manufactured homes. The Act also directed FmHA to produce new energy conserving requirements (standards) for those manufactured homes covered by the Title V program. These standards are required to meet two criteria: 1) they must be cost-effective over the life of the home or length of the mortgage, whichever is shorter; and 2) they must not increase annual mortgage payments more than they decrease annual energy expenditures.

The Act also directed the U.S. Department of Energy (DOE) to deliver a report to Congress that compares the energy and economic impacts of the new FmHA standard with those of other federal standards and compares the performance of manufactured housing with that of site-built housing. This report contains the preliminary results of the study, which was conducted by Pacific Northwest Laboratory (PNL). FmHA, under the Act, is to apply its existing Title V site-built standards to manufactured homes until the new standard is released. The final (Phase 2) study will await the issuance of the new FmHA standard. The Act requires the final DOE report within 18 months after FmHA issues its final regulations.

This preliminary report has examined the role of manufactured housing in the housing market, the energy impacts of three manufactured housing standards and three site-built standards in 13 cities, and the economic impacts of those standards in 6 cities. The three standards applied to manufactured housing are the HUD Title VI standard (Manufactured Housing Construction and Safety Standards, or MHCSS), the HUD Title II-E standard, and the existing FmHA Title V standard. Those applied to site-built homes are the HUD Minimum Property Standards (MPS), the ASHRAE 90A-80 standard, and the FmHA Title V standard.

The Act requires the examination of the actual energy consumption of homes built to the FmHA standard. Ideally, a number of manufactured homes built to

the three standards would be monitored to determine the true impacts. However, the size of the sample required would have been prohibitive within the resources of this effort. Therefore, computer simulation data embodied in extensive energy and cost data bases developed previously by DOE were used in this analysis.

Energy analyses are based on comparisons between the various standards as applied to two prototypical homes: a single-section manufactured home and a single-story detached "ranch house." The manufactured home contains 902 sq ft of conditioned floor area, while the site-built home contains 1540 sq ft. The ranch house built to the ASHRAE 90A-80 specifications was assumed as the base configuration representing typical building practice for site-built homes. The single-section home built to the HUD Title VI standards was assumed as the base configuration for manufactured homes.

Based on energy consumption alone, these analyses show that the FmHA Title V standard is the most stringent standard for both housing types. The HUD Title VI standard is the least stringent for manufactured homes, while the HUD Minimum Property Standards are the least stringent for site-built homes.

Cost-effectiveness comparisons required by the Act were made for the two prototypical homes. The two metrics used for comparison, as required by the Act, are the net life-cycle cost and the first-year cash flow. A standard is considered "economical" if it results in a discounted life-cycle cost to the consumer that is less than that of the base case standard. If the first-year cash flow, not including the down payment, is positive (i.e., annual savings exceed increases in mortgage payments), the standard passes the second test required by the Act.

The results of this preliminary economic analysis indicate that none of the site-built standards reflect minimum life-cycle cost as a basic criterion of their development. The FmHA site-built standard increases life-cycle cost in three cities and decreases it in three cities. Of the three cities in which the standard passes the life-cycle cost test, one of those fails the cash flow test. HUD's MPS increases life-cycle cost in four of the cities, decreases it in one city, and effects no change in one city.

For manufactured homes, both the FmHA standard and the HUD Title II-E standard reduce life-cycle cost and effect positive first-year cash flows in all cities analyzed when electric resistance heating is assumed. When natural gas heating is used, both standards pass the life-cycle cost test in all cities, but the FmHA standard fails the cash flow test in all but one city. However, in the worst case, net monthly expenditures in the first year are increased by less than \$9.

CONTENTS

FOREWORD	iii
SUMMARY	v
GLOSSARY	xv
1.0 LEGISLATIVE AND POLICY BACKGROUND	1.1
1.1 IMPACT OF FEDERAL GOVERNMENT ON HOUSING	1.1
1.2 LEGISLATION	1.3
2.0 THE ROLE OF MANUFACTURED HOUSING IN THE HOUSING MARKET	2.1
2.1 DEFINITION OF MANUFACTURED HOUSING	2.1
2.2 MANUFACTURED HOME CONSTRUCTION PROFILE AND CAPITAL STOCK DATA	2.3
2.2.1 Capital Stock and Cost Data	2.3
2.2.2 Location of Existing Homes	2.5
2.2.3 Manufacturing Information	2.8
2.3 CHARACTERISTICS OF MANUFACTURED HOME OCCUPANTS	2.9
3.0 ENERGY CHARACTERISTICS OF MANUFACTURED HOMES	3.1
3.1 THERMAL CONSTRUCTION CHARACTERISTICS	3.1
3.2 ENERGY CONSUMPTION DATA	3.2
4.0 REVIEW OF LITERATURE ON MANUFACTURED HOME ENERGY EFFICIENCY AND SIMULATED VERSUS MEASURED ENERGY DATA	4.1
4.1 LITERATURE RELATED TO POSSIBLE CHANGES IN EXISTING FEDERAL REGULATIONS	4.1
4.1.1 Department of Housing and Urban Development	4.1
4.1.2 Farmer's Home Administration	4.3
4.1.3 Department of Energy	4.4
4.2 OTHER LITERATURE	4.4

4.3	COMPARISON OF MEASURED AND SIMULATED ENERGY CONSUMPTION DATA	4.5
5.0	REQUIREMENTS OF RESIDENTIAL STANDARDS	5.1
5.1	BACKGROUND	5.1
5.1.1	HUD's Minimum Property Standards	5.1
5.1.2	ASHRAE 90A-80	5.1
5.1.3	FmHA Title V	5.1
5.1.4	HUD Title VI	5.2
5.1.5	HUD Title II-E	5.2
5.2	COMPONENT REQUIREMENTS	5.2
5.2.1	Insulation	5.2
5.2.2	Heat Loss/Gain Calculations	5.4
5.2.3	Duct Insulation	5.5
5.2.4	Window/Door Requirements	5.5
5.2.5	Required Ventilation	5.5
5.2.6	Heating Systems	5.5
5.2.7	Cooling Systems	5.6
5.2.8	Hot Water Systems	5.6
6.0	BUILDING PROTOTYPE DESIGN AND STANDARDS COMPLIANCE	6.1
6.1	RELATIONSHIP OF STANDARDS AND CLIMATE ZONES	6.1
6.2	DESCRIPTION OF BUILDING PROTOTYPES	6.3
6.3	COMPLIANCE FOR THE MANUFACTURED HOUSE	6.4
6.4	SINGLE-FAMILY DETACHED HOUSE COMPLIANCE DESIGN	6.13
7.0	ECONOMIC ANALYSIS METHODOLOGY	7.1
7.1	REVIEW OF LIFE-CYCLE COST ASSUMPTIONS	7.1
7.2	SUMMARY OF ENERGY COST PARAMETERS	7.4

7.3 CONSTRUCTION COST ESTIMATES	7.6
8.0 ENERGY AND COST ANALYSES	8.1
8.1 RESULTS OF ENERGY ANALYSIS	8.1
8.2 ECONOMIC ANALYSIS	8.7
9.0 CONCLUSIONS	9.1
9.1 FINDINGS FOR SITE-BUILT HOUSING	9.1
9.2 FINDINGS FOR MANUFACTURED HOUSING	9.1
REFERENCES	R.1
APPENDIX A - SYNOPSES OF LITERATURE RELATED TO THE ENERGY EFFICIENCY OF MANUFACTURED HOMES	A.1
APPENDIX B - ENERGY ASPECTS OF RESIDENTIAL STANDARDS REQUIREMENTS	B.1

TABLES

2.1	1983 Manufactured Housing Sales by Component	2.2
2.2	Capital Stock Data for Manufactured and Other Single-Family Homes	2.3
2.3	Lost Housing Units	2.5
2.4	Percentage of Total Existing Housing Stock in 1982 Located in Each Census Region	2.5
2.5	Manufactured Home Sales by State	2.6
2.6	Distribution of Homes by Urban-Rural Location	2.7
2.7	Manufactured Home Production by State in 1983	2.8
2.8	Income Characteristics of Manufactured Home Occupants	2.10
3.1	Thermal Characteristics of Manufactured and Site-Built Single-Family Detached Homes in 1982	3.3
3.2	Energy Consumption Data	3.3
3.3	In-Home Energy Expenditures Related to Household Income	3.4
4.1	Literature That Discusses the Energy Efficiency of Manufactured Homes	4.2
6.1	Heating and Cooling Degree Days for Cities Used in the Energy Analysis--Base 65°F	6.2
6.2	Climate Zone Relationship Between Standards and Cities	6.2
6.3	Manufactured Prototype Designs	6.6
6.4	Wall Heat Flow Paths for a Nominal R < 19	6.7
6.5	Wall Heat Flow Paths for a Nominal R $\geq$ 19	6.7
6.6	U-Values Corresponding to Wall Insulation Levels	6.8
6.7	U-Values Corresponding to Roof Insulation Options	6.10
6.8	Roof/Ceiling Heat Flow Paths	6.10
6.9	Floor Heat Flow Paths	6.11
6.10	U-Values Corresponding to Floor Insulation Options	6.12

6.11 Single-Family Detached Building Design	6.14
6.12 R-11 and R-13 Wall Heat Flow Paths	6.15
6.13 R-19 Wall Heat Flow Paths	6.15
6.14 R-24 Wall Heat Flow Paths	6.16
6.15 Ceiling R-Values	6.16
6.16 R-11 Floor Heat Flow Paths	6.16
7.1 Key Parameters in the Life-Cycle Cost Calculation	7.2
7.2 FEMP Residential Fuel Price Escalation Rates	7.3
7.3 Marginal Utility Rates	7.5
7.4 Heating Fuels Used in Economic Analysis	7.5
7.5 Single-Family Detached Housing Construction Costs to Consumer ...	7.7
7.6 Manufactured Housing Construction Costs to Consumer	7.7
7.7 1984 Means Regional Cost Multipliers	7.8
8.1 Summary of Load Reductions for the Manufactured Home	8.1
8.2 Summary of Load Reductions for the Single-Family Detached Home ..	8.2
8.3 Heating and Cooling Loads for the FmHA Standard	8.4
8.4 ASHRAE Standard 90A-80 vs. HUD MPS for the Single-Family Detached Home	8.8
8.5 FmHA Standard vs. HUD MPS for the Single-Family Detached Home ...	8.8
8.6 FmHA Standard vs. ASHRAE 90A-80 Standard for the Single-Family Detached Home	8.10
8.7 FmHA Standard vs. Title VI Standard for the Manufactured Home--Electric Heating	8.10
8.8 FmHA Standard vs. Title VI Standard for the Manufactured Home--Gas Heating	8.11
8.9 FmHA Standard vs. Title II-E Standard for the Manufactured Home--Electric Heating	8.11

8.10 FmHA Standard vs. Title II-E Standard for the Manufactured Home--Gas Heating	8.12
8.11 Title II-E Standards vs. Title VI Standards for the Manufactured Home--Electric Heating.....	8.12
8.12 Title II-E Standards vs. Title VI Standards for the Manufactured Home--Gas Heating	8.13

GLOSSARY

AC	Air conditioning
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
CDD	Cooling degree days
CFR	Code of Federal Regulations
DOA	U.S. Department of Agriculture
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
FHA	Federal Housing Administration
FmHA	Farmer's Home Administration
HDD	Heating degree days
HUD	U.S. Department of Housing and Urban Development
kWh	Kilowatt hours
LPG	Liquid petroleum gas
MHCSS	HUD Manufactured Home Construction and Safety Standards
Modular/sectional houses	Homes that are fully erected at the factory and shipped to the site, usually in two parts, for placement on a finished foundation. Unlike mobile homes, these units have no permanent chassis.
MPS	Minimum property standards
MSA	Metropolitan statistical area (replaced SMSA in March 1983)
NBS	National Bureau of Standards
NTIS	National Technical Information Service
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory

Panelized houses	Packages produced by a manufacturer with all or most of the materials needed to complete the houses including wall panels, roof trusses, and sometimes a floor system.
Pre-cut houses	Packages that contain most of the parts and pieces to construct a home. Generally, wall, floor, and roof panels are not included, but roof trusses may be.
SFD	Single-family detached (site-built home)
SMSA	Standard metropolitan statistical area (replaced by MSA in March 1983)
TVA	Tennessee Valley Authority
VA	Veterans' Administration

1.0 LEGISLATIVE AND POLICY BACKGROUND

This introductory chapter discusses the role of the federal government in the housing industry, and the specific legislation that resulted in this study.

1.1 IMPACT OF FEDERAL GOVERNMENT ON HOUSING

The federal government exerts considerable influence on private housing construction. The U.S. Department of Housing and Urban Development (HUD) administers Federal Housing Administration (FHA) and Veterans' Administration (VA) loan programs which, until 1984, covered about 15% to 30% of all the housing actually purchased. HUD's Minimum Property Standards, or their equivalent, are used to certify about 40% of all new site-built housing units through various federal mortgage programs; many experts feel that more like 80% actually comply but never need to be certified. The federal government, though active in the housing market through these channels, does not impose general site-built home construction standards. The government's ability to set policy through the use of secondary mortgage financing is also a very powerful force on private housing markets.

The President's Commission on Housing reported in 1982 that outstanding FHA and VA insurance and loan guarantee program funds totaled approximately \$239 billion, in addition to the \$6.2 billion in mortgage assets that were held by these agencies.

The Farmer's Home Administration (FmHA) is also responsible for administering housing loan and loan guarantee programs. The number of new homes financed or insured by FmHA or HUD is not presently known. But the number of active borrowers for FmHA Rural Housing Loans (new home purchases, as well as home improvement loans) totaled 919,342 as of April 1, 1984, representing \$21 billion of outstanding principal to the agency for insurance and loan guarantees and \$2.2 billion for mortgage assets held.

The federal role in the area of manufactured housing is also significant. Unlike site-built homes, all manufactured housing units must comply with HUD Title VI, the Manufactured Housing Construction and Safety Standards

(MHCSS). HUD Titles I and II of the National Housing Act are also available to insure loans to purchasers of such units, both old and new.

Members of HUD's Office of Policy Development and Research have indicated that in 1984, approximately 320,000 manufactured housing units were produced nationally. No more than 25,000 new units, however, were covered by HUD's Title I, II or VA housing programs. The number of units of manufactured housing purchased through other federal mortgage insurance programs is not known, but in 1982 HUD predicted that \$4.5 billion would be used to finance purchases of new mobile homes from all federal loan, loan guarantee, and mortgage programs representing all realty and chattel loans.

The main reason for the relatively low penetration of the HUD-subsidized housing loan programs is that until 1982, mobile homes could not be financed by long-term mortgage loans. Realty mortgages to insure homes for 30 years were not available under Title II before 1982. And even after this change, the typical manufactured housing purchaser was unable to take advantage of the 30 year realty mortgage because land is generally not a part of the purchase package. Many manufactured housing purchasers typically already own or lease the lots upon which they site their units.

In recent years the mobile home industry has made significant progress in solving long term impediments to sales of manufactured homes by such actions as gaining liberalized financing terms and decreasing zoning restrictions. Rapidly escalating costs for other housing types have also increased the appeal of manufactured housing, particularly to very low to moderate income consumers. This progress is the direct result of policy changes within the auspices and authorities of the Federal Housing Acts, the VA, the HUD, and the Federal Reserve Board. The key federal housing agency missing from this list is the Farmer's Home Administration.

While the FmHA has the authority to provide financial assistance for the housing needs of the poor, the FmHA has never financed manufactured housing purchases. FmHA programs extend principally to farm owners and rural families in communities of 10,000 to 20,000 people outside standard metropolitan statistical areas (SMSAs). These areas have never been covered by HUD's low income programs, and the income levels are usually too low to qualify borrowers

for other federally insured mortgage programs. It is expected that these groups are the principal targets for purchased and rented manufactured housing.

Until the Rural Housing Amendments were passed, no FmHA housing-type eligibility definitions included manufactured housing. All existing FmHA reports identifying numbers of loans and insured mortgages covering "manufactured housing" actually refer to panelized and modular housing types that are built on site and must meet FmHA Minimum Property Standards for site-built construction.

The primary problem Congress sought to eliminate by amending the Rural Housing Act was that assistance for purchasing safe, affordable housing was not being provided to those income groups that needed it most. These amendments reflect Congress' recognition of low income housing needs and the fact that existing federal housing programs have thus far been unable to accommodate the lowest income groups in the country.

1.2 LEGISLATION

The Rural Housing Amendments of 1983 are actually Title V of Public Law 98-181, passed on November 30, 1983, and known as the Supplemental Appropriations Act, 1984. No hearings were conducted on this bill before its passage, but general authorization issues were the subject of hearings on March 8, 9, 10, and 23, 1983, for both HUD and FmHA.

Regarding Title V, the Committee on Banking, Housing and Urban Affairs identified three major programmatic objectives in its review of the FmHA loans program. The Committee intended to improve targeting of assistance to the most needy persons and families in rural areas, make it possible to provide less costly housing, and account for the cost and budgetary impact of these programs.

Congress believed that the benefits of the FmHA program, as well as other federal housing programs, had not reached very low income persons. Consequently, the Committee provided that "on a national level at least 40% of the single family homes financed under Title V must be occupied by very low income persons or families." In newly constructed projects, only 5% of the units may be leased to low income families, and at least 95% must be rented to very low

income families. (FmHA guidelines define "very low" income as less than \$10,000 per household and "low" income as less than \$18,000 per household.)

To achieve these goals, the Committee felt it necessary to make units more affordable. For example, the Act permits both builders and borrowers the flexibility to use any of the following building codes: in the case of site-built housing, the FmHA Minimum Property Standards, the HUD Minimum Property Standards, or any code endorsed by the voluntary national building code groups in the U.S.; in the case of manufactured housing, the HUD Title VI MHCSS.

The Committee recognized that manufactured housing composes a substantial segment of new home sales each year. In 1983, manufactured housing composed nearly 36% of new single-family home sales, and nearly 60% of manufactured homes are found in rural areas. The Committee also recognized the important role manufactured housing could play in providing rental housing to these same low income groups.

The Committee also authorized the Secretary of Agriculture to subsidize loans for manufactured housing of the mobile home type, provided that it meets the construction and installation requirements generally established by HUD. Extension of this loan program to mobile homes was expected to expand the availability of affordable housing to many low income families in rural areas.

Section 503(a) of the Act provides that for the first time, FmHA loans may be made for manufactured housing (whether it is considered real property, personal property, or mixed real and personal property), as long as it meets specific requirements. First, manufactured homes must meet the prescribed safety standards in Title VI of the Housing and Community Development Act of 1974 and the installation, structural, and site requirements in Title II of the National Housing Act. Second, the Act required FmHA to develop and apply manufactured housing standards using its own energy requirements and to use its existing site-built standard until the new standard is issued. Legislative analyses provided to the Committee by HUD identified the combination of energy provisions in the FmHA MPS and in HUD Title II as more stringent than the current requirements under the HUD Title VI standards.

Until passage of the Act, HUD had exclusive jurisdiction over construction of all manufactured housing in the U.S. A Congressional willingness to extend the responsibility for developing manufactured housing standards to FmHA as well as HUD, together with the requirement that these standards employ the structural components of Title II rather than Title VI, indicate a strong Congressional endorsement of manufactured housing as a safe, durable, energy efficient, and affordable means of shelter.

The Secretary of Energy is charged in the Act with preparing a report for Congress that compares:

increased construction costs, actual annual energy use and the projected value of energy saved over the expected life of the home . . . of manufactured homes financed under Titles I and II of the National Housing Act, or under Title V of the Housing Act of 1949 which are built according to national manufactured housing safety standards with other homes insured under either such act.

The report is due within 18 months of FmHA's promulgation of manufactured housing energy requirements.

This report presents the results of a first-phase study responding to the Act. Since FmHA has not yet issued their new standard, this report analyzes the existing FmHA site-built standard, which applies until the new standard goes into effect. The second-phase study will address the specific requirements of the new standard.

2.0 THE ROLE OF MANUFACTURED HOUSING IN THE HOUSING MARKET

The purpose of this chapter is to characterize the role of manufactured housing in the U.S. housing market. The discussion is presented under the following topics: the definition of manufactured housing, a construction and location profile of manufactured homes and single-family site-built homes, and characteristics of manufactured housing owners.

2.1 DEFINITION OF MANUFACTURED HOUSING

The principal focus of this study is manufactured homes built to construction standards established by HUD. The Rural Housing Amendments of 1983 call for a comparison of construction costs, energy use, and value of energy consumption of manufactured homes and other homes.^(a) It was specified that the manufactured homes to be analyzed are to have been "built according to national manufactured housing safety standards." These preemptive national standards (Title VI) were issued by HUD on December 18, 1975, in response to the National Manufactured Housing Construction and Safety Standards Act of 1974. They appear in 24 CFR 3280 under the heading, Manufactured Home Construction and Safety Standards. The regulations became effective June 5, 1976. The term "manufactured house" in the HUD regulations is defined in 24 CFR 3280.2(16) as:

a structure, transportable in one or more sections, which in the traveling mode, is eight body feet or more in width or forty body feet or more in length, or, when erected on site, is three hundred twenty or more square feet, and which is built on a permanent chassis and designed to be used as a dwelling with or without a permanent foundation when connected to the required utilities, and includes the plumbing, heating, air-conditioning, and electrical systems contained therein.

Homes built to the HUD regulations are sometimes referred to as "HUD-code" or mobile homes, even though the regulations use the term "manufactured homes." One author (Nutt-Powell 1982, p. 3) contends that the term "mobile component housing" is actually more accurate. The generic term "manufactured housing" includes modular/sectional houses, panelized houses, and pre-cut

(a) These requirements come from Section 502(e)(2) of the Housing Act of 1949.

houses (LSI Systems 1984, pp. 1, 4-5), as well as mobile homes. The first three classes of homes are built to state and local building codes rather than to HUD manufactured home regulations. The 1983 sales of each component of manufactured housing are shown in Table 2.1. Another source cites 1983 manufactured home sales of 296,000 units, valued at \$5.05 billion at the manufacturers' level and \$5.87 billion at retail (Bus. Trend Analysis 1984). Unless clearly specified otherwise, the terms "manufactured" and "mobile" home in this report refer interchangeably to homes built to HUD manufacturing regulations and comparable homes built prior to the effective date of the regulations.

The HUD MHCSS regulations for manufactured home construction cover nine topics: 1) planning considerations; 2) fire safety; 3) body and frame construction requirements; 4) testing; 5) thermal protection; 6) plumbing systems; 7) heating, cooling, and fuel burning systems; 8) electrical systems; and 9) transportation. The regulations are framed to the extent possible to establish performance requirements rather than specific construction requirements. Thus the thermal standards specify a maximum overall heat transmission coefficient for a manufactured home in Btu/(hr)(sq ft)(°F) for three climate zones, but specify no explicit requirements for any particular building components (walls, floors, etc.). The one exception is windows, which must be double-paned in Zones 2 and 3.

The first major changes to the MHCSS were proposed by HUD in August 1983 (Federal Register 1983). Final changes in fire safety standards and a new rule

TABLE 2.1. 1983 Manufactured Housing Sales by Component (LSI Systems 1984)

Component	Units Sold
Manufactured homes built to HUD regulations	292,000
Modular houses	53,000
Panelized houses	69,000
Pre-cut houses	<u>17,000</u>
Total	431,000

on formaldehyde emissions from particleboard and plywood were issued in August 1984 (Federal Register 1984). Other proposed changes, including requiring manufacturers to offer improved thermal protection options to consumers, have not yet been made final.

2.2 MANUFACTURED HOME CONSTRUCTION PROFILE AND CAPITAL STOCK DATA

This section presents data on manufactured home construction starts, sales price, age of existing units, types of units produced, and unit location for both manufactured homes and other single-family homes.

2.2.1 Capital Stock and Cost Data

Table 2.2 contains information on the existing stock of manufactured homes. The most significant conclusion that can be drawn from the data is that

TABLE 2.2. Capital Stock Data for Manufactured and Other Single-Family Homes

<u>Parameter</u>	<u>Manufactured Homes</u>	<u>Privately Owned Single- Family Attached and Detached Homes</u>
Homes completed ^(a)	236,000 (1982) 292,000 (1983)	632,000 (1982)
Median sales price of new home (1983 \$) ^(b)	20,400	73,200
Average area of existing units (November 1982), sq ft ^(c,d)	860	2061 (detached homes)
Average age of existing stock (1982), years ^(a)	7.7	26.3
Total existing stock (1982) ^(c)	3,700,000	57,700,000
% of stock owner-occupied (1982) ^(c)	81	83

(a) U.S. Bureau of the Census 1984.

(b) Bus. Trend Analysts 1984.

(c) U.S. EIA 1984a.

(d) Gross area.

manufactured home construction is a much higher percentage of total single-family home construction now than it has been in the past. In 1982 manufactured homes represented 27% of new single-family home construction. Yet in the same year, manufactured homes represented only 6% of the total single-family housing stock. Manufactured homes' relatively recent increased share of total housing starts is also indicated in the figures for average age of the existing stock. The average age of existing manufactured homes in 1982 was 7.7 years, compared to 26.3 years for other single-family homes. Table 2.2 also shows that a slightly smaller fraction of manufactured home units are owner occupied than other single-family homes.

A major reason for the increase in popularity of manufactured homes is that they cost less on a per square foot basis than site-built housing. The median sales prices in Table 2.2 do not consider size differences or the fact that the sales price of site-built homes generally includes the lot. For housing units of equivalent size and features on permanent foundations and an identical lot, the rule of thumb is that a manufactured home should cost approximately 20% less than a site-built home (Nutt-Powell 1983a). Actual retail costs from 1982 indicate that manufactured homes cost \$19.22/sq ft, excluding land and set-up charges at the site but including certain furnishings such as kitchen appliances and drapes. New site-built homes cost \$39.25/sq ft, excluding furnishings and land (Bus. Trend Analysts 1984).

Although manufactured homes constitute an increasing share of new housing starts, they also constitute a disproportionately high and increasing share of lost housing units, as shown in Table 2.3. Lost housing units are those that are destroyed, converted to nonresidential use, abandoned, merged with an adjacent residence, etc. Thus during the 1970s, when manufactured homes constituted less than 6% of the total housing stock, they accounted for over 19% of lost housing units. The expected life of the existing stock of manufactured homes is thus less than that of site-built homes. Nevertheless, manufactured homes do appreciate in value. For example, a single-wide manufactured home sold in 1976, the effective date of the HUD MHCSS, was worth 103% of the original sales price (in current dollars) in 1980, and a double-wide home, 122% of the original sales price (Bus. Trend Analysts 1984).

TABLE 2.3. Lost Housing Units (Apgar 1983a)

<u>Decade</u>	<u>Total Housing Units Lost</u>	<u>Single Family</u>	<u>Multi- Family</u>	<u>Manufactured Home</u>
1960 - 1970	6,566,000	50.1%	43.6%	6.3%
1970 - 1980	2,562,000	45.1%	25.7%	19.3%

2.2.2 Location of Existing Homes

Manufactured homes tend to be located in warmer climates and more rural areas than other single-family homes. Data to support these observations are shown in Tables 2.4 and 2.5.

As shown in Table 2.4, 49% of manufactured homes in 1982 were located in the South, compared to 36% of nonmanufactured single-family homes.^(a) The percentage of total manufactured homes in the South is likely to increase further. In 1983, 67.5% of manufactured home sales were in the South (Bus. Trend Analysts 1984). The 10 states with the highest number of retail manufactured home sales are shown in Table 2.5. All but California and Arizona are in the "South" census region. These 10 states accounted for 60.9% of total manufactured home sales in 1983 (LSI Systems 1984). Further evidence that

TABLE 2.4. Percentage of Total Existing Housing Stock in 1982
Located in Each Census Region (U.S. EIA 1984a)

<u>Region</u>	<u>Manufactured Homes</u>	<u>Privately Owned Single- Family Attached and Detached Homes</u>
Northeast	11%	18%
North Central	19%	26%
South	49%	36%
West	24%	19%
Average annual HDD	4092	4490 (detached) 4747 (attached)

(a) "Northeast," "North Central," "West," and "South" correspond to the U.S. Census regions. The South region ranges from Delaware, in the northeast corner of the region, to Texas, in the southwest corner.

TABLE 2.5. Manufactured Home Sales by State (LSI Systems 1984 and Bus. Trend Analysts 1984)

State	Manufactured Home Sales (1983)	Manufactured Home Portion of New Single-Family Home Sales in Buildings Up to 4 Units (1983), %	Manufactured Home Share of Total Owner-Occupied Units (1980), %
1. Texas	42,425	16.6	5.1
2. Florida	30,884	23.2	9.8
3. North Carolina	21,317	31.1	10.3
4. Georgia	15,448	22.4	8.8
5. Louisiana	13,616	2.6	8.4
6. South Carolina	12,054	38.8	10.4
7. California	10,822	11.3	5.2
8. Alabama	9,539	47.6	9.4
9. Oklahoma	9,343	19.9	6.0
10. Arizona	7,048	16.1	13.3

manufactured homes are located in warmer climates comes from the figures in Table 2.4 for average annual heating degree days (HDD). The average for all manufactured homes is 4092. The number is higher for single-family detached homes, and higher still for single-family attached homes.

The manufactured home share of newly constructed homes and the manufactured home share of existing housing are also of interest (see Table 2.5). In all cases the percentage of manufactured home sales in 1983 significantly exceeds the overall manufactured home share of owner-occupied housing in 1980. The variation in sales is quite pronounced among the top 10 states in manufactured home sales. In California, manufactured home sales in 1983 accounted for 11.3% of new single-family homes in buildings of one to four units. In Alabama this percentage was 47.6%. Nationally, manufactured home sales represented 21.7% of single-family housing starts in 1983. The percentage by region ranged from a low of 12.4% in the Northeast to a high of 26.4% in the South (Bus. Trend Analysts 1984).

The more rural location of manufactured homes is evident from Table 2.6. Over 50% of new manufactured homes are located outside Standard Metropolitan

TABLE 2.6. Distribution of Homes by Urban-Rural Location (Apgar 1983b)

Manufactured Home Placements	SMSA %		Non-SMSA %
	Central City	Suburb	
1960 - 1970	8.0	36.6	55.4
1975 - 1980	8.3	36.9	54.8
Single-Family New Construction			
1960 - 1970	17.7	47.9	34.4
1975 - 1980	11.3	46.7	42.0

Statistical Areas (SMSA), as defined by the U.S. Office of Management and Budget.^(a) A major contributing factor to the more rural location of manufactured homes is that local zoning commonly restricts placement of manufactured homes to mobile home parks and subdivisions away from urban areas and to rural acreage. Recently, a few jurisdictions have permitted placement of manufactured homes in areas of site-built homes, but the manufactured home must normally meet the local building code as well as the HUD Title VI standard and also be placed on a foundation. The percentage of manufactured homes within an SMSA and outside an SMSA has remained essentially constant over the last 20 years. In contrast, in the 1975 to 1980 period, 58% of new single-family site-built homes were within an SMSA, dropping from 66% in the 1960 to 1970 period.

In 1980, approximately 28% of manufactured homes were sited on land owned by the manufactured home owner, i.e., individual residential lots or large rural parcels such as farms (Bus. Trend Analysts 1984). The remaining 72% of manufactured homes were on leased land, generally in mobile home parks. The percentage of manufactured homes on leased land increased from 66% to 72% between 1975 and 1980.

Manufactured homes can potentially be relocated after their original siting. The relocation expense and the wear and tear on the unit, however,

(a) SMSAs are called MSAs (Metropolitan Statistical Areas) as of March 18, 1983.

discourage such a practice. During 1973 to 1980, it is estimated that more than 200,000 homes (about 3% of all manufactured homes) were moved to new locations (Apgar 1983a).

2.2.3 Manufacturing Information

In 1983, there were 501 manufactured home manufacturing plants employing 51,175 workers (Bus. Trend Analysts 1984). The states with the highest manufactured home production tend to be in the South, which has the largest market and lower labor costs. The top 10 manufactured-home-producing states in 1983 are shown in Table 2.7.

Manufactured homes are constructed in sections to enable highway transportation. Nationally, most homes (70% to 75%) are single-section (Bus. Trend Analysts 1984), but double-wide homes are also common. Homes combining three or four sections are much less common. There is considerable geographic variation in the type of home sold. In the West, approximately 58% of new manufactured home sales are multisection units (LSI Systems 1984). In the Northeast the corresponding figure is only 13%.

TABLE 2.7. Manufactured Home Production by State in 1983 (LSI Systems 1984)

<u>State</u>	<u>Number of Units</u>	<u>Percent of Total U.S. Production</u>
1. North Carolina	43,031	14.7
2. Georgia	41,549	14.2
3. Indiana	25,724	8.8
4. North Carolina	24,584	8.4
5. Alabama	24,520	8.4
6. Florida	24,478	8.4
7. California	13,282	4.5
8. Pennsylvania	12,998	4.4
9. Tennessee	10,415	3.6
10. Mississippi	<u>8,089</u>	<u>2.8</u>
	228,670	78.2

Manufactured home units typically vary from 12 ft to 28 ft wide and from 36 ft to 80 ft long. A typical new single-wide unit is 14 ft by 70 ft, or 980 total sq ft. A typical new double-wide unit is 24 ft by 48 ft, or 1152 total sq ft (Bus. Trend Analysts 1984).

2.3 CHARACTERISTICS OF MANUFACTURED HOME OCCUPANTS

Families residing in manufactured homes are a diverse group. Approximately half of manufactured home occupants are under 30 or over 60 (Nutt-Powell 1983a). The median age of the household head is 47. By state, this figure ranges from a low of 36 in North Dakota to a high of 59 in Florida. About one-fourth of household heads are retired. In 1980, 75% of manufactured home households were two or more people (Bus. Trend Analysts 1984). The West had the highest percentage of manufactured homes with only one occupant--32.1%.

In 1980, the median years of education for manufactured-home household heads was 12.2. About 19% had some college education (Bus. Trend Analysts 1984). The Tennessee Valley Authority (TVA 1984) found that the average years of education of household heads in its service area was 10.8 for manufactured home occupants and 12.1 for other single-family home occupants.

Family income data for manufactured home and other single-family home occupants are shown in Table 2.8. Manufactured home occupants have a lower income than occupants of site-built homes, but the last line in the table suggests that recent manufactured home purchasers have higher incomes than past purchasers. Median family income in 1981 for manufactured home occupants was \$14,424 (Nutt-Powell 1983a).

TABLE 2.8. Income Characteristics of Manufactured Home Occupants

<u>Parameter</u>	<u>Manufactured Home</u>	<u>Single-Family Homes (attached and detached)</u>
Median household income in 1980, \$(a)		
All U.S.	12,000	19,800
Northeast	11,100	21,200
North Central	13,700	19,800
South	11,900	17,600
West	11,800	22,700
% of occupants with family income in 1981 that was: (b)		
<\$10,000	38	22
<\$20,000	73	47
<\$35,000	92	81
% of families earning more than \$20,000 (1983) (c)		
Manufactured home occupant <3 years	41	
All manufactured home occupants	33	

(a) Bus. Trend Analysts 1984.

(b) U.S. EIA 1984b.

(c) Wall St. Journal 1984, p. 15.

3.0 ENERGY CHARACTERISTICS OF MANUFACTURED HOMES

Section 3.1 of this chapter presents information on the thermal construction characteristics and the types of fuels used in manufactured homes and site-built single-family detached homes. Section 3.2 contains information on energy consumption for the same two classes of homes.

3.1 THERMAL CONSTRUCTION CHARACTERISTICS

Data on thermal construction characteristics and fuel types used in manufactured and site-built single-family detached homes are shown in Table 3.1. Several significant observations about the data can be made.

- The amount of heated space in manufactured homes is, on the average, about half that in site-built single-family detached homes.
- Manufactured homes are much more likely to use electricity and liquid petroleum gas (LPG) (mostly propane) for space and water heating than site-built single-family detached homes, and much less likely to use natural gas.
- Manufactured homes are sited in warmer climates (with fewer heating degree days) than site-built single-family detached homes for all categories of heating fuel.
- Manufactured homes are somewhat more likely to have air conditioning than site-built single-family detached homes, probably because manufactured homes are more commonly sited in warm climates.
- Approximately the same percentage of manufactured and site-built single-family detached homes have roof insulation; a considerably higher percentage of manufactured homes also have some wall insulation.
- Site-built single-family detached homes are more likely to have storm windows and storm doors than manufactured homes.

TABLE 3.1. Thermal Characteristics of Manufactured and Site-Built Single-Family Detached Homes in 1982 (U.S. EIA 1984a)

Parameter	Manufactured Homes	Site-Built Single-Family Detached Homes
Average total area, sq ft	860	2061
Average heated area, sq ft	846	1717
Main heating fuel, %		
Natural gas	29.3	56.8
Electricity	23.7	12.9
Fuel oil	11.6	12.6
Wood	7.5	9.7
LPG	23.8	5.0
Kerosene	4.0	0.9
Central air conditioning (AC), %	28.5	23.1
Individual room AC only, %	29.4	26.0
Water heating fuel, %		
Natural gas	23.6	54.6
Electricity	59.0	34.2
Fuel oil or kerosene	0.7	4.6
LPG	16.7	4.9
Roof entirely insulated, %	66.7	67.2
All walls insulated, %	73.5	51.5
Homes where all windows have storm windows, %	40.3	45.5
Homes with one or more sliding glass doors, %	10.2	26.6
Homes where all outside doors have storm door, %	16.4	39.8
Average annual heating degree days by main heating fuel		
Natural gas	4381	4501
Fuel oil or kerosene	5057	5334
Electricity	3386	3559
LPG	3607	3873
Wood	4728	4936

3.2 ENERGY CONSUMPTION DATA

Total residential energy consumption in the U.S. has been declining in recent years, as shown in Table 3.2. Occupants of manufactured homes consumed

TABLE 3.2. Energy Consumption Data

Parameter	April 1980 - March 1981 ^(a)		April 1982 - March 1983 ^(b)	
	Manufactured Homes	Other Single-Family Detached Homes	Manufactured Homes	Other Single-Family Detached Homes
Total in-home energy consumption, quadrillion Btu	0.39	6.61	0.27	6.04
Total energy consumption/household, million Btu	84	125	72	112
Consumption by fuel, quadrillion Btu				
Natural gas	0.11	3.59	0.08	3.34
Electricity	0.15	1.86	0.11	1.76
Fuel oil	0.05	0.90	0.03	0.71
LPG	0.08	0.26	0.05	0.23
Average heated area household, sq ft ^(c,d)	809	1,784	846	1,717
Btu/sq ft heated floor area	103,800	70,100	85,100	65,200

(a) U.S. Bureau of the Census 1984, Table 985.

(b) U.S. EIA 1984b.

(c) U.S. EIA 1982.

14% less total energy from April 1982 through March 1983 than they did for the period from April 1980 through March 1981. For other single-family detached home occupants, the decline was 10%. Electricity consumption per household in manufactured homes dropped from 10,800 kwh in 1978 to 8,700 kwh in 1982, and consumption in other single-family detached homes dropped from 10,900 kwh to 9,600 kwh (U.S. EIA 1984b).

Manufactured home households consume less energy per household than do occupants of other single-family detached homes. The reason is primarily that manufactured homes have, on the average, less than half the heated square feet of single-family detached homes (Table 3.1). Manufactured home occupants, however, consume more total energy per heated square foot than do occupants of

other single-family detached homes, as shown in Table 3.2. In the April 1980 - March 1981 period, manufactured home households consumed 48% more energy per heated square foot than households in site-built single-family detached homes. For the April 1982 - March 1983 period, this percentage dropped to 31%. Possible reasons for the drop are that the percentage of total manufactured homes built prior to the HUD 1976 construction standards is declining fairly rapidly; the percentage of new manufactured homes with extra-cost conservation packages is probably increasing; and since manufactured home households have lower median incomes (Table 2.8) than other single-family home households, they are more likely to reduce comfort levels to save money.

Even though manufactured home households consume less energy on the average than households in other single-family detached homes (Table 3.2), the amount spent on energy by manufactured home households is a higher percentage of family income, as shown in Table 3.3. This higher percentage reflects the lower household income of manufactured home occupants.

TABLE 3.3. In-Home Energy Expenditures Related to Household Income
(April 1982 - March 1983) (U.S. EIA 1984b)

<u>Home Type</u>	<u>Average Total Expenditure Per Household, \$</u>	<u>Expenditure as % of Median Income of Households Living in Structure Type</u>
Manufactured	861	6
Other single-family detached	1120	5

4.0 REVIEW OF LITERATURE ON MANUFACTURED HOME ENERGY EFFICIENCY AND SIMULATED VERSUS MEASURED ENERGY DATA

The purpose of this chapter is to briefly review publicly available literature relating to the energy efficiency of manufactured homes. Sixteen studies were examined for this review. Highlights from each of the 16 studies are included in the reference synopses in Appendix A. The study numbers are referred to in the discussion that follows and are listed in Table 4.1. The studies were found during an extensive computer-assisted literature search for reports and articles related to the energy efficiency of manufactured homes.

The material that follows is divided into three sections. Section 4.1 covers literature related to possible changes in existing thermal protection standards for manufactured homes. Section 4.2 covers literature that does not result from standards development. Section 4.3 discusses the comparison between actual measured energy consumption data and simulated data from predictive models of energy consumption. This comparison information addresses the validity of using simulated energy consumption data in this study.

4.1 LITERATURE RELATED TO POSSIBLE CHANGES IN EXISTING FEDERAL REGULATIONS

Much of the recent literature on manufactured home energy efficiency has related to possible changes and additions to federal thermal efficiency standards. Federal agencies involved in the possible changes include the U.S. Department of Housing and Urban Development (HUD), the Farmer's Home Administration (FmHA), and the U.S. Department of Energy (DDE).

4.1.1 Department of Housing and Urban Development

As discussed in Chapter 2, thermal protection requirements in Title VI (MHCSS) have been in effect since June 1976. Since then, HUD has sponsored a variety of research projects related to the quality and durability of manufactured homes, including potential changes in thermal protection requirements. A formal proposal to amend the existing regulations, including a proposal requiring manufacturers to offer consumers improved thermal protection, was published in the Federal Register (August 16, 1983, p. 37170).

TABLE 4.1. Literature That Discusses the Energy Efficiency of
Manufactured Homes^(a)

Study No.	Title
A.1	Optimum Thermal Insulation for Manufactured Homes
A.2	Comparison of Manufactured Housing Thermal Characteristics
A.3	Energy Expenditures and Conservation in Mobile Homes
A.4	Raising the Energy Efficiency of Manufactured Housing
A.5	1. Affordable Manufactured Housing Through Energy Conservation: A Guide to Designing and Constructing Energy Efficient Homes 2. Using the Slide Rule and Modifiers
A.6	Benefits of Energy Efficient Structures
A.7	Instrumentation for Side-by-Side Testing of the Energy Attributes of Mobile Homes
A.8	1. Technical Support Documentation for Proposed Modifications to Sub- part F of the Manufactured Home Construction and Safety Standards 2. Cost/Benefit Analysis of Mobile/Manufactured Home Regulations in Support of a Regulatory Impact Analysis
A.9	An Analysis of Energy Conservation Options for Manufactured Homes
A.10	Economic Cost-Benefit Analysis of Mobile Home Improved Thermal Performance
A.11	Mobile Home Heating, Cooling and Fuel Burning Systems
A.12	Field Validation of Energy Conservation Specification on Ten Test Homes Through a Metering Program
A.13	Phase-Two Report for the Development of Energy-Performance Standards for New Buildings, Task Report: Mobile Homes
A.14	Engineering-Economic Analysis of Mobile Home Thermal Performance
A.15	The Thermal Performance of a Two-Bedroom Mobile Home
A.16	Passive Solar Manufactured Buildings: Design, Construction and Class B Results

(a) See Appendix A.

The two supporting documents principally relied on by HUD in proposing changes to the thermal protection requirements are cited in Study A.8. Other studies that relate to the proposed changes in the HUD thermal requirements are A.1, A.6, A.10, A.11, and A.14. Study A.1 was recently prepared for the Manufactured Housing Institute, a trade organization. This study generally supports the new thermal requirements for manufactured homes proposed by HUD and concludes that stricter requirements cannot be economically justified. In contrast, Study A.6, prepared by Duke Power Co., Study A.10, prepared by Technology and Economics, Inc., and Study A.14, prepared by Oak Ridge National Laboratory, found that thermal protection requirements beyond those proposed by HUD can be economically justified. The different results are likely attributable to different assumptions about incremental construction costs, resulting energy savings, future energy price increases, and appropriate discount rate. For example, Study A.1 used a 14% discount rate and a 2% fuel escalation rate. Study A.10 used discount rates of 2%, 5%, and 7%, and fuel cost escalation rates of 3% and 5%.

Study A.11 was prepared for HUD by Science Applications Inc. (SAI) to determine if two typical manufactured homes actually met the existing thermal requirements and to test their heating and air conditioning equipment. Although the homes technically met the requirements, numerous deficiencies in equipment were found. These included oversized and noisy furnaces and air conditioners and poorly located duct registers and thermostats, resulting in significant temperature variations within the homes.

4.1.2 Farmer's Home Administration

The Farmer's Home Administration will also be issuing thermal requirements for manufactured homes in the near future. The Rural Housing Amendments of 1983 to the Housing Act of 1949 direct FmHA to establish energy conserving requirements. The agency is considering adopting the same requirements for manufactured homes as it currently has for site-built homes. The standard for site-built homes includes five climate zones and requires significantly more insulation than the current HUD manufactured home requirements. Study A.2 is a recent report that examines the impact on the manufactured home industry of applying FmHA's site-built home thermal efficiency standards to manufactured

homes. The authors conclude that such an application would not cause significant problems. Moreover, the authors found that many manufactured home designs available today already meet the FmHA thermal efficiency standard for site-built homes.

4.1.3 Department of Energy

The Department of Energy has also sponsored work on manufactured home energy efficiency. The early work was in support of the Energy Conservation Standards for New Buildings Act of 1976, which directed DOE to prepare energy performance standards for new buildings. The law was subsequently amended to require preparation of voluntary energy guidelines rather than standards. Study A.13 was prepared when mandatory performance standards were still required. The authors developed two prototype manufactured homes and measured potential energy savings and incremental construction, shipping, and siting costs over current design practices. No estimate of the cost-effectiveness or net economic benefits of the prototype designs was made.

Study A.5 was prepared by Steven Winter Associates for DOE in response to the amended Act's directive that DOE prepare voluntary energy guidelines for new buildings. The report and accompanying slide rule provide a convenient way to estimate the cost-effectiveness of alternative energy conservation measures for single- and double-wide manufactured homes in various climatic regions. Study A.9, also prepared by Steven Winter Associates, was a predecessor to Study A.5 and focused on methods to determine cost-effective energy conservation features for manufactured homes.

4.2 OTHER LITERATURE

The focus of this section is literature related to manufactured home energy efficiency developed apart from proposed changes in federal energy efficiency standards. The dividing line for literature that does and does not result from standards development is not sharp because all of the literature at least indirectly affects or results from the regulatory process.

Several studies have found that existing construction practices detract from the energy efficiency of manufactured homes. In addition to the work by

SAI previously discussed, Study A.15, by the National Bureau of Standards (NBS), found that the natural gas furnace in a factory-built manufactured home was considerably oversized, resulting in a significant increase in seasonal energy consumption. Other findings from the NBS study included the following:

- carefully fitted wall insulation that fully occupies the available space should be used to reduce heat loss due to convective air currents such as those found in the test home
- poorly sealed interior windows result in excessive air leakage and window condensation.

Study A.4 also cites existing shortcomings in manufactured home construction practices and discusses potential improvements, such as incorporation of certain manufactured home construction practices used in Sweden, increase in thermal mass, and use of rooftop solar collectors.

Study A.3 collected a variety of energy consumption data on manufactured homes in the TVA service area and socioeconomic information on the home occupants. The findings can be compared to the national data discussed in Chapters 2 and 3. Manufactured homes in the TVA service area are somewhat smaller and older than the national average. These TVA-area households consume 50% more electricity per square foot than do households in other single-family homes, which is also above the national average. The average household income of TVA-area manufactured home occupants is 61% of other single-family home households. Only 8% of manufactured home owners have requested a free home energy audit from TVA, compared to 30% of other single-family home owners.

4.3 COMPARISON OF MEASURED AND SIMULATED ENERGY CONSUMPTION DATA

Very little information is currently available that compares actual energy consumption in occupied or unoccupied manufactured homes to simulated consumption as estimated by a building energy use model. The only documents found to date that make this comparison are Study A.12, by McBride; Study A.15, by NBS; and Study A.16, by the Solar Energy Research Institute (SERI). McBride found that actual energy consumption was somewhat less than predicted consumption. He attributed this result to interactions among energy conservation measures

that could not be estimated with a simplified energy consumption model. NBS monitored two manufactured homes and found measured and predicted heat loss to be quite close. NBS noted that though their predicted heat loss calculations included allowances for interior furnishings and storage areas, if standard ASHRAE procedures had been used without these allowances, predicted heat loss would have exceeded measured loss. Study A.4, by Mills, presents data on monitored and simulated manufactured home energy consumption; however, there are no comparisons of monitored and simulated data for the same house. The SERI report compares data on a HUD-code manufactured home built to minimum thermal standards with one built with extra energy conservation measures. The study indirectly compares simulated and measured energy consumption. The data suggest that actual consumption exceeds predicted consumption by a factor of 2 to 3. This appears to be due to an actual infiltration rate over twice the 0.5 air change per hour predicted by the author.

A number of studies have compared measured and simulated energy consumption data for site-built buildings. A recent paper by Wagner (1984) assembles and compares the results of about 25 such studies, comprising about 100 simulations of building energy use performed under 18 models. Individual studies compared data from 1 to 243 buildings. Wagner found that differences between predictions and measurements in most of the studies were within a range of $\pm 20\%$ for both occupied and unoccupied buildings.

It could be assumed that comparison of simulated and measured data for manufactured homes would also be within the $\pm 20\%$ range, simply because manufactured homes are just another building form. However, the construction deficiencies discussed in Section 4.2, the infiltration problem noted above, and the fact that manufactured home occupants consume an average of 31% more energy per heated square foot than do site-built home occupants (Table 3.2) may make simulation of actual energy consumption more difficult. In the McBride and NBS studies, though, simulated data were within 20% of the measured energy consumption data.

5.0 REQUIREMENTS OF RESIDENTIAL STANDARDS

This chapter summarizes the energy-related aspects of the following national residential construction standards: for site-built homes, HUD's Minimum Property Standards (MPS), ASHRAE 90A-80, and FmHA's Title V; and for manufactured homes, HUD's Title VI Manufactured Home Construction and Safety Standards, and the additional standards mandated when HUD extended Title II to include manufactured homes. The energy aspects tabulated are insulation, heat loss/gain calculations, duct insulation, window/door requirements, ventilation requirements, heating systems, cooling systems, and hot water systems. The detailed requirements are presented in Appendix B.

5.1 BACKGROUND

5.1.1 HUD's Minimum Property Standards

The MPS is the first set of standards summarized in each section in Appendix B. The MPS is administered by HUD and is used by HUD and the VA as a basis for judging the structural soundness of homes under consideration in their loan assistance and guarantee programs (including Title II). The 1981 MPS Handbook, the reference used for the following tabulations, contains the most recent compilation of all the MPS guidelines.

5.1.2 ASHRAE 90A-80

The American Society of Heating, Refrigerating and Air Conditioning Engineers' ASHRAE 90A-80 is one of the most widely used set of energy standards for site-built homes. ASHRAE 90A-80 has been codified in the Council of American Building Officials' "Model Energy Codes." ASHRAE is currently in the process of updating their energy standards for site-built homes.

5.1.3 FmHA Title V

The FmHA requires that homes under consideration for the loan assistance programs mandated by Title V meet the specifications of HUD's MPS, along with additional standards promulgated by the FmHA. The FmHA standards summarized in this chapter pertain to site-built homes and to manufactured homes insured under Title V until FmHA issues new standards. The site-built FmHA standards

have been considered for both site-built and manufactured homes analyzed in this study. An FmHA instructional guide entitled, "Thermal Performance Construction Standards," published May 5, 1980, was the source of the information presented in Appendix B. The FmHA energy standards have not been revised since the publication of the instructional guide.

5.1.4 HUD Title VI (Manufactured Home Construction and Safety Standards)

In the early 1970s, the federal government sought to establish national standards for the construction of manufactured homes in response to the large number of fires in manufactured homes and the large number of complaints concerning construction. In 1974, HUD published Title VI, "Manufactured Home Construction and Safety Standards." Changes to Title VI were proposed in 1983; however, only standards concerning indoor air quality and safety have been approved. The proposed 1983 changes to Title VI are included in Appendix B for comparison.

5.1.5 HUD Title II-E

In 1983 HUD extended the loan assistance programs mandated by Title II of the Federal Housing Act to manufactured homes permanently attached to a foundation. In extending these programs, HUD specified several requirements that the manufactured homes must meet to be approved for assistance. Homes under consideration for Title II assistance must not only meet the requirements of the Manufactured Home Construction and Safety Standards, with which every manufactured home must comply, but also the additional Title II HUD requirements. These additional standards are listed under Title II-E in Appendix B.

5.2 COMPONENT REQUIREMENTS

5.2.1 Insulation (Section B.1)

As shown in Section B.1 of Appendix B, the MPS, ASHRAE 90A-80, and FmHA Title V standards provide extensive detail on insulation requirements for walls, roofs, ceilings, foundations, walls below grades, floors over unheated crawl spaces, and slabs-on-grade floors for site-built homes. For manufactured

homes, Title VI and Title II-E simply specify an overall U-value on a zone-by-zone basis for the U.S. (see Figures 5.1 and 5.2). As indicated, the changes proposed to the U-values in Title VI would make those values equal to the requirements in Title II-E.

The U-values for walls and ceilings/roofs for the MPS, ASHRAE 90A-80, and FmHA Title V standards are not directly comparable, since only the ASHRAE 90A-80 calculations consider U-values for windows and doors.

In general, the ASHRAE 90A-80 standard allows more flexibility in calculating U-values for the walls and ceilings/roofs of site-built homes, since the U-value level can be obtained from a graph based on specific numbers of heating degree days (see Figures B.1 and B.2, Section B.1.2). In the MPS and FmHA Title V standards, the U-values for walls and ceilings/roofs are based on four explicit ranges of heating degree days.

FIGURE 5.1. Title VI Zones

FIGURE 5.2. Title II-E Zones

The MPS, ASHRAE 90A-80, and FmHA Title V standards each have U-values for walls below grade and floors over unheated crawl space and have R-values for slabs-on-grade. The MPS and FmHA standards have identical requirements for site-built homes with a slab-on-grade floor or foundation walls below grade.

5.2.2 Heat Loss/Gain Calculations (Section B.2)

The MPS, ASHRAE 90A-80, and Title VI standards are similar in that 1) each allows the heat loss/gain calculations to be made in accordance with the procedures described in the ASHRAE Handbook; 2) the indoor design temperatures are almost identical; and 3) the winter/summer design temperatures are set at the 97.5%/2.5% design values listed in the ASHRAE Handbook. Proposed changes to Title VI, though, would require that the winter outdoor design temperatures be based on the zone in which the home is located (see Section B.2.4).

Air infiltration heat loss calculations are not specified in the MPS, Title V, or Title II-E standards. ASHRAE 90A-80 calls for this calculation to

be made in accordance with the procedures contained in the ASHRAE Handbook, while Title VI has a simple formula for calculating air infiltration. The proposed changes to Title VI include a modification to infiltration heat loss calculation.

5.2.3 Duct Insulation (Section B.3)

The MPS and ASHRAE 90A-80 standards have requirements for insulating heating ducts in unconditioned spaces. The ASHRAE standard allows for more design flexibility for the insulation since the requirement for the R-values of the insulation is a function of the temperature difference between the air duct and the duct surface, whereas the MPS calls for a 2 in. flexible or 1 in. thick rigid insulation of the ducts regardless of the temperature differences. In the Title VI standards, heating ducts must be insulated with R-4 insulation if the duct is exposed to the outdoors.

5.2.4 Window/Door Requirements (Section B.4)

Only the ASHRAE 90A-80, FmHA's Title V, and HUD's Title VI standards provide specifications for limiting air infiltration around doors and windows. These specifications are roughly similar, though the Title VI requirement allows more air infiltration around doors than the other standards. Title VI does require storm windows for homes in HUD Title VI Zones II and III (see Figure B.1).

5.2.5 Required Ventilation (Section B.5)

The MPS provides detail on a room-by-room basis for natural ventilation and mechanical air changes. As noted in Section B.5.2, ASHRAE Standard 62-73 provides the American Society of Heating, Refrigerating and Air Conditioning Engineers' requirements for home ventilation. None of the other standards specifies ventilation requirements.

5.2.6 Heating Systems (Section B.6)

ASHRAE 90A-80 provides a standard for the minimum steady-state combustion efficiencies for forced air and gravity furnaces of 74% and 69%, respectively. Electric heat pumps are presently to have a minimum coefficient of

performance of between 1.8 to 2.7, depending on the temperature of the outside air. Water source heat pumps must have a coefficient of performance of 3.0.

Title VI states that as of January 1, 1977, the maximum flue loss for gas and oil furnaces cannot be more than 25%. Electric heat pumps must have a coefficient of performance of 1.4 to 2.2, depending on the outdoor temperature.

A comparison between ASHRAE's energy efficiency standards for heating systems and the standards contained in Title VI is not possible, since ASHRAE has specifications concerning the coefficient of performance for gas and oil furnaces. The Title VI energy efficiency standards regulate the flue loss for gas and oil furnaces. The outdoor temperatures used for measuring the coefficient of performance of electric heat pumps are different for the ASHRAE standard and Title VI.

In view of DOE's "no standard standard" for appliances, HUD has proposed removing the heating systems standards from Title VI. If this occurs, only the ASHRAE standard will contain specifications for heating system efficiencies.

5.2.7 Cooling Systems (Section B.7)

With respect to cooling systems, the MPS provides standards for the insulation of the refrigerant and chilled water lines, while ASHRAE 90A-80 and Title VI specify efficiencies for the air conditioning systems. Title VI currently requires an overall energy efficiency ratio of 7.2 for cooling systems with a rated capacity of less than 65,000 Btu per hour. Depending on the type of equipment, ASHRAE requires that the energy efficiency ratios for systems range from 7.8 to 9.0.

HUD's response to DOE's "no standard standard" will also affect the inclusion of efficiency ratios for cooling systems in Title VI.

5.2.8 Hot Water Systems (Section B.8)

The MPS and ASHRAE 90A-80 provide standards on the insulation of hot water pipes. ASHRAE 90A-80 and Title VI provide standards for the operating efficiencies of hot water heaters. The standby heat loss and the recovery efficiencies specified in ASHRAE 90A-80 and Title VI standards are similar,

although gas and oil water heaters must have lower standby losses than those contained in Title VI in order to comply with ASHRAE 90A-80.

ASHRAE 90A-80 also calls for an electric ignition system for gas and oil heaters having a pilot input rate exceeding 0.5% of the maximum heater input rate. To conserve hot water, ASHRAE calls for a maximum water discharge rate in showers of 3 gallons per minute.

Again, in view of DOE's "no standard standard," HUD may eliminate the efficiencies specified for hot water heaters in Title VI in the near future.

6.D BUILDING PROTOTYPE DESIGN AND STANDARDS COMPLIANCE

This chapter describes the procedures and calculations used to design a hypothetical single-family detached site-built home and a hypothetical single-section manufactured house that would just meet the criteria of each of the five standards analyzed (FmHA Title V, HUD Title II-E, HUD Title VI, ASHRAE 90A-80, and HUD MPS) in each applicable zone or region of the U.S. The relationships between the standards and the climates analyzed are explained in Section 6.1, and descriptions of the prototypes used in the analysis are presented in Section 6.2. Compliance designs are developed in Section 6.3 for the three standards applicable to manufactured housing and in Section 6.4 for the three standards applicable to site-built housing.

6.1 RELATIONSHIP OF STANDARDS AND CLIMATE ZONES

The energy impacts of the five standards and two housing prototypes analyzed were examined for 13 regions of the U.S. The regions were selected to provide a comprehensive review of each standard. The heating degree days and cooling degree days for these cities, reported in the ASHRAE Handbook of Fundamentals, are listed in Table 6.1. The base for both the heating and cooling degree days is 65°F. The climate zone relationships between the standards and the 13 cities used in the analysis are shown Table 6.2. ASHRAE 90A-80 is not included in Table 6.2, since the specified U-values for the wall, roof, and floor components are a function of heating degree days without any predefined regions grouped by degree days. The cities selected for this analysis cover all the regions defined in Table 6.2 except for Zone III (Alaska) of Title VI, and Zone 1 (less than 1000 heating degree days) of the FmHA standard. In the HUD MPS standard, Region 1 contains climates with less than 2500 heating degree days, Region 2 contains climates with heating degree days between 2500 and 4500, Region 3 contains climates with heating degree days between 4500 and 8000, and Region 4 contains climates with heating degree days greater than 8000.

TABLE 6.1. Heating And Cooling Degree Days for Cities
Used In The Energy Analysis--Base 65°F

<u>City</u>	<u>HDD</u>	<u>CDD</u>
Phoenix	1765	3334
Fort Worth	2405	2500
Fresno	2611	1639
Atlanta	2961	1469
Nashville	3578	1496
Washington, D.C.	4224	1491
Albuquerque	4348	1345
Louisville	4660	1236
New York	4871	1027
Boston	5634	674
Salt Lake City	6052	958
Cleveland	6351	613
Minneapolis	8382	894

TABLE 6.2. Climate Zone Relationship Between Standards and Cities

<u>City</u>	<u>HUD Title VI</u>	<u>HUD Title II-E</u>	<u>FmHA</u>	<u>HUD MPS</u>
Phoenix	I	I	2	1
Fort Worth	I	I	2	1
Fresno	I	I	3	2
Atlanta	I	I	3	2
Nashville	I	I	3	2
Washington, D.C.	II	II	3	2
Albuquerque	I	I	3	2
Louisville	II	II	4	3
New York	II	II	4	3
Boston	II	II	4	3
Salt Lake City	II	II	5	3
Cleveland	II	II	5	3
Minneapolis	II	III	5	4

6.2 DESCRIPTION OF BUILDING PROTOTYPES

The selection of building prototypes was based upon choices available in existing data bases. The existing data bases selected contain the results of energy simulations using the computer program DOE 2.1 for a wide range of insulation packages and other conservation measures for 44 regions of the country. These data bases were developed for DOE for the Building Energy Performance Standards Program and were recently refined for use in the Federal Residential Standards Project.

The seven site-built prototypes are as follows: a ranch house, an end unit of a townhouse, a mid-unit of a townhouse, a two-story house, a split-level house, an end unit of an apartment house, and a mid-unit of an apartment house. The manufactured housing prototypes are single-section and multi-section units. Two prototypes, the single-section manufactured house and the one-story ranch house (or single-family detached house) were selected for this interim analysis. The ranch house was selected for the site-built prototype since it most closely resembles the manufactured housing prototype in terms of shell area and floor area. In the second stage of the analysis, the multi-section prototype will be included in the analysis.

The specifications for the single-section manufactured house were based on typical designs documented by Steven Winter Associates and are meant to depict a typical manufactured home. The prototype is 13 ft, 8 in. wide by 66 ft long by 7 ft, 6 in. high (floor to ceiling). Gross floor area is therefore 902 sq ft and the glazing area is 98 sq ft, about 11% of gross floor area. Constructions of specific components are described in Section 6.3.

The single-family detached house prototype is 55 ft by 28 ft with 8 ft high ceilings. The building design and size reflect average characteristics reported by a National Association of Home Builders' survey. Gross floor area is 1540 sq ft, and the glazing area is 231 sq ft, about 15% of gross floor area.

The building shell design parameters for the hypothetical manufactured and site-built prototypes developed to meet each standard were based on two criteria. First, common building practices were considered to ensure realistic

designs and combinations of conservation measures. When building designs required for the standard being analyzed could not be obtained from use of common building shell combinations, alternative combinations were used if the materials were available from most manufacturers. The second criteria considered the cost of the building components. If multiple insulation combinations appeared reasonable, the less expensive alternatives were used.

Only variations in envelope insulation levels and window configuration were ultimately considered in analysis of the standards. Three levels of infiltration were included in the energy simulations (0.4, 0.7, and 1.0 air changes per hour). However, the infiltration rate was set constant at 1.0 air changes per hour and had no effect on heating and cooling loads in the analysis of the standards. The infiltration level was not changed, since the factors affecting infiltration levels are not covered in sufficient detail by any of the standards to allow for a reasonable estimation of the differences in infiltration loads.

In addition, while duct insulation and the U-value of the door were included in the energy base case of the energy simulations, changes in duct and door insulation were not modeled or reported in the data bases. Therefore, these factors were not included in the comparison of the standards.

Thus four variables were manipulated in each design: roof/ceiling construction, wall construction, floor construction, and window configuration. Additional detail on the construction of the roof, wall, and floor components is given in the next two sections.

6.3 COMPLIANCE FOR THE MANUFACTURED HOUSE

The FmHA, HUD Title VI, and HUD Title II-E standards were applied to the prototypical single-section manufactured house in the 13 cities previously listed. The FmHA standard used for this analysis was assumed to be identical for both manufactured and site-built housing. The 13 cities cover four zones (2 through 5) as defined by FmHA, two Title VI zones (I and II), and three Title II-E zones (I, II, and III), for a total of nine designs.

The design compliance procedure for the FmHA standard differs from both the Title VI and Title II-E standards. The FmHA standard has maximum U-value requirements for each component of the envelope: roof, walls, floor, and glazing. In addition, the FmHA U-value requirements do not account for framing, whereas the other two standards do. The design process involved choosing the lowest insulation level for each individual component for which the corresponding U-value did not exceed the limit imposed by the standard for that component.

Title VI and Title II-E standards specify a maximum overall envelope U-value with no requirements for the U-value of any particular component, except windows, which must be double- or single-paned with storm windows in Zones II and III. A poorly insulated roof, for example, could be compensated for with highly insulated walls and floors so that the overall building would still comply with the standard. Clearly, a number of combinations may exist that would meet the requirements for a particular location. Therefore, the correct combination to use may depend on the manufacturer and the manufacturer's construction practices and cost of materials. The designs selected for this analysis reflect the reasonableness and cost criteria discussed earlier.

The resulting designs for each standard, by city, are presented in Table 6.3. The nominal R-values of the insulation and type of window are shown in these tables. Additional descriptions of the construction layers and the calculation of overall U-values follow.

It is important to note that the range of the data base constrained the selection of the manufactured housing prototype characteristics in Table 6.3 for a few cases related to the FmHA standard. Adjustments were necessary to ensure that the prototype design reflected realistic construction practices.

All three standards either require or allow the use of ASHRAE's procedures for heat gain/loss calculations. Therefore, the ASHRAE techniques were used to calculate the U-values of the various roof, wall, and floor constructions. It should be noted that the procedures used to define U-values differ from those used to input construction layers in the DOE 2.1 simulation code. As a consequence, the U-values shown in Tables 6.4 through 6.6 will differ slightly from those used in the energy simulations. Where possible, R-values of specific

TABLE 6.3. Manufactured Prototype Designs

City	Standard	Roof Insul. R-Value	Wall Insul. R-Value	Windows/ Sash ^(a)	Floor Insul. R-Value
Phoenix	FmHA	R-22	R-19	2,AL	R-11
	Title VI	R-7	R-7	1,AL	R-7
	Title IIE	R-7	R-11	1,AL	R-7
Fort Worth	FmHA	R-22	R-19	2,AL	R-11
	Title VI	R-7	R-7	1,AL	R-7
	Title IIE	R-7	R-11	1,AL	R-7
Fresno	FmHA	R-30	R-19	2,AL	R-19
	Title VI	R-7	R-7	1,AL	R-7
	Title IIE	R-7	R-11	1,AL	R-7
Atlanta	FmHA	R-30	R-19	2,AL	R-19
	Title VI	R-7	R-7	1,AL	R-7
	Title IIE	R-7	R-11	1,AL	R-7
Nashville	FmHA	R-30	R-19	2,AL	R-19
	Title VI	R-7	R-7	1,AL	R-7
	Title IIE	R-7	R-11	1,AL	R-7
Washington, D.C.	FmHA	R-30	R-19	2,AL	R-19
	Title VI	R-7	R-11	2,AL	R-7
	Title IIE	R-19	R-11	2,AL	R-19
Albuquerque	FmHA	R-30	R-19	2,AL	R-19
	Title VI	R-7	R-7	1,AL	R-7
	IIE	R-7	R-11	1,AL	R-7
Louisville	FmHA	R-30	R-19	3,AL	R-19
	Title VI	R-7	R-11	2,AL	R-7
	Title IIE	R-19	R-11	2,AL	R-19
New York	FmHA	R-30	R-19	3,AL	R-19
	Title VI	R-7	R-11	2,AL	R-7
	Title IIE	R-19	R-11	2,AL	R-19
Boston	FmHA	R-30	R-19	3,AL	R-19
	Title VI	R-7	R-11	2,AL	R-7
	Title IIE	R-19	R-11	2,AL	R-19
Salt Lake City	FmHA ^(b)	R-33	R-24	3,AL	R-19
	Title VI	R-7	R-11	2,AL	R-7
	Title IIE	R-19	R-11	2,AL	R-19
Cleveland	FmHA ^(b)	R-33	R-24	3,AL	R-19
	Title VI	R-7	R-11	2,AL	R-17
	Title IIE	R-19	R-11	2,AL	R-19
Minneapolis	FmHA ^(b)	R-33	R-24	3,AL	R-19
	Title VI	R-11	R-11	2,AL	R-7
	Title IIE	R-14	R-19	2,AL	R-11

(a) Number of glazings and sash type (aluminum [AL]).

(b) Though R-33 does not meet the FmHA roof requirements for Region 5, it is the highest R-value available in the data base. To compensate, the wall R-value was increased from the required R-19 to R-24, resulting in a similar overall envelope U-value.

TABLE 6.4. Wall Heat Flow Paths for a Nominal R < 19

Description	(15%) R-Value at Framing	(85%) R-Value at Insulation
Outside air film	0.17	0.17
Aluminum siding	0.016	0.016
Polystyrene sheath	R _s	R _s
Studs	R _w	--
Insulation	--	R _i
Paneling	0.195	0.195
Inside air film	0.68	0.68
Total R	1.061+R _s +R _w	1.061+R _s +R _i
Overall U	$= \left[\frac{0.15}{1.061+R_s+R_w} \right] + \left[\frac{0.85}{1.061+R_s+R_i} \right]$	

TABLE 6.5. Wall Heat Flow Paths for a Nominal R > 19

Description	(11%) R-Value at Framing	(88.2%) R-Value at Insulation	(0.08%) R-Value at Headers
Outside air film	0.17	0.17	0.17
Aluminum siding	0.016	0.016	0.016
Polystyrene sheath	R _s	R _s	R _s
Studs/headers	R _w	--	R _h
Insulation	--	R _i	--
Paneling	0.195	0.195	0.195
Inside air film	0.68	0.68	0.68
Total R	1.061+R _s +R _w	1.061+R _s +R _i	1.061+R _s +R _h
Overall U	$= \left[\frac{0.11}{1.67+R_s+R_w} \right] + \left[\frac{0.882}{1.67+R_s+R_i} \right] + \left[\frac{0.008}{1.67+R_s+R_h} \right]$		

materials and layers identical to those used in the simulations were used. It should also be recognized that the construction details discussed in the following paragraphs are based on assumptions about average design practices; they do not necessarily represent specific practices. When the exact properties

TABLE 6.6. U-Values Corresponding to Wall Insulation Levels
(refer to Tables 6.4 and 6.5)

Nominal R-Value	Batt R-Value (Ri)	Stud R-Value (Rw)	Sheath R-Value (Rs)	Header R-Value (Rh)	U-Value of Wall (VI and II-E)	U-Value of Wall (FmHA) (a)
7	7	3.125	0	--	0.1413	0.1241
11	10	3.125	0	--	0.1127	0.0904
13	10.5	3.125	0	--	0.1094	0.0865
18	13	4.375	5	--	0.0590	0.0525
19	19	6.875	0	4.375	0.0593	0.0498
24	19	6.875	5	4.375	0.0445	0.0399

(a) Neglecting heat flow through framing.

used in the data base development were not known, values were taken from the ASHRAE Handbook of Fundamentals.

Wood frame construction was assumed for the prototype walls as follows (outside to inside): vertical siding, 0.019 in. aluminum with medium yellow paint; stud framing with 1 in. by 2 in. rail at midpoint; 1 in. by 4 in. top and bottom plates and 2 in. by 4 in. double headers; glass fiber insulation, kraft faced; and 5/32 in. paneling. For insulation R-values less than R-19, the framing consists of 2 in. by 3 in. studs at 16 in. o.c. An exception is the R-18 wall, which uses 2 in. by 4 in. studs. In this configuration, the studs and headers account for 15% of the total wall area. Insulation R-values of 19 or greater require 2 in. by 6 in. stud framing at 24 in. o.c. In this case, the studs account for 11% of the wall area, the 2 in. by 4 in. headers account for 0.8%, and the insulation for 88.2%.

Nominal insulation R-values included in the energy data base are R-7, R-11, R-13, R-18 (consisting of R-13 batt plus 1 in. of polystyrene sheathing), R-19, and R-24 (consisting of R-19 batt plus 1 in. of polystyrene sheathing). The construction layers are summarized in Tables 6.4 through 6.6. Table 6.4 includes the R-value for the construction of walls with less than R-19 insulation, and Table 6.5 includes walls with R-19 or greater insulation. Notice that because of the difference in construction, the wall containing a nominal

R-value of 18 (R-13 batt plus R-5 sheathing) has a slightly lower U-value than the wall containing a nominal R-value of 19 (when calculations account for framing).

The roof consists of two major components (roof and ceiling) separated by an air space, the attic. The attic is relatively small, causing compression of insulation at the eaves in some cases. This affects the thermal characteristics of the batt and requires adjustment of the R-value in calculating the roof U-value. Since the attic is small, the roof/ceiling can be modeled as a single section, with the attic as an air layer. From outside to inside, the assumed construction is as follows: galvanized sheet steel; 2 in. by 2 in. bow trusses at 16 in. o.c.; air space (attic); glass fiber batt insulation; 2 in. by 2 in. ceiling joists (the bottom portion of the bow trusses); and 1/2 in. panel ceiling board (modeled as particle board). The nominal insulation R-values included in the data base are R-7, R-11, R-14, R-19, R-22, and R-30.

The roof/ceiling construction required several special considerations. First, the presence of the 2 in. by 2 in. bow trusses at the top of the attic (adjacent to steel roofing) was neglected. The effect of the wood below the attic was included, but required special treatment. Since the trusses are only 1-1/2 in. deep, the insulation usually laps over and covers the wood. However, the insulation over wood is compressed more than that between the trusses and has a smaller R-value. This is reflected in the third column of Table 6.7. Also, as the thickness of the insulation increases, the thickness of the air layer above it decreases, necessitating the use of a different R-value for the air layer for each batt thickness considered.

Another problem is the compression of the insulation at the eaves of the structure. The amount of compression depends on the thickness of the batt. When insulation with a nominal R-value of 22 or greater is used, the assumed attic construction is changed to allow more space between the ceiling and roof. Considering the insulation compression at the edge of the attic, an average R-value was used to represent the entire roof area. These compression-adjusted R-values are identical to those used in the development of the energy data base. Tables 6.7 and 6.8 summarize the construction of the roof/ceiling and the U-values resulting from the various nominal insulation R-values.

TABLE 6.7. U-Values Corresponding to Roof Insulation Options
(refer to Table 6.8)

Nominal R-Value	Batt R-Value (Ri)	R-Value above Wood (Ri/w)	R-Value of Air (Ra)	U-Value of Ceiling (Title VI and II-E)	U-Value of Ceiling (FmHA) (a)
7	7	6.99	1.22	0.1017	0.1033
11	11	10.73	1.22	0.0723	0.0731
14	13.89	13.33	1.098	0.0604	0.0608
19	17.96	15.04	0.915	0.0494	0.0492
22	21.74	20.67	1.037	0.0411	0.0413
30	27.64	24.18	0.732	0.0337	0.0335
33	29.11	24.83	0.621	0.0323	0.0321

(a) Neglecting heat flow through trusses.

TABLE 6.8. Roof/Ceiling Heat Flow Paths

Description	(10%) R-Value at Trusses	(90%) R-Value at Insulation
Outside air film	0.17	0.17
Steel roofing	0.016	0.016
Air space	Ra	Ra
Insulation	Ri/w	Ri
Trusses	1.88	--
Ceiling board	0.6627	0.6627
Inside air film	0.61	0.61
Total R	3.3387+Ra+(Ri/w)	1.4587+Ra+Ri
Overall U	$= \left[\frac{0.10}{3.3387+Ra+(Ri/w)} \right] + \left[\frac{0.90}{1.4587+Ra+Ri} \right]$	

The assumed floor construction, from outside to inside, is as follows:
1/16 in. bottom board, asphalt impregnated; floor joists at 16 in. o.c., trans-
verse; batt insulation fitted between the joists; 5/8 in. particle board; and
padded carpet or vinyl tile. There is also an air space, which is above the

insulation in some places and below in others. The thickness of the air layer diminishes to zero at the outer edges of the structure (Steven Winter Associates 1983a). Due to the constraints of the energy data base, the floor is assumed to be over a vented crawl space (the home is assumed to be unskirted and not on a concrete foundation). Title VI does not specify any foundation type; Title II-E requires that the manufactured housing be mounted on a permanent foundation; and the FmHA standard has different criteria for floors over vented crawl spaces, heated basements, and floors over slabs. These different treatments of foundations may influence the energy budgets of the manufactured housing prototype. The nominal insulation R-values included in the data base are R-4, R-7, R-11, R-14, R-19, R-22, and R-28. U-values for these floor constructions are shown in Tables 6.9 and 6.10. For all cases except R-28, the framing consists of 2 in. by 6 in. joists at 16 in. o.c. For R-28, 2 in. by 8 in. joists at 16 in. o.c. are required.

Modeling the floor construction is complicated because of upwardly sloping outer edges and variations in the location of the air space with respect to the

TABLE 6.9. Floor Heat Flow Paths

<u>Description</u>	<u>(10%) R-Value at Joists</u>	<u>(90%) R-Value at Insulation</u>
Outside air film	0.17	0.17
Bottom board	0.125	0.125
Air space	--	1.22
Insulation	--	Ri
Floor joists	Rw	--
Particle board	0.66	0.66
Carpet	2.08	2.08
Inside air film	0.92	0.92
Total R	3.955+Rw	5.175+Ri
Overall U	$= \left[\frac{0.10}{3.955+Rw} \right] + \left[\frac{0.90}{5.175+Ri} \right]$	

TABLE 6.10. U-Values Corresponding to Floor Insulation Options
(refer to Table 6.9)

Nominal R-Value (Ri)	Joist R-Value (Rw)	U-Value of Floor (Title VI and II-E)	U-Value of Floor (FmHA) (a)
4	6.875	0.1073	0.1090
7	6.875	0.0832	0.0821
11	6.875	0.0649	0.0618
14	6.875	0.0562	0.0522
19	6.875	0.0465	0.0414
22	6.875	0.0424	0.0368
28	9.167	0.0346	0.0301

(a) Neglecting heat flow through joists.

batt insulation. The heat flow paths were simplified, as depicted in Table 6.9. This is very similar to the assumption used in the development of the energy data base.

Exterior doors have rough openings of 32-1/2 in. by 76-1/2 in. and are constructed of honeycomb hollow core with metal skins. The two exterior doors comprise 1.12% of the total envelope area. The overall U-value, including the air film resistances, is 0.59 Btu/(hr)(sq ft)(°F). It is noted that FmHA standards require storm doors in climates that have more than 2500 heating degree days. The energy and cost data bases do not include data for storm doors, so they are not included in this analysis.

Roughly 40% of the glazing is assumed to be located on the rear of the manufactured home, and 60% on the front. The energy data base has been designed so that the heating and cooling loads reflect an average of all orientations. No windows are assumed on the ends of the structure. Nine different window configurations are considered in the energy data base (three sash types and either one, two, or three glazings). Sash types included are aluminum, aluminum with thermal breaks, and wood. The double-paned window is assumed to consist of single-paned glass plus an interior storm window. Similarly, triple-paned windows consist of double-paned glass plus an indoor storm window.

6.4 SINGLE-FAMILY DETACHED HOUSE COMPLIANCE DESIGN

The single-family detached (SFD) prototype house design was modified to comply with the FmHA Title V standard, ASHRAE Standard 90A-80, and the HUD Minimum Property Standard for the 13 cities under analysis. Each of these standards has a different approach for calculating compliance designs, although each standard either allows or requires use of ASHRAE procedures for heat gain and loss calculations as defined in the ASHRAE Handbook of Fundamentals. Compliance designs were developed for four of the five FmHA regions and the four HUD MPS regions. Since the ASHRAE standard specifies U-values as a function of heating degree days, each of the 13 cities required development of a design that complied with the local climate. However, many of the designs proved to be identical.

As noted before, the FmHA standard specifies maximum U-values for each of the building's components: ceilings, walls, floors, glazing, and doors. The ASHRAE 90A-80 standard specifies maximum U-values for the overall wall area, roof/ceiling area, and floors. The HUD MPS standard specifies maximum U-values for each of the building's components. However, the calculations of U-values for the FmHA and MPS standards do not include adjustments for the framing or window sash, while the ASHRAE standard requires those adjustments. The compliance designs for each of the standards are shown in Table 6.11.

The wall, floor, and ceiling construction profiles for the single-family detached house prototype were taken from the Lawrence Berkeley Laboratory/ Building Energy Performance Standards data base. The overall U-values for each component are based on construction profiles that include outside sheathing, interior finishes, framing, and sashes. Wall construction characteristics are shown in Tables 6.12 through 6.14.

The layers for the assumed roof/ceiling construction from outside to inside are 1/4 in. asphalt shingles, 1/2 in. plywood, 2 in. by 6 in. rafters, attic air space, insulation and 2 in. by 6 in. joists, 1/2 in. plywood, and 1/2 in. drywall. The overall R-values for the ceiling construction are shown in Table 6.15.

TABLE 6.11. Single-Family Detached Building Design

City	Standard	Roof Insul. R-Value	Walls Insul. R-Value	Windows/ Sash ^(a)	Floor Insul. R-Value
Phoenix	90A	R-19	R-11	1,AL/TB	R-0
	FmHA	R-30	R-19	2,AL	R-11
	MPS	R-19	R-11	1,AL/TB	R-0
Fort Worth	90A	R-19	R-11	2,AL	R-0
	FmHA	R-30	R-19	2,AL	R-11
	MPS	R-19	R-11	1,AL/TB	R-11
Fresno	90A	R-19	R-11	2,AL	R-0
	FmHA	R-30	R-19	2,AL	R-19
	MPS	R-19	R-11	1,AL/TB	R-11
Atlanta	90A	R-19	R-11	2,AL	R-11
	FmHA	R-30	R-19	2,AL	R-19
	MPS	R-19	R-11	1,AL/TB	R-11
Nashville	90A	R-19	R-11	2,AL	R-11
	FmHA	R-30	R-19	2,AL	R-19
	MPS	R-19	R-11	2,AL	R-19
Washington, D.C.	90A	R-19	R-11	2,AL	R-11
	FmHA	R-30	R-19	2,AL	R-19
	MPS	R-19	R-11	1,AL/TB	R-11
Albuquerque	90A	R-19	R-11	2,AL	R-11
	FmHA	R-30	R-19	2,AL	R-19
	MPS	R-19	R-11	1,AL/TB	R-11
Louisville	90A	R-19	R-11	2,AL	R-11
	FmHA	R-30	R-19	3,AL	R-19
	MPS	R-19	R-11	2,AL	R-11
New York	90A	R-19	R-11	2,AL	R-11
	FmHA	R-30	R-19	3,AL	R-19
	MPS	R-19	R-11	2,AL	R-11
Boston	90A	R-30	R-11	2,AL	R-11
	FmHA	R-30	R-19	3,AL	R-19
	MPS	R-19	R-11	2,AL	R-11
Salt Lake City	90A	R-30	R-13	2,AL	R-11
	FmHA	R-30	R-19	3,AL	R-19
	MPS	R-19	R-11	2,AL	R-11
Cleveland	90A	R-30	R-13	2,AL/TB	R-11
	FmHA	R-38	R-19	3,AL	R-19
	MPS	R-19	R-11	2,AL	R-11
Minneapolis	90A	R-30	R-19	2,AL/TB	R-11
	FmHA	R-38	R-19	3,AL	R-19
	MPS	R-19	R-11	2,AL	R-11

(a) The number of glazings and sash type (aluminum [AL] or aluminum with a thermal break [AL/TB]).

TABLE 6.12. R-11 and R-13 Wall Heat Flow Paths

<u>Description</u>	(25%) R-Value at Stud	(75%) R-11 Value at Insulation	(75%) R-13 Value at Insulation
Outside air film	0.17	0.17	0.17
1/8 in. siding	0.61	0.61	0.61
1/2 in. sheathing	1.22	1.22	1.22
Insulation	--	11	13
Stud	4.375	--	--
1/2 in. drywall	0.45	0.45	0.45
Inside air film	0.68	0.68	0.68
Total R	7.50	14.13	16.13
Overall wall R	--	11.57	12.53

TABLE 6.13. R-19 Wall Heat Flow Paths

<u>Description</u>	(20%) R-Value at Stud	(80%) R-Value Insulation
Outside air film	0.17	0.17
1/8 in. siding	0.61	0.61
1/2 in. sheathing	1.22	1.22
Insulation	--	19
Stud (2 x 6 24 o.c.)	6.875	--
1/2 in. drywall	0.45	0.45
Inside air film	0.68	0.68
Total R	10.22	22.13
Overall wall R	17.81	

The energy data base provides data for three foundation types: slab, basement, or vented crawl space. Since the single-family detached house built over a vented crawl space provided the design most consistent with that assumed in the manufactured housing prototype foundation, it was used in this analysis. The R-values used in the data base for the floor over a ventilated crawl space were 14.08 for R-11 insulation and 21.28 for the R-19 insulation. The floor construction characteristics are shown in Table 6.16.

TABLE 6.14. R-24 Wall Heat Flow Paths

<u>Description</u>	(20%) <u>R-Value at Stud</u>	(80%) <u>R-Value at Insulation</u>
Outside air film	0.17	0.17
1/8 in. siding	0.61	0.61
1 in. styrofoam	5	5
Insulation	--	19
Stud (2 by 6 24 o.c.)	6.875	--
1/2 in. drywall	0.45	0.45
Inside air film	0.68	0.68
Total R	13.78	25.91
Overall wall R	22.03	

TABLE 6.15. Ceiling R-Values

<u>Nominal Value of Insulation</u>	<u>Overall R</u>
R-19	21.270
R-30	32.759
R-38	40.901

TABLE 6.16. R-11 Floor Heat Flow Paths

<u>Description</u>	(20%) <u>R-Value at Joist</u>	(80%) <u>R-Value at Insulation</u>	(80%) <u>R-Value at Insulation</u>
Outside air film	0.17	0.17	0.17
Insulation	--	11	19
Joist (2 by 10 16 o.c.)	11.11	--	--
Wood subfloor	0.94	0.94	0.94
Carpet and pad	2.08	2.08	2.08
Inside air film	0.67	0.67	0.67
Total R	14.87	14.87	22.86
Overall floor R	14.89		20.68

7.0 ECONOMIC ANALYSIS METHODOLOGY

The economics of the energy conservation standards were tested with two approaches: life-cycle cost and the relationship between first-year annual energy savings and loan payments. The first test, assessment of life-cycle cost, used standard engineering economics practices and was performed in conformance with DOE's Federal Energy Management Program (FEMP) March 1984 guidelines. The second test mandated by the Act examined whether the increase in the first year's loan payments associated with the added cost of energy conservation features is less than the first year's fuel bill savings associated with those conservation features. The first test is used to examine the overall cost-effectiveness of the standards on the basis of life-cycle costs for owning and operating the house. The second test determines whether the conservation measures produce positive first-year cash flow (neglecting the down payment). Both tests are made from the homeowner's perspective. HUD Title VI is assumed to represent typical minimum practice for manufactured housing, while ASHRAE 90A-8D is considered the base for site-built housing.

7.1 REVIEW OF LIFE-CYCLE COST ASSUMPTIONS

The life-cycle cost measure used in this analysis was the net life-cycle cost, i.e., the difference among design standards. Net life-cycle cost was selected so that the energy savings and associated costs dealt with only the components of the house affected by the standards. The disadvantage of using the net life-cycle cost is that it is not an appropriate measure for comparing dissimilar investments (e.g., conservation options for the single-family detached and the manufactured prototypes), because it provides relative, not absolute, measures of cost-effectiveness.

Naturally, the outcome of the life-cycle cost calculation is strongly influenced by the parameters used in the input. The key parameters are listed in Table 7.1. It is important to note the difference between real and nominal dollars. The analysis was conducted in 1985 constant dollars. Therefore the discount rate and the fuel escalation rates are shown in real terms. The interest rate must be specified in nominal terms, since payments over the

TABLE 7.1. Key Parameters in the Life-Cycle Cost Calculation

<u>Parameter</u>	<u>Value/Source</u>
Real discount rate, %	10
Nominal interest rate on loan, %	13
Annual inflation rate, %	5
Length of loan, years	30
Down payment on loan, %	20
Tax bracket, %	0
Fuel costs	Applicable utility rates
Real fuel escalation rates	FEMP - March 1984

length of the loan are always made in nominal dollars. Each nominal payment must be converted back to 1985 dollars using the annual inflation rate. The discount rate is then used to convert future expenditures, loan payments, and fuel costs to base year dollars.

The selection of the discount rate is always difficult to justify when it is applied to an abstract or average case. Analyses of government energy conservation measures for buildings are typically made with either a 7% or 10% discount rate, as mandated by the Federal Energy Management Program. A 10% discount rate was selected since the Act primarily addressed the needs of lower income residents, and it is often argued that low income people tend to have high discount rates. The higher rate also makes the cost-effectiveness results more conservative.

To check for the sensitivity of the results to the discount rate, the internal rate of return (IRR) was calculated. The IRR is the rate of return that equates the discounted present value of fuel savings and associated change in operation and maintenance costs to the increase in initial investment. The nominal interest rate is based on current rates reported in the Wall Street Journal in January 1985. The down payment on the loan was set at 20% to represent average down payments for conventional loans on new construction. (In 1984 the Federal Home Loan Bank Board average for this class of loans was 21.39%.) It is recognized that this figure does not reflect down payments for nonstandard loans such as those in FmHA and HUD programs. The average down

payment on HUD Section 203B loans is approximately 4%, and the down payment for FmHA loans can be as low as 0%. In this phase of the study the effect of income tax deductions is neglected.^(a) Initial utility rates, discussed in Section 7.2, are current actual rates. Real fuel escalation rate projections are shown in Table 7.2. The escalation rates are the yearly percent increase in fuel prices over the period shown in the column heading.

The calculation of life-cycle cost considered the incremental capital cost for the conservation measures, the operation and maintenance costs, the capital replacement costs, the fuel costs, and credits associated with the salvage value and the interest deduction credits. However, since the standards did not require significantly different infiltration control measures, heating equipment efficiencies, or cooling equipment efficiencies, it was not necessary to

TABLE 7.2. FEMP Residential Fuel Price Escalation Rates (March 1984)

City	Fuel	1985-1990	1990-1995	1995-2000
Minneapolis (Region 5)	Elec	0.35	2.47	3.48
	Gas	5.41	9.11	1.54
Phoenix (Region 9)	Elec	2.42	2.76	3.6
	Gas	6.27	8.72	1.54
Washington, D.C. (Region 3)	Elec	1.38	2.45	3.47
	Gas	4.02	9.36	1.54
Boston (Region 1)	Elec	2.79	2.37	3.44
	Oil	7.49	8.09	1.39
	Gas	4.82	8.98	1.54
Nashville/ Atlanta (Region 4)	Elec	1.47	2.40	3.45
	Gas	5.46	9.56	1.54

(a) However, it can be argued that since the homeowner can deduct interest costs from his or her annual taxes, the associated interest deductions from a higher loan should be used to offset the higher loan cost. The present value of the annual interest payments can be adjusted by the owner's tax bracket to calculate the life-cycle value of the interest deductions. Inclusion of the interest deduction credit would dampen the impact of the increase in the home's cost due to the conservation measures and would make the measures more cost-effective.

consider their associated operation, maintenance, capital replacement, and salvage values. The remaining conservation measures relate to the building's shell and have lifetimes greater than 30 years. Since the shell measures have no identifiable differences in maintenance costs, only the changes in first cost had to be considered. All costs were calculated in real dollars.

7.2 SUMMARY OF ENERGY COST PARAMETERS

Utility rates for the economic analysis are based on actual rates and applicable taxes (as of January 1985) for the cities analyzed. Utility rate information used in the analysis was provided by the local utilities and incorporates information about seasonal charges, block charges, and type of electric service.

In the analysis, all heating energy use is assessed at winter fuel prices, and cooling energy use is assessed at summer electric prices. If the utility has a block rate schedule, the rate used to calculate the fuel costs is the largest block in which the customer is likely to be. Since total electric energy consumption for each prototype is not available, the appropriate block can only be estimated.^(a)

Information on typical yearly energy consumption is available from DOE's Energy Information Administration in the report Residential Energy Consumption Survey: Consumption and Expenditures April 1980 Through March 1981. The report does not present monthly end-use energy consumption information; however, it does provide average fuel bills by income, housing type, and degree days. These data were used for assessing the marginal fuel cost. Energy prices used are shown in Table 7.3.

The fuel cost savings are dependent on the selection of winter heating fuel. While it is recognized that in any location, a variety of heating fuels is used, an attempt was made to identify the predominant heating fuel and equipment for new construction in each region under analysis. Predominant fuel

(a) Due to the lack of information on total electric consumption, it is assumed that increased conservation measures do not result in energy savings that change the marginal cost of electricity.

TABLE 7.3. Marginal Utility Rates (1985 \$/MMBtu)

City	Electricity		Gas	Fuel Oil
	Summer	Winter		
Washington, D.C.	17.8144 ^(a)	17.8144 ^(a)	7.895	
Minneapolis	18.2392	15.7534	5.612	
Phoenix	27.8950	20.0171	5.132	
Nashville	12.9722	12.9722	5.124	
Atlanta	17.3530	17.2586	5.793	
Boston	24.4591	15.6692	6.692	8.2846

(a) Prices for homes not having electric heating. Homes with all electric heating, hot water, and cooling are charged \$18,5909 in the summer and winter.

types for the single-family detached prototype were identified through phone discussions with local utility staff. This information was more difficult to obtain for the manufactured prototype due to the smaller number of new hookups within the metropolitan areas. Furthermore, available data suggest that new units are almost equally split between gas and electric resistance heating. As a result, the analysis was conducted for both gas and electric resistance heating in manufactured housing. It was assumed that both prototypes had electric central air conditioners or heat pumps regardless of location. The winter fuel types used are shown in Table 7.4.

TABLE 7.4. Heating Fuels Used In Economic Analysis

City	Site-Built	Manufactured
Minneapolis	Gas	Gas/elec. resist.
Boston	Fuel oil	Gas/elec. resist.
Washington, D.C.	Elec. (heat pump)	Gas/elec. resist.
Nashville	Elec. (heat pump)	Gas/elec. resist.
Atlanta	Gas	Gas/elec. resist.
Phoenix	Elec. (heat pump)	Gas/elec. resist.

7.3 CONSTRUCTION COST ESTIMATES

A key variable in the analysis of the residential conservation standards is the change in the cost of constructing the house to the different construction standards. The primary data source for the construction costs for the Federal Residential Standards Project was Steven Winter Associates. The data collected for manufactured housing represent manufacturer costs, while the data collected for the site-built prototype represent contractor costs. These cost estimates are based on unit and labor costs derived from Means construction cost publications and phone calls to wholesalers of building materials and manufactured housing.

All construction costs were adjusted here to reflect the cost to the consumer due to changes in the building shell required for building compliance. For site-built housing this adjustment was made by adding 22% to the contractor cost. In addition, the average national sales tax of 3.25% was applied to the total consumer cost. The 22% figure is an average obtained from the National Association of Home Builders. This figure is close to the 20% markup used by the California Energy Commission in developing their standards.

Construction costs used for the shell insulation and window energy conservation measures for the single-family detached prototype are shown in Table 7.5. The cost estimates are based on take-off estimates from the building specifications as modeled in the energy simulations and include material and labor charges. The following take-offs were used to calculate total costs from unit costs: window area--231 sq ft, wall area--1136 sq ft, ceiling and floor area--1540 sq ft, perimeter length--166 linear ft (LF). The cost estimates apply only to the change in costs resulting from changing from one level of a measure to another. For example, the foundation insulation levels do not include foundation preparation costs; instead they reflect the additional cost of the insulation related materials and the labor to install those materials.

Construction costs for the manufactured housing prototype are shown in Table 7.6. These figures also represent costs to the consumer. A multiplier of 2.22 was used for the price markup from the manufactured housing producer to the consumer. This figure was obtained from HUD, based on several of their studies. The national average sales tax of 3.25% was also applied to the manufactured housing costs.

TABLE 7.5. Single-Family Detached Housing Construction Costs to Consumer (1985 dollars)

Ceiling		Wall		Foundation Insulation		Windows	
R-Value	Cost	R-Value	Cost	R-Value	Cost	Type ^(a)	Cost
0	1600.27	0	1792.36	0	0.00	1,AL	1255.78
11	2019.32	11	2117.50	11	463.58	2,AL	1585.46
19	2238.87	13	2192.82	19	698.02	3,AL	2247.81
30	3491.80	19	2480.03	30	1040.18	1,AL/TB	1120.91
38	3794.35	24	2700.75	5 x 2 ^(b)	180.10	2,AT/TB	1774.27
49	4120.40	25	2744.08	5 x 4 ^(b)	360.20	3,AT/TB	3018.06
60	4486.79			10 x 2 ^(b)	342.87	1,WOOD	3842.26
				10 x 4 ^(b)	686.01	2,WOOD	5496.65
						3,WOOD	7501.70

(a) Number of glazings and sash type (aluminum [AL] or aluminum with a thermal break [AL/TB]).

(b) Insulation of perimeter of slab--the first number is the R-value and the second number is the depth in feet.

TABLE 7.6. Manufactured Housing Construction Costs to Consumer (1985 dollars)

Ceiling		Wall		Floor		Windows	
R-Value	Cost	R-Value	Cost	R-Value	Cost	Type ^(a)	Cost
7	804.91	7	1038.82	4	898.55	1/AL	368.76
11	889.84	11	1122.41	7	938.01	2/AL	572.93
14	975.02	13	1251.27	11	1031.23	3/AL	1212.37
19	1083.43	18	2016.00	14	1124.70	1,AL/TB	984.90
22	1232.28	19	1687.68	19	1251.83	2,AL/TB	1189.07
30	1425.46	24	2452.41	22	1421.80	3,AL/TB	1828.51
33	1510.61			28	1810.49	1,WOOD	3514.11
						2,WOOD	5273.82
						3,WOOD	6346.67

(a) Number of glazings and sash type (aluminum [AL] or aluminum with a thermal break [AL/TB]).

To adjust for the regional variation in prices, the Means regional construction cost multipliers for 1984 were used. While these construction multipliers are more applicable for light commercial construction, they were the most applicable of the available adjustment factors. The regional multipliers are shown in Table 7.7.

TABLE 7.7. 1984 Means Regional Cost Multipliers

<u>City</u>	<u>Multiplier</u>
Minneapolis	1.010
Washington, D.C.	0.954
Phoenix	0.977
Atlanta	0.903
Boston	1.048
Nashville	0.845

8.0 ENERGY AND COST ANALYSES

This chapter presents the results of the energy and cost analyses of the five energy conservation standards. The chapter is divided into two sections. Section 8.1 reviews the results of the energy analysis for the 2 prototype houses and 13 cities. The results of the economic analysis are presented and discussed in Section 8.2. For this interim report, the life-cycle cost analysis was completed for 6 of the 13 cities.

8.1 RESULTS OF ENERGY ANALYSIS

The results of the energy analyses of the standards are shown in Table 8.1 for the manufactured home and Table 8.2 for the site-built home. The assumptions and calculations used to obtain these results are described in Chapter 6. These tables show the difference in annual heating and cooling load (in million Btu, or MMBtu) resulting from going from one standard to another.

TABLE 8.1. Summary of Load Reductions for the Manufactured Home (MMBtu/yr)

City	FmHA minus Title VI		FmHA minus Title II-E		Title II-E minus Title VI	
	Heating Load	Cooling Load	Heating Load	Cooling Load	Heating Load	Cooling Load
Phoenix	8.501	8.008	7.842	6.818	0.659	1.190
Fort Worth	11.786	3.793	10.834	3.215	0.952	0.578
Fresno	16.630	4.588	15.499	3.964	1.131	0.624
Atlanta	12.974	1.927	11.765	1.584	1.209	0.343
Nashville	15.308	2.037	13.919	1.684	1.389	0.353
Washington, D.C.	13.659	0.296	4.542	0.048	9.117	0.248
Albuquerque	18.088	3.006	16.482	2.595	1.606	0.411
Louisville	15.922	1.071	9.212	1.050	6.710	0.021
New York	16.755	0.341	6.666	0.553	10.089	-0.212
Boston	20.832	0.217	8.343	0.292	12.489	-0.075
Salt Lake City	21.956	1.535	8.748	1.075	13.208	0.460
Cleveland	19.118	0.262	8.637	0.575	10.481	-0.313
Minneapolis	28.658	0.752	14.324	0.243	14.334	0.509

TABLE 8.2. Summary of Load Reductions for the Single-Family Detached Home (MMBtu/yr)

City	ASHRAE minus MPS		FmHA minus ASHRAE		FmHA minus MPS	
	Heating Load	Cooling Load	Heating Load	Cooling Load	Heating Load	Cooling Load
Phoenix	0.00	0.00	11.87	24.18	11.87	24.18
Fort Worth	-9.50	-8.41	14.94	12.75	5.44	4.34
Fresno	-11.61	-11.46	21.92	17.88	10.31	6.42
Atlanta	5.13	0.88	6.22	2.12	11.35	3.00
Nashville	6.13	1.40	7.40	2.14	13.53	3.54
Washington, D.C.	6.27	1.60	9.03	2.33	15.30	3.93
Albuquerque	6.14	1.14	8.46	2.54	14.60	3.68
Louisville	0.00	0.00	12.55	2.56	12.55	2.56
New York	0.00	0.00	13.60	1.75	13.60	1.75
Boston	3.57	0.38	13.64	1.05	17.21	1.43
Salt Lake City	4.67	0.70	13.82	2.17	18.49	2.87
Cleveland	8.20	0.39	11.63	1.19	19.83	1.57
Minneapolis	16.42	0.79	11.02	1.43	27.44	2.22

The differences in energy savings do not reflect the efficiency of the heating and cooling systems; while these adjustments are necessary to calculate the actual energy savings, they were excluded here to illustrate the basic energy load effects of the standards and exclude the effect of HVAC equipment choice.

Building practices reflecting a combination of Title II-E and Title VI requirements represent common construction practices for manufactured housing prototypes. Table 8.1 compares the Title II-E and Title VI standards and illustrates that there are relatively small heating load reductions for HUD Region I (see Table 6.2), less than 2 MMBtu/yr, with larger reductions occurring for Region II, 1 to 10 MMBtu/yr. The largest load reduction is for Minneapolis, which is in Region III, for the Title II-E standard. The heating load reductions in the comparison of the FmHA and Title II-E standards range from 6 to 16 MMBtu/yr, while they range from 8 to 28 MMBtu/yr in the comparison of the FmHA and Title VI standards. A comparison of the FmHA and Title II-E standards with the Title VI standard reveals that the magnitude of the

reduction in total loads varies less about the mean reduction under the FmHA standard than under the Title II-E standard. This is attributed to the additional climate zones and degree-based definitions in the FmHA standard (Title II-E has a smaller number of zones and uses geographic-based definitions). From this perspective, compared to the HUD Title VI baseline, the FmHA standard produces more uniform energy reductions than the Title II-E standard. However, it must be noted that assessment of the regional equity of these reductions depends on the economic effects.

In Table 8.2 the ASHRAE and FmHA standard are compared with the MPS standard, and the FmHA standard is also compared with the ASHRAE 90A-80 standard. An informal survey suggests that the ASHRAE 90A-80 standard most accurately reflects current energy building standards in the U.S. for site-built residential housing. The load reduction summary for the single-family detached prototype illustrates that the FmHA standard reduces energy consumption relative to both ASHRAE Standard 90A-80 and the MPS standard. The FmHA standard reduces heating loads by 7 to 22 MMBtu/yr compared to ASHRAE Standard 90A-80. In summary, both tables indicate that the FmHA standard specifies stricter shell insulation requirements than typical building practices and the other standards analyzed.

Data on heating and cooling loads for both building prototypes for the FmHA standard are shown in Table 8.3. The loads are reported in KBtu/sq ft. The floor areas of the manufactured and single-family detached prototypes are 902 and 1540 sq ft, respectively. It is difficult to compare the equity of the standard across prototypes due to the assumptions used in the energy simulations and their associated impact on the predictions. These assumptions are outlined in the following paragraphs.

Table 8.3 shows that the manufactured housing prototype is predicted to have slightly lower heating and higher cooling loads per unit floor area than the single-family detached prototype in all cities except Phoenix. Analysis of the prototype designs suggests that the assumptions underlying the simulations used in this analysis are critical.

TABLE 8.3. Heating and Cooling Loads for the FmHA Standard (space conditioning requirements in KBtu/sq ft)

City	SFD Prototype		Manufactured Prototype	
	Heating	Cooling	Heating	Cooling
Phoenix	9.56	36.92	10.30	38.33
Fort Worth	16.89	28.76	15.65	28.60
Fresno	16.77	16.91	15.81	20.16
Atlanta	19.19	14.57	17.58	15.95
Nashville	23.73	15.61	21.19	17.36
Washington, D.C.	28.67	14.78	24.93	16.22
Albuquerque	23.76	10.30	22.37	13.32
Louisville	28.76	12.57	25.71	14.32
New York	29.81	8.49	26.08	9.61
Boston	38.07	5.50	33.75	6.77
Salt Lake City	36.52	8.16	34.64	11.67
Cleveland	39.73	4.74	36.71	6.19
Minneapolis	56.54	8.30	49.96	10.26

One set of critical assumptions relates to the building envelope and contributes to the lower heating loads per square foot in the manufactured prototype. The manufactured housing prototype has a net wall to floor area ratio of 1.17, while the single-family detached prototype has a wall to floor area ratio of only 0.70. This basic relationship should cause higher heat losses per square foot in the manufactured house. However, the theoretical lower wall heat loss per unit floor area in the single-family detached prototype is offset by the prototype's design, which incorporates a window area to floor area ratio of 15%, compared to only 11% in the manufactured housing prototype. A less significant but related factor is that the percentage of the walls occupied by framing instead of insulation is 11% for the manufactured housing prototype and 20% for the single-family detached prototype. These framing percentages are not adjusted for window area in the data base.

Infiltration rates for both prototypes are fixed at 1.0 air changes per hour for the purposes of this study. This results in a slight bias in favor of the manufactured housing prototype, since it has a 7 ft, 6 in. ceiling height,

while the single-family detached prototype has an 8 ft ceiling, thus reducing internal volume per unit of floor space. It is questionable whether the ceiling height should influence infiltration in this manner. When a basic heat loss analysis including infiltration and the building envelope is conducted, the manufactured housing prototype has a 6% higher heat loss than the single-family detached prototype when both are insulated to FmHA Zone 4 standards. It must be noted that the infiltration components of the heat loss represent 44% and 39% of the total for the single-family detached and manufactured housing prototypes, respectively, twice that of any other single component. This indicates that infiltration rates dominate the building loads, and therefore accurate infiltration rates are crucial to the results of the analysis. Further research to determine infiltration rates typical of manufactured and site-built housing types is required to accurately assess the energy and economic effects attributable to infiltration. However, the infiltration rates were held constant in the comparisons and have no bearing on the results of this economic analysis.

Another assumption about the prototype designs that has an important effect on the analysis is internal gains from appliances and occupants. The single-family detached prototype has an assumed sensible internal gain of 36.7 Btu per day per square foot of floor space, while the manufactured housing prototype has a gain of 51.4 Btu per day per square foot. The "free" heat reduces heating loads and increases cooling loads to be supplied by the HVAC equipment, and the different rates assumed for the prototypes largely account for the shift in the manufactured housing prototype loads away from heating and toward cooling when compared with the single-family detached prototype. The importance of internal gains in the results of the analysis indicates that the assumed rates deserve further analysis.

Finally, the treatment of solar gain through windows needs to be examined. Solar heat gains through windows tend to offset heat losses out the glazing during the heating season and increase cooling loads during the summer. While no external shading of the windows was assumed in the simulation analysis, it is noted that manufactured homes frequently have attached carports

and porch awnings that largely eliminate solar gains from windows. A similar effect would occur for single-family detached homes, but would be expected to be lesser in extent.

These observations highlight the differences inherent in the design assumptions. Therefore, the comparisons between housing types should be used to suggest areas for further analytic refinements, not to predict actual relative performance. On the other hand, the comparisons within a housing type provide valid indicators of the relative performance of different standards, since they rely on uniform sets of assumptions.

The energy analysis to this point has referred to building loads only. To examine the overall energy and economic impacts, fuel type, and system conversion efficiencies must be considered. Efficiencies used in subsequent analyses presented in this section neglect duct losses. It is assumed that all heat lost from ducts is transferred to the conditioned space. Gas and oil heating are assumed to be 69% efficient, the minimum requirement in the ASHRAE standard. Electric resistance heating equipment has an efficiency of 100%. In regions in which heat pumps are used in the analysis, efficiencies are based on the ASHRAE 90A-80 standard: the coefficient of performance (COP) at 46 dry bulb/43 wet bulb is 2.7, while the cooling efficiency (EER) is 7.8. The heating COP has been adjusted by the number of heating and cooling degree days in each city to reflect actual operating conditions. The adjustment factors are based upon the paper, "Development of Equipment Seasonal Performance Factors for Simplified Energy Analysis Method," in the 1982 ASHRAE Transactions. These adjustments result in heating COPs of 1.76 for Washington, D.C. and Nashville and 1.81 for Phoenix. Central air conditioning equipment is assumed to have a seasonal energy efficiency ratio (SEER) of 7.8.

The same HVAC equipment efficiencies are used for all the standards analyzed. These efficiencies reflect the lower end of the efficiency ratings currently used in the residential market and consequently are for the lower first-cost units. Obviously, as the HVAC equipment efficiency increases, the amount of energy saved due to improving the thermal integrity of the shell decreases.

Optimally, the increased cost for higher efficiency appliances should be traded off against the cost of shell conservation measures. However, the standards do not address this issue.

8.2 ECONOMIC ANALYSIS

The economic analysis of the five standards examined is presented in this section. The assumptions and methodology for the life-cycle cost analysis are detailed in Chapter 9. The most important assumptions to remember when reviewing the results are the 10% real discount rate, the 5% annual inflation rate, the 13% nominal mortgage interest rate, the 20% down payment on the purchase cost, and no income tax deduction effects. For this interim analysis, the life-cycle cost results are presented for 6 of the 13 regions analyzed. The results presented include the change in life-cycle cost, the change in first-year energy costs, the change in first-year loan payments, and the internal rate of return for the change in investment. The net life-cycle cost shows the change in total costs between different standards for each prototype over the 30-year mortgage. The first-year fuel costs and loan payments are presented to address the FmHA criterion that the homeowner not be faced with increased annual costs associated with stricter standards. Finally, the internal rate of return is provided to indicate the sensitivity of the results to the 10% discount rate selected for the study.

The Congressionally specified FmHA criterion that the increase in annual loan payments be less than the annual fuel savings can be interpreted in a number of ways. In this analysis, the interpretation assumed is that the fuel savings at the end of the first year must be greater than the increase in annual loan payments.

This criterion, however, may focus too strongly on the near-term cost effects. The following situation frequently occurs: the first-year fuel cost savings are less than the increase in annual loan cost, but the life-cycle cost decreases. For this situation to occur, there must be a number of years after the first year in which the annual fuel savings are greater than the increase

in annual loan payments. In fact, the second-year cash flow could be positive, while the standard failed the first-year cash flow test. The reasonableness of this test and the cash flow patterns deserve more analysis and consideration.

The economic analysis of the single-family detached prototype is summarized in Tables 8.4 through 8.6. Table 8.4 indicates that the ASHRAE standard reduces the life-cycle cost of the single-family detached prototype in four of the six cities when compared to the HUD MPS standard. In one city, Boston, the ASHRAE standard results in a net increase in life-cycle cost, while in another city, Phoenix, the standards result in identical shell specifications. The increase in Boston is due to the ASHRAE requirement of R-30 roof insulation. In the three moderate climate regions (Washington, D.C., Nashville, and Atlanta), the increase in the first year's loan payments is offset by a larger

TABLE 8.4. ASHRAE Standard 90A-80 vs. HUD MPS for the Single-Family Detached Home

City	Net Life-Cycle Cost, \$	Change in First-Year Payments, \$		IRR
		Loan	Fuel	
Phoenix	0.00	0.00	0.00	--
Atlanta	-392.67	47.30	-49.77	0.300
Nashville	-282.87	44.26	-53.15	0.290
Washington, D.C.	-536.95	49.47	-79.28	0.440
Boston	454.08	148.06	-46.94	--
Minneapolis	-503.34	205.49	-139.87	0.157

TABLE 8.5. FmHA Standard vs. HUD MPS for the Single-Family Detached Home

City	Net Life-Cycle Cost, \$	Change in First-Year Payments, \$		IRR
		Loan	Fuel	
Phoenix	-3414.67	240.29	-427.11	>1
Atlanta	79.88	235.66	-118.12	--
Nashville	311.23	220.52	-119.86	--
Washington, D.C.	-289.19	248.97	-193.66	0.130
Boston	-1185.99	296.87	-221.98	0.193
Minneapolis	-1109.47	320.56	-240.94	0.180

decrease in fuel costs. The worst case with respect to first-year cash flow and life-cycle cost, Boston, results in increased expenditures of approximately \$10 per month in the first year. It should be noted that in future years, the annual savings increase in all cities due to the real increase in fuel prices. The results for the three cities with reduced first-year payments are not sensitive to the discount rate, as noted by the high internal rate of return on the investment.

The comparison of the FmHA standard with the MPS standard, Table 8.5, shows that the FmHA standard reduces life-cycle cost in four of the five cities analyzed. The fuel savings at the end of the first year are less than the first year's loan payment increase in five of the cities, causing a first-year negative cash flow. Again, the maximum first-year net cost increase amounts to about \$10 per month, but becomes a positive cash flow in future years for the cases in which life-cycle cost is decreased. The internal rate of return is less than 16% in one case, indicating some sensitivity to the discount rate. In comparison with the results discussed above, the FmHA standard is more cost-effective in Boston than the ASHRAE standard, which actually increases life-cycle cost compared to the MPS standard. The fact that the FmHA standard's requirements actually exceed those of the ASHRAE standard suggests that the ASHRAE standard could be specified differently for Boston to both save more energy and reduce life-cycle costs.

As noted previously, ASHRAE Standard 90A-80 is commonly used in the U.S. Therefore the incremental benefits of the FmHA standard over ASHRAE Standard 90A-80 have been calculated and the results are presented in Table 8.6. The FmHA standard increases the building life-cycle cost for the three temperate regions, while it reduces life-cycle cost in the two cold regions and the one hot region. In both Phoenix and Boston the first-year fuel savings exceed the increased loan payment. For the three extreme climate regions the internal rates of return are all above 20%, indicating that the results are not very sensitive to the selection of the discount rate. The maximum increase in first-year payments is \$10 per month.

TABLE 8.6. FmHA Standard vs. ASHRAE 90A-80 Standard for the Single-Family Detached Home

City	Net Life-Cycle Cost, \$	Change in First-Year Payments, \$		IRR
		Loan	Fuel	
Phoenix	-3414.67	240.29	-427.11	>1
Atlanta	472.52	188.35	-68.36	--
Nashville	594.10	176.26	-66.72	--
Washington, D.C.	247.46	198.99	-114.38	--
Boston	-1640.02	148.41	-175.03	0.370
Minneapolis	-605.93	115.08	-101.07	0.226

The economic comparison of the FmHA standard with the HUD Title VI standard for manufactured housing illustrates the sensitivity of the results to the selection of heating fuel choice. Table 8.7 is based on electric resistance heating, while Table 8.8 is based on gas heating. When electric resistance heating is used, the FmHA standard is clearly cost-effective. In all six regions life-cycle was substantially decreased and the first-year fuel savings were greater than the increase in loan payments. In addition, the high internal rates of return indicate that the results are relatively insensitive to the selection of the discount rate. On the other hand, with gas heating the FmHA standard always resulted in a decrease in life-cycle cost, but there is only one case in which the first-year fuel savings were greater than the increase

TABLE 8.7. FmHA Standard vs. Title VI Standard for the Manufactured Home--Electric Heating

City	Net Life-Cycle Cost, \$	Change in First-Year Payments, \$		IRR
		Loan	Fuel	
Phoenix	-1026.83	151.38	-268.14	>1
Atlanta	-1382.04	182.04	-238.57	0.350
Nashville	-1155.50	170.35	-210.17	0.330
Washington, D.C.	-1738.51	161.32	-256.35	>1
Boston	-2041.78	252.77	-328.75	0.330
Minneapolis	-2418.84	340.40	-457.48	0.319

TABLE 8.8. FmHA Standard vs. Title VI Standard for the Manufactured Home--Gas Heating

City	Net Life-Cycle Cost, \$	Change in First-Year Payments, \$		IRR
		Loan	Fuel	
Phoenix	-1026.83	151.38	-161.20	0.280
Atlanta	-468.81	182.04	-123.59	0.163
Nashville	-619.13	170.35	-125.27	0.190
Washington, D.C.	-1070.68	161.32	-158.60	0.267
Boston,	-1309.15	252.77	-204.37	0.220
Minneapolis	-970.68	340.40	-239.10	0.167

in the loan payments. The negative cash flows, however, were no more than \$9 per month. Finally, the internal rate of return was lower than 20% in three of the cases, indicating some sensitivity to the selection of the discount rate.

The comparison of the FmHA standard with the HUD Title II-E standard is also sensitive to the selection of heating systems. The FmHA standard yields a reduction in total life-cycle costs in all cases except for gas heating in Minneapolis, Boston, and Washington, D.C. These data are shown in Tables 8.9 and 8.10. The first-year fuel savings are greater than the increased loan payments for three of the cities when electric resistance heating is used. When gas heating is used, the first-year fuel savings are never greater than

TABLE 8.9. FmHA Standard vs. Title II-E Standard for the Manufactured Home--Electric Heating

City	Net Life-Cycle Cost, \$	Change in First-Year Payments, \$		IRR
		Loan	Fuel	
Phoenix	-1866.26	142.11	-240.39	>1
Atlanta	-1171.53	173.48	-215.09	0.318
Nashville	-980.74	162.34	-190.14	0.299
Washington, D.C.	-214.03	97.60	-84.83	0.160
Boston	-174.60	182.78	-133.86	0.124
Minneapolis	-577.81	246.03	-227.60	0.162

TABLE 8.10. FmHA Standard vs. Title II-E Standard for the Manufactured Home--Gas Heating

City	Net Life-Cycle Cost, \$	Change in First-Year Payments, \$		IRR
		Loan	Fuel	
Phoenix	-839.81	142.11	-141.74	0.250
Atlanta	-343.41	173.48	-110.83	0.148
Nashville	-493.04	162.34	-112.94	0.177
Washington, D.C.	2.84	97.60	-52.34	--
Boston	181.81	182.78	-84.05	--
Minneapolis	146.02	246.03	-118.45	--

the increased loan payments. Again, the negative cash flow is fairly low, never exceeding \$10 per month where the life-cycle cost decreases. The internal rates of return indicate a slight sensitivity to the discount rate for both gas heating and electric resistance.

The third analysis of the manufactured prototype compares HUD's older Title VI energy standards with the stricter Title II-E. Regardless of the selection of heating fuel, the stricter standards yield a decrease in life-cycle cost. In all cases the first-year fuel savings were greater than the increase in annual loan payments. Tables 8.10 and 8.11 show these results. The high internal rates of return indicate that the results are not sensitive to the selection of the discount rate.

TABLE 8.11. Title II-E Standards vs. Title VI Standards for the Manufactured Home--Electric Heating

City	Net Life-Cycle Cost, \$	Change in First-Year Payments, \$		IRR
		Loan	Fuel	
Phoenix	-273.28	9.26	-27.75	>1
Atlanta	-210.51	8.56	-23.48	>1
Nashville	-174.76	8.01	-20.03	>1
Washington, D.C.	-1519.48	63.72	-171.52	>1
Boston	-1427.96	70.00	-120.32	>1
Minneapolis	-1841.03	94.36	-229.88	>1

TABLE 8.12. Title II-E Standards vs. Title VI Standards for the
Manufactured Home--Gas Heating

City	Net Life- Cycle Cost, \$	Change in First- Year Payments, \$		IRR
		Loan	Fuel	
Phoenix	-187.03	9.26	-19.46	>1
Atlanta	-125.40	8.56	-12.76	0.360
Nashville	-126.09	8.01	-12.32	0.380
Washington, D.C.	-1073.52	63.72	-106.25	>1
Boston	-1427.96	70.00	-120.32	>1
Minneapolis	-1116.70	94.36	-120.66	0.390

9.0 CONCLUSIONS

This section summarizes the important findings of this initial study. The reader is cautioned that these findings are preliminary and are based on limited analyses.

9.1 FINDINGS FOR SITE-BUILT HOUSING

Based on the preliminary analyses, the following results are considered important:

- Site-built homes built to ASHRAE Standard 90A-80 represent typical minimum energy conservation design practices.
- Site energy consumption for space conditioning varies by roughly a factor of 4 across the cities analyzed here.
- The FmHA standard results in the lowest energy use; of the three standards compared, the MPS results in the highest energy consumption. Compared to typical minimum building practice, the FmHA standard reduces consumption between about 11% and 34%, depending on location. The MPS results in consumption increases of 0% to 16%.
- Compared to typical minimum building practice, the FmHA standard decreases life-cycle cost in the hot and cold cities, but increases it in the temperate cities analyzed here. Whether the variation indicates a climate inequity in the standard has not been determined.
- Compared to typical minimum building practice, the FmHA standard produces negative first-year cash flows in all cities except Phoenix and Boston, where the highest life-cycle cost reductions occur. The negative cash flows do not exceed \$10 per month.

9.2 FINDINGS FOR MANUFACTURED HOUSING

The following preliminary findings are considered important for manufactured houses. Because the heating type used in new manufactured homes in the six cities considered here is split fairly evenly between electric resistance

and natural gas, this study presents results for each type separately. The following findings refer to gas heating:

- Manufactured homes built to HUD Title VI requirements represent typical minimum energy conservation design practices.
- Site energy consumption for space conditioning varies by approximately a factor of 2.5 across the cities analyzed here.
- The FmHA standard results in the lowest energy consumption of the three standards analyzed; the Title VI standard results in the highest consumption.
- Compared to typical minimum building practice, the FmHA standard reduces annual energy consumption by 36% to 48%, depending on location. The Title II-E standard reduces consumption by about 4% to 23%.
- Compared to typical minimum building practice, both the FmHA standard and the Title II-E standard decrease life-cycle cost.
- Compared to typical minimum building practice, the FmHA standard results in negative first-year cash flows in all cities analyzed except Phoenix. The negative cash flows do not exceed \$9 per month.

The following findings refer to manufactured homes heated by electric resistance:

- Site energy consumption for space conditioning varies by a factor of approximately 2.2 across the cities analyzed.
- Compared to typical minimum building practice, the FmHA standard reduces energy consumption by 37% to 46%, depending on location. The Title II-E standard reduces consumption by 4% to 23%.
- Compared to typical minimum building practice, both the FmHA standard and the Title II-E standard reduce life-cycle cost in all cities analyzed.

- Compared to typical minimum building practice, both the FmHA standard and the Title II-E standard effect positive first-year cash flows in all cities analyzed here.

In addition to the previous points, this preliminary analysis also suggests the following:

- The net monthly cash flow impacts of the residential building standards analyzed tend to be small, almost always less than \$10.
- The positive first-year cash flow requirement is a strict test, often causing a homebuyer to forego significant future monetary and energy savings.
- When applied to manufactured housing, the existing site-built FmHA Title V standard does not appear discriminatory. In fact, it produces life-cycle cost reductions more consistently in manufactured homes than in site-built homes in the cities analyzed here.

Again, the reader is cautioned that these findings are preliminary. However, the basic life-cycle cost results appear fairly robust, given that the significant difference in fuel prices between electric resistance and gas heating changes the magnitude, but not the trend, of life-cycle costs for manufactured homes built to different standards. In addition, the internal rate of return on conservation investments in manufactured homes is consistently high for the scenarios considered here, suggesting limited sensitivity to the assumed discount rate.

This interim report will be followed by a final report that analyzes the FmHA manufactured housing standard (yet to be issued) and compares it to the standards analyzed here. That report will expand the sample of locations analyzed and will address the sensitivity of the results to economic and engineering inputs.

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APPENDIX A

SYNOPSIS OF STUDIES RELATED TO THE ENERGY
EFFICIENCY OF MANUFACTURED HOMES

APPENDIX A

SYNOPSIS OF STUDIES RELATED TO THE ENERGY EFFICIENCY OF MANUFACTURED HOMES

A.1 Title: Optimum Thermal Insulation for Manufactured Homes
Author: Howard Gates
Date: October 17, 1984
Report No.: None

This report was prepared for the Manufactured Housing Institute, Arlington, Virginia. The principal objective was to estimate the economically optimum envelope thermal transmission coefficient for a double-wide manufactured home for eight locations. The optimum coefficient was estimated as that point where initial incremental insulation costs plus the present value of 30-year fuel costs are minimized. The least-cost thermal coefficient for each location was compared to eight existing or proposed thermal protection standards for manufactured homes.

In general, the author found that thermal efficiency requirements beyond (i.e., stricter than) those in the proposed HUD revision to the MHCSS (48 Federal Register 37142) could not be economically justified.

The American Council for an Energy-Efficient Economy (ACEEE), based in Washington, D.C., criticizes the economic assumptions in the report in a November 30, 1984 letter to HUD Secretary Pierce on several grounds:

1. ACEEE cites the 2%/yr (nominal or current dollars) fuel cost escalation rate used by Gates as unrealistically low.
2. ACEEE claims that the Gates study overestimates the cost of incremental insulation additions to manufactured homes.
3. Finally, ACEEE argues that the nominal discount rate used by Gates, 14%, is too high.

A.2 Title: Comparison of Manufactured Housing Thermal Characteristics
Author: National Conference of States on Building Codes and Standards,
Herndon, Virginia
Date: September 10, 1984
Report No.: PB85-11084-9 (NTIS)

This report was prepared for the Farmer's Home Administration, U.S. Department of Agriculture. The Rural Housing Amendments of 1983 to the Housing Act of 1949 direct FmHA to establish energy conserving requirements for manufactured homes for which it extends loans. FmHA formulated and implemented thermal construction standards for site-built housing in five climate zones in 1977 (FmHA Instruction 1924-A). This report evaluates the impact on current construction practices of applying Instruction 1924-A standard to manufactured housing. The Instruction 1924-A thermal requirements are stricter than the current HUD manufactured home thermal requirement (24 CFR 3280 Subpart F).

The authors of the study found that of 65 current manufactured housing designs reviewed, 45% already meet the Instruction 1924-A thermal requirements, and extensive redesign of the other 55% is not needed to meet these requirements.

A.3 Title: Energy Expenditures and Conservation in Mobile Homes
 Author: Building Standards Section, Tennessee Valley Authority,
 Chattanooga, Tennessee
 Date: 1984
 Report No.: None

This report was prepared by TVA staff for use in their energy conservation programs. The findings are based on power consumption in electrically heated homes in the TVA service area between January 1982 and December 1983. The findings are presented below in tabular form. A key finding is that on a square floor basis, manufactured homes consume 49% more electricity than other single-family homes.

Parameter	Manufactured Homes	Non-Manufactured Single-Family Homes
Average size of living quarters, sq ft	764	1493
Average age of home, yr	9.1	14.7
Total homes in 1983	154,500 (6.3% of total residential living units)	
% owners who have requested and received TVA free home energy survey	8.0	30.0
Average family income in 1983, \$	13,797	22,566
Average age of head(s) of household, years	46.1	51.4
Average years of education	10.8	12.1
% with air conditioning	58	71
Electricity consumption in 1983, kWh/sq ft	15.7	10.5
Electricity cost as % of family income	4.04	3.22

A.4 Title: Raising the Energy Efficiency of Manufactured Housing
Author: E. Mills, Lawrence Berkeley Laboratory, Berkeley, California
Date: May 1984
Report No.: LBL-17880. The paper also appears in Vol. 8, p. 193, of the Proceedings of the 1984 Summer Study on Energy Efficiency in Buildings, August 14-22, 1984, sponsored by the American Council for an Energy Efficient Economy, Washington, D.C.

A principal objective of this paper was to present a compilation of monitored and simulated energy consumption in various types of manufactured homes. Monitored data for seven manufactured homes and simulated data for seven different manufactured homes are presented. The data suggest that dramatic energy savings for homes built to the current HUD manufactured home thermal requirements are possible. No costs to achieve conservation are included in the paper.

A.5 Titles: 1. Affordable Manufactured Housing Through Energy Conservation:
A Guide to Designing and Constructing Energy Efficient Homes
2. Using the Slide Rule and Modifiers
Author: Steven Winter Associates, New York City
Report No.: GPO Stock No. 064000006374

These two documents were prepared for the Office of Conservation and Renewable Energy, OOE. They provide a means to determine the cost-effectiveness of alternative energy conservation options for single- and double-wide manufactured homes. The user can incorporate regional differences in climatic conditions, building materials and labor costs, energy prices, and energy types.

A.6 Title: "Benefits of Energy Efficient Structures"
Author: Duke Power Co.
Date: October 19, 1983
Report No.: None. Paper presented at the annual workshop of the Southern
Piedmont Manufactured Housing Association. Reprinted at p. 634 of
Review of Federal Policies and Building Standards Affecting Energy
Conservation in Housing, Serial No. 98-85, Hearing before the Sub-
committee on Housing and Community Development, U.S. House of Rep-
resentatives, March 21-22, 1984.

Duke Power Co. analyzed the cost effectiveness of an energy conservation package added to the existing HUD manufactured home construction requirements. The analysis was performed for both a single- and double-wide manufactured home. The package included R-30 ceiling, R-12 wall, and R-19 floor insulation in lieu of R-14, R-7, and R-7, respectively, representing the approximate insulation requirements to meet the current HUD thermal performance requirement. The package also included storm or insulated windows and doors, a vapor barrier, and insulation joints. Owners of manufactured homes built with these features receive a 10% discount on electricity purchased from Duke.

For a single-wide home, the authors estimated that the package would add \$650 to construction costs and produce \$7485 in electricity savings over 15 years. For a double-wide home, the comparable numbers were \$800 and \$11,775.

A.7 Title: Instrumentation for Side-by-Side Testing of the Energy Attributes
of Mobile Homes
Author: C. J. Cromer, Florida Solar Energy Center, Cape Canaveral, Florida
Date: June 1983
Report No.: FSEC-CR-84-83(RD)

This report was prepared for the Florida Public Service Commission. The objective was to compare the energy consumption performance of two otherwise identical manufactured homes, except that one was fitted with an energy conservation package. Manufactured Home A, built to the HUD construction standards, had R-7 wall, R-11 floor, and R-14 roof insulation. Manufactured Home B had R-13 wall, R-18 floor, R-22 roof insulation, storm windows, an R-7 hot water tank insulating jacket, and a higher efficiency air conditioning unit. All the added energy saving features proved to be cost-effective. The highest payback period among the added energy conservation features was 3.05 years for the storm windows. An extra-cost air infiltration barrier in the walls, however, did not produce a measured reduction in the air infiltration rate.

- A.8 Title: 1. Technical Support Documentation for Proposed Modifications to Subpart F of the Manufactured Home Construction and Safety Standards
2. Cost/Benefit Analysis of Mobile/Manufactured Home Regulations in Support of a Regulatory Impact Analysis

Author: Steven Winter Associates, New York, and HUD

Date: May 21, 1982 and July 15, 1982

These two documents are the principal supporting documentation for the changes that HUD is proposing (48 Federal Register 27142) to the thermal protection requirements in their Manufactured Home Construction and Safety Standards (24 CFR 3280). Other changes to the standards are also being proposed. HUD is proposing to retain its current three climate zones and to require manufacturers to offer consumers optional packages that will provide improved thermal performances.

A.9 Title: An Analysis of Energy Conservation Options for Manufactured Homes
Author: Steven Winter Associates
Date: November 1981
Report No.: DOE/CS/22046-1

This report was prepared for the National Institute of Building Sciences and DOE. Its focus was to develop flexible methods for determining cost-effective energy conservation options for manufactured homes. The following steps were used in the analysis:

1. Identification of two prototype homes (one single and one multi-section unit) representative of average manufactured homes
2. Simulation of the prototype homes to estimate baseline energy use
3. Identification of feasible energy conservation options capable of analysis from an energy and economic standpoint
4. Projection of energy savings resulting from each energy conservation option
5. Economic analysis to assess the relative attractiveness of each energy conservation option. Analyses were performed for nine geographic locations (Phoenix, San Diego, Miami, Atlanta, Lake Charles, Albuquerque, Washington, D.C., Bismarck, and Seattle) and five fuel/equipment (electric, oil, natural gas, LPG, and heat pump) types. Options were evaluated on an undiscounted simple payback basis.

Among the study findings were the following:

1. Automatic setback thermostats have low payback periods in all locations except Miami.
2. Additional floor and ceiling insulation up to R-19 has a payback period of 5 years or less in all locations except San Diego, Miami, and Seattle.
3. Additional wall insulation up to R-13 has a payback period of less than 5 years only in Bismarck, North Dakota.

4. Double pane windows have a payback period of less than 5 years only in Atlanta and Albuquerque.
5. Other energy conservation options evaluated generally have payback periods exceeding 5 years.
6. Payback periods were generally lowest in areas with electric heat.

A.10 Title: Economic Cost-Benefit Analysis of Mobile Homes Improved Thermal Performance

Author: Technology and Economics, Inc., Cambridge, Massachusetts

Date: August 1981

Report No.: PB83-185462 (NTIS)

This report was prepared for HUD and presents a cost/benefit analysis of an early recommended change in the HUD thermal protection requirements in the Manufactured Home Construction and Safety Standards (24 CFR 3280, Subpart F). The proposed changes evaluated were more stringent than the standards subsequently proposed by HUD (48 Federal Register 37412) to be made available to consumers as an option.^(a) The proposal evaluated nevertheless did not have positive net benefits for all three of the HUD climatic zones.

(a) The existing heat loss coefficients for HUD's three climatic zones are 0.157 Btu/(hr)(sq ft)(°F), 0.126 and 0.104, respectively. The new requirements proposed by HUD to be optionally available to consumers are 0.145, 0.099, and 0.087. The requirements evaluated in this report were 0.090, 0.060, and 0.050.

A.11 Title: Mobile Home Heating, Cooling and Fuel Burning Systems
Author: Science Applications, Inc.
Date: October 1979
Report No.: PB81-173981, HUD-0001925

This report was prepared for HUD and covers research performed to
1) determine the compliance of two typical manufactured homes with the HUD thermal requirements for climate Zone II; 2) identify potential areas of modification and improvement in the thermal requirements; and 3) evaluate the performance of the two homes' furnaces and heating control systems for safety, energy conservation, durability, economy, livability, and serviceability.

Among the study findings were the following:

1. the two homes generally complied with the HUD thermal requirements
2. duct systems were found to leak up to 20% of the air flowing through them
3. heat delivery to each register varied widely, with registers at the end of the line receiving as little as 18% of the heat as registers nearest the furnace
4. duct registers were not adequately designed or located, resulting in wide temperature variations
6. furnace units were unacceptably noisy
7. the thermostats were poorly located, resulting in short furnace cycles and inaccurate temperature settings.

A.12 Title: "Field Validation of Energy Conservation Specification on Ten Test Homes Through a Metering Program"
Author: M. F. McBride, Owens-Corning Fiberglas Corp.
Date: June 1979
Report No.: ASHRAE Transactions, Vol. 85, Part 2, Symposium DE-79-3, Paper No. 4

This paper was presented at the ASHRAE annual meeting held in Detroit in June 1979. The paper reports the results of energy consumption experiments on 10 unoccupied double-wide manufactured homes located in Little Rock, Arkansas. The primary objective of the work was to monitor the energy consumption of the 10 homes and demonstrate the energy saving potential of various energy conservation measures. The secondary objective was to investigate the thermal performance of the homes. Measurements were taken for one continuous year. The 10 homes included 3 reference homes built to the HUD MHCSS requirements, 3 homes with 36% more attic insulation than the reference homes, and 4 homes with substantial additional energy conservation measures including increased wall, ceiling, floor, and duct insulation; decreased window area storm windows and doors; and an extended eave overhang.

The results showed that the three homes with additional ceiling insulation used 13.5% less energy than the reference homes, and the four homes with extensive additional energy conservation measures consumed 60.1% less energy. No estimate of the cost-effectiveness of the various energy conservation measures is included in the paper.

The energy consumption for the 10 homes was also compared to predicted consumption based on design loads using the 1977 ASHRAE Handbook of Fundamentals. Predicted energy savings were 4.6% and 56.1%, respectively, for the two home groups. Actual energy savings were thus greater than predicted. The author attributes the additional saving to interactions among the various energy conservation measures that cannot be accounted for in simplified energy calculation procedures.

A.13 Title: Phase-Two Report for the Development of Energy-Performance Standards for New Buildings, Task Report: Mobile Homes
Author: National Association of Home Builders' Research Foundation and T. R. Arnold and Associates
Date: January 1979
Report No.: DOE/TIC-11454, CAS-RM-79-112

This report was coordinated by the American Institute of Architects Research Foundation for HUD. The work was performed in support of the requirement in the Energy Conservation Standards for the New Buildings Act of 1976 that DOE develop energy performance standards for new buildings. The legislation was subsequently changed to require the preparation of voluntary energy guidelines rather than mandatory performance standards.

Phase 1 of the study involved a survey to determine annual energy requirements of manufactured homes in each of the three climate zones designated in the existing HUD regulations (24 CFR 3280.506) and to establish base data on current design practices. The second phase involved developing prototype energy-saving manufactured home designs. Prototype I was designed to be the practical limit of energy efficiency improvements that could readily be implemented without changes in existing regulations. Prototype II was designed to be even more energy efficient at the expense of reducing buyer flexibility in floor plan, features, and siting. Prototype II designs were estimated to consume 46% less energy than current manufactured home construction practices.

A.14 Title: Engineering-Economic Analysis of Mobile Home Thermal Performance
Author: P. F. Hutchins, E. Hirst, Oak Ridge National Laboratory
Date: October 1978
Report No.: ORNL/CON-28

The authors conducted detailed analyses of the optimal design of new manufactured homes in nine U.S. cities. The base case was the thermal protection requirements in the Manufactured Home Construction and Safety Standards (24 CFR 3280, Subpart F) administered by HUD. Changes to the base case that were examined included additional wall (2 in. and 3.5 in.), attic (3.5 and 6 in.), and floor (3.5 and 5.5 in.) insulation; addition of storm windows; underpinning; awnings; and optimized home orientation.

The findings suggest that:

1. For all but the warmest climate (HDD less than 2000 for natural gas and less than 500 for electric or propane), additional investment in energy conserving options beyond the HUD requirements would be economically justified.
2. For natural gas heating, the energy use reduction relative to the base case is 20% to 30% in all but the warmest climates. For electric or propane heating, the reduction is 30% to 50% in northern and intermediate climates, but negligible in warmer areas.
3. Cost-effective cooling options are most effective for inland areas and can result in 5% to 10% energy savings over the base case.
4. Payback periods for energy conservation options are generally less than 5 years for any location where natural gas is the principal heating fuel and less than 2 years where electricity or LPG is used.

A.15 Title: The Thermal Performance of a Two-Bedroom Mobile Home
Author: G. J. Teftisma and B. A. Peavy, National Bureau of Standards
Date: February 1978
Report No.: PB-278 601 (NTIS) and NBS BSS 102

The principal objectives of this study were to observe measured versus predicted thermal performance and also the operating performance of a manufactured home's furnace and insulation. Findings included:

1. the factory installed natural gas furnace was oversized and significantly increased overall energy consumption
2. measured and predicted heat loss were quite close
3. the insulation installation technique permitted thermosiphoning of air and thus reduced efficiency.

A.16 Title: Passive Solar Manufactured Buildings: Design, Construction and Class B Results
Author: Solar Energy Research Institute
Date: December 1984
Report No.: SERI/SP-271-2059

This report contains eight case studies on manufactured buildings modified to include additional conservation and passive solar features. The studies include five residential and three commercial buildings. One of the five residential buildings is a HUD-code (mobile) home.

The HUD-code home was constructed by Wick Building Systems and sited at their plant in Spencer, Wisconsin. The reference home built by Wick is a 16 ft by 70 ft single-wide unit with R-11 wall and floor insulation and R-19 ceiling insulation. The redesigned unit includes R-33 roof, R-20 wall, and R-22 floor insulation, 89.25 sq ft of double-glazed south windows, and insulated curtains.

The measured energy consumption was 2 to 3 times greater than estimated consumption. This difference probably resulted from the difference in anticipated and actual infiltration rates. The home was designed to have approximately 0.5 air changes/hr. The rate as measured by a blower door test was 1.25 air changes/hr. The authors suggest that better quality control of construction could reduce the infiltration.

The incremental construction cost for the conservation measures added beyond the reference home was estimated to be \$2551. Estimated annual incremental energy savings were \$266, assuming 0.5 air changes/hr. At the measured rate, 1.25 air changes/hr, actual savings will be less. Consequently, this mix of conservation measures is not especially cost-effective.

Another observation made by the authors is that exterior south side shading would be a desirable addition. Without the shading, some venting is required year round (even in winter months) to maintain interior comfort at 78°F.

APPENDIX B

ENERGY ASPECTS OF RESIDENTIAL STANDARDS REQUIREMENTS

APPENDIX B

ENERGY ASPECTS OF RESIDENTIAL STANDARDS REQUIREMENTS

B.1 INSULATION

B.1.1 Minimum Property Standards (Site-Built Homes)

I. Maximum U-Values^(a)

Building Component	Winter Degree Days			
	2500 or Less	2501 to 4500	4501 to 8000	8001 or More
Roof deck (incl. ceiling)	0.14 ^(b)	0.08	0.08	0.08
Ceiling	0.05	0.05	0.05	0.04
Masonry walls	0.10	0.10	0.10	0.10
Frame walls	0.08	0.08	0.08	0.08
Doors and windows ^(c)	1.13	1.13	0.69	0.69

(a) Does not include adjustments made for framing in walls, ceilings or floors.

(b) For mechanical cooling use 0.08.

(c) Maximum glass area cannot exceed 15% of the gross exterior wall area, except when solar heat gain exceeds 24 hour heat loss.

II. Floors over enclosed unheated space^(a)

Winter Degree Days	Maximum U-Value ^(b)
500 or less	0.36
1000	0.32
2000	0.26
3000	0.19
4000	0.12
4501 or more	0.08

(a) A space is considered unheated unless it is provided with a positive heat supply to maintain a minimum temperature of 50°F.

(b) A U-value for a specific amount of winter degree days can be interpolated.

III. Foundation walls of heated areas below grade - Must be insulated as indicated below when habitable rooms are provided or when more than 50% of the wall is exposed to outside air.

<u>Winter Degree Days</u>	<u>Maximum U-Value^(b)</u>
2500 or less	No requirements
2501 to 4500	0.24
4501 or more	0.17

IV. Crawl space - When used as a supply or return plenum, the crawl space perimeter wall shall be insulated to provide a maximum heat loss of 35 Btu/h per linear ft of perimeter wall, assuming a crawl space air temperature of 70°F for return plenums and 110°F for supply plenums.

V. Slab-on-grade floors - The thermal resistance around the perimeter of the floor shall be:

<u>Winter Degree Days</u>	<u>Minimum R Value^(a)</u>	
	<u>Heated Slab</u>	<u>Unheated Slab</u>
500 or less	2.8	--
1,000	3.5	--
2,000	4.0	--
2,500	4.4	2.5
3,000	4.8	2.8
4,000	5.5	3.5
5,000	6.3	4.2
6,000	7.0	4.8
7,000	7.8	5.5
8,000	8.5	6.2
9,000	9.2	6.8
10,000 or greater	10.0	7.5

(a) An R-value for a specific amount of winter degree days can be interpolated.

VI. Warm geographical locations - Insulation can be omitted from seasonal homes not intended for year-round occupancy.

VII. As an alternative, ASHRAE Standard 90-75 can be used in lieu of standards for building components.

B.1.2 ASHRAE 90A-80 (Site-Built Homes)

I. Walls - The combined U-values shall not exceed values in Figure B.1, using heating degree days from 1976 ASHRAE Handbook of Fundamentals. The gross area of exterior walls consists of all opaque areas (including foundation walls between floor spandrels, peripheral edges of floors, etc.), window areas (including sash), and door areas.

The following formula can be used to determine acceptable combinations to meet the requirements of Figure B.1:

ANNUAL FAHRENHEIT HEATING DEGREE DAYS (IN THOUS.) (65F BASE)

FIGURE B.1. U_0 Walls-Type "A" Buildings--Heating

$$U_0 = \frac{(U_{\text{wall}} * A_{\text{wall}}) + (U_{\text{fenestration}} * A_{\text{fenestration}}) + (U_{\text{door}} * A_{\text{door}})}{A_0}$$

where A_0 = gross area of exterior wall.

- II. Roof/Ceiling - The combined U_0 value shall not exceed values in Figure B.2, using heating degree days from the 1976 ASHRAE Handbook. If return air ceiling plenums are employed, the roof/ceiling assembly shall not include the ceiling proper nor the plenum space as part of the assembly when computing U_0 . When computing gross area, the gross area should be based on the interior face at the upper plenum surface. The following formula can be used to determine acceptable combinations for the required U_0 value:

$$\frac{(U_{\text{roof}} * A_{\text{roof}}) + (U_{\text{skylight}} * A_{\text{skylight}})}{A_0} = U_0$$

where A_0 = gross area of roof including skylight area.

If roof/ceiling assemblies in which the finished interior surface are essentially the underside of the roof (e.g., cathedral ceilings), the U_0 cannot exceed $0.08 \text{ Btu/ft}^2 \cdot \text{h} \cdot \text{F}$.

- V. Slab-on-grade floors - The R_0 value for the perimeter of the floor shall be as shown in Figure B.2.

FIGURE B.2. R-Values--Slab-on-Grade

- VI. Crawlspace - The exterior walls of crawl spaces used as plenums for supply or return air shall be insulated to provide a thermal resistance, excluding film resistances of

$$R = \frac{t}{47.3} \frac{M^2 \cdot C^2}{W}$$

where t = the design temperature differential between the air in the plenum and the outdoor air in °C.

VII. Warm geographical locations - Locations with less than 500°F heating degree days do not require insulation if only heating is provided. If cooling is provided, U_o must be between 0.30 and 0.38 Btu/ft²*h*deg F. Peripheral insulation required for slabs-on-grades or for unheated slabs in locations with less than 2,500°F degree days.

VIII. In general, calculations are to be performed as directed in the 1977 ASHRAE Handbook.

B.1.3. FmHA (Site-Built Homes)

NEW CONSTRUCTION

I. Maximum U-Values^(a)

Building Component	Winter Degree Days ^(b)				
	1000 or Less	1001 to 2500	2501 to 4500	4501 to 6000	6001 or More
Ceilings	0.05	0.04	0.03	0.03	0.026
Walls	0.08	0.07	0.05	0.05	0.05
Floors ^(c)	0.08	0.07	0.05	0.05	0.05
Glazing	1.13	0.69	0.69	0.47	0.47
Doors	--	--	-- ^(d)	Storm Door Req. ^(e)	Storm Door Req. ^(e)

(a) Does not include adjustments made for framing.

(b) As indicated in ASHRAE's Handbook of Fundamentals or any other source of degree day data.

(c) Floors over enclosed unheated space shall not exceed values listed.

(d) A storm door is required if the door core is hollow or if the door is over 25% glass.

(e) Conventional door/storm door combination can be substituted with a 1-3/4 in. metal faced door having the same overall U-value. Glazed areas must be double glazed.

II. Foundation wall sections of heated basement - Not containing habitable living area:

Winter-Degree Days	Maximum U-Value	Glazing ^(a)
2500 or less	Not req.	1.13
2501 to 4500	0.17	1.13
4501 or more	0.10	0.69

(a) Glazing in heated basement is limited to 5% of floor area.

III. Slabs-on-grade - Minimum R-values of perimeter insulation:

<u>Winter Degree Days</u>	<u>Minimum R-Values^(a)</u>	
	<u>Heated Slab</u>	<u>Unheated Slab</u>
500 or less	2.8	--
1,000	3.5	--
2,000	4.0	2.5
3,000	4.8	2.8
4,000	5.5	3.5
5,000	6.3	4.2
6,000	7.0	4.8
7,000	7.8	5.5
8,000	8.5	6.2
9,000	9.2	6.8
10,000 or more	10.0	7.5

(a) An R-value for a specific amount of winter degree days can be interpolated.

EXISTING CONSTRUCTION

<u>I. Building Component</u>	<u>1000 or Less</u>	<u>1001 to 2500</u>	<u>2501 to 4500</u>	<u>4501 to 6000</u>	<u>6001 to 7000</u>	<u>7001 or more</u>
Ceilings	0.05	0.04	0.03	0.03	0.26	0.26
Walls ^(a)						
Floors	0.08	0.07	0.05	0.05	0.05	0.05
Glazing	1.13	0.69	0.69	0.69	0.69	0.69
Doors	--	--	-- ^(b)	Storm Door ^(c)	Storm Door ^(c)	Storm Door ^(c)

(a) Walls shall be insulated as near to new construction as economically feasible.

(b) Storm door required if the door core is hollow or over 25% glass.

(c) Conventional door/storm door combination can be substituted with a 1-3/4 in. metal faced door having the same overall U-value. Glazed areas must be double glazed.

II. Foundation wall sections of heated basement - Not containing habitable living area:

<u>Winter Degree Days</u>	<u>Maximum U-Value</u>	<u>Glazing^(a)</u>
2500 or less	Not req.	1.13
2501 to 4500	0.17	1.13
4501 or more	0.10	0.69

(a) Limited to 5% of floor area.

- III. Slabs-on-grade - Insulation is required wherever practical in areas of 2500 or more winter degree days.

OPTIONAL STANDARDS - ALL CONSTRUCTION

- I. Total exterior wall area - shall have a combined U-value not to exceed the values shown in Figure B.5.

Equation 1, formula for determining combinations (see Figure B.3):

$$U_o = \frac{U_{\text{wall}} A_{\text{wall}} + U_{\text{window}} A_{\text{window}} + U_{\text{door}} A_{\text{door}}}{A_o}$$

FIGURE B.3. U_o -Value--Walls

- II. Total ceiling including skylights - shall have a combined U value not to exceed the values shown in Figure B.4.

Equation 2 formula for determining roof/ceiling combinations:

$$U_o = \frac{U_{\text{roof}} A_{\text{roof}} + U_{\text{skylight}} A_{\text{skylight}}}{A_o}$$

ANNUAL FAHRENHEIT HEATING DEGREE DAYS (65F BASE) (IN THOUS.)

FIGURE B.4. U_o -Value--Ceilings

B.1.4 Title VI (Manufactured Homes)

I. Zones ^(b)	Overall U-Values ^(a)	
	U_o -Required	U_o -Optional ^(c,d)
Zone I	0.157	0.145
Zone II	0.126	0.099
Zone III	0.104	0.087

(a) Including framing and internal and external ducts.

(b) See Figure 5.1.

(c) To be offered to the consumer as an option. If a vapor barrier is provided, then U_o values may be multiplied by 1.08 in Zone I and 1.15 in Zones II and III.

(d) Proposed regulatory change.

B.1.5 Title II-E (Manufactured Homes)

I. Overall U_o Values

Zones ^(a)	U_o ^(b)
Zone I	0.145
Zone II	0.099
Zone III	0.087

(a) See Figure 5.2.

(b) Shall be calculated in accordance with NFPA 501-BM-1976, "Mobile Home Heating, Cooling Load Calculations."

B.2 HEAT LOSS/GAIN CALCULATIONS

B.2.1 Minimum Property Standards (Site-Built Homes)

- I. Heat loss calculations - Made in accordance with the data and procedures contained in the current ASHRAE Handbook of Fundamentals, IBR Guides, ARI, SMACNA, NEMA, NESCA or NAHB Foundation's Insulation Manual.
- II. Winter design temperatures - Inside design temperatures shall not be less than 70°F. Outside design temperatures are those established by the ASHRAE Handbook of Fundamentals at the 97-1/2% design value for the location involved.
- III. Heat gain calculations - Shall be made in accordance with SMACNA, ARI, and NESCA manuals or the ASHRAE Guide.
- IV. Summer design temperatures - Inside design temperature shall be 75°F dry bulb.

Calculations should be made using the summer design dry bulb at 2-1/2% as shown in the current ASHRAE Handbook of Fundamentals.

B.2.2 ASHRAE 90A-80 (Site-Built Homes)

- I. Heating and cooling design temperatures - Calculated in accordance with procedures in the 1977 ASHRAE Handbook from the columns of 97-1/2% values for winter and 2-1/2% values for summer design temperatures. ASHRAE Standard 55-74, "Thermal Environmental Conditions for Human Occupancy," should be used to calculate indoor comfort conditions. Worksheets contained in ASHRAE 90A-80 can also be used to determine the exterior thermal design.
- II. Winter design temperature - For indoors must be 72°F.

III. Summer design temperature - For indoors must be 78°F.

IV. Air Infiltration - Shall be calculated by the procedures in the 1977 ASHRAE Handbook.

B.2.3 FmHA (Site-Built Homes)

Not specified; use Minimum Property Standards.

B.2.4 Title VI (Manufactured Homes)

I. Heat loss/gain calculations - To be made according to the ASHRAE Handbook of Fundamentals or the NFPA Manual for Mobile Home Heating and Cooling Calculations (NFPA 501 BM-1976). The NFPA manual gives more conservative results (proposed regulation). Calculations are currently based on the 1972 ASHRAE Handbook.

*In the absence of specific data-

The indoor winter design temperature must be 70°F.

Air infiltration heat loss calculation - Computed based on perimeter length and a temperature of 70°F minus the heating system capacity certification temperature.

Infiltration heat loss = $0.7(T)$ (ft of perimeter).

Framing areas are based on 15% of wall area minus window and doors plus 10% of the floor and ceiling area.

Air supply duct cavities are assumed to be living space temperatures. Heating losses (gains) to uninsulated ducts shall be calculated based on 130°F inside the duct in the winter, 60°F in the summer.

*In the absence of specific data (proposed regulation)-

Winter design temperature - refer to Figure 5.2.

	<u>Temperature (97.5%DB) -Outdoor</u>
Zone I	+15°F
Zone II	-5°F
Zone III	-20°F

Infiltration heat loss = $(0.018) (1.0 \text{ air changes/hr}) (\text{gross floor area}) (\text{ceiling height}) (T)$

where $T = 70^\circ\text{F}$ minus outdoor design temperature.

The framing areas are 10% to 15% wall area less windows and doors plus 7% to 10% of the floor and ceiling area, depending on the type of framing.

Air supply ducts cavities are assumed to be at living temperatures unless insulated. Heating losses (gains) to uninsulated ducts shall be calculated based on 130°F inside the duct in the winter, 60°F in the summer.

B.2.5 Title II-E (Manufactured Homes)

Not specified; use Title VI.

B.3 DUCT INSULATION

B.3.1 Minimum Property Standards (Site-Built Homes)

I. Ducts installed in unconditioned spaces shall have the thermal characteristics equivalent to:

1. 2 in. flexible blanket insulation when installed in ventilated areas.
2. 1 in. flexible blanket or 3/4 in. thick rigid insulation in unventilated spaces.
3. External insulation on ducts used for cooling shall be covered with a vapor barrier, maximum permeance of 0.5, and all joints must be sealed against vapor penetration. An aluminum foil vapor barrier must be at least 2 mil thick.
4. Insulation is not required on ducts in basements or unventilated crawl spaces having tightly closing ventilating louvers, a vapor barrier ground cover, and insulated perimeter walls.
5. Preformed ducts shall have average conductance C value of 0.23 with an air/vapor barrier not exceeding a permeance of 3.0.

II. Ducts shall be designed for the shortest practical run with a minimum amount of elbows.

B.3.2 ASHRAE 90A-80 (Site-Built Homes)

I. Supply ducts - Shall be insulated to provide an R-value (excluding film resistances) of

$$R = \frac{t \text{ (ft}^2 \cdot \text{h} \cdot \text{F)}}{15 \text{ Btu}}$$

where t = the design temperature differential between the air duct and the duct surface.

For residential buildings with uninsulated roofs over attics containing ducts, the air temperatures are:

Summer Conditions	<u>°F</u>
5 in 12 and up	130
3 in 12 to 5 in 12	140
Less than 3 in 12	150
Winter Conditions	--

Insulation not required where t is less than 25°F or where ducts are installed in insulated spaces.

B.3.3 FmHA (Site-Built Homes)

- I. Ducts shall be designed and installed in such a manner as to reduce leakage. All metal-to-metal connections shall be mechanically joined and taped.

B.3.4 Title VI (Manufactured Homes)

- I. Cooling ducts - Must be completely insulated (with R-4 insulation) and wrapped with a vapor retarder (1.0 perm) if exposed to outside air. Proposed Regulation - Zone I cooling ducts should be insulated and wrapped with a vapor barrier. The ducts including registers shall have a static pressure no greater than 0.3 inches of water (manometer at room temperature).
- II. Heating ducts - When exposed to outdoors, they must be insulated with R-4 insulation.

B.3.5 Title II-E (Manufactured Homes)

Not specified; use Title VI.

B.4 WINDOW/DOOR REQUIREMENTS

B.4.1 Minimum Property Standards (Site-Built Homes)

- I. Doors - Must be caulked with a nonhardening sealant. Weatherstripping must be provided and thresholds should be tight.
- II. Windows - Must be caulked with a nonhardening sealant. Weatherstripping must be provided.

B.4.2 ASHRAE 90A-80 (Site-Built Homes)

- I. Exterior joints that are sources of air leakage (e.g., window and door frames between wall and foundations, utility services through walls) must be caulked, gasketed, or otherwise sealed.

- II. Doors - Swinging and sliding doors shall be designed to limit air infiltration rate to $0.5 \text{ ft}^3/\text{min}$ per sq ft of door area.
- III. Windows - Shall be designed to limit air infiltration to $0.5 \text{ ft}^3/\text{min}$ per ft of sash crack.

B.4.3 FmHA (Site-Built Homes)

- I. Exterior joints around windows and door frames between wall activities and window or door frames, between wall panels, at penetrations of utility services through walls, floors and roofs and other exterior openings shall be caulked, gasketed, weather-stripped or otherwise sealed.
- II. Sliding glass doors - Air infiltration rate shall not exceed $0.5 \text{ ft}^3/\text{min}$ per sq ft of door area.
- III. Windows - Air infiltration rate shall not exceed $0.5 \text{ ft}^3/\text{min}$ per ft of sash crack.

B.4.4 Title VI (Manufactured Homes)

- I. Exterior wall covering and/or sheathing shall be properly installed so that air leakage around window and door frames is minimized. Joints not designed to limit air infiltration between wall-to-wall, wall-to-ceiling and wall-to-floor connections shall be caulked or otherwise sealed (proposed regulation).
- II. Windows - Air infiltration shall not exceed 0.5 cfm/sq ft of window area. Storm windows are required for Zones II and III.
- III. Doors - Should be weatherstripped. Air infiltration shall not exceed:
 - 1.35 cfm/sq ft of door area as of 1/1/75
 - 1.20 cfm/sq ft of door area as of 1/1/76
 - 1.00 cfm/sq ft of door area as of 1/1/77.

B.4.5 Title II-E (Manufactured Homes)

Not specified.

B.5 REQUIRED VENTILATION

B.5.1 Minimum Property Standards (Site-Built Homes)

I.	Natural Ventilation Opening as a % of Floor Area	Mechanical Changes, Air Changes per Hour
Living rooms	4	--
Dining rooms	4	--
Bedrooms	4	--
Kitchens	4 or	15 (exhaust fans)
Baths	4 or	9 (exhaust fans)
Laundry	--	--
Finished basement	1	--
Basementless spaces	1/150(a)	--(c)
Attic	1/150(b)	--(c)

- (a) Basementless spaces may have a free ventilating area of 1/1500 of the ground area when the surface is covered with a vapor barrier. These spaces shall be cross ventilated.
- (b) Can be less if a vapor barrier is installed on the warm side of a ceiling or 50% of the required ventilating area is provided with fixed louvers in the upper portion of the space to be ventilated, with the remainder of the required ventilation provided by eave or cornice vents.
- (c) Minimum air changes of 0.7 cfm (at 0.03 in. SP) per sq ft of attic floor area, plus 15% for dark roofs. One sq ft of free opening per 300 cfm of fan capacity.

B.5.2 ASHRAE 90A-80 (Site-Built Homes)

- I. Ventilation air shall conform to ASHRAE Standard 62-73, "Natural and Mechanical Ventilation."

B.5.3 FmHA (Site-Built Homes)

Not specified; use Minimum Property Standards.

B.5.4 Title VI (Manufactured Homes)

- I. Free air inlet - Must be connected to sealed-combustion furnaces to reduce formaldehyde levels especially in the winter. The inlet should provide a minimum of 25 cu ft/min of air when the furnace is operating.

B.5.5 Title II-E (Manufactured Homes)

Not specified; use Title VI.

B.6 HEATING SYSTEMS

B.6.1 Minimum Property Standards (Site-Built Homes)

- I. Not specified.

B.6.2 ASHRAE 90A-80 (Site-Built Homes)

I. Gas/oil-fired combustion efficiencies

HVAC System Heating Equipment--Gas- and Oil-Fired		
Minimum Steady-State Combustion Efficiencies		
Residential/Commercial Boilers and Furnaces		
	Residential	Residential/Commercial
Furnaces with inputs less than 65.9 kW (225,000 Btu/h)		Residential furnaces with inputs 65.9 kW (225,000 Btu/hr) up to 117 kW (400,000 Btu/hr)
Boilers with inputs less than 87.8 kW (300,000 Btu/h)		Residential boilers with inputs 87.8 kW (300,000 Btu/h) up to 117 kW (400,000 Btu/h)
In accordance with DOE test procedures		Commercial boilers and furnaces with inputs up to 117 kW (400,000 Btu)
	Types of Equipment	Steady-State Combustion Efficiencies, %
Forced-air furnaces and low-pressure steam or hot-water boilers	74	74
Gravity central furnaces and other vented home heating equipment	69	--

II. Heat pumps (electrically fired) minimum COP

HVAC System Heating Equipment and System Components, Electrically Driven (Heat Pumps) ^(a,b)			
	Air-Source		Water-Source
Heat Source Entering Temperature $^{\circ}\text{C}$ ($^{\circ}\text{F}$)	8.3 DB/6.1 WB (47 DB/43 WB)	-8.3 DB/-9.4 WB (17 DB/15 WB)	15.6 (70)
Beginning January 1, 1980	2.5	1.5	2.5
Beginning January 1, 1984	2.7	1.8	3.0

- (a) Equipment as listed in Table 6.9. All performances at sea level and exclude supplementary heat.
- (b) "Equipment" here refers to central heat pumps, both air-source and water-source; "components" refers to water-source heat pumps in hydronic systems.
- (c) For both central and hydronic system water-source heat pumps, the COP values in the table do not include the power consumed by the water pump. To determine total system performance, it is the system designer's responsibility to take this power consumption into account. In addition, new (fossil fuel or electric) energy supplied to a boiler or other water heating device to restore the water-source temperature entering the heat pump shall be taken into account by the system designer (see 6.7.3.1).
- (d) Any minimum efficiency standard(s) promulgated by the federal government may supersede such minimum values established in this table.

B.6.3 FmHA (Site-Built Homes)

Not specified.

B.6.4 Title VI (Manufactured Homes)

- I. Gas and oil burning furnaces - Shall have a flue loss of not more than:

<u>Effective Date</u>	<u>Maximum Allowable Flue Loss</u>
1/1/77	25%
1/1/76	30%

- II. Electric heat pumps shall have the following efficiencies:

<u>Effective Date</u>	<u>COP Outdoor Air Temperature</u>		
	<u>45°F</u>	<u>20°F</u>	<u>0°F</u>
1/1/77	2.2	1.4	Permit shutoff
1/1/80	2.5	1.7	1.0

- III. Proposed regulation eliminates appliance efficiency standards.

B.6.5 Title II-E Manufactured Homes)

Not specified.

B.7 COOLING SYSTEMS

B.7.1 Minimum Property Standards (Site-Built Homes)

- I. Insulation - Refrigerant lines shall be insulated with a minimum 3/8 in. thick material having a moisture and thermal transmission rate not in excess of 0.1 and 0.28, respectively. Chilled water lines must be insulated to a level of maximum conductance of $C = 0.6$.

B.7.2 ASHRAE 90A-80 (Site-Built Homes)

1. Central air conditioning COP

Effective Date	HVAC System Equipment, Electrically Driven ^(a) Minimum COP (EER)--(Cooling) ^(b,c,d,e)			
	Standard Rating Capacities			
	Under 19 kW (65,000 Btu/h)		19 kW (65,000 Btu/h) and Over	
	Air-Cooled	Evaporated or Water Cooled	Air-Cooled	Evaporated or Water Cooled
Beginning January 1, 1980	1.99 (6.8)	--	2.20 (7.5)	--
Beginning January 1, 1984	2.28 (7.8)	2.58 (8.8)	2.40 (8.2) ^(f)	2.69 (9.2)

- (a) Applies to equipment as listed for Table 6.1. All performances at sea level.
- (b) EER is Energy Efficiency Ratio, defined in Section 3; COP is defined in 6.3.3.
- (c) The Department of Energy has established required test procedures for single-phased, air-cooled residential central air conditioners under 19 kW (65,000 Btu/h) in capacity, which have been incorporated into ARI Standard 210-79; EER (COP) values in Table 6.2 are based on Test A of the DOE Test Procedures.
- (d) Any minimum efficiency standard(s) promulgated by the federal government may supersede minimum values, for the products to which they apply, established in this table. See 2.3.
- (e) For room air conditioners, DOE will base its weighted average annual efficiency on EER determined in accordance with ANSI Z 234.1-1972.
- (f) Applies when return-air fans are not included under the manufacturer's model number. When return-air fans are included, the required minimum values are 2.34(8.0).

II. HVAC System components electrically driven COP

Applied HVAC System Components, Electrically Driven ^(a) Minimum COP (EER)--Cooling ^(b)							
Water Chilling Packages						Hydronic Heat Pumps	
Condenser Cooling Means	Types ^(c)	Condenser Included		Condenserless		Water Source	
		Air	Water	Air	Water	Under 19 kW (65,000 Btu/h)	19 kW (65,000 Btu/h) and Over
Beginning January 1, 1980	C	2.28(7.8) ^(d)	3.98(13.6) ^(d)	--	--	--	--
	R	2.20(7.5)	3.40(11.6)	2.78(9.5)	3.40(11.6)	--	--
Beginning January 1, 1984	C	2.34(8.0) ^(d)	4.04(13.8) ^(d)	--	--	2.64(9.0)	2.75(9.4)
	R	2.46(8.4)	3.51(12.0)	2.90(9.9)	3.51(12.0)	--	--

- (a) Applies to equipment as listed in Table 6.3.1. All performances at sea level.
- (b) Performance of water-chilling packages does not include energy to drive chilled-water and condenser-water pumps, or cooling-tower fans; for hydronic heat pumps, it does not include the energy to drive circulating water pump(s) and cooling-tower fan(s), but does include the conditioned supply-air fan-motor energy when included as part of the model number of the heat pump. The system designer shall determine the amount of the non-included energies and take them into account in determining the HVAC System COP (EER) and annual energy consumption.
- (c) C = Centrifugal or Rotary Type (ARI Standard 550-77)
R = Reciprocating Type (ARI Standard 590-76).
- (d) Where double-bundle heat recovery is employed on centrifugal or screw compressor units, a lower EER is acceptable, provided that the gain by heat exchange exceeds the loss by lower EER (see 5.9).

III. Heat operated cooling equipment COP

HVAC System Cooling Equipment, Heat-Operated ^(a)	
Heat Source	
<u>Direct Fired</u> (Gas, Oil)	<u>Indirect Fired</u> (Steam, Hot Water)
0.48	0.68

(a) As listed in Table 6.6, At sea level.

(b) Minimum COP = $\frac{\text{Net Cooling Output}}{\text{Total Heat Input (Electrical Auxiliary Inputs Excluded)}}$

B.7.3 FmHA (Site-Built Homes)

Not specified; use Minimum Property Standards.

B.7.4 Title VI (Manufactured Homes)

- I. Energy Efficiency Ratios - For rated capacities less than 65,000 Btu/hr, shall show energy efficiency ratios are not less than:

<u>Date</u>	<u>EER</u>
1/1/77	6.5
1/1/80	7.2

Proposed regulations delete energy efficiency ratios.

B.7.5 Title II-E (Manufactured Homes)

Not specified; use Title VI.

B.8 HOT WATER SYSTEMS

B.8.1 Minimum Property Standards (Site-Built Homes)

- I. Supply and return piping - In unheated attic spaces, ventilated crawl spaces, and other exposed locations, shall be insulated with insulation having a conductance value C not exceeding 0.45. Insulation on heating piping in insulated crawl spaces may be omitted where closable vents are provided.

B.8.2 ASHRAE 90A-80 (Site-Built Homes)

- I. Supply piping insulation - see Table 1.

Insulation is not required for piping installed in insulated areas.

Minimum Pipe Insulation								
Piping System Types	Fluid Temperature °C	Range °F	Insulation Thickness for Pipe Sizes(a)					
			Runouts 2 in. (b)	1 in. and Less	1 1/4-2 in.	2 1/2-4 in.	5 and 6 in.	8 in. and Larger
Heating Systems								
Steam and Hot Water								
High Pressure/Temperature	152-238	306-450	1.5	2.5	2.5	3.0	3.5	3.5
Medium Pressure/Temperature	122-151	251-305	1.5	2.0	2.5	2.5	3.0	3.0
Low Pressure/Temperature	94-121	201-250	1.0	1.5	1.5	2.0	2.0	2.0
Low Temperature	49-93	120-200	0.5	1.0	1.0	1.5	1.5	1.5
Steam Condensate (for feed water)	Any	Any	1.0	1.0	1.5	2.0	2.0	2.0
Cooling Systems								
Chilled Water,	4.5-13	40-55	0.5	0.5	0.75	1.0	1.0	1.0
Refrigerant or Brine	Below 4.5	Below 40	1.0	1.0	1.5	1.5	1.5	1.5

(a) See 5.10.1 and 5.10.2 (pipe sizes are nominal dimensions). For piping exposed to ambient temperatures, increase thickness by 0.5 in.

(b) Runouts to individual terminal units (not exceeding 12 ft in length).

For materials with R-values greater than 4.6, insulation may be reduced as follows:

$$\frac{4.6 \times \text{Fig. 1 Thickness}}{\text{Actual R}} = \text{New minimum thickness}$$

For materials with R-values less than 4.0, insulation must be increased as follows:

$$\frac{4.0 \times \text{Fig. 1 Thickness}}{\text{Actual R}} = \text{New minimum thickness}$$

- II. Hot water heaters - Electric - Storage capacity of 450 L or less and an input rating of 12 kW or less shall have a standby loss not exceeding 4 W/ft² of tank surface area or 43 W, whichever is greater. Larger electric water heaters should have an R-value of at least 10 (ft²*h*F/Btu) and the same standby heating loss as the smaller electric water heaters.

Gas/Oil - Water heaters having an input rate of 75,000 Btu/hr or less shall have a recovery efficiency not less than 75% and a standing loss not exceeding $S = 2.3 + 67/V$ where V = rated vol in gallons and where S = %/hr of stored thermal energy.

All other gas water heaters should have a thermal efficiency of 75% and other oil water heaters should have a combustion efficiency of not less than 80%. Combustion efficiency equals 100 minus flue loss. Those heaters having less than 4,000 Btu/gal of self stored water shall also have a standby not exceeding $S = 2.8 + 0.002 Q/V$ where Q=input in kW. After 1/1/82 $S = 2.8 + 67/V$.

Gas and oil heaters having a higher input rate and having a pilot input rate greater than 0.5% of the maximum heater input rate shall be equipped with an ignition system which is not a continuously burning pilot. Design ambient temperature for water is set at 65°F.

- III. Conservation of hot water - showers shall have a maximum water discharge of 3 gpm.

B.8.3 FmHA (Site-Built Homes)

Not specified, use Minimum Property Standards.

B.8.4 Title VI (Manufactured Homes)

- I. Electric water heaters manufactured after 4/1/77 shall have a standby heat loss not exceeding 4 W/ft² of tank surface area.
- II. Gas and oil-fired water heaters shall have the following standby losses after 1/1/77:

<u>Storage</u>	<u>Recovery Efficiency</u>	<u>Standby Loss</u>
Less than 25 gal	At least 75%	Not more than 7.5%
25 - 35 gal	At least 75%	Not more than 7.0%
35 or more	At least 75%	Not more than 6.0%

B.8.5 Title II-E (Manufactured Homes)

Not specified.

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