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RESIDENTIAL SPACE HEATING AND COOLING IN NEW ENGLAND 1972-2000

RICHARD DAIFUKU

December 1976

MASTER

Prepared for the
DIVISION OF BUILDINGS AND COMMUNITY SYSTEMS
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ABSTRACT

The object of this report on Residential Space Heating and air conditioning in New England is to develop a model for predicting energy demand from this sector and for assessing energy conservation policy options. To this end, the housing stock is disaggregated by type and insulation levels. This allows the definition of targets for potential insulation retrofit program, and as a result of the dynamic nature of the model, older, poorly insulated housing is allowed to be replaced over time by new units of higher thermal integrity.

Under a set of assumptions, including those pertaining to system efficiencies, electric heat pump penetration, and likely energy conservation decisions, energy use in this sector demonstrates a slight decrease at the end use level between the years 1972 and 2000. This document has provided the methodology for a computerized simulation model of residential space heating and cooling being developed for the New England Energy Management Information System (NEMIS) at the Massachusetts Institute of Technology with a data base specific to each of the six New England States.

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TABLE OF CONTENTS

	Page
I. Introduction.....	vi
II. Prototypical housing units.....	1
III. Construction and thermal integrity of prototypical building structures.....	2
A. Insulation levels for SFD, SFA and MFLR.....	2
B. Insulation levels for MFHR and mobile homes.....	7
IV. New England's space heating and cooling energy requirements.....	10
V. Conclusion.....	15

APPENDICES

1. Design parameters for prototypical building structure.....	18
2. Coefficients of transmission for the structural components of prototypical buildings.....	25
3. Methodology for calculating heating and cooling requirements of building structures.....	32
4. Heating requirements of prototypical building structures.....	39
5. Cooling requirements of prototypical building structures.....	67
6. New England's inventory of residential housing.....	86
7. Fuel mix tables.....	90
8. Saturation levels of other residential energy uses.....	102

LIST OF TABLES

	Page
I. Existing ceiling insulation, Northeast.....	4
II. Insulation levels for prototypical SFD, SFA and MFLR.....	5
III. Minimum property standards, U-factor at 4501- 8000 degree days.....	6
IV. Presence of insulation, 1973.....	8
V. Insulation levels for prototypical MFHR.....	9
VI. Living unit space heating and cooling requirements....	11
VII. Housing age distribution.....	12
VIII. New England's space heating and cooling requirements 1972-2000.....	14

I. INTRODUCTION

Space heating and air conditioning account for 59.6% of the residential energy use nationally (Dole, 1975), and over 65% in New England (Lee, 1975). At a time of rising energy costs and energy scarcity, it becomes imperative to attempt to reduce consumption in this highly visible end use sector. This can be done by the retrofitting of existing housing with insulation and improving the thermal integrity of future housing. The ASHRAE 90-75 standard (Arthur D. Little, 1975), proposed for voluntary adoption by individual building regulatory authorities, is an example of the latter approach.

The purpose of this report is to develop a model of the total fuel demand for space heating and cooling of New England's housing stock over the period 1972-2000. This model relies on an exhaustive literature search of the construction characteristics of the present housing stock. Data on the insulation levels of existing building structures are not only presented on a regional level for an "average" structure, but are also sufficiently disaggregated to potentially allow for the determination of the energy conserved through an insulation retrofit program. In this model the characteristics of new construction are assumed to depend in the near future on the existing Minimum Property Standards, and in the longer term, on the likely strengthening of these standards and the adoption of state standards.

II. PROTOTYPICAL HOUSING UNITS

In calculating heating and cooling requirements for a region, it is essential to consider representative building categories. For the purposes of this model, housing is subdivided into the following categories:

- SFD: single family detached
- SFA: single family attached (1-4 units, attached)
- MFLR: multifamily low-rise (5-19 units)
- MFHR: multifamily high rise (20 units and over)
- Mobile homes

The model incorporates an increase in the surface area of dwellings over time for two housing types, SFA and SFD; all others are assumed invariant. Tyson (1975) derived the figures used here from information provided by the National Association of Home Builders.

The U.S. Bureau of Census (1975) reports an average of 70% of new, privately owned one-family homes in the Northeast to be frame construction. This proportion is presumably higher in New England. Thus, in agreement with the assumptions of Arthur D. Little (1974), all SFD, SFA and MFLR structures are considered to have frame construction and similar levels of insulation. Two other important characteristics are associated with these three building categories: a two story height and unheated basements. The average number of stories in New England for one-family homes is 1.76 (U.S. Department of Housing and Urban Development, 1973), and this will be approximated here by a two story height. Further, 90.7 percent of the buildings were found to have basements (U.S. Bureau of Census, 1970).

The MFHR is the only masonry structure considered in the model. This building type is assumed to have a heated basement. A detailed listing of all building structure characteristics may be found in Appendix 1.

III. CONSTRUCTION AND THERMAL INTEGRITY OF PROTOTYPICAL BUILDING STRUCTURES

Based on published characteristics of exterior surface, ceiling and floor construction (Arthur D. Little, 1974 and 1975; ASHRAE, 1972), it is possible to determine the overall coefficients of transmission or U-values* for a variety of surfaces. The total resistance to heat flow through a flat ceiling, floor or wall is equal numerically to the sum of the resistances in series:

$$R_T = \sum_{i=1}^n R_i$$

where: R_i = individual resistance of a component

R_T = total resistance

The resistance to heat flow is different in summer and in winter, significantly so in the vertical direction. This difference is partly the result of lower exterior wind speeds. Wind velocities of 15 mph are assumed for winter conditions and 7.5 mph for summer conditions. However, the difference is also a function of the direction of heat flow in air spaces. More resistance is offered to flow in the downward direction than in the upward direction. A detailed tabulation of the structural components used in calculating the coefficients of transmission is presented in Appendix 2.

A. INSULATION LEVELS FOR SFD, SFA AND MFLR

Data on insulation levels are very sparse, be it nationally or regionally. Whatever information is available suffers from a small sample size or is collected from respondents unrepresentative of the population at large. For example, the ceiling insulation levels reported by homeowners in Danbury, Connecticut, for a pilot project in energy conservation appear very high when compared to the available body of data (Federal Energy Administration, 1974). A recent

* The U-value is the overall coefficient of heat transmission, i.e., the time rate of heat flow expressed in Btu per (hour) x (square foot) x (Fahrenheit degree temperature difference between air on the outside of a wall, floor, roof or ceiling). The term is also applied to the usual combination of materials, and also single materials, such as window glass. The R-value is simply the reciprocal of U (ASHRAE, 1972). Fiberglass batts most commonly have R values of 5, 7, 11 and 19 with corresponding thicknesses of 1½, 2¼, 3½ and 6 inches.

survey of 4,200 homeowners, conducted by Owens Corning Fiberglass, was used as the basis for the determination of ceiling insulation levels (see Table I). This sample size is larger by more than one order of magnitude than the preceding, although the possibility remains that the thermal integrity of homeowners' dwellings differs from the remainder of housing stock. The insulation characteristics chosen for SFD, SFA and MFLR are shown in Table II and are consistent with known practice.

It is important to note that federal standards exist setting minimum levels of insulation, the minimum property standards (MPS) (see Table III). Although these standards only have a direct effect upon approximately 35 percent of all new construction in the United States, they have an indirect effect on virtually all construction. Few residential builders will fail to meet Federal Housing Administration (FHA) standards and thereby miss the opportunity to qualify for FHA financing; conversely few builders will exceed these standards because there is little economic advantage gained (New England Energy Policy Staff, 1973). All structures built after 1972 and all electrically heated buildings are assumed to meet or exceed present FHA insulation standards. The proportion of storm windows and doors, weatherstripping and caulking is assumed to be 100% for all new and electrically heated construction. A level of 75% storm windows and doors is representative of all other construction over time (Federal Energy Administration, 1974; Donovan and Fischer, 1976), as is a figure of 50% for weatherstripping and caulking (Donovan and Fischer, 1976).

Electrically heated homes tend to have higher insulation levels than fossil fuel heated homes. This reflects the need to offset the higher cost of electrical energy. Over 80% of the electric heating units present in New England in 1972 were installed after 1965 (Center for Energy Policy, 1976). Thus only post-1965 housing units are considered candidates for electrical heating.

Present wall construction uses 2 by 4 inch studs, thus allowing the placement of a maximum of 3.5 inches of fiberglass with a resistance (R) of eleven. Pre-1940 homes are broken down into two categories: insulated and uninsulated. Prior to 1940, walls were most often insulated with "granulated mineral wool." Granulated wool is loose wool that has been granulated and rolled into pellets of about half an inch in diameter. It was used principally for insulating buildings already constructed since it could be blown into spaces between studs by an air hose. In 1942, granulated wool was the most popular form of insulation and accounted for 48.2% of all sales by weight (U.S. Department of Commerce, 1947). However, blown-in insulation is known to settle over time and has a lower R-value than fiberglass batts (2.2 per inch versus 3.7 per

Table I

Existing Ceiling Insulation, Northeast¹

<u>Thickness of insulation (inches)</u>	<u>Percentage of homes</u>
None	14.5
2.25	10.6
3	21.2
3-4	6.4
4	26.1
5	10.0
6	11.2

¹Based on survey of 4,200 homeowners by Owens Corning Fiberglass

Table II

Insulation levels for prototypical SFD, SFA and MFLR

Category	Walls	Ceiling under Attic	Ground Floor	% Storm Windows	% Storm Doors
Post - 1972					
electric	R-11	R-24	Foil + R-5	100	100
fossil	R-11	R-19	Foil + R-5	100	100
1965-1972					
electric	R-11	R-19	Foil + R-5	100	100
fossil	R-11	R-19	Foil	75	75
1940-1965	R-7	R-11	R-0	75	75
Pre-- 1940					
with insulation	90% R-8 10% R-0	R-7	R-0	75	75
without insulation	R-0	R-0	R-0	75	75

Table III

Minimum property standardsU-factor at 4501 - 8000degree days¹

<u>Building Element</u>	<u>MPS 1 and 2 family</u>	<u>MPS multi-family</u>
Net wall:		
-frame	.08	.07
-masonry	.10	.12
Glazing:	.65	where more than 25% of exposed exterior wall is glass, at least ¼ of all glass surface shall be insulating glass or storm sash
Doors	.65	
Roof-Ceiling:		
-frame	.05 ²	.05
-masonry	.05	.05
Flat roof deck	.09	.12
Floor over unheated space:		
-wood and steel frame	.08	

¹The U-values do not include adjustments for framing.

²This corresponds to an insulation level of R-19-For post-1972 electrically heated homes, the requirement for 8001 or more degree-day areas was used, i.e., u=0.04 or R-24.

Sources: Cohen and White (1975)
U.S. Department of Housing and Urban Development (1974)

inch). Petersen (1974) estimates a minimum of 10% settling. Thus pre-1940 homes with insulated walls are assumed to have insulation levels equivalent to 90% R-8 and 10% R-0. The proportion of uninsulated buildings is presented in Table IV.

B. INSULATION LEVELS FOR MFHR AND MOBILE HOMES

The construction and thermal characteristics of the pre-1972 fossil-fuel heated MFHR in this model are similar to those proposed by Arthur D. Little (1974). The electrically heated buildings and all post-1972 MFHR are assumed to meet the MPS for multifamily dwellings (Table III). This requires insulation with urea-formaldehyde, as the space available between the furring is not sufficiently deep to allow the placement of fiberglass. Insulation levels for the prototypical MFHR are given in Table V.

All existing mobile homes are assumed to be similarly constructed. This is sufficiently accurate for our purposes since mobile homes have a relatively short life-time and thus a high turnover rate.

Table IV

Presence of insulation, 1973¹

(percent of households)

	<u>Single Family Homes²</u>	<u>Multi-Family Homes³</u>
with insulation ⁴	89%	66%
without insulation ⁴	11%	34%

1. Dwellings in areas with more than 5500 degree days.
2. Including mobile homes.
3. Data for multi-family homes were derived from data published for single family homes and "all households" by applying New England's housing composition.
4. The respondents unaware of the level of insulation in their homes were apportioned to those who did in the two categories "with insulation" and "without insulation".

Source: Washington Center for Metropolitan Studies' Lifestyles and Energy Surveys-Quoted in: Newman, D.K. and Day, D. The American energy consumer. Ballinger Publishing Company, Cambridge, Mass., 1975, p. 38.

Table V

Insulation levels for prototypical MFHR

<u>Category</u>	<u>Walls</u>	<u>Ceiling</u>	<u>% Storm Windows</u>
Post - 1972			
electric	R-5.25 ¹	2.5 in. ²	100
fossil	R-5.25	2.5 in.	50
Pre - 1972			
electric	R-5.25	2.5 in.	50
fossil	R-0	2 in.	50

¹ Thermal resistance value for 1.25 in. of area
formaldehyde.

² Roof insulation for flat decks.

IV. NEW ENGLAND'S SPACE HEATING AND COOLING ENERGY REQUIREMENTS

Once construction characteristics and insulation levels are known, it is straightforward to calculate heating and cooling requirements for each type of building structure. Appendix 3 explains the methodology used for the calculations, while Appendices 4 and 5 tabulate the results for heating and cooling, respectively. When the energy requirements of each structure are known, a division by the number of units comprising each structure type yields the heating and cooling requirements for each living unit, as presented in Table VI. The energy requirements are seen to decrease with increased insulation levels or aggregation of units within a structure. It should be noted that the comparatively large heating requirements of uninsulated buildings renders them the best targets for retrofitting of insulation or removal from the housing stock.

With the unit heating and cooling requirements calculated, it becomes possible to determine the requirements for the region based on the residential inventory of housing. New England's residential inventory was determined from the housing projections developed by Lee (1976). In order to acquire a breakdown of housing by type over time, data on new construction was used (Marcin, 1972 and 1975), under the assumption that houses built after 1939 were not removed from the inventory prior to 1972. The housing distribution obtained (see Appendix 6), if averaged over all housing types approximates very closely New England's present housing mix (see Table VII).

Based on the housing distribution, the average energy requirements of a living unit type, the unit basic demand, for a given year and fuel can be calculated. This is done in the fuel mix tables (see Appendix 7). When projecting energy demand to the year 2000, all new homes built after 1985 are assumed to consume 5% less energy than in 1972 because of improved design, and 2% less because of more efficient use of the structure, and existing structures to consume 3% less because of improved efficiency and 2% less for use.

The following assumptions were made to arrive at the heating and cooling system efficiencies presented in the fuel mix tables:

1. Heating Utilization Efficiencies

<u>Fuel Type</u>	<u>Heating Utilization Efficiencies</u>	
	<u>Existing Construction</u>	<u>New Construction</u>
Gas	0.60	0.70
Oil	0.50	0.60
Electricity (resistance)	1.00	1.00

Source: Adapted from Arthur D. Little (1974).

Table VI

Living Unit Space Heating and Cooling Requirements

<u>Living Unit</u>	<u>Heating Requirement (10⁶ BTU)</u>	<u>Cooling Requirement (10⁶ BTU)</u>
SFD		
1972-1985 electric	61.6	10.33
fossil	68.5	}
1965-1972 electric	63.0	
fossil	76.5	}
1940-1965	84.5	
Pre-1940 insulated	88.8	8.53
uninsulated	145.7	8.37
		9.59
SFA		
1972-1985 electric	37.3	6.35
fossil	42.3	}
1965-1972 electric	38.3	
fossil	48.0	}
1940-1965	61.4	
Pre-1940 insulated	66.2	6.20
uninsulated	103.3	6.33
		8.10
MFLR		
1972-1985 electric	27.0	4.88
fossil	30.9	}
1965-1972 electric	27.9	
fossil	35.3	}
1940-1965	47.1	
Pre-1940 insulated	49.9	5.16
uninsulated	81.1	5.37
		6.70
MFHR		
1972-1985 electric	23.0	}
fossil	31.2	
Pre-1972 electric	29.2	}
fossil	44.9	
Mobile electric	52.6	5.04
fossil	56.1	5.39
		5.64

Table VII

Housing Age Distribution

1. From the U.S. Bureau of Census (1972).

<u>Age group</u>	<u>Percentage of housing Units in each age group</u>
1965-70	10.1
1940-65	33.5
Pre-40	56.4

2. Derived from Marcin (1972 and 1975).

<u>Age group</u>	<u>Percentage of housing Units in each age group</u>
1965-72	12.0
1940-65	31.7
Pre-1940	56.3

All pre-1972 construction is considered "existing." An average utilization efficiency for the housing stock is calculated for 1985 and 2000 for each structure type. The period 1985 to 2000 witnesses the introduction of heat pumps. As a measure of the efficiency of heat pumps, the seasonal performance factor (S.P.F.) is used rather than the coefficient of performance (C.O.P.). The C.O.P. decreases as the outside temperature drops and thus heat pump are less efficient in colder climates. The S.P.F. for a heat-pump in the Boston area is 1.71 and this figure is applied to the New England region (Chan, 1974).

2. Cooling Coefficients Of Performance

<u>Air conditioning</u>		
<u>Coefficients of performance</u>		
<u>Year</u>	<u>Room</u>	<u>Central</u>
1972	1.82	1.99
1985	2.23	2.44
2000	2.75	3.01

Source: Derived from Arthur D. Little, 1974.

The efficiencies of air conditioning units are assumed to increase over time, given a reasonably active continuation of industry and government labeling.

The energy requirements calculated for cooling in appendix 5 relate only to central systems. Determining unit demands for room air conditioners requires different assumptions. In 1972, about 18% of all homes in New England were cooled by room air conditioners. Each home averaged 1.44 units, assuming 2.5 units per home with two or more units (U.S. Bureau of Census, 1972). This average is expected to increase to 1.66 units in 1985 and then remain stationary as central air conditioning and heat pumps become more prevalent. Dole (1975) has calculated that the average room unit has a capacity of 11,750 BTU/hr. Based on an 85% use factor, the unit demand of room air conditioners can be derived from the following equation:

$$E_u = .85 \times 11,750 \times Nu \times CH \times SA \div SA_{av}$$

where: Nu = number of units

CH = number of cooling hours per year

SA = average surface area of a living unit type for a given year

SA_{av} = average surface area of all living units for a given year

This equation assumes that the number of air-conditioner units is a function of the surface area of the living unit. The values of SA_{av} are as follows:

year:	1972	1985	2000
SA _{av} , feet ² :	1290	1381	1469

The final output that can be obtained from the fuel mix table is presented in Table VIII. This is a summation of energy requirements for heating and cooling over all housing types. The total fuel demand for space heating shows a small downward trend due to the increase in the thermal integrity of the housing stock and increased utilization efficiencies. However, this decrease would actually be an increase if generation efficiencies for electricity were included in the energy demand calculations.

Table VIII

New England's Space Heating and Cooling
Requirements 1972-2000 (10¹² BTU)

	<u>1972</u>	<u>1985</u>	<u>2000</u>
Space heating:			
-methane:	111.1	104.9	83.7
-distillate:	454.6	440.4	389.8
-electricity:	7.7	25.9	56.2
Total fuel demand for space heating:	573.4	571.2	529.7
Cooling:			
-electricity:	2.40	4.21	10.25
Total for space heating and cooling:	575.8	575.4	540.0

V. CONCLUSION

In this model of residential space heating and cooling in New England, the housing stock is divided into five building structure categories. These categories are further subdivided based on available data on the thermal integrity of the structures. Energy requirements within a given structure category vary widely depending on the levels of insulation. The uninsulated buildings in New England's housing stock have energy requirements that are more than double those of recent well insulated buildings. Fortunately, from an energy consumption standpoint, many of the uninsulated buildings will be removed from the housing stock over the time interval considered. An effective retrofitting program should be directed at improving the thermal integrity of the remainder and of pre-1965 homes generally. Economic analyses are necessary to determine the optimum levels of insulation for the region based on present and projected fuel prices, as well as the expected lifetime of the structures.

Knowledge of the residential housing inventory disaggregated by type of unit renders feasible the calculation of the total fuel demand for the region. This fuel demand is not only dependent on the mix of building structures and their thermal integrities, but also on the estimates of the fuel fractions and fuel utilization efficiencies.

With likely improvements in the thermal integrity of the housing stock and in fuel utilization efficiencies over the period 1972-2000, the overall energy requirements for space heating and cooling in New England show a downward trend at the end use level. However, this trend does not take into account the conversion efficiencies of electric power generation plants of the order of 30 to 40 percent. If such efficiencies were included in the model, the total energy consumption would in fact increase.

Although other residential energy uses, e.g., cooking, water heating and lighting have not been analyzed here, saturation levels for New England have been determined and are presented in Appendix 8.

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Appendix 1

Design Parameters for Prototypical Building Structures

Design Parameters Applicable to
all Structures (except where noted)

1. All windows are assumed to be 3 x 5 feet double hung.
Therefore the crack length is $(2 \times 5) + (3 \times 3)$ or 19 feet
and the frame length is approximated by $(2 \times 5) + (2 \times 3)$
or 16 feet.
2. All doors are assumed to be 3 x 6 $\frac{2}{3}$ feet or 20 feet²
and thus have a perimeter of 19 $\frac{1}{3}$ feet.
3. All structures having basements, i.e., excluding mobile
homes, have the following design parameters:
 - Area of basement windows: 2% of floor surface area
 - Net basement wall above grade = .25 (gross basement
wall area) - area of basement windows
 - Basement wall area below grade = .75 (gross basement
wall area).
4. SFD, SFA and MFLR structures are assumed to have a roof with
a 25° pitch.

*From Petersen (1974).

Design parameters for single-family
detached structure *

	<u>Pre-1940</u>	<u>1940-65</u>	<u>Post-1965</u>
Width x length x height, feet	20 x 30 x 18	21 x 31 x 18	23 x 35 x 18
Floor-ceiling area, feet ²	1200	1302	1610
Gross wall, feet ²	1800	1872	2088
Glazing (% of floor area)	12	12	15
Glass area, feet ²	144	156	242
Sash crack length, feet	182	198	307
Frame crack length, feet	154	166	258
Door area, feet ²	40	40	40
Door crack length, feet	39	39	39
Net wall, feet ²	1616	1676	1806
Roof area, feet ²	662	718	888
End walls of attic, feet ²	93	103	123
Area of basement windows, feet ²	12	13	16
Gross area basement wall, feet ²	700	728	812
Net wall above grade, feet ²	163	169	187
Wall below grade, feet ²	525	546	609

*Derived from Anderson (1973) and Arthur D. Little (1974).

Design parameters for single-family
attached structure *

3 units per building structure. **

	<u>Pre-1940</u>	<u>1940-65</u>	<u>Post-1965</u>
Area of each unit, feet ²	1054	1088	1188
Width x length x height of building, feet	51 x 31 x 20	51 x 32 x 20	54 x 33 x 20
Ceiling-floor area of building, feet ²	1581	1632	1782
Gross wall, feet ²	3280	3320	3480
Glazing (% of floor area)	10%	10%	10%
Glass surface area, feet ²	316	326	356
Sash crack length, feet	400	413	451
Frame crack length, feet	337	348	380
Door area, feet ²	120	120	120
Door crack length, feet	116	116	116
Net wall, feet ²	2844	2874	3004
Roof area, feet ²	1744	1801	1966
End walls of attic, feet ²	224	239	253
Area of basement windows, feet ²	32	33	36
Gross area basement wall, feet ²	1148	1162	1218
Net wall above grade, feet ²	255	257	268
Wall below grade, feet ²	861	872	914

*Derived from Hittman Associates (1974) and
Arthur D. Little (1974).

**Derived from U.S. Bureau of Census (1972).

Design Parameter for multi-family
low-rise structure*

10 units in building structure**

Area of each unit = 900 feet² + 126 feet² of public area.†

Width x length x height of building, feet	38 x 135 x 20
Ceiling-floor area of building, feet ²	5130
Gross wall, feet ²	6920
Glazing (% of sidewalls)	20
Glass area, feet ²	1080
Sash crack length, feet	1368
Frame crack length, feet	1152
Door area, feet ²	50
Door crack length, feet	48
Net wall, feet ²	5790
Roof area, feet ²	5790
End walls of attic, feet ²	337
Area of basement windows, feet ²	103
Gross area basement walls, feet ²	2422
Net wall above grade, feet ²	503
Wall below grade, feet ²	1816

*Derived from Hittman Associates (1974) and Arthur D. Little (1974).

**Derived from U.S. Bureau of Census (1972).

†Derived from Hittman Associates (1974).

Design parameters for multi-
family high-rise structure*

10 story building, 6 units per floor**

Masonry construction, flat deck roof and heated basement

Area of each unit: 900 feet² + 164 feet² of public area†.

Width x length x height of building, feet	76 x 84 x 100
Ceiling-floor area of building, feet ²	6384
Gross wall, feet ²	32,000
Glazing (% of wall area)	20
Glass area, feet ²	6,400
Sash crack length, feet	8,107
Frame crack length, feet	6,827
Door area, feet ²	60
Door crack length, feet	45
Net wall, feet ²	25,540
Area of basement windows, feet ²	128
Gross area of basement walls, feet ²	2240
Net wall above grade, feet ²	432
Wall below grade, feet ²	1680

*Derived from Hittman Associates (1974) and Arthur D. Little (1974).

**Derived from Arthur D. Little (1974).

†Derived from Hittman Associates (1974).

Design parameters for
mobile home*

Width x length x height, feet	12' x 60 x 7
Ceiling-floor area, feet ²	720
Cross wall, feet ²	1008
Glazing (% of floor area)	12
Glass surface area, feet ²	86
Sash crack length, feet	108
Frame crack length, feet	92
Door area, feet ²	20
Door crack length, feet	19
Net wall, feet ²	902

*Derived from Arthur D. Little (1974).

Appendix 2

Coefficients of Transmission for
the Structural Components of Prototypical
Buildings

Coefficients of transmission for the
structural components of SFD, SFA and MFLR

Coefficients of transmission of ceiling
and pitched roof

Roof

<u>Construction</u>	<u>Resistance (heating)</u>	<u>Resistance (cooling)</u>
Outside surface	.17*	.25**
Asphalt shingle	.44	.44
Building paper	.06	.06
Plywood deck (0.5 in.)	.62	.62
Inside surface	<u>.62</u>	<u>.83†</u>
	R = 1.91	r = 2.20
	u = .53	u = .45
Frame corrected (2 x 4 in. @ 16 in. interval)	u = .42	u = .35

Ceiling

<u>Construction</u>	<u>Resistance (heating)</u>	<u>Resistance (cooling)</u>
Attic surface	.61	.92
Metal lathe and 3/4 in. plaster	.47	.47
Inside surface	<u>.61</u>	<u>.92</u>
	R = 1.69	R = 2.31

*Winter conditions (15 mph wind)

**Summer conditions (7.5 mph wind)

†Value obtained by linear interpolation (roof assumed to have
25° pitch).

Coefficients of transmission of ceiling
with different levels of insulation

<u>Ceiling insulation level</u>	<u>ceiling u-value *</u>	
	<u>winter</u>	<u>summer</u>
R - 0	0.34	0.28
R - 7	0.11	0.10
R - 11	0.080	0.076
R - 19	0.051	0.050
R - 24	0.042	0.041

*Corrected for frame of 2 x 8 in. at 16 in. intervals.

Coefficients of transmission of
frame wall

<u>Construction</u>	<u>Level of insulation</u>		
	<u>R - 0</u>	<u>R - 7</u>	<u>R - 11</u>
Outside surface*	.17	.17	.17
Wood siding, $\frac{1}{2}$ in. x 8 in.	.81	.81	.81
Building paper	.06	.06	.06
Sheathing:			
plywood, $\frac{1}{2}$ in.	.62	--	--
asphalt impregnated, $\frac{1}{2}$ in.	--	1.32	1.32
Air space	.97	.97	0
Insulation	0	7	11
Dry wall:			
plaster, $3/4$ in.	.15	--	--
gypsum board	--	.45	.45
Inside surface	<u>.68</u>	<u>.68</u>	<u>.68</u>
	R=3.46	R=11.46	R=14.44
	u= .29	u= .09	u= .07
Frame corrected			
(2 x 4 in. @ 16 in. interval)	u= .26	u= .09	u= .073

*Only winter conditions are considered. The difference between winter and summer conditions for horizontal heat flow is insignificant.

Coefficients of transmission of
unheated basements

	<u>Floor R-value</u>		
	<u>No insulation</u>	<u>foil</u>	<u>foil + R-5</u>
Upper surface	.92	.92	.92
Floor finish*	.61	.61	.61
Plywood, 5/8 in.	.78	.78	.78
Wood subfloor	.94	.94	.94
Insulation**	0	6.4	11.4
Lower surface	<u>.92</u>	<u>.92</u>	<u>.92</u>
	R=4.17	R=10.95	R=15.95
	u= .24	u= .094	u=.064
Frame corrected	u= .18	u= .090	u=.065
(2 x 8 in. @ 16 in. interval)			

*Floor finish assumed to be 20% tile, 45% carpeted, and 35% hardwood. (ASHRAE, 1972 and U.S. Department of Housing and Urban Development, 1973.)

**Foil is considered to offer resistance to downward heat flow approximately equivalent to 2 in. of fiberglass. (Cohen and White, 1975, p. 54.)

II Coefficients of transmission for
structural components of MFHR

Walls

<u>Construction</u>	<u>Wall R - value</u>	
	<u>uninsulated</u>	<u>insulated</u>
Outside surface	0.17	0.17
4 in. brick	0.80	0.80
Air space	0.97	0.97
Concrete block	0.71	0.71
Air space	0.97	--
Insulation	--	5.25*
Gypsum wallboard	0.45	0.45
Inside still air	<u>0.68</u>	<u>0.68</u>
	R=4.75	R=9.03
	u=0.21	u= .11
Furring adjustment (1x1.5 in. @ 16 in. interval)	u=0.21	u= .12

*1½ in. of urea formaldehyde.

Roof

<u>Construction</u>	<u>Insulation thickness</u>			
	<u>Heating</u>		<u>Cooling</u>	
	<u>2 in.</u>	<u>2.5 in.</u>	<u>2 in.</u>	<u>2.5 in.</u>
Outside surface	0.17	0.17	0.25	0.25
Built up roofing, 3/8 in.	0.33	0.33	0.33	0.33
Insulation	5.56	6.67	5.56	6.67
Steel decking	0	0	0	0
Air space	.99	.99	2.30	2.30
Metal lath and 3/4 in plaster aggregate	0.13	0.13	0.13	0.13
Inside surface	<u>0.61</u>	<u>0.61</u>	<u>0.92</u>	<u>0.92</u>
	R = 7.79	R = 8.90	R = 9.49	R = 10.60
	U = 0.13	U = .11	U = .11	U = 0.094

III Coefficients of Transmission for the Structural Components of Mobile Homes

Walls

<u>Construction</u>	<u>Resistance</u>
Outside surface	0.17
Precoated aluminum siding	0.61
Fiberglass, 2.5 in.	7
Plywood, 1/8 in.	0.16
Inside surface	<u>0.68</u>
	R = 8.62
	U = .12

Ceiling

<u>Construction</u>	<u>Resistance</u>	
	<u>Heating</u>	<u>Cooling</u>
Outside surface	.17	.25
30 gauge steel roof	1.10	1.10
Fiberglass, 3.5 in.	11	11
Panels, 1/4 in.	.62	.62
Inside air	<u>.61</u>	<u>.92</u>
	R = 13.50	R = 13.89
	U = 0.074	0.072

Floor

<u>Construction</u>	<u>Resistance</u>	
	<u>Heating</u>	<u>Cooling</u>
Upper surface	.92	.61
Vinyl tile , 1/8 in.	.05	.05
Particle board	.82	.02
Fiberglass, 3/5 in.	11	11
Bottom surface	<u>.92</u>	<u>.61</u>
	R = 13.71	R = 13.09
	U = 0.073	R = 0.076

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Appendix 3 ..

Methodology for Calculating Heating and Cooling Requirements of Building Structures

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DETERMINATION OF HEATING REQUIREMENTS

Three basic heat flow components determine the heating requirement of a structure. Heat can be transmitted in or out of a building by conduction through a surface or through the infiltration of outside air and the exfiltration of inside air. The other component results from internal heat gain associated with the presence of occupants and the use of lights and appliances. These three modes of heat transfer will be analyzed in turn.

1. Transmission Heat Losses

Transmission heat losses, except for ceilings under attics or floors over unheated basements, are calculated by the following equation:

$$\text{Heat loss (BTU)} = U \times A \times HH \times \Delta T$$

$$\text{where: } U = U\text{-value (BTU/hr-ft}^2\text{-}^\circ\text{F)}$$

$$A = \text{surface area (ft}^2\text{)}$$

$$HH = \text{number of heating hours (5472 for New England)}$$

$$\Delta T = 65^\circ\text{F} - \frac{\text{degree days}}{\text{heating days}} \quad (28^\circ\text{F for New England)}$$

In the case of ceilings under attics or floors over basements, the temperature prevailing within the attic or basement must be calculated before the temperature differential is determined:

$$\Delta T = t_i - t_{a/b}$$

$$\text{where: } t_i = \text{inside air temperature} \\ (70^\circ\text{F is the value used by HUD)}$$

$$t_{a/b} = \text{temperature in attic or basement.}$$

To calculate the attic temperature, t_a , the following equation is used:

$$t_a = \frac{\frac{A_c U_c t_i + t_o A_r V_r + A_w U_w + 1.08 A_c V}{A_c U_c + A_r U_r + A_w U_w + 1.08 A_c V}}$$

$$\text{where: } t_a \text{ is computed at average } t_o = 65^\circ\text{F} - \frac{\text{degree days}}{\text{heating days}}$$

$$V = \text{ventilation rate (.1 ft}^3\text{/min./ft}^2\text{ ceiling)}$$

$$1.08 = \text{specific heat of air x density of air} \\ \text{x minutes per hour}$$

$$\text{and subscripts: } c = \text{ceiling} \\ r = \text{roof} \\ w = \text{end walls of attic}$$

The temperature of unheated basements, t_b is calculated by:

$$t_b = \frac{A_f U_f t_i + t_o A_G U_G + A_{w1} U_{w1} + t_g A_b U_b + A_{w2} U_{w2}}{A_f U_f + A_G U_G + A_{w1} U_{w1} + A_b U_b + A_{w2} U_{w2}}$$

where: t_g = ground water temperature (49.2°F for New England)

t_b is computed at average $t_o = 65^\circ - \frac{\text{degree days}}{\text{heating days}}$

$U_b = .1$

$U_{w1} = .5$

$U_{w2} = .2$

with subscripts: f = floor over basement

G = window

w1 = wall above grade

w2 = wall below grade

b = basement floor

The temperature differential, ΔT , can then be replaced in equation (1) using the appropriate U-value and area for the floor or ceiling (Petersen, 1974).

In the case of heated basements, heat loss through the walls above grade and windows are calculated by equation (1), based on the following coefficients of transmission:

$U_w = 0.5$

$U_G = 1.0$

However, heat losses through the basement and wall below grade are considered a simple function of the water temperature (ASHRAE, 1972, p. 378).

(BTU/ft ²)		
Ground Water	Basement floor loss	Below grade wall loss
Temperature		
49.2°F	2.08	4.16

2. Infiltration Heat Losses

Infiltration is the second component of transfer of heat to and from a residence. It takes place by way of air flow through openings in the external surfaces of the residence. Wind action and temperature differences between the interior and the exterior of the residence (chimney or stack effect) are the driving forces that are responsible for infiltration heat transfer (Anderson, 1973).

a. Wind forces. When a pressure difference between the inside and the outside of a building is the result of wind pressure, air will enter the building through openings in the wind-

- 35 -

equation is based on experimental measurements of actual homes and is of the form (Anderson, 1973):

$$I = A + BV + C |\Delta T|$$

where: I = infiltration rate, air changes per hour
V = wind speed, miles per hour
 ΔT = temperature difference between the interior of the residence and outside, $^{\circ}\text{F}$.
C = 0.00833

The last term of this linear equation measures the stack effect. Its use may have lead to an over estimation of infiltration since the wind effect was considered to be independent. This expression has been applied to all buildings, except the mobile home where it was neglected. Extrapolating this term to calculate the stack effect for the MFHR can only be considered a very rough approximation. While the stack effect demonstrates an increase with building height, it decreases with the increased integrity of each floor to infiltration, be it within or between floors.

c. Other infiltration. Other sources of infiltration arise from the use of mechanical ventilation and air breathing equipment. The daily average flow rates are shown in Table A and must be construed as rough approximations. They were originally calculated for a prototypical gas heated home and have been adapted for use with all the housing stock.

3. Internal Heat Load

The internal heat load is the sum of three major components: lighting, appliances and occupants. This heat load reduces heating requirements in winter and increases cooling loads in the summer. The calculation of the internal heat gain for a house in the Washington-Baltimore area with 200 heating days is 13.5×10^6 BTU. This was increased for the New England area to reflect the longer heating season. Further, an assumption was made that internal heat loads are proportional to the surface area. Thus the internal heat loads is assumed to be 9.09×10^3 BTU/sq ft/ heating season.

DETERMINATION OF COOLING REQUIREMENTS

The method for calculating cooling loads resembles closely that to calculate heating loads:

$$\text{Heat gain (BTU)} = U \times A \times CH \times \Delta T$$

Where: U = U-value ($\text{BTU/hr-ft}^2\text{-}^{\circ}\text{F}$)

A = surface area (ft^2)

CH = number of cooling hours (400 for New England).

Table A

Daily Average Air Flow Rates *

Mechanical ventilation (for both fossil fuel and electric heated homes)

Fans 12.0 CFM x .264** = 3.2 CFM
door openings 4.25 CFM/occupant†

Air Breathing Equipment (fossil fuel heated homes only)

Furnace 0.331 CFM/10⁶ BTU Heating Requirements
Hot water heater 2.12 CFM/Occupant

*Source = Adapted from Anderson, (1973) p. 33

** Saturation derived from FHA homes, (1973).

† SFD, SFA: 4 occupants/unit

MFLR: 3 occupants/unit

MFHR: 1.5 occupants/unit

MOBILE: 2 occupants/unit

ΔT = Temperature differential based on "Design equivalent temperature differences" (ASHRAE, 1972, p. 441, Table 50). Medium temperature ranges and a design temperature of 90°F were used for the walls, doors and flat roof.

Floors over basements do not contribute to cooling load requirements. However, in the case of ceilings under attics, it was necessary to take account of the temperature prevailing with the attic to calculate the temperature differential (Petersen, 1974, p. 56):

$$t_a = \frac{A_c U_c t_i + A_r U_r t_{sr} + A_w U_w t_{sw} + 1.08 A_c V t_o}{A_c U_c + A_r U_r + A_w U_w + 1.08 A_c V}$$

where: t_{sr} = sol air temperature equivalent of roof (110°F for New England)
 t_{sw} = sol air temperature equivalent of walls (91.1°F for New England)
 t_o = outside dry bulb temperature (90°F for New England)
 t_i = interior temperature (75°F)

Heat gain through windows was calculated by using a parameter dependent on the buildings orientation as well as the type of shading. Hittman Associates (1974) considers that 70% of the windows have drapes, 20% have shades and 10% are open. These same proportions were used to derive a value applicable to all housing type. The glazing distribution was then derived from the literature and field observation:

Type of Structure	N	Distribution of glazing	
		E-W	S
SFD	35%	25%	40%
SFA	37.5%	17.5%	45.0%
MFLR	45.0%	-----	55.0%
MFHR	42.5%	15.0%	42.5%
MOBILE	40.0%	20%	40.0%

Natural leakage in winter is much smaller than in summer. The chimney effect is, of course, absent in summer and the wind velocity is considered to be 50% lower. A value of 1.1 BTU/hr per square foot of exposed gross wall surface area is used to calculate natural infiltration (ASHRAE, 1972, p. 442).

The sum of the heat gain from the various structural components, the sensible heat gain, is multiplied by 1.105 to give the component load. This multiplier is itself the product of 1.3, to account for latent heat gain, and 0.85, a "use factor". Dole (1975) assumes an 85% use factor for air conditioners to account for the fact that many housing units are empty during the day. Finally, an internal heat gain factor is added to the component load based on assumptions similar to those for heating. The internal heat load is assumed to be 2.37×10^3 BTU/sq.ft/ cooling season.

Appendix 4

Heating Requirements of Prototypical Building Structures

<u>Structure Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>	<u>Heat Loss (10⁶ BTU)</u>
SFD	- walls					
	R-11	0.073	1806	5472	28	20.2
1972-1985	-ceiling roof					
electric	R-24	0.042	805	5472	39.3	7.3
	-basement floor					
	R-5 + foil	0.065	805	5472	24.2	6.9
	-windows					
	100% storm (metal)	0.56	242	5472	28	20.7
	-doors					
	100% storm	0.27	40	5472	28	1.7
	<u>Infiltration Heat Losses</u>	<u>B-coef. length</u>				
	-sash crack					
	weatherstrip	0.0954	307	5472	28	4.5
	-frame crack					
	caulk	0.0299	258	5472	28	1.2
	-door					
	weatherstrip	0.19	39	5472	28	1.1
	-stack effect					9.3
	-air breathing*					
	equipment					3.3
	<u>Internal Heat Load</u>					<u>-14.6</u>
	<u>Unit demand</u>					61.6

*Includes mechanical ventilation.

Structure Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
SFD	-walls					
	R-11	0.073	1806	5472	28	20.2
1972-1985	-ceiling roof					
fossil	R-19	0.051	805	5472	38.8	8.7
	-basement floor					
	R-5 + foil	0.065	805	5472	24.2	6.9
	-windows					
	100% storm (metal)	0.56	242	5472	28	20.7
	-doors					
	100% storm	0.27	40	5472	28	1.7
	<u>Infiltration Heat Losses</u>	<u>B. Coef.</u>	<u>Length</u>			
	-sash crack					
	weatherstrip	0.0954	307	5472	28	4.5
	-frame crack					
	caulk	0.0299	258	5472	28	1.2
	-door					
	weatherstrip	0.19	39	5472	28	1.1
	-stack effect					9.3
	-air breathing					
	equipment					8.8
	<u>Internal Heat Load</u>					<u>-14.6</u>
	<u>Unit demand</u>					68.5

Structure							Heat Loss
<u>Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>		<u>(10⁶ BTU)</u>
SFD	-walls						
	R-11	0.073	1806	5472	28	20.2	
1965-1972							
electric	-ceiling roof						
	R-19	0.051	805	5472	38.8	8.7	
	-basement floor						
	R-5 + foil	0.065	805	5472	24.2	6.9	
	-windows						
	100% storm (metal)	0.56	242	5472	28	20.7	
	-doors						
	100% storm	0.27	40	5472	28	1.7	
	<u>Infiltration Heat Losses</u>	<u>B.Coef .</u>	<u>Length</u>				
	-sash crack						
	weatherstrip	0.954	307	5472	28	4.5	
	-frame crack						
	caulk	0.0299	258	5472	28	1.2	
	-door						
	weatherstrip	0.19	39	5472	28	1.1	
	-stack effect					9.3	
	-air breathing						
	equipment					3.3	
	<u>Internal Heat Load</u>					- 14.6	
	<u>Unit demand</u>					63.0	

Structure Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
SFD	-walls					
	R-11	0.073	1806	5472	28	20.2
1965-1972	-ceiling roof					
fossil	R-19	0.051	805	5472	38.8	8.7
	-basement floor					
	Foil	0.090	805	5472	22.9	6.9
	-windows					
	75% storm (metal)	0.702	242	5472	28	26.0
	-doors					
	75% storm	0.31	40	5472	28	1.9
	<u>Infiltration Heat Losses</u>	<u>B Coef.</u>	<u>Length</u>			
	-sash crack					
	50% weatherstrip	.130	307	5472	28	6.1
	-frame crack					
	caulk	0.0299	258	5472	28	1.2
	-door crack					
	50% weatherstrip	0.259	39	5472	28	1.5
	-air breathing equipment					9.3
	-stack effect					9.3
	<u>Internal Heat Load</u>					<u>-14.6</u>
	<u>Unit demand</u>					76.5

Structure Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
SFD	-walls					
	R-7	0.09	1676	5472	28	23.1
1940-1965	-ceiling roof					
	R-11	0.08	651	5472	37.1	10.6
	-basement floor					
	R-0	0.18	651	5472	19.8	12.7
	-windows					
	75% storm (wood)	0.63	156	5472	28	15.1
	-doors					
	75% storm	0.31	40	5472	28	1.9
	<u>Infiltration Heat Losses B Coef. Length</u>					
	-sash crack					
	50% weatherstrip	0.266	198	5472	28	8.1
	-frame crack					
		0.1495	166	5472	28	3.8
	-door crack					
	50% weatherstrip	0.674	39	5472	28	4.0
	-air breathing equipment					9.5
	-stack effect					7.5
	<u>Internal Heat Load</u>					
						- 11.8
	<u>Unit demand</u>					
						84.5

Structure Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
SFD	-walls 90% R-8 10% R-0	0.11	1616	5472	28	27.2
Pre-1940 insulated	-ceiling roof R-7	0.11	600	5472	35.6	12.9
	-basement floor R-0	0.18	600	5472	20.0	11.8
	-windows 75% storm (wood)	0.63	144	5472	28	13.9
	-doors 75% storm	0.31	40	5472	28	1.9
	<u>Infiltration Heat Losses</u>	<u>B coef.</u>	<u>Length</u>			
	-sash crack 50% weatherstrip	.266	182	5472	28	7.4
	-frame crack	.1495	154	5472	28	3.5
	-door crack 50% weatherstrip	.674	39	5472	28	4.0
	-air breathing equipment					10.2
	-stack effect					6.9
	<u>Internal Heat Load</u>					<u>-10.9</u>
	<u>Unit demand</u>					88.8

Structure							Heat Loss
<u>Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>		<u>(10⁶ BTU)</u>
SFD	-walls						
	R-0	0.26	1616	5472	28		64.4
Pre-1940	-ceiling roof						
uninsulated	R-0	0.34	600	5472	27		30.1
	-basement floor						
	R-0	0.18	600	5472	20.0		11.8
	-windows						
	75% storm (wood)	0.63	144	5472	28		13.9
	-doors						
	75% storm	0.31	40	5472	28		1.9
	<u>Infiltration Heat Losses</u>	<u>B-coef.</u>	<u>Length</u>				
	-sash crack						
	50% weatherstrip	0.266	182	5472	28		7.4
	-frame crack						
		0.1495	154	5472	28		3.5
	-door crack						
	50% weatherstrip	0.674	39	5472	28		4.0
	-air breathing equipment						12.7
	-stack effect						6.9
	<u>Internal Heat Load</u>						<u>-10.9</u>
	<u>Unit demand</u>						145.7

Structure						Heat Loss
<u>Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>	<u>(10⁶ BTU)</u>
SFA	-walls					
	R-11	0.073	3004	5472	28	33.6
1972-1985	-ceiling roof					
electric	R-24	0.042	1782	5472	39.3	16.1
	-basement floor					
	R-5 + foil	0.065	1782	5472	22.6	14.4
	-windows					
	100% storm (metal)	0.56	356	5472	28	30.5
	-doors					
	100% storm	0.27	120	5472	28	5.0
	<u>Infiltration Heat Losses</u>	<u>B-coef.</u>	<u>Length</u>			
	-sash crack					
	weatherstrip	0.0954	451	5472	28	6.6
	-frame crack					
	caulk	0.0299	380	5472	28	1.7
	-door crack					
	weatherstrip	0.19	116	5472	28	3.4
	-air breathing					
	equipment (includes mechanical ventilation)					10.0
	-stack effect					22.9
	<u>Internal Heat Load</u>					<u>-32.4</u>
	<u>Unit demand</u>					111.8

<u>Structure</u> <u>Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>	<u>Heat Loss</u> <u>(10⁶ BTU)</u>
SFA	-walls					
	R-11	0.073	3004	5472	28	33.6
1972-1985	-ceiling roof					
fossil	R-19	0.051	1782	5472	38.8	19.3
	-basement floor					
	R- 5 + foil	0.065	1782	5472	22.6	14.4
	-windows					
	100% storm (metal)	0.56	356	5472	28	30.5
	-doors					
	100% storm	0.27	120	5472	28	5.0
	<u>Infiltration Heat Losses</u>	<u>B-coef.</u>				
	-sash crack					
	weatherstrip	0.0954	451	5472	28	6.6
	-frame crack					
	caulk	0.0299	380	5472	28	1.7
	-door crack					
	weatherstrip	0.19	116	5472	28	3.4
	-air breathing					
	equipment					21.0
	-stack effect					22.9
	<u>Internal Heat Load</u>					<u>-32.4</u>
	<u>Unit demand</u>					126.8

Structure	Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
SFA	-walls						
	R-11		0.073	3504	5472	28	33.6
1965-1972	-ceiling roof						
electric	R-19		0.051	1782	5472	39.3	19.3
	-basement floor						
	R-5 + foil		0.065	1782	5472	22.6	14.4
	-windows						
	100% storm (metal)		0.56	356	5472	28	30.5
	-doors						
	100% storm		0.27	120	5472	28	5.0
	<u>Infiltration Heat Losses</u>		<u>B-Coef. Length</u>				
	-sash crack						
	weatherstrip		0.0954	451	5472	28	6.6
	-frame crack						
	caulk		0.0299	380	5472	28	1.7
	-door crack						
	weatherstrip		0.19	116	5472	28	3.4
	-air breathing						
	equipment						10.0
	-stack effect						22.9
	<u>Internal Heat Load</u>						<u>-32.4</u>
	<u>Unit demand</u>						115.0

<u>Structure</u> <u>Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>	<u>Heat Loss</u> <u>(10⁶ BTU)</u>
SFA	-walls					
	R-11	0.073	3004	5472	28	33.6
1965-1972	-ceiling roof					
fossil	R-19	0.051	1782	5472	39.3	19.3
	-basement floor					
	Foil	0.090	1782	5472	21.2	18.6
	-windows					
	75% storm (metal)	0.702	356	5472	28	38.3
	-doors					
	75% storm	0.31	120	5472	28	5.7
	<u>Infiltration Heat Losses</u>	<u>B-coef.</u>	<u>Length</u>			
	-sash crack					
	50% weatherstrip	0.13	451	5472	28	9.0
	-frame crack					
	caulk	0.0299	380	5472	28	1.7
	-door crack					
	50% weathercrack	0.259	116	5472	28	4.6
	-air breathing					
	equipment					22.7
	-stack effect					22.9
	<u>Internal Heat Load</u>					<u>-32.4</u>
	<u>Unit demand</u>					144.0

Structure							Heat Loss
<u>Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>		<u>(10⁶ BTU)</u>
SFA	-walls						
	R-7	0.09	28.74	5472	28		39.6
1940-1965	-ceiling roof						
	R-11	0.08	1632	5472	37.2		26.6
	-basement floor						
	R-0	0.18	1632	5472	17.4		28.0
	-windows						
	75% storm (wood)	0.63	326	5472	28		31.5
	-doors						
	75% storm	0.31	120	5472	28		5.7
	<u>Infiltration Heat Losses</u>	<u>B-coef.</u>	<u>Length</u>				
	-sash crack						
	50% weatherstrip	0.266	413	5472	28		16.8
	-frame crack						
		0.1495	348	5472	28		8.0
	-door crack						
	50% weatherstrip	0.674	117	5472	28		12.1
	-air breathing equipment						24.6
	-stack effect						21.0
	<u>Internal Heat Load</u>						<u>-29.7</u>
	<u>Unit Demand</u>						184.2

<u>Structure Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>	<u>Heat Loss (10⁶ BTU)</u>
SFA	-walls					
	90% R-8 10% R-0	0.11	2844	5472	28	47.9
Pre-1940	-ceiling roof					
insulated	R-7	0.11	1581	5472	35.6	33.8
	-basement floor					
	R-0	0.18	1581	5472	17.5	27.3
	-windows					
	75% storm (wood)	0.63	316	5472	28	30.5
	-doors					
	75% sotrm	0.31	120	5472	28	5.7
	<u>Infiltration Heat Losses</u>	<u>B-Coef.</u>	<u>Length</u>			
	-sash crack					
	50% weatherstrip	.266	400	5472	28	16.3
	-frame crack					
		.1495	337	5472	28	7.7
	-door crack					
	50% weatherstrip	.674	117	5472	28	12.1
	-air breathing equipment					26.2
	-stack effect					19.7
	<u>Internal Heat Load</u>					<u>-28.7</u>
	<u>Unit demand</u>					198.5

Structure		Transmission Heat Losses		U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
Category								
SFA	-walls							
	R-0			0.26	2844	5472	28	113.3
Pre-1940								
insulated	-ceiling roof							
	R-0			0.34	1581	5472	26.8	79.2
	-basement floor							
	R-0			0.18	1581	5472	17.5	27.3
	-windows							
	75% storm (wood)			0.63	316	5472	28	30.5
	-doors							
	75% storm			0.31	120	5472	28	5.7
	<u>Infiltration Heat Losses</u> B-Coef. Length							
	-sash crack							
	50% weatherstrip			.266	400	5472	28	16.3
	-frame crack							
				.1495	337	5472	28	7.7
	-door crack							
	50% weatherstrip			.674	117	5472	28	7.7
	-air breathing							
	equipment							31.3
	-stack effect							19.7
	<u>Internal Heat Load</u>							
								-28.7
	<u>Unit demand</u>							
								310.0

Structure						
<u>Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>	<u>Heat Loss (10⁶ BTU)</u>
MFLR	-walls					
	R-11	0.073	5790	5472	28	64.8
1972-1985	-ceiling roof					
electric	R-24	0.042	5130	5472	39.2	46.2
	-basement floor					
	R-5 + foil	0.065	5130	5472	21.2	38.7
	-windows					
	100% storm (metal)	0.56	1080	5472	28	92.7
	-doors					
	100% storm	0.27	50	5472	28	2.1
<u>Infiltration Heat Losses</u>						
		<u>B-Coef.</u>	<u>Length</u>			
	-sash crack					
	weatherstrip	0.0954	1368	5472	28	20.0
	-frame crack					
	caulk	0.0299	1152	5472	28	5.3
	-door crack					
	weatherstrip	0.19	48	5472	28	1.4
	-air breathing					
	equipment					26.4
	-stack effect					65.9
<u>Internal Heat Load</u>						<u>-93.2</u>
<u>Unit Demand</u>						270.3

Structure	Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
MFLR	-walls						
	R-11		0.073	5790	5472	28	64.8
1972-1985	-ceiling roof						
fossil	R-19		0.051	5130	5472	38.7	55.3
	-basement floor						
	R-5 + foil		0.065	5130	5472	21.2	38.7
	-windows						
	100% storm (metal)		0.56	1080	5472	28	92.7
	-doors						
	100% storm		0.27	50	5472	28	2.1
	<u>Infiltration Heat Losses</u>		<u>B-Coef.</u>	<u>Length</u>			
	-sash crack						
	weatherstrip		0.0954	1368	5472	28	20.0
	-frame crack						
	caulk		0.0299	1152	5472	28	5.3
	-door crack						
	weatherstrip		0.19	48	5472	28	1.4
	-air breathing						
	equipment						55.9
	-stack effect						65.9
	<u>Internal Heat Load</u>						<u>-93.2</u>
	<u>Unit demand</u>						308.9

Structure Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
MFLR	-walls					
	R-11	0.073	5790	5472	28	64.8
1965-1972	-ceiling roof					
electric	R-19	0.051	5130	5472	38.7	55.3
	-basement floor					
	R-5 + foil	0.065	5130	5472	21.2	38.7
	-windows					
	(100% storm) metal	0.56	1080	5472	28	92.7
	-doors					
	100% storm	0.27	50	5472	28	2.1
	<u>Infiltration Heat Losses</u>	<u>B-Coef.</u>	<u>Length</u>			
	-sash crack					
	weatherstrip	0.0954	1368	5472	28	20.0
	-frame crack					
	caulk	0.0299	1152	5472	28	5.3
	-door crack					
	weatherstrip	0.19	48	5472	28	1.4
	-air breathing					
	equipment					26.4
	-stack effect					65.9
	<u>Internal Heat Load</u>					<u>-93.2</u>
	<u>Unit demand</u>					279.4

<u>Structure Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>	<u>Heat Loss (10⁶ BTU)</u>
MFLR	-walls					
	R-11	0.073	5790	5472	28	64.8
1965-1972						
fossil	-ceiling roof					
	R-19	0.051	5130	5472	38.7	55.3
	-basement floor					
	Foil	0.090	5130	5472	19.5	49.3
	-windows					
	75% storm (metal)	0.702	1080	5472	28	116.2
	-doors					
	75% storm	0.31	50	5472	28	2.4
	<u>Infiltration Heat Losses</u>	<u>B-Coef.</u>	<u>Length</u>			
	-sash crack					
	50% weatherstrip	0.13	1368	5472	28	27.2
	-frame crack					
	caulk	0.0299	1152	5472	28	5.3
	-door crack					
	50% weatherstrip	0.259	48	5472	28	1.9
	-air breathing equipment					58.2
	-stack effect					65.9
	<u>Internal Heat Load</u>					<u>-93.2</u>
	<u>Unit demand</u>					353.3

Structure							
<u>Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>	<u>Heat Loss</u> <u>(10⁶ BTU)</u>	
MFLR	-walls						
	R-7	0.09	5790	5472	28	79.8	
1940-1965	-ceiling roof						
	R-11	0.08	5130	5472	36.9	82.8	
	-basement floor						
	R-0	0.18	5130	5472	15.4	77.8	
	-windows						
	75% storm (wood)	0.63	1080	5472	28	104.2	
	-doors						
	75% storm	0.31	50	5472	28	2.4	
	<u>Infiltration Heat Losses</u>	<u>B-Coef.</u>	<u>Length</u>				
	-sash crack						
	50% weatherstrip	0.266	1368	5472	28	55.7	
	-frame crack						
		0.1495	1152	5472	28	26.4	
	-door crack						
	50% weatherstrip	0.674	48	5472	28	5.0	
	-air breathing equipment					64.3	
	-stack effect					65.9	
	<u>Internal Heat Load</u>					<u>-93.2</u>	
	<u>Unit Demand</u>					471.1	

<u>Structure Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>	<u>Heat Loss (10⁶ BTU)</u>
MFLR	-walls 90% R-8 10% R-0	0.11	5790	5472	28	97.6
Pre-1940 insulated	-ceiling roof R-7	0.11	5130	5472	35.4	109.3
	-basement floor R-0	0.18	5130	5472	15.4	77.8
	-windows 75% storm (wood)	0.63	1080	5472	28	104.2
	-doors 75% storm	0.31	50	5472	28	2.4
	<u>Infiltration Heat Losses</u>	<u>B-Coef.</u>	<u>Length</u>			
	-sash crack 50% weatherstrip	0.266	1368	5472	28	55.7
	-frame crack	0.1495	1152	5472	28	26.4
	-door crack 50% weatherstrip	0.674	48	5472	28	5.0
	-air breathing equipment					65.7
	-stack effect					65.9
	<u>Internal Heat Load</u>					<u>-93.2</u>
	<u>Unit demand</u>					499.0

<u>Structure</u> <u>Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>	<u>Heat Loss</u> <u>(10⁶ BTU)</u>
MFLR	-walls					
Pre-1940	R-0	0.26	5790	5472	28	230.7
uninsulated	-ceiling roof					
	R-0	0.34	5130	5472	26.6	254.1
	-basement floor					
	R-0	0.18	5130	5472	15.4	77.8
	-windows					
	75% storm (wood)	0.63	1080	5472	28	104.2
	-doors					
	75% storm	0.31	50	5472	28	2.4
	<u>Infiltration Heat Losses</u>	<u>B-Coef.</u>	<u>Length</u>			
	-sash crack					
	50% weatherstrip	.266	1368	5472	28	55.7
	-frame crack					
		.1495	1152	5472	28	26.4
	-door crack					
	50% weatherstrip	.674	48	5472	28	5.0
	-air breathing equipment					82.0
	-stack effect					65.9
	<u>Internal Heat Load</u>					<u>-93.2</u>
	<u>Unit demand</u>					811.0

Structure	Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
MFHR	-walls						
	Masonry-insulated		.12	25540	5472	28	469.6
1972-1985	-ceiling roof						
electric	flat deck (2.5" insulation)		.11	6384	5472	28	107.6
	-basement floor						
	Heated						163.6
	-windows						
	100% storm (metal)		.56	6400	5472	28	549.1
	-doors						
	solid wood		.43	20	5472	28	1.3
	vestibule ~ storm		.27	40	5472	28	1.7
	<u>Infiltration Heat Losses</u>		<u>B-Coef.</u>	<u>Length</u>			
	-sash crack		.1015	8107	5472	28	126.1
	-frame crack						
	caulk		.0299	6827	5472	28	31.3
	-door crack						
	solid wood		.418	19	5472	28	1.2
	storm		.293	26	5472	28	1.2
	-air breathing						
	equipment						95.1
	-stack effect						410.2
	<u>Internal Heat Load</u>						<u>-580.0</u>
	<u>Unit Demand</u>						1378.0

Structure Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
MFHR	-walls					
	R-5 masonry	.12	25.540	5472	28	469.6
1972-1985	-ceiling roof					
fossil	Flat deck (2.5" insulation)	.11	6384	5472	28	107.6
	-basement floor Heated					163.6
	-windows					
	50% storm (metal)	.845	6400	5472	28	828.6
	-doors					
	solid wood	.43	20	5472	28	1.3
	vestibule ~ storm	.27	40	5472	28	1.7
	<u>Infiltration Heat Losses</u>	<u>B-Coef.</u>	<u>Length</u>			
	-sash crack	.1775	8107	5472	28	220.5
	-frame crack caulk	0.0299	6827	5472	28	31.3
	-door crack					
	solid wood	.418	19	5472	28	1.2
	storm	.293	26	5472	28	1.2
	-air breathing equipment					218.1
	-stack effect					410.2
	<u>Internal Heat Load</u>					<u>-580.0</u>
	<u>Unit Demand</u>					1874.9

Structure Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
MFHR	-walls					
	R-5 masonry	.12	25,540	5472	28	469.6
Pre-1972	-ceiling roof					
electric	Flat deck (2.5" insulation)	.11	6384	5472	28	107.6
	-basement floor heated					163.6
	-windows					
	50% storm (metal)	.845	6400	5472	28	828.6
	-doors					
	solid wood	.43	20	5472	28	1.3
	vestibule ~ storm	.27	40	5472	28	1.7
	<u>Infiltration Heat Losses</u>	<u>B-coef.</u>	<u>Length</u>			
	-sash crack	.1775	8107	5472	28	220.5
	-frame crack caulk	0.0299	6827	5472	28	31.3
	-door crack					
	solid wood	.418	19	5472	28	1.2
	storm	.293	26	5472	28	1.2
	-air breathing equipment					95.1
	-stack effect					410.2
	<u>Internal Heat Load</u>					<u>-580.0</u>
	Unit demand					1751.9

Structure							Heat Loss
<u>Category</u>	<u>Transmission Heat Losses</u>	<u>U-Value</u>	<u>Area</u>	<u>HH</u>	<u>ΔT</u>		<u>(10⁶ BTU)</u>
MFHR	-walls						
	masonry	.21	25540	5472	28		821.8
Pre-1972							
fossil	-ceiling - roof						
	flat deck (2"						
	insulation)	.13	6384	5472	28		127.2
	-basement floor						
	heated						163.6
	-windows						
	50% storm (wood)	.76	6400	5472	28		745.2
	-doors						
	solid wood	.43	20	5472	28		1.3
	vestibule storm	.27	40	5472	28		1.7
	<u>Infiltration Heat Losses</u>	<u>B-coef.</u>	<u>Length</u>				
	-sash crack	.4435	8107	5472	28		550.9
	-frame crack	.1495	6827	5472	28		156.4
	-door crack						
	solid wood	1.33	19	5472	28		3.9
	storm	.655	26	5472	28		2.6
	-air breathing						
	equipment						290.2
	-stack effect						410.2
	<u>Internal Heat Load</u>						<u>-580.0</u>
	Unit demand						2696.0

Structure Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10 ⁶ BTU)
Mobile	-walls	.12	902	5472	28	16.6
electric	-ceiling-roof	.074	720	5472	28	8.2
	-basement floor	.073	720	5472	28	8.1
	-windows metal	1.13	86	5472	28	14.9
	-doors solid wood	.43	20	5472	28	1.3
	<u>Infiltration Heat Losses</u>	<u>B-coef.</u>	<u>Length</u>			
	-sash crack	.209	108	5472	28	3.5
	-frame crack	.1495	92	5472	28	2.1
	-door crack	.874	19	5472	28	2.5
	-air breathing equipment					1.9
	-stack effect					-----
	<u>Internal Heat Load</u>					<u>-6.5</u>
	Unit demand					52.6

Structure Category	Transmission Heat Losses	U-Value	Area	HH	ΔT	Heat Loss (10^6 BTU)
Mobile	-walls	.12	902	5472	28	16.6
fossil	-ceiling roof	.074	720	5472	28	8.2
	-basement floor	0.073	720	5472	28	8.1
	-windows metal	1.13	86	5472	28	14.9
	-doors solid wood	.43	20	5472	28	1.3
	<u>Infiltration Heat Losses</u>	<u>B-coef. Length</u>				
	-sash crack	.209	108	5472	28	3.5
	-frame crack	.1495	92	5472	28	2.1
	-door crack	.874	19	5472	28	2.5
	-air breathing equipment					5.4
	-stack effect					----
	<u>Internal Heat Load</u>					<u>-6.5</u>
	Unit demand					56.1

Appendix 5

Cooling Requirements of Prototypical Building Structures

<u>Structure</u> <u>Category</u>	<u>Transmission Heat Gain</u>	<u>U-Value</u>	<u>Area</u>	<u>CH</u>	<u>ΔT</u>	<u>Heat Gain</u> <u>(10⁶ BTU)</u>
SFD	-walls					
	R-11	0.073	1806	400	18.6	.98
1972-1985	-ceiling roof					
electric	R-24	0.041	805	400	27.5	.37
	-windows					
	x30.5		242	400		2.95
	-doors					
		0.42	40	400	18.6	.12
<u>Infiltration Heat Gain</u>						
	x1.1		2088	400		.92

Σ = 5.34

	<u>x1.105</u>
Component load	5.90
+Internal heat load	<u>4.43</u>
Unit demand	10.33

Structure Category	Transmission Heat Gain	U-Value	Area	CH	ΔT	Heat Gain (10^6 BTU)
SFD	-walls					
	R-11	0.073	1806	400	18.6	.98
1965-1972 and 1972-85						
	-ceiling roof					
fossil	R-19	.050	805	400	27.0	.43
	-windows					
	x30.5		242	400		2.95
	-doors					
		0.42	40	400	18.6	.12
	<u>Infiltration Heat Gain</u>					
	x1.1		2088	400		.92

$\Sigma =$ 5.40

	<u>x1.105</u>
Component load	5.97
+Internal heat load	<u>4.43</u>
Unit demand	10.40

Structure Category	Transmission Heat Gain	U-Value	Area	CH	ΔT	Heat Gain (10^6 BTU)
SFD	-walls R-7	0.09	1676	400	18.6	1.12
1940-1965	-ceiling roof R-11	0.076	651	400	25.9	0.52
	-windows x30.5		156	400		1.90
	-doors	.42	40	400	18.6	.12
	<u>Infiltration Heat Gain</u>					
	x1.1		1872	400		.82

$\Sigma = 4.48$

Component load	<u>x1.105</u> 4.95
+Internal heat load	<u>3.58</u>
Unit demand	8.53

<u>Structure Category</u>	<u>Transmission Heat Gain</u>	<u>U-Value</u>	<u>Area</u>	<u>CH</u>	<u>ΔT</u>	<u>Heat Gain (10⁶ BTU)</u>
SFD	-walls					
	90% R-8 10% R-0	0.11	1616	400	18.6	1.32
Pre-1940						
insulated	-ceiling roof	.10	600	400	24.9	.60
	R-7					
	-windows					
	x30.5		144	400		1.76
	-doors					
		.42	40	400	18.6	.12
	<u>Infiltration Heat Gain</u>					
	x1.1		1800	400		.79
						Σ = 4.59
						<u>x1.105</u>
	Compenent Load					5.07
	+Internal heat load					<u>3.30</u>
	Unit Demand					8.37

<u>Structure</u> <u>Category</u>	<u>Transmission Heat Gain</u>	<u>U-Value</u>	<u>Area</u>	<u>CH</u>	<u>ΔT</u>	<u>Heat Gain</u> <u>(10⁶ BTU)</u>
SFD	-walls					
	R-0	.25	1616	400	18.6	3.01
Pre-1940	-ceiling roof					
uninsulated	R-0	.28	600	400	19.3	1.31
	-windows					
	x30.5		144	400		1.76
	-doors					
		.42	40	400	18.6	.12
<u>Infiltration Heat Gain</u>						
	x1.1		1800	400		.79
						Σ = 5.99
						<u>x1.105</u>
Component load						6.29
+Internal heat load						<u>3.30</u>
Unit demand						9.59

Structure							Heat Gain
<u>Category</u>	<u>Transmission Heat Gain</u>	<u>U-Value</u>	<u>Area</u>	<u>CH</u>	<u>ΔT</u>		<u>(10⁶ BTU)</u>
SFA	-walls						
	R-11	.073	3004	400	18.6		1.63
1972-1985	-ceiling roof						
electric	R-24	.041	1782	400	27.5		.81
	-windows						
	x28.3		356	400			4.03
	-doors						
		.42	120	400	18.6		.37
	<u>Infiltration Heat Gain</u>						
	x1.1		3480	400			1.53
						Σ =	8.37
							<u>x1.105</u>
	Component						9.25
	+Internal heat load						<u>9.80</u>
	Unit demand						19.05

Structure Category	Transmission Heat Gain	U-Value	Area	CH	ΔT	Heat Gain (10 ⁶ BTU)
SFA	-walls					
	R-11	.073	3004	400	18.6	1.63
1965-1972 and 1972-85						
	-ceiling roof					
fossil	R-19	.041	1782	400	27.1	.96
	-windows					
	x28.3		356	400		4.03
	-doors					
		.42	120	400	18.6	.37
	<u>Infiltration Heat Gain</u>					
	x1.1		3480	400		1.53
					$\Sigma =$	8.52
						<u>x1.105</u>
	Component load					9.41
	+Internal heat load					<u>9.80</u>
	Unit demand					19.21

Structure Category	Transmission Heat Gain	U-Value	Area	CH	ΔT	Heat Gain (10^6 BTU)
SFA	-walls					
	R-7	0.09	2874	400	18.6	1.92
1940-1965	-ceiling roof					
	R-11	0.076	1632	400	25.9	1.28
	-windows					
	x28.3		326	400		3.69
	-doors					
		.42	40	400	18.6	.37
	<u>Infiltration Heat Gain</u>					
	x1.1		3320	400		1.46
					$\Sigma =$	8.72
						<u>x1.105</u>
	Component load					9.64
	+Internal heat load					<u>8.97</u>
	Unit demand					18.61

Structure	Transmission Heat Gain		U-Value	Area	CH	ΔT	Heat Gain (10 ⁶ BTU)
Category							
SFA	-walls						
	90% R-8	10% R-0	.11	2844	400	18.6	2.35
Pre-1940							
insulated	-ceiling roof						
	R-7		.10	1581	400	24.9	1.57
	-windows						
	x28.3			316	400		3.58
	-doors						
			.42	120	400	18.6	.37
	<u>Infiltration Heat Gain</u>						
	x1.1			3280	400		1.44

$$\Sigma = 9.31$$

$$\text{Component load} \quad \frac{x1.105}{10.29}$$

$$+ \text{Internal heat load} \quad \underline{8.69}$$

$$\text{Unit demand} \quad 18.98$$

Structure						Heat Gain
<u>Category</u>	<u>Transmission Heat Gain</u>	<u>U-Value</u>	<u>Area</u>	<u>CH</u>	<u>ΔT</u>	<u>(10⁶ BTU)</u>
SFA	-walls					
	R-0	.25	2844	400	18.6	5.29
Pre-1940						
	-ceiling roof					
uninsulated	R-0	.28	1581	400	19.4	3.44
	-windows					
	x28.3		316	400		3.58
	-doors	.42	120	400	18.6	.37
	<u>Infiltration Heat Gain</u>					
	x1.1		3280	400		1.44

$$\Sigma = 14.12$$

Component load	<u>x1.105</u> 15.60
+Internal heat load	<u>8.69</u>
Unit demand	24.29

Structure							Heat Gain
<u>Category</u>	<u>Transmission Heat Gain</u>	<u>U-Value</u>	<u>Area</u>	<u>CH</u>	<u>AT</u>		<u>(10⁶ BTU)</u>
MFLR	-walls						
	R-11	.073	5790	400	18.6		3.14
1972-1985							
	-ceiling roof						
electric	R-24	0.041	5130	400	27.9		2.35
	-windows						
	x23.05		1080	400			9.96
	-doors						
		.42	50	400	18.6		.16
	<u>Infiltration Heat Gain</u>						
	x1.1		6920	400			3.04
						$\Sigma =$	18.65
							<u>x1.105</u>
	Component load						20.61
	+Internal heat load						<u>28.21</u>
	Unit demand						48.82

Structure Category	Transmission Heat Gain	U-Value	Area	CH	ΔT	Heat Gain (10^6 BTU)
MFLR	-walls					
	R-11	.073	5790	400	18.6	3.14
1965-1972 and 1972-85						
	-ceiling roof					
fossil	R-19	.050	5130	400	27.5	2.82
	-windows					
	x23.05		1080	400		9.96
	-doors					
		.42	50	400	18.6	.16
	<u>Infiltration Heat Gain</u>					
	x1.1		6920	400		3.04
					$\Sigma =$	19.12
						<u>x1.105</u>
	Component load					21.13
	+Internal heat load					<u>28.21</u>
	Unit demand					49.34

Structure							Heat Gain
<u>Category</u>	<u>Transmission Heat Gain</u>	<u>U-Value</u>	<u>Area</u>	<u>CH</u>	<u>ΔT</u>		<u>(10⁶ BTU)</u>
MFLR	-walls						
	R-7	.09	5790	400	18.6		3.88
1940-1965	-ceiling roof						
	R-11	.076	5130	400	26.3		4.09
	-windows						
	x23.05		1080	400			9.96
	-doors						
		.42	50	400	18.6		.16
	<u>Infiltration Heat Gain</u>						
	x1.1		6920	400			3.04
						Σ =	21.13
							<u>x1.105</u>
	Component load						23.35
	+Internal heat load						<u>20.21</u>
	Unit demand						51.56

Structure	Category	Transmission Heat Gain	U-Value	Area	CH	ΔT	Heat Gain (10^6 BTU)
MFLR	-walls	90% R- 8 10% R-0	.11	5790	400	18.6	4.74
Pre-140							
insulated	-ceiling roof		.10	5130	400	25.2	5.17
	-windows	x23.05		1080	400		9.96
	-doors		.42	50	400	18.6	.16
<u>Infiltration Heat Gain</u>							
	x1.1			6920	400		3.04
							$\Sigma = 23.07$
							<u>x1.105</u>
Component load							25.49
+Internal heat load							<u>28.21</u>
Unit demand							53.70

Structure							Heat Gain
<u>Category</u>	<u>Transmission Heat Gain</u>	<u>U-Value</u>	<u>Area</u>	<u>CH</u>	<u>ΔT</u>		<u>(10⁶ BTU)</u>
MFLR	-walls						
	R-0	.25	5790	400	18.6		10.76
Pre-1940							
	-ceiling roof						
uninsulated	R-0	.28		400	19.5		11.19
	-windows						
	x23.05		1080	400			9.96
	-doors						
		.42	50	400	18.6		.16
	<u>Infiltration Heat Gain</u>						
	x1.1		6920	400			3.04
						Σ =	35.11
							<u>X1.105</u>
						Component load	38.80
						+Internal heat load	<u>28.21</u>
						Unit demand	67.01

Structure Category	Transmission Heat Gain	U-Value	Area	CH	ΔT	Heat Gain (10 ⁶ BTU)
MFHR	-walls					
	masonry-insulated	.12	25540	400	18.6	22.80
1972-1985 and 1965-72						
	-ceiling roof					
electric	flat deck (2.5" insulation)	.094	6384	400	35	8.40
	-windows					
	x27.2		6400	400		69.63
	-doors					
		.42	60	400	18.6	.19
	<u>Infiltration Heat Gain</u>					
	x1.1		32,000	400		14.08
					$\Sigma =$	115.10
						<u>x1.105</u>
	Component load					127.19
	+Internal heat load					<u>175.51</u>
	Unit demand					302.70

Structure Category	Transmission Heat Gain	U-Value	Area	CH	ΔT	Heat Gain (10 ⁶ BTU)
MFHR	-walls					
	masonry	.21	25540	400	18.6	39.90
Pre-1972	-ceiling roof					
fossil	flat deck (2" insulation)	.11	6384	400	35	9.83
	-windows					
	x27.2		6400	400		69.63
	-doors					
		.42	60	400	18.6	.19
<u>Infiltration Heat Gain</u>						
	x1.1		32,000	400		14.08
						$\Sigma = 133.63$
Component load						<u>x1.105</u> 147.66
+Internal heat load						<u>175.51</u>
Unit demand						323.17

<u>Structure Category</u>	<u>Transmission Heat Gain</u>	<u>U-Value</u>	<u>Area</u>	<u>CH</u>	<u>ΔT</u>	<u>Heat Gain (10⁶ BTU)</u>
Mobile	-walls	.11	902	400	18.6	.74
	-ceiling roof	.072	720	400	35	.73
	-windows x31.7		86	400		1.07
	-doors	.42	20	400	18.6	0.06
	-floor (open crawl space)	.076	720	400	10.0	.22
	<u>Infiltration Heat Gain</u>					
	x1.1		1008	400		0.49

Σ = 3.31

Component load	<u>x1.105</u> 3.66
+Internal heat load	<u>1.98</u>
Unit demand	5.64

Appendix 6

New England's Inventory
of Residential Housing,

The basic accounting identity for projecting the 1972 housing stock to the year 1985 or 2000 is (Arthur D. Little, 1974):

$$HS_{te} = HS_B + C_t - R_t$$

where HS_{te} : housing stock at the end of a projection interval.

HS_B : housing stock at the beginning of the projection interval.

C_t : number of new units constructed over the housing interval.

R_t : net number of units removed from the housing stock over the projection interval

Two projection intervals are considered, 1972-1985 and 1985-2000. All the buildings removed during the intervals are assumed to pre-date 1965.

Residential Inventory
and Age Structure (10³ Housing Units)*

	<u>1972 Inventory</u>				
	<u>SFD</u>	<u>SFA</u>	<u>MFLR</u>	<u>MFHR</u>	<u>MOBILE</u>
1965-72** _e	81	46	15	6	<div style="display: flex; align-items: center;"> <div style="flex: 1; border-left: 1px solid black; border-right: 1px solid black; padding: 0 5px;"> <div style="display: flex; justify-content: space-between; padding: 0 5px;"> d=109 e=6 </div> <div style="display: flex; justify-content: space-between; padding: 0 5px;"> m=33 d=55 </div> </div> </div>
— _d	125	70	23		
— _m	37	21	6		
1940-65 _d	624	228	34		
— _m	185	68	10		
Pre-1940 _{du}	172	298	96		
— _{mu}	51	87	29		
Pre-1940 _{di}	557	248	119		
— _{mi}	<u>171</u>	<u>74</u>	<u>36</u>		
Total	2023	1140	368	148	61

*Based on dee (1976) and Marcin (1972 and 1975).

**First subscript refers to fuel type; e: electricity, d: distillate, and m: methane. For pre-1940 housing and the second subscript refers to level of insulation; i: insulated, and u: uninsulated.

1985 Inventory

	<u>SFD</u>	<u>SFA</u>	<u>MFLR</u>	<u>MFHR</u>	<u>MOBILE</u>
1972-85 _e	191	93	55	13	}
_____d	379	172	117	25	
_____m	100	79	20	8	
1965-72 _e	81	46	15	6	
_____d	125	70	23	}	}
_____m	37	21	6		
1940-65 _d	546	154	24		
_____m	162	46	7		
Pre-1940 du	151	201	69	}	}
_____mu	45	59	21		
Pre-1940 di	505	167	86		
_____mi	<u>150</u>	<u>50</u>	<u>26</u>		
Total	2472	1138	469	157	209

e=21

d=188

d=79

m=23

2000 Inventory

	<u>SFD</u>	<u>SFA</u>	<u>MFLR</u>	<u>MFHR</u>	<u>MOBILE</u>
1985-2000 _e	527	184	108	26	20
_____d	456	200	94	29	180
_____m	57	36	30	5	<div style="display: flex; align-items: center; justify-content: center;"><div style="border-left: 1px solid black; height: 100%; margin-right: 5px;"></div><div style="text-align: center;">e=10 d=86</div></div>
1972-85 _e	191	93	55	13	
_____d	379	172	117	25	
_____m	100	79	20	8	
1965-72 _e	81	46	15	6	
_____d	125	70	23	<div style="display: flex; align-items: center; justify-content: center;"><div style="border-left: 1px solid black; height: 100%; margin-right: 5px;"></div><div style="text-align: center;">d=48 m=15</div></div>	
_____m	37	21	6		
1940-65 _d	435	67	11		
_____m	129	20	3		
Pre-1940 du	120	87	32		
_____mu	36	26	10		
Pre-1940 di	403	73	39		
_____mi	<u>120</u>	<u>22</u>	<u>12</u>		
Total	3196	1196	575	175	296

The following parameters found in the fuel mix tables must be defined before the projections of energy demand and the fuel mix for the reference years are developed.

1. Unit basic demand, E_u : the heating or cooling requirements of an average unit for a given reference year (assuming 100% system efficiency).

$$E_u = E_{ij} = \frac{\sum_{k=1}^n N_{ijk} H_{ijk}}{\sum_{k=1}^n N_{ijk}}$$

where: N = number of housing units

H = heating or cooling requirements of a unit

and subscripts: i = fuel type

j = structure category

k = age category of structure.

2. Saturation, S : fraction of the potential demand for a particular energy use actually being fulfilled at a given time.

3. Fuel fraction, f_i : fraction of the total number of energy consuming units (basis) that is satisfied by using the i th fuel.

4. Relative system efficiency, e_i : the relative effectiveness with which fuel, i , is used in demand category.

5. Fuel demand D_i : the quantity of a fuel, i , actually consumed in a specific demand category

$$D_i = E_{ij} \times S \times \text{Basis} \times f_i \div e_i.$$

6. Total fuel demand, D : The total fuel required to satisfy the requirements of a specific demand category

$$D = \sum_{i=1}^m D_i$$

Residential Sector
Category: SFD
End Use: Space heat

	1972			1985			2000		
	fi	ei	Di	fi	ei	Di	fi	ei	Di
Methane	.22	.60	68.7	.20	.62	69.9	0.15	0.63	61.0
Distillate	.74	.50	277.2	.69	.52	285.7	0.60	.54	274.5
Electricity Res.	.04	1	5.1	0.11	1	16.9	0.17	1	31.4
Heat pump							0.08	1.71	8.6
Total fuel demand, D, 10^{12} BTU			351.3			372.5			375.5
Basis 10^3 Households			2023			2472			3196
Saturation, S	1			1			1		
Unit basic demand, Eu, (10^6 BTU/house- hold): methane			92.6			87.6			80.1
distillate			92.6			87.1			77.3
electricity			63.1			62.0			57.8

Residential Sector

Category: SFA

End Use: Space Heat

	1972			1985			2000		
	fi	ei	Di	fi	ei	Di	fi	ei	Di
Methane	0.22	0.6	32.0	0.22	0.63	26.3	0.17	0.66	16.4
Distillate	0.74	0.5	129.1	0.66	0.52	99.8	0.56	0.55	64.9
Electricity Res.	0.04	1	1.7	0.12	1	5.2	0.18	1	7.6
Heat pump							0.09	1.71	2.2
Total fuel demand, D, 10 ¹² BTU			162.8			131.3			91.1
Basis 10 ³ Households			1,140			1158			1196
Saturation, S	1			1			1		
Unit basic demand, Eu, (10 ⁶ BTU/ household):									
methane			76.5			65.0			53.3
distillate			76.6			67.9			53.3
electricity			37.3			37.6			35.1

Residential Sector
Category: MFLR
End Use: Space Heat

	1972			1985			2000		
	fi	ei	Di	fi	ei	Di	fi	ei	Di
Methane	0.22	0.6	8.0	0.17	0.63	6.6	0.14	0.66	4.7
Distillate	0.74	0.5	32.3	0.68	0.54	8.6	0.55	0.57	20.6
Electricity	0.04	1	0.4	0.15	1	1.9	0.21	1	3.1
Heat pump							0.10	1.71	0.9
Total fuel demand, D, 10 ¹² BTU			40.7			37.1			29.3
Basis 10 ³ Households			368			460			575
Saturation, S	1			1			1		
Unit basic demand, Eu, (10 ⁶ BTU/house- hold): methane			59.3			52.3			38.7
distillate			59.3			48.4			37.1
electricity			27.0			27.2			25.4

Residential Sector
Category: MFHR
End Use: Space Heat

	1972			1985			2000		
	fi	ei	Di	fi	ei	Di	fi	ei	Di
Methane	0.22	0.6	2.4	0.21	0.63	2.1	0.16	0.65	1.6
Distillate	0.74	0.5	9.8	0.67	0.52	8.4	0.58	0.55	6.5
Electricity Res.	0.04	1	0.2	0.12	1	0.5	0.18	1	0.7
Heat pump							.08	1.71	0.2
Total fuel demand, D, 10 ¹² BTU			12.4			12.0			9.0
Basis 10 ³ Households			148			157			175
Saturation, S	1			1			1		
Unit basic demand, Eu, (10 ⁶ BTU/ Household): Methane			44.9			41.4			36.5
Distillate			44.9			41.6			35.4
Electricity			29.2			25.0			22.4

Residential Sector
Category: Mobile
End Use: Space Heat

	1972			1985			2000		
	fi	ei	Di	fi	ei	Di	fi	ei	Di
Methane									
Distillate	.90	.5	6.2	.90	.59	17.9	.90	.60	23.3
Electricity	.10	1	.3	.10	1	1.1	.10	1	1.5
Total fuel demand, D, 10 ¹² BTU			6.5			19.0			24.8
Basis 10 ³ Households			61			209			296
Saturation, S	1								
Unit basic demand, Eu, (10 ⁶ BTU/house- hold): methane									
distillate			56.1			56.1			52.5
electricity			52.6			52.6			49.3

Residential Sector
Category: SFD
End Use: Air Conditioning

	1972			1985			2000		
	fi	ei	Di	fi	ei	Di	fi	ei	Di
Methane									
Distillate									
Electricity Room	0.18	1.82	1.26	0.23	2.23	1.92	0.49	2.75	5.33
Central	0.02	1.99	0.18	0.09	2.44	0.84	0.20	3.01	1.93
Total fuel demand, D, 10 ¹² BTU			1.44			2.76			7.26
Basis 10 ³ households			2023			2472			3196
Saturation, S	0.2			0.32			0.69		
Unit base demand, Eu Room:			6.30			7.55			7.56
(10 ⁶ BTU/household) Central:			8.81			9.26			9.12

Residential Sector
Category: SFA
End Use: Air Conditioning

	1972			1985			2000		
	fi	ei	Di	fi	ei	Di	fi	ei	Di
Methane									
Distillate									
Electricity Room	0.18	1.82	0.59	0.23	2.23	0.73	0.49	2.75	1.27
Central	0.02	1.99	0.08	0.09	2.44	0.29	0.20	3.01	0.48
Total fuel demand, D, 10 ¹² BTU			0.67			1.02			1.75
Basis 10 ³ households			1,140			1158			1196
Saturation, S	0.2			0.32			0.69		
Unit basic demand, Eu Room			5.26			6.09			5.95
(10 ⁶ BTU/household) Central:			6.90			6.73			6.03

Residential Sector
Category: MFLR
End Use: Air Conitioning

	1972			1985			2000		
	fi	ei	Di	fi	ei	Di	fi	ei	Di
Methane									
Distillate									
Electricity Room	0.18	1.82	0.16	0.23	2.33	0.23	0.49	2.75	0.47
Central	0.02	1.99	0.02	0.09	2.44	0.09	0.20	3.01	0.18
Total fuel demand, D, 10 ¹² BTU			0.18			0.32			0.65
Basis 10 ³ households			368			469			575
Saturation, S	0.20			0.32			0.69		
Unit basic demand, Eu. Room (10 ⁶ BTU/household)			4.39			4.92			4.63
Central			5.74			5.38			4.80

Residential Sector
Category: MFHR
End Use: Air Conditioning

	1972			1985			2000		
	fi	ei	Di	fi	ei	Di	fi	ei	Di
Methane									
Distillate									
Electricity Room	0.18	1.82	0.06	0.23	2.33	0.081	0.49	2.75	0.14
Central	0.02	1.99	0.01	0.09	2.44	0.03	0.20	3.01	0.06
Total fuel demand, D, 10 ¹² BTU			0.07			0.11			0.20
Basis 10 ³ households			148			157			175
Saturation, S	0.2			0.32			0.69		
Unit basic demand, Eu Room			4.39			4.92			4.63
(10 ⁶ BTU/household) Central			5.38			5.27			4.87

Residential Sector
Category: Mobile
End Use: Air Conditioning

	1972			1985			2000		
	fi	ei	Di	fi	ei	Di	fi	ei	Di
Methane									
Distillate									
Electricity	0.20	1.82	0.04	0.32	2.33	0.16	0.69	2.75	0.39
Total fuel demand, D, 10 ¹² BTU			0.04			0.16			0.39
Basis 10 ³ households			61			209			296
Saturation, S	0.20			0.32			0.69		
Unit basic demand, Eu (10 ⁶ BTU/household)			5.64			5.64			5.29

Appendix 8

Saturation Levels of Other Residential Energy Uses

ANNUAL UNIT DEMAND AND SATURATION FOR
LIGHTING AND MISCELLANEOUS ELECTRIC APPLIANCES
IN NEW ENGLAND

<u>END USE DEVICE</u>	<u>SATURATION</u>			<u>UNIT DEMAND (10⁶ Btu)</u>		
	<u>1972</u>	<u>1985</u>	<u>2000</u>	<u>1972</u>	<u>1985</u>	<u>2000</u>
Lighting	1.00	1.00	1.00	3.10	3.10	3.10
Dishwasher	0.23	0.70	0.90	1.30	1.15	1.15
Washing Machine	0.75	0.80	0.85	0.35	0.35	0.35
Dryer	0.41	0.60	0.80	3.40	3.40	3.40
Color TV	0.43	0.90	1.00	2.10	1.50	1.50
B & W TV	0.82	0.80	0.70	1.20	0.40	0.40
Freezer	0.19	0.35	0.50	4.80	4.50	4.20
Refrigerator	1.00	1.10	1.25	4.50	4.50	4.50
Misc. Small Appliances	0.60	0.70	0.85	2.50	2.50	2.50
Average	0.60	0.73	0.88			

SOURCE: U.S. Bureau of Census (1972)
and Lee (1976)

Breakdown By Fuel Type For Cooling and
Water Heating of Housing Units in New England in 1970

<u>Fuel</u>	<u>Percentage of homes using a given fuel</u>	
	<u>Cooking</u>	<u>Waterheating</u>
Utility gas	40.2	31.0
Electricity	48.1	21.3
Liquid propane gas	9.5	4.1
Fuel oil	1.3	41.4
Coal	.1	.1
Wood	.3	.1
Other	.1	.2
None	.4	1.7

Source: U.S. Bureau of Census (1972).