DEVELOPMENT OF
RESIDENTIAL BUILDINGS
ENERGY CONSERVATION RESEARCH,
DEVELOPMENT AND DEMONSTRATION
STRATEGIES

HIT-681
Final Report

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I. INTRODUCTION

The objective of this study is to provide detailed information which assists ERDA (U.S. Energy Research and Development Administration) in planning and establishing priorities for RD&D (research, development, and demonstration) activities in buildings energy conservation. This objective includes:

- The identification and prioritization of building structural component and HVAC (heating, ventilating, and air conditioning) systems modifications which are state-of-the-art and which could be significantly improved with funding of RD&D strategies. The strategies are based on cost impact, energy conservation potential, and regional location.
- The evaluation of available implementation strategies for the prioritized strategies in new and retrofit applications. The implementation strategies include economic, political, and institutional factors.

The results of the study were developed through three analyses which consist of the following methodologies.

- (1) Analysis of Technically Optimum Basic Structural RD&D Strategies for Energy Conservation in Characteristic Residential Structures

Characteristic SFD (single-family detached), SFA (single-family attached), and MFLR (multifamily low-rise) structures are identified and analyzed for energy utilization in the warm, moderate, and cold climates of Houston, Baltimore, and Chicago. The energy requirements for conduction losses and gains for heating and cooling are examined for each of the structural components -- roof (ceiling), walls, floors, doors, and windows. In addition, the energy utilization effects of radiation, infiltration, and internal heat gain are evaluated. State-of-the-art energy conservation measures are identified to determine the point of departure from which RD&D strategies are developed. The RD&D strategies are related to conduction, radiation, and infiltration heat transfer effects and are further analyzed for potential economic and energy conservation benefits. The state-of-the-art and the RD&D strategies are prioritized in order of potential energy conservation and economic benefit.

(2) Analysis of Technically Optimum Basic HVAC System
RD&D Strategies for Energy Conservation in Characteristic Residential Buildings

Characteristic HVAC systems are identified for each of the characteristic structures in each location. The HVAC systems specified and analyzed include electric (resistance and heat pump), natural gas, and oil-energy sources. The energy utilization characteristics for meeting the heating and cooling loads are evaluated as well as the relative number of installations of each type of HVAC system to establish the baseline system performance characteristics. Each component of the HVAC systems are evaluated relative to energy requirements including the heating, cooling, control, and distribution losses or gains in order to establish the energy conservation potential of RD&D strategies for improving the components. State-of-the-art component modifications are identified in order to establish a point of departure for identifying the RD&D strategies. Each strategy is analyzed to determine the potential energy conservation for new construction and retrofit applications. The differential costs for each strategy when compared to the baseline HVAC system component performance characteristics are developed to evaluate the economic benefits to be gained and identify the allowable costs of investment for the strategy. The RD&D strategies as well as state-of-the-art modifications are prioritized on the bases of energy conserved and economic benefits for new construction and retrofit applications.

(3) Analysis of the Implementation Feasibility and Overall
Prioritization of Strategies

Characteristics of the economic, political, and institutional factors are developed in order to evaluate the feasibility for implementing the RD&D strategies. Affected private sector groups are identified, and the barriers, and constraints within the public sector are reviewed to determine how policies affect strategy implementation. The roles, strengths, and positions of the groups are identified and related to economic, political, and institutional factors for each energy conservation strategy. A matrix is developed from which the strategies could be prioritized based upon potential national energy savings, economic, and the actions of institutions in the public and private sectors.

II. SUMMARY

The objectives of this study were to provide detailed information which will assist ERDA in planning and establishing priorities for future research, development, and demonstration activities in areas of building energy conservation. Analyses were performed to: (1) identify and prioritize both structural component modifications and climate control systems based on cost impact, energy conservation potential, and regional location; and (2) evaluate the potential of each strategy for mass implementation by considering economic, political and other institutional factors. Table II-1 summarizes the major findings developed during the course of performance of this effort. Several of the key elements presented in Table II-1 include:

- identification and listing of selected energy saving strategies
- estimate of the national energy saving potentials due to implementation of the selected strategies
- evaluation of technological and economical feasibility of the strategies
- delineation of institutional factors which affect the implementation of the selected strategies
- dichotomization of those strategies which are state-of-the-art improvements for buildings and those strategies which can be considered for future research, development, and demonstration activity for ERDA.

The following two sections of the executive summary provide background information supporting the findings summarized in Table II-1. Part A provides a description and analysis of structural and HVAC components. Part B is an identification and analysis of factors affecting implementation.

TABLE II-1. SUMMARY OF RESIDENTIAL ENERGY
CONSERVATION COMPONENT STRATEGIES

COMPONENT STRATEGIES	NATIONAL POTENTIAL ENERGY SAVINGS (10 ⁶ Btu/year)	FEASIBILITY **	
		Technological	Economic
I. STRUCTURAL SYSTEM			
A. Insulation (Decrease Conduction)			
1. Opaque Surfaces	17,300,000,000	X	
2. Window		X	X
B. Infiltration (Reduce infiltration 30%)			
1. Test Procedure	2,580,000,000		X
2. Building Designs			X
3. Building Orientation		X	X
4. Paths Study		X	X
C. Others			
1. Variable Transmission Glass (Radiation)	2,400		X
2. Windows - Building Orientation	7,100	X	X
II. CLIMATE CONTROL SYSTEM			
A. Furnaces			
1. Condensing Flue Gas	9,000		
2. Upper Limit Non-Condensing Flue Gas	5,900	X	X
*3. Locate Ducts Entirely in Conditioned Space	2,700	X	X
4. Demand Ignition	1,200	X	X
5. Automatic Flue Control	2,100	X	X
6. Sized for Peak Load	1,400	X	X
7. Outside Preheated Combustion and Dilution Air	1,700	X	X
8. Sized for 25 Percent Above Peak Load	1,100	X	X
9. Better Insulated Ducts with Less Leakage	1,300	X	X
10. 13% Excess Air	210	X	X
B. Heat Pumps and Air Conditioners			
1. Improve Compressor Efficiency	580	X	
2. Improve the Heat Transfer Effectiveness of the Outdoor Coil	300	X	
3. Improve Indoor Coil Heat Transfer Effectiveness	150	X	
4. Improve Fan Efficiency	52	X	
5. Improve Compressor Motor Efficiency	53	X	

* For both cooling and heating.

** "X" signifies that strategy is feasible.

TABLE II-1 (Continued)

INSTITUTIONAL FACTORS AFFECTING IMPLEMENTATION	STATE-OF-THE-ART STRATEGIES	RD&D RECOMMENDATIONS
<ul style="list-style-type: none"> • Cost is a primary factor toward improving the state-of-the-art of insulation. • Other factors such as consumer knowledge, technical availability, development of performance standards, etc. will have considerable effect on implementation. 	<ul style="list-style-type: none"> • All insulation components pay for themselves only in electric resistance/air conditioned residences. • In northern climates better insulated windows are the only insulation component which pay for themselves in fossil fuel/electric air conditioned residences. 	<ul style="list-style-type: none"> • R&D is required to lower costs of insulation materials. • New materials with equal or less conductance must be devised.
<ul style="list-style-type: none"> • Infiltration is dependent on such a variety of variables (e.g., craftsmanship, weather, load shifts, etc.) that deriving standards for infiltration strategies will prove to be an obstacle toward implementation. Establishing codes, developing test procedures, and standards development will cause an increase in costs for these strategies. 	<ul style="list-style-type: none"> • Storm windows, weatherstripping, and caulking pay for themselves only in new electric resistance/air conditioned houses. 	<ul style="list-style-type: none"> • Initiate air infiltration studies: <ol style="list-style-type: none"> 1. Devise infiltration test procedure 2. Investigate infiltration paths 3. Optimize building design • Lower retrofit costs by using new materials and/or new application techniques. • Develop codes for air infiltration in new construction.
<ul style="list-style-type: none"> • A consumer bases his decision to buy on real competitive costs rather than energy savings therefore the availability of information will affect implementation. • Windows of new design, color, or varying visibility may affect consumer purchasing behavior. 	<ul style="list-style-type: none"> • Radiation benefit pays for triple glazing windows in northern climates. 	<ul style="list-style-type: none"> • Invent new windows which gather the full insulation benefit during the winter. • Optimize window placement within residences
<ul style="list-style-type: none"> • Lack of available information for consumers regarding energy conservation components for service, • Certification and listing, standards development, and code development for new and improved furnace system components. • Increased cost for product development and commercialization will affect implementation. 	<ul style="list-style-type: none"> • All energy conservation furnaces strategies are technologically feasible, except condensing furnace. • Locating ducts in conditioned space is low cost and potentially a larger energy saver. 	<ul style="list-style-type: none"> • Increase development of condensing flue gas furnace. • Largest potential for savings exist in structural systems rather than climate control systems of residences.
<ul style="list-style-type: none"> • In some cases, the technology does not exist to increase the operating levels of efficiency for various components • There are high costs associated with the developmental phases of high efficiency components. • Performance standards will need to be developed for higher efficiency products. • Manufacturers will require large amounts of capital to develop certify and commercialize new products. 	<ul style="list-style-type: none"> • Locating ducts in conditioned space is low cost and potentially a large energy saver 	<ul style="list-style-type: none"> • Improve compressor efficiency • Largest potential for savings exist in structural systems rather than climate control systems of residences.

A. Analysis of Individual Structural and HVAC Components

The building elements which affect residential energy use in three building types, single-family detached, single-family attached, and multifamily low-rise, were identified and studied for their impacts on the energy use of residences. The analysis was divided into two parts, those related to the structural elements or basically the thermal integrity of the structure and those related to the climate control systems which have to meet the building heating and cooling loads. The evaluation of each strategy included the assessment of energy use, disaggregated into load affecting parameters of three climatological conditions, Baltimore, Chicago, and Houston. The findings and the conclusions derived from this extensive and detailed study are presented in the following sections.

1. Structural System

Many structural strategies were identified in this study. The strategies involved such particulars as decreasing overall thermal envelope conductance to such items as decreasing infiltration. Even though the thermal mass effects of walls were included in the computer analysis utilized, it was felt from previous studies that the mass effects on a structure was to only level the loads, and as far as an energy conservation strategy, the savings in special cases would reach 2 to 3 percent. Only in certain segments of the United States where a large temperature difference exists in a given day does there arise any potential for energy conservation, and since those climatological areas represent a small percentage of the total number of residential structures within the United States, the effects of increasing thermal mass were not considered as a separate strategy.

Most of the structural strategies identified were considered technologically feasible, while those strategies that were found to be economically feasible with present fuel and construction costs were defined as state-of-the-art strategies. Those that were not found to be economically feasible were identified as warranting future funding as possible RD&D strategies. The structural strategies studied can be categorized under the following three areas:

- insulation;
- infiltration; and
- others.

a. Insulation. The assessment of strategies involving insulation include a detailed evaluation of all load-affecting structural components such as; walls, roof, floor, windows, and doors. Those strategies which rendered energy conservation and were economically feasible were classified as state-of-the-art; those which offered a load reduction but for which economic feasibilities are questionable, were considered RD&D strategies.

(1) State-of-the-Art. Comparisons were made between base structural components in the three building types and those of thermally optimized structures of the similar types. This comparison showed that the greatest energy saving potential lies on thermal improvement of structural components in the residential sector, and the assurance that present residential construction practices can meet the variety of insulation values considered in this evaluation.

The contributing factor which resulted in certain structural components to be considered as RD&D strategies was the fact that the construction costs (economics) prevented some of the component changes from being economically feasible for residential applications. Of all the strategies studied aimed at higher insulation levels, only better insulated windows (R-2.4, equivalent to triple glazing) in the northern climates paid for themselves under present construction costs. These conclusions were drawn from residences with the base climate control systems of gas heating and electric cooling. For the case of all-electric residences, all of the component insulation strategies were cost effective, and therefore would be considered state-of-the-art.

(2) RD&D. It is recommended that the future residential building related RD&D strategies consider the development of insulation materials which would be lower in cost when compared with those presently available and offer equivalent or better insulating qualities. The strategies should include the development of insulation materials for the two following applications:

- windows
- opaque surfaces

b. Infiltration. The largest component of loads, when compared to other individual structural components is the infiltration of air into the structures. When all the insulation components were combined and compared to infiltration alone, the greatest reduction in load (i.e., magnitude of the load) was achieved by increasing the overall insulation value in the three basic structures.

(1) State-of-the-Art. Reducing the amount of infiltration by 30 percent in the gas heated structures was found to be uneconomical. If, however, the base structures were electric resistance heated, then the installation of weatherstripping, caulking, and storm windows as measures to reduce infiltration 30 percent would pay for itself on a new construction basis only. Therefore, reducing infiltration by 30 percent can be considered state-of-the-art only for new residential structures with electric resistance heat.

(2) RD&D. Since reducing infiltration by 30 percent at present construction and fuel costs was found to be uneconomical, it is recommended that the following be considered as possible RD&D strategies:

- (a) Infiltration - Test Procedure
- (b) Infiltration - Building Design
- (c) Infiltration - Building Orientation
- (d) Infiltration Paths Study

c. Others. The reduction of radiation is an important factor in reducing the solar heat gain during the cooling season without losing its benefits during winter. It is recommended that the following areas be studied as RD&D strategies.

- (1) Variable Transmission Glass
- (2) Windows - Building Orientation

2. Climate Control System

A detailed analysis of climate control systems of various types selected for use in the residential structures was performed. This included the disaggregation of the systems into energy-use affecting components as well as the classification of the system by fuel type. By giving consideration to the three different climatological conditions, the seasonal performance of systems and sub-systems were determined for both state-of-the-art and future technologies.

In the following sections, the summary of the detailed analysis performed, and the findings obtained, is presented for each system, or subsystem studied. Note, that while many climate control system modifications were analyzed, it was not possible to study every known improvement in great depth. For example, the dynamic thermal response of the furnace heat exchanger, or the effect of a modulating furnace (i.e. those that fire at different rates in order to more efficiently satisfy partial loads) were items not considered, as either, would have required very sophisticated computer analysis.

a. Fossil Fuel Furnaces. Although, the evaluation of gas and oil furnaces were performed individually, the improvement strategies with most energy saving potentials were identified as follows:

- Develop and implement the use of furnaces with condensing flue gas
- Reduce flue gas temperature in non-condensing flue gas furnaces
- Locate ducts entirely within the conditioned space
- Implement the use of demand ignition

(1) Condensing Flue Gas. The efficiency of a furnace whose flue gases are cooled to a low enough temperature so that the latent heat of vaporization of the water content of the gases is recovered offers a potential 20% increase in efficiency over presently marketed non-condensing furnaces. The potential energy savings attainable with such a unit makes condensing furnaces a good choice for future RD&D.

(2) Reduce Flue Gas Temperature. The efficiency of a non-condensing flue gas furnace may be increased by reducing the temperature of the exiting flue gases. The reduction of flue gas temperature without condensation offers a potential increase in efficiency of 10 percent for a gas furnace. This efficiency increase is possible with presently available equipment, therefore, increasing the efficiency of a non-condensing flue gas furnace would be considered state-of-the-art.

(3) Locate Ducts Entirely in Conditioned Space. In climatic areas such as Baltimore and Chicago where heating loads are substantial, the placement of ducts entirely within the conditioned space reduces energy

resource requirements by about 10 percent. This strategy would not require any new technology and its development would be considered state-of-the-art.

(4) Demand Ignition. In warmer climates such as in Houston, 45 percent of gas use accounts for pilot light ignition. The implementation of electronic (demand) ignition system not only reduces the gas use up to 45 percent, it reduces the electricity consumption during cooling season considerably.

(5) Other Strategies Considered. Other strategies which were evaluated for their energy saving potentials are listed below in order of their impact on energy savings. Since some of these strategies show some difference between oil and gas furnaces, they are listed separately. Also, the colder climates, Baltimore and Chicago, are separated from the warmer climate, Houston.

(a) Gas Furnaces

● Colder;

- Automatic flue control (state-of-the-art)
- Furnace sized for peak load (state-of-the-art)
- Outside preheated combustion and dilution air (state-of-the-art)
- Smaller fan with lower shut off temperature (state-of-the-art)
- Furnace sized for 25 percent above peak load (state-of-the-art)
- Improvement in duct insulation and fabrication (state-of-the-art)
- Less excess combustion air (state-of-the-art)

• Warmer;

- Automatic flue control (RD&D warmer climates)
- Ducts in conditioned space (state-of-the-art)
- Outside preheated combustion and dilution air (state-of-the-art)
- Furnace sized for peak load (state-of-the-art)
- Improvement in duct insulation and fabrication (state-of-the-art)
- Smaller fan with lower shut off temperature (state-of-the-art)
- Less excess combustion air (state-of-the-art)

(b) Oil Furnaces

• Colder Climates

- Automatic flue control (state-of-the-art)
- Outside preheated combustion and dilution air (state-of-the-art)
- Better insulated ducts with less leakage (state-of-the-art)
- Smaller fan with lower shut off temperature (state-of-the-art)
- Furnace sized for peak load (state-of-the-art)
- Furnace sized for 25 percent above peak load (state-of-the-art)

- Less excess combustion air
(state-of-the-art)

- Warmer Climates. The oil furnace is not a significant source of heating in Houston; so, a ranking for RD&D strategies is not applicable.

b. Electric Furnaces. The conversion of electrical energy to heat is assumed to be a 100 percent efficient process; therefore, the only area for improvement in electric furnaces is the distribution system. Two strategies were identified for improvement of the distribution system associated with an electric furnace:

- (1) Locate ducts entirely within conditioned space (state-of-the-art)
- (2) Insulate ducts better and seal any joints better (state-of-the-art) for less leakage

c. Heat Pumps and Central Air Conditioners. The heat pumps studied were used for both heating and cooling. This section is therefore based on the savings in the heating and cooling modes combined. Since the performance of the heat pump in the heating mode is so dependent on outdoor temperature, this section is divided into colder climates (Baltimore and Chicago) and warmer climate (Houston). For each climatic type, the relative savings of the strategies considered are discussed.

(1) Colder Climates. In climates with substantial heating loads the most important strategies to implement are:

- Improve compressor efficiency (RD&D)
- Improve the heat transfer effectiveness of the outdoor coil (RD&D)
- Locate ducts in the conditioned space (state-of-the-art)
- Other strategies considered - the remaining strategies considered are listed here in descending order according to their potential energy savings in colder climates.
 - Improve indoor coil heat transfer effectiveness (RD&D)
 - Improve fan efficiency (RD&D)

- Improve compressor motor efficiency (RD&D)

B. Implementation Feasibility of the Strategies

Each identified strategy has been measured according to energy saving potential and economics of its application. In order to develop a set of appropriate RD&D strategies, a study of socio-economic/political/institutional factors which affect the feasibility for implementation of the energy saving strategies was performed.

Many potential energy saving strategies exist that can be used in both the public and private sectors; however, these energy-saving strategies can be restricted from utilization due to social/economic/political interest. Institutional interests, can act to slow and in some cases restrict the rate at which new technologies are implemented. Also, there exist practices and procedures in the public and private sectors which act to slow the market entrance of new or retrofit technologies.

The Energy Research and Development Administration has begun to focus on institutional factors in an attempt to develop programs and policies to mitigate institutional barriers and thereby assist the implementation of energy saving strategies. Also, ERDA recognizes that significant national energy savings can be attained if energy saving strategies are utilized in residential buildings. Therefore, information was gathered to: (1) identify those public and private sector institutions having the most affect on implementation in the residential sector, (2) identify the factors associated with institutional interests with potential to impact implementation and (3) determine a rank order of selected strategies according to their feasibility for mass implementation.

1. Institutions Affecting Implementation

Some of the major public and private institutions interested in the residential sector and which could impact the effectiveness of an energy saving strategy are discussed in Section VI of this report and include:

- Architects and Engineers
- Builders/Developers
- Building Code Group

- Certifying and Listing Organizations
- Consumer Groups
- Finance Institutions
- Insurance Groups
- Government
- Manufacturers of Structural Materials and building Components
- Professional, Technical and Trade Associations
- Utilities

These groups affect market entrance of energy saving strategies through the various roles each performs in the implementation process within the residential sector. Simply, there are three phases of the implementation process in which identified energy-saving strategies are affected, and they are:

- Phase I - Technical - Authoritative Approvals: The general consumer public (due to a lack of technical expertise) has deferred to a few recognized technical societies their trust that products carrying their labels and stamps of approval are safe for the use for which they are intended. These technical societies develop codes and standards and certify and list products. Groups which interact in this phase are: trade associations, finance groups, consumer groups, government groups, utilities and others. These groups can affect the implementation of energy saving products through their efforts to identify safe technical parameters for product usage.
- Phase II - Institutional Adherence: Once a strategy has been approved by the recognized authorities in Phase I, it must be found acceptable to other institutions that have adopted previous standards for product usage. For example, local code officials allow those products to be used in their communities that meet existing standards, but do not allow new or innovative products that meet new standards that have not yet been adopted by the locality.

- Phase III - Consumer Acceptance: Consumers, due to tastes, beliefs, finances or perceptions, may not utilize an energy saving technology. The consumer is the last line for making the decision to put into effect an energy saving strategy. When the consumer, either by intention or circumstance, does not see fit to utilize the strategy, the utility of the strategy and potential effectiveness is negated.

2. Socio-Economic-Political Factors Affecting Implementation

In order to rank the selected strategies according to their feasibility of implementation a set of criteria (for evaluative purposes) needed to be developed. From the institutional factors which affect implementation were identified as having varying effects on the selected RD&D strategies. Further explanations of these factors are provided in Chapter VI. Table II-2 summarizes the effects of these factors, and lists the rankings of the selected strategies as affected by implementation factors.

3. Strategies Most Feasible for Implementation

In previous work efforts in this program, technical RD&D strategies were developed for improving energy utilization (and conservation) in the structural envelope and in HVAC systems in residential buildings. The strategies in the report were evaluated for their feasibility to obtain implementation. A measurement of 'ability to implement' was developed based upon:

- the potential national energy savings attributable to each strategy; and
- interplay of institutional factors and the experience of existing precedents in public sector practices in energy conservation.

The feasibility factor was developed from a weighted ranking technique when considering institutional factors.

After conducting this analysis, it was possible to rank the selected strategies in order of their feasibility to realize mass implementation. The strategies utilized in the analysis are ranked below in their determined order:

- Formed-in-place Insulation
- Floor Insulation over Non-climate Controlled Spaces

TABLE II-2. COMPOSITE RATING FOR SELECTED STRATEGIES

Selected Strategies	Primary Implementation Factors														Accumulated Composite Scores	Final Rating	Ranking of Selected Strategies
	Lack of Information	High Cost	Time Associated with Code and Standards Development and Certification	Lack of a Regulatory Agency	Unavailability of Technology	Lack of Financial Incentives	Lack of Acceptable Standards	Consumer Tastes and Behavior	Local Code Official	Antiquated Codes	Lack of Technical Expertise	Lack of Performance Standards	Limited Priority on Energy Savings				
wt=2 i k	wt=3 i k	wt=3 i k	wt=1 i k	wt=3 i k	wt=2 i k	wt=3 i k	wt=1 i k	wt=2 i k	wt=2 i k	wt=1 i k	wt=2 i k	wt=1 i k					
Insulation (Conductance and Radiation):																	
1. Windows - Conductance and Radiation	1 2	2 6	0 0	0 0	0 2	4 1	3 2	2 0	0 0	0 0	0 0	0 0	0 0	38	132	12	
2. Formed-in-place Insulation - in the walls	0 0	2 6	2 6	0 0	0 2	4 0	0 0	0 1	2 2	4 0	0 0	0 0	0 0	22	909	1	
3. Floor Insulation	2 4	2 6	0 0	0 0	0 0	0 0	0 0	2 2	0 0	0 0	0 0	1 2	0 0	14	643	2	
4. Better Insulation	1 2	2 6	0 0	0 0	2 6	2 4	0 0	0 0	0 0	0 0	0 0	0 0	0 0	18	106	15	
5. Variable Transmission Glass	2 4	1 3	0 0	1 1	0 0	2 4	0 0	1 1	0 0	0 0	0 0	0 0	0 0	13	185	10	
6. Windows - Building Orientation	1 2	0 0	0 0	0 0	0 0	2 4	0 0	2 2	1 2	2 4	0 0	0 0	0 0	14	507	4	
Infiltration																	
1. Test Procedure	0 0	2 6	2 6	1 1	2 6	0 0	2 6	0 0	2 4	2 4	1 1	2 4	0 0	38	132	13	
2. Building Design	2 4	2 6	0 0	1 1	0 0	0 0	0 0	2 2	0 0	0 0	0 0	1 2	0 0	15	113	14	
3. Building Orientation	2 4	0 0	0 0	0 0	0 0	0 0	0 0	1 1	0 0	0 0	0 0	0 0	0 0	5	170	11	
4. Infiltration Paths Study	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 1	2 4	1 1	6	584	3	
Heat Pumps and Air Conditioners																	
1. Improve Compressor Efficiency	1 2	1 3	1 3	0 0	2 6	2 4	0 0	0 0	0 0	0 0	1 1	2 4	0 0	23	25	21	
2. Increase Outdoor Coil Effectiveness	1 2	2 6	0 0	0 0	1 3	1 2	0 0	0 0	0 0	0 0	1 1	2 4	0 0	18	16	22	
*3. Place Ducts in Conditioned Space	2 4	2 6	0 0	0 0	0 0	0 0	0 0	1 1	0 0	0 0	0 0	1 2	0 0	13	208	9	
4. Increase Indoor Coil Effectiveness	1 2	1 3	1 3	0 0	2 6	2 4	0 0	0 0	0 0	0 0	1 1	2 4	0 0	23	7	25	
5. Improve Fan Efficiency	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2 4	0 0	4	13	24	
6. Improve Compressor Motor Efficiency	1 2	2 6	0 0	0 0	1 3	0 0	0 0	0 0	0 0	0 0	1 1	0 0	1 1	13	4	26	
Furnaces																	
1. Demand Ignition	2 4	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	4	300	5	
2. Outside Preheated Combustion and Dilution Air	1 2	2 6	1 3	0 0	1 3	1 2	2 6	0 0	1 2	2 4	0 0	0 0	0 0	28	61	19	
3. Automatic Flue Control	1 2	1 3	2 6	0 0	0 0	2 4	2 6	0 0	2 4	2 4	1 1	2 4	1 1	35	60	20	
4. 13 Percent Excess Combustion Air	1 2	0 0	2 6	0 0	0 0	0 0	1 3	0 0	0 0	0 0	0 0	2 4	1 1	16	13	23	
5. Furnace Sized for 25 Percent Above Peak Design Building Load	2 4	0 0	0 0	1 1	0 0	0 0	2 6	2 2	1 2	1 2	0 0	0 0	0 0	17	65	18	
6. Furnace Sized for Peak Load Leakage	2 4	0 0	0 0	1 1	0 0	0 0	2 6	2 2	1 2	1 2	0 0	0 0	0 0	17	82	16	
7. Better Insulated Ducts with Less Leakage	1 2	2 6	0 0	0 0	0 0	1 2	0 0	2 2	0 0	0 0	0 0	2 4	0 0	16	81	17	
8. Approaching the Upper Efficiency with Less Limit of Noncondensing Flue Gas Furnace	2 4	0 0	2 6	0 0	1 3	0 0	1 3	0 0	1 2	1 2	0 0	2 4	0 0	24	246	7	
9. Condensing Flue Gas	1 2	1 3	2 6	0 0	2 6	2 4	1 3	0 0	2 4	1 2	0 0	0 0	0 0	30	300	6	
10. Smaller Fan (Lower Fan Shut Off Temperature)	2 4	0 0	0 0	0 0	0 0	0 0	0 0	1 2	0 0	0 0	0 0	0 0	0 0	6	233	8	

- Window - Conductance and Radiation
- Infiltration Paths
- Window-- Building Orientation
- Demand Ignition
- Condensing Flue Gas with Demand Ignition (increasing efficiency approximately 20 percent)
- Approaching the Upper Efficiency Limit without condensing Flue Gas (increasing efficiency 10 percent for gas and 12 percent for oil)
- Lower Distribution Fan Shut off Temperature
- Place Ducts in Conditioned Space
- Variable Transmission Glass
- Infiltration - Building Orientation
- Infiltration Test Procedure
- Infiltration - Building Design
- Better Insulation
- Furnace Sized for Peak Load
- Improvement in Duct Insulation and Fabrication
- Furnace Sized for 25 percent above Peak Design Building Load
- Outside Preheated Combustion and Combustion and Dilution Air
- Automatic Flue Control
- Improved Compressor Efficiency
- Increased Outdoor Coil Effectiveness
- Improved Fan Efficiency
- Thirteen Percent Excess Combustion Air
- Increased Indoor Coil Effectiveness
- Improved Compressor Motor Efficiency

C. Recommendations

As the result of this study, the following research, development, and demonstration (RD&D) strategies for residential housing were developed.

1. Insulation

The largest potential for energy savings exists in the development of new types of residential building insulation materials which offer equivalent or better insulating properties at a lower cost. More efforts should be made to make insulating the walls more practical and economically attractive. Improvement of the insulation properties of walls, windows and floors would greatly reduce energy usage of residential structures in the United States if applied on both a new and retrofit basis.

2. Infiltration

As it was indicated before, infiltration is the largest single load component in the residential structure, but at the same time it is the least understood item in the building load evaluations. This is mainly due to numerous factors which can affect the infiltration rate through cracks and openings in the envelope of the structures. Some of these openings can be easily detected and therefore, by application of weatherstripping and caulking could reduce the air infiltration. Normally the problem arises when these cracks and openings are not as visible and cannot be easily detected. In this case, an infiltration detection procedure could be developed to assist the builders or homeowners in overcoming the problem of excess air infiltration in the residential buildings.

3. Furnace

Through improvements made in the state-of-the-art of furnaces and their components, a potential for the reduction of residential energy usage exists. This reduction by no means matches the large potential for energy savings achievable through improvements in insulation and reductions in infiltration, but the savings are large enough to rank furnace improvements as third among the list of recommendations.

4. Heat Pumps and Air Conditioners

Major institutional constraints exist for the development and improvement of heat pumps and air conditioners because of the approval process that they must adhere to. But, major energy savings can be attained through the development and improvement of individual components. A list of those strategies most feasible for implementation in this category are presented in the following:

a. Improved Compressor Efficiency. Through the improvement of compressor efficiencies, major energy savings can be made where heat pumps and air conditioners are in residential buildings.

b. Increased Outdoor and Indoor Coil Effectiveness for Heat Pumps. The implementation of this strategy reduces electrical energy requirements of the heat pump by 23 percent. Improved effectiveness of this type of component demonstrates major energy savings.

5. Ducts in Conditioned Space

Ducts can be placed within the conditioned space of the structure, thus eliminating all conduction, radiation, and leakage losses. There are other strategies, which through their implementation produce major energy savings and also confront significant restrictions attributable to socio/economic/political factors. By reducing the impacts of some of the major restricting factors, most of the strategies identified in this report have the potential to realize mass implementation.

The results of the analysis methods are combined to form conclusions and recommendations to ERDA for RD&D and implementation strategies directed to improving energy conservation in residential structures. The recommendations are formatted as a list of RD&D strategies for consideration by ERDA in stimulating on a significant scale the introduction of energy conserving building designs and modifications, construction techniques, and HVAC system improvements which will reduce energy resource consumption for residential buildings in the United States.

III. CHARACTERIZATION OF RESIDENTIAL BUILDINGS

A. Identification of Residential Buildings

Typical, characteristic, new residential buildings for the purpose of this study were synthesized based on data previously acquired by HAI in performing Residential Energy Consumption studies for the U.S. Department of Housing and Urban Development (Ref. 1). Three such typical residences were selected, including a single-family detached (SFD), a single-family attached (SFA), and a multifamily low-rise apartment (MFLR).

The design and structural features considered important in defining these residences include:

- (1) Structural parameters such as construction details, dimensions, and materials used.
- (2) Energy utilization parameters such as heating and cooling equipment, types of fuels and energy used, appliances and their energy use profiles.

Whereas specific life-styles were not prescribed for the residents of the characteristic residences, a certain number of life-style parameters were imposed, by necessity, for the analyses. These included thermostat set point temperature, a mix of appliances and daily usage, use of ventilation fans, and number of door openings. Most of these parameters were defined for average conditions and no attempt was made to modify the parameters to allow for variations caused by weekends or holidays, vacations, entertaining of large groups, difference in age or affluence of the residents, etc. Occupancy loads were, however, adjusted for weekends. In consideration of the sizes and quality of the characteristic residences, and of the appliances included in these residences, it can be assumed that the residences would be occupied by individuals or families in the middle income group. It should also be recognized that the life-style of any given resident (in a real case) could vary greatly from the average conditions defined for these analyses, and that variations in occupant life-style can affect the building energy consumption in a significant way.

Considering the objectives of this study the basic physical and structural parameters of the synthesized buildings are kept the same for the three locations. This results in a common base for the analysis of climatological

effects on the selected strategies. Although the selected buildings differ in minor details from those characterized for Baltimore, Chicago, and Houston per Reference 1, these differences have minor to negligible effects on overall energy requirements, particularly when large changes of thermal integrity of the residences are to be analyzed.

1. Single-Family Detached

The single-family detached residence is still the most prevalent form of housing in the U.S. In 1974, some 74 percent of the existing stock of 77 million year-round dwelling units nationwide were in single-family buildings (Ref. 2). Recent demographic trends, combined with costs of building materials, land, and financing, however, have begun to diminish the domination which the single-family home has held.

The single-family residence considered typical for the past 20 years is smaller than the homes of the late 1960's which makes it the "affordable" size of the 50's and the mid 70's. The selected residence is a single story, three bedroom house having 1200 square feet of living area. Figure III-1 shows the floor plan for this house. The house is conventional wood frame with brick veneer, and built with a full basement, common to Chicago and Baltimore, whereas slab on grade would be common in Houston. The analysis methodology is basically unaffected but reference to an insulated floor in Houston would have to be looked at as theoretical.

The detailed design and construction parameters of the selected residence are presented in Table III-1. These parameters meet the HUD Minimum Property Standards (MPS) 1973 Volume 1, One and Two Family Dwellings. Also included in Table III-1 are the appliance mix present in the single-family residence and annual energy use of these appliances by fuel type, number of occupants, and climate control systems.

2. Single-Family Attached

General trends in the housing market over the last several years, especially in large metropolitan areas, indicate that the construction of single-family attached housing units (townhouses) is increasing rapidly.

Figure III-1. Floor Plan for Selected Single-Family House

**TABLE III-1. STRUCTURAL AND ENERGY CONSUMPTION
PARAMETERS FOR THE BASE SINGLE-FAMILY DETACHED RESIDENCE**

STRUCTURAL PARAMETERS:

Basic House Design	.3-Bedroom Rancher, One story, 8 ft stories
Foundation	Full Basement, Poured Concrete
Construction	Wood Frame, 2x4 Studs 16" on ctr.
Exterior walls:	
Composition	Brick Veneer, 4" 1/2" Insulation Board 3-1/2" Fiberglass Batts 1/2" Gypsum Board
Wall Framing area, ft ²	203 sq. ft.
Total Wall area, ft ²	935 sq. ft.
Roof:	
Type	Gable
Composition	Asphalt Shingles, 3/8" Plywood Sheathing, Air Space, 6" Fiber- glass Loose-Fill Insulation, 1/2" Gypsum Board
Roof Framing area, ft ²	78 sq. ft.
Total Roof area, ft ²	1200 sq. ft.
Floor:	
Total Floor area, ft ²	1200 sq. ft.
Windows:	
Type	Double Hung, Wood
Glazing	Single
Area, ft ²	105 sq. ft.
Exterior doors:	
Type	Wood Frame
Number	Two
Area, ft ²	40 sq. ft.
Patio door(s):	
Type	Aluminum, Sliding
Glazing	Double
Area, ft ²	40 sq. ft.

ENERGY CONSUMPTION PARAMETERS:*

Energy consuming equipment:	
Heating system	Gas, Forced Air
Cooling system	Electric, Forced Air
Hot water heater	Gas (270 Therms/year)
Cooking range/oven	Electric (1200 kWh/year)
Clothes dryer	Electric (990 kWh/year)
Refrigerator/freezer	Electric (1830 kWh/year)
Lights	Electric-Incandescent (2140 kWh/year)
Color TV	Electric (500 kWh/year)
Furnace fan	Electric (394 kWh/year)
Dishwasher	Electric (363 kWh/year)
Clothes washer	Electric (103 kWh/year)
Iron	Electric (144 kWh/year)
Coffee maker	Electric (106 kWh/year)
Miscellaneous	Electric (900 kWh/year)

HEATING/COOLING LOAD PARAMETERS:

People per unit	Two adults, two children
Typical weather year	5 yr. average (1970-75)
Monthly Heating Degree Days ¹	
Monthly Cooling Degree Days ¹	
Monthly Discomfort Cooling Index ¹	

* Figures shown in parentheses represent energy input to structure for each appliance (based on data in Reference 7)

¹ Dependent upon location (See Table IV-2)

In the nation as a whole, the housing starts for single-family attached were estimated to be 19 percent of the housing start in 1973, while it was 9 percent in 1965 (Ref. 3). These trends indicate that, in the future, construction of single-family attached residences will dominate in large urban areas.

The selected single-family attached structure consists of eight, two-story units in a row; each unit has 1320 square feet of living area and three bedrooms. Each unit has its own gas-fired forced-air heating system and central electric air conditioning system. The exterior wall of the townhouse is conventional wood frame with brick veneer. The unit floor plan of this residence is presented in Figure III-2.

The detailed design and construction parameters of the selected residence are presented in Table III-2. This table also includes the appliance mix and rated annual energy use by fuel type.

3. Multifamily Low-Rise

Generally speaking, the multifamily low-rise residence is one which does not require elevators. The low-rise building may contain either for-rent or for-sale dwelling units, though the for-rent variety is most common. In the United States there were approximately 256,000 low-rise dwelling units constructed in 1974 (Ref. 1), and there are indications that low-rise buildings will take a larger portion of housing starts in the future.

The selected low-rise structure has two stories and consists of 24, two-bedroom apartments. All apartments are identical in size with each having 980 square feet of living area. The exterior walls are masonry veneer as described above. Each unit contains its own gas-fired, forced-air heating system and electric air conditioning system. The floor plan indicating the unit distribution within the low-rise structure is given in Figure III-3.

The detailed design and construction parameters of the selected structure are presented in Table III-3. The appliance energy use and other related parameters are also included in this table.

SECOND FLOOR

FIRST FLOOR

Figure III-2. Floor Plan for the Selected Single-Family Attached

Figure III-3. Floor Plan for the Selected Multifamily Low-Rise

**TABLE III-2. STRUCTURAL AND ENERGY CONSUMPTION
PARAMETERS FOR THE BASE SINGLE-FAMILY ATTACHED RESIDENCE**

GENERAL PARAMETERS:

Arrangement	Rectangular Structure, Eight Town House units in a Row	Roof:	Hip
Basic Design	2-Story, 3 Bedroom	Type	Asphalt shingles; 1/2" Plywood sheathing, Air space, 6" Loose Fill
Foundation	Full Basement, Poured Concrete	Composition	Insulation, 1/2" Gypsum Board

DIMENSIONAL PARAMETERS:

(Areas are per townhouse unit, not per floor level)

	Intermediate Units	End Units
Floor area, ft ²	1320	1320
Wall framing area, ft ²	98	168
Total exterior wall area, ft ²	503	1007
Window glass area, ft ²	77	101
Exterior door(s), ft ²	20	20
Patio door(s), ft ²	40	40
Roof framing area, ft ²	44	44
Total roof area, ft ²	660	660
Story height, ft ²	8	8

CONSTRUCTION PARAMETERS:

Construction type	Wood Frame, 2x4 Studs, 16" on ctr
Exterior walls:	
Composition	Brick Veneer, 4"
	1/2" Insulation Board
	1-1/4" Air Space
	2-1/4" Fiberglass Batts
	1/2" Gypsum Board
Interior walls:	1/2" Gypsum Board
	2x4 Studs, 16" on ctr
	1/2" Gypsum Board
Exterior door(s)	Wood
Windows:	
Glazing	Single
Frames	Single Hung, Aluminum
Patio door:	
Glazing	Single
Frames	Aluminum

ENERGY CONSUMPTION PARAMETERS:*

Heating system	Forced Air, Gas
Cooling system	Forced Air, Electric
Hot water heater	Gas, (270 Therms/Year)
Cooking range	Electric (1200 kWh/year)
Clothes dryer	Electric (990 kWh/year)
Refrigerator/freezer	Electric (1830 kWh/year)
Lights	Electric-Incandescent (1463 kWh/year)
Color TV	Electric (500 kWh/year)
Furnace fan	Electric (394 kWh/year)
Dishwasher	Electric (363 kWh/year)
Clothes washer	Electric (103 kWh/year)
Iron	Electric (144 kWh/year)
Coffee maker	Electric (106 kWh/year)
Miscellaneous	Electric (900 kWh/year)

HEATING/COOLING LOAD PARAMETERS:

People per unit	Two Adults, Two Children
Typical weather year	5 yr. average (1970-75)
Monthly Heating Degree Days	}
Monthly Cooling Degree Days	
Monthly Discomfort Cooling Index	

* Figures shown in parentheses represent energy input to structure for each appliance (based on data in Reference 7)

1 Dependent upon location (See Table IV-2)

TABLE III-3. STRUCTURAL AND ENERGY CONSUMPTION
PARAMETERS FOR THE BASE MULTIFAMILY LOW-RISE RESIDENCE

GENERAL PARAMETERS:

Arrangement	Eight units per enclosed stairwell. Three enclosed stairwells per building.
Number of stories	Two
Apartments	24 (2-Bedroom units)

DIMENSIONAL PARAMETERS:

	Twenty-four	
	Interior Units	End Units
Floor area, ft ²	980	980
Wall framing area, ft ²	88	120
Total exterior wall area, ft ²	395	619
Window glass, ft ²	49	49
Door(s), ft ²	20	20
Patio/balcony door(s), ft ²	40	40
Roof framing area, ft ²	65	65
Total roof area, ft ²	980	980
Story height, ft ²	8	8

CONSTRUCTION PARAMETERS:

Construction type	Wood Frame, 2x4 Studs 16" on ctr
Foundation	Slab-on-Grade with Perimeter Insulation
Exterior walls	Brick Veneer, 1½"
Composition	Insulation Board, Air Space, 2½" Batt Insulation Gypsum Board
Interior walls:	1/2" Gypsum Board 2x3 Studs 16" ctr 1/2" Gypsum Board
Entrance doors, per unit:	One
Frame	Steel
Patio doors, per unit:	Single
Glazing	Single Hung, Aluminum
Frames	
Windows:	
Glazing	Single
Frames	Single Hung, Aluminum

Roof:

Type	Gable
Composition	Asphalt Shingles, 3/8" Plywood Air Space, 6" Loose Fill Fiberglass Insulation, 1/2" Gypsum Board

ENERGY CONSUMPTION PARAMETERS:*

Electric metering	Individual (per apartment)
Equipment in each structure:	
Central heating system	Individual forced air furnaces, gas
Hot water heater	Gas
Clothes washers	Electric (84 kWh/year)
Clothes dryers	Electric (804 kWh/year)
Equipment in each apartment:	Individual Unit
Cooling system	Electric
Cooking range/oven	Electric (975 kWh/year)
Refrigerator	Electric (1487 kWh/year)
Dishwasher	Electric (295 kWh/year)
Lights	Electric (1555 kWh/year)
TV	Electric (406 kWh/year)
Iron	Electric (117 kWh/year)
Coffee maker	Electric (86 kWh/year)
Misc. appliances	Electric (731 kWh/year)

HEATING/COOLING LOAD PARAMETERS:

People per unit	Two Adults & One Child
Typical weather year	5 yr. average (1970-75)
Monthly Heating Degree Days ¹	
Monthly Cooling Degree Days ¹	
Monthly Discomfort Cooling Index ¹	

* Figures shown in parentheses represent energy input to structure for each appliance (based on data in Reference 7)

¹ Dependent upon location (See Table IV-2)

B. Identification of Characteristic Climates

In order to evaluate the effect of different climatic conditions on heating and cooling loads and their related energy use, three cities were selected. These cities, Chicago, Baltimore, and Houston, represent cold, moderate, and hot climates respectively. Although these three climates are not totally representative of the contiguous United States, they do represent areas with the largest population density as well as being representative of areas with the highest potential for energy resource conservation.

1. Chicago

Chicago is in a region of frequently changeable weather. The climate is predominantly continental, ranging from relatively warm in summer to relatively cold in winter. However, the continentality is partially modified by Lake Michigan, and to a lesser extent by other Great Lakes. In late autumn and winter, air masses that are initially very cold often reach the City only after being tempered by passage over one or more of the lakes. Similarly, in late spring and summer, air masses reaching the City from the north, northeast, or east are cooler because of movement over the Great Lakes. Very low winter temperatures most often occur in air that flows southward to the west of Lake Superior before reaching the Chicago area. In summer the higher temperatures are with south or southwest flow and are therefore not influenced by the lakes, the only modifying effect being a local lake breeze. Strong south or southwest flow may overcome the lake breeze and cause high temperatures to extend over the entire City.

The Chicago weather, representing cold climates, is characterized by 6127 heating degree days and 925 cooling degree days. The yearly mean wind velocity is 10.3 mph. There are normally 94 clear days, 102 partly cloudy days, and 169 cloudy days per year in the Chicago area (Ref. 4).

2. Baltimore

Baltimore is in a region about midway between the rigorous climates of the north and the mild climates of the south, and adjacent to the modifying influences of the Chesapeake Bay and Atlantic Ocean to the east and the Appalachian Mountains to the west. Since this region is near the average path of the low pressure systems which

move across the country, changes in wind direction are frequent and contribute to the changeable character of the weather. The net effect of the mountains to the west and the Bay and Ocean to the east is to produce a more equable climate compared with other continental locations farther inland at the same latitude. While hot, humid, muggy periods of weather are not uncommon during the warmer months, they are frequently attended by afternoon or evening thundershowers or nighttime breezes which provide some relief from uncomfortable conditions.

The Baltimore weather, representing moderate climates, is characterized by 4729 heating degree days and 1108 cooling degree days. The yearly mean wind velocity is 9.5 mph. There are normally 105 clear days, 110 partly cloudy days, and 150 cloudy days per year in Baltimore area (Ref. 4).

3. Houston

Houston is located in the flat Coastal Plains, about 50 miles from the Gulf of Mexico and about 25 miles from Galveston Bay. The climate is predominantly marine. Prevailing winds are from the southeast and south, except in January, when frequent passages of high pressure areas bring invasions of polar air and prevailing northerly winds. Temperatures are moderated by the influence of winds from the Gulf which result in mild winters and, on the whole, relatively cool summer nights. Another effect of the nearness of the Gulf is abundant rainfall except for rare extended dry periods. Polar air penetrates the area frequently enough to provide stimulating variability in the weather.

The Houston weather, representing regions with dominant cooling loads, is characterized by 1434 heating degree days and 2889 cooling degree days. The yearly mean wind velocity is 7.4 mph, with a fastest recorded wind velocity of 46 mph, in July 1969. There are normally 91 clear days, 112 partly cloudy days, and 162 cloudy days per year in Houston area (Ref. 4).

IV. ANALYSIS OF STRUCTURAL COMPONENTS AND THERMAL LOAD CHARACTERISTICS

A. Identification of Structural Components and Their Associated Loads

Annual heating and cooling loads were computed for the three selected buildings utilizing a spacial short form computer model and the three selected weather conditions. The buildings load-affecting components were identified and their contribution, both positive and negative, to the buildings heating and cooling loads were determined.

1. Description of Computer Program and Load Calculations Procedures

The computer program used in determining the heating and cooling loads for the selected residences was recently developed model that utilizes a set of simple, but sophisticated algorithms. The algorithms, which are based on equations of heat and mass transfer, were originally developed by HAI for use in hand calculation methodologies which are based on state-of-the-art building energy models (Ref. 5). The accuracy of the computer model has been verified when compared to the HAI's Building Energy Analysis Model (BEAM). Due to its simplicity and operation cost, the model was proven to be the best tool for the type of evaluations required for this study.

The computer model performs a heat balance on the building structure by giving consideration to the loads due to building envelope, floor, solar radiation, internal heat gain, and infiltration. In the following, the procedures employed in computation of each of the five load effecting elements are presented.

a. Building Envelope. The load due to conductive heat transfer through the building envelope is primarily a function of the envelope area, the conductance of envelope materials, the inside and outside temperatures as shown by the following relationship (Ref. 6).

$$Q_{\text{Envelope}} = (QH_1)(HDD)(C_1)(A)(1+F_1(T-72)) \quad (1)$$

where:

Q_{Envelope} = building envelope load;

QH_1 = load at a reference heating degree day, building equivalent U value, and inside set point temperature (obtained from Ref. 6);

HDD = heating degree days (indication of outside temperature);

C_1 = deviation of building equivalent U value from the reference U value (obtained from Ref. 6);

A = building envelope area;

F_1 = factor indicating deviation of inside set point temperature from the reference value (obtained from Ref. 6); and

T = inside set-point temperature.

In order to obtain C_1 , the building equivalent U values were determined from the sum of the products of all envelope component U values and areas, then the sum of the products were divided by the total envelope area that is,

$$U_{\text{Eq}} = \frac{\sum_{i=1}^n A_i U_i}{\sum_{i=1}^n A_i}$$

where A_i 's are exterior surface areas of unique composite surfaces and U_i 's are composite surface conductances. The products of $A \cdot U$'s identify the different building component most affecting the U_{Eq} of the structure.

Higher $A \cdot U$ values represent higher loads, therefore, the major analysis efforts in evaluation of different building component loads were placed on the components with the relatively high $A \cdot U$ values. These values for the component of the three selected buildings were computed and presented in Table IV-1.

TABLE IV-1. A·U VALUES FOR THE
SELECTED ENVELOPE COMPONENT

Building Component	SFD	SFA	MFLR
Wall	78.5	493.1	1104.7
Window	146.5	1117.8	2426.5
Roof	78.0	337.9	858.5
Door	16.5	66.1	156.5

As indicated in Table IV-1, the windows and doors have highest and lowest A·U values respectively, therefore, windows were regarded as a building component with the highest potential of improvement while doors had the least potential.

b. Floor. The heat flux through floors and underground walls normally is treated as a steady state conduction heat transfer, with temperature difference being the difference between inside set point temperature and monthly average ground temperature as shown in equation (2). The heat flux for that period of time in each month during which the building stays in the heating mode was determined to be the heating load due to the floor. The cooling load was also determined by addition of the floor heat fluxes during the cooling hours.

$$QH_{\text{floor}} = (CH_F)(A_F U_F)(T_{\text{sp}} - T_G) \quad (2)$$

where:

QH_{floor} = load due to floor;

CH_F = duration of heating/cooling mode (obtained from Ref. 6);

A_F = floor area;

U_F = floor U value;

T_{sp} = inside set point temperature;

T_G = monthly ground temperature.

c. Solar Radiation. Solar radiation heat gain through the windows of the building were considered to be dependent on three primary variables: the total area of windows, the incident solar radiation available at any location and the solar altitude, the angle between the sun's ray and its projection on the horizontal plane. The relationship of these three

primary variables with the total solar radiation heat gain is given by equation (3).

$$Q_{H_{rad.}} = N_{days} \times IR \times A_w \times CR \quad (3)$$

where:

N_{days} = number of days in the month or period of study;

IR = incident solar radiation on a horizontal plane;

A_w = total glass area in building;

CR = latitude correction factor (obtained from Ref. 6).

d. Internal Loads. The internal heat generation due to occupants, lighting, appliances, and equipment were calculated as a function of the level of occupancy, lighting, and equipment operation and the number of hours during which the building is in the heating/cooling mode. The duration of heating and cooling period was adjusted to reflect different levels of thermal integrity values of the building.

e. Infiltration. The infiltration load was computed as weather conditions, and the inside set point temperature as prescribed in equation (4).

$$Q_{INF} = (CFM)(Q_{H_2})(1 + F_2(T-T_2)) \quad (4)$$

where:

Q_{INF} = infiltration load;

CFM = infiltration rate;

Q_{H_2} = load per CFM at the reference temperature (obtained from Ref. 6);

F_2 = factor indicating deviation of inside set point temperature from the reference temperature (obtained from Ref. 6);

T = indoor set-point temperature.

The infiltration rates were calculated by using a correlation methodology given by Reference 6. In this methodology window area, number of doors, wind velocity, and average mechanical ventilation are utilized to estimate the infiltration rates.

Algebraic addition of the five loads calculated in the above procedure results in the total building heating/cooling loads which had to be met by the heating/cooling systems. This addition was done in the following manner:

For Heating mode:

$$Q_{\text{Loss}} = Q_{\text{Envelope}} + Q_{\text{Floor}} + Q_{\text{Infiltration}}$$

$$Q_{\text{Gain}} = Q_{\text{Radiation}} + Q_{\text{Internal}}$$

$$Q_{\text{Total}} = Q_{\text{Loss}} - Q_{\text{Gain}}$$

For Cooling mode;

$$Q_{\text{Gain}} = Q_{\text{Envelope}} + Q_{\text{Infiltration}} + Q_{\text{Radiation}} + Q_{\text{Internal}}$$

$$Q_{\text{Loss}} = Q_{\text{Floor}}$$

$$Q_{\text{Total}} = Q_{\text{Gain}} - Q_{\text{Loss}}$$

The heating and cooling systems energy use were computed by use of the following equation.

$$Q = \frac{Q_{\text{Total}}}{(E_{\text{sys}})(1-E_{\text{dis}})}$$

where:

Q = system energy use for heating/cooling;

Q_i = component heating/cooling load;

E_{sys} = furnace efficiency/air conditioner C.O.P.;

E_{dis} = distribution losses, in percent of the net load.

The input data required by the computer program included:

- (1) Building envelope conductance, or U value;
- (2) Building envelope area;
- (3) Inside set-point temperature;
- (4) Air change rate, or rate of infiltration;

- (5) Underground wall and floor conductance;
- (6) Underground wall and floor area;
- (7) Ground temperature;
- (8) Window area;
- (9) Level of incident solar radiation;
- (10) Latitude;
- (11) Number of occupants in building;
- (12) Level of lighting energy use;
- (13) Climatic variables (including heating degree days, cooling degree days, and discomfort index cooling degree days); and
- (14) Comfort control system efficiencies.

The output included the monthly and annual heating and cooling load due to conduction through walls and roofs, floors, doors and windows, solar radiation gain through windows, the internal loads due to people, lighting, equipment, and infiltration. Each of these component loads was significantly impacted by variation of one or more of the above parametric values. The degree of variation was dependent on the building type and its geographic location.

2. Heating and Cooling Loads In Base Residences

The structural parameters and floor plan configurations defined for each selected (base) residence in Chapter III were used in formulating inputs to the computer program. Climatological data including heating and cooling degree days, incident solar radiation, ground temperature, and wind velocity for the three locations were obtained by averaging weather data for the years 1970 through 1975. The obtained data is presented in Table IV-2. Using the structural and weather inputs, the monthly and annual heating and cooling loads for the base buildings were determined and also disaggregated into the following structural components:

- (a) Roof/Ceiling;
- (b) Doors;
- (c) Floor;
- (d) Walls;
- (e) Windows;
- (f) Internal Loads;
- (g) Infiltration.

TABLE IV-2. CLIMATOLOGICAL DATA

	<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>	<u>JUN</u>	<u>JUL</u>	<u>AUG</u>	<u>SEPT</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>	<u>TOTAL</u>
<u>MONTHLY HEATING DEGREE DAYS</u>													
Baltimore	901.0	818.0	640.0	374.0	127.0	0.0	0.0	0.0	33.0	227.0	530.0	775.0	4425
Chicago	1243.0	1049.0	838.0	509.0	226.0	0.0	0.0	0.0	102.0	294.0	687.0	1065.0	6013
Houston	355.0	298.0	150.0	63.0	0.0	0.0	0.0	0.0	0.0	0.0	200.0	241.0	1387
<u>MONTHLY COOLING DEGREE DAYS</u>													
Baltimore	0.0	0.0	0.0	0.0	50.0	212.0	354.0	344.0	152.0	0.0	0.0	0.0	1112
Chicago	0.0	0.0	0.0	0.0	46.0	210.0	320.0	293.0	114.0	0.0	0.0	0.0	983
Houston	0.0	0.0	0.0	126.0	307.0	458.0	542.0	490.0	371.0	250.0	70.0	0.0	2570
<u>MONTHLY DISCOMFORT COOLING INDEX</u>													
Baltimore	0.0	0.0	0.0	0.0	109.0	315.0	388.0	372.0	175.0	0.0	0.0	0.0	
Chicago	0.0	0.0	0.0	0.0	95.0	300.0	302.0	326.0	97.0	0.0	0.0	0.0	
Houston	0.0	0.0	0.0	158.0	419.0	413.0	550.0	550.0	428.0	295.0	105.0	0.0	
<u>MONTHLY INCIDENT RADIATION (LY/DAY)</u>													
Baltimore	175.0	243.0	340.0	419.0	488.0	577.0	542.0	469.0	383.0	294.0	189.0	155.0	
Chicago	96.0	147.0	227.0	331.0	424.0	458.0	473.0	403.0	313.0	207.0	120.0	76.0	
Houston	262.0	330.0	413.0	474.0	561.0	604.0	629.0	558.0	470.0	488.0	285.0	240.0	
<u>MONTHLY GROUND TEMPERATURE (°F)</u>													
Baltimore	44.0	45.7	47.4	49.0	54.7	60.4	66.0	65.3	64.6	64.0	57.3	50.6	
Chicago	42.0	43.7	45.4	47.0	53.0	59.0	65.0	63.7	62.4	61.0	44.7	48.4	
Houston	61.0	62.3	63.6	65.0	70.3	75.6	81.0	79.7	78.4	77.0	71.7	66.4	
<u>WIND VELOCITY (MPH)</u>													
Baltimore	9.5												
Chicago	10.3												
Houston	7.4												

The disaggregated loads for windows were further separated into the conduction and radiation contributions to the net heat flow. The computed heating and cooling loads for the base structures, disaggregated into load effecting parameters, are presented in Tables IV-3, IV-4, and IV-5. In these tables some of the parameters dealing with the thermal integrity of the base structures are also included. The disaggregated loads due each component were converted to energy cost by using the actual fuel cost, Tables IV-6 and IV-7, for the three cities. The fuel cost due each component of the base building are presented in Tables IV-8, IV-9, and IV-10.

B. Definition and Evaluation of Strategies for Each Component

Each of the structural components into which the loads were disaggregated was examined for potential energy conservation of RD&D strategies. The components considered were ceiling, doors, floor, walls, windows, and infiltration. For each component, potential heating and cooling load reductions were identified for the three cities, Baltimore, Chicago, and Houston.

In order to improve the thermal performance of any individual component of the heating or cooling load, the rate of heat transfer from one space to another must be changed. This is relatively easy to do when one mode of heat transfer, conduction, radiation, or convection, is usually dominant in the control of heat flow in any given component. In some cases, however, heat flow is much more complicated when more than one mode of heat transfer at a time is a major contributor to the net heat flow. This may be further complicated by the fact that different heat transfer modes may cancel each other at some times while reinforcing each other at other times. Such complex situations were dealt with properly, and the modes of heat transfer were uncoupled and separately analyzed.

When trying to improve the thermal integrity of a residence, the traditional approach has been to add more insulation. This strategy is practical only up to a certain point because conduction is inversely proportional to the thickness of any particular insulating material. If a reasonable amount of insulation is already in place, making a substantial reduction in the conduction requires the addition of extremely thick layers of insulation, which may cause problems in construction. For example, different construction techniques may be

TABLE IV-3. SPECIFICATIONS AND DISAGGREGATED LOADS
FOR SINGLE-FAMILY DETACHED (BASE)

SPECIFICATIONS			
Component	Conductance	Comments	
Roof	0.065	6" Loose Fill Insulation (R-13)	
Doors	0.413	Wood Doors	
Floor	0.200	Uninsulated	
Walls	0.084	3-1/2" Glass Fiber Batts (R-11)	
Windows	1.01	Single Glazing	
Infiltration Parameters		Yes	No
Weatherstripping			X
Storm Windows			X
Storm Doors			X
Caulking			X

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses						
Roof	95	12	131	12	30	14
Doors	20	3	28	3	6	3
Floor	216	27	260	25	30	14
Walls	96	12	132	12	30	14
Window Conduction	179	23	245	23	57	27
Infiltration	188	23	261	25	58	28
Total Heat Losses	794	100	1057	100	211	100
Heat Gains						
Window Radiation	69	9	53	5	51	24
Internal	171	22	193	18	76	36
Heating System (net heating load)	554	69	811	77	84	40
Total Heat Gains	794	100	1057	100	211	100

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	11	4	9	4	30	5
Doors	2	1	2	1	6	1
Floor						
Walls	11	4	9	4	11	2
Window Conduction	20	7	17	7	30	5
Window Radiation	28	10	23	10	54	9
Infiltration	60	22	45	19	56	10
					139	24
Internal Heat Gains	137	52	131	55	243	44
Total Heat Gains	269	100	236	100	569	100
Heat Losses						
Floor	89	33	96	40		
Cooling System (net cooling load)	180	67	140	60	569	100
Total Heat Losses	269	100	236	100	569	100

* 1 Therm = 1×10^5 Btu.

TABLE IV-4. SPECIFICATIONS AND DISAGGREGATED LOADS
FOR SINGLE-FAMILY ATTACHED (BASE)

SPECIFICATIONS			
Component	Conductance	Comments	
Roof	0.064	6" Loose Fill Insulation (R-13)	
Doors	0.413	Wood Doors	
Floor	0.200	Uninsulated	
Walls	0.099	2-1/4" Glass Fiber Insulation (R-7)	
Windows	1.136	Single Glazing	
Infiltration Parameters		Yes	No
Weatherstripping			X
Storm Windows			X
Storm Doors			X
Caulking			X

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses						
Roof	416	9	575	9	133	10
Doors	81	2	113	2	26	2
Floor	878	18	1062	16	124	9
Walls	606	13	836	13	193	14
Window Conduction	1376	29	1900	29	438	32
Infiltration	1454	29	2058	31	463	33
Total Heat Losses	4811	100	6544	100	1377	100
Heat Gains						
Window Radiation	424	9	362	6	347	25
Internal	1262	26	1438	22	580	42
Heating System (net heating load)	3125	65	4744	72	450	33
Total Heat Gains	4811	100	6544	100	1377	100

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	48	2	41	2	131	3
Doors	10	1	8	0	26	1
Floor	-	-	-	-	52	1
Walls	71	4	59	3	191	5
Window Conduction	160	8	134	8	433	10
Window Radiation	187	10	153	10	376	9
Infiltration	466	24	354	21	1110	27
Internal Heat Gains	1008	51	960	56	1840	44
Total Heat Gains	1950	100	1709	100	4159	100
Heat Losses						
Floor	359	18	382	22	-	-
Cooling System (net cooling load)	1591	82	1327	78	4159	100
Total Heat Losses	1950	100	1709	100	4159	100

* 1 Therm = 1×10^5 Btu.

TABLE IV-5. SPECIFICATIONS AND DISAGGREGATED LOADS
FOR MULTIFAMILY LOW-RISE (BASE)

SPECIFICATIONS			
Component	Conductance	Comments	
Roof	0.073	6" Loose Fill Insulation (R-13)	
Doors	0.326	Steel Doors	
Floor	0.1	Poured Concrete, Uninsulated	
Walls	0.098	2-1/4" Glass Fiber Insulation (R-7)	
Windows	1.136	Single Glazing	
Infiltration Parameters		Yes	No
Weatherstripping			X
Storm Windows			X
Storm Doors			X
Caulking			X

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses						
Roof	1042	12	1440	12	313	14
Doors	193	2	265	2	56	2
Floor	834	10	987	8	70	3
Walls	1368	16	1844	16	416	18
Window Conduction	2996	35	4112	35	846	37
Infiltration	2196	25	3096	27	599	26
Total Heat Losses	8629	100	11784	100	2300	100
Heat Gains						
Window Radiation	924	11	754	6	608	26
Internal	3136	36	3512	30	1268	55
Heating System (net heating load)	4569	53	7518	64	424	19
Total Heat Gains	8629	100	11784	100	2300	100

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	119	3	99	3	322	4
Doors	2	0	2	0	42	0
Floor	-	-	-	-	47	1
Walls	161	4	134	4	434	5
Window Conduction	351	8	294	8	878	10
Window Radiation	406	10	331	9	816	9
Infiltration	707	17	540	14	1657	19
Internal Heat Gains	2448	58	2341	62	4512	52
Total Heat Gains	4194	100	3741	100	8707	100
Heat Losses						
Floor	326	8	347	9	-	-
Cooling System (net cooling load)	3868	92	3394	91	8707	100
Total Heat Losses	4194	100	3741	100	8707	100

* 1 Therm = 1×10^5 Btu.

TABLE IV-6. ELECTRICITY COSTS

Baltimore					Over 500		
KWH	0-40	40-150	150-300	300-500	Summer	Winter	
COST, \$/KWH	.0836	.0579	.0445	.369	.0369	.0284	
Chicago							
KWH	0	0-200	Over 200				
COST, \$/KWH	1.20	.0512	.0401				
Houston						Over 600	
KWH	0	0-20	20-110	110-300	300-600	Summer	Winter
COST, \$/KWH	2.10	.002	.0431	.0326	.0273	.0273	.0210

TABLE IV-7. GAS COSTS

Baltimore						
CCF	0-2	2-10	Over 10			
COST \$/CCF	.829	.313	.278			
Chicago						
CCF	0-10	10-20	20-40	40-320	320-4000	
COST \$/CCF	.3257	.2147	.2047	.1937	.1768	
Houston						
CCF	0	0-4	4-30	30-60	60-160	Over 160
COST \$/CCF	2.00	.192	.315	.302	.282	.247

TABLE IV-8. SINGLE-FAMILY DETACHED (BASE) ANNUAL
ENERGY COSTS RELATED TO EACH STRUCTURAL COMPONENT

Component	BALTIMORE			CHICAGO			HOUSTON		
	Heating	Cooling	Total	Heating	Cooling	Total	Heating	Cooling	Total
Roof/Ceiling	\$ 33	\$ 7	\$ 40	\$ 37	\$ 6	\$ 43	\$14	\$ 14	\$ 28
Doors	7	2	9	8	1	9	3	3	6
Floors	74	-60	14	73	-70	3	13	5	18
Walls	33	7	40	37	7	44	14	15	19
Window-Conduction	61	14	75	69	12	81	26	27	53
Window-Radiation	-24	19	-5	-15	17	2	-23	28	5
Internal	-59	93	34	-54	96	42	35	122	87
Infiltration	65	40	105	73	33	106	27	69	96
TOTAL	\$190	\$121	\$311	\$228	\$103	\$331	\$38	\$284	\$322

TABLE IV-9. SINGLE-FAMILY ATTACHED (BASE AVERAGE INDIVIDUAL UNIT) ANNUAL ENERGY COSTS RELATED TO EACH STRUCTURAL COMPONENT

Component	BALTIMORE			CHICAGO			HOUSTON		
	Heating	Cooling	Total	Heating	Cooling	Total	Heating	Cooling	Total
Roof/Ceiling	\$ 18	\$ 4	\$ 22	\$ 20	\$ 4	\$ 24	\$ 8	\$ 8	\$ 16
Doors	3	1	4	4	1	4	1	2	3
Floors	38	-31	7	37	-35	2	7	3	10
Walls	39	6	45	29	5	34	11	12	23
Window-Conduction	59	14	73	67	12	79	25	27	52
Window-Radiation	-18	16	-2	-13	14	1	-20	24	4
Internal	-54	86	32	-51	89	38	-33	116	83
Infiltration	62	40	102	72	33	105	26	70	96
TOTAL	\$147	\$135	\$282	\$167	\$123	\$290	\$26	\$263	\$289

TABLE IV-10. MULTIFAMILY LOW-RISE (BASE AVERAGE INDIVIDUAL APARTMENT)
ANNUAL ENERGY COSTS RELATED TO EACH STRUCTURAL COMPONENT

Component	BALTIMORE			CHICAGO			HOUSTON		
	Heating	Cooling	Total	Heating	Cooling	Total	Heating	Cooling	Total
Roof/Ceiling	\$15	\$ 3	\$ 18	\$17	\$ 3	\$ 20	\$ 6	\$ 7	\$ 13
Doors	3	0	3	3	0	3	1	1	2
Floors	12	-9	3	12	-11	1	1	1	2
Walls	20	5	25	22	4	26	8	9	17
Window-Conduction	43	10	53	48	9	57	16	18	34
Window-Radiation	-13	11	-2	-9	10	1	-12	17	5
Internal	-45	69	24	-41	72	31	-24	94	70
Infiltration	31	20	51	36	17	53	11	35	46
TOTAL	\$65	\$127	\$192	\$88	\$104	\$192	\$ 8	\$181	\$189

required to handle large thicknesses of insulation in a wall. If, however, a component holds very little insulation to begin with, the addition of even a small amount of insulation will result in a significant reduction in the thermal conduction.

In the following paragraphs the load due to each of the identified load components is discussed and the analysis of improvement strategies are presented. A summary of these strategies and their effect on heating and cooling loads is also included at the end of this section.

1. Ceilings

a. Characteristics of Ceiling. The ceilings of the base buildings all have 6" loose fill insulation (R-13). The heat loss through the ceiling accounts for 12 to 23 percent of the heating load in Baltimore and Chicago, and 30 to 75 percent of the heating load in Houston. (The 75 percent figure occurs in low-rise apartments). The heat gain through the ceiling accounts for 3 to 6 percent of the cooling load in all three cities.

b. Strategies for Improving Performance of Ceilings. Two general strategies which pertain to ceilings are:

- (1) Reduce the thermal conduction of the ceiling.
- (2) Regulate solar gain through the roof.

Reducing the conduction of the ceiling can be accomplished either by using thicker insulation, or using more efficient insulation, that is, one with a higher resistance to heat flow than materials presently used. If a new, efficient insulation is to be developed, it must be done within the cost constraints outlined in Section F of this chapter.

One can increase the solar gain through the roof by using a dark-colored roof, which typically absorbs 20 to 30 percent more incident solar radiation than a light-colored roof. The disadvantage of this strategy is that the dark roof will also absorb solar radiation in the summer. This additional solar load in the summer may be reduced by properly ventilating the attic space. No conclusive studies have been performed to date demonstrating the effectiveness of attic ventilation.

Table IV-11 shows the heat loss through the ceiling in winter and heat gain in the summer at various levels of insulation.

2. Doors

a. Characteristics of Doors. Doors represent the smallest contribution to heating and cooling loads of all the components. They account for 2 to 4 percent* of the heating load in Baltimore and Chicago, 6 to 12 percent* of the heating load in Houston, and less than one percent* of the cooling load in all three cities. Currently available metal clad foam core doors can reduce conduction losses/gains through the doors to between one-third and one-fourth of the conduction losses/gains through the doors in the base residences. Further development of doors could not greatly affect the heating and cooling loads of the residence and it is not recommended as an area for RD&D programs.

3. Floor

a. Characteristics of Floor. The contribution of a floor over a non-climate controlled space to the heating and cooling load is quite different from any other component because it is proportional to ground temperature, which is warmer than outdoor air temperature in the winter and cooler in the summer. In many parts of the country, the cooler ground temperature in summer causes a heat loss through the floor, which helps to lower cooling loads. However, leaving the floor uninsulated to take advantage of this cooling in summer causes large heat losses in the winter. Since the detrimental effect of heat loss in the winter is larger than the beneficial effect of heat loss in the summer, insulating the floor has a net beneficial effect in cooler climate locations.

Heat loss through the floor accounts for about 35 percent of the heating load in the SFD residences, 25 percent of the heating load in SFA residences and 15 percent of the heating load in MFLR residences in all three cities. During the cooling season in Baltimore and Chicago, floors reduce the cooling load by about 60 percent in SFD residences, by about 25 percent in SFA residences, and by 10 percent in MFLR residences. The contribution of the floor to the cooling load in Houston is very small (less than two percent) in all three residential buildings.

* This does not include infiltration of outdoor air through the cracks around the doors. Infiltration is considered separately in this section.

TABLE IV-11. HEAT LOSS/GAIN THROUGH THE
CEILING AT VARIOUS LEVELS OF INSULATION

Insulation Level	Heat Loss, Winter: Therms/Building									Heat Gain, Summer: Therms/Building								
	Baltimore			Chicago			Houston			Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
R-13 (Base)	-95	-415	-1060	-131	-574	-1460	-30	-131	-271	+11	+48	+123	+9	+41	+103	+29	+131	+333
R-19	-72	-324	- 881	-100	-448	-1220	-23	-103	-226	+ 8	+38	+102	+7	+31	+ 86	+22	+102	+277
R30	-52	-233	- 692	- 72	-322	- 957	-17	- 74	-178	+ 6	+27	+ 80	+5	+23	+ 67	+16	+73	+217
R38	-45	-200	- 610	- 62	-227	-856	-14	- 64	-159	+ 5	+23	+ 72	+4	+19	+60	+13	+63	+194

b. Strategies for Improving the Performance of Floors. Because of unique characteristic of floors in reducing the cooling load (in Baltimore and Chicago), insulating the floor is not the only strategy to pursue. The ideal strategy would result in an insulated floor in the winter and an uninsulated floor in the summer. This could be achieved by insulating the floor, and routing the return air for the cooling system through the basement. Thus, the advantage of the cool basement can be used in the summer while the floor is insulated in the winter. Such an operation would not be achievable in MFLR residences in the three cities nor in SFD and SFA without a basement (e.g., Houston).

Table IV-12 shows the heat loss through the floor in the winter at various levels of insulation.

4. Walls

a. Characteristics of Walls. Walls account for 16 to 30 percent of the heating load in Baltimore and Chicago and 36 to 43 percent in Houston. They only account for 4 to 6 percent of the cooling load in all three cities.

b. Strategies for Improving the Performance of Walls. It is difficult to develop strategies to deal with improving the performance of walls because walls are in an intermediate group as far as their importance in the overall energy use of a residence. Walls usually are slightly more important overall than ceilings, but this may be due to the fact that ceilings are generally more easily insulated with thicker layers of insulation than walls. An increase in the thickness of the wall can cause construction problems such as fitting of window and door frames; therefore, the best approach to follow in improving the performance of walls is to develop a more efficient insulation (which could be used to insulate other components as well). This new insulating material should have the conductance of foam insulations, or better, while having fiberglass cost ranges.

Table IV-13 shows the heat loss in winter and heat gain in summer through walls insulated to various levels.

5. Windows

a. Characteristics of Windows. During the heating season, the window affects the overall heat balance in a house by losing heat to the outside through conduction and gaining heat by allowing solar radiation to penetrate into the house. The combined effect is a net loss during the

TABLE IV-12. HEAT LOSS/GAIN THROUGH THE
FLOORS AT VARIOUS LEVELS OF INSULATION

Insulation Level	Heat Loss, Winter: Therms/Bldg.						Heat Loss/Gain, Summer: Therms/Bldg.					
	Baltimore		Chicago		Houston		Baltimore		Chicago		Houston	
	SFD	SFA	SFD	SFA	SFD	SFA	SFD	SFA	SFD	SFA	SFD	SFA
None (Base)	-216	-874	-260	-1060	-30	-123	-84	-329	-88	-346	+13	+154
R-19	- 48	-197	- 59	- 238	- 7	- 28	-19	- 74	-20	- 78	+ 3	+ 12
R-30	- 35	-144	- 43	- 174	- 5	- 20	-14	- 54	-15	- 57	+ 2	+ 9

TABLE IV-13. HEAT LOSS/GAIN THROUGH THE
WALLS AT VARIOUS LEVELS OF INSULATION

	Heat Loss, Winter: Therms/Building									Heat Gain, Summer: Therms/Building								
	Baltimore			Chicago			Houston			Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
BASE	-96	-606	-1360	-132	-838	-1880	-30	-193	-349	+11	+71	+159	+9	+59	+133	+29	+191	+429
R-17	-61	-388	- 939	- 84	-536	-1300	-20	-124	-241	+7	+45	+109	+6	+37	+ 91	+18	+121	+294
R-31	-43	-282	-708	-59	-390	- 998	-14	- 90	-188	+5	+32	+ 84	+4	+27	+70	+13	+ 88	+227

heating season for base residences. Considered as a combined effect, that is, conduction losses and radiation gains of the windows added together, windows do not represent a very large contribution to the heating load (only doors contribute less in Baltimore and Chicago). However, if the conduction and radiation are considered separately, they are among the largest contributors to the heating load with conduction representing a very large heat loss and radiation representing a large heat gain.

During the cooling season, window conduction and radiation reinforce each other to make windows one of the three largest components of cooling loads in all three of the cities considered in this study.

b. Strategies for Improving the Performance of Windows.
In developing strategies to improve the performance of windows, it must be remembered that conduction causes an increase in both heating and cooling loads and radiation decreases heating loads and increases cooling loads. The thermal conductance of a window is typically an order of magnitude higher than the thermal conductance of solid components, indicating that large improvements are possible.

Window conduction can be reduced by more than 65 percent using currently available technologies. These include double glazing, storm windows, and combinations of both double glazing and storm windows. (Storm windows give the additional benefit of reduced infiltration, which is discussed later in this section.) Table IV-14 shows the heat loss in winter and heat gain in the summer due to window conduction at various levels of insulation.

The development of strategies to deal with radiation gain through windows is more complex since the radiation is desirable for part of the year and undesirable for the rest of the year. Four alternative methods of controlling solar gain through windows are:

- (1) Use glass (lights) with different transmission factors as needed.
- (2) Develop a glass or a film to be applied to the glass surface with a variable transmission factor, allowing more radiation to penetrate in the winter than in the summer.
- (3) Use operable shading devices.
- (4) Use fixed shading devices which are designed to allow winter sun to enter the building but to exclude summer sun.

TABLE IV-14. HEAT LOSS/GAIN THROUGH
WINDOWS AT VARIOUS LEVELS OF INSULATION

Insulation Level	Heat Loss, Winter: Therms/Building									Heat Gain, Summer: Therms/Building								
	Baltimore			Chicago			Houston			Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
Single-Glazing (Base)	-179	-1370	-2980	-245	-1900	-4130	-46	-438	-767	+20	+160	+348	+17	+134	+291	+54	+433	+942
Double-Glazing or Storm Windows	-120	-494	-1040	-165	-683	-1460	-33	-135	-85	+13	+54	+119	+11	+45	+99	+36	+147	+320
Double-Glazing plus Storm Windows	-72	494	-1040	-100	-683	-1400	-10	-127	*	+8	+54	+119	+6	+45	+99	+21	+147	+320
Window Area Reduction (30%)	-123	-962	-2070	-169	-1320	-2860	-39	-304	-566	+14	+109	+237	+11	+91	+198	+37	+295	+641

*No Heating Required.

Following is a discussion of each of the above strategies.

(1) Use Glass with a Specific Transmissivity.

Such products are presently available but their use is limited to climates in which cooling is the predominant load. If a window in a house in a climate such as Baltimore or Chicago had a very low transmissivity, the dollar savings realized in the cooling would almost offset the increase in heating costs.

(2) Variable Transmission Glass. A window material, which would transmit a large percentage of solar radiation when it is cold outside (less than 65°F) and much less radiation when it is warmer, could reduce cooling loads without increasing heating loads. If transmissivity could be reduced by 50 percent during warm periods, cooling loads could be reduced by 4 to 8 percent without increasing heating loads.

(3) Operable Shading Devices. When used properly, operable shading devices provide the highest degree of solar radiation control. Although exterior shading devices are more effective in controlling sunlight than internal devices, even internal devices such as blinds or shutters are more effective than reducing the transmissivity of the window glass.

An operable shading device, which could prevent 90 percent of unwanted solar radiation from entering the residence, would decrease cooling loads by 9 to 15 percent in Baltimore and Chicago and 8 to 9 percent in Houston.

(4) Fixed Shading Devices. Fixed shading devices have the advantage that they are less likely to need maintenance or repair than operable devices but fixed shading devices are less effective. (In climates like that of Houston, fixed shading can be almost as effective as operable shading devices because shading is almost always required). Designed as a building projection, roof overhang, or even landscaping, fixed shading radiation entering a structure in the summer, but this would probably also reduce the amount of radiation received in the winter by about 10 percent.

Design considerations can also have significant impact on window performance. For example, triple glazed windows (double glazed plus storm window) facing south will have a net heat gain during the winter. If a house is to be built in a climate where heating is the dominant load, large south windows would render benefits. However, if cooling loads are very large, then south windows should be minimized and shaded to avoid excessive solar gain during the cooling season.

Table IV-15 shows the gains and losses through one square foot of window facing in various directions. The following assumptions were made for the analysis:

- (1) The triple glazed window has a U-value of 0.39;
- (2) Including 50 percent of maximum possible solar insolation;
- (3) The location chosen is 40° N latitude;
- (4) Temperature difference between indoor and, outdoor is as follows;

(a) December	$\Delta T = 35^\circ$
(b) January	$\Delta T = 37^\circ$
(c) February	$\Delta T = 35^\circ$
(d) March	$\Delta T = 28^\circ$

Table IV-16 shows the same information for one square foot of window that has an operable insulation device which is assumed to be in place 12 hours per day. When the insulating panel is in place, the U value is assumed to be 0.13.

The effect of windows on heating and cooling loads can also be minimized by reducing the window area in a building. This design consideration can have significant impact on the heating and cooling loads of all types of residential buildings. The effect of window area reduction was included in Table IV-14.

6. Infiltration

a. Characteristics of Infiltration. Infiltration is the largest single contributing factor to heating and cooling loads. It accounts for 32 to 47 percent of heating loads in Baltimore and Chicago and about 100 percent in Houston. Infiltration also accounts for 16 to 33 percent of the cooling load in all three cities.

TABLE IV-15. WINDOW GAINS AND
LOSSES, DOUBLE GLAZED WINDOW

	<u>GAIN</u>	<u>LOSS</u>	<u>NET</u>
South Facing Window			
January	514	-346	168
February	510	-328	182
March	437	-262	175
December	492	-328	164
Southeast or Southwest Window			
January	370	-346	24
February	406	-328	78
March	416	-262	154
December	349	-328	21
East or West Window			
January	160	-346	-186
February	226	-328	-102
March	303	-262	41
December	136	-328	-192

TABLE IV-16. WINDOW GAINS AND LOSSES
DOUBLE GLAZED WINDOW WITH OPERABLE INSULATING PANEL

	<u>GAIN</u>	<u>LOSS (DAY)</u>	<u>LOSS (NIGHT)</u>	<u>NET</u>
South Window				
January	463	-250	-66	147
February	459	-234	-62	163
March	393	-179	-51	163
December	443	-234	-62	147
Southeast or Southwest Window				
January	333	-250	-66	17
February	365	-234	-62	69
March	374	-179	-51	144
December	314	-234	-62	18
East or West Window				
January	144	-250	-66	-172
February	203	-234	-62	- 93
March	273	-179	-51	43
December	122	-234	-62	-174

b. Strategies for Improving Performance of Infiltration.
Concentration in three key areas can greatly reduce infiltration:

- (1) The net crack area through which air infiltrates must be minimized.
- (2) The stagnation pressure against the building due to wind must be reduced.
- (3) Better control of workmanship in building construction (infiltration test procedures) must be achieved.

Following is a discussion of these three general strategies.

(1) Reduce Crack Area. Infiltration is directly proportional to the equivalent orifice area through which air can flow. If cracks in the building structure are filled in or sealed, infiltration is greatly reduced. One strategy, which very effectively seals structure crackage while insulating the building, is a foamed in place insulation. If a material could be developed which had a low conductance, was relatively easy to install, and was not prohibitively expensive to foam in place, it could be used to essentially wrap the entire building in a wind proof, insulating barrier. Such a material would also have to comply with fire and other building codes. Cracks around window and door frames and around other penetrations of the building exterior would still have to be effectively sealed to minimize infiltration.

The structural components which have the greatest effect on infiltration are windows and doors. Therefore, the typical approaches to reduce infiltration are to weatherstrip windows and doors, caulk around window frames and door frames, and add storm windows and storm doors. Although these measures represent very specific measures, they can be used as indications of the general strategy of reducing infiltration by a certain percentage through a reduction in equivalent orifice area. Table IV-17 shows the infiltration portion of heating and cooling loads at various levels of infiltration reduction in the three cities and for the three types of residences. For each type of residence, the first line represents the base house; the second line represents the addition of storm windows and storm doors to the base house; the third line adds weatherstripping to the second line; and the fourth line adds caulking of window and door frames to the third line. Because those specific physical characteristics were used in developing Table IV-17, the percent reduction of infiltration load varies slightly from city to city and among residency types. However, the range of variation is quite small with storm doors and storm windows causing a 6 to 13 percent reduction

TABLE IV-17. INFILTRATION LOADS AT VARIOUS INFILTRATION RATES

STRUCTURE	INFILTRATION LOADS (THERM = 10 ⁵ Btu)									
	BALTIMORE			CHICAGO			HOUSTON			
	Infiltration Rates/ Reduction	Heating (Therms)	Cooling (Therms)	Infiltration Rates/ Reduction	Heating (Therms)	Cooling (Therms)	Infiltration Rates/ Reduction	Heating (Therms)	Cooling (Therms)	
SFD	Base	125 CFM	188	59	131 CFM	260	45	106 CFM	58	138
	1.	12%	163	52	11%	231	40	11%	44	124
	2.	27%	134	43	28%	187	32	24%	37	105
	3.	31%	127	41	30%	180	31	27%	36	101
SFA	Base	489 CFM	1460	467	1035 CFM	2050	353	841 CFM	460	1100
	1.	11%	1300	418	6%	1930	332	9%	356	1000
	2.	26%	1080	348	26%	1520	262	23%	275	849
	3.	29%	1040	333	29%	1460	251	26%	263	812
MFLR	Base	1505 CFM	2220	711	1568 CFM	3100	534	1254 CFM	533	1640
	1.	13%	1860	622	12%	2660	270	10%	143	1480
	2.	27%	1550	519	28%	2070	385	25%	*	1230
	3.	31%	1370	489	32%	1960	363	28%	*	1190

* No Heating Required.

1. Addition of storm doors and windows.
2. Addition of storm doors and windows plus weatherstripping.
3. Addition of storm doors and windows plus weatherstripping and caulking.

in infiltration loads, storm doors and windows plus weatherstripping causing a 23 to 28 percent reduction, and storm doors and windows plus weatherstripping and caulking causing a 26 to 32 percent reduction.

(2) Reduce Stagnation Pressure. Infiltration is directly proportional to the stagnation pressure, which is a function of the square of wind velocity. Any reduction in wind speed at the building would produce a second degree reduction in infiltration. For example, a 25 percent reduction in wind speed would produce a 44 percent reduction in infiltration due to wind. Such a reduction could be achieved by the use of landscaping and other design considerations such as building orientation and configuration.

If a solid barrier, such as an earth berm, or solid wall is used as wind break, typically a 50 percent reduction in wind speed will be experienced as much as 15 barrier heights downwind of the wind break. Trees and shrubs, which let some wind through, provide an extended range of moderate wind protection. A wind break of trees usually will not reduce wind speed by more than 75 percent at any point. But an area downwind of the trees for a distance equivalent to 30 times the height of the trees may experience a reduction in wind speed of more than 25 percent.

(3) Better Control of Workmanship in Building Construction (Infiltration Test Procedures).

Since effective crack area is a function of workmanship, it could be reduced by essentially enforcing high quality workmanship. This could be done through building inspection which must be passed before a new residence may be occupied. The building inspection could include an infiltration test which would be used to determine the equivalent orifice area in the building envelope. Such a test would force builders to supervise construction more carefully to ensure proper workmanship. It is anticipated that better control of workmanship in residential building construction would render savings up to 30 percent of the present infiltration energy use.

C. Combinations of Identified Strategies

In the previous section, the effect of individual strategies upon the loads for the three base structures were studied for each climatic location. The three base structures represent typical construction of new residential buildings found in the early seventies. The loads that the heating and cooling systems had to meet were reduced significantly when combinations or groups of strategies were evaluated and compared to the base structures. These groupings, or combinations of strategies were categorized as follows:

- (1) BASE
- (2) ENERGY CONSERVING
- (3) IMPROVED
- (4) OPTIMIZED

The combination of structural strategies found in the three ENERGY CONSERVING structures represents today's typical new residential dwelling. Tables A-4, A-7, and A-10 placed in Appendix A show the specification for the ENERGY CONSERVING residential structure (SFD, SFA, MFLR), along with their disaggregated loads for both heating and cooling modes. While the specifications suggest a certain type of insulating material, the value of the conductance (or the R value) is of more importance. It is these values that presently known materials (or materials developed as the result of RD&D programs) should satisfy. Following the ENERGY CONSERVING structures are the IMPROVED and OPTIMIZED versions of the original selected structures. Again, specifications for these two designs were evaluated, and disaggregated component loads were calculated for the structures in the three climatic locations and the results are presented in Tables A-4 through A-12 in Appendix A. In order to demonstrate the effects of the four strategy combinations, Figures IV-1 through IV-6 graphically illustrate the relative reduction of the component heating and cooling loads in the three climatic locations as a result of the applying combinations of different strategies to the single-family detached structure. As more insulation was incorporated into the single-family residence, the loads for those components affected by the additional insulations were reduced significantly while the proportional contribution due to internal and infiltration loads increased.

When all the component loads were normalized with respect to total heat gains and losses, as shown in Tables A-4 through A-12, it was found that the component percentage of the total heat gains or losses remained independent of structural type and climatic location. This was found to be

Figure V-1. Single-Family Detached -- Baltimore, Heating

Figure IV-2. Single-Family Detached -- Chicago, Heating

Figure IV-3. Single-Family Detached -- Houston, Heating

Figure IV-4. Single-Family Detached -- Baltimore, Cooling

Figure IV-5. Single-Family Detached -- Chicago, Cooling

Figure IV-6. Single-Family Detached -- Houston, Cooling

true with northern locations while exceptions were found in those structures located in the southern (Houston) climatological region. Therefore, when comparing strategy combinations, it is more important to examine the magnitudes of the components of the heating and cooling loads than to examine the percentage contribution of the components.

Table IV-18, summarizes the net heating and cooling loads for the base residential structures and the three strategy combinations in the three climatic areas.

D. Ranking of RD&D Component Strategies

Based on the energy saving potential of each component studied, a list of strategies were identified. These strategies were ranked according to the maximum potential for national energy savings within the residential sector.

The procedure used in estimating national energy savings were as follows: first, all thermal load reductions due to each component strategy were converted to primary energy using seasonal efficiencies obtained from the climate control systems section of this report, and primary efficiencies from Reference 7. For the four climatological regions (Northeast, North Central, South, and West), the number of residential structures in the current building stock were disaggregated according to fuel, system, and structural type. By giving consideration to weighted regional degree days, weighted regional building U-values, and the number of housing types per region, the following individual component strategies were ranked in order of the magnitude of their national energy saving potentials.

- (1) 30% infiltration reduction
- (2) 26% infiltration reduction
- (3) 11% infiltration reduction
- (4) R-31 wall insulation
- (5) 30% window area reduction
- (6) R-17 wall insulation
- (7) R-30 floor insulation
- (8) R-19 floor insulation
- (9) R-38 roof insulation
- (10) R-30 roof insulation
- (11) R-19 roof insulation
- (12) R-10 door insulation

TABLE IV-18. NET HEATING AND COOLING LOADS FOR
STRUCTURAL STRATEGY COMBINATIONS (THERM = 10^5 BTU)

Structures	Strategy Combinations	Baltimore		Chicago		Houston	
		Heating (Therms)	Cooling (Therms)	Heating (Therms)	Cooling (Therms)	Heating (Therms)	Cooling (Therms)
SFD	Base	554	180	811	140	84	569
	Energy Conserving	437	158	647	123	52	513
	Improved	141	205	256	181	*	450
	Optimized	99	204	202	179	*	434
SFA	Base	3125	1591	4744	1327	450	4159
	Energy Conserving	2187	1420	3418	1165	191	3733
	Improved	800	1559	1582	1371	*	3355
	Optimized	585	1547	1280	1368	*	3271
MFLR	Base	4569	3868	7518	3394	424	8707
	Energy Conserving	2738	3545	4826	3134	84	7905
	Improved	1462	3296	3053	2928	*	7360
	Optimized	1016	3225	2389	2890	*	7147

* No Heating Required.

The ranking of these strategies show the largest energy savings are caused by the reduction of air infiltration. This is true only when comparing infiltration reductions to individual structural component improvements. However, in a comparison of infiltration reductions to the overall building thermal insulation improvement, the latter will result in more energy savings than the reduction of infiltration alone.

E. Economic Analysis

The purpose of this section is to provide a tool for determining the economic constraints on an energy conserving item which may result from the implementation of specific strategies. All energy conserving features considered are state-of-the-art technology and further RD&D is only required for the purpose of cost reduction. Since the amount of future cost reductions are not presently known, a different approach for the normal cost benefit and payback is taken.

The economic analysis assumes that the cost of an energy conserving item will be covered by a loan. The loan may be for any term and at any interest rate. Fuel prices are averaged over a given period and the energy cost savings are balanced against the payments on the loan to determine the maximum price the consumer would be willing to pay for an energy conserving item given a specific level of fuel savings.

The equation for finding the maximum allowable cost of an energy conserving item is given by:

$$C_{\max} = \frac{1000 \times S}{12 \times M} \times \frac{\sum_{N=1}^P \left[F(E)^{N-1} \right]}{P} \quad (1)$$

where:

$C_{\max}$ = maximum allowable cost of the energy conserving item

S = savings in therms/year resulting from the energy conserving item

M = monthly payment per \$1000 borrowed (found in standard financial tables)

F = current or base cost of fuel in dollars/
therm

E = fuel escalation rate

P = period over which fuel prices are being
considered.

NOTE: S and F may be terms of the units of a particular type of fuel. For example, S may be in gallons of oil per year and F in dollars per gallon of oil, but one of the two terms may not have units of a particular fuel and the other have units of therms.

An inaccuracy inherent in equation (1) is that a summation method allows fuel prices to rise only once a year. To be more accurate, fuel rates should be allowed to rise continuously over the entire year. (In fact, fuel rates rise in discrete steps, but their behavior is more closely approximated by a continuous curve than by a one-year step.) The continuous form of equation (1) would be:

$$C_{\max} = \frac{1000 \times S}{12 \times M} \times \frac{\int_0^P F \times E^n \, dn}{P} \quad (2)$$

Evaluating the integral gives:

$$C_{\max} = \frac{1000 \times S \times F \times (E^P - 1)}{12 \times M \times P \times \ln E} \quad (3)$$

Notice that the solution from equation (3) would show that if a one-year period were examined, fuel costs would be higher at the end of the year than at the beginning, resulting in a slightly higher $C_{\max}$ than in equation (1), which assumes that fuel costs would be the same at the end of the first year as at the beginning.

Equation (3) is applicable to both new and retrofit cases, if proper interpretation is given to two variables, M and $C_{\max}$. As mentioned above, M is the monthly payment per \$1000 borrowed. This will obviously change depending on the number of months of the loan and the interest rate. Since retrofit measures may typically be financed by a shorter term, higher interest loan than new construction, M might typically be larger for retrofit installations than for new installations, resulting in a lower $C_{\max}$ for retrofit than new construction. $C_{\max}$ may have to be

interpreted differently for retrofit than for new construction depending on the circumstance. In new construction, C_{max} can almost always be interpreted as the incremental cost of the energy conserving feature over the base case. For example, when considering the possibility of the installation of double glazed windows instead of single glazed in new construction, C_{max} would be the difference in cost between the single glazing and the double glazing. But in the case of retrofit, C_{max} would be the total cost of the double glazed windows less any salvage value of the old windows. If, for some reason, the windows must be replaced anyway, then the retrofit case would be the same as the new construction case, i.e., C_{max} would be the difference in cost between the single and double glazed windows.

In order to evaluate the cost effectiveness of the investigated strategies it was necessary to utilize this economic analysis method. The maximum allowable costs (C_{max}) of implementation of energy conserving structural strategies were compared to the estimated new construction costs for each structural type in the three climatic areas. If the new construction and retrofit costs (material plus labor) fell below the maximum allowable costs of implementation, then the strategies were considered to be presently economically feasible, and were viewed as state-of-the-art. Those strategies which had higher costs of construction or retrofit than allowable were considered as areas which warrant future RD&D effort.

The following sections summarize the economic effects of upgrading combinations of structural components in the base structures to the optimized structures found in Section IV-D. The base structures were assumed to have gas heating systems with a seasonal operating efficiency of sixty-seven percent and electric cooling with a seasonal coefficient of performance (C.O.P.) of 1.76.

In Tables IV-20 through IV-25, the following values were assigned to the parameters in equation (3):

- P = 10 years
- E = 1.05 (5% per year)
- M = \$8.05 for new construction
- M = \$21.75 for retrofit

Table IV-19 shows the assumed present cost of various fuels (F) in each city.

TABLE IV-19. COST OF FUEL - \$/THERM

	<u>Gas</u>	<u>Oil</u>	<u>Electricity</u>
Baltimore	.22	.33	1.07
Chicago	.19	.34	1.16
Houston	.31	-	.71

a. Roof/Ceilings. All ceilings of the base structures were initially given an insulation level of R-13. Table IV-20 illustrates the maximum allowable expenditure (i.e. the break even point between amortized expenditure and annual fuel savings) and the current estimated costs of increasing the ceiling insulation to R-38.

Increasing the ceiling insulation to R-38 was not economically feasible for retrofit (i.e. adding insulation to structural types built in the early seventies), or new construction, indicating that RD&D funds could be usefully directed toward development of low cost roof insulation.

b. Doors. The doors contributed the smallest amount to the heating and cooling loads, and consequently resulted in the smallest amount of annual energy savings. The achievable savings in energy through insulating the doors were not economical according to today's costs (Table IV-21).

Since the current best possible door did not pay for itself, the door became a candidate for future RD&D strategies. However, because the savings available through insulating the doors is so small, it is a low priority component for RD&D.

c. Floors. Leaving the floors uninsulated in the winter causes significant heat losses, while in the summer, because of cooler ground temperatures in many parts of the country, cooling loads can be reduced. R-30 insulation was added to the uninsulated floors of the base SFD and SFA structures. No insulation was added to the MFLR because the floor was a concrete slab on grade. Table IV-22 shows that it costs more to insulate the floors in the SFD and SFA than maximum allowable expenditure permits. This indicates that future RD&D should include low cost floor insulations.

By routing return air through the basement in the summer, the benefit of the cooler basement would result in greater energy savings, and a strategy which was more economically attractive.

TABLE IV-20. MAXIMUM ALLOWABLE COST OF IMPLEMENTATION VERSUS
MATERIAL AND LABOR COSTS FOR INCREASING CEILING INSULATION FROM R-13 TO R-38

LOCATION	MAXIMUM ALLOWABLE COST OF IMPLEMENTATION (DOLLARS)						MATERIAL PLUS LABOR COSTS (DOLLARS)					
	SFD		SFA		MFLR		SFD		SFA		MFLR	
	New ¹	Retrofit ²	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit
Baltimore	334	124	1387	514	2881	1067	425	535	2320	2820	5089	5400
Chicago	345	128	1494	553	3522	1304	↓	↓	↓	↓	↓	↓
Houston	307	114	1387	514	3202	1186	↓	↓	↓	↓	↓	↓

¹New construction assumes 9 percent loan for 30 years.

²Retrofit assumes 11 percent loan for 5 years.

TABLE IV-21. MAXIMUM ALLOWABLE COST OF IMPLEMENTATION VERSUS
MATERIAL AND LABOR COSTS FOR INCREASING DOOR INSULATION FROM R-2.5 to R-10

LOCATION	MAXIMUM ALLOWABLE COST OF IMPLEMENTATION (DOLLARS)						MATERIAL PLUS LABOR COSTS (DOLLARS)					
	SFD		SFA		MFLR		SFD		SFA		MFLR	
	New ¹	Retrofit ²	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit
Baltimore	107	40	320	119	640	237	210	650	840	2800	2500	7200
Chicago	93	35	427	158	640	237	↓	↓	↓	↓	↓	↓
Houston	67	25	320	119	640	237	↓	↓	↓	↓	↓	↓

¹New construction assumes 9 percent loan for 30 years.

²Retrofit assumes 11 percent loan from 5 years.

TABLE IV-22. MAXIMUM ALLOWABLE COST OF IMPLEMENTATION VERSUS
MATERIAL AND LABOR COSTS FOR INCREASING FLOOR INSULATION FROM R-5 TO R-30

LOCATION	MAXIMUM ALLOWABLE COST OF IMPLEMENTATION (DOLLARS)						MATERIAL PLUS LABOR COSTS (DOLLARS)					
	SFD		SFA		MFLR		SFD			SFA	MFLR	
	New ¹	Retrofit ²	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit
Baltimore	173	64	640	237	*	*	515	630	2342	3225	*	*
Chicago	40	15	320	119								
Houston	253	94	960	356								

¹New construction assumes 9 percent loan for 30 years.

²Retrofit assumes 11 percent loan for 5 years.

* MFLR has concrete slab on grade with no floor insulation.

d. Walls. According to results in Table IV-23, present construction costs cause the increase of wall insulation to R-31 to be economically infeasible for both retrofit and new construction. Current construction techniques do not allow the addition of thick layers of insulation without significant increases in cost. The very high cost of insulating walls make them a component which requires future RD&D efforts to reduce initial and installation costs.

e. Windows. This section considers only the conduction and radiation effects of installing double glazed or storm windows. Infiltration effects will be considered separately in Section F.

In the colder climates (Baltimore and Chicago), it was found that the installation of double glazed windows plus storm windows was economically feasible for new construction as can be seen in Table-24. On a retrofit basis, however, double glazing plus storm windows does not appear to be an economically attractive alternative, indicating that more RD&D efforts should be directed at increasing the insulating ability of windows at lower costs.

f. Infiltration. This section considers only the infiltration effects of the addition of weatherstripping, caulking, storm doors, and storm windows to the base structures. Table IV-25 shows that for both retrofit and new construction the reduction of infiltration through the addition of weatherstripping, caulking, storm doors and storm windows is not an economically feasible measure. This indicates the need for more RD&D funding in this area.

Note: When the similar evaluation is made for residences heated with electricity, the economic feasibility of the component strategies would be different due to the higher cost of electricity when compared to gas. Table IV-26 shows the findings of such an evaluation for the single-family detached. It demonstrates that all the component strategies are cost-effective on a new construction basis in all-electric structures.

F. Structural Summary

In the previous sections, detailed analyses were performed of the heat gains and losses of structural components of the base SFD, SFA, and MFLR in the Baltimore, Chicago and Houston areas. Those structural strategies that were found

TABLE IV-23. MAXIMUM ALLOWABLE COST OF IMPLEMENTATION VERSUS MATERIAL COSTS FOR INCREASING WALL INSULATION FROM R-7³ TO R-31

LOCATION	MAXIMUM ALLOWABLE COST OF IMPLEMENTATION (DOLLARS)						MATERIAL PLUS LABOR COSTS (DOLLARS)					
	SFD		SFA		MFLR		SFD		SFA		MFLR	
	New ¹	Retrofit ²	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit
Baltimore	347	128	3308	1225	4802	1778	798	*	4384	*	9817	*
Chicago	373	138	2028	751	4482	1660	↓	↓	↓	↓	↓	↓
Houston	187	69	1921	611	4162	1541	↓	↓	↓	↓	↓	↓

¹New construction assumes 9 percent loan for 30 years.

²Retroft assumes 11 percent loan for 5 years.

³SFD increased from R-11 to R-31.

* Cost estimates impossible due to the physical construction constraints of base structures.

TABLE IV-24. MAXIMUM ALLOWABLE COST OF IMPLEMENTATION VERSUS MATERIAL AND LABOR COSTS FOR INCREASING WINDOW INSULATION FROM R-1 TO R-2.4*

LOCATION	MAXIMUM ALLOWABLE COST OF IMPLEMENTATION (DOLLARS)						MATERIAL PLUS LABOR COSTS (DOLLARS)					
	SFD		SFA		MFLR		SFD		SFA		MFLR	
	New ¹	Retrofit ²	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit
Baltimore	574	212	4910	1818	10565	3912	541	2450	2163	8300	6489	25800
Chicago	654	242	5229	1937	11846	4387	↓	↓	↓	↓	↓	↓
Houston	320	118	2775	1028	5442	2016	↓	↓	↓	↓	↓	↓

¹New construction assumes 9 percent loan for 30 years.

²Retrofit assumes 11 percent loan for 5 years.

* Considers conduction and radiation effects only.

TABLE IV-25. MAXIMUM ALLOWABLE COST OF IMPLEMENTATION VERSUS
MATERIAL AND LABOR COSTS FOR REDUCING INFILTRATION THROUGH BOTH DOORS AND WINDOWS BY 30 PERCENT

LOCATION	MAXIMUM ALLOWABLE COST OF IMPLEMENTATION (DOLLARS)						MATERIAL PLUS LABOR COSTS (DOLLARS)					
	SFD		SFA		MFLR		SFD		SFA		MFLR	
	New ¹	Retrofit ²	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit	New	Retrofit
Baltimore	507	188	3628	1344	6723	2490	683	910	3591	4240	7508	11700
Chicago	480	178	3735	1383	6403	2371	↓	↓	↓	↓	↓	↓
Houston	416	227	4696	1739	6723	2490	↓	↓	↓	↓	↓	↓

¹New construction assumes 9 percent loan for 30 years.

²Retrofit assumes 11 percent loan for 5 years.

TABLE IV-26. MAXIMUM ALLOWABLE COST OF IMPLEMENTATION VERSUS MATERIAL AND LABOR COSTS FOR THE COMPONENTS FOUND IN AN ELECTRIC RESISTANCE/AIR CONDITION SINGLE-FAMILY DETACHED (SFD)

Component	Maximum Allowable Cost Of Implementation (Dollars)						Material Plus Labor Costs (Dollrs)	
	Baltimore		Chicago		Houston		Baltimore - Chicago - Houston	
	New ¹	Retrofit ²	New	Retrofit	New	Retrofit	New	Retrofit
Roof (R-38)	1014	375	11520	4272	8016	2976	425	535
Door (R-10)	307	114	3200	1184	1272	480	210	650
Floors (R-30)	2335	865	24976	9248	9936	3672	515	630
Walls (R-31)	1054	390	10672	3952	9936	3672	798	*
Windows (R.2.4)	1668	618	20808	7704	12168	4512	541	2450
Infiltration (30% Reduction)	1400	519	14192	5256	17616	6528	683	910

¹New construction assumes nine percent loan for 30 years.

²Retrofit assumes eleven percent loan for five years.

* Cost estimates impossible due to the physical construction constraints of base structures.

to be economically feasible with present fuel and construction costs were defined as state-of-the-art strategies. Those that were not economical, warrant future funding as possible RD&D strategies. The structural strategies studied can be categorized under the following three areas.

- (1) insulation;
- (2) infiltration; and
- (3) others.

Present insulation technology endeavors to optimize the thermal conduction of insulation materials to that of air, which is .015 Btu/hr ft °F at 75°F. Foam insulations (styrofoam and expanded polyurethane) have exceeded this value by a small amount. This is accomplished by using fluorocarbons in the cellular makeup of the foam. However, foam presently is not cost effective in residential structures. Therefore, future RD&D should include material developments which would go beyond the thermal conductance of air, while having lower costs than presently available materials such as foam. Quite possibly, the cost of foam could be lowered, and its thermal conductivity improved.

1. Insulation

In this study the roof, doors, floors, and windows are all structural components for which strategies involving increased insulation were developed. The strategies were classified as state-of-the-art or RD&D, depending on whether they were currently economically feasible.

a. State-of-the-Art. In the previous section, a comparison was made between the base structures and the strategies included in the optimized structures. Among the strategies aimed at higher insulation levels, only better insulated windows (R-2.4) in the northern climates paid for themselves under present construction costs. These conclusions were drawn from residences with the base climate control systems of gas heating and electric cooling. For the case of all-electric residences, all of the component insulation strategies are cost effective.

b. RD&D. It is recommended that the future building related RD&D programs consider the development of insulation materials which would be lower in cost when compared with those presently available, offer equivalent or better insulating qualities.

2. Infiltration

The largest component of loads, when compared to other individual structural components is the infiltration of air into the structures being studied. When all the insulation components were combined and compared to infiltration alone, the greatest reduction in load (i.e. magnitude of the load) was achieved by increasing the overall insulation value in the components of the SFD, SFA and MFLR structures. Therefore, when examined as one of many single structural components, infiltration by far was the greatest contributing factor to the heating and cooling loads. But the largest savings can result from the increase of the overall level of insulation (i.e. decreasing the conductance) of the residential structure. Following this application, the next greatest reduction could be attained by decreasing the heat losses and gains due to infiltration.

a. State-of-the-Art. Reducing the amount of infiltration by 30 percent in the base SFD, SFA and MFLR structures was found to be uneconomical. If, however, the base structures were electric resistance heated, then the installation of weatherstripping, caulking, and storm windows as measures to reduce infiltration 30 percent would pay for itself on a new construction basis only. Therefore, reducing infiltration by 30 percent can be considered state-of-the-art only for new residential structures with electric resistance heat.

b. RD&D. Since reducing infiltration by 30 percent at present construction and fuel costs was found to be uneconomical, it is recommended that the following be considered as possible RD&D strategies:

- (1) Infiltration - Test Procedure
- (2) Infiltration - Building Design
- (3) Infiltration - Building Orientation
- (4) Infiltration Paths Study

c. Others. The reduction of radiation is an important factor in reducing heat gains during the cooling season. It is recommended that the following areas be studied as RD&D strategies.

- (1) Variable Transmission Glass
- (2) Windows - Building Orientation

V. HEATING, VENTILATING AND AIR CONDITIONING SYSTEMS ANALYSIS

In this chapter, the analysis of HVAC systems is undertaken to identify RD&D strategies which are applicable to the systems considered. Characteristic HVAC systems are developed and their installation statistics are presented. The method of study for each type of system is outlined and the energy use of the characteristic systems is disaggregated into the system components. RD&D strategies are developed based on an analysis of the disaggregated components. Those components which showed potentially high energy savings were considered the most important targets of the RD&D strategies. An economic analysis of implementation of the strategies presented is based on the allowable cost to a homeowner for each strategy, i.e., given the estimated energy savings due to implementation of the strategy, identify how much money the homeowner will be willing to spend on the item. The economic analysis is performed separately for new construction and retrofit of existing residences. The strategies are then ranked in order of the impact of their energy savings and economic benefits.

A. Characteristic HVAC Systems

In this section, each characteristic HVAC system is described for each residence type and for each location. Installation statistics for each type of heating system are also presented. In addition to the characteristic heating and cooling systems, the characteristic duct layout is also presented. Only air distribution systems were considered in this study.

1. The Characteristic Residential Natural Gas Warm Air Furnace

The typical furnace for each climatic location is sized for twice the building peak design load. They range in size from 120,000 Btu/hr (input) in the Chicago (SFD) to 40,000 Btu/hr (input) in the Houston (MFLR). To meet the American Gas Association's Standards, all gas furnaces are designed to operate with a minimum steady-state efficiency of 75 percent. The furnaces are naturally aspirated and are supplied with 50 percent excess combustion air. A detailed analysis of the various losses occurring in the gas furnace may be seen in Tables V-4 through V-12. Figure V-1 is a schematic diagram of a typical gas warm air furnace. Forty-two percent of all residential heating units in the United States are gas warm air furnaces. (Refer to Table V-1 for the exact number of gas furnaces in operation in the United States as of 1975.)

1. Circulating fan
2. Automatic regulator/valve
3. Controls system
limit switch
safety switch
room thermostat
4. Stack

- A. Automatic flue damper (not typical)
- B. Draft diverter
- C. Burner orifice
- D. Input valve
- E. Pilot light or electronic ignition
- F. Filters

Figure V-1. Typical Residential Gas Warm Air Furnace

TABLE V-1. 1975 TOTAL NUMBER OF EXISTING RESIDENTIAL HEATING UNITS (THOUSANDS) IN U.S.

		<u>Percent</u>
Gas Furnaces ^a	32989.9	42.4
Gas Boilers ^a	8270.0	10.6
Oil Furnaces ^b	6461.1	8.3
Oil Boilers ^b	5559.8	7.1
Electric Heat Pump ^c	470.0	0.6
Electric Baseboard ^d	8063.4	10.4
Electric Furnaces ^d	4833.6	6.2
Other*	10210.3	13.2
None	<u>933.5</u> 77791.6	<u>1.2</u> 100.0
Total Residential Housing Units 1973 (thousands) ^d	75293	
Total Residential Housing Starts 1974 ^e	1337.7	
Total Residential Housing Starts 1975 ^e	<u>1160.9</u>	
Total Residential Housing Units 1975	77791.6	

* Includes room heaters with and without flues, fireplaces, stoves, or portable heaters.

^a "Gas Househeating Survey," AGA Dept. of Statistics, American Gas Association, Arlington, VA, 1976.

^b Fuel Oil and Oil Heat Magazine, New York, N.Y.: Private Communication, January 1977, Avg. Firing Rate 1 gal/hr, Max. Firing Rate 5-6 gal/hr.

^c Air Conditioning and Refrigeration Business Magazine, Cleveland, Ohio, March 1976.

^d Estimates Based on Statistics from Bureau of the Census, U.S. Department of Commerce, Annual Housing Survey: 1973, General Housing Characteristics, United States and Regions, Part A, Series H-150-73A.

^e Housing Starts Bulletin, Economic News Notes for the Building Industry, National Association of Home Builders, Vol. XXII, No. 2, February 18, 1976.

2. The Characteristic Residential Oil Warm Air Furnace

The input ratings for oil furnaces are the same as the natural gas furnaces. Each characteristic unit is certified with a minimum steady-state efficiency of 75 percent. Eight percent of all heating units in the United States are oil warm air furnaces. The control settings are assumed to be the same as for the gas furnace, thus allowing for similar operating characteristics. Figure V-2 is a schematic diagram of a typical oil warm air furnace.

3. The Characteristic Residential Electric Resistance Warm Air Furnace

The input ratings of the electric resistance furnaces are the same as for the fossil fuel furnaces. The input into an electric furnace is equal to its output. The only losses occur in its distribution system. It is estimated that 6.2 percent of all heating units in the United States in 1975 were electric resistance warm air furnaces.

4. The Characteristic Heat Pump

Because heat pumps on the market have such a wide range of performance (Ref. 9), a characteristic heat pump was developed by averaging performance data from several major manufacturers. The size of the heat pump selected for each residence was based on standard practice, that is, the unit was sized for the cooling load. Two-ton units were sized for the SFA and MFLR residences in all three locations. The SFD residence in Baltimore and Chicago received 2-1/2 ton units, and the SFD residence in Houston received a 3 ton unit. It is estimated that heat pumps heated and cooled less than one percent of all U.S. residences as of 1975 (Ref. 10).

5. The Characteristic Central Air Conditioners

The characteristic central air conditioning systems used in this study have an energy efficiency ratio (EER)* of 6.8 (C.O.P. = 1.99). This was taken as an average of the EER of over 7,000 models of air conditioners certified by ARI (Ref. 9 and 10). In 1975, over 61 percent of all air conditioners sold in the U.S. with capacity less than 65,000 Btuh had an EER of between 6.5 and 7.5 (Ref. 10).

**EER (Energy Efficiency Ratio) - A ratio calculated by dividing the cooling capacity in Btuh by the power input in watts at any given set of rating conditions, expressed in Btuh per watt (Btuh/watt).*

1. Circulating fan	A. Barometric draft regulator
2. Electronic ignition	B. Burner orifice
3. Control system
limit switch
safety switch
room thermostat	C. Filters
4. Pump/blower	D. Automatic flue damper (not typical)
5. Stack	

Figure V-2. Typical Residential Oil Warm Air Furnace

6. The Characteristic Duct Design

Figures V-3 through V-5 show the floor plans of the characteristic residences with the duct layout indicated by a broken line. The ducts were sized according to the maximum CFM requirement, which was the peak cooling load in all three types of residences and in all three locations.

B. HVAC Systems Components

1. Heating Systems

a. Method of Study for Fossil Fuel Warm Air Furnaces.

There are many losses associated with the operation of a fossil fuel furnace. These are divided into two main categories.

- (1) On-cycle losses
- (2) Off-cycle losses

Mathematically, a fossil fuel furnace can be modeled approximately by a square wave function as illustrated below.

Figure V-6. Model of an Operating Fossil Fuel Furnace Over a Time Period θ .

Figure V-3. Duct Layout for Characteristic (SFD) Residence

SECOND FLOOR

FIRST FLOOR

Figure V-4. Duct Layout for Characteristic (SFA) Residence

Figure V-5. Duct Layout for Characteristic (MFLR) Residence

The time duration of an on-period, and an off-period is known as one full cycle. A more detailed illustration of a cycle can be seen in Figure V-9 later in this section.

Energy is lost during both the on and off periods of a cycle. Once the on/off cycle losses are estimated, the efficiency of a fossil fuel furnace over a winter heating season can be calculated by

$$\text{Seasonal Efficiency} = \frac{\text{Total winter heating season furnace output}}{\text{Total winter heating season fuel usage}} \times 100$$

A more accurate estimate can be made by performing calculations on a hourly basis, as shown in the following equation.

$$\text{Seasonal Efficiency} = \frac{\sum_{i=1}^N (\text{Hourly heating load})_i}{\sum_{i=1}^N (\text{Hourly distribution efficiency})_i \times (\text{Hourly fuel usage})_i \times (\text{Btu content of fuel})_i}$$

where N = number of winter heating season hours

The seasonal efficiency is an indicator of the effect of on/off cycle losses on the operation of a fossil fuel furnace over a winter heating season.

This section will explain the assumptions and procedures that were used in estimating the losses associated with the various components in gas and oil residential warm air furnaces. Furthermore, Figures V-1 and V-2 illustrate the basic components found in typical warm air fossil fuel furnaces. All assumptions are identical.

(1) Off-Cycle Losses. Earlier Figure V-6 illustrated the period ($\Delta\theta$ off) in which a furnace is off. Several off-cycle losses can be attributed to the fossil fuel warm air furnace. These are as follows:

- Heat losses
 - Infiltration losses
 - Pilot light losses (gas furnace only)
- } Total stack loss
(Furnace off)

(a) Heat Losses. In order to estimate the heat that does not enter the distribution system during the time period between the circulating fan shut off and the burner start up, it is necessary to make the following assumptions:

- The time that the furnace is off ($\Delta\theta$ off) is independent of furnace capacity.

• For similar structures, $\Delta\theta_{off}$ (Figure V-6) is dependent on climatic region only. (If in one climatic region, several structurally different buildings exist, but they have the same instantaneous building heat load (Btu/hr), then they will all have the same $\Delta\theta_{off}$).

Using information gathered from Reference 11, the fossil fuel warm air furnace heat losses can be approximated. It is assumed (using Figure V-7) that a typical furnace can be off no less than 30 minutes, followed by being on for at least 11.5 minutes.

Figure V-7. Furnace On-Time Versus Subsequent Off-Time Over a Period of Seven Days (Ref. 11).

With a $\Delta\theta_{on}$ of approximately 11.5 minutes, the temperature difference between the exit air and the return air shown in Figure V-8 is found to be 78°F. This is on the high side if the return air is assumed to be at room temperature.

Figure V-8. Supply Duct Temperature Minus Return Duct Temperature Versus Time and Exponential Curve Fitted to Data (Ref. 11)

The off-cycle heat loss per cycle is represented by the shaded area in Figure V-9. The equation used in calculating the heat lost is:

$$\text{Btu Heat Loss per Cycle} = \left(\text{Shaded Area in Figure V-9} \right) \left(C_{p \text{ Air}} \right) \left(\rho_{\text{Air}} \right) \left(\text{of Circulating Fan} \right) \left(T_{\text{Supply Air}} - T_{\text{Return Air}} \right)$$

Figure V-9. Temperature and Heat Convection in a Duct for Different On-Times (Ref. 11)
(Duct time constant ≈ 2 min.)

where,

Shaded area $\approx$.88 min.
in Figure V-9

T = 78°F

C_p (Air) = .24 Btu/lbm °F

ρ_{Air} = .073 lbm/cu ft

CFM = 650 cfm circulating fan for
100,000 Btu/hr gas furnace
(Refs. 11 and 12)

The heat loss per cycle for the furnace found in Reference 11 is 780 Btu/cycle. This is the assumed heat loss per cycle for the 100,000 Btu/hr (input) fossil fuel warm air furnace used in the Baltimore SFD.

In order to check the magnitude of this approximation, the following equation is utilized.

$$\text{Btu Heat loss per cycle} = \left(\text{Furnace Rating} \right) \left[\left(\theta_{\text{furnace on}} - \theta_{\text{furnace fan on}} \right) - \left(\theta_{\text{furnace off}} - \theta_{\text{furnace fan off}} \right) \right]$$

where,

θ = time (hr)

furnace rating = (Btu/hr)

Using information gathered from Reference 13, the time difference in the preceding equation amounted to 23 seconds. The two provided methods for calculating the heat loss per cycle produce values that are comparable. Thus, the heat loss per cycle is a reasonable estimate for a 100,000 Btu/hr (input) furnace. The heat loss per cycle varies according to the size of the furnace. It is assumed that the heat loss per cycle is proportional to the size of the furnace (i.e. the smaller the furnace, the smaller the heat loss per cycle).

The number of cycles per season is required in order to calculate the total heat lost during the off periods of a furnace. The seasonal on-time hours are approximated by:.

$$\text{Total seasonal furnace on-time} \approx \frac{\text{Building seasonal load}}{\text{Furnace rating (output)}}$$

Dividing the total on-time hours during a season by the furnace on-time per cycle will result in the number of cycles per season.

$$\text{Number of cycles per season} = \frac{\text{Total furnace on-time}}{\text{Furnace on-time per cycle}}$$

Note that the furnace on-time per cycle, previously stated as 11.5 minutes for a 100,000 Btu/hr (input) furnace, will increase as the furnace size decreases relative to load. It will not increase proportionally because additional on-time will be needed to replace the heat lost up the stack while the furnace is operating. As an example, using a 3°F throttling range for the thermostat, a 100,000 Btu/hr (input) furnace is on for 11.5 minutes. A 50,000 Btu/hr (input) furnace will run 23 minutes to supply the same amount of heat to the residence but it will run four minutes longer (27 minutes) before the 3°F throttling range of the thermostat is satisfied because of additional heat loss caused by the operation of the furnace.

Having found the number of cycles per season, it is possible to calculate the off-cycle heat losses during the winter heating season by using the equation:.

$$\begin{array}{l} \text{Seasonal} \\ \text{Off-cycle} \\ \text{Heat loss} \\ \text{(Btu)} \end{array} = \left(\frac{\text{No. of cycles}}{\text{season}} \right) \left(\frac{\text{Heat lost}}{\text{cycle}} \right)$$

(b) Infiltration Losses (Furnace Off). During the off-cycle period, air is drawn from the conditioned space in the structure through the furnace and up the stack by the buoyancy effect of less dense warm air. The amount of air flow is dependent upon the conditioned air intake temperature, the flue temperature, outside temperature, and wind velocity. This air is commonly known as infiltration. Table V-2 illustrates the

relative amounts of air flowing through a furnace as a function of outside temperature, average stack temperatures and flue temperature.

TABLE V-2. CF AIR RATIOS BETWEEN FURNACE AIR INLET AND STACK EXIT

Outside Temperature	0°F	10°F	20°F	30°F	40°F	50°F	60°F
Avg. Stack* Temp.	Flue* Temp.						
430°F	800°F	1.0	1.0	1.0	1.0	1.0	1.0
380°F	700°F	.97	.97	.96	.96	.96	.96
330°F	660°F	.93	.93	.92	.91	.91	.91
280°F	500°F	.88	.88	.87	.87	.86	.85
230°F	400°F	.83	.82	.81	.80	.79	.78
180°F	300°F	.76	.75	.74	.72	.71	.69
130°F	200°F	.68	.66	.64	.62	.59	.57
105°F	150°F	.62	.60	.57	.54	.51	.48
80°F	100°F	.55	.53	.49	.45	.41	.36
70°F	80°F	.53	.48	.46	.40	.35	.29
63°F	65°F	.49	.47	.42	.38	.32	.24

* Assumes conditioned air temperature @ 60°F.

Note: Average stack temperature is that temperature that is measured just following the draft diverter in a gas warm air furnace or the barometric draft regulator in an oil warm air furnace.

An example of the usefulness of Table V-2 is illustrated below. Suppose that

- Outside temperature = 30°F
- Flue temperature = 400°F
- Stack exit temperature = 70°F

Assume that a gas warm air furnace uses 29 cubic feet of air per one cubic foot of gas (includes both combustion and dilution air). Referring to Table V-2, the following results:

$$\frac{.40}{.80} \times \frac{29 \text{ CF Air}}{1 \text{ CF Gas}} = 14.5 \text{ cu. ft.}$$

This means that 50 percent or about 15 cubic feet of air is flowing up the stack during off-time periods. A portion of this air is being drawn into the furnace

air inlet, and another portion is being drawn through the draft diverter. The result is entered into the following equation to obtain the cubic feet of air per hour flowing up the stack during off cycle periods:

$$\text{Off cycle CPH}_{\text{Air}} = \left(\frac{\text{CF}_{\text{Air}}}{\text{Unit fuel}} \right) \left[\frac{\left(\frac{\text{Furnace Rating (input)}}{\text{Fuel heat content}} \right)}{\text{unit fuel}} \right]$$

For the three climatic regions studied, it is assumed that the number of winter heating hours are as follows (Ref. 4).

Total Hours of Winter Heating

•	Chicago	6096	hrs
•	Baltimore	5496	hrs
•	Houston	3384	hrs

By subtracting the on-time hours of the furnace, calculated in the sections under heat losses, it is possible to arrive at the total number of off-time hours. The average winter season temperatures for each climatic region are as follows (Ref. 71).

Average Winter Temperature

•	Chicago	40°F
•	Baltimore	43°F
•	Houston	56°F

Substituting all of the preceding values into the following equation will provide the off-cycle infiltration losses.

$$\text{Off-Cycle infiltration loss (Btu)} = \left(\text{CPH}_{\text{Air}} \right) \left(\text{Furnace Seasonal off-time hours} \right) \left(p_{\text{Air}} \right) \left(C_{p \text{ Air}} \right) \left(T_{\text{Room}} - T_{\text{Winter Avg.}} \right)$$

(c) Pilot Light Losses. Pilot lights are commonly found in many residential gas warm air furnaces. It is only recently that pilot lights are being replaced by electric ignition. The losses associated with the pilot light occur during the off-time period of the operation of a gas furnace. From

Reference 14, a typical pilot light burns 800 Btu/hr. Substituting into the following equation will result in the heat lost due to the pilot light during the winter heating season.

$$\begin{array}{l} \text{Pilot} \\ \text{light} \\ \text{loss} \\ \text{(Btu)} \end{array} = \left(\frac{\text{Furnace Seasonal}}{\text{Off-Time Hours}} \right) \left(800 \frac{\text{Btu}}{\text{hr}} \right)$$

(2) On-Cycle Losses. During the time period on (Figure V-6) or the period in which a fossil fuel furnace is on, the following losses are associated with the various furnace components:

• Combustion losses	} Total stack loss
(Furnace on)
• Infiltration losses	
• Jacket losses	
• Pump/blower losses (oil furnace only)	

(a) Combustion Losses. When a fuel with a certain heat content is burned in a typical fossil fuel warm air furnace, the heat that is released for use in the conditioned space does not equal the heat content of the fuel. This is a combustion and heat transfer loss.

Assuming stoichiometric or perfect combustion (i.e., 100 percent burn of fuel with only stoichiometrically required oxygen), it is possible to obtain the theoretical steady-state efficiency of a fossil fuel furnace as a function of flue gas temperature.

$$\begin{array}{l} \text{Steady-state} \\ \text{Efficiency} \\ (N_{ss}) \end{array} = \frac{\text{Useful Output}}{\text{Gross Input}}$$

The theoretical values are given in Table V-3.

TABLE V-3. THEORETICAL STEADY-STATE EFFICIENCIES (REF. 15)

(1) Natural gas having 1059 Btu/cu ft gross heating value at 60°F

- (a) With flue temperature of 500°F
Output is 863 Btu/cu ft available heat
 $N_{ss} = (863/1059) \times 100 = 81.5\%$
- (b) With flue temperature of 400°F
Output is 887 Btu/cu ft available heat
 $N_{ss} = (887/1059) \times 100 = 83.3\%$

- (c) With flue temperature of 300°F
 (approximate limit for non-condensing
 flue gas)
 Output is 910 Btu/cu ft available heat
 $N_{ss} = (910/1059) \times 100 = 85.9\%$
- (2) Number 2 fuel oil having 138,000 Btu/gal gross
 heating value at 60°F
- (a) With flue temperature of 500°F
 Output is 118,000 Btu/gal available heat
 $N_{ss} = (118,000/138,000) \times 100 = 85.5\%$
- (b) With flue gas temperature of 400°F
 Output is 121,000 Btu/gal available heat
 $N_{ss} = (121,000/138,000) \times 100 = 87.7\%$
- (c) With flue gas temperature of 300°F
 (approximate limit for non-condensing
 flue gas)
 Output is 124,000 Btu/gal available heat
 $N_{ss} = (124,000/138,000) \times 100 = 89.9\%$

The effect of flue temperature is further illustrated in Figures V-10 and V-11. Notice that the available heat output increases as the flue temperature decreases. As the flue gas temperature decreases, more heat is being extracted for use in the conditioned spaces. A dangerous consequence of this temperature decrease is the resultant condensation of flue gases. A furnace would be operating more efficiently, but the highly corrosive flue gases would cause a failure of the flue pipe. The combustion losses are estimated by the following equation.

$$\begin{array}{l} \text{Combustion} \\ \text{losses} \\ \text{during furnace} \\ \text{on-time} \\ \text{(Btu)} \end{array} = \left(\frac{\text{Building seasonal load}}{\text{Average Steady-State efficiency}} \right) \times (\text{Building seasonal load})$$

NATURAL GAS FURNACES

Gross Heating Value = 1,000 Btu/cu.ft. at 60F, SP

NOTE: a EXCLUDES JACKET LOSSES OF 1 TO 5%. NEW FURNACES WILL HAVE JACKET LOSSES OF ABOUT 1%.

Figure V-10. Steady-State Efficiency Versus Flue Gas Temperature for Natural Gas Furnaces (Der. Ref. 15)

FUEL OIL FURNACES (FORCED DRAFT)
Gross Heating Value = 138,000 Btu/gal at 60F, SP

NOTE: a EXCLUDES JACKET LOSSES OF 1 to 5%. NEW FURNACE WILL HAVE JACKET LOSSES OF ABOUT 1%.

Figure V-11. Steady-State Efficiency Versus Flue Gas Temperature for Oil Furnaces (Der. Ref. 15)

(b) Infiltration Losses (Furnace On).

During the period a residential fossil fuel warm air furnace is on, air is continuously drawn into the furnace air inlet for combustion purposes and into the flue as dilution air.

The combustion process requires the correct amount of air, in order to insure complete burning. If combustion air is deficient, incomplete burning will result, with large amounts of carbon monoxide, hydrogen, hydrocarbons, and soot being produced. The percent in air deficiency is approximately equal to the percent loss due to the resultant incomplete combustion, i.e. a 10 percent deficiency of air results in a direct loss of 10 percent of furnace output (Ref. 15). In fossil fuel furnaces, incomplete combustion seldom occurs unless it is intentional, because more than sufficient air is usually supplied.

With the correct amount of combustion air supplied to the furnace, complete burning will result, with CO_2 and H_2O as theoretically the only products of combustion. In reality, hydrocarbons are produced which result in the formation of smoke and soot. The amount produced by a gas furnace is minor when compared to an oil furnace. Figure V-12 provides a graphic illustration of the composition of the products of combustion for a given air-to-fuel ratio.

Figure V-12. Percent Combustion Gas Volume Versus Air-Fuel Ratio (Ref. 15)

Every cubic foot of natural gas requires 10 cubic feet of air for complete combustion (Refs. 15 and 16). Likewise, one gallon of No. 2 fuel oil requires 1365 cubic feet of air. Smoke and soot may be produced at maximum CO₂ flue gas content (see Figure V-12) unless excellent mixing of fuel and air can be achieved in the burner.

In order to meet environmental air pollution standards, the smoke level is reduced by adding some excess air. Typically, 50 percent excess air is supplied to the combustion process. In calculating the infiltration losses (furnace off) in Tables V-4 through V-22, it is assumed for the base system that the gas and oil warm air furnaces are supplied with excess air as follows. In the burning of one cubic foot of natural gas, instead of drawing 10 cubic feet of air, the furnace draws 14 cubic feet of air. In the burning of one gallon of number 2 fuel oil, rather than using 1365 cubic feet of air, the furnace will be furnished with 2080 cubic feet of air. Figures V-13 and V-14 typify the gaseous flow in operating residential oil and gas warm air furnaces.

A certain amount of dilution air is necessary to provide proper flow of air and combustion gases up the stack. It is assumed that 15 cubic feet of dilution air is required for every cubic foot of natural gas consumed in the gas warm air furnace (Refs. 15 and 16). Furthermore, it is assumed that 1080 cubic feet of dilution air is utilized for every gallon of fuel oil combusted in the oil warm-air furnace. The amount of dilution and combustion air is constantly changing because it is a function of the outdoor weather conditions. The amounts stated are necessary so that relative comparisons can be made between different size furnaces in varying climatic regions.

In estimating the total amount of losses occurring during on-time periods, it is necessary to use the assumed values for air flow, and obtain the total amount of air flowing up the stack. This reveals that for the two furnace types, the following amounts of air are flowing up the stack.

Gas warm air furnace 29 CF _{Air/CF_{Gas}}	} @ 50 % excess combustion air
Oil warm air furnace 3130 CF _{Air/Gal_{Oil}}

Figure V-13. Air Flow in a Typical Residential Gas Warm Air Furnace

$$\begin{array}{ccccccc}
 685 \text{ ft}^3 & 1080 \text{ ft}^3 & 1365 \text{ ft}^3 & & 3130 \text{ ft}^3 \\
 \bigcirc & + & \bigcirc & + & \bigcirc & = & \bigcirc \\
 \text{Excess} & & \text{Dilution} & & \text{Combustion} & & \text{Total Furnace} \\
 \text{Air} & & \text{Air} & & \text{Air} & & \text{Air Requirements/gal oil}
 \end{array}$$

Figure V-14. Air Flow in a Typical Residential Oil Warm Air Furnace

These values are used in estimating the on/off infiltration losses. The off-cycle losses were formulated earlier in section (1). It is now possible to obtain a value for the infiltration losses occurring during the seasonal on-time period of a fossil fuel furnace. Substituting into the following equation yields the total amount of air going up the stack during the winter heating season.

$$\begin{aligned} \text{Total on-time} \\ \text{Winter} \\ \text{Heating} \\ \text{Season} \\ \text{(CF)} \end{aligned} = \left(\frac{\text{Winter building} \\ \text{Heating load}}{\text{Seasonal} \\ \text{Efficiency}} \right) \left(\frac{1}{\text{Btu heat content} \\ \text{unit fuel}} \right) \left(\frac{\text{CF}_{\text{Air}}}{\text{unit fuel}} \right)$$

The total winter season air flow is then entered into the succeeding equation.

$$\begin{aligned} \text{On-cycle} \\ \text{infiltration} = \\ \text{losses} \\ \text{(Btu)} \end{aligned} = \left[\begin{array}{c} \text{Total} \\ \text{on-time} \\ \text{Winter} \\ \text{heating} \\ \text{season} \\ \text{(CF)} \end{array} \right] \left[\rho_{\text{Air}} \right] \left[C_{P \text{ Air}} \right] \left[T_{\text{Room}} - T_{\text{Winter Avg.}} \right]$$

After accounting for every loss, it is possible to arrive at the seasonal efficiency by going to Tables V-5 through V-23 and substituting into the following equation.

$$\begin{aligned} \text{Seasonal} \\ \text{Efficiency for} = \\ \text{the heating} \end{aligned} = \frac{\text{Building heat load}}{\text{Total Seasonal Fuel Heat Energy Input}} \begin{aligned} \text{season} \end{aligned}$$

Once the seasonal efficiency is calculated, the value is inserted into the equation for the total winter heating on-time air flow up the stack, yielding an improved estimate for the on-cycle infiltration losses.

(c) Jacket Losses. The heat lost through the jacket or shell of a fossil fuel furnace comprises one to five percent of the total fuel Btu input. Most furnace manufacturers insulate the jacket of their furnace with one inch of fiberglass insulation (Ref. 17). The thickness of the insulation can be increased, but the achievable savings would be small compared to the increase in product cost. A better alternative is to locate the furnace in the conditioned portion of a structure. The jacket losses are effectively zero, because the heat dissipated through the jacket would be used in heating the conditioned portion of the structure.

For the three climatic locations the jacket losses were assumed to be the following percentages of the total Btu fuel input.

- Baltimore 3%
- Chicago 3.5%
- Houston 2.5%

To estimate the jacket losses the following equation is provided.

$$\text{Jacket losses (Btu)} = \left(\frac{\text{Furnace Rating (Input)}}{\text{Percent Jacket Loss}} \right) \left(\frac{\text{Furnace Seasonal On-time hours}}{\text{Seasonal On-time hours}} \right)$$

(d) Pump/Blower Losses (Oil Furnace Only). Figure V-2, illustrates the pump blower section of a oil warm air furnace. Its main purpose is to pump oil and combustion air into a nozzle for proper mixing and inject the mixture into the furnace combustion chamber. Typically, the pump/blower ranges from 1/16 HP to 1/4 HP for residential oil furnaces. The fan section can operate at two speeds (725 rpm or 3450 rpm (Ref. 18). The amount of energy used in driving the pump/blower is calculated by.

$$\begin{array}{l} \text{Seasonal} \\ \text{Energy} \\ \text{Usage} \\ \text{for forced} \\ \text{draft-blower} \\ \text{(Btu)} \end{array} = \left(\frac{\text{Pump/Blower Input Energy Usage}}{\text{Total Seasonal On-Time Hours}} \right)$$

b. Method of Study for Electric Furnaces. The conversion of electrical energy to heat through the use of an electrical resistance heater was assumed to be a 100% efficient process. The only area for study of electric furnaces, therefore, was the distribution system. The electric furnace was studied under the same two distribution system modifications as the fossil fuel furnaces, reducing duct losses by 50% through more insulation and less leakage, and eliminating duct losses entirely by locating the ducts entirely within the conditioned space.

c. Method of Study for Heat Pumps. In order to study the variation of the heat pump's performance as a function of climate as well as its response to energy conserving strategies in these climates, a characteristic heat pump was evaluated. The building heating loads for SFD, SFA, and MFLR in Baltimore, Chicago and Houston (calculated in Task 200) were averaged on a per-degree-of-temperature-difference basis, and the heat pump performance was then applied to each location based on temperature distribution and heating loads associated with each temperature. Following is a discussion of each step in the above method.

(1) Development of Characteristic Heat Pump. Heat pump performance data from several manufacturers were collected and a best fit performance curve was derived from the data (Ref. 19 through 23). The performance specifications thus derived were heat pump capacity and C.O.P. as a function of outdoor temperature. Table V-4 shows heat pump capacity and C.O.P. as a function of temperature. The figures in Table V-4 are for a three-ton heat pump. The 2 1/2-ton and 2-ton heat pumps developed have proportionally smaller capacities at each temperature.

(2) Building Heating Load as Function of Temperature Difference. The building heating loads (developed in Task 200 interim report) for SFD, SFA and MFLR in Baltimore, Chicago and Houston, plus duct losses were divided by the appropriate number of heating degree days and then divided by 24 to give the average building load per degree of temperature difference between indoor and outdoor. Duct losses were included since they are a load which must be met by the heating system.

(3) Application of Heat Pump Characteristics to Each Residence. Using the same temperature ranges for which heat pump characteristics were defined, average building heating loads were calculated for each temperature range for SFD, SFA, and MFLR in Baltimore, Chicago, and Houston. Using temperature distribution data for each location, the number of hours of occurrence of each temperature range was multiplied by the building loads and heat pump output to determine the amount of auxiliary

TABLE V-4. CHARACTERISTIC THREE-TON
HEAT PUMP PERFORMANCE SPECIFICATIONS

<u>Outdoor Temperature Range (°F)</u>	<u>Maximum Heating Output Excluding Auxiliary Resistance Heat (Btu/Hr)</u>	<u>Coefficient of Performance</u>
Below -10	--	--
-10 - -6	10500	1.07
-5 - -1	13000	1.18
0 - 4	15200	1.32
5 - 9	17600	1.47
10 - 14	20000	1.61
15 - 19	22000	1.73
20 - 24	24500	1.84
25 - 29	27000	2.02
30 - 34	29300	2.13
35 - 39	31700	2.23
40 - 44	34000	2.33
45 - 49	36100	2.44
50 - 54	38600	2.54
55 - 59	40600	2.63
60 - 64	43000	2.72

heat required at each temperature and on a seasonal basis. Then the heat pump output excluding auxiliary heat was divided by the C.O.P. for the appropriate temperature range to give energy input to the system. The proportion of building load to heat pump output excluding auxiliary heat gives the percentage of time the system must operate at each temperature. Multiplying the percentage of operating time by hours of occurrence of each temperature range gives the total seasonal operating hours at each temperature. Summing the operating hours for each temperature range gives total seasonal operating hours for the system. When outdoor temperature is above -10°F (100% auxiliary heat) but below that temperature at which no auxiliary heat is required, the system is assumed to remain on 100 percent of the time.

Once the total operating time is known, it can be multiplied by the fan power requirement to find the total energy consumed by the fans for the season.

The energy required for defrosting was calculated based on known data for Albany, New York. The energy required for defrost cycles in Albany was multiplied by the proportion of operating hours under frost-forming conditions in each location compared to Albany.

2. Cooling Systems

Both central air conditioning systems and heat pump cooling systems were studied in a similar way as heat pumps in the heating mode. A characteristic system was defined by averaging the performance characteristics of all the units under 65,000 Btuh listed in reference 62. Central air conditioning systems were found to be slightly more efficient than heat pumps in the cooling mode. Strategies identified for air conditioners and heat pump cooling systems were the same as for heat pump heating systems.

C. RD&D Strategies

In this section RD&D strategies are defined for each type of heating and cooling system. The strategies are analyzed to determine the estimated effect on energy resource utilization due to their implementation. Strategies were selected based on an evaluation of all system components and a determination of which components represented the largest potential savings.

1. Heating Systems

RD&D strategies for heating systems are presented below. The heating systems have been broken down into four categories:

- Gas Furnaces
- Oil Furnaces
- Electric Furnaces
- Heat Pumps

a. Gas Furnaces. Strategies for gas furnaces are summarized in Tables V-5 through V-14.

(1) Installation of Electronic Ignition. The majority of residential gas warm air furnaces are presently ignited with a pilot light. A pilot light typically burns 800 Btu/hr (Ref. 9). By replacing the pilot light, between 38-45 therms/year can be saved in the Baltimore and Chicago regions. This represents a savings of 3 to 12 percent for the structures studied (SFD, SFA, MFLR). In Houston, 27 therms/year can be saved. The implementation of this strategy can save 17 to 45 percent of the total heating requirements in Houston.

The heat requirements in the warmer climatic regions are small. Consequently, the energy lost due to the pilot light amounts to a large percentage of the total yearly heating requirements, resulting in large savings with an electronic ignition installation.

(2) Outside Preheated Combustion and Dilution Air. A typical gas warm air furnace draws combustion and dilution air from within a structure. National Fire Prevention Association (NFPA) codes state that the furnace air inlet and the draft diverter must be in the same pressure zone (Ref. 46). By placing the furnace outside of the structure or running ductwork to the furnace, it is possible to draw outside air for combustion and dilution purposes. This eliminates the infiltration losses due

TABLE V-5
BALTIMORE (SFD) GAS HEATING STRATEGIES/COMPONENT MATRIX

COMPONENTS	Heating Load (Therms)	HEATING SYSTEM LOSSES (THERMS)										Total Heat Requirements (Therms)	Amount of Savings (Therms)
		Furnace On					Furnace Off		Circulating Fan		Ducts		
		Burner	Total Stack Losses		Jacket	Pilot	Total Stack Losses		Impeller	Motor			
			Furnace Air Inlet	Draft Diverter			Furnace Air Inlet	Draft Diverter					
Base System: 100,000 Btu/hr (input) Gas Warm Air Furnace (Sized typically for approx. twice the building peak design load) $N_{SS} = .75$ 50% excess combustion air													
STRATEGIES													
Base System	554	185	6	7	22	38	42	12	-2	-6	55	921	
Electronic ignition (No pilot light)	554	185	6	7	22	--	42	12	-2	-6	55	883	38
Outside preheated combustion and dilution air	554	185	-	-	22	38	30	--	-2	-6	55	884	37
Automatic flue damper	554	185	6	7	22	38	8	2	-2	-6	55	887	34
13% excess combustion air	554	185	5	6	22	38	41	12	-2	-6	55	918	3
Furnace sized for 25% above peak design building load	554	185	6	6	22	35	23	7	-1	-4	55	893	28
Furnace sized for peak load	554	185	6	6	22	32	18	5	-1	-5	55	878	43
Better insulated ducts with less leakage	554	185	6	7	22	38	42	12	-2	-6	28	894	27
Ducts in conditioned space	554	185	6	7	22	38	42	12	-2	-6	--	866	55
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{SS} approx. 10%)	554	90	5	6	19	--	36	11	-2	-6	55	776	145
Condensing flue gas furnace with electronic ignition (increasing N_{SS} approx. 20%)	554	23	4	5	17	--	33	11	-2	-5	55	702	219
Smaller fan operating a longer time (i.e. lower fan shut off temperature)	554	185	6	7	22	38	18	12	-2	-6	55	897	24

TABLE V-6
CHICAGO (SFD) GAS HEATING STRATEGIES/COMPONENTS MATRIX

STRATEGIES	COMPONENTS	HEATING SYSTEM LOSSES (THERMS)											Total Heat Requirements (Therms)	Amount of Savings (Therms)
		Furnace On					Furnace Off		Circulating Fan		Ducts			
		Burner	Furnace Air Inlet	Draft Diverter	Jacket	Pilot	Furnace Air Inlet	Draft Diverter	Impeller	Motor				
												Total Stack Losses		
Base System	811	270	10	11	38	42	72	20	-2	-10	81	1356		
Electronic ignition (No pilot light)	811	270	10	11	38	--	72	20	-2	-10	81	1313	43	
Outside preheated combustion and dilution air	811	270	--	--	38	42	53	--	-2	-10	81	1295	61	
Automatic flue damper	811	270	10	11	38	42	14	4	-2	-10	81	1281	75	
13% excess combustion air	811	270	9	10	38	42	70	18	-2	-10	81	1349	7	
Furnace sized for 25% above peak design building load	811	270	10	10	38	36	38	11	-2	-10	81	1305	51	
Furnace sized for peak load	811	270	10	10	38	34	30	8	-2	-6	81	1292	64	
Better insulated ducts with less leakage	811	270	10	11	38	42	72	20	-2	-10	40	1314	42	
Ducts in conditioned space	811	270	10	11	38	42	72	20	-2	-10	--	1275	81	
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N _{ss} approx. 10%)	811	132	9	9	33	--	62	18	-2	-8	81	1155	201	
Condensing flue gas furnace with electronic ignition (increasing N _{ss} approx. 20%)	811	34	8	7	30	--	56	16	-2	-7	81	1043	313	
Smaller fan operating a longer time (i.e. lower fan shut off temperature)	811	270	10	11	38	43	30	19	-2	-10	81	1294	62	

TABLE V-7
HOUSTON (SFD) GAS HEATING STRATEGIES/COMPONENTS MATRIX

Base System:

80,000 Btu/hr (input)
Gas Warm Air Furnace
(Sized typically for
approx. twice the
building peak design
load) $N_{SS} = .75$
50% excess combustion
air

STRATEGIES

COMPONENTS

Heating Load (Therms)	HEATING SYSTEM LOSSES (THERMS)										Total Heat Requirements (Therms)	Amount of Savings (Therms)
	Furnace On				Furnace Off			Circulating Fan		Ducts		
	Burner	Total Stack Losses		Jacket	Pilot	Total Stack Losses		Impeller	Motor			
		Furnace Air Inlet	Draft Diverter			Furnace Air Inlet	Draft Diverter					
84	28	*	*	3	26	6	3	-*	-2	8	159	
84	28	*	*	3	-	6	3	-*	-2	8	132	27
84	28	-	-	3	26	3	-	-*	-2	8	152	7
84	28	*	*	3	26	1	-*	-*	-2	8	150	9
84	28	*	*	3	26	5	3	-*	-2	8	158	1
84	28	*	*	3	26	3	2	-*	-*	8	154	5
84	28	*	1	3	26	3	2	-*	-*	8	154	5
84	28	*	*	3	26	6	3	-*	-2	4	155	4
84	28	*	*	3	26	6	3	-*	-2	-	151	8
84	14	*	*	3	-	6	3	-*	-*	8	118	41
84	4	*	*	2	-	6	3	-*	-*	8	107	52
84	28	*	*	3	26	4	3	-*	-2	8	156	3

Less than one therm, [3() = 1 therm]

TABLE V-8
BALTIMORE (SFA) GAS HEATING STRATEGIES/COMPONENTS MATRIX

STRATEGIES	COMPONENTS	HEATING SYSTEM LOSSES (THERMS)											Total Heat Requirements (Therms)	Amount of Savings (Therms)
		Heating Load (Therms)	Furnace On				Furnace Off			Circulating Fan		Ducts		
			Burner	Furnace Air Inlet	Draft Diverter	Jacket	Pilot	Total Stack Losses		Impeller	Motor			
Base System:														
80,000 Btu/hr (input)														
Gas Warm Air Furnace														
(Sized typically for approx. twice the building peak design load) $N_{ss} = .75$														
50% excess combustion air														
Base System		427	142	5	5	17	38	28	10	-1	-5	42	714	
Electronic ignition (No pilot light)		427	142	5	5	17	-	28	10	-1	-5	42	676	38
Outside preheated combustion and dilution air		427	142	-	-	17	38	19	-	-1	-5	42	685	29
Automatic flue damper		427	142	5	5	17	38	6	2	-1	-5	42	684	30
13% excess combustion air		427	142	4	5	17	38	28	9	-1	-5	42	712	2
Furnace sized for 25% above peak design building load		427	142	5	5	17	35	15	6	-1	-4	42	694	20
Furnace sized for peak load		427	142	5	5	17	33	12	4	-1	-5	42	687	27
Better insulated ducts with less leakage		427	142	5	5	17	38	28	10	-1	-5	21	693	21
Ducts in conditioned space		427	142	5	5	17	38	28	10	-1	-5	-	672	42
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 10%)		427	70	4	4	15	-	29	10	-1	-4	42	591	123
Condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 20%)		427	18	4	4	13	-	29	10	-1	-4	42	547	167
Smaller fan operating a longer time (i.e. lower fan shut off temperature)		427	142	5	5	17	38	19	10	-1	-4	42	705	9

TABLE V-9
CHICAGO (SFA) GAS HEATING STRATEGIES/COMPONENTS MATRIX

Base System:

100,000 Btu/hr (input)
Gas Warm Air Furnace
(Sized typically for
approx. twice the
building peak design
load) $N_{SS} = .75$
50% excess combustion
air

STRATEGIES

COMPONENTS	HEATING SYSTEM LOSSES (THERMS)												Total Heat Requirements (Therms)	Amount of Savings (Therms)
	Heating Load (Therms)	Furnace On				Furnace Off			Circulating Fan		Ducts			
		Burner	Total Stack Losses		Jacket	Pilot	Total Stack Losses		Impeller	Motor				
			Furnace Air Inlet	Draft Diverter			Furnace Air Inlet	Draft Diverter						
Base System: 100,000 Btu/hr (input) Gas Warm Air Furnace (Sized typically for approx. twice the building peak design load) $N_{SS} = .75$ 50% excess combustion air														
STRATEGIES														
Base System	593	198	7	8	28	42	48	17	-2	-8	59	1000		
Electronic ignition (No pilot light)	593	198	7	8	28	-	48	17	-2	-8	59	958	42	
Outside preheated combustion and dilution air	593	198	-	-	28	42	32	-	-2	-8	59	952	48	
Automatic flue damper	593	198	7	8	28	42	10	3	-2	-8	59	948	52	
13% excess combustion air	593	198	7	7	28	42	46	16	-2	-8	59	996	4	
Furnace sized for 25% above peak design building load	593	198	7	8	28	39	16	6	-1	-4	59	954	46	
Furnace sized for peak load	593	198	7	8	28	36	12	4	-2	-7	59	945	55	
Better insulated ducts with less leakage	593	198	7	8	28	42	48	17	-2	-8	29	970	30	
Ducts in conditioned space	593	198	7	8	28	42	48	17	-2	-8	-	941	59	
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{SS} approx. 10%)	593	97	6	7	24	-	48	18	-2	-7	59	852	148	
Condensing flue gas furnace with electronic ignition (increasing N_{SS} approx. 20%)	593	25	6	6	22	-	48	18	-2	-6	59	777	223	
Smaller fan operating a longer time (i.e. lower fan shut off temperature)	593	198	7	8	28	42	12	17	-2	-6	59	964	36	

TABLE V-10
HOUSTON (SFA) GAS HEATING STRATEGIES/COMPONENTS MATRIX

Base System:

60,000 Btu/hr (input)
Gas Warm Air Furnace
(Sized typically for
approx. twice the
building peak design
load) $N_{ss} = .75$
50% excess combustion
air

STRATEGIES

COMPONENTS	HEATING SYSTEM LOSSES (THERMS)											Total Heat Requirements (Therms)	Amount of Savings (Therms)
	Heating Load (Therms)	Furnace On				Furnace Off			Circulating Fan		Ducts		
		Burner	Total Stack Losses		Jacket	Pilot	Total Stack Losses		Impeller	Motor			
			Furnace Air Inlet	Draft Diverter			Furnace Air Inlet	Draft Diverter					
Base System: 60,000 Btu/hr (input) Gas Warm Air Furnace (Sized typically for approx. twice the building peak design load) $N_{ss} = .75$ 50% excess combustion air													
STRATEGIES													
Base System	56	19	*	*	2	26	4	2	—*	—*	6	115	
Electronic ignition (No pilot light)	56	19	*	*	2	—	4	2	—*	—*	6	89	26
Outside preheated combustion and dilution air	56	19	—	—		26	2	—	—*	—*	6	109	6
Automatic flue damper	56	19	*	*	2	26	*	*	—*	—*	6	110	5
13% excess combustion air	56	19	*	*	2	26	4	2	—*	—*	6	115	0
Furnace sized for 25% above peak design building load	56	19	*	*	2	25	3	2	—*	—*	6	113	2
Furnace sized for peak load	56	19	*	*	2	25	2	1	—*	—*	6	111	4
Better insulated ducts with less leakage	56	19	*	*	2	26	4	2	—*	—*	3	112	3
Ducts in conditioned space	56	19	*	*	2	26	4	2	—*	—*	—	109	6
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 10%)	56	9	*	1	2	—	4	2	—*	—*	6	79	36
Condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 20%)	56	2	*	*	2	—	3	2	—*	—*	6	71	44
Smaller fan operating a longer time (i.e. lower fan shut off temperature)	56	19	*	*	2	26	2	2	—*	—*	6	113	2

Less than one therm, [3() = 1 therm]

TABLE V-11
BALTIMORE (MFLR) GAS HEATING STRATEGIES/COMPONENTS MATRIX

STRATEGIES	COMPONENTS	HEATING SYSTEM LOSSES (THERMS)											Total Heat Requirements (Therms)	Amount of Savings (Therms)		
		Heating Load (Therms)	Furnace On				Furnace Off			Circulating Fan		Ducts				
			Burner	Total Stack Losses	Furnace Air Inlet	Draft Diverter	Jacket	Pilot	Total Stack Losses	Furnace Air Inlet	Draft Diverter				Impeller	Motor
Base System: 60,000 Btu/hr (input) Gas Warm Air Furnace (Sized typically for approx. twice the building peak design load) $N_{ss} = .75$ 50% excess combustion air																
Base System		190	63	2	2	8	41	13	8	-1	-3	19	347			
Electronic ignition (No pilot light)		190	63	2	2	8	--	13	8	-1	-3	19	306	41		
Outside preheated combustion and dilution air		190	63	-	-	8	41	6	-	-1	-3	19	327	20		
Automatic flue damper		190	63	2	2	8	41	3	2	-1	-3	19	330	17		
13% excess combustion air		190	63	2	2	8	41	12	7	-1	-3	19	344	3		
Furnace sized for 25% above peak design building load		190	63	2	2	8	41	8	5	-1	-2	19	338	9		
Furnace sized for peak load		190	63	2	2	8	41	6	4	-1	-2	19	331	16		
Better insulated ducts with less leakage		190	63	2	2	8	41	13	8	-1	-3	9	336	11		
Ducts in conditioned space		190	63	2	2	8	41	13	8	-1	-3	--	327	20		
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 10%)		190	31	2	2	7	--	13	5	-1	-2	19	269	78		
Condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 20%)		190	8	1	2	6	--	13	5	-1	-2	19	244	103		
Smaller fan operating a longer time (i.e. lower fan shut off temperature)		190	63	2	2	8	41	7	8	-1	-3	19	340	7		

TABLE V-12
CHICAGO (MFLR) GAS HEATING STRATEGIES/COMPONENTS MATRIX

Base System:

80,000 Btu/hr (input)
Gas Warm Air Furnace
(Sized typically for
approx. twice the
building peak design
load) $N_{SS} = .75$
50% excess combustion
air

STRATEGIES

STRATEGIES	COMPONENTS	HEATING SYSTEM LOSSES (THERMS)											Total Heat Requirements (Therms)	Amount of Savings (Therms)
		Heating Load (Therms)	Furnace On				Furnace Off			Circulating Fan		Ducts		
			Burner	Total Stack Losses		Jacket	Pilot	Total Stack Losses		Impeller	Motor			
				Furnace Air Inlet	Draft Diverter			Furnace Air Inlet	Draft Diverter					
Base System:														
80,000 Btu/hr (input)														
Gas Warm Air Furnace														
(Sized typically for approx. twice the building peak design load) $N_{SS} = .75$														
50% excess combustion air														
Base System	313	104	4	4	15	45	27	15	-1	-3	31	558		
Electronic ignition (No pilot light)	313	104	4	4	15	--	27	15	-1	-3	31	513	45	
Outside preheated combustion and dilution air	313	104	-	-	15	45	14	--	-1	-3	31	522	36	
Automatic flue damper	313	104	4	4	15	45	5	3	-1	-3	31	524	34	
13% excess combustion air	313	104	4	4	15	45	26	13	-1	-3	31	555	3	
Furnace sized for 25% above peak design building load	313	104	4	4	15	42	15	8	-1	-3	31	536	22	
Furnace sized for peak load	313	104	4	4	15	40	10	7	-1	-3	31	528	30	
Better insulated ducts with less leakage	313	104	4	4	15	45	27	15	-1	-3	15	542	16	
Ducts in conditioned space	313	104	4	4	15	45	27	15	-1	-3	--	527	31	
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{SS} approx. 10%)	313	51	3	4	13	--	25	15	-1	-3	31	455	103	
Condensing flue gas furnace with electronic ignition (increasing N_{SS} approx. 20%)	313	13	3	3	12	--	23	15	-1	-2	31	413	145	
Smaller fan operating a longer time (i.e. lower fan shut off temperature)	313	104	4	4	15	45	13	15	-1	-3	31	544	14	

TABLE V-13
HOUSTON (MFLR) GAS HEATING STRATEGIES/COMPONENTS MATRIX

Base System:

40,000 Btu/hr (input)
Gas Warm Air Furnace
(Sized typically for
approx. twice the
building peak design
load) $N_{ss} = .75$
50% excess combustion
air

COMPONENTS

STRATEGIES

Heating Load (Therms)	HEATING SYSTEM LOSSES (THERMS)											Total Heat Requirements (Therms)	Amount of Savings (Therms)
	Furnace On				Furnace Off				Circulating Fan		Ducts		
	Burner	Total Stack Losses		Jacket	Pilot	Total Stack Losses		Impeller	Motor				
		Furnace Air Inlet	Draft Diverter			Furnace Air Inlet	Draft Diverter						
20	6	*	*	1	27	2	2	-*	-*	2	60		
20	6	*	*	1	--	2	2	-*	-*	2	33	27	
20	6	-	-	1	27	*	-	-*	-*	2	56	4	
20	6	*	*	1	27	*	*	-*	-*	2	57	3	
20	6	*	*	1	27	1	2	-*	-*	2	59	1	
20	6	*	*	1	26	1	1	-*	-*	2	57	3	
20	6	*	*	1	26	*	*	-*	-*	2	56	4	
20	6	*	*	1	27	2	2	-*	-*	1	59	1	
20	6	*	*	1	27	2	2	-*	-*	-	58	2	
20	3	*	*	1	-	1	2	-*	-*	2	29	31	
20	*	*	*	1	-	1	2	-*	-*	2	27	33	
20	6	*	*	1	27	1	2	-*	-*	2	59	1	

Less than one therm, [3() = 1 therm]

TABLE V-14. SAVINGS IN THERMS AS A RESULT OF EACH STRATEGY: GAS FURNACE

Strategies	Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
Electronic Ignition	38	38	41	43	42	45	27	26	27
Outside preheated combustion and dilution air	37	29	20	61	48	36	7	6	4
Automatic flue damper	34	30	17	75	52	34	9	5	3
13% excess air	3	2	3	7	4	3	1	0	1
Furnace sized for 25% above peak design building load	28	20	9	51	46	22	5	2	3
Furnace sized for peak load	43	27	16	64	55	30	5	4	4
Better insulated ducts with less leakage	27	21	11	42	30	16	4	3	1
Ducts in conditioned space	55	42	20	81	59	31	8	6	2
Approaching the upper efficiency limit of a non-condensing furnace with electronic ignition (increasing N_{SS} approx. 10%)	145	123	78	201	148	103	41	36	31
Condensing flue gas furnace with electronic ignition (increasing N_{SS} approx. 20%)	219	167	103	313	223	145	52	44	33
Smaller fan operating a longer time (i.e., lower fan shut off temperature)	24	9	7	62	36	14	3	2	1

to the operation of a gas warm air furnace. The savings in the Baltimore and Chicago regions fall between 37 and 61 therms/year. This represents a 4 to 7 percent savings in the yearly heating requirement of the three structures (SFD, SFA, MFLR) studied. Likewise, 4 to 7 therms/year can be saved in the Houston area. Depending on the structure, a yearly savings of 4 to 7 percent of the total heat requirements can be achieved.

(3) Automatic Flue Damper. An automatic flue damper effectively closes off the stack during the periods when a furnace is not operating. This eliminates most of the off-cycle heat losses, but not all of them. The damper is controlled as a function of the flue temperature, thus some heat escapes before it closes. The automatic flue damper produces a yearly savings in the Baltimore and Chicago regions of 34 to 75 therms/year. This translates into a reduction in the total heat requirements of between 4 and 6 percent. In Houston 1 to 6 therms/year can be saved. This represents a 4 to 6 percent savings in the total gas furnace heating requirements.

(4) Thirteen Percent Excess Combustion Air. The typical residential gas furnace studied is operating with 50 percent excess combustion air. In order to study the effect of less excess air, 13 percent excess air is arbitrarily chosen. Less combustion air will mean that a gas furnace is operating with a higher steady-state efficiency. The amount of soot and smoke emission may increase; however, 2 to 7 therms/year can be saved in the Baltimore and Chicago regions. This represents a savings of less than one percent of the total heating requirements. No savings of any significance are achievable in the Houston region.

(5) Furnace Sized for 25 Percent Above the Peak Design Building Load. The majority of the residential gas warm air furnaces are sized for approximately twice the peak design building heat load. Decreasing the furnace size by 37 percent saves 9 to 51 therms/year in the Baltimore and Chicago regions. This amounts to a 3 to 5 percent savings in the total heat requirements. Two to five therms/year can be saved in the Houston area. This represents 2 to 5 percent savings in the total heat requirements of the structures studied.

(6) Furnace Sized for Peak Design Building Load. The implementation of this strategy requires no changes in the construction of presently available gas warm air furnaces. A savings of 17 to 75 therms/year in Baltimore and Chicago is achievable. This represents a 4 to 6 percent savings in the total yearly heating requirements, and this includes the

use of a gas pilot light. In the warmer regions, such as Houston, 4 to 5 therms/year can be conserved, or 3 to 7 percent of the heat load.

(7) Better Insulated Ducts With Less Leakage. The losses from the ducts in unconditioned spaces account for 10 percent of the heating load. By cutting losses due to conduction, radiation and leakage in half, it is possible to save 11 to 42 therms/year in the Baltimore and Chicago areas, with a 3 percent savings in the yearly heating requirements of the SFD, SFA, MFLR. Only 1 to 4 therms/year is conserved in the Houston area. This represents a 2 to 3 percent savings.

(8) Ducts In Conditioned Space. All the duct losses can be recovered by placing them within the conditioned space of each structure (SFD, SFA, MFLR). Once this is done, 20 to 81 therms/year can be saved in the Baltimore and Chicago regions. A 6 percent reduction in heating energy is therefore realized. 2 to 6 therms/year or 3 to 5 percent of the total heating requirement is conserved in Houston.

(9) Approaching the Upper Efficiency Limit of a Non-Condensing Natural Gas Furnace With Electronic Ignition. The typical gas furnace is assumed to meet the American Gas Association standards of a steady-state efficiency of at least 75 percent. By increasing the steady-state efficiency 10 percent, the upper efficiency limit of a non-condensing is approached (see Table V-3). Increasing the efficiency any higher will result in the condensation of flue gases. The majority of the naturally aspirated gas furnaces operate with a 75 to 80 percent steady-state efficiency. Switching from a naturally aspirated gas furnace to a forced draft gas furnace will raise the steady-state efficiency closer to the upper limit.

It is possible to save 78 to 201 therms/year or 15 to 22 percent of the total heating requirements in the Baltimore and Chicago areas while in the Houston area, 31 to 41 therms/year are saved. The total heating requirements are reduced by 26 to 52 percent.

(10) Condensing Flue Gas Natural Gas Furnace With Electronic Ignition. Increasing the steady-state efficiency by 20 percent will result in a gas furnace whose flue gases are condensing. The American Gas Association states that a condensing flue gas furnace will operate with a steady-state efficiency of 95 to 96 percent (Ref. 30).

TABLE V-15
BALTIMORE (SFD) OIL HEATING STRATEGIES/COMPONENTS MATRIX

COMPONENTS	HEATING SYSTEM LOSSES (THERMS)												Total Heat Requirements (Therms)	Amount of Savings (Therms)
	Heating Load (Therms)	Furnace On					Furnace Off		Circulating Fan		Ducts			
		Burner	Total Stack Losses			Jacket	Pump/Blower	Total Stack Losses		Impeller		Motor		
			Furnace Air Inlet	Barometric Draft Regulator				Furnace Air Inlet	Draft Diverter					
STRATEGIES														
Base System: 100,000 Btu/hr (input) Oil Warm Air Furnace (Sized typically for approx. twice the building peak design load) $N_{SS} = .75$ 50% excess combustion air		554	185	6	3	22	2	39	10	-2	-6	55	876	
Outside preheated combustion and dilution air		554	185	-	-	22	2	30	-	-2	-6	55	848	28
Automatic flue damper		554	185	6	3	22	2	8	2	-2	-6	55	837	39
13% excess combustion air		554	185	6	2	22	2	38	8	-2	-6	55	872	4
Furnace sized for 25% above peak design building load		554	185	6	3	22	4	35	6	-1	-4	55	870	6
Furnace sized for peak load		554	185	6	3	22	6	34	4	-1	-5	55	869	7
Better insulated ducts with less leakage		554	185	6	3	22	2	39	10	-2	-6	28	849	27
Ducts in conditioned space		554	185	6	3	22	2	39	10	-2	-6	-	821	55
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{SS} approx. 12%)		554	90	6	3	19	2	40	10	-2	-6	55	779	97
Condensing flue gas furnace with electronic ignition (increasing N_{SS} approx. 20%)		554	23	6	2	17	2	40	10	-2	-6	55	709	167
Smaller fan operating a longer time (i.e. lower fan shut off temperature)		554	185	6	3	22	2	15	10	-2	-6	55	852	24

TABLE V-16
CHICAGO (SFD) OIL HEATING STRATEGIES/COMPONENTS MATRIX

COMPONENTS	HEATING SYSTEM LOSSES (THERMS)												Total Heat Requirements (Therms)	Amount of Savings (Therms)
	Heating Load (Therms)	Furnace On					Furnace Off		Circulating Fan		Ducts			
		Burner	Total Stack Losses			Pump/Blower	Total Stack Losses		Impeller	Motor				
			Furnace Air Inlet	Barometric Draft Regulator	Jacket		Furnace Air Inlet	Draft Diverter						
STRATEGIES														
Base System:														
120,000 Btu/hr (input)														
Oil Warm Air Furnace														
(Sized typically for approx. twice the building peak design load) $N_{ss} = .75$														
50% excess combustion air														
Base System	811	270	10	5	38	6	67	16	-2	-10	81	1304		
Outside preheated combustion and dilution air	811	270	-	-	38	6	53	-	-2	-10	81	1259	45	
Automatic flue damper	811	270	10	5	38	6	13	3	-2	-10	81	1237	67	
13% excess combustion air	811	270	9	4	38	6	65	14	-2	-10	81	1298	6	
Furnace sized for 25% above peak design building load	811	270	10	5	38	6	61	9	-2	-10	81	1291	13	
Furnace sized for peak load	811	270	10	5	38	6	59	7	-2	-6	81	1287	17	
Better insulated ducts with less leakage	811	270	10	5	38	6	67	16	-2	-10	40	1263	41	
Ducts in conditioned space	811	270	10	5	38	6	67	16	-2	-10	--	1223	81	
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 12%)	811	132	10	4	32	4	68	16	-2	-8	81	1158	146	
Condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 20%)	811	34	9	4	30	4	68	16	-2	-7	81	1057	247	
Smaller fan operating a longer time (i.e. lower fan shut off temperature)	811	270	10	5	38	6	25	16	-2	-10	81	1262	42	

TABLE V-17.
HOUSTON (SFD) OIL HEATING STRATEGIES/COMPONENTS MATRIX

COMPONENTS	HEATING SYSTEM LOSSES (THERMS)											Total Heat Requirements (Therms)	Amount of Savings (Therms)	
	Heating Load (Therms)	Furnace On					Furnace Off		Circulating Fan		Ducts			
		Burner	Total Stack Losses			Jacket	Pump/Blower	Total Stack Losses		Impeller				Motor
			Furnace Air Inlet	Barometric Draft Regulator				Furnace Air Inlet	Draft Diverter					
Base System: 80,000 Btu/hr (input) Oil Warm Air Furnace (Sized typically for approx. twice the building peak design load) $N_{SS} = .75$ 50% excess combustion air														
STRATEGIES														
Base System	84	28	*	*	3	*	5	2	-*	-2	8	131		
Outside preheated combustion and dilution air	84	28	-	-	3	*	3	-	-*	-2	8	126	5	
Automatic flue damper	84	28	*	*	3	*	1	*	-*	-2	8	125	6	
13% excess combustion air	84	28	*	*	3	*	5	2	-*	-2	8	131	-	
Furnace sized for 25% above peak design building load	84	28	*	*	3	*	4	2	-*	-*	8	130	1	
Furnace sized for peak load	84	28	*	*	3	*	4	1	-*	-*	8	130	1	
Better insulated ducts with less leakage	84	23	*	*	3	*	5	2	-*	-2	4	127	4	
Ducts in conditioned space	84	28	*	*	3	*	5	2	-*	-2	2	125	6	
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{SS} approx. 12%)	84	14	*	*	2	*	5	2	-*	-*	8	116	15	
Condensing flue gas furnace with electronic ignition (increasing N_{SS} approx. 20%)	84	4	*	*	2	*	5	2	-*	-*	8	106	25	
Smaller fan operating a longer time (i.e. lower fan shut off temperature)	84	28	*	*	3	*	3	2	-*	-2	8	129	2	

Less than one therm [$3() \approx 1$ therm]

TABLE V-18
BALTIMORE (SFA) OIL HEATING STRATEGIES/COMPONENTS MATRIX

STRATEGIES	COMPONENTS	HEATING SYSTEM LOSSES (THERMS)												Total Heat Requirements (Therms)	Amount of Savings (Therms)
		Heating Load (Therms)	Furnace On						Furnace Off		Circulating Fan		Ducts		
			Burner	Total Stack Losses			Jacket	Pump/Blower	Total Stack Losses		Impeller	Motor			
				Furnace Air Inlet	Barometric Draft Regulator				Furnace Air Inlet	Draft Diverter					
Base System: 80,000 Btu/hr (input) Oil Warm Air Furnace (Sized typically for approx. twice the building peak design load) $N_{ss} = .75$ 50% excess combustion air															

TABLE V-19
CHICAGO (SFA) OIL HEATING STRATEGIES/COMPONENTS MATRIX

COMPONENTS	HEATING SYSTEM LOSSES (THERMS)											Total Heat Requirements (Therms)	Amount of Savings (Therms)
	Heating Load (Therms)	Furnace On					Furnace Off		Circulating Fan		Ducts		
		Total Stack Losses			Pump/Blower	Total Stack Losses	Impeller	Motor					
		Burner	Furnace Air Inlet	Barometric Draft Regulator					Jacket	Furnace Air Inlet			
Base System: 100,000 Btu/hr (input) Oil Warm Air Furnace (Sized typically for approx. twice the building peak design load) $N_{ss} = .75$ 50% excess combustion air													
STRATEGIES													
Base System	593	198	7	3	28	3	44	14	-2	-8	59	949	
Outside preheated combustion and dilution air	593	198	-	-	28	3	32	-	-2	-8	59	913	36
Automatic flue damper	593	198	7	3	28	3	9	3	-2	-8	59	903	46
13% excess combustion air	593	198	6	3	28	3	43	11	-2	-8	59	944	5
Furnace sized for 25% above peak design building load	593	198	7	3	28	4	39	8	-1	-4	59	939	10
Furnace sized for peak load	593	198	7	3	28	7	37	5	-1	-7	59	937	12
Better insulated ducts with less leakage	593	198	7	3	28	3	44	14	-2	-8	29	919	30
Ducts in conditioned space	593	198	7	3	28	3	44	14	-2	-8	-	890	59
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 12%)	593	97	7	3	23	2	45	14	-2	-6	59	843	160
Condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 20%)	593	25	6	3	22	2	45	14	-2	-6	59	769	234
Smaller fan operating a longer time (i.e. lower fan shut off temperature)	593	198	7	3	28	3	18	14	-2	-8	59	923	26

TABLE V-20
HOUSTON (SFA) OIL HEATING STRATEGIES/COMPONENTS MATRIX

STRATEGIES	COMPONENTS	HEATING SYSTEM LOSSES (THERMS)											Total Heat Requirements (Therms)	Amount of Savings (Therms)	
		Heating Load (Therms)	Furnace On						Furnace Off		Circulating Fan				Ducts
			Total Stack Losses			Jacket	Pump/Blower	Total Stack Losses		Impeller	Motor				
			Burner	Furnace Air Inlet	Barometric Draft Regulator			Furnace Air Inlet	Draft Diverter						
Base System: 60,000 Btu/hr (input) Oil Warm Air Furnace (Sized typically for approx. twice the building peak design load) $N_{ss} = .75$ 50% excess combustion air															
Base System	56	19	*	*	2	*	3	2	-*	-1	6	89			
Outside preheated combustion and dilution air	56	19	-	-	2	*	2	-	-*	-1	6	85	4		
Automatic flue damper	56	19	*	*	2	*	1	-	-*	-1	6	85	4		
13% excess combustion air	56	19	*	*	2	*	3	2	-*	-1	6	89	-		
Furnace sized for 25% above peak design building load	56	19	*	*	2	*	3	1	-*	-*	6	88	1		
Furnace sized for peak load	56	19	*	*	2	*	3	1	-*	-*	6	88	1		
Better insulated ducts with less leakage	56	19	*	*	2	*	3	2	-*	-*	3	86	3		
Ducts in conditioned space	56	19	*	*	2	*	3	2	-*	-*	-	83	6		
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 12%)	56	9	*	*	2	*	3	2	-*	-*	6	79	10		
Condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 20%)	56	2	*	*	1	*	3	2	-*	-*	6	71	18		
Smaller fan operating a longer time (i.e. lower fan shut off temperature)	56	19	*	*	2	*	3	2	-*	-1	6	89	-		

* Less than one therm, [3(*) $\approx$ 1 therm]

TABLE V-21
BALTIMORE (MFLR) OIL HEATING STRATEGIES/COMPONENTS MATRIX

Base System:

60,000 Btu/hr (input)
Oil Warm Air Furnace
(Sized typically for
approx. twice the
building peak design
load) $N_{ss} = .75$
50% excess combustion
air

STRATEGIES

Heating Load (Therms)			HEATING SYSTEM LOSSES (THERMS)					Total Heat Requirements (Therms)	Amount of Savings (Therms)				
Burner	Total Stack Losses		Furnace On	Furnace Off	Circulating Fan	Ducts							
	Furnace Air Inlet	Barometric Draft Regulator					Jacket			Pump/Blower	Total Stack Losses	Impeller	Motor

Base System	190	63	2	1	8	2	12	6	-1	-3	19	303	
Outside preheated combustion and dilution air	190	63	-	-	8	2	6	-	-1	-3	19	288	15
Automatic flue damper	190	63	2	1	8	2	2	1	-1	-3	19	288	15
13% excess combustion air	190	63	2	1	8	2	11	5	-1	-3	19	301	2
Furnace sized for 25% above peak design building load	190	63	2	1	8	2	9	4	-1	-2	19	298	5
Furnace sized for peak load	190	63	2	1	8	1	9	3	-1	-2	19	296	7
Better insulated ducts with less leakage	190	63	2	1	8	2	7	2	-1	-3	9	284	19
Ducts in conditioned space	190	63	2	1	8	2	7	2	-1	-3	-	275	28
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 12%)	190	31	2	1	6	2	12	7	-1	-2	19	270	33
Condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 20%)	190	8	2	1	6	1	12	6	-1	-2	19	245	58
Smaller fan operating a longer time (i.e. lower fan shut off temperature)	190	63	2	1	8	2	7	6	-1	-3	19	298	5

TABLE V-22
CHICAGO (MFLR) OIL HEATING STRATEGIES/COMPONENTS MATRIX

COMPONENTS	HEATING SYSTEM LOSSES (THERMS)												Total Heat Requirements (Therms)	Amount of Savings (Therms)
	Heating Load (Therms)	Furnace On						Furnace Off		Circulating Fan		Ducts		
		Burner	Total Stack Losses			Jacket	Pump/Blower	Total Stack Losses		Impeller	Motor			
			Furnace Air Inlet	Barometric Draft Regulator	Furnace Air Inlet			Draft Diverter						
STRATEGIES														
Base System:														
80,000 Btu/hr (input)														
Oil Warm Air Furnace														
(Sized typically for approx. twice the building peak design load) $N_{ss} = .75$														
50% excess combustion air														

TABLE V-23
HOUSTON (MFLR) OIL HEATING STRATEGIES/COMPONENTS MATRIX

COMPONENTS	HEATING SYSTEM LOSSES (THERMS)											Total Heat Requirements (Therms)	Amount of Savings (Therms)
	Heating Load (Therms)	Furnace On					Furnace Off		Circulating Fan		Ducts		
		Burner	Total Stack Losses			Pump/Blower	Total Stack Losses		Impeller	Motor			
			Furnace Air Inlet	Barometric Draft Regulator	Jacket		Furnace Air Inlet	Draft Diverter					
Base System: 40,000 Btu/hr (input) Oil Warm Air Furnace (Sized typically for approx. twice the building peak design load) $N_{ss} = .75$ 50% excess combustion air													
STRATEGIES													

Base System	20	6	*	*	1	*	1	1	-*	-*	2	32	
Outside preheated combustion and dilution air	20	6	-	-	1	*	*	-	-*	-*	2	30	2
Automatic flue damper	20	6	*	*	1	*	*	*	-*	-*	2	31	1
13% excess combustion air	20	6	*	*	1	*	*	*	-*	-*	2	31	1
Furnace sized for 25% above peak design building load	20	6	*	*	1	*	*	*	-*	-*	2	31	1
Furnace sized for peak load	20	6	*	*	1	*	*	*	-*	-*	2	31	1
Better insulated ducts with less leakage	20	6	*	*	1	*	1	1	-*	-*	1	31	1
Ducts in conditioned space	20	6	*	*	1	*	1	1	-*	-*	-	30	2
Approaching the upper efficiency limit of a non-condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 12%)	20	3	*	*	*	*	1	1	-*	-*	2	28	4
Condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 20%)	20	*	*	*	*	*	1	1	-*	-*	2	25	7
Smaller fan operating a longer time (i.e. lower fan shut off temperature)	20	6	*	*	1	*	1	1	-*	-*	2	32	-

* Less than one therm, [3(*) $\cong$ 1 therm]

TABLE V-24. SAVINGS IN THERMS AS A RESULT OF EACH STRATEGY: OIL FURNACE

Strategies	Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
Outside preheated combustion and dilution air	28	26	15	45	36	28	5	4	2
Automatic flue damper	39	30	15	67	46	29	6	4	1
13% excess air	4	7	2	6	5	12	0	0	1
Furnace sized for 25% above peak design building load	6	6	5	13	10	8	1	1	1
Furnace sized for peak load	7	13	7	17	12	12	1	1	1
Better insulated ducts with less leakage	27	22	19	41	30	16	4	3	1
Ducts in conditioned space	55	43	28	81	59	31	6	6	2
Approaching the upper efficiency limit of a non-condensing furnace with electronic ignition (increasing N_{ss} approx. 12%)	97	78	33	146	160	57	15	10	4
Condensing flue gas furnace with electronic ignition (increasing N_{ss} approx. 20%)	167	132	58	247	234	97	25	18	7
Smaller fan operating a longer time (i.e., lower fan shut off temperature)	24	15	5	42	26	11	2	0	0

Such a furnace could realize savings of 103 to 313 therms/year. This is a 22 to 30 percent drop in the total heating energy requirements of the structures studied. In the Houston area, 33 to 52 therms/year are conserved, with a 33 to 55 percent savings in the total heat energy requirements.

(11) Smaller Fan Operating a Longer Time (i.e. Lower Fan Shut-Off Temperature). Typically, the circulating fan is set to come on after the temperature in the supply bonnet (supply air furnace exit) reaches 125°F to 140°F. It will then shut off at about 100°F. By setting the fan shut off temperature to 5°F above room temperature, (Ref. 17), the fan will run longer after the furnace shuts off. This will eliminate most of the heat lost during the off-cycle periods, because it will be utilized to heat the conditioned spaces. Seven to sixty-two therms/year can be saved in the Baltimore and Chicago regions. This is a 1 to 5 percent reduction in the total heating requirements. In the Houston area 1 to 3 therms/year is conserved, with a 2 percent reduction in heating requirements.

b. Oil Furnaces. Strategies for oil furnaces are summarized in Tables V-15 through V-24.

(1) Outside, Preheated Combustion and Dilution Air. Combustion and dilution air requirements for a typical oil warm air furnace are drawn from within a structure via the air inlet and the barometric draft regulator (see Figure V-2). Outside air for combustion and dilution purposes can be made available by placing the furnace outside of the structure or running ductwork to the furnace. This will eliminate those infiltration losses generated during the on/off periods of furnace operation. A 3 to 6 percent reduction in heat requirements or 15 to 45 therms/year can be saved in the Baltimore/Chicago regions. Two to five therms/year can be saved in the Houston region by using outside air. This represents a decrease of 4 to 6 percent in the total heating requirements. The oil warm air furnace is not considered as a primary source of residential heating in the Houston area. Those few units that are heated by oil run on diesel fuel rather than No. 2 fuel oil (Ref. 68). The heat content of both are very similar. Since few residential structures are heated by fuel oil in the Houston area, the savings resulting from an implementation of a strategy is for theoretical purposes only.

(2) Automatic Flue Damper. As stated previously in strategies for the gas warm air furnace, an automatic flue damper is designed to eliminate most of the off-cycle heat losses. This results in conserving 5 to 6 percent of the

heat requirements in the different structures (SFD, SFA, MFLR) in the Baltimore and Chicago regions if flue temperatures are in the 450 to 800°F range. More precisely, 15 to 67 therms/year are saved. Theoretically in the Houston area, 1 to 6 therms/year are conserved (a 3 to 5 percent reduction in the seasonal heating energy requirement).

(3) Thirteen Percent Excess Combustion Air. As a strategy, reducing the excess combustion air supplied from 50 percent to 13 percent for an oil warm air furnace conserves 2 to 12 therms/year in the Baltimore/Chicago areas. This is a decrease of 5 to 6 percent in the total heat requirements. Negligibly little will be saved in Houston region. This strategy may increase smoke and soot in the flue gas.

(4) Furnace Sized for 25 Percent Above the Peak Design Building Load. The majority of the residential oil warm air furnaces are sized for approximately twice the peak design building heat load. As a strategy, a 62 percent reduction in the furnace capacity will result in a yearly savings of 5 to 13 therms. This will conserve 1 to 2 percent of the total heating requirements in the Baltimore/Chicago areas. Theoretically, an oil furnace sized for 25 percent above the design load instead of 100 percent in Houston will save 1 therm/year which is an insignificant amount.

(5) Furnace Sized for Peak Design Building Load. The implementation of this strategy will result in a savings of 7 to 17 therms/year in the Baltimore and Chicago areas. This is a 2 percent reduction in the total heat energy requirements of the structures reviewed. In the Houston area, 1 therm/year is saved.

(6) Better Insulated Ducts With Less Leakage. The losses from ducts placed in unconditioned spaces account for 10 percent of the heating load. By eliminating these losses it is possible to save 19 to 41 therms/year in the Baltimore and Chicago areas. This represents 3 to 6 percent of total heat requirements. In warmer climates, such as Houston, 1 to 4 therms/year can be conserved (a resultant savings in total heat requirements of 3 percent).

(7) Ducts in Conditioned Space. Ducts can be placed within the conditioned space of the structure thus eliminating all conduction, radiation, and leakage losses. The implementation of this strategy in the Baltimore and Chicago areas saves 28 to 81 therms/year. This is a 6 to 9 percent savings in the total heat requirements.

(8) Approaching the Upper Efficiency Limit of a Non-Condensing Oil Furnace With Electronic Ignition. The characteristic oil warm air furnace operates with a steady-state efficiency of 75 percent. Referring to Table V-3, it is only possible to increase the steady-state efficiency about 12 percent and still not have condensation of the flue gases. Increasing the steady-state efficiency to this limit will result in a savings of 33 to 160 therms/year in the Baltimore and Chicago areas. This is a reduction of 11 to 16 percent of the total heat requirements. Furthermore, 4 to 15 therms/year are conserved in the Houston region or a savings of 11 to 13 percent.

(9) Condensing Flue Gas Oil Furnace With Electronic Ignition. A 20 percent increase in the steady-state efficiency will result in an oil furnace whose flue gases are condensing. Such a furnace will save 58 to 247 therms/year, with a 19 to 23 percent reduction in yearly heating requirements in the Baltimore and Chicago areas. In Houston, the savings is 7 to 25 therms/year with a 19 to 20 percent reduction in heating requirements.

(10) Smaller Fan Operating Over a Longer Time (i.e. Lower Fan Shut-Off Temperature). Assuming that the controls for the oil furnace is set for the same conditions as for the gas furnace, a circulating fan operating longer after furnace shut-off, will save 5 to 42 therms/year in the Baltimore and Chicago areas. This lowers the total heat requirement by 2 to 3 percent. In Houston the heat requirements are reduced by 0 to 2 percent with an annual savings of 0 to 2 therms.

c. Electric Furnaces. Strategies are summarized in Tables V-25 through V-34.

(1) Better Insulated Ducts With Leakage. Effectively cutting the conduction, radiation and leakage losses in the duct systems in half can save 11 to 42 therms/year in the Baltimore and Chicago areas. This is a 4 to 5 percent drop in the total heating requirements of the electric resistance warm air furnace. In warmer climates such as Houston, 1 to 4 therms/year is conserved, with a similar lowering of 4 to 5 percent in the total heating requirements.

(2) Ducts in Conditioned Space. Table V-34 shows that between 20 and 81 therms/year would be conserved in the Baltimore and Chicago areas by placing the ducts in the conditioned space. This strategy eliminates all duct losses. A 9 percent reduction in total heating

TABLE V-25. BALTIMORE (SFD) ELECTRIC HEATING
STRATEGIES/COMPONENTS MATRIX

Strategies	Components	(Therms) HEATING LOSSES				Total Heat Requirements (Therms)	Amount of Savings (Therms)	
		Heating Load (Therms)	Furnace On		Circulating Fan			Ducts
			Jacket	Impeller				
Base System: 100,000 Btu/hr (input) Electric Warm Air Furnace (Sized typically for approximately twice the peak design load)								
Base System		554	22	-2	-6	55	631	
Better insulated ducts with less leakage		554	22	-2	-6	28	604	27
Ducts in conditioned space		554	22	-2	-6	0	576	55

TABLE V-26. CHICAGO (SFD) ELECTRIC HEATING STRATEGIES/COMPONENTS. MATRIX

Strategies	Components					Total Heat Requirements (Therms)	Amount of Savings (Therms)
	(Therms)						
	Heating Load (Therms)	Furnace On	Circulating Fan		Ducts		
	Jacket	Impeller	Motor				
Base System:							
120,000 Btu/hr (input)							
Electric Warm Air Furnace							
(Sized typically for approximately twice the peak design load)							
Base System	811	38	-2	-10	81	930	
Better insulated ducts with less leakage	811	38	-2	-10	40	889	41
Ducts in conditioned space	811	38	-2	-10	0	849	81

TABLE V-27. HOUSTON (SFD) ELECTRIC HEATING
STRATEGIES/COMPONENTS MATRIX

Strategies	Components	(Therms) HEATING LOSSES					Total Heat Requirements (Therms)	Amount of Savings (Therms)	
		Heating Load (Therms)	Furnace On		Circulating Fan				Ducts
			Jacket	Impeller	Motor				
Base System:									
80,000 Btu/hr (input)									
Electric Warm Air Furnace									
(Sized typically for approximately twice the peak design load)									
Base System		84	3	-*	-2	8	95		
Better insulated ducts with less leakage		84	3	-*	-2	4	91	4	
Ducts in conditioned space		81	3	-*	-2	0	87	8	

* Less than one therm

TABLE V-28 BALTIMORE (SFA) ELECTRIC HEATING
STRATEGIES/COMPONENTS MATRIX

Strategies	Components	(Therms) HEATING LOSSES				Total Heat Requirements (Therms)	Amount of Savings (Therms)	
		Heating Load (Therms)	Furnace On	Circulating Fan				Ducts
				Jacket	Impeller			
Base System: 80,000 Btu/hr (input) Electric Warm Air Furnace (Sized typically for approximately twice the peak design load)								
Base System		427	17	-1	-5	42	486	
Better insulated ducts with less leakage		427	17	-1	-5	21	465 21	
Ducts in conditioned space		427	17	-1	-5	0	444 42	

TABLE V-29. CHICAGO (SFA) ELECTRIC HEATING
STRATEGIES/COMPONENTS MATRIX

Strategies	Components	(Therms) HEATING LOSSES					Total Heat Requirements (Therms)	Amount of Savings (Therms)
		Heating Load (Therms)	Furnace On	Circulating Fan		Ducts		
				Jacket	Impeller			
Base System: - 100,000 Btu/hr.(input) Electric Warm Air Furnace (Sized typically for approximately twice the peak design load)								
Base System		593	28	-2	-8	59	680	
Better insulated ducts with less leakage		593	28	-2	-8	29	650	30
Ducts in conditioned space		593	28	-2	-8	0	621	59

TABLE V-3Q HOUSTON (SFA) ELECTRIC HEATING
STRATEGIES/COMPONENTS MATRIX

Strategies	Components	(Therms) HEATING LOSSES				Total Heat Requirements (Therms)	Amount of Savings (Therms)	
		Heating Load (Therms)	Furnace On	Circulating Fan				Ducts
				Impeller	Motor			
Base System: 60,000 Btu/hr (input) Electric Warm Air Furnace (Sized typically for approximately twice the peak design load)								
Base System		56	2	-*	-*	6	64	
Better insulated ducts with less leakage		56	2	-*	-*	3	61	3
Ducts in conditioned space		56	2	-*	-*	0	58	6

*Less than one therm

TABLE V-31 BALTIMORE (MFLR) ELECTRIC HEATING
STRATEGIES/COMPONENTS MATRIX

Strategies	Components	(Therms) HEATING LOSSES					Total Heat Requirements (Therms)	Amount of Savings (Therms)	
		Heating Load (Therms)	Furnace On		Circulating Fan				Ducts
			Jacket	Impeller	Motor				
Base System: 60,000 Btu/hr (input) Electric Warm Air Furnace (Sized typically for approximately twice the peak design load)									
Base System		190	8	-1	-3	19	217		
Better insulated ducts with less leakage		190	8	-1	-3	9	207	10	
Ducts in conditioned space		190	8	-1	-3	0	198	19	

TABLE V-32. CHICAGO (MFLR) ELECTRIC HEATING
STRATEGIES/COMPONENTS MATRIX

Base System: 80,000 Btu/hr (input) Electric Warm Air Furnace (Sized typically for approximately twice the peak design load)	(Therms) HEATING LOSSES					Total Heat Requirements (Therms)	Amount of Savings (Therms)
	Components Heating Load (Therms)	Furnace On	Circulating Fan		Ducts		
			Jacket	Impeller Motor			
Strategies							
Base System	313	15	-1	-3	31	359	
Better insulated ducts with less leakage	313	15	-1	-3	15	343	16
Ducts in conditioned space	313	15	-1	-3	0	328	31

TABLE V-33. HOUSTON (MFLR) ELECTRIC HEATING
STRATEGIES/COMPONENTS MATRIX

Strategies	Components	(Therms) HEATING LOSSES				Total Heat Requirements (Therms)	Amount of Savings (Therms)	
		Heating Load (Therms)	Furnace On		Ducts			
			Jacket	Circulating Fan Impeller Motor				
Base System:- 40,000 Btu/hr (input) Electric Warm Air Furnace (Sized typically for approximately twice the peak design load)		20	1	-*	-*	2	23	
		20	1	-*	-*	1	22	1
		20	1	-*	-*	0	21	2

*Less than one therm

TABLE V-34. SAVINGS IN THERMS AS A RESULT OF EACH STRATEGY:
ELECTRIC RESISTANCE FURNACE

	BALTIMORE			CHICAGO			HOUSTON		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
Better insulated ducts with less leakage	27	21	11	42	30	16	4	3	1
Ducts in conditioned space	55	42	20	81	59	31	8	6	2

requirements is possible. In Houston, it is possible to save 2 to 8 therms/year, with an 8 to 9 percent drop in the total heating requirements.

d. Heat Pumps

(1) Improvement of Compressor Efficiency. The efficiency of the compressor of the characteristic heat pump was calculated in the following manner: Starting with the total energy consumption of the heat pump, each energy consuming component was subtracted (including inefficiencies in the compressor motor) until only the energy input to the compressor itself remained. This energy requirement was compared to the energy requirement of a perfect Carnot cycle. The result shows that the characteristic heat pump compressor is 44 percent efficient. As a series of strategies, the performance of the heat pump was examined when the compressor efficiency was increased from 44 percent to 60, 80 and 100 percent (a 100 percent efficiency would be impossible to achieve, but represents the upper limit of savings available by only improving the compressor). In each case of increased compressor efficiency, the capacity of the heat pump at each temperature was assumed to remain the same as in the characteristic heat pump. Thus running time for the system did not change and auxiliary (resistance) heat requirement did not change. The energy required for defrosting the outdoor coil did change since that is done by reversing the cycle of the heat pump and the compressor efficiency is involved.

Table V-35 shows the savings achieved for each increase in compressor efficiency. These savings are for the heating season only.

TABLE V-35. SAVINGS IN THERMS DUE TO
INCREASED COMPRESSOR EFFICIENCY

Compressor Efficiency	SAVINGS IN THERMS								
	Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
0.44	0	0	0	0	0	0	0	0	0
0.60	59	45	20	85	60	35	9	5	1.8
0.80	100	74	34	143	101	59	14	9	3.0
1.00*	126	93	43	178	126	73	18	11	3.3

*Not possible. Theoretical limit only.

(2) Improved Effectiveness of Outdoor Coil. In order to transfer heat between the heat pump system and the outdoor environment, (heat flow from the environment into the system in the heating mode and from the system to the environment in the cooling mode) a temperature differential must exist between the heat exchange surface and the environment. The temperature of the working fluid in the heat exchanger is one of the parameters that controls the efficiency of the entire heat pump system. If the temperature difference between the working fluid and the environment could be decreased, the coefficient of performance of the system would be increased.

The effectiveness of the outdoor coil of the characteristic heat pump was calculated by comparing the energy required to run the system with a temperature difference between the system and the outdoors of as high as 25°F to the energy required to run the system with the ideal case, $\Delta T = 0^\circ\text{F}$. Although the ideal case could never be achieved, it represents the limit of savings available by only improving the outdoor coil effectiveness. The characteristic heat pump was found to have an outdoor coil effectiveness of 72 percent. A series of strategies to improve the heat pump's performance in both heating and cooling is to increase the effectiveness of the outdoor coil from 72 percent to 80, 90, and 100 percent. As the effectiveness of the outdoor coil was increased, all other performance characteristics of the heat pump were assumed to remain constant, including the energy requirement of the fans.

Table V-36 shows the energy savings in therms which would result from each increase in the effectiveness of the outdoor coil. These savings are for the heating season only.

TABLE V-36. ENERGY SAVINGS DUE TO INCREASED EFFECTIVENESS OF OUTDOOR COIL

Outdoor Coil Effectiveness	SAVINGS IN THERMS								
	Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
0.72	0	0	0	0	0	0	0	0	0
0.80	21	17	7	33	22	13	3	2	0.7
0.90	44	33	15	64	45	26	6	4	1.4
1.00*	62	47	21	89	63	37	9	6	1.9

*Not possible. Theoretical limit only.

(3) Increase Indoor Coil Effectiveness. An analysis of the indoor coil similar to the one performed for the outdoor coil reveals the effectiveness of the indoor coil of the characteristic heat pump is 89 percent. As a two-step strategy, the impact on the heat pump's performance was examined as the effectiveness of the indoor coil was increased from 89 to 95 and 100 percent. As the coil effectiveness was increased, all other performance characteristics were assumed to remain constant, including fan energy requirements.

Table V-37 shows the energy savings in therms which would result from each increase in the effectiveness of the indoor coil. The Figures in Table V-37 reflect only the heating season.

TABLE V-37. ENERGY SAVINGS DUE TO INCREASE IN EFFECTIVENESS OF INDOOR COIL

Indoor Coil Effectiveness	SAVINGS IN THERMS								
	Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
0.89	0	0	0	0	0	0	0	0	0
0.95	14	11	5	21	15	8	2	1	0.4
1.00*	24	18	9	36	25	15	4	2	0.7

*Not possible. Theoretical limit only.

(4) Increase Fan Efficiency. The efficiency of the fans in the characteristic heat pump is 68 percent. This is based on an 80 percent efficiency for the impeller and an 85 percent efficiency for the fan motor. A two-step strategy was identified in which the overall efficiency of the fans was increased from 68 to 85 and 100 percent. These increased fan efficiencies were applied to the indoor and outdoor fans simultaneously. All other system performance characteristics were assumed to remain constant, including fan capacities, so the increased fan efficiency did not result in shorter running time for the system.

Table V-38 shows the savings in therms which would result from each increase in the efficiency of the heat pump's fans. Only the savings from the heating season are included in Table V-38.

TABLE V-38. ENERGY SAVINGS DUE TO INCREASE
IN FAN EFFICIENCY

Fan Efficiency	SAVINGS IN THERMS								
	Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
0.68	0	0	0	0	0	0	0	0	0
0.85	8	9	4	13	12	7	1	1	0.3
1.0*	13	13	6	21	19	11	2	3	0.6

*Not possible. Theoretical limit only.

(5) Increase Efficiency of Compressor Motor. The motor that drives the compressor of the characteristic heat pump has an associated efficiency of 96 percent. One strategy identified was to increase the efficiency of the compressor motor to its theoretical limit, or 100 percent; although this theoretical limit could not be achieved, it represents the upper limit of savings available by just increasing the efficiency of the compressor motor. All other performance characteristics of the heat pump were assumed to remain constant as the compressor motor efficiency was increased.

Table V-39 shows the energy savings in therms in each location due to increasing the compressor motor efficiency to 1.0. Table V-39 includes only savings in the heating mode.

TABLE V-39. ENERGY SAVINGS DUE TO INCREASED
EFFICIENCY OF COMPRESSOR MOTOR

Compressor Motor Efficiency	SAVINGS IN THERMS								
	Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
0.96	0	0	0	0	0	0	0	0	0
1.0*	8	6	3	14	9	5	1	1	0.3

*Not possible. Theoretical limit only.

(6) Locate Ducts Entirely Within Conditioned Space. The losses from ducts in unconditioned spaces in the characteristic system accounted for 10 percent of the heating load and 5 percent of the cooling load. With poor workmanship and materials, duct losses could be as high as 40 to 50 percent of the load. By locating the ducts entirely within the conditioned space, any conduction, radiation, or leakage losses from the ducts are gains in the conditioned space, so that duct losses are effectively reduced to zero.

The implementation of this strategy, assuming all other system performance characteristics remain constant, results in shorter running time for all components since the load which must be met by the system is reduced.

Table V-40 shows the savings in therms in each location due to locating the ducts entirely within the conditioned space. Only the savings from the heating season are included in Table V-40.

TABLE V-40. ENERGY SAVINGS DUE TO LOCATING DUCTS ENTIRELY WITHIN CONDITIONED SPACE

	Baltimore			Chicago			Houston		
	<u>SFD</u>	<u>SFA</u>	<u>MFLR</u>	<u>SFD</u>	<u>SFA</u>	<u>MFLR</u>	<u>SFD</u>	<u>SFA</u>	<u>MFLR</u>
Savings	30	22	8	54	35	17	3	2	0.2

2. Cooling Systems

The components that comprise the cooling systems (both central air conditioners and heat pumps) are the same as those which comprise the heat pump used for heating. The strategies identified for cooling are therefore the same as those developed for heat pumps used for heating. The effects of implementation of each strategy can be seen in Tables V-41 through V-49 for heat pumps. Those strategies which have a different effect for central air conditioning systems than for heat pumps are shown in Table V-51. The savings due to implementation of cooling strategies are presented in Table V-52 for central air conditioners and Table V-53 for heat pumps.

3. Composite Systems

The combined energy savings due to implementation of each strategy for heating and cooling operation of a heat pump are presented in Table V-54.

TABLE V-41. BALTIMORE (SFD) HEAT PUMP STRATEGY/COMPONENT MATRIX

Strategies	Components	Compressor Energy Input		Condenser Fan Energy Input		Evaporator Fan Energy Input		Defrost Cycle Energy Input		Resistance Heat Energy Input		Total Energy Input		Total Energy Output		Heat Pump C.O.P.		Duct Losses		Energy Delivered To/ Extracted From Conditioned Space		System C.O.P.	
		Heat	Cool	Heat	Cool	Heat	Cool	Heat	Heat	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool
BASE		214	85	29	4	15	8	12	23	292	97	609	188	2.08	1.94	54	9	554	179	1.89	1.85		
1. Compressor Efficiency = .60		157	62	29	4	15	8	9	23	233	74	609	188	2.61	2.54	54	9	554	179	2.38	2.42		
2. Compressor Efficiency = .80		118	47	29	4	15	8	7	23	192	59	609	188	3.17	3.19	54	9	554	179	2.89	3.03		
3. Compressor Efficiency = 1.00		94	37	29	4	15	8	5	23	166	49	609	188	3.67	3.84	54	9	554	179	3.34	3.65		
4. Outdoor Coil Effectiveness = .80		193	77	29	4	15	8	11	23	271	89	609	188	2.25	2.11	54	9	554	179	2.04	2.01		
5. Outdoor Coil Effectiveness = .90		171	68	29	4	15	8	10	23	248	80	609	188	2.46	2.35	54	9	554	179	2.23	2.24		
6. Outdoor Coil Effectiveness = 1.00		154	61	29	4	15	8	9	23	230	73	609	188	2.65	2.58	54	9	554	179	2.41	2.45		
7. Indoor Coil Effectiveness = .95		200	80	29	4	15	8	11	23	278	92	609	188	2.19	2.04	54	9	554	179	1.99	1.95		
8. Indoor Coil Effectiveness = 1.0		190	76	29	4	15	8	11	23	268	88	609	188	2.27	2.14	54	9	554	179	2.07	2.03		
9. Fan Efficiency = .85		214	85	23	3	12	6	12	23	284	94	609	188	2.14	2.00	54	9	554	179	1.95	1.90		
10. Fan Efficiency = 1.0		214	85	20	3	10	5	12	23	279	93	609	188	2.18	2.02	54	9	554	179	1.99	1.92		
11. Compressor Motor Efficiency = 1.0		205	82	29	4	15	8	12	23	284	94	609	188	2.14	2.00	54	9	554	179	1.95	1.90		
12. Ducts Entirely in Conditioned Space		196	80	27	4	11	8	11	14	262	92	554	179	2.11	1.94	0	0	554	179	2.11	1.94		

TABLE V-42. CHICAGO (SFD) HEAT PUMP STRATEGY/COMPONENT MATRIX

Strategies	Components	Compressor Energy Input		Condenser Fan Energy Input		Evaporator Fan Energy Input		Defrost Cycle Energy Input		Resistance Heat Energy Input		Total Energy Input		Total Energy Output		Heat Pump C.O.P.		Duct Losses		Energy Delivered To/Extracted From Conditioned Space		System C.O.P.	
		Heat	Cool	Heat	Cool	Heat	Cool	Heat	Heat	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool
BASE		301	67	42	3	21	6	15	106	484	76	895	147	1.84	1.93	81	7	814	140	1.68	1.84		
1. Compressor Efficiency = .60		221	49	42	3	21	6	11	106	401	58	895	147	2.23	2.53	81	7	814	140	2.03	2.41		
2. Compressor Efficiency = .80		166	37	42	3	21	6	8	106	343	46	895	147	2.61	3.20	81	7	814	140	2.37	3.04		
3. Compressor Efficiency = 1.00		132	29	42	3	21	6	7	106	308	38	895	147	2.91	3.87	81	7	814	140	2.64	3.68		
4. Outdoor Coil Effectiveness = .80		271	60	42	3	21	6	13	106	453	69	895	147	1.98	2.13	81	7	814	140	1.80	2.03		
5. Outdoor Coil Effectiveness = .90		241	54	42	3	21	6	12	106	422	63	895	147	2.12	2.33	81	7	814	140	1.93	2.22		
6. Outdoor Coil Effectiveness = 1.00		217	48	42	3	21	6	11	106	397	57	895	147	2.25	2.58	81	7	814	140	2.05	2.46		
7. Indoor Coil Effectiveness = .95		282	63	42	3	21	6	14	106	465	72	895	147	1.92	2.04	81	7	814	140	1.75	1.94		
8. Indoor Coil Effectiveness = 1.0		268	60	42	3	21	6	13	106	450	69	895	147	1.99	2.13	81	7	814	140	1.81	2.03		
9. Fan Efficiency = .85		301	67	34	2	17	5	15	106	473	74	895	147	1.89	1.99	81	7	814	140	1.72	1.89		
10. Fan Efficiency = 1.0		301	67	29	2	14	4	15	106	465	73	895	147	1.92	2.01	81	7	814	140	1.75	1.92		
11. Compressor Motor Efficiency = 1.0		289	64	42	3	21	6	14	106	472	73	895	147	1.90	2.01	81	7	814	140	1.72	1.92		
12. Ducts Entirely in Conditioned Space		282	64	40	3	20	6	13	77	432	73	814	140	1.88	1.93	0	0	814	140	1.88	1.93		

TABLE V-43. HOUSTON (SFD) HEAT PUMP STRATEGY/COMPONENT MATRIX

Strategies	Components	Compressor Energy Input		Condenser Fan Energy Input		Evaporator Fan Energy Input		Defrost Cycle Energy Input		Resistance Heat Energy Input		Total Energy Input		Total Energy Output		Heat Pump C.O.P.		Duct Losses		Energy Delivered To/Extracted From Conditioned Space		System C.O.P.	
		Heat	Cool	Heat	Cool	Heat	Cool	Heat	Heat	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool
BASE		32	290	3	11	2	22	1	0	38	323	92	625	2.39	1.93	8	62	84	563	2.17	1.74		
1. Compressor Efficiency = .60		23	213	3	11	2	22	1	0	29	246	92	625	3.17	2.54	8	62	84	563	2.90	2.29		
2. Compressor Efficiency = .80		18	169	3	11	2	22	1	0	24	193	92	625	3.83	3.24	8	62	84	563	3.50	2.92		
3. Compressor Efficiency = 1.00		14	128	3	11	2	22	1	0	20	161	92	625	4.60	3.88	8	62	84	563	4.20	3.50		
4. Outdoor Coil Effectiveness = .80		29	261	3	11	2	22	1	0	35	294	92	625	2.63	2.13	8	62	84	563	2.40	1.91		
5. Outdoor Coil Effectiveness = .90		26	232	3	11	2	22	1	0	32	265	92	625	2.87	2.36	8	62	84	563	2.62	2.12		
6. Outdoor Coil Effectiveness = 1.00		23	209	3	11	2	22	1	0	29	242	92	625	3.17	2.58	8	62	84	563	2.90	2.33		
7. Indoor Coil Effectiveness = .95		30	272	3	11	2	22	1	0	36	305	92	625	2.56	2.05	8	62	84	563	2.33	1.85		
8. Indoor Coil Effectiveness = 1.0		28	258	3	11	2	22	1	0	34	291	92	625	2.71	2.15	8	62	84	563	2.47	1.93		
9. Fan Efficiency = .85		32	290	2	9	2	18	1	0	37	317	92	625	2.49	1.97	8	62	84	563	2.27	1.78		
10. Fan Efficiency = 1.0		32	290	2	7	2	15	1	0	36	312	92	625	2.56	2.00	8	62	84	563	2.33	1.80		
11. Compressor Motor Efficiency = 1.0		31	278	3	11	2	22	1	0	37	311	92	625	2.49	2.01	8	62	84	563	2.27	1.81		
12. Ducts Entirely in Conditioned Space		29	262	3	10	2	20	1	0	35	292	84	563	2.40	1.93	0	0	84	563	2.40	1.93		

TABLE V-44. BALTIMORE (SFA) HEAT PUMP STRATEGY/COMPONENT MATRIX

Strategies	Components		Compressor Energy Input		Condenser Fan Energy Input		Evaporator Fan Energy Input		Defrost Cycle Energy Input		Resistance Heat Energy Input		Total Energy Input		Total Energy Output		Heat Pump C.O.P.		Duct Losses		Energy Delivered To/ Extracted From Conditioned Space		System C.O.P.	
			Heat	Cool	Heat	Cool	Heat	Cool	Heat	Heat	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool
BASE			156	91	28	6	14	11	10	16	224	108	469	209	2.09	1.94	42	10	427	199	1.91	1.84		
1. Compressor Efficiency = .60			114	67	28	6	14	11	7	16	179	84	469	209	2.62	2.49	42	10	427	199	2.39	2.37		
2. Compressor Efficiency = .80			86	50	28	6	14	11	6	16	150	67	469	209	3.13	3.12	42	10	427	199	2.85	2.97		
3. Compressor Efficiency = 1.00			69	40	28	6	14	11	4	16	131	57	469	209	3.58	3.67	42	10	427	199	3.26	3.49		
4. Outdoor Coil Effectiveness = .80			140	82	28	6	14	11	9	16	207	99	469	209	2.27	2.11	42	10	427	199	2.06	2.01		
5. Outdoor Coil Effectiveness = .90			125	73	28	6	14	11	8	16	191	90	469	209	2.46	2.32	42	10	427	199	2.24	2.21		
6. Outdoor Coil Effectiveness = 1.00			112	66	28	6	14	11	7	16	177	83	469	209	2.65	2.52	42	10	427	199	2.41	2.40		
7. Indoor Coil Effectiveness = .95			146	85	28	6	14	11	9	16	213	102	469	209	2.20	2.05	42	10	427	199	2.00	1.95		
8. Indoor Coil Effectiveness = 1.0			139	81	28	6	14	11	9	16	206	98	469	209	2.28	2.13	42	10	427	199	2.07	2.03		
9. Fan Efficiency = .85			156	91	22	5	11	9	10	16	215	105	469	209	2.18	1.99	42	10	427	199	1.99	1.90		
10. Fan Efficiency = 1.0			156	91	19	4	10	7	10	16	211	102	469	209	2.22	2.05	42	10	427	199	2.02	1.95		
11. Compressor Motor Efficiency = 1.0			150	87	28	6	14	11	10	16	218	104	469	209	2.15	2.01	42	10	427	199	1.96	1.91		
12. Ducts Entirely in Conditioned Space			145	87	26	5	13	11	9	9	202	103	427	199	2.11	1.94	0	0	427	199	2.11	1.94		

TABLE V-45. CHICAGO (SFA) HEAT PUMP STRATEGY/COMPONENT MATRIX

Strategies	Components	Compressor Energy Input		Condenser Fan Energy Input		Evaporator Fan Energy Input		Defrost Cycle Energy Input		Resistance Heat Energy Input		Total Energy Input		Total Energy Output		Heat Pump C.O.P.		Duct Losses		Energy Delivered To/Extracted From Conditioned Space		System C.O.P.	
		Heat	Cool	Heat	Cool	Heat	Cool	Heat	Heat	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool
	BASE	214	76	40	5	20	9	11	63	348	90	652	173	1.87	1.92	59	9	593	165	1.70	1.83		
1.	Compressor Efficiency = .60	157	56	40	5	20	9	8	63	288	70	652	173	2.26	2.47	59	9	593	165	2.06	2.36		
2.	Compressor Efficiency = .80	118	42	40	5	20	9	6	63	247	56	652	173	2.64	3.09	59	9	593	165	2.40	2.95		
3.	Compressor Efficiency = 1.00	94	33	40	5	20	9	5	63	222	47	652	173	2.94	3.68	59	9	593	165	2.67	3.51		
4.	Outdoor Coil Effectiveness = .80	193	68	40	5	20	9	10	63	326	82	652	173	2.00	2.11	59	9	593	165	1.82	2.01		
5.	Outdoor Coil Effectiveness = .90	171	61	40	5	20	9	9	63	303	75	652	173	2.15	2.31	59	9	593	165	1.96	2.20		
6.	Outdoor Coil Effectiveness = 1.00	154	55	40	5	20	9	8	63	285	69	652	173	2.29	2.51	59	9	593	165	2.08	2.39		
7.	Indoor Coil Effectiveness = .95	200	71	40	5	20	9	10	63	333	85	652	173	1.96	2.04	59	9	593	165	1.78	1.94		
8.	Indoor Coil Effectiveness = 1.0	190	68	40	5	20	9	10	63	323	82	652	173	2.02	2.11	59	9	593	165	1.84	2.01		
9.	Fan Efficiency = .85	214	76	32	4	16	7	11	63	336	87	652	173	1.94	1.99	59	9	593	165	1.76	1.90		
10.	Fan Efficiency = 1.0	214	76	27	3	14	6	11	63	329	85	652	173	1.98	2.04	59	9	593	165	1.80	1.94		
11.	Compressor Motor Efficiency = 1.0	205	73	40	5	20	9	11	63	339	87	652	173	1.92	1.99	59	9	593	165	1.75	1.90		
12.	Ducts Entirely in Conditioned Space	200	73	37	4	19	9	10	47	313	86	593	165	1.89	1.92	0	0	593	165	1.89	1.92		

TABLE V-46. HOUSTON (SFA) HEAT PUMP STRATEGY/COMPONENT MATRIX

Strategies	Compressor Energy Input		Condenser Fan Energy Input		Evaporator Fan Energy Input		Defrost Cycle Energy Input	Resistance Heat Energy Input	Total Energy Input		Total Energy Output		Heat Pump C.O.P.		Duct Losses		Energy Delivered To/ Extracted From Conditioned Space		System C.O.P.	
	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Heat	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool
BASE	20	251	3	15	2	30	1	0	26	296	61	573	2.31	1.94	6	27	55	546	2.12	1.84
1. Compressor Efficiency = .60	15	184	3	15	2	30	1	0	21	229	61	573	2.90	2.50	6	27	55	546	2.62	2.38
2. Compressor Efficiency = .80	11	138	3	15	2	30	1	0	17	183	61	573	3.59	3.13	6	27	55	546	3.24	2.98
3. Compressor Efficiency = 1.00	9	110	3	15	2	30	1	0	15	155	61	573	4.07	3.70	6	27	55	546	3.67	3.52
4. Outdoor Coil Effectiveness = .80	18	226	3	15	2	30	1	0	24	271	61	573	2.54	2.11	6	27	55	546	2.29	2.01
5. Outdoor Coil Effectiveness = .90	16	201	3	15	2	30	1	0	22	246	61	573	2.77	2.33	6	27	55	546	2.50	2.22
6. Outdoor Coil Effectiveness = 1.00	14	181	3	15	2	30	1	0	20	226	61	573	3.05	2.54	6	27	55	546	2.75	2.42
7. Indoor Coil Effectiveness = .95	19	235	3	15	2	30	1	0	25	280	61	573	2.44	2.05	6	27	55	564	2.20	1.95
8. Indoor Coil Effectiveness = 1.0	18	223	3	15	2	30	1	0	24	268	61	573	2.54	2.14	6	27	55	546	2.29	2.04
9. Fan Efficiency = .85	20	251	2	12	2	24	1	0	25	287	61	573	2.44	2.00	6	27	55	546	2.20	1.90
10. Fan Efficiency = 1.0	20	251	2	10	1	20	1	0	23	281	61	573	2.65	2.04	6	27	55	546	2.39	1.94
11. Compressor Motor Efficiency = 1.0	19	241	3	15	2	30	1	0	25	286	61	573	2.44	2.00	6	27	55	546	2.20	1.91
12. Ducts Entirely in Conditioned Space	18	238	3	14	2	29	1	0	24	281	55	546	2.33	1.94	0	0	55	546	2.33	1.94

TABLE V-47. BALTIMORE (MFLR) HEAT PUMP STRATEGY/COMPONENT MATRIX

Strategies	Components	Compressor Energy Input		Condenser Fan Energy Input		Evaporator Fan Energy Input		Defrost Cycle Energy Input		Resistance Heat Energy Input		Total Energy Input		Total Energy Output		Heat Pump C.O.P.		Duct Losses		Energy Delivered To/Extracted From Conditioned Space		System C.O.P.	
		Heat	Cool	Heat	Cool	Heat	Cool	Heat	Heat	Heat	Heat	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool
BASE		72	74	13	4	7	9	5	0	97	87	210	169	2.16	1.94	19	8	191	161	1.97	1.85		
1. Compressor Efficiency = .60		53	54	13	4	7	9	4	0	77	67	210	169	2.73	2.52	19	8	191	161	2.48	2.40		
2. Compressor Efficiency = .80		40	41	13	4	7	9	3	0	63	54	210	169	3.33	3.13	19	8	191	161	3.03	2.98		
3. Compressor Efficiency = 1.00		32	33	13	4	7	9	2	0	54	46	210	169	3.89	3.67	19	8	191	161	3.54	3.50		
4. Outdoor Coil Effectiveness = .80		65	67	13	4	7	9	5	0	90	80	210	169	2.33	2.11	19	8	191	161	2.12	2.01		
5. Outdoor Coil Effectiveness = .90		58	59	13	4	7	9	4	0	82	72	210	169	2.56	2.35	19	8	191	161	2.33	2.24		
6. Outdoor Coil Effectiveness = 1.00		52	53	13	4	7	9	4	0	76	66	210	169	2.76	2.56	19	8	191	161	2.51	2.44		
7. Indoor Coil Effectiveness = .95		67	69	13	4	7	9	5	0	92	82	210	169	2.28	2.06	19	8	191	161	2.08	1.96		
8. Indoor Coil Effectiveness = 1.0		64	66	13	4	7	9	4	0	88	79	210	169	2.39	2.14	19	8	191	161	2.17	2.04		
9. Fan Efficiency = .85		72	74	10	3	6	7	5	0	93	84	210	169	2.26	2.01	19	8	191	161	2.05	1.92		
10. Fan Efficiency = 1.0		72	74	9	3	5	6	5	0	91	83	210	169	2.31	2.04	19	8	191	161	2.10	1.94		
11. Compressor Motor Efficiency = 1.0		69	71	13	4	7	9	5	0	94	84	210	169	2.23	2.01	19	8	191	161	2.03	1.92		
12. Ducts Entirely in Conditioned Space		66	70	12	4	6	5	5	0	89	83	191	161	2.15	1.94	0	0	191	161	2.15	1.94		

TABLE V-48. CHICAGO (MFLR) HEAT PUMP STRATEGY/COMPONENT MATRIX

Strategies	Components	Compressor Energy Input		Condenser Fan Energy Input		Evaporator Fan Energy Input		Defrost Cycle Energy Input		Resistance Heat Energy Input		Total Energy Input		Total Energy Output		Heat Pump C.O.P.		Duct Losses		Energy Delivered To/Extracted From Conditioned Space		System C.O.P.	
		Heat	Cool	Heat	Cool	Heat	Cool	Heat	Heat	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool
BASE		124	65	24	4	12	8	7	8	175	77	344	149	1.96	1.94	31	7	313	142	1.79	1.84		
1. Compressor Efficiency = .60		91	48	24	4	12	8	5	8	140	60	344	149	2.46	2.48	31	7	313	142	2.24	2.37		
2. Compressor Efficiency = .80		68	36	24	4	12	8	4	8	116	48	344	194	2.97	3.10	31	7	313	142	2.70	2.96		
3. Compressor Efficiency = 1.00		55	29	24	4	12	8	3	8	102	41	344	149	3.37	3.63	31	7	313	142	3.07	3.46		
4. Outdoor Coil Effectiveness = .80		112	58	24	4	12	8	6	8	162	70	344	149	2.12	2.13	31	7	313	142	1.93	2.03		
5. Outdoor Coil Effectiveness = .90		99	52	24	4	12	8	6	8	149	64	344	149	2.31	2.33	31	7	313	142	2.10	2.22		
6. Outdoor Coil Effectiveness = 1.00		89	47	24	4	12	8	5	8	138	59	344	149	2.49	2.53	31	7	313	142	2.27	2.41		
7. Indoor Coil Effectiveness = .95		116	61	24	4	12	8	7	8	167	73	344	149	2.06	2.04	31	7	313	142	1.87	1.95		
8. Indoor Coil Effectiveness = 1.0		110	58	24	4	12	8	6	8	160	70	344	149	2.15	2.13	31	7	313	142	1.96	2.03		
9. Fan Efficiency = .85		124	65	19	3	10	6	7	8	168	74	344	149	2.05	2.01	31	7	313	142	1.86	1.92		
10. Fan Efficiency = 1.0		124	65	17	3	8	6	7	8	164	74	344	149	2.10	2.01	31	7	313	142	1.91	1.92		
11. Compressor Motor Efficiency = 1.0		119	62	24	4	12	8	7	8	170	76	344	149	2.02	1.96	31	7	313	142	1.84	1.87		
12. Ducts Entirely in Conditioned Space		112	61	23	4	11	8	6	6	158	73	313	142	1.98	1.94	0	0	313	142	1.98	1.94		

TABLE V-49. HOUSTON (MFLR) HEAT PUMP STRATEGY/COMPONENT MATRIX

Strategies	Components	Compressor Energy Input		Condenser Fan Energy Input		Evaporator Fan Energy Input		Defrost Cycle Energy Input		Resistance Heat Energy Input		Total Energy Input		Total Energy Output		Heat Pump C.O.P.		Duct Losses		Energy Delivered To/ Extracted From Conditioned Space		System C.O.P.	
		Heat	Cool	Heat	Cool	Heat	Cool	Heat	Heat	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool	Heat	Cool
BASE		6.5	174	1.1	11	0.6	21	0.3	0	8.5	206	20.7	399	2.44	1.94	0.8	19	19.9	380	2.34	1.84		
1. Compressor Efficiency = .60		4.8	128	1.1	11	0.6	21	0.2	0	6.7	160	20.7	399	3.09	2.49	0.8	19	19.9	380	2.97	2.37		
2. Compressor Efficiency = .80		3.6	96	1.1	11	0.6	21	0.2	0	5.5	128	20.7	399	3.76	3.12	0.8	19	19.9	380	3.62	2.97		
3. Compressor Efficiency = 1.00		2.9	77	1.1	11	0.6	21	0.1	0	4.7	109	20.7	399	4.40	3.66	0.8	19	19.9	380	4.23	3.49		
4. Outdoor Coil Effectiveness = .80		5.8	157	1.1	11	0.6	21	0.3	0	7.8	189	20.7	399	2.65	2.11	0.8	19	19.9	380	2.55	2.01		
5. Outdoor Coil Effectiveness = .90		5.2	139	1.1	11	0.6	21	0.2	0	7.1	171	20.7	399	2.92	2.33	0.8	19	19.9	380	2.80	2.22		
6. Outdoor Coil Effectiveness = 1.00		4.7	125	1.1	11	0.6	21	0.2	0	6.6	165	20.7	399	3.14	2.42	0.8	19	19.9	380	3.02	2.30		
7. Indoor Coil Effectiveness = .95		6.1	163	1.1	11	0.6	21	0.3	0	8.1	195	20.7	399	2.56	2.05	0.8	19	19.9	380	2.46	1.95		
8. Indoor Coil Effectiveness = 1.0		5.8	155	1.1	11	0.6	21	0.3	0	7.8	187	20.7	399	2.65	2.13	0.8	19	19.9	380	2.55	2.03		
9. Fan Efficiency = .85		6.5	174	0.9	9	0.5	17	0.3	0	8.2	200	20.7	399	2.52	1.99	0.8	19	19.9	380	2.43	1.90		
10. Fan Efficiency = 1.0		6.5	174	0.7	7	0.4	14	0.3	0	7.9	195	20.7	399	2.62	2.05	0.8	19	19.9	380	2.52	1.95		
11. Compressor Motor Efficiency = 1.0		6.2	167	1.1	11	0.6	21	0.3	0	8.2	199	20.7	399	2.52	2.01	0.8	19	19.9	380	2.43	1.91		
12. Ducts Entirely in Conditioned Space		6.4	166	1.1	10	0.5	20	0.3	0	8.3	196	19.9	380	2.40	1.94	0	0	19.9	380	2.40	1.94		

TABLE V-50. SAVINGS AS A RESULT OF EACH STRATEGY: HEAT PUMP, HEATING MODE

	Savings in Therms								
	Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
Compressor Efficiency = .6	59	45	20	85	60	35	9	5	1.8
Compressor Efficiency = .8	100	74	34	143	101	59	14	9	3.0
Compressor Efficiency = 1.0	126	93	43	178	126	73	18	11	3.8
Outdoor Coil Effectiveness = .8	21	17	7	33	22	13	3	2	0.7
Outdoor Coil Effectiveness = .9	44	33	15	64	45	26	6	4	1.4
Outdoor Coil Effectiveness = 1.0	62	47	21	89	63	37	9	6	1.9
Indoor Coil Effectiveness = .95	14	11	5	21	15	8	2	1	0.4
Indoor Coil Effectiveness = 1.0	24	18	9	36	25	15	4	2	0.7
Fan Efficiency = .85	8	9	4	13	12	7	1	1	0.3
Fan Efficiency = 1.0	13	13	6	21	19	11	2	3	0.6
Compressor Motor Efficiency = 1.0	8	6	3	14	9	5	1	1	0.3
Ducts in Conditioned Space	30	22	8	54	35	17	3	2	0.2

TABLE V-51. AIR CONDITIONING STRATEGY/COMPONENT MATRIX*

			Compressor	Condensor Fan	Evaporator Fan	Total	Total	Air Conditioner	Duct	Heat Extracted	System
			Energy Input	Energy Input	Energy Input	Energy Input	Cooling Output	C.O.P.	Losses	From Conditioned Space	C.O.P.
Base	Baltimore	SFD	82	4	8	94	188	1.99	9	179	1.90
		SFA	88	6	11	105	209	1.99	10	199	1.90
		MFLR	72	4	9	85	169	1.99	8	161	1.89
	Chicago	SFD	65	3	6	74	147	1.99	7	140	1.89
		SFA	73	5	9	87	173	1.99	9	165	1.90
		MFLR	69	2	4	75	149	1.99	7	142	1.89
	Houston	SFD	281	11	22	314	625	1.99	62	563	1.79
		SFA	243	15	30	288	573	1.99	27	546	1.90
		MFLR	169	11	21	201	399	1.99	19	380	1.89
Ducts In Conditioned Space	Baltimore	SFD	78	4	8	90	179	1.99	0	179	1.99
		SFA	84	5	11	100	199	1.99	0	199	1.99
		MFLR	68	4	9	81	161	1.99	0	161	1.99
	Chicago	SFD	61	3	6	70	140	1.99	0	140	1.99
		SFA	70	4	9	83	165	1.99	0	165	1.99
		MFLR	59	4	8	71	142	1.99	0	142	1.99
	Houston	SFD	253	10	20	283	563	1.99	0	563	1.99
		SFA	231	14	29	274	546	1.99	0	546	1.99
		MFLR	161	10	20	191	380	1.99	0	380	1.99
Fan Efficiency = .85	Baltimore	SFD	82	3	6	91	188	2.07	9	179	1.97
		SFA	88	5	9	102	209	2.05	10	199	1.95
		MFLR	72	3	7	82	169	2.06	8	161	1.96
	Chicago	SFD	65	2	5	72	147	2.04	7	140	1.94
		SFA	73	4	7	84	173	2.06	9	165	1.96
		MFLR	69	2	3	74	149	2.01	7	142	1.92
	Houston	SFD	281	9	18	308	625	2.03	62	563	1.83
		SFA	243	12	24	279	573	2.05	27	546	1.96
		MFLR	169	9	17	195	399	2.05	19	380	1.95
Fan Efficiency = 1.0	Baltimore	SFD	82	3	5	90	188	2.09	9	179	1.99
		SFA	88	4	7	99	209	2.11	10	199	2.01
		MFLR	72	3	6	81	169	2.09	8	161	1.99
	Chicago	SFD	65	2	4	71	147	2.07	7	140	1.97
		SFA	73	3	6	82	173	2.11	9	165	2.01
		MFLR	69	1	3	73	149	2.04	7	142	1.95
	Houston	SFD	281	7	15	303	625	2.06	62	563	1.86
		SFA	243	10	20	273	573	2.10	27	546	2.00
		MFLR	169	7	14	190	399	2.10	19	380	2.00
Compressor Motor Efficiency = 1.0	Baltimore	SFD	79	4	8	91	188	2.07	9	179	1.97
		SFA	84	6	11	101	209	2.07	10	199	1.97
		MFLR	69	4	9	82	169	2.06	8	161	1.96
	Chicago	SFD	62	3	6	71	147	2.07	7	140	1.97
		SFA	70	5	9	84	173	2.06	9	165	1.96
		MFLR	66	2	4	72	149	2.07	7	142	1.97
	Houston	SFD	270	11	22	303	625	2.06	62	563	1.86
		SFA	233	15	30	278	573	2.06	27	546	1.96
		MFLR	162	11	21	194	399	2.06	19	380	1.96

*All strategies other than those listed here are the same as the cooling mode for the heat pump.

TABLE V-52. SAVINGS AS A RESULT OF EACH STRATEGY: CENTRAL AIR CONDITIONING

	Savings in Therms								
	Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
Compressor Efficiency = .6	20	21	18	16	17	15	68	59	41
Compressor Efficiency = .8	35	38	31	28	31	27	121	105	73
Compressor Efficiency = 1.0	45	48	39	36	40	34	153	133	92
Outdoor Coil Effectiveness = .8	5	6	5	5	5	5	20	17	12
Outdoor Coil Effectiveness = .9	14	15	13	11	12	11	49	42	30
Outdoor Coil Effectiveness = 1.0	21	22	19	17	18	16	72	62	36
Indoor Coil Effectiveness = .95	2	3	3	2	2	2	9	8	6
Indoor Coil Effectiveness = 1.0	6	7	6	5	5	5	23	20	14
Fan Efficiency = .85	3	3	3	2	3	1	6	9	6
Fan Efficiency = 1.0	4	6	4	3	5	2	11	15	11
Compressor Motor Efficiency = 1.0	3	4	3	3	3	3	11	10	7
Ducts in Conditioned Space	4	5	4	4	4	4	31	14	10

TABLE V-53. SAVINGS AS A RESULT OF EACH STRATEGY: HEAT PUMP, COOLING MODE

	Savings in Therms								
	Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
Compressor Efficiency = .6	23	24	20	18	20	17	77	67	46
Compressor Efficiency = .8	38	41	33	30	34	29	130	113	78
Compressor Efficiency = 1.0	48	51	41	38	43	36	162	141	97
Outdoor Coil Effectiveness = .8	8	9	7	7	8	7	29	25	17
Outdoor Coil Effectiveness = .9	17	18	15	13	15	13	58	50	35
Outdoor Coil Effectiveness = 1.0	24	25	21	19	21	18	81	70	41
Indoor Coil Effectiveness = .95	5	6	5	4	5	4	18	16	11
Indoor Coil Effectiveness = 1.0	9	10	8	7	8	7	32	28	19
Fan Efficiency = .85	3	3	3	2	3	3	6	9	6
Fan Efficiency = 1.0	4	6	4	3	5	3	11	15	11
Compressor Motor Efficiency = 1.0	3	4	3	3	3	1	12	10	7
Ducts in Conditioned Space	5	5	4	3	4	4	31	15	10

TABLE V-54. SAVINGS AS A RESULT OF EACH STRATEGY: HEAT PUMP, HEATING AND COOLING

	Savings in Therms								
	Baltimore			Chicago			Houston		
	SFD	SFA	MFLR	SFD	SFA	MFLR	SFD	SFA	MFLR
Compressor Efficiency = .6	82	69	40	103	80	52	86	72	48
Compressor Efficiency = .8	138	115	67	173	135	88	144	122	81
Compressor Efficiency = 1.0	174	144	84	216	169	109	180	152	101
Outdoor Coil Effectiveness = .8	29	26	14	40	30	20	32	27	18
Outdoor Coil Effectiveness = .9	61	51	30	77	60	39	64	54	36
Outdoor Coil Effectiveness = 1.0	86	72	42	108	84	55	90	76	43
Indoor Coil Effectiveness = .95	19	17	10	25	20	12	20	17	11
Indoor Coil Effectiveness = 1.0	33	28	17	43	33	22	36	30	20
Fan Efficiency = .85	11	12	7	15	15	10	7	10	6
Fan Efficiency = 1.0	17	19	10	24	24	14	13	18	12
Compressor Motor Efficiency = 1.0	11	10	6	17	12	26	13	11	7
Ducts in Conditioned Space	35	27	12	57	39	21	34	17	10

D. Economic Analysis

The purpose of this section is to provide a tool for determining the maximum initial cost of any new or retrofit energy conserving feature for residences. Since many of the energy conserving features considered are beyond today's technology, with their associated costs unknown, a slightly different approach to payback period must be taken.

The payback period in this analysis is the period of time over which fuel prices are considered. The cost of fuel is averaged over the payback period, and the cost of the energy conserving item is then balanced against its resultant savings to determine the maximum allowable cost of the item. It is assumed that the cost of the energy conserving item is covered by a loan (over any period of time and at any interest rate) which will be repaid in equal monthly installments.

The equation for finding the maximum allowable cost of an energy conserving item is given by:

$$C_{\max} = \frac{1000 \times S}{12 \times M} \times \frac{\sum_{N=1}^P [F (E)^{N-1}]}{P} \quad (1)$$

where

$C_{\max}$ is the maximum allowable cost of the energy conserving item

S is the savings in therms/year resulting from the energy conserving item

M is the monthly payment per \$1000 borrowed (found in standard financial tables)

F is the current or base cost of fuel in dollars/therms

E is the fuel escalation rate

P is the period over which fuel prices are being considered.

NOTE: S and F may be in terms of the units of a particular type of fuel. For example, S may be in gallons of oil per year and F in dollars per gallon of oil, but one of the two terms may not have units of a particular fuel and the other have units of therms.

An inaccuracy inherent in equation (1) is that a summation method allows fuel prices to rise only once a year. To be more accurate, fuel rates should be allowed to rise continuously over the entire year. (In fact, fuel rates rise in discrete steps, but their behavior is more closely approximated by a continuous curve than by a one-year step.) The continuous form of equation (1) would be:

$$C_{\max} = \frac{1000 \times S}{12 \times M} \times \frac{\int_0^P [F \times E^n] dn}{P} \quad (2)$$

Evaluating the integral gives:

$$C_{\max} = \frac{1000 \times S \times F \times (E^P - 1)}{12 \times M \times P \times \ln E} \quad (3)$$

Notice that the solution from equation (3) would show that if a one-year period were examined, fuel costs would be higher at the end of the year than at the beginning, resulting in a slightly higher $C_{\max}$ than in equation (1), which assumes that fuel costs would be the same at the end of the first year as at the beginning.

Equation (3) is applicable to both new and retrofit cases, if proper interpretation is given to two variables, M and $C_{\max}$. As mentioned above, M is the monthly payment per \$1000 borrowed. This will obviously change depending on the number of months of the loan and the interest rate. Since retrofit measures would typically be financed by a shorter term, higher interest loan than new construction, M will typically be larger for retrofit installations than for new installations, resulting in a lower $C_{\max}$ for retrofit than new construction. $C_{\max}$ may have to be interpreted differently for retrofit than for new construction depending on the circumstance. In new construction, $C_{\max}$ can almost always be interpreted as the incremental cost of the energy conserving feature over the base case. For example, when considering the possibility of the installation of a high-efficiency furnace instead of a base furnace, $C_{\max}$ would be the difference in cost between the base furnace and the high efficiency furnace. But in the case of retrofit, $C_{\max}$ would be the total cost of the high efficiency furnace less any salvage value of the old furnace. If the furnace must be replaced anyway, then the retrofit case would be the same as the new construction case, i.e., $C_{\max}$ would be the difference in cost between the base and high efficiency furnace.

In tables V-56 through V-64, for illustrative purposes, equation (3) has been solved assigning the following values:

P = 10 years

E = 1.05 percent per year

M = \$21.75/month for retrofit*

M = \$8.05/month for new construction**

Table V-55 shows the present cost of various fuels (F) in each city.

TABLE V-55. COST OF FUEL - \$/THERM

	<u>Gas</u>	<u>Oil</u>	<u>Electricity</u>
Baltimore	.22	.33	1.07
Chicago	.19	.34	1.16
Houston	.31	-	.71

* Retrofit assumes 11 percent loan for five years.

** New construction assumes nine percent loan for 30 years.

TABLE V-56. BALTIMORE (SFD) MAXIMUM ALLOWABLE COST
OF IMPLEMENTATION OF ENERGY CONSERVATION STRATEGIES

STRATEGIES	GAS FURNACE		OIL FURNACE		ELECTRIC FURNACE		HEAT PUMP*		CENTRAL AIR CONDITIONING	
	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT
Electronic Ignition	117	43								
Outside Preheated Combustion and Dilution Air	114	42	122	45						
Automatic Flue Damper	105	39	169	63						
13% Excess Air	9	3	17	6						
Furnace Sized for 25% above Peak Load	87	32	26	10						
Furnace Sized for Peak Load	133	49	30	11						
Better Insulated Ducts with Less Leakage	83	31	117	43	385	142				
Ducts Entirely in Conditioned Space	170	63	239	88	784	290	499	185	57	21
Upper Limit Efficiency Non-Condensing Furnace with Electronic Ignition	448	166	422	156						
Condensing Furnace with Electronic Ignition	677	251	726	269						
Smaller Fan with Lower Fan Shut Off Temperature	74	27	104	39						
Compressor Efficiency = .60							1169	433	285	106
Compressor Efficiency = .80							1967	728	499	185
Compressor Efficiency = 1.00							2480	918	641	237
Outdoor Coil Effectiveness = .80							413	153	71	26
Outdoor Coil Effectiveness = .90							870	322	200	74
Outdoor Coil Effectiveness = 1.00							1226	454	299	111
Indoor Coil Effectiveness = .95							271	100	29	11
Indoor Coil Effectiveness = 1.00							470	174	86	32
Fan Efficiency = .85							157	58	43	16
Fan Efficiency = 1.00							242	90	57	21
Compressor Motor Efficiency = 1.00							156	58	43	16

*Includes savings in both heating and cooling modes.

TABLE V-57. CHICAGO (SFD) MAXIMUM ALLOWABLE
COST OF IMPLEMENTATION OF ENERGY CONSERVATION STRATEGIES

STRATEGIES	GAS FURNACE		OIL FURNACE		ELECTRIC FURNACE		HEAT PUMP*		CENTRAL AIR CONDITIONING	
	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT
Electronic Ignition	109	40								
Outside Preheated Combustion and Dilution Air	155	57	203	75						
Automatic Flue Damper	190	70	303	112						
13% Excess Air	18	7	27	10						
Furnace Sized for 25% above Peak Load	129	48	59	22						
Furnace Sized for Peak Load	162	60	77	28						
Better Insulated Ducts with Less Leakage	106	39	185	69	651	241				
Ducts Entirely in Conditioned Space	205	76	366	135	1255	464	883	327	62	23
Upper Limit Efficiency Non-Condensing Furnace with Electronic Ignition	509	189	660	244						
Condensing Furnace with Electronic Ignition	793	294	1116	413						
Smaller Fan with Lower Fan Shut Off Temperature	157	58	190	70						
Compressor Efficiency = .60							1595	590	248	92
Compressor Efficiency = .80							2680	992	434	161
Compressor Efficiency = 1.00							3346	1238	558	206
Outdoor Coil Effectiveness = .80							620	229	77	29
Outdoor Coil Effectiveness = .90							1193	441	170	63
Outdoor Coil Effectiveness = 1.00							1673	619	263	97
Indoor Coil Effectiveness = .95							387	143	31	11
Indoor Coil Effectiveness = 1.00							666	247	77	29
Fan Efficiency = .85							232	86	31	11
Fan Efficiency = 1.00							372	138	46	17
Compressor Motor Efficiency = 1.00							263	97	46	17

*Includes savings in both heating and cooling modes.

TABLE V-58. HOUSTON (SFD) MAXIMUM ALLOWABLE
COST OF IMPLEMENTATION OF ENERGY CONSERVATION STRATEGIES

STRATEGIES	GAS FURNACE		OIL FURNACE		ELECTRIC FURNACE		HEAT PUMP*		CENTRAL AIR CONDITIONING	
	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT
Electronic Ignition	111	41								
Outside Preheated Combustion and Dilution Air	29	11								
Automatic Flue Damper	37	14								
13% Excess Air	4	2								
Furnace Sized for 25% above Peak Load	21	8								
Furnace Sized for Peak Load	21	8								
Better Insulated Ducts with Less Leakage	16	6								
Ducts Entirely in Conditioned Space	33	12								
Upper Limit Efficiency Non-Condensing Furnace with Electronic Ignition	169	63								
Condensing Furnace with Electronic Ignition	214	79								
Smaller Fan with Lower Fan Shut Off Temperature	12	5								
Compressor Efficiency = .60							907	336	717	265
Compressor Efficiency = .80							1518	562	1276	472
Compressor Efficiency = 1.00							1898	703	1613	597
Outdoor Coil Effectiveness = .80							337	125	211	78
Outdoor Coil Effectiveness = .90							675	250	517	191
Outdoor Coil Effectiveness = 1.00							949	351	759	281
Indoor Coil Effectiveness = .95							211	78	95	35
Indoor Coil Effectiveness = 1.00							380	141	243	90
Fan Efficiency = .85							74	27	63	23
Fan Efficiency = 1.00							137	51	116	43
Compressor Motor Efficiency = 1.00							137	51	116	43

* Includes savings in both heating and cooling mode.

TABLE V-59. BALTIMORE (SFA) MAXIMUM ALLOWABLE
COST OF IMPLEMENTATION OF ENERGY CONSERVATION STRATEGIES

STRATEGIES	GAS FURNACE		OIL FURNACE		ELECTRIC FURNACE		HEAT PUMP*		CENTRAL AIR CONDITIONING	
	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT
Electronic Ignition	117	43								
Outside Preheated Combustion and Dilution Air	90	33	87	42						
Automatic Flue Damper	93	34	100	48						
13% Excess Air	6	2	23	11						
Furnace Sized for 25% above Peak Load	62	23	20	10						
Furnace Sized for Peak Load	83	31	43	21						
Better Insulated Ducts with Less Leakage	65	24	74	35	299	111				
Ducts Entirely in Conditioned Space	130	48	144	69	599	222	385	142	71	26
Upper Limit Efficiency Non-Condensing Furnace with Electronic Ignition	380	141	261	126						
Condensing Furnace with Electronic Ignition	516	191	442	212						
Smaller Fan with Lower Fan Shut Off Temperature	28	10	50	24						
Compressor Efficiency = .60							984	364	299	111
Compressor Efficiency = .80							1639	607	542	200
Compressor Efficiency = 1.00							2053	760	684	253
Outdoor Coil Effectiveness = .80							371	137	86	32
Outdoor Coil Effectiveness = .90							727	269	214	79
Outdoor Coil Effectiveness = 1.00							1026	380	314	116
Indoor Coil Effectiveness = .95							242	90	43	16
Indoor Coil Effectiveness = 1.00							399	148	100	37
Fan Efficiency = .85							171	63	43	16
Fan Efficiency = 1.00							271	100	86	32
Compressor Motor Efficiency = 1.00							143	53	57	21

*Includes savings in both heating and cooling modes.

TABLE V-60. CHICAGO (SFA) MAXIMUM ALLOWABLE
COST OF IMPLEMENTATION OF ENERGY CONSERVATION STRATEGIES

STRATEGIES	GAS FURNACE		OIL FURNACE		ELECTRIC FURNACE		HEAT PUMP*		CENTRAL AIR CONDITIONING	
	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT
Electronic Ignition	106	39								
Outside Preheated Combustion and Dilution Air	122	45	163	60						
Automatic Flue Damper	132	49	208	77						
13% Excess Air	10	4	23	8						
Furnace Sized for 25% above Peak Load	117	43	45	17						
Furnace Sized for Peak Load	139	52	54	20						
Better Insulated Ducts with Less Leakage	76	28	136	50	465	172				
Ducts Entirely in Conditioned Space	150	55	267	99	914	338	604	224	62	23
Upper Limit Efficiency Non-Condensing Furnace with Electronic Ignition	375	139	723	268						
Condensing Furnace with Electronic Ignition	565	209	1057	391						
Smaller Fan with Lower Fan Shut Off Temperature	91	34	117	43						
Compressor Efficiency = .60							1239	459	263	97
Compressor Efficiency = .80							2091	774	480	178
Compressor Efficiency = 1.00							2618	969	620	229
Outdoor Coil Effectiveness = .80							465	172	77	29
Outdoor Coil Effectiveness = .90							929	344	186	69
Outdoor Coil Effectiveness = 1.00							1301	482	279	103
Indoor Coil Effectiveness = .95							310	115	31	11
Indoor Coil Effectiveness = 1.00							511	189	77	29
Fan Efficiency = .85							232	86	46	17
Fan Efficiency = 1.00							372	138	77	29
Compressor Motor Efficiency = 1.00							186	69	46	17

*Includes savings in both heating and cooling modes.

TABLE V-61. HOUSTON (SFA) MAXIMUM ALLOWABLE COST OF
IMPLEMENTATION OF ENERGY CONSERVATION STRATEGIES

STRATEGIES	GAS FURNACE		OIL FURNACE		ELECTRIC FURNACE		HEAT PUMP*		CENTRAL AIR CONDITIONING	
	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT
Electronic Ignition	107	40								
Outside Preheated Combustion and Dilution Air	25	9	NO							
Automatic Flue Damper	21	8	OIL							
13% Excess Air	0	0	FURNACES							
Furnace Sized for 25% above Peak Load	8	3	IN							
Furnace Sized for Peak Load	16	6	HOUSTON							
Better Insulated Ducts with Less Leakage	12	5	(REF. 68)		32	12				
Ducts Entirely in Conditioned Space	25	9			63	23	179	66	148	55
Upper Limit Efficiency Non-Condensing Furnace with Electronic Ignition	148	55								
Condensing Furnace with Electronic Ignition	181	67								
Smaller Fan with Lower Fan Shut Off Temperature	8	3								
Compressor Efficiency = .60							759	281	622	230
Compressor Efficiency = .80							1286	476	1107	410
Compressor Efficiency = 1.00							1603	593	1402	519
Outdoor Coil Effectiveness = .80							285	105	179	66
Outdoor Coil Effectiveness = .90							569	211	443	164
Outdoor Coil Effectiveness = 1.00							801	297	654	242
Indoor Coil Effectiveness = .95							179	66	84	31
Indoor Coil Effectiveness = 1.00							316	117	211	78
Fan Efficiency = .85							105	39	95	35
Fan Efficiency = 1.00							190	70	158	59
Compressor Motor Efficiency = 1.00							116	43	105	39

* Includes savings in both heating and cooling modes.

TABLE V-62. BALTIMORE (MFLR) MAXIMUM ALLOWABLE
COST OF IMPLEMENTATION OF ENERGY CONSERVATION STRATEGIES

STRATEGIES	GAS FURNACE		OIL FURNACE		ELECTRIC FURNACE		HEAT PUMP*		CENTRAL AIR CONDITIONING	
	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT
Electronic Ignition	127	47								
Outside Preheated Combustion and Dilution Air	62	23	65	24						
Automatic Flue Damper	53	19	65	24						
13% Excess Air	9	3	9	3						
Furnace Sized for 25% above Peak Load	28	10	22	8						
Furnace Sized for Peak Load	49	18	30	11						
Better Insulated Ducts with Less Leakage	34	13	48	18	157	58				
Ducts Entirely in Conditioned Space	62	23	87	32	285	105	171	63	57	21
Upper Limit Efficiency Non-Condensing Furnace with Electronic Ignition	241	89	143	53						
Condensing Furnace with Electronic Ignition	318	118	252	93						
Smaller Fan with Lower Fan Shut Off Temperature	22	8	22	8						
Compressor Efficiency = .60							570	211	257	95
Compressor Efficiency = .80							955	353	442	164
Compressor Efficiency = 1.00							1197	443	556	206
Outdoor Coil Effectiveness = .80							200	74	71	26
Outdoor Coil Effectiveness = .90							428	158	185	69
Outdoor Coil Effectiveness = 1.00							599	222	271	100
Indoor Coil Effectiveness = .95							143	53	43	16
Indoor Coil Effectiveness = 1.00							242	90	86	32
Fan Efficiency = .85							100	37	43	16
Fan Efficiency = 1.00							143	53	57	21
Compressor Motor Efficiency = 1.00							86	32	43	16

*Includes savings in both heating and cooling modes.

TABLE V-63. CHICAGO (MFLR) MAXIMUM ALLOWABLE COST OF IMPLEMENTATION OF ENERGY CONSERVATION STRATEGIES

STRATEGIES	GAS FURNACE		OIL FURNACE		ELECTRIC FURNACE		HEAT PUMP*		CENTRAL AIR CONDITIONING	
	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT
Electronic Ignition	114	42								
Outside Preheated Combustion and Dilution Air	91	34	127	47						
Automatic Flue Damper	86	32	131	48						
13% Excess Air	8	3	54	20						
Furnace Sized for 25% above Peak Load	56	21	36	13						
Furnace Sized for Peak Load	76	28	54	20						
Better Insulated Ducts with Less Leakage	41	15	72	27	248	92				
Ducts Entirely in Conditioned Space	79	29	140	52	480	178	325	120	62	23
Upper Limit Efficiency Non-Condensing Furnace with Electronic Ignition	261	97	258	95						
Condensing Furnace with Electronic Ignition	367	136	438	162						
Smaller Fan with Lower Fan Shut Off Temperature	35	13	50	18						
Compressor Efficiency = .60							805	298	232	86
Compressor Efficiency = .80							1363	505	418	155
Compressor Efficiency = 1.00							1688	625	527	195
Outdoor Coil Effectiveness = .80							310	115	77	29
Outdoor Coil Effectiveness = .90							604	224	170	63
Outdoor Coil Effectiveness = 1.00							852	315	248	92
Indoor Coil Effectiveness = .95							186	69	31	11
Indoor Coil Effectiveness = 1.00							341	126	77	29
Fan Efficiency = .85							155	57	15	6
Fan Efficiency = 1.00							217	80	31	11
Compressor Motor Efficiency = 1.00							403	149	46	17

*Includes savings in both heating and cooling modes

TABLE V-64. HOUSTON (MFLR) MAXIMUM ALLOWABLE
COST OF IMPLEMENTATION OF ENERGY CONSERVATION STRATEGIES

STRATEGIES	GAS FURNACE		OIL FURNACE		ELECTRIC FURNACE		HEAT PUMP*		CENTRAL AIR CONDITIONING	
	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT	NEW	RETROFIT
Electronic Ignition	111	41								
Outside Preheated Combustion and Dilution Air	16	6	NO							
Automatic Flue Damper	12	5	OIL							
13% Excess Air	4	2	FURNACES							
Furnace Sized for 25% above Peak Load	12	5	IN							
Furnace Sized for Peak Load	16	6	HOUSTON							
Better Insulated Ducts with Less Leakage	4	2	(REF. 68)		11	4				
Ducts Entirely in Conditioned Space	8	3			21	8	105	39	105	39
Upper Limit Efficiency Non-Condensing Furnace with Electronic Ignition	128	47								
Condensing Furnace with Electronic Ignition	136	50								
Smaller Fan with Lower Fan Shut Off Temperature	4	2								
Compressor Efficiency = .60							506	187	432	160
Compressor Efficiency = .80							854	316	770	285
Compressor Efficiency = 1.00							*1065	394	970	359
Outdoor Coil Effectiveness = .80							190	70	127	47
Outdoor Coil Effectiveness = .90							380	141	316	117
Outdoor Coil Effectiveness = 1.00							453	168	380	141
Indoor Coil Effectiveness = .95							116	43	63	23
Indoor Coil Effectiveness = 1.00							211	78	148	55
Fan Efficiency = .85							63	23	63	23
Fan Efficiency = 1.00							127	47	116	43
Compressor Motor Efficiency = 1.00							74	27	74	27

*Includes savings in both heating and cooling modes.

E. Ranking of RD&D Strategies

1. Heating Systems

The following sections illustrate the possible savings as a result of an RD&D strategy application to the heating systems of the three types of structures (SFD, SFA, MFLR) in the Baltimore, Chicago, and Houston climatic areas. The heating system strategies are ranked from those that yield the greatest energy savings, to those that yield the smallest savings. The rankings are not intended to show their relative cost/benefits.

a. Ranking of RD&D Strategies for the Gas Warm Air Furnace

(1) Baltimore and Chicago Areas (Colder Climate Conditions)

- (a) Condensing flue gas with demand ignition ($N_{ss} = .96$)
- (b) Approaching the upper efficiency limit without condensing flue gas ($N_{ss} = .86$)
- (c) Ducts in conditioned space
- (d) Automatic flue control
- (e) Furnace sized for peak load
- (f) Outside preheated combustion and dilution air
- (g) Smaller fan operating a longer time (i.e., lower fan shut off temperature)
- (h) Demand ignition
- (i) Furnace sized for 25 percent above peak design building load
- (j) Improvement in duct insulation and fabrication
- (k) 13 percent excess air

(2) Houston Area (Warmer Climatic Conditions)

- (a) Condensing flue gas with demand ignition ($N_{ss} = .96$)

- (b) Approaching the upper efficiency limit without condensing flue gas ($N_{ss} = .86$)
- (c) Demand ignition
- (d) Automatic flue control
- (e) Ducts in conditioned space
- (f) Outside preheated combustion and dilution air
- (g) Furnace sized for peak load
- (h) Furnace sized for 25 percent above peak design building load
- (i) Improvement in duct insulation and fabrication
- (j) Smaller fan operating a longer time (i.e., lower fan shut off temperature)
- (k) 13 percent excess air

b. Ranking of RD&D Strategies for the Oil Warm Air Furnace

- (1) Baltimore and Chicago Areas (Colder Climatic Conditions)
 - (a) Condensing flue gas with demand ignition ($N_{ss} = .96$)
 - (b) Approaching the upper efficiency limit without condensing flue gas ($N_{ss} = .88$)
 - (c) Ducts in conditioned space
 - (d) Automatic flue control
 - (e) Outside preheated combustion and dilution air
 - (f) Improvement in duct insulation and fabrication
 - (g) Smaller fan operating a longer time (i.e., lower shut off temperature)
 - (h) Furnace sized for peak load

(i) Furnace sized for 25 percent above peak design building load

(j) 13 percent excess air

(2) Houston Area (Warmer Climatic Conditions)

The oil furnace is not the main source of heating, and so a ranking for RD&D strategies is not applicable (Ref. 68).

d. Ranking of RD&D Strategies for Heat Pumps

The following ranking of strategies for heat pumps considers savings from operating in the heating mode only.

- (1) Improve compressor efficiency
- (2) Improve outdoor coil effectiveness
- (3) Locate ducts entirely within conditioned space
- (4) Improve indoor coil effectiveness
- (5) Improve fan efficiency
- (6) Improve compressor motor efficiency

2. Cooling Systems

The following ranking of strategies for cooling systems is applicable to both heat pumps and central air conditioning systems. The strategies are ranked in order from those that yield the highest energy savings to those that yield the smallest savings. The rankings are not intended to reflect the relative cost/benefits of the strategies.

- (a) Improve compressor efficiency
- (b) Improve outdoor coil effectiveness
- (c) Improve indoor coil effectiveness
- (d) Locate ducts entirely within conditioned space
- (e) Improve fan efficiency
- (f) Improve compressor motor efficiency

3. Composite Systems

The following ranking of strategies applies to heat pumps used in both the heating and cooling modes. The combined savings in the two modes were added together as a basis for this ranking. The strategies are ranked in order from those that yield the highest energy savings to those that yield the least savings. The rankings are not intended to reflect the relative cost/benefits of the strategies.

VI. EVALUATION OF THE IMPLEMENTATION FEASIBILITY FOR THE APPLICATION OF SUGGESTED STRATEGIES FOR NEW AND RETROFIT INSTALLATION

This section of the report focuses on evaluating the feasibility of implementation of energy conserving strategies for use in residential buildings. It centers on identifying institutional factors in the public and private sectors and determining their affect on the implementation of energy saving strategies.

There exists many residential energy saving strategies that can be used in both the public and private sector; however, these strategies can be restrained from usage due to social/economic/political interests. Various institutional interests, in performance of their roles, can affect the rate at which new technologies are implemented. Also, there exists practices, procedures, and policies in the public and private sectors which affect the market entrance of new or retrofit technologies applicable for residential buildings.

Private sector institutions can affect implementation as:

- suppliers and consumers of building supplies;
- suppliers and users of residential space; and
- suppliers and consumers of energy.

A listing of the groups most affected by the selected strategies has been compiled and provided on page VI-9.

Also, the public sector has contributed toward affecting the implementation of selected strategies. Activities conducted in the public sector that influence the implementation of a strategy can be delineated by identifying public sector functions such as those listed below:

- enacting legislation;
- enforcing/management of policies; and
- providing financial incentives.

From the examination of roles, functions, and procedures, carried out by public and private sector groups, factors on implementation can be identified. Another factor that is critical in determining which of the selected strategies will realize mass implementation is potential national energy saving.

Identified in the following sections of this report are:

- A ranking of the selected strategies based on their potential national energy savings.
- A determination of the public and private sector groups and associated factors which could affect the implementation of a strategy.
- A determination of the strength or role of each group for each of the selected strategies.
- A final ranking of the selected strategies based upon their potential for energy savings and institutional factors which affect implementation of the energy saving strategies.

A. Selection of Strategies Which Are
Most Effective in Generating Energy
Savings at the National Level

In this section, those strategies with the greatest potential for energy savings at the national level are identified. The methodology used in arriving at the national energy savings potential of each strategy is also presented. Briefly, the methodology consists of gathering data on the distribution of housing type and heating system by region as well as air conditioning saturation by housing type. The number of residences represented by the nine characteristic residences can then be determined and multiplied by the savings for each residence to arrive at the total annual national energy savings potential for each residence type. Summing over all residence types gives the annual national energy savings potential for each strategy.

1. Number of Residential Units Represented by Each
of the Nine Characteristic Residences

Data on the distribution of housing type by region and saturation of air conditioning by region allows the determination of the number of heated and cooled residential units. These units are represented by each of the nine characteristic residences shown in Table VI-1.

TABLE VI-1. NUMBER OF RESIDENTIAL UNITS REPRESENTED
BY EACH CHARACTERISTIC RESIDENCE - 10⁶ UNITS

	SFD		SFA		MFLR	
	Heat	Cool*	Heat	Cool*	Heat	Cool*
Baltimore	4.65	0.60	0.69	0.09	0.39	0.10
Chicago	20.43	1.82	6.48	0.58	4.42	0.97
Houston	13.83	2.49	2.09	0.38	1.82	0.67

*Cooling in this table refers only to residential units with central air conditioning systems. Window units are not considered in this study.

Data on the distribution of heating systems by housing type allows the further breakdown shown in Table III-2.

TABLE VI-2. HEATING SYSTEM DISTRIBUTION BY
RESIDENCE TYPE AND BY REGION - 10⁶ UNITS

		Gas	Oil	Electric Resistance	Heat Pump
Baltimore	SFD	2.91	0.73	0.96	0.05
	SFA	0.43	0.06	0.14	0.006
	MFLR	0.25	0.06	0.08	0.003
Chicago	SFD	12.0	7.44	0.85	0.14
	SFA	3.81	2.35	0.27	0.05
	MFLR	2.60	1.61	0.18	0.03
Houston	SFD	8.45	3.63	1.66	0.09
	SFA	1.28	0.55	0.25	0.01
	MFLR	1.11	0.48	0.22	0.01

In developing the numbers in Tables VI-1 and VI-2, it was assumed that the Chicago characteristic residences were representative of residences in the North Central and North East regions. Baltimore was assumed to be representative of the Middle Atlantic region while Houston was assumed to represent the South and West.

2. National Energy Savings Potential for Each Strategy

The energy savings per unit for each strategy (developed in Task 2 for structural strategies and Task 3 for HVAC system strategies) were multiplied by the number of units represented by each characteristic residence. The resultant national energy savings are shown in Table VI-3 for structural strategies and Table VI-4 for HVAC system strategies.

TABLE VI-3. ANNUAL NATIONAL ENERGY
SAVINGS POTENTIAL FOR EACH
STRUCTURAL STRATEGY

<u>Structural Strategy</u>	<u>Potential Energy Savings</u> (10 ⁶ Therms)
<u>Insulation (Conductance and Radiation)</u>	
Windows - Conduction and Radiation	10,000
Foamed Insulation	20,000
Floor Insulation	9,000
Better Insulation (High Values)	19,000
Window - Orientation	7,100
Variable - Transmission Glass	2,400
<u>Infiltration</u>	
Infiltration Test Procedure	5,000
Infiltration - Building Design	1,700
Infiltration - Building Orientation	850
Infiltration Path - Study	3,500

3. Ranking of Strategies Based on Potential National Energy Savings

Based on the potential savings at the national level shown in Tables VI-3 and VI-4, the following relative ranking of strategies was developed. Both structural and HVAC system strategies are included, the list is presented in descending order with the strategy that has greatest potential

TABLE VI-4. ANNUAL NATIONAL ENERGY SAVINGS POTENTIAL FOR EACH HVAC STRATEGY
(10⁶ Therms)

Strategy	Gas Furnace	Oil Furnace	Electric Furnace ³	Heat Pump ^{1,3}	Air Conditioning ³	Total Energy Savings Potential
Electronic Ignition	1200	-	-	-	-	1200
Outside Preheated Combustion and Dilution Air	1200	500	-	-	-	1700
Automatic Flue Damper	1400	710	-	-	-	2100
13 Percent Excess Air	130	80	-	-	-	210
Furnace Sized for 25 Percent Peak Load	1000	140	-	-	-	1100
Furnace Sized for Peak Load	1200	190	-	-	-	1400
Upper Limit Efficiency Non-Condensing	4200	1700	-	-	-	5900
Condensing Furnace with Electronic Ignition	6200	2800	-	-	-	9000
Smaller Fan with Lower Fan Shut-Off Temperature	1000	420	-	-	-	1400
Better Insulated and Less Leakage Ducts	790	440	80	-	-	1300
Ducts Entirely in Conditioned Space	1500	860	170	20	110	2700
Increase Compressor Efficiency (Upper Limit) ²	-	-	-	56	520	580
Increase Outdoor Coil Effectiveness (Upper Limit) ²	-	-	-	27	270	300
Increase Indoor Coil Effectiveness (Upper Limit) ²	-	-	-	13	130	150
Increase Fan Efficiency (Upper Limit) ²	-	-	-	6	46	52
Increase Compressor Motor Efficiency (Upper Limit) ²	-	-	-	5	48	53

NOTES: 1 - Includes both heating and cooling modes.

2 - In Task 300, more than one level of improvement was identified for these strategies. This table considers only the highest level of improvement for these strategies.

3 - The number in these columns represent energy saved at the building boundary.

for energy savings first, and the strategy with least potential for energy savings last. This ranking considers only potential national energy savings.

- (a) Insulation (High R-value and Reduced Infiltration)
- (b) Better Insulation (High R-value Only)
- (c) Windows - Conduction and Radiation (Operable Opaque Insulating Panel)
- (d) Floor Insulation (Effective in Winter Only)
- (e) Condensing Furnace with Electronic Ignition
- (f) Windows - Orientation
- (g) Upper Limit Efficiency Noncondensing Furnace
- (h) Infiltration Test Procedure
- (i) Ducts Entirely in Conditioned Space
- (j) Infiltration Paths
- (k) Variable Transmission Glass
- (l) Automatic Flue Damper
- (m) Infiltration - Building Design (Vestibule Doors, etc.)
- (n) Outside Preheated Combustion and Dilution Air
- (o) Smaller Fan with Lower Shut-Off Temperature
- (p) Furnace Sized for Peak Load
- (q) Better Insulated Ducts with Less Leakage
- (r) Electronic Ignition
- (s) Furnace Sized 25 Percent Above Peak Load
- (t) Infiltration - Building Orientation
- (u) Increased Compressor Efficiency
- (v) Increase Outdoor Coil Effectiveness
- (w) Less Excess Combustion Air
- (x) Increase Indoor Coil Effectiveness

(y) Increase Fan Efficiency

(z) Increase Compressor Motor Efficiency

This information will be utilized in a final ranking to determine the feasibility of mass implementation of these strategies when confronted by various institutional factors in both the public and private sector.

B. Private Sector Groups that Could
Affect the Implementation of the Selected Strategies

The private sector is one area in which affects on implementation of the strategies will occur. There exists a great number of potential impacts which could affect the implementation of the selected strategies. Private sector factors are identified through a careful examination of the roles performed by the potentially most affected private sector groups in residential building technology. In the sections to follow, the focus will be to: 1) identify the most affected private sector interests, and 2) identify the potential constraints associated with these interests on implementation.

1. Private Sector Institutions and Roles

Many private sector groups are affected by as well as affect the implementation of the selected strategies. From contacting various individuals who participate in residential building development and in energy conservation projects several potential impact areas from the implementation of the selected strategies have been identified below:

- (a) Building designs
- (b) Building purchasing considerations
- (c) Product designs
- (d) Product development
- (e) Product purchasing considerations
- (f) Product market penetration
- (g) Mortgage and investment considerations

- (h) Codes, standards, certifications, and listing practices and procedures
- (i) Energy use
- (j) Others

Impacts in these and other areas will produce effects on various private sector groups. For example, design changes in residential buildings may produce changes in architectural thinking and advancements. This change in thinking may produce unconventional housing designs and structures which consumers are unprepared to accept. Other impacts may develop, such as: new products may stimulate standards making groups to develop new standards, or cause code groups to update antiquated codes, or cause certification institutions to develop new testing practices and procedures for certification.

The magnitude of any one or combination of impacts on private sector groups may effect the feasibility of implementation for certain suggested strategies. For example, new energy efficient products not meeting local building code specifications have been known to be restricted from market entrance.

Furthermore, the intensity of the impact resulting from the implementation of a strategy may vary within affected private sector groups. For example, the development of a new foamed-in-place insulation will have an unfavorable impact on other insulation manufacturers due to increased competition. Simultaneously, the purchasing behavior of building owners - who would buy the insulation - may be favorably altered due to the products energy saving potential.

The net result of this situation may demonstrate: on the side of manufacturers - to restrict the product's development, and on the side of the consumer to favor the development of the new product. Thus, the degree that the implementation of a strategy may be affected depends somewhat on the particular interests and political strength of the interests affected. If, for example, a large number of groups are affected in a favorable fashion, the feasibility of implementation for the strategy would most likely be deemed as favorable. But, if a strategy would be found unfavorable to a large number of groups or a few "key" groups (i.e., building code groups), the feasibility of implementing a particular strategy may be cited as unfavorable. Therefore, it is important at this point to identify

the private sector groups most likely to be affected by or effect the implementation of the strategies and the roles these groups play. The following is a list of private sector groups thought to be most affected by the selected strategies:

- (a) Architects and Engineers:
 - (1) American Institute of Architects
 - (2) National Society of Professional Engineers
- (b) Builders/Developers:
 - (1) National Association of Home Builders
 - (2) Buildings Research Advisory Board/National Academy of Sciences
 - (3) American Institute of Architecture
 - (4) American Society of Planning Officials
- (c) Building Code Groups:
 - (1) International Conference of Building Officials
 - (2) Southern Building Code Congress International, Inc.
 - (3) Building Code Officials and Code Administration
 - (4) American Insurance Association
 - (5) Independent State Code Groups
- (d) Certifying and Listing Organization:
 - (1) American Gas Association
 - (2) Air Conditioning and Refrigeration Institute
 - (3) Underwriters Laboratory
- (e) Consumer Groups:
 - (1) United States Consumers Union
 - (2) Consumers Research, Inc.
 - (3) National Consumers League

(f) Finance Institutions:

- (1) U.S. League of Savings Associations
- (2) Mortgage Bankers Association
- (3) Federal Home Loan Bank Board
- (4) Federal Housing Administration

(g) Insurance Groups:

- (1) American Insurance Association

(h) Manufacturers of Structural Materials and Building Components

(i) Professional, Technical and Trade Associations

- (1) American Institute of Architecture
- (2) Building Research Advisory Board/National Academy of Science
- (3) Air Conditioning and Refrigeration Institute
- (4) American Society of Heating, Refrigeration and Air Conditioning Engineers
- (5) National Fire Protection Association
- (6) American Society for Testing Materials
- (7) American National Standards Institute
- (8) American Society of Mechanical Engineers
- (9) American Gas Association
- (10) National Association of Home Builders
- (11) American Insurance Association
- (12) Energy Research Council
- (13) National Oil Jobbers Council

(j) Utilities

(1) Gas

(2) Oil

(3) Electric

Provided in Figure VI-1 is a brief identification of the roles commonly associated with each affected group. For an explanation of the roles performed by each of the above groups refer to Appendix B.

2. Implementation Factors

As stated earlier, the ease of implementing a strategy is contingent upon the positive and negative impacts on private sector groups. For each of the groups previously identified various implementation considerations are identified below:

(a) Development of a standard acceptable to all areas of the country. This factor would encompass those private sector groups directly involved in the standards development, code development, certification, and listing processes. Standards development is based on "consensus" standards developed by specialized technical groups and other interested groups. Standards development is a crucial factor affecting the implementation of product, material, or building configuration strategies due to the number of private sector interests affected by the standards making process. Private sector code standards and certification groups are actively seeking new ways in which a consistent set of standards, practices, and procedures can be enacted in order to alleviate the problems in this area.

(b) Cost of new technologies. The cost of new technologies is significant primarily from the aspect of consumers, financiers/lenders and manufacturers. Consumers may not choose to buy the technology; financiers may not finance users or developers of the technology; and manufacturers may not have the resources to develop the energy saving technology.

AFFECTED GROUPS	PRIMARY ROLES		
Architects/Engineers	a) building designer	b) consumer educator	c) specifier of equipment and materials
Builders/Developers and Engineers	a) builder/specifier	b) builder/purchaser	c) consumer educator
Certification and Listing and Standard Development Organization	a) product testor	b) standards development	
Building Code Groups	a) code developer	b) standards developers	c) inspector and information dissemination
Consumer Groups	a) consumer protection	b) consumer educators	
Finance Groups	a) mortgagors (loans) and investors (product development and commercialization)		
Insurance Organizations	a) product liability (quality, performance and safety)		
Manufacturer	a) suppliers (products)	b) standards developers	
Professional, Technical and Trade Associations	a) information disseminators (professional, technical and trade education)	b) standards developers	
Utility	a) supplier	b) consumer educators	c) standards developers

Figure VI-1. Affected Groups and Their Roles

- (c) Awareness of the technology. This factor is dependent upon the educational practices of various private sector educators. If the strategy is available and groups are not aware of its existence, then implementation can be severely restricted. Utilities and others have developed massive campaigns to make customers aware of available energy conserving technology and practices.
- (d) Consumer tastes and behavior. A consumer's behavior is in many cases unpredictable. Turning down thermostats is a good practice, but enforcing its implementation is another task. A new design of a residential structure may prove energy efficient, but not aesthetically pleasing to consumers. The net result will be restricted implementation. Other aspects affecting consumer behavior include: sight, smell, taste, and perceptions.
- (e) Availability of resources. If energy, mineral, or other resources are not available, the implementation of a strategy may be restrained or limited by the amount of available resources or access to resources.
- (f) Management/Enforcement bodies to assist the implementation of a strategy. Without appropriate management or enforcement bodies, the implementation of various strategies may fall upon "deaf ears." Certain strategies may need some type of oversight or enforcement agent to insure proper and safe implementation. In the area of standards development the American National Standards Institute has taken the lead to organize a consistent set of standards for usage in both the public and private sector.

From these and other considerations a number of factors arise which can be related to the roles performed by the various groups. Furthermore, some factors will have more of an impact on strategy implementation than others. The constraints attributable to private sector energy conservation activities are:

- (a) Lack of information dissemination. Lack of information is a barrier primarily for consumers and producers of energy conserving products. If these two groups are unaware of the various strategies to be implemented, a restriction will exist.

- (b) High cost of a strategy. Restraints can arise if a strategy requires excessive costs for implementation. These costs can be in the form of: production, commercialization, standards development, certification and listing, and other costs.
- (c) Liability of retrofit and new technologies. Private sector participants in the certification and listing process do not want to take the responsibility for new products that may cause death or damage and, which are not approved by nationally recognized approval agents. Therefore, a barrier arises for new or material strategies which do not have formalized institutional approvals (i.e., certification, listing and standards making organizations or the like).
- (d) Time associated with standards development, certification, or code development. For those strategies requiring new codes, standards, or unconventional certification testing, the time associated with the above processes may cause significant restraints on implementation. Small businesses cannot afford excessive time allotments for product approvals to achieve successful market penetration of products due to limited available capital resources.
- (e) Lack of a programmatic management body. New or innovative energy conserving strategies may require a management body to insure implementation. A management body may serve to educate, provide funding, develop policies, organize or centralize code groups, standards making bodies, etc. to insure the implementation of a strategy. The process of determining which groups would best provide this function may cause institutional constraints on the strategies.
- (f) Technology availability. A strategy may require the existence of a product or test procedure that cannot be made available due to the limited development of the state-of-the-art of technology. Thus, if new technology needs to be developed to support the implementation of a strategy, market impact will be significantly affected.

- (g) Lack of financial mechanisms to obtain funding.
Some strategies may require funding mechanisms to encourage consumers to utilize various strategies. Also, producers, in order to develop and market a strategy, may need commercialization and product development funds. Further, code standard development and certification and listing costs may require additional funds to encourage the implementation of various strategies.

The implementation of any of the selected strategies may be affected by some or all of these factors, while some of the negative impacts are attributable more to some private sector groups than to others. For example, it is readily acknowledged that the development of a product standard is more significant to those private sector groups directly involved in the standard being developed, than to groups which are not. Standards development for home insulation is initially more important to insulation manufacturers, fire code officials, certification/listing organizations, and consumers than it would be to a pipe fitters association, steel groups, and others.

Also, the manner in which these factors affect the implementation of a strategy is important. Using the standards development example, various private sector groups could restrain the implementation of a strategy which may (due to the consensus process) demand the cooperation of standards making groups or certification and listing institutions to insure implementation. Restrictions or delays on implementation may occur during the course of "due process" for standards development. Moreover, agencies chartered to implement or enforce existing standards (i.e., code groups) usage are not always effective in the implementation of a standard at the local level once it is developed.

Note that the private sector is taking affirmative action to alleviate many of the existing institutional problems. Utilities, for example, provide technical assistance in many areas of standards development, code development and coordination, and educating customers identifying energy conserving product categories and practices (e.g., dial down the thermostats, use insulation, etc.) which could be implemented to reduce customer bills. Architects provide suggestions to consumers and professional organizations are actively participating in conferences to further educate other professionals in the area of energy conservation. The Major Building Code Groups (BOCA, ICBO, SBCCI, ATA, and others) and professional groups (ARI, ASHREA, ASTM, ANSI, ASME,

<div>Private Sector Factor</div> <div>Private Sector Functional Roles in Residential Energy Conservation</div>	Lack of Information	High Costs of a Strategy	Liability of Retrofit and New Technologies	Time for Code and Standard and Certification	Lack of a Regulatory Agency	Unavailability of Technology	Lack of Financial Mechanisms	Acceptable Standards	Consumer Tastes and Behavior	Availability of Natural Resources
Building Designer	X	X				X	X	X	X	
Building Specifier	X	X				X	X	X	X	
Product Testing		X	X	X	X	X	X	X	X	
Code Developer	X	X		X	X			X	X	
Mortgager		X					X	X		
Investors/Lenders		X					X	X	X	
Insurers			X			X		X	X	
Suppliers of Products	X	X	X	X		X		X		
Suppliers of Natural Resources	X	X		X			X			X
Standards Development	X	X		X	X		X	X		
Consumer	X	X	X			X	X		X	
Education	X			X			X	X		
Inspector/Building Agency	X		X		X			X	X	

Figure VI-2. Private Sector Constraints

NAHB, NOJC, and others) are working together to ease the problems associated with implementation of acceptable energy saving strategies.

Provided in Figure VI-2 on page VI-16, is a matrix of the identified factors and the identified roles of the private sector groups. This chart identifies various impact areas and also indicates the roles of groups which will be affected due to a particular factor. For example, financial incentives will primarily affect consumers in their effort to utilize a product, and producers in their effort to develop and make energy saving products commercially available.

In the following section, public sector factors which may affect implementation will be identified.

C. Identification of Impact Areas Within the Public Sector that Could Effect the Implementation of the Selected Strategies

Local, state and Federal governments will have significant impact on the implementation of the selected strategies identified in this report.

Some of the public sector interests that will affect implementation are identified below:

- (1) Energy Research and Development Administration
- (2) Housing and Urban Development
- (3) U.S. Patent Office
- (4) U.S. Congress
- (5) U.S. Senate Subcommittee on Antitrust and Monopoly
- (6) General Services Administration
- (7) Health, Education, and Welfare
- (8) National Bureau of Standards
- (9) Small Business Administration
- (10) Federal Trade Commission
- (11) National Safety Council

- (12) Consumer Products Safety Commission
- (13) Federal Power Commission
- (14) State and Local Governments and Commissions
- (15) Others

Three functions performed by the public sector which will affect the implementation of the selected strategies are:

- (1) Specification/procurement practices
- (2) Legislative development
- (3) Enforcement/management of programs, legislation and policies.

These functions are carried out on each of the three levels of government. Federal, state, and local governments procure products, materials, buildings, and services. Various procurement practices by the Federal government may affect the implementation of new or retrofit energy conserving products. Government procurement lists such as the Federal Supply Schedule (FSS) (developed by the General Services Administration) and "Use of Materials Bulletins" (which signifies the Federal Housing Administration's approvals of new materials for housing) identify products and product standards for materials and components which may be purchased by public agencies. In order for a product to appear on the FSS the product must first adhere to nationally recognized standards, most of which are developed in the private sector. Standards which are prescriptive in nature can dictate the design and function of a product. Thus, new products not consistent with these standards do not qualify for inclusion on government lists.

In addition, the public sector is engaged in policy and legislative development. In this capacity, policy measures which do not encourage the implementation of the selected strategies may act to limit their utility. Antiquated or prescriptive codes which are adopted into law have already been identified as a restrictive measure and inadequate financial incentives for stimulating the implementation of energy saving measures act as a restriction on implementation.

The public sector is responsible for implementing, managing, and enforcing programs and legislation. As a part of this responsibility, the public sector can identify an administering body to insure proper or safe product utilization. For some selected strategies it may not be clear which administrative agent of the public sector would best serve as an effective vehicle for implementing, managing, or enforcing a particular strategy's use. Institutional constraints may arise during the process of determining which administrative body would have operational jurisdiction over implementing a strategy. Furthermore, some organizations may not have the administrative flexibility to immediately incorporate energy saving strategies into their programmatic structure. For various strategies, time will be required to develop a management and implementation capability. The time needed to organize a nationally effective body to put a strategy into effect may be considered a restrictive factor.

Institutions within the public sector which perform the identified functions will affect the implementation of the selected strategies in three significant areas:

- (1) Building code development and enforcement
- (2) Standards development and enforcement
- (3) Financial programs in the form of subsidies, loans and grants

By affecting any one of these three areas, the public sector could affect most of the strategies identified within this report.

In the following section, each of the three areas will be discussed as they relate to the identified functions of the public sector. The following discussions will also include further identification of institutional factors attributable to the performance of these functions. A chart of these factors is presented on page VI-22.

a. Building code development and enforcement in the public sector. Affects on implementation of various strategies will arise in the functional areas of public sector: building code enforcement, building code development, and procurement practices. On the local level, the code official (the enforcement officer for codes and standards) plays a key role in the implementation of new or retrofit strategies. The building code official has been described as:

"...a law enforcement officer, a highly specialized law enforcement officer whose prime mission is the prevention and correction, or

abatement of violations...[He] designs nothing, repairs nothing. His responsibility is merely to see those persons who are engaged in these activities do so within the requirement of the law." (Ref. 28).

This official is in the position to restrict new technologies from being used in his community. The local code official is also responsible for interpreting code specifications for buildings. In this capacity, the code official has discretionary powers to allow various products and materials to be utilized. A general practice of code officials is to allow for the utilization of well known (off-the-shelf) type items as opposed to new inventions which have not obtained certification/listing or approval from a nationally recognized testing laboratory.

Another factor which may impact a strategy is localism. There are several thousand local code jurisdictions and each adheres to a different set of standards. Standards which are accepted by various localities usually filter down to these communities from regionally organized code groups, i.e., the International Conference of Building Officials (west); the Building Officials Code Administration (north central/northeast); and the Southern Building Codes Congress (south). Code differentiation continues due to the fact that Federal and State officials have not taken the necessary steps to coordinate, revise or update codes within the United States. Within various localities, local industries and utilities assist local officials to decide which codes should be utilized. This practice exists because code officials do not have expertise in all technical areas of residential technology. The influence exerted by local interests could cause restrictions for some of the proposed strategies depending on the locality, the parties-at-interests, and the affect of a strategy.

The Federal government is primarily responsible for assisting the development of codes. But in this capacity, the Federal government lacks the technical expertise in all areas to provide adequate assistance. In general, the public sector yields to private sector specialists for authoritative advice on identifying acceptable uses and development of new technologies. Private sector conventionalism then becomes the mode for government acceptance.

To alleviate some of the problems associated with code development and enforcement, programs are being reviewed and action is being taken by Federal, State, local, and private sector interests. With the development of ASHRAE 90-75 (a performance standard) a number of activities and programs have begun the coordination and assistance for the development of

code. Energy Research and Development Administration, with cooperation from other Federal Agencies, code groups (National Conference of States on Building Codes and Standards) and state organizations are attempting to provide mechanisms for: code development and enforcement, training, education and other activities.

b. Standards development and enforcement in the public sector. Major constraints to implementation will be generated in the area of standards development. Various public sector agencies assist with the development of standards. Standards developed in the United States are called "consensus standards." Consensus standards are those standards developed and agreed upon by trade associations, engineering societies, testing laboratories, building code organizations, government agencies, manufacturers and consumers. The public sector's role in the consensus process has been reduced due to limited public sector technical expertise in all areas of product development.

The National Bureau of Standards (NBS) and other executive agencies have been chartered to provide technical expertise to assist standards development for the United States. Yet, for the last decade, the public sector has contributed minimally to this effort. A reason for the public sectors lesser involvement is that executive agencies who work in these areas lack adequate resources and manpower to be technically expert in all phases of materials and product testing research, although some agencies (i.e., ERDA, NBS, HUD, and others) have been actively pursuing programs which would supplement standards development.

The Laboratory Evaluation and Accreditation Project (LEAP) is an attempt to actively participate in product testing by providing guidelines for evaluating and accrediting laboratories to test products. Other actions include the establishment of a laboratory accreditation mechanism for the product approval process (i.e., the National Voluntary Laboratory Accreditation Program - NVLAP). Although, these actions are primarily focused on assisting product certification rather than standards development, their impact on implementation of energy saving strategies will be significant.

Within the NBS is the National Institute of Building Science (NIBS). NIBS was authorized by the Housing and Community Development Act of 1974 (PL 93-383). This organization was established "to encourage and provide for the maximum participation feasible of public and private scientific, technical, and financial organizations, institutions, and agencies now engaged in activities pertinent to

Public Sector Factor \ Public Sector Functional Residential Energy Conservation Impact Areas	Mandates	Local Code Officials	Antiquated Codes	Regionalized Fragmentation	Lack of Technical Expertise	Localism	A Few Nationally Recognized Authorities	Government Listing Practices	High Costs in Dollars	Lack of Performance Standards	Length of Time for Code, Standards making Certification	Lack of Regulatory Agency	Priority on Energy Saving Strategies	Lack of Financial Incentives
Building Code Development and Management • Management/Enforcement • Development • Specification/Procurement Practices	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Standards Development and Management • Management/Enforcement • Development • Specification/Procurement Practices	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Financial Incentives • Management/Enforcement • Development • Specification/Procurement Practices	X			X	X	X			X		X	X	X	X

Figure VI-3. Public Sector Constraints

the development, promulgation, and maintenance of performance criteria, standards, and other technical provisions for building codes and other regulations." At this time the full impact of NIBS has not been established, but its existence demonstrates the public sectors concern in this area (Ref. 31).

c. Financial programs in the form of subsidies, loans, and grants in the public sector. The cost of utilizing a strategy may be prohibitive for the home owner. For those strategies requiring high costs for utilization the inadequacy of funding programs may affect the implementation of a strategy. Currently, home owners receive tax deductions for home improvements, but not necessarily for utilizing energy conserving products or other structures having energy saving potential. Also, small businesses with new energy conserving products have a difficult time existing without proper funding. Two bodies which currently make funds available are the Small Business Administration and the NBS/ERDA's Office of Energy Related Inventions. Both of these agencies provide funding mechanisms for inventors and businesses alike. Nevertheless, the Small Business Administration nor the Office of Energy Related Inventions (an NBS, FEA, and ERDA project) can make available enough funds for all inventors and all small business ventures. Thus, various selected strategies which demonstrate a high cost for implementation may be restricted due to a lack of financial incentives or resources.

The potential private and public sector factors previously identified will have some impact on the implementation of most of the selected strategies. In part D of this report, an analysis has been conducted to identify which strategies will be affected by various public and private sector institutions.

D. Determination of the Position and Influence
of Each Socio/Economic/Political Factor in
Each Proposed Strategy

There are many groups which affect the implementation of the selected strategies, but some groups have more impact than others due to their particular position or role. Within this section of the report a determination of strength of role will be ascertained to identify those groups which have major affects on implementation. The determination is based upon a time phasing of a strategy -- from its initial development to consumer implementation.

Buildings and building component development and commercialization are dependent upon a hierarchical structure of approvals (see Figure VI-4). This structure is time phased, that is, a strategy will not (in the normal case) progress to implementation Phase II prior to having been approved by specified institutions from Phase I. Similarly, a strategy will not realize total implementation in Phase III until it has met the approvals in Phases I and II. The strength of an institution is, therefore, dependent upon position in the time-phased process from strategy development to strategy implementation. Furthermore, from the determination of the strength of these institutions, it becomes possible to identify the primary factors that may restrict the implementation of a strategy. The phases to be used in the evaluation of institutional strength are discussed below:

- (1) Phase I - Technical Authoritative Approvals. The consumer public recognizes the fact that consumers generally lack the technical expertise to identify safe and viable product for use in the home. Around the turn of this century insurance groups sponsored testing laboratories and other organizations to identify products and practices which would be safe for consumers. The strongest groups within this phase tend to be certification/listing institutions, code groups, and standard making organizations. The once small-testing-laboratories have today developed into nationally recognized certification and listing organizations. Some of the well-known agencies of this type are the Underwriters Laboratory (UL), specialists in electrical products; the American Refrigeration Institute (ARI), concerned with cooling equipment; and the American Gas Association (AGA), concerned with gas furnaces and other gas operated devices. Also, building code groups - made up of individuals who are expert in housing, design, components, play an important role in the determination of new and innovative structures, building techniques, and components which would provide a safe environment for homeowners. This group is responsible for the development of codes and generalized practices for buildings and building equipment and also to insure safety and reliability. The findings of these groups are widely accepted, but adherence to particular codes and standards by local building inspectors and consumers is varied. The general public (due to a lack of technical expertise) has deferred their trusts to a few recognized technical societies. It is generally accepted that

products carrying nationally recognized stamps and approvals are safe for the use which they are intended.

In the developmental stage, a large number of trade groups, utilities finance organizations, consumer groups, and government officials will participate, primarily, in standards development. Trade associations, manufacturers, utilities, and others participate in product development and (depending on the strategy) they may also have the strength to restrict a products implementation. For example, an insulation trade association (ita) may identify a type of new insulation as unsafe. Therefore, those people that adhere to an "ita" ruling will not use the product.

- (2) Phase II - Institutional Adherence. Once products or strategies are approved by the various recognized authorities, it must then be found acceptable to other institutions that have adopted previous codes standards and certified product specification. For example, finance groups adhere to a practice of not lending funds to manufacturers that produce new products that have not received a recognized approval. Furthermore, many code regulations (which utilize prescriptive standards) may need to be altered to allow for new performance product standards. Also, there are a range of institutions (i.e., the Federal government) that adhere to already existing standards and (depending upon the strategy) these government institutions may have to change certain accepted practices in order to allow for, or to make acceptable the new standard for public sector use. These interim organizations can affect the implementation of the selected strategies if they do not act to alter modes of practice and procedures. It is in this manner that these institutions can affect new and innovative strategies.

- (3) Phase III - Consumer Acceptance. Given that the strategy is approved and adhered to by the institutions, there is no guarantee that the strategy will be implemented by various consumers. The consumer will not accept the strategy unless prior knowledge of the strategy's existence is available to him. Also, the consumer may not use the strategy because of his particular tastes and behavior. The consumer is the last line for putting the strategy into effect. When the consumer, either

Figure VI-4. Hierarchical Structure of Approvals.

by intention or by circumstance, does not see fit to utilize the strategy, the strategy's utility and potential effectiveness is negated (Ref. 29).

Figure VI-5 is a matrix of the recommended strategies and institutions most likely to have the greatest impact on a selected strategy. Strategies that require new products or new designs will be affected by Phase I groups. Strategies that exist or already meet established standards will be influenced primarily by Phase II groups. And, strategies accepted in Phase I, adhered to by various institutions in Phase II, will principally be affected by those consumer groups in Phase III. Using this chart, a determination of the strength of the group or groups which are most likely to restrict a strategy have been identified. This determination is based upon discussions with representatives from these institutions, relevant literature, and in-house experience.

From careful examination of the groups which have been identified as having the greatest impact on the strategies, it becomes possible to create a matrix of strategies and institutional factors associated with those groups which can affect the utilization of the selected strategies. This matrix is presented in Figure VI-6.

In the following section, selected energy conservation strategies are discussed in light of two factors:

- (1) Barriers which confront the strategies
- (2) Major institutions which will have the greatest impact on the strategies

1. Insulation (Conductance and Radiation)

a. Windows Conductance and Radiation. The primary constraints on the implementation of this strategy are high costs and consumer tastes. The costs for producing a window which will be energy saving may be high depending on the process to be utilized. If production costs are high, then the cost to the consumer will be raised proportionately. When purchasing windows, the consumer bases his decision of what window to buy on real competitive costs rather than energy savings over long periods of time. Furthermore, consumer tastes play a large role on the implementation of this strategy. Windows of new design, color, or varying visibility levels may cause consumption aversion for consumers.

Strategies	PHASE - I								PHASE - II							PHASE - III		
	Authoritative Approvals								Institutional Adherence							Consumer Acceptance		
	Certification/Listing	Standard Development	Code Groups	Trade Associations	Manufacturers	Utilities	Government	Finance	Code Groups	Finance	Insurance	Trade Associations	Local Code Official	Government	Utility	Standard Development	Consumer (Private Sector)	Government (Public Sector)
Institutions with the Strongest Position or Role to Influence a Particular Strategy																		
<u>Insulation (Conductance and Radiation)</u>																		
Window - Conduction and Radiation	*	*	*														*	*
Foamed Insulation - in the walls	*	*	*														*	*
Floor Insulation	*	*	*														*	*
Better Insulation	*	*	*	*	*				*	*		*					*	*
Variable Transmission Glass	*	*	*	*	*				*	*		*					*	*
Windows Building Orientation	*	*	*	*	*				*	*	*	*	*			*	*	*
<u>Infiltration</u>																		
Test Procedure			*	*		*			*								*	*
Building Design			*	*		*			*			*		*			*	*
Building Orientation			*	*		*			*			*		*			*	*
Infiltration Path Study			*	*		*	*		*			*		*	*		*	*
<u>Heat Pumps and Air Conditioners</u>																		
Improved Compressor Efficiency for Heat Pumps	*	*	*	*	*		*		*									
Increased Outdoor Coil Effectiveness for Heat Pumps	*	*	*	*	*		*		*	*	*	*	*	*	*	*	*	*
Place Ducts in Conditioned Space	*	*	*	*	*		*		*	*	*	*	*	*	*	*	*	*
Increased Indoor Coil Effect for Heat Pumps	*	*	*	*	*		*		*	*	*	*	*	*	*	*	*	*
Improved Fan Efficiency	*	*	*	*	*		*		*	*	*	*	*	*	*	*	*	*
Improved Compressor Efficiency for Heat Pumps	*	*	*	*	*		*		*	*	*	*	*	*	*	*	*	*
<u>Furnaces</u>																		
Electronic Ignition	*	*	*	*	*	*	*		*			*	*	*	*	*	*	*
Outside Preheated Combustion and Dilution Air	*	*	*	*	*	*	*		*			*	*	*	*	*	*	*
Automatic Flue Damper	*	*	*	*	*	*	*		*			*	*	*	*	*	*	*
13 Percent Excess Combustion	*	*	*	*	*	*	*		*			*	*	*	*	*	*	*
Furnace Size 25 Percent Above	*	*	*	*	*	*	*		*			*	*	*	*	*	*	*
Furnace Sized for Peak Load	*	*	*	*	*	*	*		*			*	*	*	*	*	*	*
Better Insulated Ducts with Less Leakage	*	*	*	*	*	*	*		*			*	*	*	*	*	*	*
Ducts in Conditioned Space	*	*	*	*	*	*	*		*			*	*	*	*	*	*	*
Upper Efficiency Limit of a Non-Condensing	*	*	*	*	*	*	*		*			*	*	*	*	*	*	*
Condensing the Gas Furnace Electric Ignition	*	*	*	*	*	*	*		*			*	*	*	*	*	*	*
Smaller Fan	*	*	*	*	*	*	*		*			*	*	*	*	*	*	*

* - Strongest Institutional Interests
 x - Group with a Major Impact

Figure VI-5. Matrix of Strategies and Institutional Groups

Major Institutional Factors Attributable to the Public and Private Sectors	Selected Strategies										
	Lack of Information	High Cost of Strategy	Certification	Time for Code/Standard Development and Certification	Lack of a Regulatory Agency	Unavailability of Technology	Lack of Financial Incentives	Lack of Acceptable Standards	Consumer Tastes and Behavior	Local Code Official	Antiquated Codes and Standards
Insulation (Conductance and Radiation)											
1. Windows - Conductance and Radiation	x	x		x	x		x	x	x		
2. Foamed Insulation - in the walls	x	x	x				x				
3. Floor Insulation	x	x					x				
4. Better Insulation	x	x					x				
5. Variable Transmission Glass	x	x					x				
6. Windows - Building Orientation	x						x				
Infiltration											
1. Test Procedure		x	x	x	x	x	x	x			
2. Building Design	x	x									
3. Building Orientation	x										
4. Infiltration Paths Study											
Heat Pumps and Air Conditioners											
1. Improved Compressor Efficiency	x	x		x		x	x				
2. Increased Outdoor Coil Effectiveness	x	x				x	x				
3. Place Ducts in Conditioned Space	x	x									
4. Increase Indoor Coil Effectiveness	x	x		x		x	x				
5. Improve Fan Efficiency											
6. Improve Compressor Motor Efficiency	x	x				x					
Furnaces											
1. Electronic Ignition (No Pilot Light) - Gas Furnaces Only	x										
2. Outside Preheated Combustion and Dilution Air	x	x	x	x			x	x			
3. Automatic Flue Damper	x	x	x	x			x	x			
4. 13 Percent Excess Combustion Air	x		x	x			x	x			
5. Furnace Sized for 25 Percent Above Peak Design Building Load	x				x		x	x	x	x	x
6. Furnace Sized for Peak Load	x										
7. Better Insulated Ducts with Less Leakage	x	x					x				
8. Ducts in Conditioned Space	x										
9. Approaching the Upper Efficiency Limit of Non-Condensing Flue Gas Furnace (increasing N_{ss} approx. 10% gas and 12% oil)	x	x	x	x		x		x	x	x	
10. Condensing Flue Gas Furnace with Electronic Ignition (increasing N_{ss} approx. 20%)	x	x	x	x		x	x	x		x	
11. Smaller Fan Operating a Longer Time (i.e. Lower Fan Shut-Off Temp.)	x							x			

Figure VI-6. Matrix of Barriers and Selected Strategies

Windows have well established codes (of primary interest is fire codes and size and number of windows) and certification processes and procedures; so, in this case neither poses a major barrier to implementation. Due to the competitive nature of window development, some manufacturers or trade groups may oppose this strategy, but this opposition would not have strong support. The primary barrier to implementation would exist on the consumer side. Consumer tastes and behavior will be a major barrier to implementation. Lending and finance institutions will also have some impact. If manufacturers need additional funds for either product development or commercialization for products or processes (not approved by nationally recognized institutes) and cannot obtain these funds because of the newness or innovativeness of the product, then implementation will be obstructed. Also, utilities and the Federal government may impact on window implementation by not disseminating information concerning cost effective ways to save energy.

b. Formed in Place Insulation. The development of an insulation foam that could be formed in place, economical, and safely utilized would be of great benefit. Current costs associated with the development of foamed insulations are extremely high and the barriers associated with many new foams (i.e., polyurethane) are highly restrictive. Cost is one barrier which may discourage consumers from purchasing the new foams. More importantly, many code officials will not sanction new foams which do not meet American Society of Testing Materials (ASTM) fire standards or National Fire Protection Association (NFPA) fire standards. Also, many code jurisdictions do not have appropriate codes for foam insulation and in such cases antiquated codes on the local/regional level will cause a constraint on implementation.

The groups most likely to have an impact on implementation will be standards making groups -- ASTM and NFPA. Once developed the standards may be adopted by code groups who participate in standards development. Once a particular standard is put into codes, various regions and localities, may in fact adopt the codes which are then enforced by local code officials. Also, insulation manufacturers and trade associations could have an impact on implementation. In a system based on consensus, the support or lack of support for a product type "in the field" will have an impact on implementation. Other groups likely to have some impact are financial groups, utilities, insurance groups and consumers.

c. Floor Insulation. Insulating a residential building is a common practice, but insulating the floor over non-climate controlled space is not.* The primary barriers to implementation of this strategy are cost and lack of information. The additional

* Common practice is no floor insulation for gas or oil heated structures; usually 3-1/2 inches of insulation is installed in the floor of electrically heated structures.

cost required to insulate the floor of a residence may discourage consumers from utilizing this strategy. Furthermore, most consumers are unaware of the fact that insulating floors is energy conserving. Also, if the insulation is installed in a permanent fashion, consumers may feel that they are cooling the basement rather than holding in useable heat in the main living space. Keeping the basement cool may not be favorable to many consumers, thus causing a restriction on implementation; however, it is conceivable to insulate all basement walls and floors.

From this discussion it becomes obvious that consumers will be the primary obstacle toward implementing this strategy. But, code groups, finance groups, utilities, builders, developers, and insurance groups could have an impact by informing or not informing consumers of this energy saving option.

d. Better Insulation. Cost is the primary barrier to improving the state-of-the-art of insulation. Existing insulation materials are probably the most cost effective and there is a lack of financial incentives for both consumers and insulation manufacturers to commercialize or develop new insulation. Furthermore, the insulation strategy under consideration is currently technologically unavailable. A new insulation will be required to be tested against NFPA and ASTM standards. Insulation manufacturers must see the market potential for a new insulation before making a commitment to develop it. An improved insulation will need the assistance of financial incentives if energy saving is to be a priority.

The primary groups which will influence the implementation of improving insulation will be the insulation manufacturers, government/private sector (financial groups), insulation trade associations and standard development groups. Each of these groups would be concerned with developmental and marketing aspects of this product type. It will be through the efforts of these groups that the implementation of this strategy will be affected.

e. Windows - Building Orientation. Constraints confronting this strategy are primarily due to a lack of knowledge on the part of consumers, designers, and builders concerning the energy conservation aspects of window orientation. The financial incentives for seriously considering this strategy as an energy saving technique do not exist. Also, local codes (i.e., a window must be large enough for an average fireman with a back pack to fit through) can restrict the implementation of this strategy.

Windows in building orientation are obviously the option of builders, developers, architects, and consumers. And, if code groups and government agents or other institutions were to place emphasis on energy savings, the implementation of this strategy could be affected.

f. Variable Transmission Glass. This strategy has few constraints obstructing its implementation. The barrier which will have the most affect on this strategy will be cost. An associated barrier with cost is the lack of financial incentives to produce variable transmission glass and to install it as an energy conserving package for a residence. These two barriers coupled with the current unavailability of technology and consumers tastes and behavior will act to restrict the implementation of this energy saving strategy.

Institutions most likely to affect the implementation of variable transmission glass are the glass manufacturers, glass trade associations, consumers, and government. The manufacturers and trade associations need to envision the incentives (financial and energy savings) attributable to produce and encourage market acceptance of variable transmission glass. Consumers also need to be aware of the products existence and the amount of energy which could be saved once it was installed. Finally, the government, through the use of information and provisions for financial incentives, could create or develop a market potential for this particular strategy.

2. Infiltration

As is clearly evident, there are numerous constraints that exist for the development of infiltration test procedures. There does not exist a standard procedure or standardized equipment to assess infiltration. Also, there exist a lack of consensus of how to evaluate test procedures. Therefore, to develop test procedures for infiltration assessments a large number of organizations would need to concur on standardized procedures. This due process of standards development will require a great deal of time in that it is necessary to organize a standards committee, technical subcommittees, and establish an oversight or enforcement committee to insure that proper assessment procedures are developed. The time and resources needed to establish and utilize this procedure would create substantive costs for builders and consumers. These costs would inevitably be passed on to the consumer through the builder. Furthermore, infiltration test procedures are intended to be used by local building authorities. Also, it is a well established fact that local

building code enforcers do not readily adopt new methods into their standard operating practices until the product can be shown to be safe and reliable. This judgment is usually predetermined by a recognized national authority. It will take time to implement this strategy if it is intended to be used on the local level or it may not filter down to all communities. Also, new test methods will require new levels of expertise for evaluators of test procedures; therefore, lack of experience with the test procedure may cause restrictions on implementation.

A major interest group which affects the implementation of this strategy is building code organizations. These organizations affect this strategy in two ways: first, in the developmental stage of making codes for infiltration standards and second, local building code enforcement agencies (which are in some cases affected by local industry and utilities) must learn to accept and utilize test procedures as a part of their standard operating practices for evaluative purposes. Since building code organizations obtain technical expertise from the building community, trade associations, builders, and developers, these groups will also cause indirect affects on the implementation of the strategy.

b. Infiltration - Building Design. Infiltration can be reduced through effective building design. There exists no performance requirements governing building designs. Building design can in many cases be developed in such a manner as to shield doors or windows from prevailing winds, etc. But, most consumers are unaware of factors which influence infiltration and are, therefore, apt to purchase buildings not designed for additional energy savings. In addition, consumers may not like the new and innovative designs for their own particular reasons, since the costs for designing an optimal energy saving housing unit could be excessive, and since contractors, planners, and realtors try to keep residences in an affordable range for consumers, problems arise.

A building design is primarily influenced by builders, contractors, architects, trade associations, local governments (zones), utilities, and finance institutions. But in the final analysis, the building design is dependent upon the consumers taste and his conventional behavior.

d. Infiltration Paths. Study and identification of infiltration paths could prove to be a worthwhile strategy for implementation. However, infiltration is dependent on so many variables (craftsmanship, weather, land shifts, settling, etc.) that deriving a consensus standard for this strategy will be a major barrier.

This strategy will have national impact and would be affected by building code and trade association groups due to the variability of any analysis. The Federal Government as well as state and local governments should participate to insure that proper analysis is made of infiltration paths in buildings. Additionally, utilities will be interested in the energy savings and energy usage attributable to the identification of infiltration paths.

3. Heat Pumps and Air Conditioners

The RD&D strategies developed are based upon an analysis each of disaggregated components. Therefore, the discussion of components in this section will identify the barriers and institutions that will have major impact on the implementation of strategies identified for various components.

a. Improved Compressor Efficiency for Heat Pumps. Currently, the technology does not exist to increase the operating level of efficiency of compressors used for heat pumps. Also, there are high costs associated with the developmental phase of higher efficiency compressors which primarily affect manufacturers. Manufacturers will need large amounts of capital to develop, certify, and commercialize new compressor products. Also, within this developmental phase, performance standards will need to be developed to include high efficiency compressors. Once these problem areas are overcome, heat pump utilization will need to be publicized to inform consumers that such products are available and meet required standards.

The groups most likely to affect implementation of this RD&D strategy are compressor and heat pump manufacturers and trade associations. These organizations must be prepared to confront and overcome other institutional constraints (mentioned above). In the area of heat pump certification, the Air Conditioning and Refrigeration Institute (ARI) and Underwriters Laboratory (UL) are the primary institutional concerns that will list and certify that products meet some specified standard. Lending institutions could provide investment capital for development of this strategy while the government could play an active role in developing performance standards and providing financial incentives for manufacturers to develop and commercialize new compressors.

b. Increased Outdoor and Indoor Coil Effectiveness for Heat Pumps. As was mentioned in previous reports, the cost for increasing the effectiveness for coils will be exceedingly high for the consumer due to the high costs of development. Furthermore, developing a performance standard as the theoretical limits of efficiency are approached

will create controversy among manufacturers and trade associations. Once again ARI and UL will play a significant role in certifying that a product will meet a specific performance standard. Also, lending institutions will affect implementation by making available the funds necessary for coil development.

c. Place Ducts in Conditioned Space. Placing ducts in conditioned space will produce considerable energy savings for the building owner. This strategy is unconventional in that most homeowners do not think of putting soffits in the main rooms of a residence. Thus, the primary impediments to implementing this strategy is lack of knowledge on the part of consumers, developers, builders, and architects in placing ducts in the living space in a manner which is aesthetically pleasing and useful. Also, building code inspectors could affect the implementation of this strategy by not approving ducts in the living space due to a lack of knowledge that this is an acceptable practice.

d. Improve Fan Efficiency. The barriers to making fans more efficient is restrictive due to a physical constraint. Fans currently operate at high efficiencies; to make them more efficient would require increased costs for the manufacturers and consumers. Another barrier can exist in the area of certification. Depending on the design of the product, it could take six weeks to six years if the design is not in accordance with some previously specified standard. The normal time period for certification takes six weeks to six months, depending on the timing and number of products awaiting certification.

The primary groups that will have major impacts on implementation of increasing fan efficiency are UL, ARI, fan manufacturers, other standards making groups, and finance institutions.

e. Improved Compressor Motor Efficiency. The motor efficiency of compressor motors is currently very high. To improve upon this and to reach for a theoretical limit for motor efficiency could be a costly task. Manufacturers and engineers generally accept the state-of-the-art of motor efficiency and generally do not explore increasing motor efficiencies due to extensive RD&D costs. The primary interest groups involved with implementing this strategy are Underwriters Laboratory, The Air Conditioning and Refrigeration Institute, manufacturers of compressor motors and heat pumps, and finance institutions.

4. Furnaces

Furnace improvements can offer increased energy savings for the nation. Within this section will be identified the potential barriers and institutions that affect the utilization of each of the selected strategies.

a. Electronic Ignition (Pilot Light) - Gas Furnaces Only. The primary barrier to use of electronic ignition devices is a lack of information. A private study released by Michigan Consolidated Gas Company, located in Detroit, Michigan, identified for its customers that this device is cost effective when used in gas furnaces. But, many consumers nationwide are not aware that increased energy savings may be realized through use of this product. Information dissemination could affect the implementation of this strategy. The primary disseminators of information concerning gas fired furnaces are the utilities.

b. Outside Preheated Combustion and Dilution Air. The typical warm air gas furnace draws combustion and dilution air from within a structure. Placing the furnace outside the structure may find opposition from local code officials, since an atypical placement is not specifically allowed in many local codes. The National Fire Protection Association (NFPA) codes require that the furnace air inlet and the draft diverter be placed in the same pressure zone. The strategy discussed herein may be restricted if the interpretation of this code combined with the atypical positioning of the furnace is found to be an unacceptable practice. The cost of utilizing this strategy will be excessive for consumers. Increasing cost result, due to the excessive time needed for certification and code alteration. Also, new standards for certification of this new process will have to be developed. These and other constraints, such as a lack of financial incentives, affect the implementation of this strategy (Ref. 32).

Several groups, due to the nature of the constraints identified above, have significant affects on the implementation of the strategy. In the area of certification, standards development, and code enforcement three groups have a major impact: the American Gas Association, the National Fire Protection Association, and building code organizations. Also, insurance groups will be interested in developments in the area of casualty, potential fire damage, and liability concerning this strategy.

c. Automatic Flue Damper. The automatic damper is a strategy that has been extensively examined and has a documented history of implementation restriction (Ref. 30).

Automatic damper manufacturers have attempted to market this product, but have encountered market restrictions. As with many furnaces and boilers used in residential structures, local code jurisdictions have mandated that various equipment must carry the labels of nationally recognized certifying institutions to demonstrate safety. The automated stack damper (first certification attempts made in 1968) cannot obtain certification due to the fact that no standards exist to develop certification tests. The major problem restricting this product's implementation is in developing a standard to test the device as a retrofit item to a gas-fired furnace (Ref. 34). Also, the Federal government refuses to place this product on an acceptable product listing because it has not been accepted in the private sector (Ref. 34).

The institutions which have had the greatest affect on implementation of this product are Underwriters Laboratory, the American Gas Association, local code enforcement agents, utilities, insurance institutions, and manufacturers. These groups have been working together to define acceptable standards for testing purposes.

d. Thirteen Percent Excess Combustion Air. Currently, no performance standards exist to test a process for thirteen percent excess combustion air. Thus, certification for furnaces capable of thirteen percent will require greater time for certification.

The American Gas Association, utilities, and manufacturer trade associations can affect implementation by working to develop performance standards for decreased combustion air levels. Also, this process may cause an excess amount of soot and smoke emissions. Therefore, environmental quality will be an issue which may have some impacts on implementation.

e. Furnace Sized for Twenty-Five Percent Above and Peak Design Building Load. Furnace sizing will experience two primary affects due to a lack of consumers knowledge concerning furnace sizing and due to a failure to develop acceptable performance standards for furnace size. Consumers are not aware that most furnaces are sized for twice the peak design building load. It has been suggested that consumers given the choice between a smaller furnace and a larger sized furnace at similar cost, will tend to select the larger sized furnace thinking they are getting more heat for the money. Also, there exists a lack of standards defining the most efficient furnace size. Furnace size has in some cases been mandated in localities based upon the antiquated coal-fired and wood burning furnaces. Thus, the local codes may have some affect on implementation.

The American Gas Association (for gas-fired furnaces), the National Oil Jobbers Council (for oil-fired furnaces), and code groups will inevitably have the greatest affects on implementation. These groups serve to educate the consumer public as to what are the proper sized furnace for a locality. Also, these are the primary agents which would aid the development and enforcement of proper standards for oil and gas furnaces. The Federal government as well as manufacturers and trade associations, should participate in this effort.

f. Furnace Sized for Peak Loads. Furnace sizing experience two primary effects due to a lack of consumers knowledge concerning furnace sizing and due to a failure to develop an acceptable performance standard for furnace size. Consumers are not aware that most furnaces are sized for twice the peak design building load. It has been suggested that consumers given the choice between a smaller furnace and a larger sized furnace at similar cost, will tend to select the larger sized furnace thinking they are getting more heat for the money. Also, there exists a lack of standards defining the most efficient furnace size. Furnace size has in some cases been mandated in localities based upon the antiquated coal-fired and wood burning furnaces. Thus, the local codes may have some affect on implementation.

The American Gas Association (for gas-fired furnaces), the National Oil Jobbers Council (for oil-fired furnaces), and code groups will inevitably have the greatest affects on implementation. These groups serve to educate the consumer public as to what are the proper sized furnace for a locality. Also, these are the primary agents which would aid the development and enforcement of proper standards for oil and gas furnaces. The Federal government as well as manufacturers and trade associations, should participate in this effort.

g. Better Insulated Ducts with Less Leakage. Cost is the primary restriction on strategies to better insulate ducts and reduce leakage. The cost of better insulated ducts is high and there are few financial incentives for homeowners to install ducts that are better insulated. Also, consumers are not aware that better insulated ducts effect energy savings. Currently, ducts lose useful energy, thus, reducing the effectiveness of air transfer to the living space. Appropriate performance standards for ducts would increase energy savings.

There are a number of institutions that impact implementation of this strategy. Building code groups will be concerned that the ducts are properly installed, sealed and the insulation used in the duct has met nationally

recognized codes and standards. Consumers want to install a cost effective product which will save energy. Manufacturers need to realize a market potential for this product, but if the cost is prohibited for consumers, manufacturers will not improve duct efficiency. Insurance companies will need assurance that this strategy is not dangerous and will not cause unnecessary safety hazards.

h. Ducts in Conductioned Space. Placing ducts in conditioned space will produce considerable energy savings for the building owner. This strategy is unconventional in that most homeowners do not think of putting soffits in the main rooms of a residence. Thus, the primary impediments to implementing this strategy is lack of knowledge on the part of consumers, developers, builders and architects in placing ducts in the living space in a manner that is aesthetically pleasing and useful. Also, building code inspectors could affect the implementation of this strategy by not approving ducts in the living space due to a lack of knowledge that this could be an acceptable practice.

i. Approaching the Upper Efficiency Limit of a Noncondensing Flue Gas Furnace (increasing efficiency ten percent gas and twelve percent oil).

(same as j. below).

j. Condensing Flue Gas Furnace With Electronic Ignition (increasing efficiency approximately twenty percent). Due to their nature, strategies in

Sections i and j confront similar restraints and will be affected by similar institutional interests.

The technological hardware for these strategies is currently unavailable for commercial residential usage. In any case, the new technology will require time for certification, and, in those instances not governed by existing standards, excessive time requirements may be necessary to develop adequate standards and proper building codes. For both of these strategies, standards currently exist for conventional units, but, where these specify efficiency at seventy-five percent, eight-five percent may be possible. Other areas which require further examination are: the cost to develop this strategy, local code restrictions by local code enforcement bodies, and development of performance standards.

Certification, listing, and code institutions will affect the development of more efficient furnace systems. Furnace manufacturers and trade associations will also be involved in development, but standards, certification, and code committees may require a financial stimulus to encourage further development in this area. Safety will be a

major concern and will be affected by insurance organizations, consumers, federal government and other safety related organizations. Utilities concerned with gas and oil utilization will have an impact on the implementation phase of this strategy. Also, many other institutions, such as finance institutions (by not providing incentives or loans for development and utilization), could have an impact on implementing this strategy.

k. Smaller Fan Operating a Longer Time (i.e. lower fan shutoff temperature). Implementation of smaller fans operating a longer time will be restricted if furnace manufacturers fail to install small fans on new furnaces. Also, consumers will tend to buy larger units thinking they are getting better buys. Thus, the lack of information concerning the utilization of smaller fans will have an impact on implementation. The primary groups that could encourage utilization are HVAC contractors, service groups, and consumers. Furnace manufacturers, trade associations, utilities, and government could affect this strategy by not advocating the utilization of small fans in furnace operations. Ultimately the utilization of acceptable and currently available technology falls on the consumer.

Note that in each case the same groups that affect the implementation in a restrictive sense also are the primary mechanisms for increasing the feasibility of the very same strategies and as was delineated in the beginning of this section these groups are taking the lead to alleviate some of the major institutional problems. The emphasis here is to identify some of the major factors of restriction and identify which strategies are immediately most feasible to implement.

E. Determination of the Ranking of Various Strategies Based Upon the Socioeconomic Factors Associated With the Mass Implementation of the Technical Options

It has been shown that considerable national energy savings will be realized if the selected strategies receive widescale implementation. Furthermore, a ranking of each selected strategy based upon their national energy saving potential has been developed. But, it has also been shown that the implementation of selected strategies can be affected by various institutional socioeconomic factors which in fact may act to restrict implementation. Within this section of the report, a ranking is developed which incorporates both potential national energy savings and the measure of restrictiveness for each of the selected strategies.

1. Criteria to Rank the Selected Strategies

This section of the report contains a ranking of selected strategies according to their ability to realize mass implementation. The ranking process utilizes two criteria:

- (a) potential for significant national energy savings, and
- (b) a measure of restrictiveness for each of the selected strategies.

The procedure used to arrive at the potential annual energy saved nationally as a result of the implementation of each suggested strategy is relatively simple. Data was collected from various sources regarding the distribution of housing type by region, the distribution of furnace type by region, and the saturation of central air conditioning by housing type. Using these data, the number of residential units represented by each of the nine characteristic residences was calculated for each of the four heating systems considered (gas, oil, electric furnace, heat pump) and for central air conditioning. The number of characteristic residences of each type were then multiplied by the savings for each residence (developed in Task 3) to arrive at the total savings per year on a national basis for each residence type. All the residence types were summed to give the total potential national savings per year for each strategy.

The second criteria to be utilized in the ranking is a measure of restrictiveness. In order to develop a measure of restrictiveness, two factors associated with a constraint must be identified:

- (a) the seriousness of a barrier, and
- (b) the applicability of each constraint to each strategy.

The resulting measure is indicative of the cumulative affect of the institutional economic/social/political effects that emanate from the public and private sector interests.

The seriousness of a barrier as it relates to the other barriers can be determined. Cost, time, standards development and other constraints are critical in implementing any of the selected strategies and can be identified as being of greater importance than, for example, having a limited priority on energy savings or limited availability of information. Therefore, the factors identified can be related to each other, due to the overall seriousness each exhibits for any strategy.

Furthermore, a particular constraint has more of an affect on some selected strategies than anothers. For example, products or processes that are commercially available and having met various codes and standards, may be primarily affected by consumer behavior and/or local authorities. But, for strategies not having been certified or having failed to be consistant with existing codes and standards, the primary barriers for that particular strategy will be time, cost, and development of proper standards. Therefore, it can be noted that barriers will have varying affects or applicability for a selected strategy.

Thus, the value for restrictiveness will incorporate both the seriousness of a particular restraint as it relates to other barriers and the applicability of a barrier to each of the selected strategies. By utilizing the calculations for potential national energy savings and the measure of restrictiveness, it becomes possible to rank the selected strategies as to their feasibility to realize mass implementation.

2. Methodology to Rank the Selected Strategies and the Ranking of Selected Strategies

As stated previously, the ranking methodology incorporates two measures:

- (a) potential national energy savings, and
- (b) restrictiveness.

The figure for potential national energy savings for each selected strategy is utilized to demonstrate the variability of the magnitude of energy savings between each of the selected strategies. Also, this figure serves as a positive weighting factor on implementation. Theoretically, those selected strategies with the greatest potential for energy savings have greater probability to realize mass implementation. But, each of the selected strategies confronts some type of restriction due to institutional factors. Therefore, a measure which minimizes the positive criteria of energy savings needs to be developed.

Restrictiveness (as previously noted) is attributable to two significant criteria:

- (a) barrier seriousness, and
- (b) barrier applicability.

Quantitative measures for both of the above factors are ascertained by assigning a weighting factor to the seriousness of a particular constraint. This weighting takes the values identified below:

Seriousness	
High	= 3
Medium	= 2
Low	= 1

Also, each barrier is valued as to its applicability to a particular strategy. These values are given below:

Applicability	
High	= 2
Medium	= 1
Low	= 0

In this case, a barrier may be highly applicable to a particular strategy or it may have little or no affect on a strategy. Assignment of applicability values to each strategy and seriousness values to barriers is based upon information obtained during the course of this project.

Thus, a measure of ability to implement for each selected strategy can be developed by: 1) compounding the seriousness and applicability scores, 2) then summing those total values "k", and finally (3) taking the inverse of that number. The final figure will be used to determine a ranking value. By combining the energy savings with the measure of ability to implement and utilizing the model identified below, a ranking results:

Energy Savings x Restrictiveness = Ranking value

where: total value = $i \times wt = k$

and: ability to implement = $\frac{1}{\sum k}$

Consequently, the selected strategies with a large energy saving and which encounter a minimal number of barriers produces a high ranking. Also, a strategy with an exceedingly large amount of potential energy savings and confronting many barriers may receive a high ranking due to the priority or extensiveness on energy savings potential. The net result promulgate a ranking of selected strategies. Strategies having the largest values are indicative of those strategies most likely to experience mass implementation. The final results are presented in Table VI-5.

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Primary Implementation Factors		Energy Savings		Lack of Information		High Cost		Time Associated with Code and Standards Development and Certification		Lack of a Regulatory Agency		Unavailability of Technology		Lack of Financial Incentives		Lack of Acceptable Standards		Consumer Tastes and Behavior		Local Code Official		Antiquated Codes		Lack of Technical Expertise		Lack of Performance Standards		Limited Priority on Energy Savings		Accumulated Composite Scores		Final Rating	
Selected Strategies		Wt=2 T K		Wt=3 T K		Wt=3 T K		Wt=1 T K		Wt=3 T K		Wt=2 T K		Wt=3 T K		Wt=1 T K		Wt=2 T K		Wt=1 T K		Wt=2 T K		Wt=1 T K		Wt=2 T K		Wt=1 T K					
Insulation (Conductance and Radiation)																																	
1. Windows - Conductance and Radiation		10,000	1	2	2	6	0	0	0	0	0	0	2	4	1	3	2	2	0	0	0	0	0	0	0	0	0	0	0	38	132		
2. Foamed Insulation - in the walls		20,000	0	0	2	6	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	22	909		
3. Floor Insulation		9,000	2	4	2	6	0	0	0	0	0	0	2	6	2	4	0	0	2	0	0	0	0	0	0	0	0	0	0	14	643		
4. Better Insulation		1,900	1	2	2	6	0	0	0	0	0	0	2	4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	18	106		
5. Variable Transmission Glass		2,400	2	4	1	3	0	0	1	1	0	0	0	2	4	0	0	0	2	1	0	0	0	0	0	0	0	0	0	13	185		
6. Windows - Building Orientation		7,100	1	2	0	0	0	0	0	0	0	0	0	2	4	0	0	2	2	1	2	2	4	0	0	0	0	0	0	14	507		
Infiltration																																	
1. Test Procedure		5,000	0	0	2	6	0	0	0	0	0	0	2	6	0	0	0	0	2	4	0	0	0	0	0	0	0	0	0	38	132		
2. Building Design		1,700	2	4	2	6	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	5	113		
3. Building Orientation		850	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	15	170		
4. Infiltration Paths Study		3,500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	584		
Heat Pumps and Air Conditioners																																	
1. Improve Compressor Efficiency		880	1	2	1	3	1	3	0	0	0	0	2	6	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	23	25		
2. Increase Outdoor Coil Effectiveness		300	1	2	2	6	0	0	0	0	0	0	1	3	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	18	16		
3. Place Ducts in Conditioned Space		2,700	2	4	2	6	0	0	0	0	0	0	2	6	2	4	0	0	1	0	0	0	0	0	0	0	0	0	0	13	208		
4. Increase Indoor Coil Effectiveness		150	2	4	1	3	0	0	0	0	0	0	2	6	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	23	7		
5. Improve Fan Efficiency		52	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	13		
6. Improve Compressor Motor Efficiency		53	1	2	2	6	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	4		
Furnaces																																	
1. Electronic Ignition		1,200	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	300		
2. Outside Preheated Combustion and Dilution Air		1,700	1	2	2	6	1	3	0	0	0	0	1	3	1	2	2	6	0	0	0	0	0	0	0	0	0	0	0	28	61		
3. Automatic Flue Damper		2,100	1	2	1	3	2	6	0	0	0	0	0	0	2	4	2	6	0	0	0	0	0	0	0	0	0	0	0	35	60		
4. 13 Percent Excess Combustion Air		1,200	1	2	0	0	2	6	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	16	13		
5. Furnace Sited for 25 Percent Above Peak Design Building Load		1,100	2	4	0	0	0	0	0	0	0	0	1	3	0	0	0	2	6	2	2	1	2	0	0	0	0	0	0	17	65		
6. Furnace Sited for Peak Load Leakage		1,400	2	4	0	0	0	0	0	0	0	0	1	3	0	0	0	2	6	2	2	1	2	0	0	0	0	0	0	17	82		
7. Better Insulated Ducts with Less Leakage		1,300	1	2	2	6	0	0	0	0	0	0	0	0	1	2	0	0	2	2	0	0	0	0	0	0	0	0	0	16	81		
8. Approaching the Upper Efficiency with Less Limit of Noncondensing Flue Gas Furnace		5,900	2	4	0	0	2	6	0	0	0	0	1	3	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	24	246		
9. Condensing Flue Gas Furnace		5,000	1	2	1	3	2	6	0	0	0	0	2	6	2	4	1	3	0	0	0	0	0	0	0	0	0	0	0	30	300		
10. Smaller Fan (Lower Fan Shut Off Temperature)		1,490	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	233		

The following is the final ranking of selected strategies based upon measures concerning realization of mass implementation:

- (a) Foamed Insulation
- (b) Floor Insulation
- (c) Window - Conductance and Radiation
- (d) Infiltration Paths
- (e) Window - Building Orientation
- (f) Electronic Ignition
- (g) Condensing Flue Gas Furnace with Electronic Ignition (increasing efficiency approximately 20 percent)
- (h) Approaching the Upper Efficiency Limit of a Non-condensing Flue Gas Furnace (increasing efficiency 10 percent gas and 12 percent oil)
- (i) Smaller Fan
- (j) Place Ducts in Conditioned Space
- (k) Variable Transmission Glass
- (l) Infiltration - Building Orientation
- (m) Infiltration Test Procedure
- (n) Infiltration - Building Design
- (o) Insulation (Improved)
- (p) Furnace Sized Peak Load
- (q) Better Insulated Ducts with Less Leakage
- (r) Furnace Sized for 25 percent above Peak Design Building Load
- (s) Outside Preheated Combustion and Combustion and Dilution Air
- (t) Automatic Flue Damper
- (u) Improved Compressor Efficiency

- (v) Increased Outdoor Coil Effectiveness
- (w) Improved Fan Efficiency
- (x) Thirteen Percent Excess Combustion Air
- (y) Increased Indoor Coil Effectiveness
- (z) Improved Compressor Motor Efficiency

Brief descriptions of these ranked strategies are contained in Appendix B.

F. Institutional Summary

It has been shown that there are many energy saving strategies which if implemented would provide significant energy savings, but implementation for some of these strategies has been impeded by various institutional practices and procedures. Furthermore, these same institutions which restrict the putting into use of a strategy are now providing the mechanisms to increase the ability to implement a given strategy. Thus, this section has been divided into three parts which include:

- (1) the most feasible RD&D strategies for implementation,
- (2) current actions which limit the effects of restrictions on implementation, and
- (3) identification of other areas for policy actions.

1. The Most Feasible RD&D Strategies for Implementation

Of all the strategies considered in the report some demonstrated that they were more feasible to implement than others when considering various institutional factors. In previous sections, the selected energy saving strategies were also differentiated by these state-of-the-art from those considered to require future RD&D funding. The focus of this chapter was to identify those RD&D strategies most feasible to achieve mass implementation. A list of such strategies has been provided below in descending order, that is those strategies listed first are most likely to be put into effect based on the analysis:

- (a) Insulation (Conductance and Radiation) - The development of new insulation materials (e.g., foams, variable transmission glass and others)

which would be lower in cost when compared with those presently available would be the most feasible strategy to implement. Major energy savings can be attained for the nation as a whole if new improved, yet cost effective, insulations were produced. Foam insulation has proven to be one step toward achieving the desired energy conserving affects. This product category will meet with some institutional restrictions. Once a new product is found safe for the use it was intended other institutions due to traditional use of such products would readily accept (commercial and consumer institutions) the implementation of the products.

- (b) Infiltration - Infiltration has been identified as the largest component affecting loads when compared to other individual structural components. Increased energy savings can result from decreasing the conductance of a residential structure by identifying the primary areas where infiltration occurs and major areas for heat gains and heat losses or increased loads. Thus, emphasis should be placed upon identifying these losses or gains and establishing a procedure to test for infiltration gains and losses in order to improve the overall energy efficiency of a structure.

Costs, standards, performance requirements, and other areas of institutional concern will act to restrict this strategies implementation, but as credible studies concerning infiltration become available many of these problems will be ameliorated.

- (c) Fossil Fuel Furnaces (Gas and Oil) - Of those furnace strategies considered, lowering the temperature so that the latent heat of vaporization of the water content of flue gases is recovered offers an increase in furnace efficiency. To develop an efficient condensing furnace would require additional RD&D funding.

The primary difficulty for implementation is in the area of codes and standards development. The development of such a product would require appropriate standards and codes applicable to all areas of the country. Also, the high costs of such a product would require financial incentives for both the manufacturer and the consumer to insure mass implementation.

(d) Heat Pumps and Air Conditioners - Strategies to improve the effectiveness of heat pumps and air conditioners which are considered for RD&D include:

- (1) improve compressor efficiency,
- (2) improve the heat transfer effectiveness of outdoor and indoor coil
- (3) improve fan efficiency, and
- (4) improve compressor motor efficiency.

But all of these improvements will experience some restrictions from implementation due to institutional constraints. These constraints will have lesser effects as institutional mechanisms develop toward making product design and product development implementation more efficient.

2. Current Action Which Limits the Effects of Institutional Constraints

This report has emphasized those areas that act as institutional constraints on implementation (e.g., lack of information, cost, and others) but it must also be fully recognized that actions are being taken to mitigate the affects of these constraints. Therefore, some of the current action aimed at mitigating these barriers will be identified. The areas in which policies are being initiated in the areas of:

- (a) code development and coordination,
- (b) standards development,
- (c) costs, and
- (d) information dissemination.

a. Codes. Code development and coordination is being conducted in cooperative efforts between Federal, State, and local governments. Currently, the Energy Research and Development Administration has sponsored a program involving the National Conference of States on Building Codes and Standards (NCSBCS). This project is designed for two purposes:

- (1) develop a model energy conservation code for new building construction based on ASHRAE 90-75, and

- (2) development and testing of an energy conservation educational program for state and local officials.

A draft of the model energy code is developed and is being reviewed. Educational materials are ready for prototype courses to be conducted on a state-by-state basis. Thus, local officials with the help of local interests will have more information on which to implement appropriate building codes.

b. Standards. Energy conservation products can be assessed by prescriptive standards or performance standards with regard to safety requirements of products. Performance standards enhance the energy conservation nature of a product or a system of products. ASHRAE (a private sector technical association) was asked to develop an energy conservation performance standards. The standards developed have become known as ASHRAE 90-75. (ASHRAE 90-75 is a consensus-type standard.) Also, The Housing and Urban Development executive agency is identifying requirements for new construction in the development of Minimum Property Standards as applied to HUD-financed projects. Thus, it is evident that many activities are underway. Other activities are being enacted at the state level. For example, many states have energy councils as well as energy legislation. In a report published by Robert Eisenhard from the National Bureau of Standards (Survey of State Energy Legislation) it is shown that there exist concern for implementing energy conservation initiatives. Yet, to date these endeavors are very limited and sporadically accepted.

c. Costs. The cost of energy conservation strategies are usually beyond that of manufacturers and consumers. Financial incentives and disincentives to develop codes and standards, purchase new energy conserving equipment, to make home improvements and others have been initiated by ERDA, FEA, and HUD.

d. Information Dissemination. Energy conservation information dissemination programs are being conducted by both private sector and public sector concerns. As noted, utilities attempt to inform customers that they can save energy by using insulation, dial down thermostats, and others. Also, Federal, State, and local governments provide energy conservation publications to inform consumers of residential structures and products.

3. Other Policy Actions

There are a number of policy initiatives currently being conducted, but there exist other policy initiatives which if enacted would affect the feasibility to implement the suggested strategies. Below is a partial list of potential programs:

- (a) FEA state plan requiring the development of build-int thermal and lighting standards in order to participate in Federal funding,
- (b) HUD mandatory standards,
- (c) Laboratory Evaluation and Accreditation Project to accredit testing laboratories (National Voluntary Accreditation Program),
- (d) Private sector and public sector financial incentives and tax incentives,
- (e) Increase training activities,
- (f) Increase educational programs,
- (g) Create energy conservation legislation,
- (h) More coordination of code and standard development,
- (i) Performance standards development, and
- (j) Increased involvement of state and local agencies.

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a. This ranking applies to the Baltimore SFD and SFA, Chicago SFD, SFA, and MFLR, and Houston SFD and MFLR residences.

- (1) Improve compressor efficiency
- (2) Improve outdoor coil effectiveness
- (3) Locate ducts entirely within conditioned space
- (4) Improve indoor coil effectiveness
- (5) Improve fan efficiency
- (6) Improve compressor motor efficiency

b. This ranking applies to the Baltimore MFLR and Houston SFA residences.

- (1) Improve compressor efficiency
- (2) Improve outdoor coil effectiveness
- (3) Improve indoor coil effectiveness
- (4) Locate ducts entirely within conditioned space
- (5) Improve fan efficiency
- (6) Improve compressor motor efficiency

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APPENDIX A

ANALYSIS OF VARIOUS MATERIALS, AND DISAGGREGATED STRUCTURAL LOADS FOR THE SINGLE-FAMILY DETACHED, SINGLE-FAMILY ATTACHED AND MULTIFAMILY LOW-RISE STRUCTURES

Within this appendix the following are presented in the form of tables:

- Material components for selected residential structures
- Specifications and disaggregated loads detailing modifications on selected residential structures
- Disaggregated structural loads matrixes for selected residential structures

TABLE A-1. MATERIAL COMPONENTS FOR THE BASE
SINGLE FAMILY DETACHED RESIDENCE

COMPONENTS	"U" VALUE (BTU/HR-FT ² -°F)	THICKNESS (FT.)	CONDUCTIVITY (BTU/HR-FT-°F)	"R" VALUE (HR-FT ² -°F/BTU)
<u>WALL</u>				
Outside Film Coefficient		-----	-----	0.25
Brick Veneer		0.333	0.757	0.44
Insulation Board	0.071	0.042	0.032	1.31
3-1/2" Batt Insulation		0.292	0.0265	11.02
Gypsum Board		0.042	0.093	0.45
Inside Film Coefficient		-----	-----	0.68
				R=14.15
<u>WALL*</u>				
Outside Film Coefficient		-----	-----	0.25
Brick Veneer		0.333	0.757	0.44
Insulation Board	0.133	0.042	0.032	1.31
Wood (2"x4")		0.290	-----	4.37
Gypsum Board		0.042	0.093	0.45
Inside Film Coefficient		-----	-----	0.68
				R= 7.50
<u>ROOF</u>				
Outside Film Coefficient		-----	-----	0.25
Asphalt Shingles		0.042	0.096	0.44
Wood Sheathing		0.042	0.065	0.65
Air Space	0.061	-----	-----	0.96
Loose Fill Insulation		0.500	-----	13.13
Gypsum Board		0.042	0.093	0.45
Inside Film Coefficient		-----	-----	0.61
				R=16.49
<u>ROOF*</u>				
Outside Film Coefficient		-----	-----	0.25
Asphalt Shingles		0.042	0.096	0.44
Wood Sheathing		0.042	0.065	0.65
Wood (2"x4")	0.148	0.290	-----	4.37
Gypsum Board		0.042	0.093	0.45
Inside Film Coefficient		-----	-----	0.61
				R= 6.77
<u>DOOR</u>				
Outside Film Coefficient		-----	-----	0.25
Wood Door	0.413	-----	-----	1.49
Inside Film Coefficient		-----	-----	0.68
				R= 2.42
<u>FLOOR</u>				
Full Concrete Basement	0.200	-----	-----	5.00
<u>WINDOWS</u>				
Single	1.136	-----	-----	0.88
Double	0.689	-----	-----	1.45

*Includes all structural components

TABLE A-2. MATERIAL COMPONENTS FOR THE BASE
SINGLE FAMILY ATTACHED RESIDENCE

COMPONENTS	"U" VALUE (BTU/HR-FT ² -°F)	THICKNESS (FT.)	CONDUCTIVITY (BTU/HR-FT-°F)	"R" VALUE (HR-FT ² -°F/BTU)
<u>WALL</u>				
Outside Film Coefficient		-----	-----	0.25
Brick Veneer		0.333	0.757	0.44
Insulation Board		0.042	0.032	1.31
Air Space	0.089	0.104	-----	1.01
2-1/4" Batt Insulation		0.187	0.0265	7.05
Gypsum Board		0.042	0.093	0.45
Inside Film Coefficient		-----	-----	0.68
				R=11.19
<u>WALL*</u>				
Outside Film Coefficient		-----	-----	0.25
Brick Veneer		0.333	0.757	0.44
Insulation Board	0.133	0.042	0.032	1.31
Wood (2"x4")		0.290	-----	4.37
Gypsum Board		0.042	0.093	0.45
Inside Film Coefficient		-----	-----	0.68
				R=7.50
<u>ROOF</u>				
Outside Film Coefficient		-----	-----	0.25
Wood Shakers		0.073	0.065	1.12
Spaced Boards		0.033	0.085	0.39
Air Space	0.059	-----	-----	0.96
Loose Fill Insulation		0.500	-----	13.13
Gypsum Board		0.042	0.093	0.45
Inside Film Coefficient		-----	-----	0.61
				R=16.91
<u>ROOF*</u>				
Outside Film Coefficient		-----	-----	0.25
Wood Shakers		0.073	0.065	1.12
Spaced Boards	0.139	0.033	0.085	0.39
Wood (2"x4")		0.290	-----	4.37
Gypsum Board		0.042	0.093	0.45
Inside Film Coefficient		-----	-----	0.61
				R=7.19
<u>DOOR</u>				
Outside Film Coefficient		-----	-----	0.25
Wood Door	0.413	-----	-----	1.49
Inside Film Coefficient		-----	-----	0.68
				R=2.42
<u>FLOOR</u>				
Full Concrete Basement	0.200	-----	-----	5.00
<u>WINDOWS</u>				
Single	1.136	-----	-----	0.88
Double	0.689	-----	-----	1.45

*Includes all structural components

TABLE A-3. MATERIAL COMPONENTS FOR THE BASE
MULTIFAMILY LOW-RISE RESIDENCE

COMPONENTS	"U" VALUE (BTU/HR-FT ² -°F)	THICKNESS (FT.)	CONDUCTIVITY (BTU/HR-FT - °F)	"R" VALUE (HR-FT ² -°F/BTU)
<u>WALL</u>				
Outside Film Coefficient		-----	-----	0.25
Brick Veneer		0.333	0.757	0.44
Insulation Board		0.042	0.032	1.31
Air Space	0.089	0.104	-----	1.01
2-1/4" Batt Insulation		0.187	0.0265	7.05
Gypsum Board		0.042	0.0930	0.45
Inside Film Coefficient		-----	-----	0.68
				R=11.19
<u>WALL*</u>				
Outside Film Coefficient		-----	-----	0.25
Brick Veneer		0.333	0.757	0.44
Insulation Board	0.133	0.042	0.032	1.31
Wood (2"x4")		0.290	-----	4.37
Gypsum Board		0.042	0.093	0.45
Inside Film Coefficient		-----	-----	0.68
				R=7.50
<u>WALL (Stairwell)</u>				
Stairwell Film Coefficient		-----	-----	0.60
Brick Veneer		0.333	0.757	0.44
Insulation Board		0.042	0.032	1.31
Air Space		0.104	-----	1.01
2-1/4" Batt Insulation	0.087	0.187	0.0265	7.05
Gypsum Board		0.042	0.0930	0.45
Inside Film Coefficient		-----	-----	0.68
				R=11.54
<u>ROOF</u>				
Outside Film Coefficient		-----	-----	0.25
Asphalt Shingles		0.042	0.096	0.44
Wood Sheathing		0.042	0.065	0.65
Air Space		-----	-----	0.96
Loose Fill Insulation	0.059	0.500	-----	13.13
Gypsum Board		0.042	0.0930	0.45
Inside Film Coefficient		-----	-----	0.61
				R=16.49
<u>ROOF*</u>				
Outside Film Coefficient		-----	-----	0.25
Asphalt Shingles		0.042	0.096	0.44
Wood Sheathing		0.042	0.065	0.65
Wood (2"x4")	0.148	0.290	-----	4.37
Gypsum Board		0.042	0.093	0.45
Inside Film Coefficient		-----	-----	0.61
				R=6.77
<u>DOOR</u>				
Stairwell Film Coefficient	0.326	-----	-----	0.60
Steel Door		-----	-----	1.79
Inside Film Coefficient		-----	-----	0.68
				R=3.07
<u>FLOOR</u>				
Concrete Slab	0.100	-----	-----	10.00
<u>WINDOWS</u>				
Single	1.116	-----	-----	0.88
Double	0.689	-----	-----	1.45

*Includes all structural components

TABLE A-4. SPECIFICATIONS AND DISAGGREGATED LOADS
FOR SINGLE-FAMILY DETACHED (ENERGY CONSERVING)

SPECIFICATIONS			
Component	Conductance	Comments	
Roof	0.050	6" Glass Fiber Insulation (R-19)	
Doors	0.112	Metal/Foam Sandwich	
Floor	0.200	Uninsulated	
Walls	0.084	3-1/2" Glass Fiber Insulation (R-11)	
Windows	0.689	Double Glazing	
Infiltration Parameters		Yes	No
Weatherstripping		X	
Storm Windows			X
Storm Doors			X
Caulking			X

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses						
Roof	71	11	99	11	20	13
Doors	5	1	7	1	1	0
Floor	211	32	256	29	30	20
Walls	93	14	129	15	26	17
Window Conduction	118	18	164	18	32	21
Infiltration	163	24	232	26	44	29
Total Heat Losses	661	100	887	100	153	100
Heat Gains						
Window Radiation	58	9	50	6	38	25
Internal	166	25	190	21	63	41
Heating System (net heating load)	437	66	647	73	52	34
Total Heat Gains	661	100	887	100	153	100

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	8	3	6	3	21	4
Doors	1	0	1	0	1	0
Floor	-	-	-	-	11	2
Walls	10	4	8	4	27	5
Window Conduction	13	5	11	5	35	7
Window Radiation	26	11	21	10	51	10
Infiltration	52	21	40	18	124	24
Internal Heat Gains	137	56	131	60	243	55
Total Heat Gains	247	100	218	100	513	100
Heat Losses						
Floor	89	36	95	44	-	-
Cooling System (net cooling load)	158	64	123	56	513	100
Total Heat Losses	247	100	218	100	513	100

* 1 Therm = 1×10^5 Btu.

TABLE A-5. SPECIFICATIONS AND DISAGGREGATED LOADS
FOR SINGLE-FAMILY DETACHED (IMPROVED)

SPECIFICATIONS			
Component	Conductance	Comments	
Roof	0.036	10" Glass Fiber Insulation (R-30)	
Doors	0.102	Metal/Foam Sandwich and Storm Doors	
Floor	0.045	6" Glass Fiber Insulation (R-19)	
Walls	0.054	3½" Glass Fiber Insulation & 1" Rigid Foam Board (R-17)	
Windows	0.420	Double Glazing and Storm Windows	
Infiltration Parameters		Yes	No
Weatherstripping		X	
Storm Windows		X	
Storm Doors		X	
Caulking			X

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses					NO HEATING REQUIRED	
Roof	47	14	63	14		
Doors	4	1	6	1		
Floor	44	13	52	11		
Walls	55	16	74	16		
Window Conduction	66	19	90	20		
Infiltration	129	37	175	38		
Total Heat Losses	345	100	460	100		
Heat Gains						
Window Radiation	49	14	35	8		
Internal	155	44	169	37		
Heating System (net heating load)	141	42	256	55		
Total Heat Gains	345	100	460	100		

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	5	2	4	2	13	3
Doors	1	0	1	0	1	0
Floor	-	-	-	-	2	0
Walls	6	3	5	2	15	3
Window Conduction	7	3	6	3	17	4
Window Radiation	25	11	21	10	52	12
Infiltration	43	19	33	16	104	23
Internal Heat Gains	139	62	133	67	246	55
Total Heat Gains	226	100	203	100	450	100
Heat Losses						
Floor	21	9	22	11	-	-
Cooling System (net cooling load)	205	91	181	89	450	100
Total Heat Losses	226	100	203	100	450	100

* 1 Therm = 1×10^5 Btu.

TABLE A-6 . SPECIFICATIONS AND DISAGGREGATED LOADS
FOR SINGLE-FAMILY DETACHED (OPTIMIZED)

SPECIFICATIONS			
Component	Conductance	Comments	
Roof	0.031	12" Glass Fiber Insulation (R-38)	
Doors	0.102	Metal/Foam Sandwich and Storm Doors	
Floor	0.033	10" Glass Fiber Insulation (R-30)	
Walls	0.038	6" Glass Fiber Insulation and 2" Rigid Foam (R-31)	
Windows	0.420	Double Glazing and Storm Windows	
Infiltration Parameters		Yes	No
Weatherstripping		X	
Storm Windows		X	
Storm Doors		X	
Caulking		X	

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses					NO HEATING REQUIRED	
Roof	38	13	54	13		
Doors	4	1	6	1		
Floor	32	11	38	9		
Walls	36	13	51	13		
Window Conduction	62	22	88	22		
Infiltration	115	40	168	42		
Total Heat Losses	287	100	405	100		
Heat Gains						
Window Radiation	45	16	35	9		
Internal	143	50	168	41		
Heating System (net heating load)	99	34	202	50		
Total Heat Gains	287	100	405	100		

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	4	2	3	2	10	2
Doors	1	0	1	0	1	0
Floor	-	-	-	-	2	0
Walls	4	2	3	2	10	2
Window Conduction	6	3	5	3	16	4
Window Radiation	26	12	21	11	52	12
Infiltration	41	19	31	16	100	23
Internal Heat Gains	137	62	131	66	243	57
Total Heat Gains	219	100	195	100	434	100
Heat Losses						
Floor	15	7	16	8	-	-
Cooling System (net cooling load)	204	93	179	92	434	100
Total Heat Losses	219	100	195	100	434	100

* 1 Therm = 1×10^5 Btu.

TABLE A-7. SPECIFICATIONS AND DISAGGREGATED LOADS
FOR SINGLE-FAMILY ATTACHED (ENERGY CONSERVING)

SPECIFICATIONS			
Component	Conductance	Comments	
Roof	0.050	6" Glass Fiber Insulation (R-19)	
Doors	0.112	Metal/Foam Sandwich	
Floor	0.200	Uninsulated	
Walls	0.081	3-1/2" Glass Fiber Insulation (R-11)	
Windows	0.689	Double Glazing	
Infiltration Parameters		Yes	No
Weatherstripping		X	
Storm Windows			X
Storm Doors			X
Caulking			X

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses						
Roof	317	8	438	8	83	10
Doors	22	1	30	1	6	1
Floor	856	22	1040	20	116	13
Walls	503	13	696	14	133	15
Window Conduction	813	21	1126	22	213	25
Infiltration	1294	35	1824	35	332	36
Total Heat Losses	3805	100	5154	100	863	100
Heat Gains						
Window Radiation	394	10	336	7	232	27
Internal	1224	32	1400	27	440	51
Heating System (net heating load)	2187	58	3418	66	191	78
Total Heat Gains	3805	100	5154	100	863	100

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	35	2	29	2	95	3
Doors	2	0	2	0	6	0
Floor	-	-	-	-	52	1
Walls	56	3	47	3	151	4
Window Conduction	90	5	72	5	244	7
Window Radiation	173	10	123	8	349	9
Infiltration	415	23	314	20	996	27
Internal Heat Gains	1008	57	960	62	1840	49
Total Heat Gains	1779	100	1547	100	3733	100
Heat Losses						
Floor	359	20	382	25	-	-
Cooling System (net cooling load)	1420	80	1165	75	3733	100
Total Heat Losses	1779	100	1547	100	3733	100

* 1 Therm = 1×10^5 Btu.

TABLE A-8. SPECIFICATIONS AND DISAGGREGATED LOADS
FOR SINGLE-FAMILY ATTACHED (IMPROVED)

SPECIFICATIONS			
Component	Conductance	Comments	
Roof	0.036	10" Glass Fiber Insulation (R-30)	
Doors	0.102	Metal/Foam Sandwich and Storm Door	
Floor	0.045	6" Glass Fiber Insulation (R-19)	
Walls	0.063	3½" Glass Fiber Insulation & 1" Rigid Foam Board (R-17)	
Windows	0.420	Double Glazing and Storm Window	
Infiltration Parameters		Yes	No
Weatherstripping		X	
Storm Windows		X	
Storm Doors		X	
Caulking			X

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses					NO HEATING REQUIRED	
Roof	205	9	288	9		
Doors	18	1	25	1		
Floor	176	8	213	7		
Walls	360	16	502	16		
Window Conduction	446	20	626	20		
Infiltration	986	46	1404	53		
Total Heat Losses	2191	100	3058	100		
Heat Gains						
Window Radiation	313	14	236	8		
Internal	1078	49	1240	41		
Heating System (net heating load)	800	63	1582	51		
Total Heat Gains	2191	100	3058	100		

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	23	1	19	1	61	2
Doors	2	0	2	0	5	0
Floor	-	-	-	-	12	0
Walls	39	2	33	2	106	3
Window Conduction	49	3	41	3	132	4
Window Radiation	173	11	142	10	349	10
Infiltration	346	21	260	18	850	25
Internal Heat Gains	1008	62	960	66	1840	44
Total Heat Gains	1640	100	1457	100	3355	100
Heat Losses						
Floor	81	5	86	6	-	-
Cooling System (net cooling load)	1559	95	1371	94	3355	100
Total Heat Losses	1640	100	1457	100	3355	100

* 1 Therm = 1×10^4 Btu.

TABLE A-9 . SPECIFICATIONS AND DISAGGREGATED LOADS
FOR SINGLE-FAMILY ATTACHED (OPTIMIZED)

SPECIFICATIONS				
Component	Conductance	Comments		
Roof	0.031	12" Glass Fiber Insulation (R-38)		
Doors	0.102	Metal/Foam Sandwich Plus Storm Door		
Floor	0.033	10" Glass Fiber Insulation (R-30)		
Walls	0.046	6" Glass Fiber Insulation and 2" Rigid Foam (R-31)		
Windows	0.42	Insulation Double Glazed Plus Storm Window		
	Infiltration Parameters		Yes	No
	Weatherstripping		X	
	Storm Windows		X	
	Storm Doors		X	
	Caulking		X	

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses						
Roof	174	9	244	9		
Doors	17	1	24	1		
Floor	129	7	155	6		
Walls	270	14	377	14		
Window Conduction	440	22	616	22		
Infiltration	944	47	1338	48		
Total Heat Losses	1974	100	2754	100		
Heat Gains						
Window Radiation	313	16	236	9		
Internal	1076	55	1238	45		
Heating System (net heating load)	585	29	1280	46		
Total Heat Gains	1974	100	2754	100		
					NO HEATING REQUIRED	

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	18	1	15	1	50	2
Doors	2	0	2	0	5	0
Floor	-	-	-	-	9	0
Walls	28	2	24	2	76	2
Window Conduction	46	3	39	3	125	4
Window Radiation	173	11	142	10	349	11
Infiltration	331	21	249	17	817	25
Internal Heat Gains	1008	62	960	67	1840	56
Total Heat Gains	1606	100	1431	100	3271	100
Heat Losses						
Floor	59	4	63	4	-	-
Cooling System (net cooling load)	1547	96	1368	96	3271	100
Total Heat Losses	1606	100	1431	100	3271	100

* 1 Therm = 1×10^5 Btu.

TABLE A-10. SPECIFICATIONS AND DISAGGREGATED LOADS
FOR MULTIFAMILY LOW-RISE (ENERGY CONSERVING)

SPECIFICATIONS			
Component	Conductance	Comments	
Roof	0.061	6" Glass Fiber Insulation (R-19)	
Doors	0.112	Metal/Foam Sandwich	
Floor	0.1	Poured Concrete, Uninsulated	
Walls	0.084	3-1/2" Glass Fiber Insulation (R-11)	
Windows	0.689	Double Glazing	
Infiltration Parameters		Yes	No
Weatherstripping		X	
Storm Windows			X
Storm Doors			X
Caulking			X

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses						
Roof	325	13	1122	13	181	23
Doors	62	1	62	1	8	1
Floor	744	12	949	11	14	2
Walls	1100	18	1547	18	144	19
Window Conduction	1694	27	2387	27	210	27
Infiltration	1824	29	2624	30	222	28
Total Heat Losses	6249	100	8691	100	778	100
Heat Gains						
Window Radiation	707	11	597	7	211	27
Internal	2804	45	3268	38	483	62
Heating System (net heating load)	2738	44	4826	55	84	11
Total Heat Gains	6249	100	8691	100	778	100

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	92	2	77	2	248	3
Doors	7	0	6	0	20	0
Floor	-	-	-	-	45	1
Walls	127	3	108	3	349	4
Window Conduction	198	5	168	5	541	7
Window Radiation	377	10	307	9	712	9
Infiltration	622	16	473	14	1478	17
Internal Heat Gains	2448	64	2342	67	4512	59
Total Heat Gains	3871	100	3481	100	7905	100
Heat Losses						
Floor	326	8	347	10	-	-
Cooling System (net cooling load)	3545	92	3134	90	7905	100
Total Heat Losses	3871	100	3481	100	7905	100

* 1 Therm = 1×10^5 Btu.

TABLE A-11. SPECIFICATIONS AND DISAGGREGATED LOADS
FOR MULTIFAMILY LOW-RISE (IMPROVED)

SPECIFICATIONS			
Component	Conductance	Comments	
Roof	0.048	10" Glass Fiber Insulation (R-30)	
Doors	0.102	Metal/Foam Sandwich and Storm Door	
Floor	0.1	Poured Concrete, Uninsulated	
Walls	0.068	3½" Glass Fiber Insulation & 1" Rigid Foam Board (R-17)	
Windows	0.42	Double Glazing and Storm Window	
Infiltration Parameters		Yes	No
Weatherstripping		X	
Storm Windows		X	
Storm Doors		X	
Caulking			X

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses						
Roof	594	13	846	13		
Doors	52	1	74	1		
Floor	718	15	844	13		
Walls	956	20	1346	21		
Window Conduction	968	20	1352	21		
Infiltration	1434	31	2044	31		
Total Heat Losses	4722	100	6506	100		
Heat Gains						
Window Radiation	660	14	493	8	NO HEATING REQUIRED	
Internal	2600	55	2960	45		
Heating System (net heating load)	1462	69	3053	47		
Total Heat Gains	4722	100	6506	100		

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	64	2	54	2	172	2
Doors	6	0	5	0	38	1
Floor	-	-	-	-	47	1
Walls	108	3	90	3	294	4
Window Conduction	111	3	93	3	299	4
Window Radiation	378	10	307	9	756	10
Infiltration	511	14	386	12	1242	17
Internal Heat Gains	2444	68	2340	71	4512	61
Total Heat Gains	3622	100	3275	100	7360	100
Heat Losses						
Floor	326	10	347	11	-	-
Cooling System (net cooling load)	3296	90	2928	89	7360	100
Total Heat Losses	3622	100	3275	100	7360	100

* 1 Therm = 1×10^5 Btu.

TABLE A-12. SPECIFICATIONS AND DISAGGREGATED LOADS
FOR MULTIFAMILY LOW-RISE (OPTIMIZED)

SPECIFICATIONS			
Component	Conductance	Comments	
Roof	0.043	12" Glass Fiber Insulation (R-38)	
Doors	0.102	Metal/Foam Sandwich and Storm Door	
Floor	0.1	Poured Concrete, Uninsulated	
Walls	0.053	6" Glass Fiber Insulation & 2" Rigid Foam Board (R-31)	
Windows	0.42	Double Glazing and Storm Window	
Infiltration Parameters		Yes	No
Weatherstripping		X	
Storm Windows		X	
Storm Doors		X	
Caulking		X	

DISAGGREGATED HEATING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Losses					NO HEATING REQUIRED	
Roof	476	12	706	13		
Doors	48	1	71	1		
Floor	670	17	832	15		
Walls	581	15	852	15		
Window Conduction	870	22	1292	23		
Infiltration	1238	33	1866	33		
Total Heat Losses	3883	100	5619	100		
Heat Gains						
Window Radiation	567	15	450	8		
Internal	2300	59	2780	49		
Heating System (net heating load)	1016	26	2389	43		
Total Heat Gains	3883	100	5619	100		

DISAGGREGATED COOLING LOADS						
Component	Baltimore		Chicago		Houston	
	Therms*	Percent	Therms	Percent	Therms	Percent
Structural Heat Gains						
Roof	55	2	45	1	149	2
Doors	6	0	5	0	16	0
Floor	-	-	-	-	47	1
Walls	70	2	59	2	191	3
Window Conduction	108	3	90	3	288	4
Window Radiation	377	11	331	10	756	11
Infiltration	487	14	367	11	1188	17
Internal Heat Gains	2448	68	2340	73	4512	62
Total Heat Gains	3551	100	3237	100	7147	100
Heat Losses						
Floor	326	9	347	11	-	-
Cooling System (net cooling load)	3225	91	2890	89	7147	100
Total Heat Losses	3551	100	3237	100	7147	100

* 1 Therm = 1×10^5 Btu.

TABLE A-13. DISAGGREGATED STRUCTURAL COMPONENT LOADS MATRIX FOR
BALTIMORE SINGLE-FAMILY DETACHED

(1 Therm = 10^5 Btu)

Structural Component Strategies	Roof		Doors		Floor		Walls		Window (Conduction)		Window (Radiation)		Internal		Infiltration		Heating		Cooling		Net Annual Structural Load (Therm)	
	Heating		Heating		Heating		Heating		Heating		Heating		Heating		Heating		Total Structural Heat Loss		Total Structural Heat Gain		Heating	Cooling
	Roof	Cooling	Doors	Cooling	Floor	Cooling	Walls	Cooling	Window (Conduction)	Cooling	Window (Radiation)	Cooling	Internal	Cooling	Infiltration	Cooling	Total Structural Heat Loss	Total Structural Heat Gain	Total Structural Heat Loss	Total Structural Heat Gain		
BASE BUILDING	-95	+11	-20	+2	-216	-84	-96	+11	-179	+20	+69	+26	+171	129	-188	+59	-794	+240	-84	+260	-554	+118
1) Roof																						
R-19	-72	+8	-20	+2	-213	-84	-95	+11	-177	+20	+62	+28	+168	+130	-184	+59	-761	+230	-84	+258	-531	+174
R-30	-52	+6	-20	+2	-213	-84	-94	+11	-176	+20	+62	+28	+167	+130	-184	+59	-739	+229	-84	+256	-510	+172
R-38	-45	+5	-20	+2	-212	-84	-94	+10	-176	+20	+62	+28	+167	+130	-184	+59	-731	+229	-84	+256	-502	+172
2) Floor																						
R-19	-95	+11	-20	+2	-48	-19	-95	+11	-177	+20	+62	+28	+169	+129	-184	+59	-619	+231	-19	+260	-388	+241
R-30	-95	+11	-20	+2	-35	-14	-95	+11	-177	+20	+62	+28	+169	+129	-184	+59	-606	+231	-14	+260	-375	+246
3) Wall																						
R-17	-94	+11	-20	+2	-213	-84	-61	+7	-176	+20	+62	+28	+168	+130	-184	+60	-748	+230	-84	+258	-518	+174
R-31	-94	+10	-20	+2	-212	-84	-43	+5	-176	+20	+62	+28	+167	+130	-184	+60	-729	+229	-84	+255	-500	+171
4) Windows																						
Double Glazing (with weather- stripping)	-93	+10	-20	+2	-212	-84	-94	+10	-120	+13	+58	+26	+167	+130	-163	+52	-702	+225	-84	+243	-477	+159
Double Glazing (with storm windows and weather- stripping)	-92	+10	-20	+2	-210	-85	-93	+10	-72	+8	+58	+26	+165	+131	-134	+43	-621	+223	-85	+230	-398	+145
Double Glazing (with caulked storm windows and weather- stripping)	-92	+10	-20	+2	-210	-85	-93	+10	-72	+8	+58	+26	+165	+131	-127	+41	-614	+223	-85	+228	-391	+143
30 Percent Window Reduction	-94	+10	-20	+2	-214	-84	-100	+11	-123	+14	+48	+19	+169	+130	-167	+52	-718	+217	-84	+238	-501	+154

TABLE A-14. DISAGGREGATED STRUCTURAL COMPONENT LOADS MATRIX FOR
CHICAGO SINGLE-FAMILY DETACHED

(1 Therm = 10^5 Btu)

Structural Component Strategies	Roof		Doors		Floor		Walls		Window (Conduction)		Window (Radiation)		Internal		Infiltration		Heating		Cooling		Net Annual Structural Load (Therms)	
																	Total Structural Heat Loss	Total Structural Heat Gain	Total Structural Heat Loss	Total Structural Heat Gain	Heating	Cooling
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling						
BASE BUILDING	-131	+9	-28	+2	-260	-88	-132	+9	-245	+17	+53	+23	+193	+122	-260	+45	-1056	+246	-88	+226	-810	+138
1) Roof																						
R-19	-100	+7	-28	+2	-259	-89	-131	+9	-244	+17	+53	+23	+192	+122	-260	+45	-1022	+245	-89	+225	-777	+136
R-30	-72	+5	-27	+2	-258	-89	-131	+9	-243	+16	+53	+23	+191	+123	-260	+45	-991	+244	-89	+223	-747	+134
R-38	-62	+4	-27	+2	-258	-89	-131	+9	-243	+16	+53	+23	+191	+123	-260	+45	-981	+244	-89	+222	-737	+133
2) Floor																						
R-19	-131	+9	-28	+2	-59	-20	-132	+9	-245	+17	+53	+23	+193	+122	-260	+45	-855	+246	-20	+227	-609	+207
R-30	-131	+9	-28	+2	-43	-15	-132	+9	-245	+17	+53	+23	+193	+122	-260	+45	-839	+246	-15	+227	-593	+212
3) Wall																						
R-17	-130	+9	-28	+2	-259	-89	-84	+6	-244	+16	+53	+23	+192	+123	-260	+45	-1005	+245	-89	+224	-760	+135
R-31	-129	+9	-27	+2	-258	-89	-59	+4	-243	+16	+53	+23	+191	+123	-260	+45	-976	+244	-89	+222	-732	+133
4) Windows																						
Double Glazing (with weather-stripping)	-129	+9	-27	+2	-258	-89	-130	+9	-165	+11	+49	+21	+191	+123	-231	+40	-823	+240	-89	+215	-583	+126
Double Glazing (with storm windows and weather-stripping)	-127	+8	-27	+2	-256	-90	-128	+8	-100	+6	+49	+21	+189	+124	-187	+32	-825	+238	-90	+201	-587	+111
Double Glazing (with caulked storm windows and weather-stripping)	-127	+8	-27	+2	-256	-90	-128	+8	-100	+6	+49	+21	+189	+124	-180	+31	-818	+238	-90	+200	-580	+110
30 Percent Window Reduction	-129	+9	-27	+2	-258	-89	-136	+9	-169	+11	+37	+16	+191	+123	-231	+40	-950	+228	-89	+210	-722	+121

TABLE A-15. DISAGGREGATED STRUCTURAL COMPONENT LOADS MATRIX FOR
HOUSTON SINGLE-FAMILY DETACHED

(1 Therm = 10^5 Btu)

Structural Component Strategies	Roof		Doors		Floor		Walls		Window (Conduction)		Window (Radiation)		Internal		Infiltration		Heating Total Structural Heat Loss		Cooling Total Structural Heat Gain		Net Annual Structural Load (Therms)	
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
BASE BUILDING	-30	+29	-6	+6	-30	+13	-30	+29	-56	+54	+51	+56	+76	+235	-58	+138	-210	+127	*	+560	-83	+560
1) Roof																						
R-19	-23	+22	-6	+6	-29	+13	-30	+29	-56	+56	+51	+56	+75	+236	-58	+138	-202	+126	*	+556	-76	+556
R-30	-17	+16	-6	+6	-29	+13	-30	+28	-56	+53	+51	+56	+75	+236	-58	+138	-196	+126	*	+546	-70	+546
R-38	-14	+13	-6	+6	-29	+13	-30	+28	-56	+53	+51	+56	+75	+236	-58	+138	-193	+126	*	+543	-67	+543
2) Floor																						
R-19	-30	+29	-6	+6	-7	+3	-30	+29	-57	+54	+51	+56	+76	+235	-58	+138	-188	+127	*	+550	-61	+550
R-30	-30	+29	-6	+6	-5	+2	-30	+29	-57	+54	+51	+56	+76	+235	-58	+138	-186	+127	*	+549	-59	+549
3) Wall																						
R-17	-30	+28	-6	+6	-29	+13	-20	+18	-56	+53	+51	+56	+75	+236	-58	+138	-199	+126	*	+548	-72	+548
R-31	-30	+28	-6	+6	-29	+12	-14	+13	-56	+52	+51	+56	+75	+236	-58	+138	-193	+126	*	+541	-67	+541
4) Windows																						
Double Glazing (with weather- stripping)	-26	+28	-5	+6	-30	+12	-26	+28	-33	+36	+37	+51	+63	+237	-44	+124	-164	+100	*	+522	-64	+522
Double Glazing (with storm windows and weather- stripping)	-25	+27	-5	+6	-30	+12	-25	+27	-20	+21	+37	+51	+62	+238	-37	+105	-142	+99	*	+487	-53	+487
Double Glazing (with caulked storm windows and weather- stripping)	-25	+27	-5	+6	-30	+12	-25	+27	-20	+21	+37	+51	+62	+238	-36	+101	-141	+99	*	+483	-42	+483
30 Percent Window Reduction	-30	+20	-6	+6	-29	+12	-31	+30	-39	+37	+35	+39	+75	+236	-52	+124	-187	+110	*	+504	-77	+504

*No Heating Required

TABLE A-16. DISAGGREGATED STRUCTURAL COMPONENT LOADS MATRIX FOR
BALTIMORE SINGLE-FAMILY ATTACHED

(1 Therm = 10^5 Btu)

Structural Component Strategies	Roof		Doors		Floor		Walls		Window (Conduction)		Window (Radiation)		Internal		Infiltration		Heating		Cooling		Net Annual Structural Load (Therms)	
	Heating		Heating		Heating		Heating		Heating		Heating		Heating		Heating		Total Structural Heat Loss	Total Structural Heat Gain	Total Structural Heat Loss	Total Structural Heat Gain		
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
BASE BUILDING	-415	+48	-81	+9	-874	-329	-606	+71	-1370	+160	+422	+187	+1260	+930	-1460	+467	-4806	+1682	-329	+1872	-3124	+1543
1) Roof																						
R-19	-324	+38	-81	+9	-871	-330	-605	+70	-1370	+159	+422	+187	+1260	+933	-1460	+467	-4711	+1682	-330	+1863	-3029	+1533
R-30	-233	+27	-81	+9	-870	-331	-604	+70	-1370	+158	+422	+187	+1250	+936	-1460	+467	-4618	+1672	-331	+1854	-2946	+1523
R-38	-200	+23	-81	+9	-868	-331	-603	+70	-1370	+158	+422	+187	+1250	+937	-1460	+467	-4582	+1672	-331	+1851	-2910	+1520
2) Floor																						
R-19	-415	+48	-81	+9	-197	-74	-606	+71	-1370	+160	+422	+187	+1260	+930	-1460	+467	-4129	+1682	-74	+1872	-2447	+1798
R-30	-415	+48	-81	+9	-144	-54	-606	+71	-1370	+160	+422	+187	+1260	+930	-1460	+467	-4076	+1682	-54	+1872	-2394	+1818
3) Wall																						
R-17	-413	+48	-81	+9	-868	-331	-388	+45	-1370	+158	+422	+187	+1250	+937	-1460	+467	-4580	+1672	-331	+1851	-2908	+1520
R-31	-412	+48	-81	+9	-864	-332	-282	+32	-1360	+158	+422	+187	+1250	+940	-1460	+467	-4459	+1672	-332	+1841	-2787	+1509
4) Windows																						
Double Glazing (with weather-stripping)	-404	+44	-79	+9	-848	-339	-589	+65	-494	+54	+391	+174	+1220	+956	-1300	+418	-3714	+1611	-339	+1720	-2103	+1381
Double Glazing (with storm windows and weather-stripping)	-404	+44	-79	+9	-848	-339	-589	+65	-494	+54	+391	+174	+1220	+956	-1080	+348	-3494	+1611	-339	+1650	-1883	+1311
Double Glazing (with caulked storm windows and weather-stripping)	-404	+44	-79	+9	-848	-339	-589	+65	-494	+54	+391	+174	+1220	+956	-1040	+333	-3454	+1611	-339	+1635	-1843	+1296
30 Percent Window Reduction	-641	+73	-81	+9	-869	-333	-641	+73	-962	+109	+328	+131	+1260	+942	-1490	+467	-4684	+1588	-333	+1804	-3096	+1471

TABLE A-17. DISAGGREGATED STRUCTURAL COMPONENT LOADS MATRIX FOR
CHICAGO SINGLE-FAMILY ATTACHED

(1 Therm = 10^5 Btu)

Structural Component Strategies	Roof		Doors		Floor		Walls		Window (Conduction)		Window (Radiation)		Internal		Infiltration		Heating Total Structural Heat Loss		Cooling Total Structural Heat Gain		Net Annual Structural Load (Therms)	
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
BASE BUILDING	- 574	+ 41	- 112	+ 8	-1060	- 346	- 838	+ 59	-1900	+ 134	+ 361	+ 153	+ 1440	+ 874	-2050	+ 353	- 6534	+ 1801	- 346	+ 1622	-4733	+1276
1) Roof																						
R-17	- 448	+ 31	- 112	+ 8	-1050	- 347	- 837	+ 59	-1900	+ 133	+ 361	+ 153	+ 1430	+ 877	-2050	+ 353	- 6397	+ 1791	- 347	+ 1614	-4606	+1267
R-30	- 322	+ 23	- 112	+ 8	-1050	- 348	- 835	+ 58	-1890	+ 132	+ 361	+ 153	+ 1430	+ 880	-2050	+ 353	- 6259	+ 1791	- 348	+ 1607	-4466	+1259
R-36	- 227	+ 19	- 112	+ 8	-1050	- 349	- 834	+ 58	-1890	+ 132	+ 361	+ 153	+ 1430	+ 881	-2050	+ 353	- 6163	+ 1791	- 349	+ 1604	-4372	+1255
2) Floor																						
R-19	- 574	+ 41	- 112	+ 8	- 238	- 78	- 838	+ 59	-1900	+ 134	+ 361	+ 153	+1440	+ 874	-2050	+ 353	- 5712	+ 1801	- 78	+ 1622	-3911	+1544
R-30	- 574	+ 41	- 112	+ 8	- 174	- 57	- 838	+ 59	-1900	+ 134	+ 361	+ 153	+1440	+ 874	-2050	+ 353	- 5648	+ 1801	- 57	+ 1622	-3847	+1565
3) Wall																						
R-17	- 572	+ 40	- 112	+ 8	-1050	- 349	- 536	+ 37	-1890	+ 132	+ 361	+ 153	+1430	+ 881	-2050	+ 353	- 6210	+ 1791	- 349	+ 1604	-4419	+1255
R-31	- 570	+ 40	- 111	+ 8	-1050	- 350	- 390	+ 27	-1890	+ 131	+ 361	+ 153	+1420	+ 885	-2050	+ 353	- 6061	+ 1781	- 350	+ 1597	-4280	+1247
4) Windows																						
Double Glazing (with weather- stripping)	- 558	+ 37	- 109	+ 7	-1030	- 358	- 815	+ 54	- 683	+ 45	+ 335	+ 142	+1390	+ 903	-1930	+ 332	- 5125	+ 1725	- 358	+ 1520	-3400	+1162
Double Glazing (with storm windows and weather- stripping)	- 558	+ 37	- 109	+ 7	-1030	- 358	- 815	+ 54	- 683	+ 45	+ 335	+ 142	+1390	+ 903	-1520	+ 262	- 4715	+ 1725	- 358	+ 1450	-2990	+1092
Double Glazing (with caulked storm windows and weather- stripping)	- 558	+ 37	- 109	+ 7	-1030	- 358	- 815	+ 54	- 683	+ 45	+ 335	+ 142	+1390	+ 903	-1460	+ 251	- 4655	+ 1725	- 358	+ 1439	-2930	+1081
30 Percent Window Reduction	- 569	+ 39	- 111	+ 8	-1050	- 351	- 879	+ 61	-1320	+ 91	+ 253	+ 107	+1420	+ 887	-2050	+ 353	- 5979	+ 1673	- 351	+ 1546	-4306	+1195

TABLE A-18. DISAGGREGATED STRUCTURAL COMPONENT LOADS MATRIX FOR
HOUSTON SINGLE-FAMILY ATTACHED

(1 Therm = 10⁵ Btu)

Structural Component Strategies	Roof		Doors		Floor		Walls		Window (Conduction)		Window (Radiation)		Internal		Infiltration		Heating Total Structural Heat Loss		Cooling Total Structural Heat Gain		Net Annual Structural Load (Therms)	
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Total Structural Heat Loss	Total Structural Heat Gain	Total Structural Heat Loss	Total Structural Heat Gain	Heating	Cooling
BASE BUILDING	- 132	+ 131	- 26	+ 26	- 123	+ 54	- 193	+ 191	- 438	+ 433	+ 344	+ 376	+ 579	+1710	- 460	+1100	-1372	+ 923	*	+4021	- 449	+4021
1) Roof																						
R-19	- 103	+ 102	- 26	+ 26	- 122	+ 54	- 193	+ 190	- 437	+ 431	+ 344	+ 376	+ 576	+1720	- 460	+1100	-1341	+ 920	*	+3999	- 421	+3999
R-30	- 74	+ 73	- 26	+ 25	- 121	+ 54	- 192	+ 189	- 436	+ 428	+ 344	+ 376	+ 572	+1720	- 460	+1100	-1309	+ 916	*	+3965	- 393	+3965
R-38	- 64	+ 63	- 26	+ 26	- 121	+ 54	- 192	+ 188	- 436	+ 427	+ 344	+ 376	+ 570	+1720	- 460	+1100	-1299	+ 914	*	+3954	- 385	+3954
2) Floor																						
R-19	- 132	+ 131	- 26	+ 26	- 28	+ 12	- 193	+ 191	- 438	+ 433	+ 344	+ 376	+ 579	+1710	- 460	+1100	-1277	+ 923	*	+3979	- 354	+3979
R-30	- 132	+ 131	- 26	+ 26	- 20	+ 9	- 193	+ 191	- 438	+ 433	+ 344	+ 376	+ 579	+1710	- 460	+1100	-1269	+ 923	*	+3976	- 346	+3976
3) Wall																						
R-17	- 132	+ 129	- 26	+ 25	- 121	+ 54	- 124	+ 121	- 438	+ 427	+ 344	+ 376	+ 570	+1720	- 460	+1100	-1301	+ 914	*	+3952	- 387	+3952
R-31	- 131	+ 128	- 26	+ 25	- 120	+ 54	- 90	+ 88	- 435	+ 423	+ 344	+ 376	+ 566	+1730	- 460	+1100	-1262	+ 910	*	+3924	- 352	+3924
4) Windows																						
Double Glazing (with weather- stripping)	- 110	+ 120	- 22	+ 23	- 121	+ 53	- 161	+ 175	- 135	+ 147	+ 254	+ 349	+ 460	+1760	- 356	+1000	- 905	+ 714	*	+3627	- 191	+3627
Double Glazing (with storm windows and weather- stripping)	- 104	+ 120	- 20	+ 23	- 113	+ 53	- 151	+ 175	- 127	+ 147	+ 220	+ 349	+ 430	+1760	- 275	+ 849	- 790	+ 650	*	+3476	- 140	+3476
Double Glazing (with caulked storm windows and weather- stripping)	- 104	+ 120	- 20	+ 23	- 113	+ 53	- 151	+ 175	- 127	+ 147	+ 220	+ 349	+ 430	+1760	- 263	+ 812	- 778	+ 650	*	+3439	- 128	+3439
30 Percent Window Reduction	- 131	+ 127	- 26	+ 25	- 120	+ 54	- 203	+ 197	- 304	+ 295	+ 241	+ 264	+ 564	+1730	- 460	+1100	-1244	+ 805	*	+3792	- 439	+3792

*No Heating Required

TABLE A-19. DISAGGREGATED STRUCTURAL COMPONENT LOADS MATRIX FOR
BALTIMORE MULTIFAMILY LOW-RISE

(1 Therm = 10^5 Btu)

Structural Component Strategies	Roof		Doors		Floor		Walls		Window (Conduction)		Window (Radiation)		Internal		Infiltration		Heating		Cooling		Net Annual Structural Load (Therms)	
																	Total Structural Heat Loss	Total Structural Heat Gain	Total Structural Heat Loss	Total Structural Heat Gain	Heating	Cooling
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling						
BASE BUILDING	-1060	+ 123	- 192	+ 23	- 834	- 313	-1360	+ 159	-2980	+ 348	+ 915	+ 406	+3140	+2310	-2220	+ 711	-8646	+4055	- 313	+4080	-4591	+3767
1) Roof																						
R-19	- 881	+ 102	- 192	+ 22	- 832	- 314	-1360	+ 158	-2980	+ 347	+ 915	+ 406	+3130	+2320	-2220	+ 711	-8465	+4045	- 314	+4066	-4420	+3752
R-30	- 692	+ 80	- 192	+ 22	- 829	- 315	-1350	+ 157	-2970	+ 345	+ 915	+ 406	+3120	+2320	-2220	+ 711	-8253	+4035	- 315	+4041	-4218	+3726
R-38	- 619	+ 72	- 192	+ 22	- 828	- 315	-1350	+ 156	-2970	+ 344	+ 915	+ 406	+3110	+2330	-2220	+ 711	-8179	+4025	- 315	+4041	-4154	+3726
2) Floor																						
R-19																						
R-30																						
3) Wall																						
R-17	-1050	+ 122	- 192	+ 22	- 829	- 315	- 939	+ 109	-2970	+ 344	+ 915	+ 406	+3110	+2330	-2220	+ 711	-8200	+4025	- 315	+4044	-4175	+3729
R-31	-1020	+ 121	- 185	+ 22	- 784	- 316	- 708	+ 84	-2880	+ 341	+ 783	+ 406	+2950	+2330	-2130	+ 711	-7707	+3733	- 316	+4015	-3974	+3699
4) Windows																						
Double Glazing (with weather-stripping)	- 997	+ 113	- 182	+ 21	- 771	- 322	-1280	+ 146	-1040	+ 119	+ 726	+ 377	+2900	+2370	-1860	+ 622	-6130	+3626	- 322	+3768	-2504	+3446
Double Glazing (with storm windows and weather-stripping)	- 997	+ 113	- 182	+ 21	- 771	- 322	-1280	+ 146	-1040	+ 119	+ 726	+ 377	+2900	+2370	-1550	+ 519	-5820	+3626	- 322	+3665	-2194	+3343
Double Glazing (with caulked storm windows and weather-stripping)	- 945	+ 113	- 172	+ 21	- 749	- 322	-1220	+ 146	- 987	+ 119	+ 652	+ 377	+2670	+2370	-1370	+ 489	-5443	+3322	- 322	+3635	-2121	+3313
30 Percent Window Reduction	-1050	+ 120	- 191	+ 22	- 823	- 317	-1420	+ 163	-2070	+ 237	+ 641	+ 284	+3090	+2340	-2220	+ 711	-7774	+3731	- 317	+3877	-4043	+3560

TABLE A-20. DISAGGREGATED STRUCTURAL COMPONENT LOADS MATRIX FOR
CHICAGO MULTIFAMILY LOW-RISE
(1 Therm = 10^5 Btu)

Structural Component Strategies	Roof		Doors		Floor		Walls		Window (Conduction)		Window (Radiation)		Internal		Infiltration		Heating Total Structural Heat Loss		Cooling Total Structural Heat Gain		Net Annual Structural Load (Therms)	
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
BASE BUILDING	-1460	+ 103	- 266	+ 19	-1010	- 329	-1880	+ 133	-4130	+ 291	+ 783	+ 332	+3570	+2170	-3100	+ 534	-11846	+ 4353	- 329	+ 3582	- 7493	+ 3253
1) Roof																						
R-19	-1220	+ 86	- 266	+ 19	-1010	-330	-1880	+ 132	-4120	+ 290	+ 783	+ 332	+3560	+2180	-3100	+ 534	-11596	+ 4343	- 330	+ 3573	- 7253	+ 3243
R-30	- 957	+ 67	- 265	+ 19	-1000	-331	-1870	+ 131	-4110	+ 288	+ 783	+ 332	+3550	+2190	-3100	+ 534	-11302	+ 4333	- 331	+ 3561	- 6969	+ 3230
R-38	- 856	+ 60	- 265	+ 19	-1000	-332	-1870	+ 131	-4110	+ 287	+ 783	+ 332	+3550	+2190	-3100	+ 534	-11201	+ 4333	- 332	+ 3553	- 6868	+ 3221
2) Floor																						
R-19																						
R-30																						
3) Wall																						
R-17	-1450	+ 102	- 265	+ 19	-1000	-332	-1300	+ 91	-4110	+ 288	+ 783	+ 332	+3550	+2190	-3100	+ 534	-11225	+ 4333	- 332	+ 3556	- 6892	+ 3224
R-31	-1420	+ 101	- 260	+ 18	- 982	-333	- 998	+ 70	-4030	+ 285	+ 686	+ 332	+3410	+2200	-3020	+ 534	-10710	+ 4096	- 333	+ 3540	- 6614	+ 3207
4) Windows																						
Double Glazing (with weather- stripping)	-1400	+ 95	- 255	+ 17	- 967	-340	-1800	+ 122	-1460	+ 99	+ 636	+ 308	+3360	+2240	-2660	+ 470	- 8542	+ 3996	- 340	+ 3351	- 4546	+ 3011
Double Glazing (with storm windows and weather- stripping)	-1340	+ 95	- 245	+ 17	- 906	-340	-1730	+ 122	-1400	+ 99	+ 510	+ 308	+3130	+2240	-2070	+ 385	- 7691	+ 3640	- 340	+ 3266	- 4051	+ 2926
Double Glazing (with caulked storm windows and weather- stripping)	-1340	+ 95	- 245	+ 17	- 906	-340	-1730	+ 122	-1400	+ 99	+ 510	+ 308	+3130	+2240	-1960	+ 363	- 7581	+ 3640	- 340	+ 3244	- 3941	+ 2904
30 Percent Window Reduction	-1450	+ 100	- 264	+ 18	- 997	- 334	-1970	+ 136	-2860	+ 198	+ 548	+ 233	+3530	+2200	-3100	+ 534	-10641	+ 4078	- 334	+ 3419	- 6563	+ 3085

TABLE A-21. DISAGGREGATED STRUCTURAL COMPONENT LOADS MATRIX FOR
HOUSTON MULTIFAMILY LOW-RISE

(1 Therm = 10^5 Btu)

Structural Component Strategies	Roof		Doors		Floor		Walls		Window (Conduction)		Window (Radiation)		Internal		Infiltration		Heating		Cooling		Net Annual Structural Load (Therms)	
																	Total Structural Heat Loss	Total Structural Heat Gain	Total Structural Heat Loss	Total Structural Heat Gain		
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling					Heating	Cooling
BASE BUILDING	-271	+333	-50	+61	-115	+52	-349	+429	-767	+942	+514	+817	+1140	+4260	-533	+1640	-2085	+1654	*	+8534	-431	+8534
1) Roof																						
R-19	-226	+277	-49	+60	-114	+52	-349	+429	-766	+937	+514	+817	+1130	+4270	-533	+1640	-2037	+1644	*	+8482	-393	+8482
R-30	-178	+217	-49	+60	-113	+52	-348	+424	-764	+931	+514	+817	+1120	+4280	-533	+1640	-1985	+1634	*	+8421	-351	+8421
R-38	-159	+194	-49	+60	-113	+52	-348	+423	-764	+929	+514	+817	+1120	+4280	-533	+1640	-1966	+1634	*	+8395	-332	+8395
2) Floor																						
R-17																						
R-20																						
3) Wall																						
R-17	-270	+329	-49	+60	-113	+52	-241	+294	-764	+930	+514	+817	+1120	+4280	-533	+1640	-1970	+1634	*	+8402	-336	+8402
R-31	-270	+327	-49	+60	-113	+52	-123	+227	-762	+923	+514	+817	+1110	+4290	-533	+1640	-1915	+1624	*	+8336	-291	+8336
4) Windows																						
Double Glazing (with weather-stripping)	-82	+307	-15	+56	-42	+51	-105	+395	-85	+320	+135	+757	+318	+4370	-143	+1480	-472	+453	*	+7736	-19	+7736
Double Glazing (with storm windows and weather-stripping)	*	+307	*	+56	*	+51	*	+395	*	+320	*	+757	*	+4370	*	+1230	*	*	*	+7486	*	+7486
Double Glazing (with caulked storm windows and weather-stripping)	*	+307	*	+56	*	+51	*	+395	*	+320	*	+757	*	+4370	*	+1190	*	*	*	+7446	*	+7446
30 Percent Window Reduction	-286	+324	-52	+59	-120	+51	-389	+441	-566	+641	+416	+572	+1190	+4310	-585	+1640	-1998	+1606	*	+8038	-392	+8038

*: Heating Required

APPENDIX B

IDENTIFICATION OF ROLES FOR PRIVATE SECTOR GROUPS

Within this appendix brief descriptions of the roles for the following groups have been identified.

- Architect/Engineer
- Building Code Groups
- Builders/Developers
- Certification/Listing and Standards
- Development Organizations
- Consumer Groups
- Finance Groups
- Manufacturers
- Professional, Trade and Technical Associations
- Utilities

Architect/Engineer

Architect/engineer perform three primary roles. First and foremost architect/engineers design and construct buildings which are imbued with utility as well as aesthetics. Secondly, they serve as a consumer/educator for clients. The architect and engineer are usually in the best position to suggest materials and products which if implemented would be most cost effective for the client. And finally, the architect and engineer are specifiers of equipment and materials. In many cases the architect or engineer will specify a particular material developed by a particular manufacturer to insure building quality control within nationally recognized limits.

Builders/Developers

Builders/developers are primarily concerned with construction and installment of equipment. But, the builder/developer performs three roles that should be identified. Basically, the builder/developer will be assigned the three roles of the Architect (primarily in the case of the single-family development). The builder/developer is a consumer of materials, supplies, and equipment/systems for buildings. In the case where the architect is not involved the builder/developer acquires the role of specifier of materials and equipment. Finally, the builder/developer is a source of information for the consumer. In this position the builder/developer identifies proper structures, construction techniques, materials and equipment which may be utilized in the home to conserve energy.

Certification/Listing and Standards Development Organizations

Certification/listing and standards development organizations are engaged in standards development and in the testing of devices and construction materials in order to protect consumers from loss of life, casualty or loss of property. These groups represent specialized interests and concerns. For example, Underwriters Laboratory (a nationally recognized listing laboratory) is predominantly noted for testing electrical equipment and appliances used in the home. These organizations promote a voluntary process for manufacturers to certify that the manufacturer's product is safe and reliable within established limitations. These limits are determined by a specialized standards institutions

or specialized certification and listing testing laboratories. The procedure for certification begins when the manufacturer submits a product to a recognized testing laboratory. The laboratory will test the product to determine whether it adheres to nationally recognized standards. After the product has been subjected to rigorous testing and has been found to be consistent with nationally recognized standards, the testing laboratory will affix its symbol to the product. Thereby, the product has been certified as being safe for the use it was intended.

These groups have served the public for over eighty years promoting safe and reliable products and developing uniform testing standards.

Building Code Groups

Building code groups perform three primary roles - 1) building code developers, 2) standards developers, and 3) building inspectors -- on three regional levels -- federal, state, and local. As building code developers, representations from each regional level as well as specialized technical interests interact to create uniform codes. Codes are comprised of definition of terms, licensing agreements and standards/specifications which may be mandated or "carry the force of law." Individuals from specialized code groups (i.e., building officials code administration, International Conference of Building Officials, Building Officials Code Administrators, Southern Building Codes Congress, and others) take part in developing specifications for new and retrofit technologies, new construction techniques and innovative uses of materials. Finally, code groups participate in inspection activities, to assure that buildings adhere to regionally initiated codes and standards.

Consumer Groups

Consumer organizations provide an additional check on products or materials coming to the market place to assure consumer protection. Consumer organizations participate in standard development, product testing, and code development activities to see that the user is protected from unsafe products. Also, consumer organizations attempt to educate the user/purchaser by indicating which products or materials are inferior or hazardous, as well as recognizing energy efficient and safe products and materials for use in a residential dwelling.

Finance Groups

Two financial groups which may have significant impact on implementation of the selected strategies are lending institutions and insurance groups. Lending institutions provide capital to purchasers and renovators of buildings as well as provide investment capital for product development and commercialization. A lending institution's primary consideration toward granting a loan or mortgage is the "ability" of the borrower or mortgagee to pay the money back. A lending institution may develop its own criteria or standards which a residence must meet prior to the borrower being granted the loan. If these requirements are not adhered to the loan or mortgage will not be granted. Product development as well as commercialization investment criteria many times depends on the market potential of a product. The criteria utilized by lending institutions to determine marketability is whether or not a product has been certified or listed by a nationally recognized institution.

Insurance groups play a significant role which may affect the implementation of a strategy. Insurance companies are willing to insure the use of safe and reliable products for utilization in a residence. An insurance company may require that a home be equipped only with products and materials adhering to nationally recognized standards and specifications. Therefore, residences not in compliance with insurance company requirements may tend to discourage potential buyers regardless of the energy efficiency qualities of the residences.

Manufacturers

Manufacturers perform two roles which may affect the implementation of a strategy: (1) suppliers of products and (2) aiding the development of standards. For those strategies that call for new or retrofit technologies, manufacturers be the suppliers of new materials, new products, or supplying innovative uses of new materials or products. Also, as evidenced by Hittman's "Barriers Study" manufacturers may inhibit or enhance energy conservation strategies through their participation in areas of standards development (i.e., flue gas damper case cited in the Hittman report).

Professional, Trade and Technical Associations

Traditionally, these groups are comprised of technical proficient specialists who maintain an interest in a particular product or occupational groups. For example, the interests of the heating, refrigerating, and air conditioning manufacturers and engineers are represented by the American Society of Heating, Refrigerating, and Air Conditioning Engineers. Another example is that wood products and interests are maintained by the National Forests Products Association. The primary roles of these organizations are information dissemination and standards development. These associations conduct, through their membership the actual research and testing needed to develop specific standards. Further, inventors and researchers of new housing products need to know what standards their product may be required to meet. Also, from a business standpoint, manufacturers and engineers need to know the state-of-the-art of products produced in the field in order to keep pace with their competition. Therefore, these Associations perform a significant role of disseminating information to specific interested parties in the field.

Utilities

Utilities may have significant impact on the selected strategies. Three roles have been specified for utilities and they are:

- Supplier of energy resources,
- Consumer educators, and
- Standards developers.

Utilities provide resources for residential dwellings. In this capacity utilities reach more individuals on the local level than any other industrial concern. And as a supplier of energy, utilities are most sensitive to the recently felt energy crisis spurring increased fuel prices; consequently, utilities have taken the initiative to educate consumers on ways to minimize their monthly utility bills by suggesting products (i.e., insulation) or behavior patterns (i.e. turn down thermostats at night) which would encourage effective energy conservation.

Finally, utilities play an active role on standards development committees for two reasons: one is to keep abreast of new energy conservation products systems and practices, and secondly, to make accessible technical engineering expertise to develop tests and standards which would allow for safe, reliable, and energy efficient products.