THE ECONOMIC AND SOCIETAL CONSIDERATIONS IN THE SELECTION OF A SPACE AND WATER HEATING AND AIR CONDITIONING SYSTEM FOR A MULTIFAMILY OR COMMERCIAL BUILDING.

by

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Abstract

In many cities in the U.S, as much as 30% of the cities population lives in apartment buildings. And 50% of all new construction today is for office/apartment type buildings. The selection of the type of space heating and cooling, and water heating equipment for the office/apartment building is not easy to do.

There is a very wide selection of equipment available today. Some equipment is inexpensive (first cost) while other more expensive equipment offers higher energy efficiency and lower annual energy bills.

This analysis will review nine (9) equipment options and will determine the "best" system from nine (9) different perspectives (building owner, tenant, utility company suppling power, etc.). This study will provide valuable information for all parties involved directly or indirectly in the ownership, purchase, supply, or the societal impacts of operating energy using equipment in office/apartment type buildings. Detailed information such as equipment costs, annual operating costs, costs over the life of the

equipment, society costs, etc. are presented. The societal effects (the total resource energy used) of equipment selections are also presented.

This study also provides the "best" system to meet all the needs/requirements of the nine perspectives and it will provide the "best" system per the specific needs (eg. lowest first cost) of the concerned party (eg. building owner, tenant, etc.). The results of this study can be used as a equipment selection tool by all concerned parties.

This study presents information on four different climatic regions in the United States.

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NOMENCLATURE

A/C	Air conditioning
BTU	British thermal unit
C	Indicator of a income producing or non-income
CCF	Cubic foot of natural gas
COP	Coefficient of performance
D	Ratio of down payment to initial investment
d	Discount rate
i	General inflation rate
iF	Fuel inflation rate
KW	Kilowatt of electric power
LCC	Life cycle cost
m	Annual mortgage interest rate
MMBTU	1000 btu's
Ms	Ratio of first year miscellaneous costs (parasitic power, insurance and maintenance) to initial investment
Nd	Depreciation lifetime in years
Ne	Term of the economic analysis
Nl	Term of loan

Nmin	Years over which mortgage payments contribute to the analysis (usually the minimum of Ne or Nd)
N'min	Years over which mortgage payments contribute to the analysis (usually the minimum of Ne or Nd)
PLF	Part load factor
P1	Ratio of life cycle fuel cost savings to the first year fuel cost savings
P2	Ratio of life cycle expenditures incurred because of the additional capital investment to the initial investment producing (1 or 0, respectively)
Rv	Ratio of resale value at the end of the period of analysis to the initial investment
R Value	Resistance to heat flow (ft2-hr-degree f/btu)
SPF	Seasonal performance factor
t	Effective income tax rate
Therm	Cubic foot of natural gas
tR	Property tax rate based on assessed value
V	Ratio of assessed valuation of the equipment in the first year to the initial investment in the system

Chapter 1: Introduction

Approximately 50% of all new construction in the United States today is for apartment and office type buildings. Today's wide array of heating, cooling, and water heating equipment poses a real dilemma for the builder or owner in selecting a system. Should one select low efficiency and low cost equipment or high efficiency and higher cost equipment or even something in between?

With today's large selection of energy equipment options, it is often almost impossible to determine which system is most appropriate for a particular building owner or developers situation. Should only first cost be considered? What other criteria should be considered in the selection of equipment? Should the space heating, cooling, water heating system be contained in each apartment or is a central system the better selection? These are questions that the typical building owner and developer needs to be able to answer in order to make an intelligent decision on equipment selection. This report will assist the building owner and developer in making these decisions based on sound engineering and economic analysis of the equipment options.

This study investigates nine different equipment options from nine different perspectives and presents a ranking of the "best" to "worst" of each system for each perspective.

The space heating, cooling and water heating systems selected for analysis are:

1. Electric baseboard space heating, electric water heater and a through-the-wall air conditioner.
2. Standard efficiency gas furnace, electric water heater and a through-the-wall air conditioner.
3. Same as number 2, except with a gas water heater.
4. Heat pump space heating and air conditioning and an electric water heater.
5. High efficiency gas furnace, high efficiency gas water heating and a high efficiency through-the-wall air conditioning unit.
6. High efficiency gas water heater that is used to provide space heating and water heating with an add-on air conditioning unit.
7. Central water loop heat pump system which provides

space heating and air conditioning, and a gas water heating system.

8. Central gas boiler space heating, electric water heating and a through-the-wall air conditioning system.
9. High efficiency integrated heat pump which provides space and water heating and air conditioning.

These systems are described in more detail in Chapter 3. The nine different perspectives reviewed in this analysis are:

1. The building owner.
2. The building tenant.
3. The electric utility which is capacity short and needs to build additional capacity or is promoting demand-side energy reduction programs.
4. The electric utility which is profit oriented.
5. The gas utility which is profit oriented.
6. The combined utility (gas and electric) that is profit oriented.
7. The state public utility regulatory agency.

8. The bennevolent dictator (best for society).

9. The minimum total resource energy used.

These perspectives are reviewed in detail in Chapter 5. This study will allow any reader to determine, according to which perspective profile they fit, the "best" system for their building.

This study has used a "base" building, which is described in detail in Chapter 2, that represents a typical 1000 square foot apartment. The physical parameters of this building were input into a computer software analysis program, titled "FLOAD", developed at the University of Wisconsin-Madison, to estimate: heating, cooling and water heating loads, annual energy costs and life cycle costs for commercial buildings. The use of this analysis software is explained in more detail in Chapter 4.

To further expand the usefulness of this study, the analysis is performed for four different locations in the United States: Madison, Los Angeles, Atlanta and New York. This will allow building owners, architects, engineers, utility staff, renters and the local utility regulators to use this thesis for equipment selections for apartment and office buildings anywhere in the United States.

Chapter 2: Base Building used for the Analysis.

The base building selected for use in this study represents a typical two bedroom apartment with 1000 square feet of living space located in a upper level of a three story apartment building. The apartment used for the analysis will have two sides exposed (a corner unit) to the environment. This selection will make the heating and air conditioning loads at the maximum level as compared to a single wall exposed unit.

The base building unit selected is an actual apartment in Madison, Wisconsin. The energy loads for this apartment were calculated using the FLOAD software (described in detail in Chapter 4). The energy loads are:

Heating Load = 15,400 Btu/Hr

Cooling Load = 8,000 Btu/Hr

The building layout is shown in Figure 2.1. The apartment size is 50 foot long by 20 foot wide. The apartment building has four apartment units per floor and the building is three stories high, resulting in twelve apartment units per building. This is typical of the apartments in the Madison, Wisconsin area and through-out the United States. A hallway separates the units at each floor.

The apartment building construction meets the minimum energy and construction codes of the State of Wisconsin.

2.1 Building Construction Specifications.

The basic construction specifications for this base apartment are:

Wall area = 1260 ft2

Wall R Value = 16.4 ft2-hr-f/btu

Window area = 48 ft2

Window R Value = 2.2 ft2-hr-f/btu

Door area = 48 ft2

Door R value = 2.2 ft2-hr-f/btu

Ceiling area = 1000 ft2

Ceiling R value = 26.3 ft2-hr-f/btu

The input data for the FLOAD software is listed in

Appendix A.

The buildings orientation is set-up as 110 Degree's from the south, which sets the buildings orientation as northwest. This was selected so that the solar load would not dominate the summer cooling load.

The monthly heating, cooling, and water heating loads for this Base apartment are shown in Figure 2.2, for Madison, Wisconsin. Los Angeles, Atlanta and New York are shown in Appendix B.

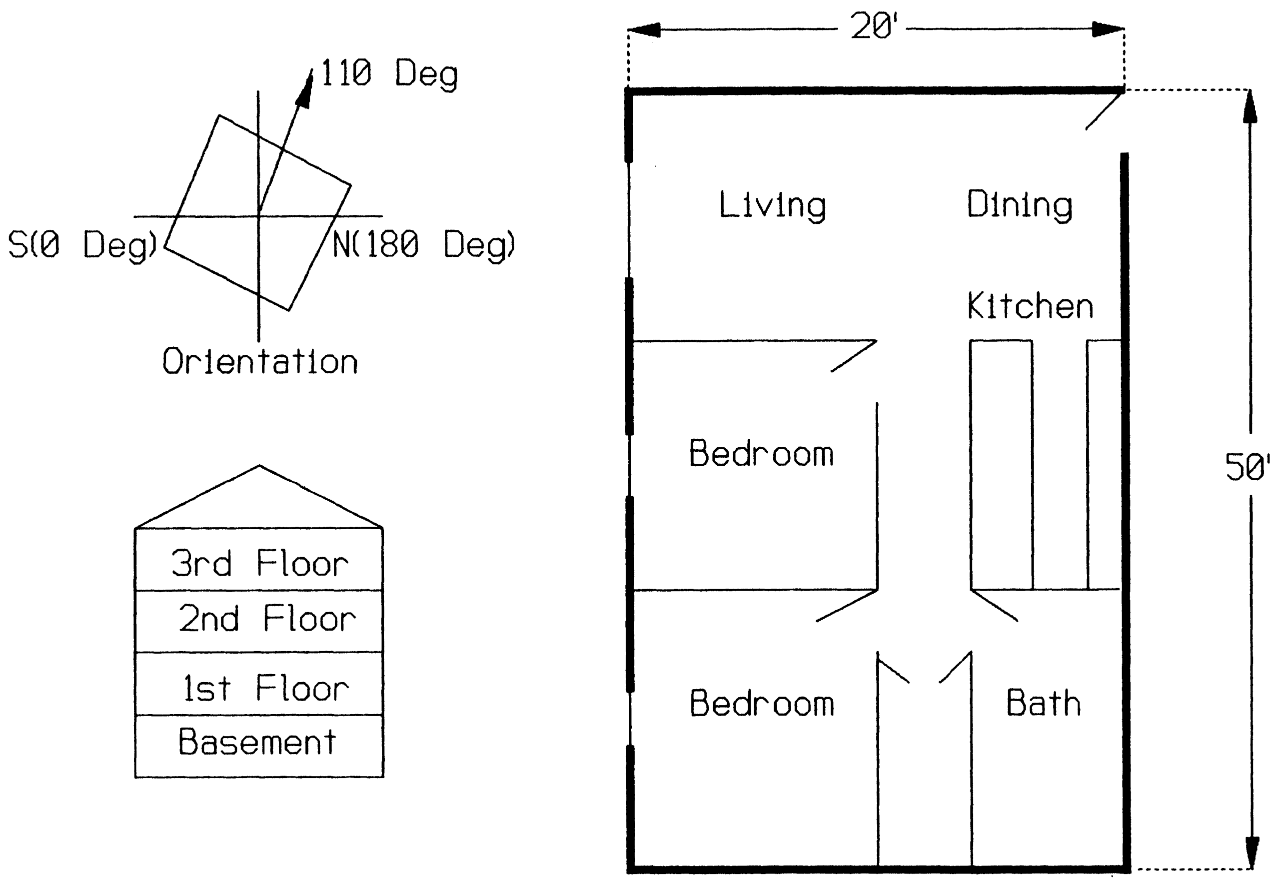


Figure 2.1-Sample Apartment

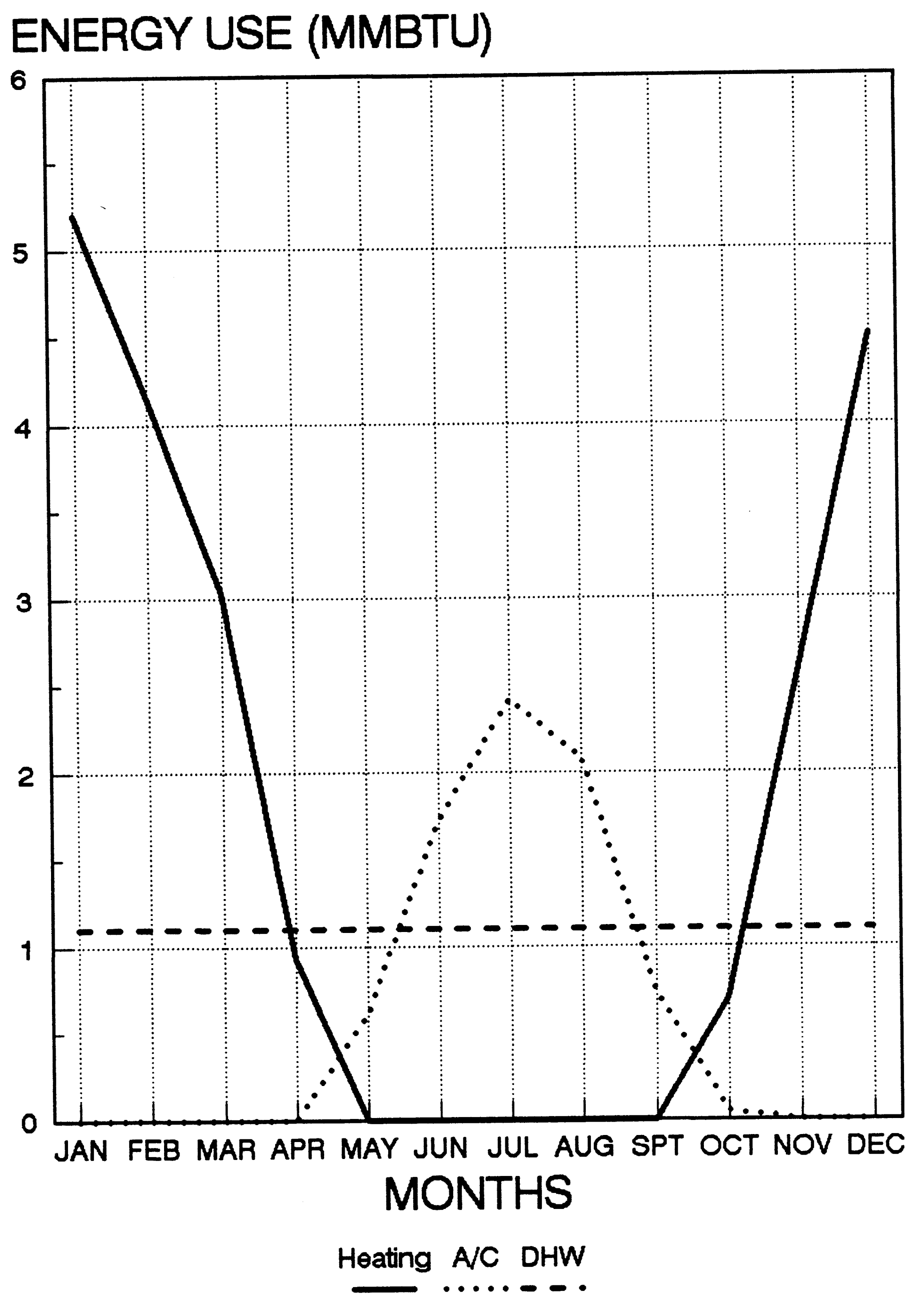


Figure 2.2-Monthly Heating,Cooling and Water Heating Energy Loads for the Base Apartment for Madison,Wisconsin

Chapter 3.

Space Heating, Air Conditioning and Domestic Water Heating Equipment System Descriptions.

This chapter will present the technical specifications of each of the nine system combinations that have been selected for study in this analysis. The selection of nine different equipment selections represents the complete range (at the time of this study) of equipment that is available for purchase today for apartment or office type buildings.

The equipment options include two central type systems;

1. A central boiler
2. A water loop heat pump system.

And it includes seven inside the building unit systems;

1. Baseboard electric
2. Low efficiency gas furnace (with a electric water heater)
3. High efficiency gas furnace
4. Standard efficiency heat pump

5. High efficiency heat pump
6. Water heater space and domestic water heating system
7. Low efficiency gas furnace

The main variations in the above systems are the different space heating systems. The water heater and air conditioner units selected are either standard efficiency or high efficiency based on the type of space heating equipment and its efficiency. High efficiency space heating equipment was paired with high efficiency water heating and air conditioning equipment, for a total high efficiency system. Low efficiency space heating systems were paired with low efficiency water heating and air conditioning equipment, for a total low (standard) efficiency system.

The technical details of each of the above mentioned systems and of each of their components (eg. Water heater and A/C unit) are listed in Appendix C-Equipment Specifications. A sample of the equipment specification format is shown in Table 3.1. A standard format is used so that comparisons can be made between the different equipment types. It should be noted that each of the nine equipment systems are installed within each apartment or office unit's space, except for two central building systems (boiler and water loop heat pump system).

Table 3.2 shows the summary of all the systems used in this study and sets them up as system #'s 1-9. These system numbers will be used through out this report.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER:

EQUIPMENT TYPE:

MANUFACTURER:

MODEL NUMBER:

BTU INPUT/OUTPUT:

EQUIPMENT SUPPLIES: ( )Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS:

ESTIMATED EQUIPMENT INSTALLATION COSTS:

RATED EFFICIENCY:

TECHNICAL INFORMATION REFERENCES:

OTHER SPECIFICATIONS:

TABLE 3.1 Sample Equipment Specifications.

System #1:	Baseboard Electric Space Heating Low Efficiency Electric Water Heater Low Efficiency Through-the-Wall Air Conditioner
System #2:	Low Efficiency Gas Furnace Low Efficiency Electric Water Heater Low Efficiency Through-the-Wall Air Conditioner
System #3:	Low Efficiency Gas Furnace Low Efficiency Gas Water Heater Low Efficiency Through-the-Wall Air Conditioner
System #4:	Low Efficiency Heat Pump Space Heating and Cooling Low Efficiency Electric Water Heater
System #5:	High Efficiency Gas Furnace High Efficiency Gas Water Heater High Efficiency Through-the-Wall Air Conditioner
System #6:	High Efficiency Gas Water Heater for Space and Domestic Water Heating High Efficiency Add-on Air Conditioner
System #7:	Low Efficiency Central Building Electric Water Loop Heat Pump Space Heating and Air Conditioning Low Efficiency Gas Water Heater
System #8:	Low Efficiency Central Building Gas Boiler Space Heating Low Efficiency Electric Water Heater Low Efficiency Through-the-Wall Air Conditioner
System #9:	High Efficiency Integrated Electric Heat Pump that Supplies Space and Water Heating and Air Conditioning

TABLE 3.2
HEATING AND COOLING SYSTEM NUMBERING

Chapter 4

Analysis Methods

This chapter describes the analysis methods and tools used to obtain and process information on each of the nine equipment systems that were described in Chapter 3. This includes equipment purchase and installation costs, annual operating costs and life cycle costs of owning and operating this equipment. The results of using these analysis methods are reported in later chapters in this report.

4.1 Survey to Obtain Equipment and Installation Costs

To obtain equipment costs and installation costs for this equipment a cost estimate form was developed and sent to three local Madison heating and cooling equipment contractors. Three bids were obtained on each piece of equipment and were then averaged to obtain the costs used in this analysis. A sample of the cost estimate form used is shown in Appendix D. The cost estimate form asked the vender to provide costs on a per apartment basis. For the central building systems the assumption was that the building consisted of twelve units. The costs of each piece of equipment of each system number and the high and low bids from contractors are shown in Table 4.1.1. The variation in contractor bids on the nine equipment systems ranged from a high variation of 18% for system #4 (Low Efficiency Heat Pump System) to a low of 6% for system #5 (High Efficiency Gas Furnace). The total costs of each system are summarized in Table 4.1.2.

4.2 Use of F-LOAD Software to Determine Annual Fuel Costs.

F-LOAD is a interactive computer program for estimating building heating and cooling loads. The methods used in the computations are based on those published by ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) and NBS (National Bureau of Standards) for calculating the design heating and cooling loads and for estimating seasonal equipment energy consumption. The program includes the capacity to do life-cycle cost analyses and year-by-year cash flow analysis. This software program was developed and copyrighted by F-CHART SOFTWARE in Middleton, Wisconsin.

The program is structured to allow the user to evaluate the first year and life-time energy and cost savings of various heating, cooling and water heating equipment for a particular building's construction and operation. The F-LOAD program contains weather data for 329 north American locations. The F-LOAD program will run on all PC based machines with as little as 256K of memory.

In order for F-LOAD to calculate the heating and cooling load, the building's construction must be specified. A sample of the input data for the buildings construction and operation are detailed in Appendix A. F-LOAD calculates the energy used by the heating and cooling equipment and accounts for the effects of temperature and part-load operation on the equipment performance. To perform these calculations, the following information on each piece of equipment was determined;

1. Equipment Capacity vs Ambient Temperature
2. Equipment Efficiency vs Ambient Temperature
3. Part-Load Operation Factor vs Load/Equipment Capacity

A sample of this FLOAD equipment input information is shown in Table 4.2.1. This equipment specification information was obtained directly from the equipment manufacturers published catalogs. These technical specifications are obtained by the manufacturers testing their equipment according to ARI (Air Conditioning Research Institute) and GAMA (Gas Appliance Manufacturers Association

Inc.) standards. The equipment values of Table 4.2.1 are displayed graphically in Figure 4.2.1 to 4.2.3.

Once the building construction and operation information and equipment specifications are input into the computer program, the program calculates the heating and cooling energy required for the building using the city specified. Also calculated is the design heating and cooling loads for the building and the economics of operating this equipment. The first year energy and life cycle costs of operating the equipment are determined. A sample of this output information is shown in Appendix A.

Each of the nine equipment configurations, as listed on Table 3.2, were set-up and run independently using F-LOAD software to determine the first year energy costs and energy use for these systems for the typical apartment unit as described in Chapter 2.

This summary of the energy use and energy costs for the nine equipment configurations for water heating, electric utilities, space heating and space cooling in Madison, Wisconsin are shown in Table 4.2.2.

4.3 Determination of Life Cycle Costs Using the P1 and P2 Method.

Life Cycle Cost (LCC) is the sum of all the costs associated with an energy delivery system over its lifetime or over a selected period of analysis, expressed in today's dollars, which takes into account the time value of money. The basic idea of life cycle costs is that anticipated future costs are brought back to the present cost (discounted) by calculating how much would have to be invested at a market discount rate (rate of return on the best alternative investment) to have the funds available when they will be needed. A life cycle cost analysis includes inflation when estimating future expenses. (Duffie and Beckman, 1980, 382).

The life cycle cost of the nine equipment configurations is just one of the analysis methods used in this study to select the most appropriate system depending on your perspective (outlined briefly in Chapter 1 and in more detail in Chapter 5).

A simple method of determining life cycle costs, called the P1 and P2 method, has been developed (Duffie and Beckman, 1980, 399) when the first year fuel costs and equipment costs have been determined. The life cycle costs (LCC) are:

$$LCC = P1 * \text{First Year Fuel Costs} + P2 * \text{Equipment Costs} \tag{4.3.1}$$

Where: P1 is the ratio of life cycle fuel cost savings to the first year fuel cost savings and is given by;

$$P1 = (1-Ct)\ PWF\ (Ne,\ iF,\ d) \tag{4.3.2}$$

Where:

The factor PWF is a present worth factor that determines the current value, in today's dollars, considering the duration (years) of the investment (Ne), the inflation rate (iF), and the investor's best alternative investment rate (d). This study uses the figures of 5% (2% for natural gas) as the annual inflation rate, 8% as a investors best alternative investment, and all the equipment is assumed to have a 20 year life expectancy.

So:

P1 (Electric) = (1-1*0.45) PWF (20, 5%, 8%)

P1 (Electric) = 7.90

P1 (Gas) = (1-1*0.45) PWF (20, 2%, 8%)

P1 (Gas) = 6.24

and:

P2 is the ratio of the life cycle expenditures incurred because of the additional capital investment to the initial investment.

$$P2 = D + (1-D)\frac{PWF\ (Nmin,\ 0,\ d)}{PWF\ (Nl,\ 0,\ m)} - (1-D)t$$

$$*((PWF(Nmin,\ m,\ d)(m-\frac{1}{PWF(Nl,\ 0,\ m)}) + \frac{PWF(Nmin,\ 0,\ d)}{PWF(Nl,\ 0,\ m)})$$

$$+ (1-Ct)Ms * PWF(Ne, i, d) + tr(1-t)V * PWF(Ne, i, d)$$

$$- \frac{Ct}{Nd} PWF(N'min, 0, d) - \frac{Rv}{(1+d)Ne} \qquad (4.3.3)$$

Where:

m = Annual mortgage interest rate

i = General inflation rate

Nl = Term of the loan

Nmin = Years over which mortgage payments contribute to the analysis (usually the minimum of Ne or Nd)

Nd = Depreciation lifetime in years

N'min = Years over which mortgage payments contribute to the analysis (usually the minimum of Ne or Nd)

t = Property tax rate based on assessed value

D = Ratio of down payment to initial investment

Ms = Ratio of first year miscellaneous costs (parasitic power, insurance and maintenance) to initial investment

V = Ratio of assessed valuation of the energy system in the first year to the initial investment in the system

Rv = Ratio of resale value at end of period of analysis to initial investment

The P2 formula can be simplified to:

$$P2=(1) + (2) + (3) + (4) + (5) + (6) + (7) \qquad (4.3.4)$$

Where:

(1) = Down Payment

(2) = LCC of Mortgage Principle and Interest

(3) = Income Tax Deduction of the Interest

(4) = Miscellaneous Costs (Insurance and Maintenance)

(5) = Net Property Tax Costs

(6) = Straight Line Depreciation Tax Deduction

(7) = Present Worth of the Resale Value

$$P2 = (0.10) + (1.04) + (-0.31) + (0.08) + (0.08) + (-.022) + (-0.31)$$

$$P2 = 0.75$$

Now with the equipment costs from Table 4.1.2, the fuel costs (first year) from Table 4.2.2, P1 (7.90 for electric and 6.24 for gas) and P2 (0.75) the life cycle cost (LCC) for each system (1 through 9) can be determined by using:

LCC = P1 * First Year Fuel Costs + P2 * Equipment Costs (4.3.1). The results of the life cycle cost calculations are shown on Table 4.3.1.

4.4 Lowest On-Peak KW Analysis

The annual on-peak electric demand (kw) period for utility's is from May to September. Summer air conditioning load requires the highest kw production and is the major contributor to the electric summer peak load. Therefore, none of the electric (baseboard or heat pump) space heating systems will contribute to the electric peak load (kw).

A utilities daily on-peak hours are usually from 10:00 am to 9:00 pm, with the highest peak occurring from 1:00pm to 7:00pm. For this analysis, a electric water heater's contribution to the on-peak load will <u>not</u> be considered since the operation of a air conditioner and water heater together is not a typical occurrence. If this does occur the water heater operation to reheat water occurs usually within a 10 to 20 minute time period as compared to the operation of a air conditioner for usually many hours.

To determine the lowest on-peak KW of all the nine equipment systems, only their air conditioning equipment was considered. The KW value for each system was determined by reviewing manufacturers performance / test data as listed by the ARI (American Refrigeration Institute). The ARI develops test methodology and standards[1] that are used by all air conditioning manufacturers to test the performance of their equipment. For this analysis the following formula was used:

$$COP = \frac{\text{Cooling provided by the system (BTU/HR)}}{\text{Energy consumed by the system (KW)}} \qquad (4.4.1)$$

This data is from the ARI steady-state rating at 95 Degrees F, for cooling system testing. This data was obtained for each of the nine equipment systems and the KW was determined by modifying the above formula to show;

$$\text{Work (KW)} = \frac{\text{Cooling provided by the system (BTU/HR)}}{\text{COP @95 Degrees F, ARI Standard}} \qquad (4.4.2)$$

<u>4.5 Annual Energy Used</u>

As explained in Section 4.2, the F-LOAD software used to determine annual fuel costs also calculates the annual amounts of energy used, in KWH and in CCF of natural gas, for each piece of equipment and for each of the nine equipment systems.

A sample of the F-LOAD software output is in Appendix A.

4.6 Multiple Selection Criteria Analysis

One of the nine perspectives, the Regulatory perspective, has more than one priority that is used to select the "best" equipment system. This perspective is from a utility regulatory agency that promotes conservation and demand-side planning.[2] The regulatory agency has three main priorities in regulating utilities;

1. Promotion of the lowest life cycle cost equipment so that the state population will benefit from the lowest energy and equipment costs over the life of the investment.

2. Promotion of energy using equipment that will reduce peak KW usage. This will reduce the need to build additional generating capacity, the cost of which is added to utility customer bills.

3. Promotion of low energy costs for utility customers. This is reflected by the customers annual energy bill.

A matrix was developed to rank the equipment systems because this perspective has three priorities rather than just one as the other perspectives have. The three priorities are listed in order of importance to the regulatory agency. A <u>rating</u> number is assigned to the order (based on importance to the regulatory agency) of the priorities;

<u>Rating</u>

3 = The first selection criteria is Lowest LCC

2 = The second selection criteria is Lowest On-Peak KW

1 = The third selection criteria is Lowest First Year Energy Costs

Then a <u>score</u> is assigned to each equipment system based on their ranking of meeting the selection criteria requirement (eg. Lowest LCC):

Score

3 = The top three equipment systems

2 = The middle three equipment systems

1 = The lowest three equipment systems

For each selection criteria, the score and rating for each equipment system is multiplied to obtain a total. Then all three selection criteria totals are added to obtain a Final Score. The highest final score indicates the equipment system that best meets all the three selection criteria's requirements.

4.7 Total Resource Energy Used Analysis

This analysis method determines the total amount of energy used at the end-use location and the energy used to produce and transport that end-use energy from its origin. The inefficiencies of all the energy sources from supply, delivery and consumption are calculated and totaled to determine the Total Resource Energy Used by a equipment system.

The analysis method used to calculate the Total Resource Energy Used by the Nine Equipment Systems is:

On-site energy used by the buildings heating, cooling and water heating equipment (measured in MMBTU'S)

Is Divided by

The fraction of resource energy delivered to this equipment, as determined by the efficiency of this delivery equipment (for example coal or nuclear powered electric power plants only deliver 30% of the energy they consume due to inevitable thermodynamic inefficiencies, combustion and transmission losses or a natural gas pipeline supply system where only 95% of the energy is delivered due to pumping and distribution losses).

Is Divided by

The efficiency of the equipment or the SPF (seasonal performance factor when heat pump equipment is used).

This equals

The total resource energy used (in MMBTU'S) by each of the nine equipment systems. (4.7.1)

A sample calculation using equation (4.7.1) for equipment system #1 (reference Appendix E) shows that the following values for a Electric Baseboard space heating system are:

On-site end use energy = 21.13 MMBTU

Percent of energy delivered to the site = 30%

Efficiency of the equipment = 100%[3]

Then the calculation is:

(21.13 MMBTU / 0.3) / 1.00[4] = 70.43 MMBTU

Total Resource Energy Used = 70.43 MMBTU

Appendix E has the calculations for each of the nine equipment systems.

[1] Standard for Unitary Air Conditioning and Air Source Heat Pump Equipment (Standard 210/240), ARI, Arlington, Virginia.

[2] Planning to reduce peak KW demand by promoting customer side of the meter conservation activities.

[3] The efficiency of the equipment is accounted for in the FLOAD software end-use energy.

[4] Appendix E calculations do not include the efficiency of the equipment, since this has been accounted for in the FLOAD software.

System Number		Equipment Costs	Install Costs	Total Costs	Bid Range
No.1	Space Heating	$242	$150	$392	$1403
	Water Heater	$327	$112	$439	to
	A/C Unit	$522	$50	$572	$1550
	Totals	$1091	$312	$1403	
No.2					
	Space Heating	$900	$400	$1300	$2311
	Water Heater	$327	$112	$439	to
	A/C Unit	$522	$50	$572	$2650
	Totals	$1749	$562	$2311	
No.3					
	Space Heating	$900	$400	$1300	$2782
	Water Heater	$245	$112	$357	to
	A/C Unit	$775	$350	$1125	$3150
	Totals	$1920	$862	$2782	
No.4					
	Heat Pump	$1500	$2300	$3800	$4239
	Water Heater	$327	$112	$439	to
	Totals	$1827	$2412	$4239	$5000
No.5					
	Space Heater	$1200	$450	$1650	$3317
	Water Heater	$355	$112	$467	to
	A/C Unit	$800	$400	$1200	$3500
	Totals	$2355	$962	$3317	
No.6					
	Space/Water Heater	$1265	$270	$1535	$2735
	A/C Unit	$800	$400	$1200	to
	Totals	$2065	$670	$2735	$2900
No.7					
	Central Heat Pump	$6500	---	$6500	$6857
	Water Heater	$245	$112	$357	to
	Totals	$6745	$112	$6857	$7900
No.8					
	Central Boiler	$106	$750	$856	$1867
	Water Heater	$327	$112	$439	to
	A/C Unit	$522	$50	$572	$2000
	Totals	$955	$912	$1867	
No.9					
	Heat Pump	$5400	$1600	$7000	N/A

Contractor Cost Estimates
Table 4.1.1

System Number		System Costs
#1:	Baseboard Electric Space Heating Low Efficiency Electric Water Heater Low Efficiency Through the Wall A/C	$1403
#2:	Low Efficiency Gas Furnace Low Efficiency Electric Water Heater Low Efficiency Through the Wall A/C	$2311
#3:	Low Efficiency Gas Furnace Low Efficiency Gas Water Heater Low Efficiency Through the Wall A/C	$2782
#4:	Low Efficiency Heat Pump Space Heating and Cooling Low Efficiency Electric Water Heater	$4239
#5:	High Efficiency Gas Furnace High Efficiency Gas Water Heater High Efficiency Through the Wall A/C	$3317
#6:	High Efficiency Gas Water Heater for Space and Domestic Water Heating High Efficiency Add-on A/C	$2735
#7:	Low Efficiency Central Building Electric Water Loop Heat Pump Space Heating and Air Conditioning Low Efficiency Gas Water Heater	$6857
#8:	Low Efficiency Central Building Gas Boiler Space Heating Low Efficiency Electric Water Heater Low Efficiency Through the Wall A/C	$1867
#9:	High Efficiency Integrated Electric Heat Pump that Supplies Space and Water Heating and A/C	$7000

SUMMARY OF SYSTEM COSTS
TABLE 4.1.2

CARRIER HYDROTECH 2000 HEAT PUMP

Capacity (Btu/hour)	Temperature (F Degree)
4970	0.0
6960	10.0
8940	20.0
10930	30.0
12920	40.0
14900	50.0
16890	60.0

Strip Heater Capacity: 18000 (Btu/hour)

Efficiency (COP)	Temperature (F Degree)
1.69	0.0
2.18	10.0
2.60	20.0
2.96	30.0
3.28	40.0
3.56	50.0
3.80	60.0

Part Load Factor	Load/Capacity
0.75	0.00
0.80	0.20
0.85	0.40
0.90	0.60
0.95	0.80
1.00	1.00

Table 4.2.1-FLOAD Equipment Input Information

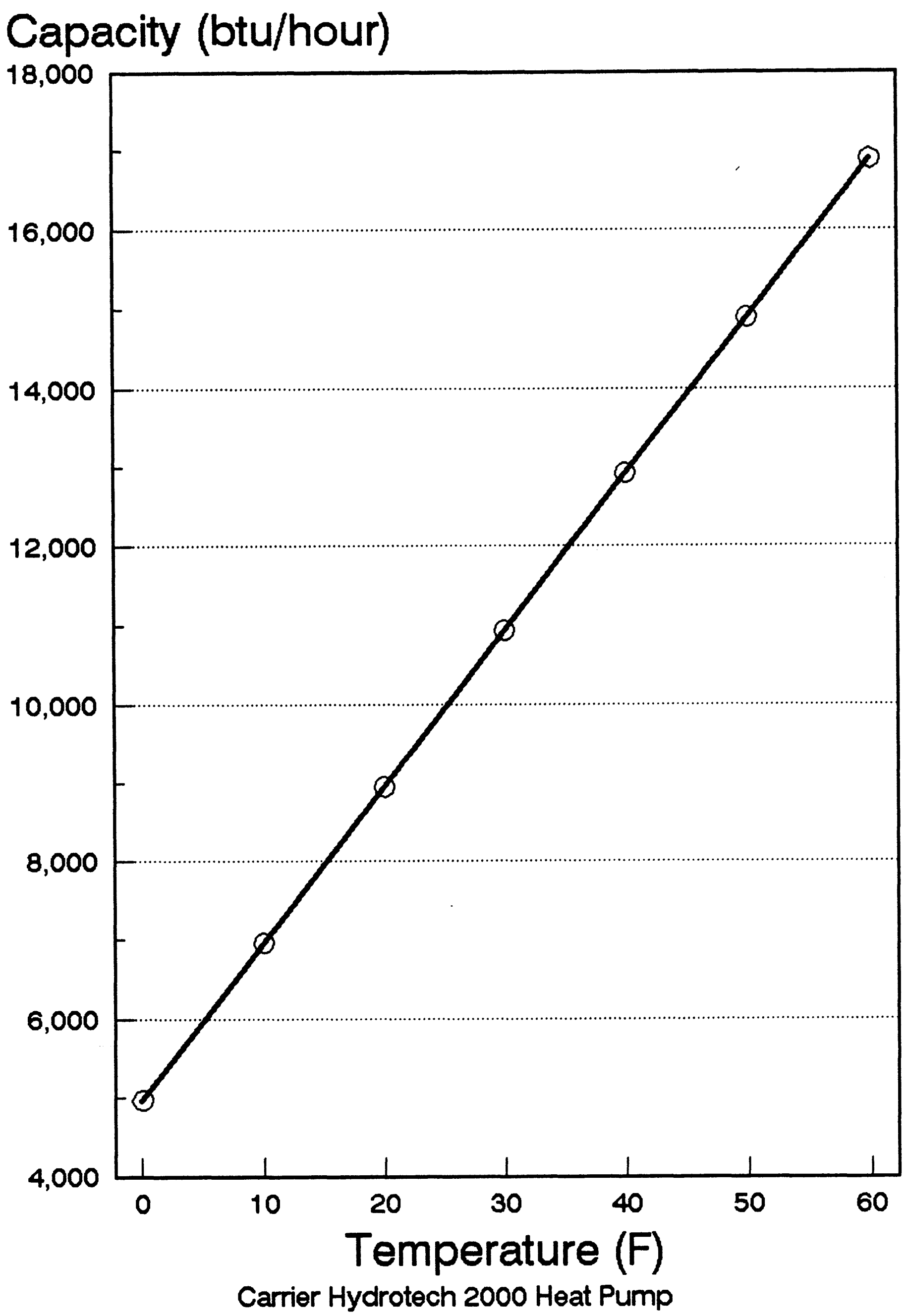


Figure 4.2.1-Graphical Display of Table 4.2.1

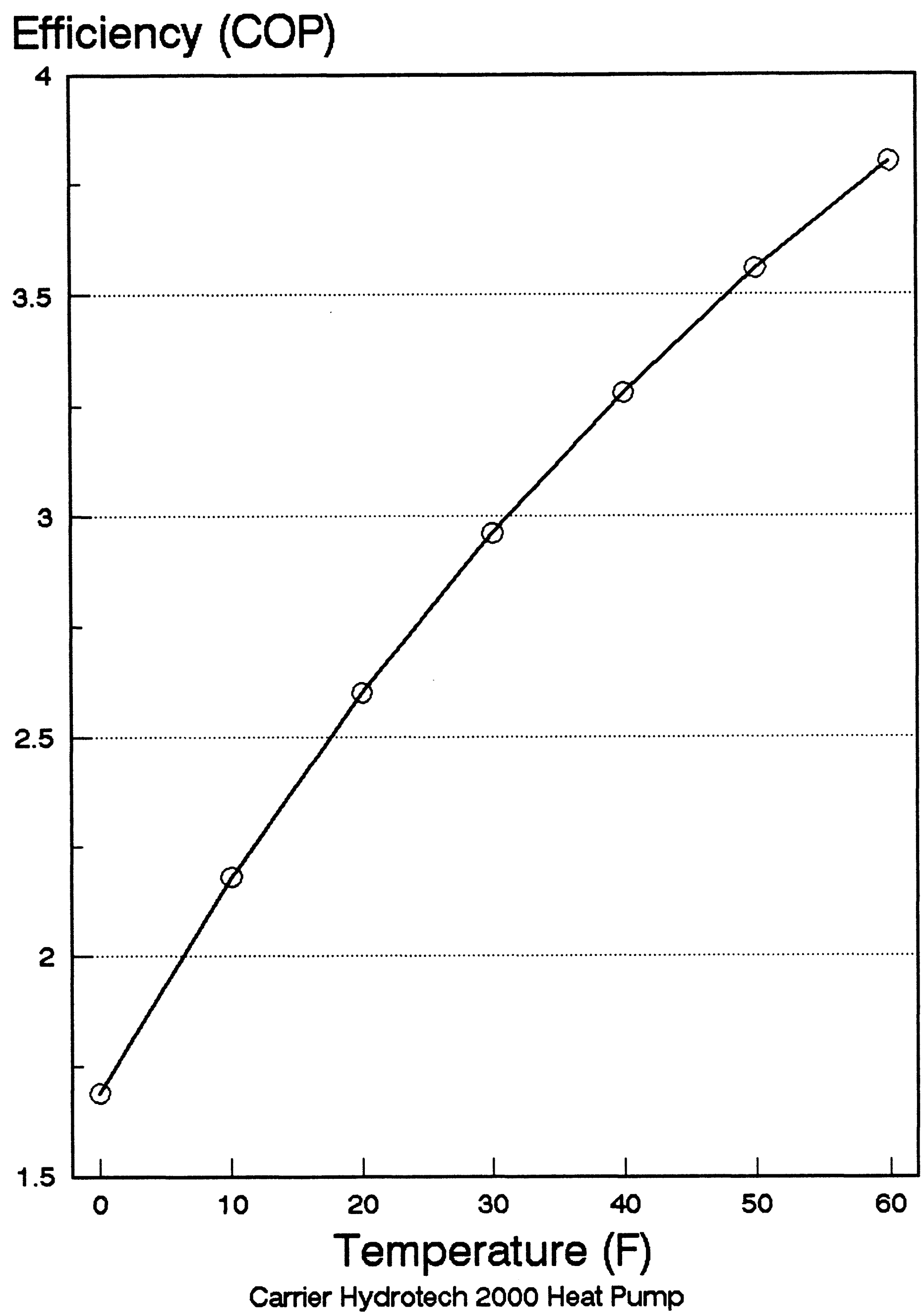


Figure 4.2.2-Graphical Display of Table 4.2.1

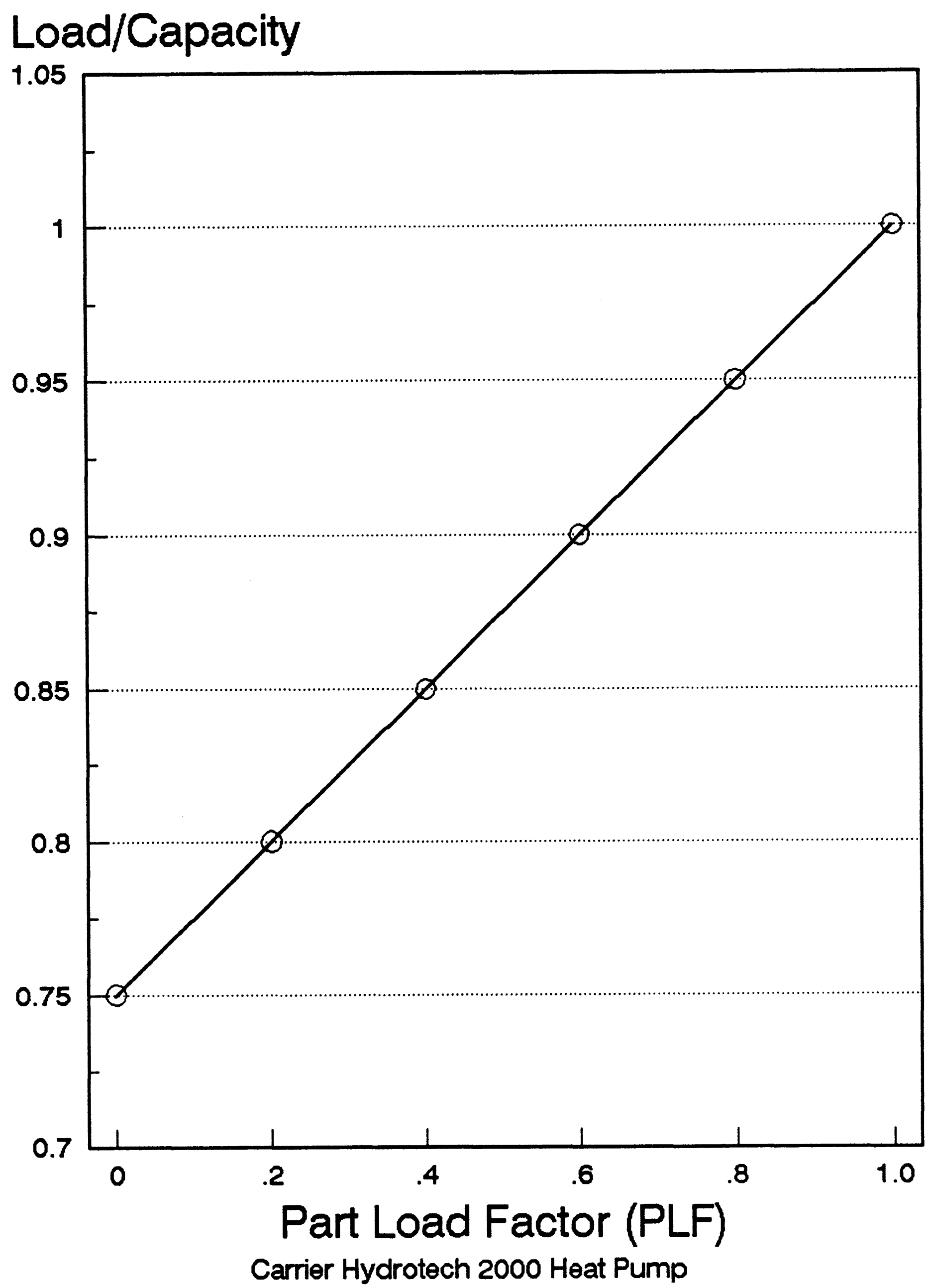


Figure 4.2.3-Graphical Display of Table 4.2.1

System Number	Equipment Type	Energy Use (BTU)	Energy Costs*
1	Water Heater(E)	13.20	$290
	Elec Utilities	9.24	$203
	Space Heating(E)	21.13	$464
	Cooling	3.78	$83
	Totals	47.35	$1040
2	Water Heater(E)	15.57	$290
	Elec Utilities	9.24	$203
	Space Heating(G)	27.70	$176
	Cooling	3.78	$83
	Totals	56.29	$ 752
3	Water Heater(G)	19.81	$126
	Elec Utilities	9.24	$203
	Space Heating(G)	27.70	$176
	Cooling	3.78	$83
	Totals	60.53	$ 588
4	Water Heater(E)	13.20	$290
	Elec Utilities	9.24	$203
	Space Heating(E)	12.52	$275
	Cooling	2.87	$63
	Totals	37.84	$ 831
5	Water Heater(G)	19.02	$121
	Elec Utilities	9.24	$203
	Space Heating(G)	22.64	$144
	Cooling	3.14	$69
	Totals	54.04	$ 536
6	Water Heater(G)	13.68	$ 87
	Elec Utilities	9.24	$203
	Space Heating(G)	25.94	$165
	Cooling	3.78	$83
	Totals	52.00	$ 538

*Based on $0.075 per KWH and $0.636 per ccf(therm) of natural gas.

(E)=Electric and (G)=Gas

Table 4.2.2 Energy Use and Energy Cost for Equipment Configurations 1 through 9 for Madison, Wisconsin.

System Number	Equipment Type	Energy Use (BTU)	Energy Costs*
7	Water Heater(G)	19.81	$126
	Elec Utilities	9.24	$203
	Space Heating(E)	8.48	$158
	Cooling	2.69	$59
	Totals	40.22	$ 546
8	Water Heater(E)	15.57	$290
	Elec Utilities	9.24	$203
	Space Heating(G)	47.48	$302
	Cooling	3.78	$83
	Totals	76.07	$ 878
9	Water Heater(E)	11.88	$261
	Elec Utilities	9.24	$203
	Space Heating(E)	8.20	$180
	Cooling	2.00	$44
	Totals	31.33	$ 688

*Based on $0.075 per KWH and $0.636 per ccf(therm) of natural gas.

(E)=Electric and (G)=Gas

Table 4.2.2 (Con't) Energy Use and Energy Cost for Equipment Configurations 1 through 9 for Madison, Wisconsin.

System Number	LCC	P1	Fuel Costs	P2	Equipment Costs
1	$9256	7.90	$1039	0.75	$1403
2	$6428	6.24	$752	0.75	$2311
3	$5750	6.24	$587	0.75	$2782
4	$8690	7.90	$831	0.75	$2839
5	$5832	6.24	$536	0.75	$3317
6	$5403	6.24	$537	0.75	$2735
7	$9451	7.90	$546	0.75	$6857
8	$6882	6.24	$878	0.75	$1867
9	$10680	7.90	$688	0.75	$7000

Table 4.3.1 Summary of Life Cycle Costs for the Nine System Configurations

Chapter 5: Equipment Selection Criteria

This chapter reviews nine different perspectives from which the selection of the heating, cooling and water heating equipment for the apartment or office buildings will be made. The ranked order of the equipment changes depending on who you are and what your financial and societal concerns are. Is lowest first cost the main concern or is it the lowest cost over the life of the equipment? Is the system that uses the least amount of energy the most cost effective? Should the fuel supply source be considered when selecting equipment (eg. Electric baseboard heating where the electricity is supplied by a coal power plant)?

There is not a right or wrong selection. But for each persons perspective, there is a best choice. This chapter will discuss and describe each of nine different perspectives and the top three equipment selections for each perspective. The nine perspectives are:

1. The building owner.
2. The building tenant.

3. The electric utility which is capacity short and needs to build additional capacity or is promoting demand-side energy reduction programs.
4. The electric utility which is profit oriented.
5. The gas utility which is profit oriented.
6. The combined utility (gas and electric) that is profit oriented.
7. The state public utility regulatory agency.
8. The bennevolent dictator (best for society).
9. The minimum total resource energy used.

These nine perspectives each have certain criteria that is used to select the best equipment system. These criteria are described in Sections 5.1 to 5.9 of this chapter. Table 5.0.1 summarizes the nine perspectives and ranks the equipment systems that meet the criteria of each perspective from best to worst (left to right in the Table). The analysis methods used to rank the equipment systems in each perspective were described in Chapter 4. A discussion of the results (rankings) for each of the nine perspectives will occur in Chapter 10 (Conclusions and Recommendations).

5.1 The Building Owner Perspective

This perspective is for the building owner or possibly a developer who's primary concern is cost of the equipment. The building owner is not concerned about the energy costs of the selected equipment because the tenants will be paying the fuel bills not the building owner. The building owner or developer is assumed to be only a short term owner and therefore not concerned about the energy costs of the equipment or the rentability of the building space from the cost of energy standpoint. Here the lowest first cost equipment is the best selection. The analysis method used, lowest first cost, was detailed in Section 4.1 and the equipment system costs are shown in Table 4.1.2.

The lowest equipment costs are ranked in Table 5.1.1.

The top three selections for the building owners perspective are:

1. System #1-Baseboard electric space heating, low efficiency electric water heater and a low efficiency through the wall air conditioning unit. First cost is $1403.

2. System #8-Low efficiency central building gas fired boiler, low efficiency electric water heater and a low efficiency through the wall air conditioner. First cost is $1867.

3. System #2-Low efficiency gas furnace, low efficiency electric water heater and a low efficiency through the wall air conditioner. First cost is $2311.

5.2 The Tenant Perspective

This perspective is from the tenant who is a renter or lessee of the apartment or office space. The concern here is to obtain the lowest annual operating cost of the equipment. The analysis method used to determine the annual operating costs was detailed in Section 4.2 and the annual operating costs are shown in Table 4.2.2. Table 5.2.1 shows the annual operating costs of the systems, ranked from the lowest to the highest.

The top three choices for the tenant perspective by lowest annual operating costs are:

1. System #5 - High efficiency gas furnace, high

efficiency gas water heater and the high efficiency through the wall air conditioner. The first years annual operating cost is $536.

2. System #6 - The high efficiency gas water heater used for space and domestic water heating with a high efficiency add-on air conditioner. The first year operating cost is $537.

3. System #7 - Central building electric water loop heat pump system for space heating and cooling with a low efficiency gas water heater. The first years annual operating cost is $546.

The annual operating costs of the top three equipment systems are all quite close with only a difference of $13 between them.

5.3: Combined (Gas and Electric) Utility - Needing Capacity

This perspective is for the combined gas and electric utility that will be suppling electric power and natural gas for this building. The utility is in need of additional electrical capacity and is encouraging its customers to conserve energy and to install the most efficient electric using equipment. This is a summer peaking electric utility. This utility is also under direction from its local state regulatory agency to promote energy conservation and to keep its customers energy bills low. This means that the utility promotes high efficiency electric <u>and</u> gas equipment. The utilities format in adding new customers to its system is to recommend high efficiency gas equipment for space and water heating and to recommend high efficiency electric air conditioners to reduce summer time peak KW use. This allows the utility to add load to their gas system and to keep their electric load to a minimum during peak use times (summer between noon to 7 pm).

The selection of the top three systems for this perspective is based on the highest efficiency air conditioner that will contribute the least (KW) to the electric peak load. Also, the water heater that is natural gas fired rather than electric, that will not contribute to the summer electric peak load, is a factor in the selection of the top three systems. The analysis method used to calculate the on-peak KW for these equipment systems was detailed in Section 4.4. Table 5.3.1 shows the ranking of the equipment based on the lowest peak KW use.

The top three systems are:

1. System #9 - High efficiency integrated electric heat pump that supplies space and water heating and air conditioning. Peak electric load is 2.5 KW.

2. System #7 - Water loop heat pump system for space heating and cooling with a gas water heater. Peak electric load is 3.2 KW.

3. System #5 - High efficiency gas furnace, high efficiency gas water heater and high efficiency through the wall air conditioner. Peak electric load is 3.5 KW.

For these three selected systems, each has a gas water heater so that there is no contribution to the peak electric KW and the highest efficiency air conditioner received the highest ranking.

5.4: Gas Utility Profit Orientated Perspective

This perspective is for a gas utility that is looking to add additional customers to its gas supply system for the purpose of making a profit. In this perspective, the utility will recommend low efficiency gas equipment to maximize their profit. The analysis method used to determine annual energy usage was detailed in Sections 4.5 and 4.2. Table 5.4.1 ranks the systems based on the highest annual natural gas use.

The top three systems selected based on highest natural gas use are:

1. System #3 - Low efficiency gas furnace, low efficiency gas water heater and low efficiency through the wall air conditioning system. Annual natural gas (therms) used are 475.

2. System #8 - Low efficiency central gas boiler, electric water heater and low efficiency through the wall air conditioning system. Annual natural gas (therms) used are 475.

3. System #5 - High efficiency gas furnace, high

efficiency gas water heater and a high efficiency through the wall air conditioning system. Annual natural gas (therms) used are 417.

5.5 Electric Utility - Profit Orientated Perspective

This perspective looks at a electric utility that is looking to add additional customers to its electric supply system for the purpose of making a profit. The utility has adequate electric capacity. In this perspective the utility will be recommending low efficiency electric equipment to increase their profit. The analysis method used to determine annual energy usage was detailed in Sections 4.5 and 4.2.

Table 5.5.1 shows the ranking of the systems based on the highest annual electric usage.

The top three systems are:

1. System #1 - Electric baseboard space heating, electric water heating and low efficiency through the

wall air conditioning. Annual electricity use is 13,867 kwh.

2. System #4 - Low efficiency heat pump space heating and cooling and a low efficiency electric water heater. Annual electricity use is 11,080 kwh.

3. System #9 - High efficiency heat pump space heating and cooling and a high efficiency heat pump water heater. Annual electricity use is 9,173 kwh.

5.6 Combined Utility (Gas and Electric) Profit Orientated Perspective

This perspective looks at a profit oriented utility that serves both gas and electricity. For this perspective, the utility will promote to customers either gas or electric equipment. The profit margin is higher on electric sales than on gas sales. The retained earnings (profit) is about $0.05 for each kwh sold verses $0.01 for each therm sold, as shown in Figures 5.6.1 and 5.6.2, respectively. For this reason, a combined utility will promote the sale of low efficiency electric equipment to maximize profits.

The analysis method used to determine annual energy usage was detailed in Sections 4.5 and 4.2. The ranking of the systems is shown in Table 5.6.1. The top three systems are:

1. System #1 - Electric baseboard space heating, electric low efficiency water heater and low efficiency through the wall air conditioner. Annual electricity use is 13,867 kwh.

2. System #4 - Low efficiency heat pump for space heating and air conditioning with a low efficiency electric water heater. Annual electricity use is 11,080 kwh.

3. System #9 - High efficiency heat pump for space heating and air conditioning and a heat pump water heater. Annual electricity use is 9,173 kwh.

5.7 Public Service Commission (Regulatory) Perspective

This perspective is from a utility regulatory agency that promotes conservation and demand-side planning. The regulatory agency has three main priorities (as listed in Section 4.6) in regulating utilities.

A matrix was developed to rank the equipment systems since this perspective has three priorities rather than just one as the other perspectives do. Section 4.6, of Chapter 4-Analysis Methods, details the matrix that was used to select the "best" equipment systems for this perspective. The analysis method used to determine a final score for this perspective was detailed in Section 4.6. Table 5.7.1 details the process and final scores for all the equipment systems.

The top three rated systems are:

1. System #5 - High efficiency gas furnace, high efficiency water heater and a high efficiency through the wall air conditioner. Score = 18.

2. System #6 - High efficiency gas water heater for space and domestic water heating and a high efficiency add-on air conditioner. Score = 16.

3. System #3 - Combination water heater used for space and water heating with a add-on air conditioner. Score = 15.

5.8 The Bennevolent Dictator Perspective

The definition of a Bennevolent Dictator as described in Webster's dictionary is that bennevolent means "organized for the purpose of doing good" and dictator is "one who rules absolutely". This perspective is then summarized to mean that the equipment will be selected by someone who has full authority to select the best system and wants to select the system that will benefit all users with low energy costs over the life of the equipment and with a low first cost that the buyer can afford. This system benefits the buyer (low first cost), the tenant (low annual energy costs), and society (low use of our natural resources). This perspective is attempting to benefit all parties involved.

This perspective will find that the lowest life cycle cost (LCC) of the equipment will best benefit their needs. This means the cost of the equipment and the amount of energy that it uses over a 20 year life span is calculated in today's dollars. The lowest LCC equipment will be the best selection. The analysis method used to determine LCC for all equipment systems was detailed in Section 4.3 and the values are shown in Table 4.3.1.

A listing of the calculated life cycle costs for all nine equipment systems ranked by lowest LCC first are shown in Table 5.8.1

The top three equipment selections for the Bennevolent Dictator perspective are:

1. System #6 - High efficiency gas water heater that is used for space and domestic water heating with a high efficiency add-on air conditioner. The LCC is $5403.

2. System #3 - Low efficiency gas furnace, low efficiency gas water heater and a low efficiency through the wall air conditioner. The LCC is $5750.

3. System #5 - High efficiency gas furnace, high efficiency gas water heater and a high efficiency through the wall air conditioner. The LCC is $5832.

The LCC analysis shows that system #6 with the gas water heater that is used for space heating and water heating with it's low first cost (the cost of the furnace is eliminated) of $2735 and it's low annual operating cost of $538 per year has the lowest LCC.

The second selected system for low LCC is a surprise. The low efficiency gas furnace, low efficiency water heater and the low efficiency air conditioner (system #3) shows up second because of its low first cost of $2782 and reasonable annual operating costs of $588 per year. The high efficiency gas system (system #5) shows a higher LCC cost mainly because the first cost of $3317 is $535 higher than the low efficiency gas system and the annual operating costs are only $51 ($587-$536) lower than the low efficiency system. The small improvement in annual operating costs does not offset the higher initial cost over the 20 year life of the system. Consequently, the high efficiency equipment is not the best selection when viewed from the LCC perspective.

5.9 Lowest Total Resource Energy Used Perspective

This perspective looks at the total amount of energy used by each system based on the energy supply source (eg. coal fired power plant, natural gas pipeline, etc.), the end-use source (eg. natural gas furnace, electric baseboard space heating, etc.) and the efficiency of the supply and end-use sources. The analysis method used to determine the total resource energy used was detailed in Section 4.7. Appendix E shows the calculations of total resource energy used for each of the nine equipment systems. The supply and end-use energy or the total resource energy used, measured in BTU'S, are shown in Table 5.9.1.

The lowest amount of total resource energy (Btu's) used will benefit all society by preserving resources. Those resources that we do use are used as efficiently as possible.

The top three systems that use the least amount of total resource energy are:

1. System #5 - High efficiency gas furnace, high efficiency gas water heater and a high efficiency air conditioner. Total resource energy used is 83 MMBTU'S.

2. System #6 - The high efficiency gas water heater for space heating and domestic water heating, with a high efficiency air conditioner. Total resource energy used is 84 MMBTU'S.

3. System #7 - The water loop heat pump system that supplies space and air conditioning with a low efficiency gas water heater. Total resource energy used is 89 MMBTU'S.

Selection Perspective	System Number (Best to Worst)								
1. Building Owner	1	8	2	6	3	5	4	7	9
2. Tenant	5	6	7	3	9	2	4	8	1
3. Utility Needing Capacity	9	7	5	3	6	1	2	8	4
4. Electric Utility Profit	1	4	9	2	8	7	6	3	5
5. Gas Utility Profit	3	8	5	6	2	7	1	4	9
6. Combined Utility Profit	1	4	9	2	8	7	6	3	5
7. Regulatory Agency	5	6	3	7	2	9	8	4	1
8. Bennevolent Dictator	6	3	5	2	8	1	4	7	9
9. Total Resource Energy	5	6	7	3	9	2	4	8	1

System Number Descriptions

#1: Electric Baseboard Heating, Electric Water Heater, and Standard A/C.
#2: Gas Furnace, Electric Water Heater, and Standard A/C.
#3: Gas Furnace, Gas Water Heater, and Standard A/C.
#4: Heat Pump and Electric Water Heater
#5: High Efficiency Gas Furnace, High Efficiency Gas Water Heater, and High Efficiency A/C
#6: High Efficiency Gas Water Heater for Space and Water Heating and High Efficiency A/C
#7: Central Water Loop Heat Pump System and Gas Water Heater
#8: Central Gas Boiler System, Electric Water Heater, and Standard A/C
#9: High Efficiency Integrated Heat Pump for Space and Water Heating and Standard A/C

Table 5.0.1-Equipment Rankings per each Selection Perspective for Madison, Wisconsin

Building Owners Perspective

System Number	Equipment First Cost
1	$1403
8	$1867
2	$2311
6	$2735
3	$2783
5	$3317
4	$4239
7	$6857
9	$7000

Table 5.1.1 Top Equipment Selections for the Building Owners Perspective

Tenant Perspective

System Number	First Year Annual Operating Costs
5	$536
6	$537
7	$546
3	$587
9	$688
2	$752
4	$831
8	$878
1	$1039

Table 5.2.1 Top Equipment Selections for the Tenant Perspective

Combined Utility - Needing Capacity

System #	On - Peak KW
9	2.5
7	3.2
5	3.5
3	4.1
6	4.1
1	4.1
2	4.1
8	4.1
4	4.3

Table 5.3.1 Top Equipment Selections

for the Combined Utility - Needing Capacity Perspective

Gas Utility - Profit Orientated Perspective

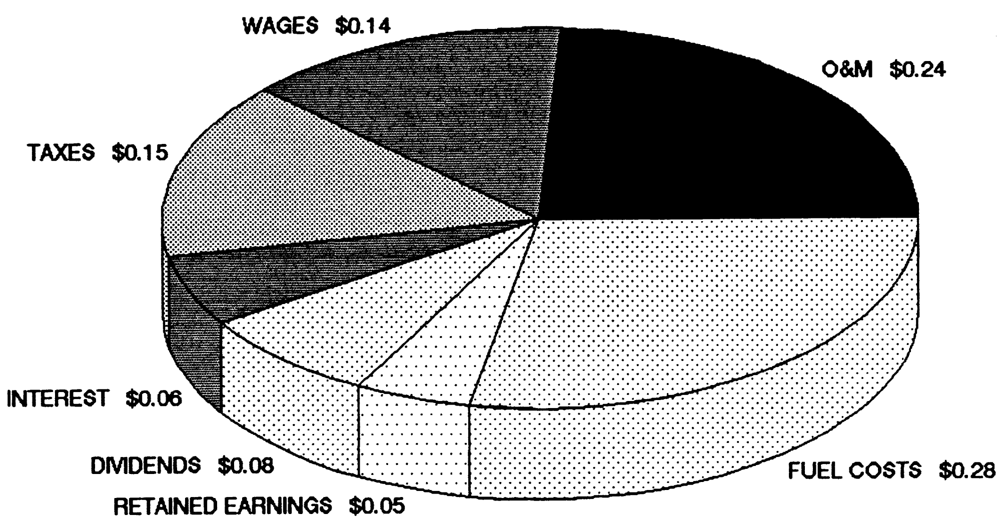
System #	Annual therms used
3	475
8	475
5	417
6	396
2	277
7	198
1	0
4	0
9	0

Table 5.4.1 Top Equipment Selections for the Gas Utility - Profit Orientated Perspective

Electric Utility - Profit Orientated Perspective

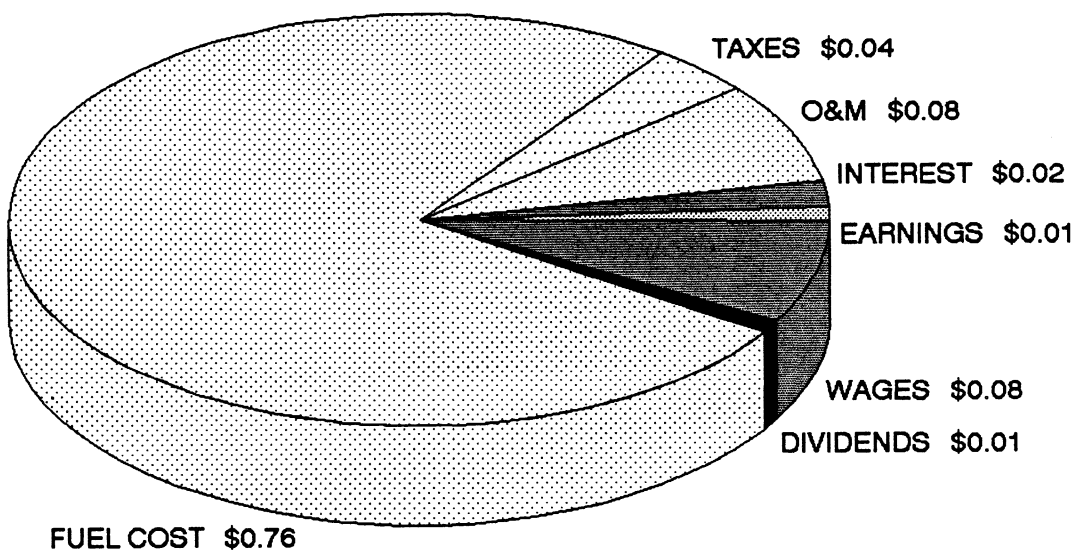
System #	Annual Electric Use (kwh)
1	13,867
4	11,080
9	9,173
2	7,680
8	7,680
7	5,600
6	3,813
3	3,813
5	3,627

Table 5.5.1 Top Equipment Selections for the Electric Utility - Profit Orientated Perspective



For Wisconsin Power and Light-1985

Figure 5.6.1-Electric Utility Costs



For Wisconsin Power and Light-1985

Figure 5.6.2-Natural Gas Utility Costs

Combined Utility - Profit Orientated

System #	Annual Electric Use (kwh)
1	13,867
4	11,080
9	9,173
2	7,680
8	7,680
7	5,600
6	3,813
3	3,813
5	3,627

Table 5.6.1 - Top Equipment Selections for the Combined Utility - Profit Orientated.

Regulatory Agency Perspective

First Selection Criteria

System Number	Lowest LCC	Score	*	Rating	=	Total
1	$9256	1	*	3	=	3
2	$6428	2	*	3	=	6
3	$5750	3	*	3	=	9
4	$8690	2	*	3	=	6
5	$5832	3	*	3	=	9
6	$5403	3	*	3	=	9
7	$9451	1	*	3	=	3
8	$6882	2	*	3	=	6
9	$10680	1	*	3	=	3

Second Selection Criteria

System Number	Lowest On-Peak KW	Score	*	Rating	=	Total
1	4.1	2	*	2	=	4
2	4.1	2	*	2	=	4
3	4.1	2	*	2	=	4
4	4.3	1	*	2	=	2
5	3.5	3	*	2	=	6
6	4.1	2	*	2	=	4
7	3.2	3	*	2	=	6
8	4.1	2	*	2	=	4
9	2.5	3	*	2	=	6

Score	Ratings
3=Top Three Systems	3=First Criteria
2=Middle Three Systems	2=Second Criteria
1=Lowest Three Systems	1=Third Criteria

Table 5.7.1-Top Equipment Selections for the Regulatory Agency Perspective

Regulatory Agency Perspective

Third Selection Criteria

System Number	Lowest 1st Yr Energy Costs	Score	*	Rating	=	Total
1	$1040	1	*	1	=	1
2	$752	1	*	1	=	1
3	$588	2	*	1	=	2
4	$831	2	*	1	=	2
5	$536	3	*	1	=	3
6	$538	3	*	1	=	3
7	$546	3	*	1	=	3
8	$878	1	*	1	=	1
9	$688	2	*	1	=	2

Top Equipment Selections

System Number	Final Score
5	18
6	16
3	15
7	12
2	11
9	11
8	11
4	10
1	8

Score	Ratings
3=Top Three Systems	3=First Criteria
2=Middle Three Systems	2=Second Criteria
1=Lowest Three Systems	1=Third Criteria

Highest Final Score = Best System That Meets All the Selection Criteria.

Table 5.7.1 (cont'd) -Top Equipment Selections for the Regulatory Agency Perspective

Bennevolent Dictators Perspective

System Number	Life Cycle Cost
6	$5403
3	$5750
5	$5832
2	$6428
8	$6882
4	$8690
1	$9256
7	$9451
9	$10680

Table 5.8.1 Top Equipment Selections
for the Bennevolent Dictators Perspective

Total Resource Energy Used Perspective

System #	Total Resource Energy Used (MMBTU)
5	83
6	84
7	89
3	93
9	104
2	124
4	134
8	145
1	166

Table 5.9.1 - Top Equipment Selections for the Total Resource Energy Used Perspective

Chapter 6: Uncertainty Analysis

In Chapter 4, the analysis methods used in this study were explained and documented. These analysis methods were used to rank the equipment systems in the nine perspectives as described in Chapter 5. The top three equipment systems for each perspective were determined by the analysis methods of Chapter 4 and were shown in Chapter 5. This chapter investigates "what if" the calculations are not accurate due to uncertainties in the assumed prices or inflation rates. The question that needs to be answered is if the calculated values change will this also change the ranking of the equipment systems selected as "the best" in each of the nine perspectives as presented in Chapter 5 ?

To determine if the ranking order of equipment systems will change due to changes in the analysis calculations, an uncertainty analysis was performed on the LCC equations contained in Section 4.3. Because LCC is used in two of the nine perspectives (Regulatory Perspective Section 5.5 and the Bennevolent Dictator Perspective Section 5.8) and because the LCC formula (4.3.1, 4.3.2 and 4.3.3) has many variables, this is seen as the most appropriate test of a uncertainty analysis. The LCC formula used in this analysis is :

LCC = P1 * First Year Fuel Costs + P2 * Equipment Costs (4.3.1)

To examine this situation, each variable in equation 4.3.1 above, was varied by + or - 10% and the LCC value was calculated. The results are shown in Tables 6.1.1 thru 6.1.4. Also, all the variables were varied simultaneously by + or - 10% and the LCC value was calculated as is shown in Table 6.0.5. The varying of all the variables by + or -10% represents the worst case scenario when all the variables are inaccurate or have been changed somehow (eg. Price increases). This should not happen, but the exercise is being performed to determine if the equipment selection order will change in this extreme situation.

The LCC values changed by + or - 1% to 10% when a single variable was modified by + or - 10%.

The results of varying the formula variables in Equation 4.3.1 are:

Varied by + or -10%	Affect on LCC	Shown in Table #
Equipment Costs	1-6%	6.0.1
Fuel Costs	5-10%	6.0.2
P2	1-6%	6.0.3
P1	5-10%	6.0.4

It should be noted that the equipment cost and P2 show identical change values (1-6%) as do fuel costs and P1 (5-10%). This is appropriate since these variables are combined on each side of Equation 4.3.1. When all the variables were modified by + or - 10% simultaneously, LCC values varied by + or - 23%. This value did not vary per system number because when all variables are varied by + or -10%, the changes to LCC are similar for all systems as is shown in Table 6.0.6.

The important point of the uncertainty analysis is that even though the changes to the LCC value varied by 1% to 23%, the order of LCC values when ranked from lowest to highest did not change when either one or all of the variables were changed by + or - 10%. This is shown in Table 6.0.6. The only change that occurred was in the order of the 7th and 8th ranked systems, numbers 7 and 8, that changed positions. None of the other system rankings changed.

This indicates that inaccuracies (of + or - 10%) in the variables in the LCC formula (4.3.1) will not affect the ranking of the LCC values for the nine equipment systems being analyzed in this study, even in the extreme situation where all the variables are varied by + or -10%.

With the uncertainty analysis for LCC showing no changes in the ranking of the equipment systems, and since the other perspectives have only singular variables, the ranking of the equipment systems will also <u>not</u> change for all the other perspectives. This assumes that any changes to the variables affect <u>all</u> of the equipment systems equally. Individual equipment system variable changes will obviously affect the perspectives results (eg. Annual fuel costs) and most likely will also affect the ranking of this equipment comparison to the other equipment systems which <u>did</u> <u>not</u> have a variable change.

A example of this is that the natural gas and electric fuel rates were changed for <u>only</u> one equipment system. This would obviously change the annual fuel cost for this system and it would probably change the ranking of this equipment in comparison to the other eight equipment systems whose fuel costs <u>did</u> <u>not</u> change. But when the fuel costs for all the equipment systems are <u>all</u> changed equally, the rankings should not change. It is assumed here that all variances will be applied to <u>all</u> equipment systems.

Based on the above analysis, the ranking of the equipment systems as shown in Table 5.0.1 should not change even with discrepancies of + or - 10% in the calculations from Chapter 4.

Uncertainty Analysis-Varies Equipment Costs by +or-10%

LCC=P1*Fuel Costs +P2*Equipment Costs

Equation Variables Not Varied by +or- 10%

System Number	P1	P2	Fuel Costs
1	7.90	0.75	$1,039
2	6.24	0.75	$752
3	6.24	0.75	$587
4	7.90	0.75	$831
5	6.24	0.75	$536
6	6.24	0.75	$537
7	7.90	0.75	$546
8	6.24	0.75	$876
9	7.90	0.75	$688

Equation Variables Varied by +or- 10%

System Number	Equip Costs	+10%	-10%
1	$1,403	$1,543	$1,263
2	$2,311	$2,542	$2,080
3	$2,782	$3,060	$2,504
4	$2,839	$3,123	$2,555
5	$3,317	$3,649	$2,985
6	$2,735	$3,009	$2,462
7	$6,857	$7,543	$6,171
8	$1,867	$2,054	$1,680
9	$7,000	$7,700	$6,300

Equation Result by Varing Equipment Costs by +or- 10%

System Number	LCC	+10%	-10%	% Variance
1	$9,260	$9,366	$9,155	1%
2	$6,426	$6,599	$6,252	3%
3	$5,749	$5,958	$5,541	4%
4	$8,694	$8,907	$8,481	3%
5	$5,832	$6,081	$5,584	4%
6	$5,402	$5,607	$5,197	4%
7	$9,456	$9,970	$8,942	6%
8	$6,866	$7,007	$6,726	2%
9	$10,685	$11,210	$10,160	5%

Table 6.0.1-Uncertainty Analysis That Varies Equipment Costs

Uncertainty Analysis-Varies Fuel Costs by +or-10%

LCC=P1*Fuel Costs +P2*Equipment Costs

Equation Variables Not Varied by +or- 10%

System Number	P1	P2	Equip Costs
1	7.90	0.75	$1,403
2	6.24	0.75	$2,311
3	6.24	0.75	$2,782
4	7.90	0.75	$2,839
5	6.24	0.75	$3,317
6	6.24	0.75	$2,735
7	7.90	0.75	$6,857
8	6.24	0.75	$1,867
9	7.90	0.75	$7,000

Equation Variables Varied by +or- 10%

System Number	Fuel Costs	+10%	-10%
1	$1,039	$1,143	$935
2	$752	$827	$677
3	$587	$646	$528
4	$831	$914	$748
5	$536	$590	$482
6	$537	$591	$483
7	$546	$601	$491
8	$876	$964	$788
9	$688	$757	$619

Equation Result by Varing Fuel Costs by +or- 10%

System Number	LCC	+10%	-10%	% Variance
1	$9,260	$10,081	$8,440	10%
2	$6,426	$6,895	$5,956	8%
3	$5,749	$6,116	$5,383	7%
4	$8,694	$9,351	$8,038	8%
5	$5,832	$6,167	$5,498	6%
6	$5,402	$5,737	$5,067	7%
7	$9,456	$9,887	$9,025	5%
8	$6,866	$7,413	$6,320	9%
9	$10,685	$11,229	$10,142	5%

Table 6.0.2-Uncertainty Analysis That Varies Fuel Costs

Uncertainty Analysis-Varies P2 by +or-10%

LCC=P1*Fuel Costs +P2*Equipment Costs

Equation Variables Not Varied by +or- 10%

System Number	P1	Equip Costs	Fuel Costs
1	7.90	$1,403	$1,039
2	6.24	$2,311	$752
3	6.24	$2,782	$587
4	7.90	$2,839	$831
5	6.24	$3,317	$536
6	6.24	$2,735	$537
7	7.90	$6,857	$546
8	6.24	$1,867	$876
9	7.90	$7,000	$688

Equation Variables Varied by +or- 10%

System Number	P2	+10%	-10%
1	0.75	0.83	0.68
2	0.75	0.83	0.68
3	0.75	0.83	0.68
4	0.75	0.83	0.68
5	0.75	0.83	0.68
6	0.75	0.83	0.68
7	0.75	0.83	0.68
8	0.75	0.83	0.68
9	0.75	0.83	0.68

Equation Result by Varing P2 by +or- 10%

System Number	LCC	+10%	-10%	% Variance
1	$9,260	$9,366	$9,155	1%
2	$6,426	$6,599	$6,252	3%
3	$5,749	$5,958	$5,541	4%
4	$8,694	$8,907	$8,481	3%
5	$5,832	$6,081	$5,584	4%
6	$5,402	$5,607	$5,197	4%
7	$9,456	$9,970	$8,942	6%
8	$6,866	$7,007	$6,726	2%
9	$10,685	$11,210	$10,160	5%

Table 6.0.3-Uncertainty Analysis That Varies P2

Uncertainty Analysis-Varies P1 by +or-10%

LCC=P1*Fuel Costs +P2*Equipment Costs

Equation Variables Not Varied by +or- 10%

System Number	Equip Costs	P2	Fuel Costs
1	$1,403	0.75	$1,039
2	$2,311	0.75	$752
3	$2,782	0.75	$587
4	$2,839	0.75	$831
5	$3,317	0.75	$536
6	$2,735	0.75	$537
7	$6,857	0.75	$546
8	$1,867	0.75	$876
9	$7,000	0.75	$688

Equation Variables Varied by +or- 10%

System Number	P1	+10%	-10%
1	7.90	8.69	7.11
2	6.24	6.86	5.62
3	6.24	6.86	5.62
4	7.90	8.69	7.11
5	6.24	6.86	5.62
6	6.24	6.86	5.62
7	7.90	8.69	7.11
8	6.24	6.86	5.62
9	7.90	8.69	7.11

Equation Result by Varing P1 by +or- 10%

System Number	LCC	+10%	-10%	% Variance
1	$9,260	$10,081	$8,440	10%
2	$6,426	$6,895	$5,956	8%
3	$5,749	$6,116	$5,383	7%
4	$8,694	$9,351	$8,038	8%
5	$5,832	$6,167	$5,498	6%
6	$5,402	$5,737	$5,067	7%
7	$9,456	$9,887	$9,025	5%
8	$6,866	$7,413	$6,320	9%
9	$10,685	$11,229	$10,142	5%

Table 6.0.4-Uncertainty Analysis That Varies P1

Uncertainty Analysis-Varies All Variables by +or-10%

LCC=P1*Fuel Costs +P2*Equipment Costs

System Number	P1	+10%	-10%
1	7.90	8.69	7.11
2	6.24	6.86	5.62
3	6.24	6.86	5.62
4	7.90	8.69	7.11
5	6.24	6.86	5.62
6	6.24	6.86	5.62
7	7.90	8.69	7.11
8	6.24	6.86	5.62
9	7.90	8.69	7.11

System Number	Equip Costs	+10%	-10%
1	$1,403	$1,543	$1,263
2	$2,311	$2,542	$2,080
3	$2,782	$3,060	$2,504
4	$2,839	$3,123	$2,555
5	$3,317	$3,649	$2,985
6	$2,735	$3,009	$2,462
7	$6,857	$7,543	$6,171
8	$1,867	$2,054	$1,680
9	$7,000	$7,700	$6,300

System Number	P2	+10%	-10%
1	0.75	0.83	0.68
2	0.75	0.83	0.68
3	0.75	0.83	0.68
4	0.75	0.83	0.68
5	0.75	0.83	0.68
6	0.75	0.83	0.68
7	0.75	0.83	0.68
8	0.75	0.83	0.68
9	0.75	0.83	0.68

Table 6.0.5-Uncertainty Analysis That Varies All Formula Variables

Uncertainty Analysis-Varies All Variables by +or-10%

LCC=P1*Fuel Costs +P2*Equipment Costs

System Number	Fuel Costs	+10%	-10%
1	$1,039	$1,143	$935
2	$752	$827	$677
3	$587	$646	$528
4	$831	$914	$748
5	$536	$590	$482
6	$537	$591	$483
7	$546	$601	$491
8	$876	$964	$788
9	$688	$757	$619

Equation Result by Varing All Variables by +or- 10%

System Number	LCC	+10%	-10%	% Variance
1	$9,260	$11,205	$7,501	23%
2	$6,426	$7,775	$5,205	23%
3	$5,749	$6,957	$4,657	23%
4	$8,694	$10,520	$7,042	23%
5	$5,832	$7,057	$4,724	23%
6	$5,402	$6,537	$4,376	23%
7	$9,456	$11,442	$7,659	23%
8	$6,866	$8,308	$5,562	23%
9	$10,685	$12,929	$8,655	23%

Table 6.0.5 (Cont'd)-Uncertainty Analysis That Varies All Formula Variables

Uncertainty Analysis-Ranking LCC for all Variables

System Numbers are Ranked by Lowest to Highest LCC

System Number	Base LCC
6	$5,402
3	$5,749
5	$5,832
2	$6,426
8	$6,866
4	$8,694
1	$9,260
7	$9,456
9	$10,685

P1	
System Number	LCC +10%
6	$5,737
3	$6,116
5	$6,167
2	$6,895
8	$7,413
4	$9,351
7	$9,887
1	$10,081
9	$11,229

Fuel Costs	
System Number	LCC +10%
6	$5,737
3	$6,116
5	$6,167
2	$6,895
8	$7,413
4	$9,351
7	$9,887
1	$10,081
9	$11,229

System Number	Base LCC
6	$5,402
3	$5,749
5	$5,832
2	$6,426
8	$6,866
4	$8,694
1	$9,260
7	$9,456
9	$10,685

P2	
System Number	LCC +10%
6	$5,607
3	$5,958
5	$6,081
2	$6,599
8	$7,007
4	$8,907
1	$9,366
7	$9,970
9	$11,210

Equip Costs	
System Number	LCC +10%
6	$5,607
3	$5,958
5	$6,081
2	$6,599
8	$7,007
4	$8,907
1	$9,366
7	$9,970
9	$11,210

System Number	Base LCC
6	$5,402
3	$5,749
5	$5,832
2	$6,426
8	$6,866
4	$8,694
1	$9,260
7	$9,456
9	$10,685

All Variables	
System Number	LCC +10%
6	$6,537
3	$6,957
5	$7,057
2	$7,775
8	$8,308
4	$10,520
1	$11,205
7	$11,442
9	$12,929

Table 6.0.6-Uncertainty Analysis to Compare the Ranking of Equipment Systems

Chapter 7

Analysis of the Base Building in other United States Cities

In an effort to expand the usefulness of this research, the base building being analyzed here has been modeled in three other U.S. Cities: Atlanta, Georgia; New York City, New York; and Los Angeles, California. These cities were selected to obtain a reasonable cross-section of the U.S. climate regions: The Midwest-Madison, Wisconsin; The Northeast-New York City; The South-Atlanta, Georgia; and the West-Los Angeles, California.

These climate regions show a large difference in there heating and cooling degree days[1]:

Cities	Heating Degree Days	Cooling Degree Days
Madison	7,863	424
Atlanta	2,929	1,469
New York	4,811	1,027
Los Angeles	2,061	357

The input data for the F-Load software program for the base building using nine different equipment systems was modified only by changing the city location and the cost of electricity and natural gas for each city. The fuel costs are:

City	Utility	Electricity Cost ($/KWH)	Gas Cost ($/therm)
Madison	Madison G & E[2]	$0.075	$0.636
Atlanta	Georgia Power[3]	$0.0728	$0.8318
New York	Consolidated[4]	$0.1141	$0.8407
Los Angeles	PG&E[5]	$0.1183	$0.5228

The design heating and cooling loads for the base building in each of the four cities is:

City	Design Heating Load (BTU/HR)	Design Cooling Load (BTU/HR)
Madison	15,400	8,000
Atlanta	9,300	8,400
New York	10,300	7,900
Los Angeles	4,800	6,400

F-Load computer runs were performed for each of the nine equipment systems for each of the four cities. Then all of the nine perspectives were determined for each of the cities. The results of each perspective selection for all of the nine equipment systems for each of the four cities are shown in Tables 7.1 to 7.9.

7.1-Review of the Analysis Parameters of the Nine Selection Perspectives for the Four Cities

In Chapter 4, the analysis methods were discussed in detail. These same analysis methods are modified slightly for each of the three additional cities that have been used. The modifications for each perspective are discussed below:

Building Owners Perspective (Table 7.1) - This perspective looks at the equipment first cost. For this analysis it is assumed that the equipment costs do not change for these four cities.

Tenant Perspective (Table 7.2) - This perspective looks at first year operating costs of each equipment system. These costs are determined by using the F-Load analysis program for each city and the appropriate fuel cost figures for each city.

Combined Utility-Needing Capacity Perspective (Table 7.3) - This perspective looks at the On-Peak KW requirements of each equipment systems air conditioning system. The on-peak KW requirements do not change based on the equipment location in a different city.

Gas Utility-Profit Orientated Perspective (Table 7.4) - This perspective looks at the annual therms used for each of the nine equipment systems. The F-Load software program was used to determine these values which are dependent on the heating and cooling degree days of each city's location.

Electric Utility-Profit Orientated Perspective (Table 7.5) - This perspective looks at the annual electric use (KWH) of the equipment systems. The F-Load software program was also used to determine these values which are dependent on the heating and cooling degree days of each city location.

Combined Utility-Profit Orientated Perspective (Table 7.6) - This perspective is quite similar to the Electric Utility-Profit Orientated Perspective since it looks at annual electric use (KWH). Since the profit on electricity sales is over four times that of natural gas, this perspective looks only at the electric use.

Regulatory Agency Perspective (Table 7.7) - This perspective uses a matrix to determine a "final score" because this perspective reviews a total of three different perspective views (as described in Section 4.6). The matrix was performed for all the cities.

Bennevolent Dictator Perspective (Table 7.8) - This perspective looks at Life Cycle Cost (LCC). Formula 4.3.1 was used with each city's first year costs to determine the life cycle costs. This formula also uses equipment costs, but these are assumed to not change.

Total Resource Energy Used Perspective (Table 7.9) - This perspective used Formula 4.7.1 to determine the total amount of energy used from the production site to the end-use. The equipment and the production sites are not changing, but the climate changes for each city so the amount of energy used will change.

7.2-Summary/Comparison of the Equipment Rankings per each Selection Perspective for all Four Cities.

The equipment systems that "best" meet the requirements of each selection perspective have been ranked in Tables 7.10 to 7.12 for each of the new cities. These can be compared visually to the city of Madison in Table 5.0.1.

Table 7.13 compares each city's equipment ranking for each selection perspective. This allows the reader to compare the top ranked system for each selection perspective on a per city (U.S location) basis. In most of the selection perspectives the changes are not dramatic but there are changes to the equipment rankings that are due to the climatic differences of each city and the fuel price differences.

The specific ranking changes that occur in the equipment selections for each selection perspective for each city (as listed in Table 7.13) are discussed below:

Building Owner Perspective

This perspective uses the equipment costs which are assumed to be the same for each city, so there is no changes between the cities. The top rated system with the lowest equipment cost is system #1; the electric baseboard heating system with a low efficiency water heater and a low efficiency air conditioner.

Tenant Perspective

The tenant perspective uses the lowest annual fuel costs to rank the equipment systems. For all four cities, systems #5, #6 and #7 are the top three systems but there rankings are in different orders. In Madison and New York, the combination of heating degree days and gas costs for these cities result in the highest annual energy bills for the four cities. System #5 has the lowest energy use gas furnace of all the equipment systems, so system #5 is the top selection for these two cities.

For the cities of Atlanta and Los Angeles, the cooling load is the controlling factor in the equipment rankings. System #7, the water loop heat pump system has lower cooling costs than the high efficiency air conditioning unit in system #5, so system #7 has the highest ranking for these two cities.

Utility-Needing Capacity

Since the electric capacity (KW) of each equipment system does not change per location (city), the equipment rankings do not change for the four cities. Systems #9, #7 and #5 have the most efficient air conditioning systems and thus the lowest KW and are respectively the highest ranked systems in this perspective.

Electric Utility-Profit Oriented

Systems #1 and #4, respectively, have the highest electric use (KWH) because of the low efficiency water heaters and the low efficiency air conditioners (through the wall for system #1 and a heat pump unit for system #4). City location does not significantly change the ranking of these systems.

Gas Utility-Profit Oriented

The low efficiency gas furnace and water heater of system #3 is the top selection for all four cities, where the highest therm use receives the highest ranking.

Combined Utility-Profit Oriented

Because the profits on electric sales are four times as high as on gas sales, only the highest electric use systems are considered. This perspective has the same results as the Electric Utility-Profit Oriented Perspective shown above, systems #1 and #4 are the top selections.

Regulatory Agency Perspective

It is assumed that this perspective does not change for all four cities. The top rated system for all four cities is #5; the high efficiency gas furnace, high efficiency gas water heater and high efficiency air conditioner. The second highest rated system is #6; the high efficiency gas water heater used for space and water heating with a high efficiency air conditioner.

Bennevolent Dictator

This perspective looks strictly at the lowest life cycle cost (LCC) and it is assumed that the equipment costs don't change, only the fuel costs and weather conditions for the four cities. The top three selections are all the same for all four cities. The top selection is system #6; the high efficiency gas water heater used for space and water heating with a high efficiency air conditioner. Second, is system #3; the low efficiency gas furnace, low efficiency water heater and low efficiency air conditioner. Third, is system #5; the high efficiency gas furnace, high efficiency water heater and high efficiency air conditioner. It is interesting to note that the additional cost of the high efficiency equipment verses it's energy savings did not result in a lower LCC than the low efficiency equipment!

Total Resource Perspective

The top rated equipment system for all four cities is system #7; the central water loop heat pump system and gas water heater. The next two highly rated equipment systems are systems #5 and #6, the high efficiency gas furnace, high efficiency water heater and high efficiency air conditioner and the high efficiency gas water heater space heating system.

Further conclusions will be summarized in the final chapter (#10).

[1] Reference 1981 ASHRAE Fundamentals Chapter 24-Table 4 and Chapter 28-Table 4.

[2] Madison Gas and Electric Company
P.O. Box 1231
Madison, Wi 53701-1231

[3] Georgia Power Company
333 Piedmont avenue NE
Atlanta, Ga 30308
404-526-6526
Supplies Electricity

Atlanta Gas Light Company
235 Peachtree Street NE
P.O. Box 4569
Atlanta, Ga 30302
404-584-4000
Supplies Natural Gas

[4] Consolidated Edison Company of New York
4 Irving Place
New York, NY 10003
212-460-4600
Supplies Electricity and Natural Gas

[5] Pacific Gas and Electric Company
77 Beale Street
San Francisco, Ca 94106
415-972-7000
Supplies Electricity and Natural Gas

Building Owners Perspective
Summary for all Four Cities

	Equipment First Cost			
System Number	Madison	Atlanta	New York	Los Angeles
1	$1403	$1403	$1403	$1403
2	$2311	$2311	$2311	$2311
3	$2783	$2783	$2783	$2783
4	$4239	$4239	$4239	$4239
5	$3317	$3317	$3317	$3317
6	$2735	$2735	$2735	$2735
7	$6857	$6857	$6857	$6857
8	$1867	$1867	$1867	$1867
9	$7000	$7000	$7000	$7000

Table 7.1 Summary for the

Building Owners Perspective for all Four Cities

Tenant Perspective
Summary for all Four Cities

System Number	Madison	Atlanta	New York	Los Angeles
	First Year Operating Costs			
1	$753	$731	$1281	$972
2	$752	$677	$1030	$952
3	$587	$574	$775	$643
4	$831	$634	$1064	$907
5	$536	$533	$717	$605
6	$537	$526	$720	$615
7	$546	$505	$727	$582
8	$878	$725	$1128	$957
9	$688	$561	$931	$810

Table 7.2 Summary for the Tenant Perspective for all Four Cities

Combined Utility-Needing Capacity Perspective
Summary for all Four Cities

	On-Peak KW			
System Number	Madison	Atlanta	New York	Los Angeles
1	4.1	4.1	4.1	4.1
2	4.1	4.1	4.1	4.1
3	4.1	4.1	4.1	4.1
4	4.3	4.3	4.3	4.3
5	3.5	3.5	3.5	3.5
6	4.1	4.1	4.1	4.1
7	3.2	3.2	3.2	3.2
8	4.1	4.1	4.1	4.1
9	2.5	2.5	2.5	2.5

Table 7.3 Summary for the Combined

Utility-Needing Capacity Perspective for all Four Cities

Gas Utility-Profit Orientated Perspective Summary for all Four Cities

System Number	Madison	Atlanta	New York	Los Angeles
	Annual Therms Used			
1	0	0	0	0
2	277	68	148	9
3	475	242	332	182
4	0	0	0	0
5	417	228	300	181
6	396	184	266	129
7	198	175	184	173
8	475	125	263	19
9	0	0	0	0

Table 7.4 Summary for the Gas Utility-Profit Orientated Perspective for all Four Cities

Electric Utility-Profit Orientated Perspective
Summary for all Four Cities

	Annual Electric Use (KWH)			
System Number	Madison	Atlanta	New York	Los Angeles
1	13,867	10,053	11,240	8,227
2	7,680	8,533	7,960	8,013
3	3,813	5,133	4,360	4,640
4	11,080	8,707	9,347	7,667
5	3,627	4,720	4,080	4,320
6	3,813	5,133	4,360	4,640
7	5,600	4,960	5,027	4,173
8	7,680	8,533	7,960	8,013
9	9,173	7,707	8,173	6,853

Table 7.5 Summary for the Electric Utility-Profit Orientated Perspective for all Four Cities

Combined Utility-Profit Orientated Perspective
Summary for all Four Cities

System Number	Annual Electric Use (KWH) Madison	Atlanta	New York	Los Angeles
1	13,867	10,053	11,240	8,227
2	7,680	8,533	7,960	8,013
3	3,813	5,133	4,360	4,640
4	11,080	8,707	9,347	7,667
5	3,627	4,720	4,080	4,320
6	3,813	5,133	4,360	4,640
7	5,600	4,960	5,027	4,173
8	7,680	8,533	7,960	8,013
9	9,173	7,707	8,173	6,853

Table 7.6 Summary for the Combined

Utility-Profit Orientated Perspective for all Four Cities

Regulatory Agency Perspective
Summary for all Four Cities

Final Score

System Number	Madison	Atlanta	New York	Los Angeles
1	8	11	8	11
2	11	11	12	11
3	15	15	15	15
4	10	7	6	7
5	18	18	18	18
6	16	16	16	16
7	12	12	15	12
8	11	11	11	11
9	11	11	11	11

Table 7.7 Summary for the Regulatory Agency Perspective for all Four Cities

Bennevolent Dictators Perspective
Summary for all Four Cities

	Life Cycle Cost ($)			
System Number	Madison	Atlanta	New York	Los Angeles
1	$9,256	$6,827	$11,172	$8,731
2	$6,428	$5,958	$8,160	$7,674
3	$5,750	$5,669	$6,923	$6,100
4	$8,690	$8,188	$11,585	$10,345
5	$5,832	$5,814	$6,962	$6,263
6	$5,403	$5,333	$6,544	$5,889
7	$9,451	$9,132	$10,886	$9,741
8	$6,882	$5,924	$8,439	$7,372
9	$10,680	$9,682	$12,605	$11,649

Table 7.8 Summary for the Bennevolent Dictators Perspective for all Four Cities

Total Resource Energy Used Perspective
Summary for all Four Cities

System Number	Madison	Atlanta	New York	Los Angeles
	Total Resource Energy Used (MMBTU)			
1	166	114	123	93
2	124	104	106	92
3	93	84	84	72
4	134	99	106	87
5	83	78	78	68
6	84	79	77	66
7	89	75	76	65
8	145	110	118	93
9	104	88	93	78

Table 7.9 Summary for the Total Resource Energy Used Perspective for all Four Cities

Selection Perspective	System Number (Best to Worst)								
1. Building Owner	1	8	2	6	3	5	4	7	9
2. Tenant	5	6	7	3	9	2	4	8	1
3. Utility Needing Capacity	9	7	5	3	6	1	2	8	4
4. Electric Utility Profit	1	4	9	2	8	7	6	3	5
5. Gas Utility Profit	3	5	6	8	7	2	1	4	9
6. Combined Utility Profit	1	4	9	2	8	3	6	7	5
7. Regulatory Agency	5	6	3	7	2	9	8	1	4
8. Bennevolent Dictator	6	3	5	2	8	7	1	4	9
9. Total Resource Energy	7	6	5	3	9	4	2	8	1

System Number Descriptions

#1: Electric Baseboard Heating, Electric Water Heater, and Standard A/C.
#2: Gas Furnace, Electric Water Heater, and Standard A/C.
#3: Gas Furnace, Gas Water Heater, and Standard A/C.
#4: Heat Pump and Electric Water Heater
#5: High Efficiency Gas Furnace, High Efficiency Gas Water Heater, and High Efficiency A/C
#6: High Efficiency Gas Water Heater for Space and Water Heating and High Efficiency A/C
#7: Central Water Loop Heat Pump System and Gas Water Heater
#8: Central Gas Boiler System, Electric Water Heater, and Standard A/C
#9: High Efficiency Integrated Heat Pump for Space and Water Heating and Standard A/C

Table 7.10-Equipment Rankings per each Selection Perspective for New York, New York

Selection Perspective	System Number (Best to Worst)								
1. Building Owner	1	8	2	6	3	5	4	7	9
2. Tenant	7	5	6	3	9	4	2	8	1
3. Utility Needing Capacity	9	7	5	3	6	1	2	8	4
4. Electric Utility Profit	1	2	8	4	9	6	3	5	7
5. Gas Utility Profit	3	5	7	6	8	2	1	4	9
6. Combined Utility Profit	1	2	8	4	9	6	3	5	7
7. Regulatory Agency	5	6	3	7	8	2	9	1	4
8. Bennevolent Dictator	6	3	5	8	2	1	7	4	9
9. Total Resource Energy	7	6	5	3	9	4	2	8	1

System Number Descriptions

#1: Electric Baseboard Heating, Electric Water Heater, and Standard A/C.
#2: Gas Furnace, Electric Water Heater, and Standard A/C.
#3: Gas Furnace, Gas Water Heater, and Standard A/C.
#4: Heat Pump and Electric Water Heater
#5: High Efficiency Gas Furnace, High Efficiency Gas Water Heater, and High Efficiency A/C
#6: High Efficiency Gas Water Heater for Space and Water Heating and High Efficiency A/C
#7: Central Water Loop Heat Pump System and Gas Water Heater
#8: Central Gas Boiler System, Electric Water Heater, and Standard A/C
#9: High Efficiency Integrated Heat Pump for Space and Water Heating and Standard A/C

Table 7.11-Equipment Rankings per each Selection Perspective for Los Angeles, California

Selection Perspective	System Number (Best to Worst)								
1. Building Owner	1	8	2	6	3	5	4	7	9
2. Tenant	7	6	5	9	3	4	2	8	1
3. Utility Needing Capacity	9	7	5	3	6	1	2	8	4
4. Electric Utility Profit	1	4	2	8	9	6	3	7	5
5. Gas Utility Profit	3	5	6	7	8	2	1	4	9
6. Combined Utility Profit	1	4	2	8	9	6	3	7	5
7. Regulatory Agency	5	6	3	7	2	9	8	1	4
8. Bennevolent Dictator	6	3	5	8	2	1	4	7	9
9. Total Resource Energy	7	5	6	3	9	4	2	8	1

System Number Descriptions

#1: Electric Baseboard Heating, Electric Water Heater, and Standard A/C.
#2: Gas Furnace, Electric Water Heater, and Standard A/C.
#3: Gas Furnace, Gas Water Heater, and Standard A/C.
#4: Heat Pump and Electric Water Heater
#5: High Efficiency Gas Furnace, High Efficiency Gas Water Heater, and High Efficiency A/C
#6: High Efficiency Gas Water Heater for Space and Water Heating and High Efficiency A/C
#7: Central Water Loop Heat Pump System and Gas Water Heater
#8: Central Gas Boiler System, Electric Water Heater, and Standard A/C
#9: High Efficiency Integrated Heat Pump for Space and Water Heating and Standard A/C

Table 7.12-Equipment Rankings per each Selection Perspective for Atlanta, Georgia

Selection Perspective		System Number (Best to Worst)								
1. Building Owner	Madison	1	8	2	6	3	5	4	7	9
	Atlanta	1	8	2	6	3	5	4	7	9
	New York	1	8	2	6	3	5	4	7	9
	Los Angeles	1	8	2	6	3	5	4	7	9
2. Tenant	Madison	5	6	7	3	9	2	4	8	1
	Atlanta	7	6	5	9	3	4	2	8	1
	New York	5	6	7	3	9	2	4	8	1
	Los Angeles	7	5	6	3	9	4	2	8	1

System Number Descriptions

#1: Electric Baseboard Heating, Electric Water Heater, and Standard A/C.
#2: Gas Furnace, Electric Water Heater, and Standard A/C.
#3: Gas Furnace, Gas Water Heater, and Standard A/C.
#4: Heat Pump and Electric Water Heater
#5: High Efficiency Gas Furnace, High Efficiency Gas Water Heater, and High Efficiency A/C
#6: High Efficiency Gas Water Heater for Space and Water Heating and High Efficiency A/C
#7: Central Water Loop Heat Pump System and Gas Water Heater
#8: Central Gas Boiler System, Electric Water Heater, and Standard A/C
#9: High Efficiency Integrated Heat Pump for Space and Water Heating and Standard A/C

Table 7.13-Equipment Rankings per each Selection Perspective for all Four Cities

Selection Perspective	System Number (Best to Worst)								
3. Utility-Needs Capc,Madison	9	7	5	3	6	1	2	8	4
Atlanta	9	7	5	3	6	1	2	8	4
New York	9	7	5	3	6	1	2	8	4
Los Angeles	9	7	5	3	6	1	2	8	4
4. Elec Util-Profit Madison	1	4	9	2	8	7	6	3	5
Atlanta	1	4	2	8	9	6	3	7	5
New York	1	4	9	2	8	7	6	3	5
Los Angeles	1	2	8	4	9	6	3	5	7

System Number Descriptions

#1: Electric Baseboard Heating, Electric Water Heater, and Standard A/C.
#2: Gas Furnace, Electric Water Heater, and Standard A/C.
#3: Gas Furnace, Gas Water Heater, and Standard A/C.
#4: Heat Pump and Electric Water Heater
#5: High Efficiency Gas Furnace, High Efficiency Gas Water Heater, and High Efficiency A/C
#6: High Efficiency Gas Water Heater for Space and Water Heating and High Efficiency A/C
#7: Central Water Loop Heat Pump System and Gas Water Heater
#8: Central Gas Boiler System, Electric Water Heater, and Standard A/C
#9: High Efficiency Integrated Heat Pump for Space and Water Heating and Standard A/C

Table 7.13 (cont'd)-Equipment Rankings per each Selection Perspective for all Four Cities

Selection Perspective	System Number (Best to Worst)								
5. Gas Utility-Profit,Madison	3	8	5	6	2	7	1	4	9
Atlanta	3	5	6	7	8	2	1	4	9
New York	3	5	6	8	7	2	1	4	9
Los Angeles	3	5	7	6	8	2	1	4	9
6. Comb Util-Profit Madison	1	4	9	2	8	3	6	7	5
Atlanta	1	4	2	8	9	6	3	7	5
New York	1	4	9	2	8	3	6	7	5
Los Angeles	1	2	8	4	9	6	3	5	7

System Number Descriptions

#1: Electric Baseboard Heating, Electric Water Heater, and Standard A/C.
#2: Gas Furnace, Electric Water Heater, and Standard A/C.
#3: Gas Furnace, Gas Water Heater, and Standard A/C.
#4: Heat Pump and Electric Water Heater
#5: High Efficiency Gas Furnace, High Efficiency Gas Water Heater, and High Efficiency A/C
#6: High Efficiency Gas Water Heater for Space and Water Heating and High Efficiency A/C
#7: Central Water Loop Heat Pump System and Gas Water Heater
#8: Central Gas Boiler System, Electric Water Heater, and Standard A/C
#9: High Efficiency Integrated Heat Pump for Space and Water Heating and Standard A/C

Table 7.13 (cont'd)-Equipment Rankings per each Selection Perspective for all Four Cities

Selection Perspective		System Number (Best to Worst)								
7. Regulatory Agency	Madison	5	6	3	7	2	9	8	1	4
	Atlanta	5	6	3	7	2	9	8	1	4
	New York	5	6	3	7	2	9	8	1	4
	Los Angeles	5	6	3	7	8	2	9	1	4
8. Bennevolent Dict.	Madison	6	3	5	2	8	1	4	7	9
	Atlanta	6	3	5	8	2	1	4	7	9
	New York	6	3	5	2	8	7	1	4	9
	Los Angeles	6	3	5	8	2	1	7	4	9

System Number Descriptions

#1: Electric Baseboard Heating, Electric Water Heater, and Standard A/C.
#2: Gas Furnace, Electric Water Heater, and Standard A/C.
#3: Gas Furnace, Gas Water Heater, and Standard A/C.
#4: Heat Pump and Electric Water Heater
#5: High Efficiency Gas Furnace, High Efficiency Gas Water Heater, and High Efficiency A/C
#6: High Efficiency Gas Water Heater for Space and Water Heating and High Efficiency A/C
#7: Central Water Loop Heat Pump System and Gas Water Heater
#8: Central Gas Boiler System, Electric Water Heater, and Standard A/C
#9: High Efficiency Integrated Heat Pump for Space and Water Heating and Standard A/C

Table 7.13 (cont'd)-Equipment Rankings per each Selection Perspective for all Four Cities

Selection Perspective		System Number (Best to Worst)								
9. Total Resource	Madison	5	6	7	3	9	2	4	8	1
	Atlanta	7	5	6	3	9	4	2	8	1
	New York	7	6	5	3	9	4	2	8	1
	Los Angeles	7	6	5	3	9	4	2	8	1

System Number Descriptions

#1: Electric Baseboard Heating, Electric Water Heater, and Standard A/C.
#2: Gas Furnace, Electric Water Heater, and Standard A/C.
#3: Gas Furnace, Gas Water Heater, and Standard A/C.
#4: Heat Pump and Electric Water Heater
#5: High Efficiency Gas Furnace, High Efficiency Gas Water Heater, and High Efficiency A/C
#6: High Efficiency Gas Water Heater for Space and Water Heating and High Efficiency A/C
#7: Central Water Loop Heat Pump System and Gas Water Heater
#8: Central Gas Boiler System, Electric Water Heater, and Standard A/C
#9: High Efficiency Integrated Heat Pump for Space and Water Heating and Standard A/C

Table 7.13 (cont'd)-Equipment Rankings per each Selection Perspective for all Four Cities

Chapter 8 - Societal Impacts of Equipment System Selections

Of the nine selection perspectives that were reviewed in Chapter 5, only the Total Resource Energy Used Perspective was not based on economic information for the selection of the "best" equipment selection. This perspective looks at the total amount of energy (in MMBTU'S) that each equipment system uses from the supply source to the end-use with all the supply, generation and usage inefficiencies included. The system using the least amount of energy (MMBTU'S), is the most efficient from a societal energy use perspective. Knowing that our energy supplies (coal, natural gas and uranium) are not endless, this perspective needs to be considered in more detail and that is the reason for this chapter.

One way to compare the Total Resource Energy Used by each equipment system is to convert all energy use (electricity and natural gas) to a common BTU basis. This was the format used in Chapter 5, Section 5.9, so that all the nine equipment systems could be compared on a equal basis. A alternate method is to retain the energy values in their standard form of kilowatt-hours of electricity (KWH) and therms of natural gas (cubic feet). These values can then be viewed more realistically in volumes of natural gas, tons of coal and in grams of uranium fuel pellets that are used to generate a amount of electricity or natural gas. This gives us a more "real world' perspective on the societal (environmental) effect of selecting one equipment system over another. Tables 8.1.1 through 8.1.5 look only at results from Madison, Wisconsin. Since the system rankings from Chapter 7 showed that the top equipment selections were for the most part unchanged by location, the conclusions of this chapter will be based on Madison data but they will apply to the other cities as well. Table 8.1.1 shows each of the nine equipment systems, their Total Resource Energy Used (in MMBTU'S) and the total amount of natural gas (in therms) and electrical energy (in KWH) for a year. Table 8.1.2 shows these values converted into volumes of natural gas (cubic feet)[1] and tons of coal[2] and grams of uranium fuel pellets[3] that are used to produce electricity[4].

The difference between the top rated system #5 (High efficiency gas furnace, high efficiency gas water heater and a high efficiency air conditioner) , which uses the least amount of energy, and the lowest rated system, #1, (Electric baseboard heating, electric water heater and a low efficiency air conditioner) is 82 MMBTU'S or a 200% difference or: 3.64 tons of coal, 1.49 grams of uranium fuel pellets and 438 cubic feet of natural gas. This is based on a power plant that uses 70% coal and 30% nuclear energy.

The above values take on a whole new meaning when they are put into real life measurement values. Table 8.1.3 shows the magnitude of "real world" energy use when these equipment systems are operated for a one year and twenty year period (the theoretical life of the equipment). Now the comparison between the top rated system #5 and the bottom rated system #1 has a greater variation in "real world" terms after twenty years of operation: 72.8 tons of coal, 29.8 grams of uranium fuel pellets, and 8,760 cubic feet of natural gas.

These figures take on a additional order of magnitude when we consider the potential that for the City of Madison it is estimated that 1400 new apartment/offices will be built on a annual basis over the next decade[5]. Table 8.1.4 shows the Real World Energy Sources used on a projected rate of 1400 new apartments / offices that will be built in Madison, Wisconsin for the current year.

Table 8.1.5 looks at the situation of the 1400 new apartment / offices having equipment systems installed each year for the next twenty years. This analysis method may not be a accurate forecast but it is being used to simply show the magnitude of the total energy used when one equipment system is selected instead of another for this period of time. Here we see a total difference between system #5, the top rated system, and system #1, the bottom rated system of: 1,076,000 tons of coal, 440,000 grams of uranium fuel pellets, and 129,509,000 cubic feet of natural gas!

Further estimates could be performed to estimate the impact on a entire United States basis. This will not be attempted in this report but the point has been made that the differences can be staggering! Futhermore, the air pollution effect will not be considered here but coal burning does produce air pollution and this can be reduced when less coal is burned.

8.1 - Comparing the Societal Effects of Equipment Selection to the other Equipment Selection Perspectives.

As stated earlier, the Total Resource Energy Used Perspective does not involve a economic selection as compared to the Bennevolent Dictator (Life Cycle Cost), the Tenant perspective (First year energy cost) or the Owners Perspective (First cost). So it will be easy to overlook the societal effects of the Total Resource Energy Perspective when straight economics are considered.

A look at the above listed selection perspectives, for Madison, shows that the top three selected systems for each perspective do not closely match those of the Total Resource Energy Used perspective.

Perspective	Top Three Equipment Systems
Tenant	5, 6, 7
Bennevolent Dictator	6, 3, 5
Owner	1, 8, 9
Total Resource Energy Used	5, 6, 7

Only system #5 and #6 would provide appropriate matches if the Bennevolent Dictator (Life cycle cost) and tenants perspective (First year energy costs) were selected.

The point is that even though the Total Resource Energy Perspective is not a economic consideration for the person making the equipment selection, that the societal effects should at least be considered before making a final equipment decision! The system that is selected for economic reasons as a "best" system may be a "loser" from a societal perspective.

[1] One therm of natural gas = One Cubic foot (CCF) of natural gas.

[2] One ton of coal = 7,027 KWH

[3] One gram of U-235 Uranium (fissionable material) = 7,347 KWH

[4] A assumption is made that this electrical energy is supplied by a power supply mix of 70% coal fired plants and 30% nuclear plants.

[5] Obtained from the Department of Industry, Labor and Human Relations estimate of new construction activity for the City of Madison and surrounding communities.

Total Resource Energy used by the Nine Equipment Systems

System Number	Total Resource Energy Used (MMBTU)	Type of Fuel Used by each System: Natural Gas Used (Therms)	Electrical Energy Used (KWH)
1	166	0	48,604
2	124	292	27,865
3	93	500	12,708
4	134	0	39,235
5	83	438	12,084
6	84	417	16,300
7	89	208	11,645
8	145	500	27,904
9	104	0	30,451

Where:

1 BTU*2.928E-4 = KWH

1 Therm = 100,000 BTU

MMBTU = 1E+6 BTU

Table 8.1.1 - Total Resource Energy Used by the Nine Equipment Systems in Madison, Wisconsin

Real World Energy used by the Nine Equipment Systems

System Number	Total Resource Energy (MMBTU)	Natural Gas Used (Cubic ft)	Tons of Coal	Grams of Uranium
		Real World Energy Equivalents*		
1	166	0	4.84	1.98
2	124	292	2.78	1.14
3	93	500	1.27	0.52
4	134	0	3.91	1.60
5	83	438	1.20	0.49
6	84	417	0.70	0.67
7	89	208	1.16	0.48
8	145	500	2.78	1.14
9	104	0	3.03	1.24

* Based on a power plant that uses 70% coal and 30% nuclear power.

Where:

1 Ton of Coal = 7,027 KWH

1 Gram of U-235 = 7,347 KWH

Table 8.1.2 - Real World Energy Sources used by the Nine Equipment Systems in Madison, Wisconsin

Real World Energy Sources Used Based on One Equipment System being Used for Twenty Years

	One Year			Twenty Years		
System Number	Natural Gas (CCF)	Tons of Coal	Grams of Uranium	Natural Gas (CCF)	Tons of Coal	Grams of Uranium
1	0	4.84	1.98	0	96.80	39.60
2	292	2.78	1.14	5,840	55.60	22.80
3	500	1.27	0.52	10,000	25.40	10.40
4	0	3.91	1.60	0	78.20	32.00
5	438	1.20	0.49	8,760	24.00	9.80
6	417	0.70	0.67	8,340	14.00	13.40
7	208	1.16	0.48	4,160	23.20	9.60
8	500	2.78	1.14	10,000	55.60	22.80
9	0	3.03	1.24	0	60.60	24.80

Table 8.1.3 - Real World Energy Sources Used Based on One Equipment System Being Used for Twenty Years in Madison, Wisconsin

Real World Energy Sources Used based on a Projected Growth Rate for One Year

System Number	Natural Gas (CCF)	Tons of Coal	Grams of Uranium
	Growth of 1400 Aparments for One Year		
1	0	6,776	2,772
2	408,800	3,892	1,596
3	700,000	1,778	728
4	0	5,474	2,240
5	613,200	1,680	686
6	583,800	980	938
7	291,200	1,624	672
8	700,000	3,892	1,596
9	0	4,242	1,736

Table 8.1.4 - Real World Energy Sources used based on a Projected Growth Rate for One Year in Madison, Wisconsin

Real World Energy Sources Used based on a Projected Growth Rate over Twenty Years

Annual Growth of 1400 Aparments for Twenty Years

System Number	Natural Gas (CCF)	Tons of Coal	Grams of Uranium
1	0	1,431,000	585,000
2	86,339,000	822,000	337,000
3	147,842,000	376,000	154,000
4	0	1,156,000	473,000
5	129,509,000	355,000	145,000
6	123,300,000	207,000	198,000
7	61,502,000	343,000	142,000
8	147,841,000	822,000	337,000
9	0	896,000	367,000

Table 8.1.5 - Real World Energy Sources Used based on a Projected Growth Rate Over Twenty Years in Madison, Wisconsin

Chapter 9 - Selection of a Equipment System that Satisfies the Majority of the Selection Perspectives.

One obvious question that arises when trying to conclude this study is "what system(s) best satisfies all or most of the selection perspectives?" It is doubtful that a equipment selector (builder, tenant, etc.) will ever be in a position that he/she will have to consider all nine perspectives considered in this study. But for the sake of trying to answer the above question for analytical purposes, a method has been used to make this determination. Table 9.0.1 (for Madison, Wisconsin) shows an analysis method that ranks the top equipment systems for each of the nine selection perspectives. A ranking method is used that separates the nine equipment systems in three categories: top, middle and low. These three categories each contain three systems since we have a total of nine equipment systems. Each equipment system that ranks in the top category (top three selections) for each selection perspective receives a point rating. The equipment system with the highest number of top ratings for all nine perspectives is the system that "best" meets the requirements of all nine of the selection perspectives. The top ranked equipment systems that "best" meet all the selection perspective requirements are:

System #5.- The high efficiency gas furnace, high efficiency gas water heater and the high efficiency air conditioner.

Second choice is:

System #6 - The high efficiency gas water heater for space and domestic water heating and the high efficiency air conditioner.

Table 9.0.2 (for Madison, Wisconsin) takes a more conservative approach in ranking the "best" equipment system. This approach again separates the nine equipment systems into three categories: top, middle, and low. Each category contains three equipment systems since there are nine equipment systems in this study. For each selection perspective, a point is given to the equipment system for its ranking in any of the categories (top, middle and low). The highest points for the top and middle categories is the equipment system that "best" meets the requirements of the nine selection perspectives by ranking in at least the top two thirds (top and middle categories) of each perspective.

The equipment system that "best" fits these parameters are:

System #2 - The low efficiency gas furnace, low efficiency gas water heater and the low efficiency air conditioner.

Second choices are:

System #5 - The high efficiency gas furnace, high efficiency gas water heater and the high efficiency air conditioner.

System #6 - The high efficiency gas water heater for space and domestic water heating and the high efficiency air conditioner.

System #7 - The low efficiency central building electric water loop heat pump space heating and air conditioning system and low efficiency gas water heater.

9.1 - Top Equipment Selections for New York, Atlanta and Los Angeles

Tables 9.1.1 to 9.1.6 shows the same results as shown above for the cities of New York, Atlanta and Los Angeles. The system that "best" meets the requirements for these cities are:

New York

The top equipment selections are:

System #5 - The high efficiency gas furnace, high efficiency gas water heater and the high efficiency air conditioner.

The second choice is;

System #6 - The high efficiency gas water heater for space and domestic water heating and the high efficiency air conditioner.

The top and middle equipment selection first choice is:

System #3 - The low efficiency gas furnace, low efficiency gas water heater and the low efficiency air conditioner.

Second choices are :

Systems #2, #5, #6, and #7

Los Angeles

The top equipment selections are:

System #5 - The high efficiency gas furnace, high efficiency gas water heater and the high efficiency air conditioner.

The second choice is;

System #6 - The high efficiency gas water heater for space and domestic water heating and the high efficiency air conditioner.

The top and middle equipment selection first choice is:

System #6 - The high efficiency gas water heater for space and domestic water heating and the high efficiency air conditioner.

Second choices are :

Systems #3 and #5.

Atlanta

The top equipment selections are:

System #5 - The high efficiency gas furnace, high efficiency gas water heater and the high efficiency air conditioner.

The second choice is;

System #6 - The high efficiency gas water heater for space and domestic water heating and the high efficiency air conditioner.

The top and middle equipment selection first choice is:

System #6 - The high efficiency gas water heater for space and domestic water heating and the high efficiency air conditioner.

Second choices are :

Systems #3, and #5

9.2 - Summary of the Top Equipment Systems

Table 9.2.1 shows a summary of the top equipment systems from Tables 9.0.1 to 9.1.6. From the method of selecting the system that ranks highest in the top three selections for all the selection perspectives, system #5 is the clear winner in all four cities. System #5 consists of a high efficiency gas furnace, high efficiency gas water heater and the high efficiency air conditioner. The second choice is System #6, the high efficiency gas water heater for space and domestic water heating and the high efficiency air conditioner.

When we look at the first choices for the equipment systems that rank in the top and middle categories, we find that systems #2, #3 and #6 are the top choices. The second choices get quite a bit more diverse and this method starts to lose it's effectiveness since too many systems are listed. They are: #3, #5, #6 and #7. The only similarity is that system #5 appears in all of the cities second selections.

Chapter 10 will summarize all of these results.

System Number		Selection Perspectives #1	#2	#3	#4	#5	#6	#7	#8	#9	Top Total
1	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	1	0	0	0	0	1	0	
	Low	0	1	0	0	1	0	1	0	1	
2	Top	1	0	0	0	0	0	0	0	0	1
	Mid	0	1	0	1	1	1	1	1	1	
	Low	0	0	1	0	0	0	0	0	0	
3	Top	0	0	0	0	1	0	1	1	0	3
	Mid	1	1	1	0	0	0	0	0	1	
	Low	0	0	0	1	0	1	0	0	0	
4	Top	0	0	0	1	0	1	0	0	0	2
	Mid	0	0	0	0	0	0	0	0	0	
	Low	1	1	1	0	1	0	1	1	1	
5	Top	0	1	1	0	1	0	1	1	1	6
	Mid	1	0	0	0	0	0	0	0	0	
	Low	0	0	0	1	0	1	0	0	0	
6	Top	0	1	0	0	0	0	1	1	1	4
	Mid	1	0	1	0	1	0	0	0	0	
	Low	0	0	0	1	0	1	0	0	0	
7	Top	0	1	1	0	0	0	0	0	1	3
	Mid	0	0	0	1	1	1	1	0	0	
	Low	1	0	0	0	0	0	0	1	0	
8	Top	1	0	0	0	1	0	0	0	0	2
	Mid	0	0	0	1	0	1	0	1	0	
	Low	0	1	1	0	0	0	1	0	1	
9	Top	0	0	1	1	0	1	0	0	0	3
	Mid	0	1	0	0	0	0	1	0	1	
	Low	1	0	0	0	1	0	0	1	0	

Top Equipment System Highest Score = 6 = System #5

Table 9.0.1 - Top Equipment System that meets all the Perspective Requirements for Madison

System Number		Selection Perspectives #1	#2	#3	#4	#5	#6	#7	#8	#9	Top & Mid Total
1	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	1	0	0	0	0	1	0	2
	Low	0	1	0	0	1	0	1	0	1	5
2	Top	1	0	0	0	0	0	0	0	0	1
	Mid	0	1	0	1	1	1	1	1	1	7
	Low	0	0	1	0	0	0	0	0	0	8
3	Top	0	0	0	0	1	0	1	1	0	3
	Mid	1	1	1	0	0	0	0	0	1	4
	Low	0	0	0	1	0	1	0	0	0	7
4	Top	0	0	0	1	0	1	0	0	0	2
	Mid	0	0	0	0	0	0	0	0	0	0
	Low	1	1	1	0	1	0	1	1	1	2
5	Top	0	1	1	0	1	0	1	1	1	6
	Mid	1	0	0	0	0	0	0	0	0	1
	Low	0	0	0	1	0	1	0	0	0	7
6	Top	0	1	0	0	0	0	1	1	1	4
	Mid	1	0	1	0	1	0	0	0	0	3
	Low	0	0	0	1	0	1	0	0	0	7
7	Top	0	1	1	0	0	0	0	0	1	3
	Mid	0	0	0	1	1	1	1	0	0	4
	Low	1	0	0	0	0	0	0	1	0	7
8	Top	1	0	0	0	1	0	0	0	0	2
	Mid	0	0	0	1	0	1	0	1	0	3
	Low	0	1	1	0	0	0	1	0	1	5
9	Top	0	0	1	1	0	1	0	0	0	3
	Mid	0	1	0	0	0	0	1	0	1	3
	Low	1	0	0	0	1	0	0	1	0	6

Top & Mid Equipment System Highest Score = 8 = System #2

Table 9.0.2 - Top & Mid Equipment System that meets all the Perspective Requirements for Madison

System Number		Selection Perspectives #1	#2	#3	#4	#5	#6	#7	#8	#9	Top Total
1	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	1	0	0	0	0	0	0	
	Low	0	1	0	0	1	0	1	1	1	
2	Top	1	0	0	0	0	0	0	0	0	1
	Mid	0	1	0	1	1	1	1	1	0	
	Low	0	0	1	0	0	0	0	0	1	
3	Top	0	0	0	0	1	0	1	1	0	3
	Mid	1	1	1	0	0	1	0	0	1	
	Low	0	0	0	1	0	0	0	0	0	
4	Top	0	0	0	1	0	1	0	0	0	2
	Mid	0	0	0	0	0	0	0	0	1	
	Low	1	1	1	0	1	0	1	1	0	
5	Top	0	1	1	0	1	0	1	1	1	6
	Mid	1	0	0	0	0	0	0	0	0	
	Low	0	0	0	1	0	1	0	0	0	
6	Top	0	1	0	0	1	0	1	1	1	5
	Mid	1	0	1	0	0	0	0	0	0	
	Low	0	0	0	1	0	1	0	0	0	
7	Top	0	1	1	0	0	0	0	0	1	3
	Mid	0	0	0	1	1	0	1	1	0	
	Low	1	0	0	0	0	1	0	0	0	
8	Top	1	0	0	0	0	0	0	0	0	1
	Mid	0	0	0	1	1	1	0	1	0	
	Low	0	1	1	0	0	0	1	0	1	
9	Top	0	0	1	1	0	1	0	0	0	3
	Mid	0	1	0	0	0	0	1	0	1	
	Low	1	0	0	0	1	0	0	1	0	

Top Equipment System Highest Score = 6 = System #5

Table 9.1.1 - Top Equipment System that meets all the Perspective Requirements for New York

System Number		Selection Perspectives #1	#2	#3	#4	#5	#6	#7	#8	#9	Top & Mid Total
1	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	1	0	0	0	0	0	0	1
	Low	0	1	0	0	1	0	1	1	1	4
2	Top	1	0	0	0	0	0	0	0	0	1
	Mid	0	1	0	1	1	1	1	1	0	6
	Low	0	0	1	0	0	0	0	0	1	7
3	Top	0	0	0	0	1	0	1	1	0	3
	Mid	1	1	1	0	0	1	0	0	1	5
	Low	0	0	0	1	0	0	0	0	0	8
4	Top	0	0	0	1	0	1	0	0	0	2
	Mid	0	0	0	0	0	0	0	0	1	1
	Low	1	1	1	0	1	0	1	1	0	3
5	Top	0	1	1	0	1	0	1	1	1	6
	Mid	1	0	0	0	0	0	0	0	0	1
	Low	0	0	0	1	0	1	0	0	0	7
6	Top	0	1	0	0	1	0	1	1	1	5
	Mid	1	0	1	0	0	0	0	0	0	2
	Low	0	0	0	1	0	1	0	0	0	7
7	Top	0	1	1	0	0	0	0	0	1	3
	Mid	0	0	0	1	1	0	1	1	0	4
	Low	1	0	0	0	0	1	0	0	0	7
8	Top	1	0	0	0	0	0	0	0	0	1
	Mid	0	0	0	1	1	1	0	1	0	4
	Low	0	1	1	0	0	0	1	0	1	5
9	Top	0	0	1	1	0	1	0	0	0	3
	Mid	0	1	0	0	0	0	1	0	1	3
	Low	1	0	0	0	1	0	0	1	0	6

Top & Mid Equipment System Highest Score = 8 = System #3

Table 9.1.2 - Top & Mid Equipment System that meets all the Perspective Requirements for New York

System Number		Selection Perspectives #1	#2	#3	#4	#5	#6	#7	#8	#9	Top Total
1	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	1	0	0	0	0	1	0	
	Low	0	1	0	0	1	0	1	0	1	
2	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	0	0	1	0	1	1	0	
	Low	0	1	1	0	0	0	0	0	1	
3	Top	0	0	0	0	1	0	1	1	0	3
	Mid	1	1	1	0	0	0	0	0	1	
	Low	0	0	0	1	0	1	0	0	0	
4	Top	0	0	0	1	0	1	0	0	0	2
	Mid	0	1	0	0	0	0	0	0	1	
	Low	1	0	1	0	1	0	1	1	0	
5	Top	0	1	1	0	1	0	1	1	1	6
	Mid	1	0	0	0	0	0	0	0	0	
	Low	0	0	0	1	0	1	0	0	0	
6	Top	0	1	0	0	1	0	1	1	1	5
	Mid	1	0	1	1	0	1	0	0	0	
	Low	0	0	0	0	0	0	0	0	0	
7	Top	0	1	1	0	0	0	0	0	1	3
	Mid	0	0	0	0	1	0	1	0	0	
	Low	1	0	0	1	0	1	0	1	0	
8	Top	1	0	0	0	0	0	0	0	0	1
	Mid	0	0	0	1	1	1	0	1	0	
	Low	0	1	1	0	0	0	1	0	1	
9	Top	0	0	1	0	0	0	0	0	0	1
	Mid	0	1	0	1	0	1	1	0	1	
	Low	1	0	0	0	1	0	0	1	0	

Top Equipment System Highest Score = 6 = System #5

Table 9.1.3 - Top Equipment System that meets all the Perspective Requirements for Atlanta

System Number		Selection Perspectives #1	#2	#3	#4	#5	#6	#7	#8	#9	Top & Mid Total
1	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	1	0	0	0	0	1	0	2
	Low	0	1	0	0	1	0	1	0	1	5
2	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	0	0	1	0	1	1	0	3
	Low	0	1	1	0	0	0	0	0	1	6
3	Top	0	0	0	0	1	0	1	1	0	3
	Mid	1	1	1	0	0	0	0	0	1	4
	Low	0	0	0	1	0	1	0	0	0	7
4	Top	0	0	0	1	0	1	0	0	0	2
	Mid	0	1	0	0	0	0	0	0	1	2
	Low	1	0	1	0	1	0	1	1	0	4
5	Top	0	1	1	0	1	0	1	1	1	6
	Mid	1	0	0	0	0	0	0	0	0	1
	Low	0	0	0	1	0	1	0	0	0	7
6	Top	0	1	0	0	1	0	1	1	1	5
	Mid	1	0	1	1	0	1	0	0	0	4
	Low	0	0	0	0	0	0	0	0	0	9
7	Top	0	1	1	0	0	0	0	0	1	3
	Mid	0	0	0	0	1	0	1	0	0	2
	Low	1	0	0	1	0	1	0	1	0	5
8	Top	1	0	0	0	0	0	0	0	0	1
	Mid	0	0	0	1	1	1	0	1	0	4
	Low	0	1	1	0	0	0	1	0	1	5
9	Top	0	0	1	0	0	0	0	0	0	1
	Mid	0	1	0	1	0	1	1	0	1	5
	Low	1	0	0	0	1	0	0	1	0	6

Top & Mid Equipment System Highest Score = 9 = System #6

Table 9.1.4 - Top & Mid Equipment System that meets all the Perspective Requirements for Atlanta

System Number		#1	#2	#3	#4	#5	#6	#7	#8	#9	Top Total
		Selection Perspectives									
1	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	1	0	0	0	0	1	0	
	Low	0	1	0	0	1	0	1	0	1	
2	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	0	0	1	0	1	1	0	
	Low	0	1	1	0	0	0	0	0	1	
3	Top	0	0	0	0	1	0	1	1	0	3
	Mid	1	1	1	0	0	0	0	0	1	
	Low	0	0	0	1	0	1	0	0	0	
4	Top	0	0	0	0	0	0	0	0	0	0
	Mid	0	1	0	1	0	1	0	0	1	
	Low	1	0	1	0	1	0	1	1	0	
5	Top	0	1	1	0	1	0	1	1	1	6
	Mid	1	0	0	0	0	0	0	0	0	
	Low	0	0	0	1	0	1	0	0	0	
6	Top	0	1	0	0	0	0	1	1	1	4
	Mid	1	0	1	1	1	1	0	0	0	
	Low	0	0	0	0	0	0	0	0	0	
7	Top	0	1	1	0	1	0	0	0	1	4
	Mid	0	0	0	0	0	0	1	0	0	
	Low	1	0	0	1	0	1	0	1	0	
8	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	0	0	1	0	1	1	0	
	Low	0	1	1	0	0	0	0	0	1	
9	Top	0	0	1	0	0	0	0	0	0	1
	Mid	0	1	0	1	0	1	0	0	1	
	Low	1	0	0	0	1	0	1	1	0	

Top Equipment System Highest Score = 6 = System #5

Table 9.1.5 - Top Equipment System that meets all the Perspective Requirements for Los Angeles

System Number		Selection Perspectives #1	#2	#3	#4	#5	#6	#7	#8	#9	Top & Mid Total
1	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	1	0	0	0	0	1	0	2
	Low	0	1	0	0	1	0	1	0	1	5
2	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	0	0	1	0	1	1	0	3
	Low	0	1	1	0	0	0	0	0	1	6
3	Top	0	0	0	0	1	0	1	1	0	3
	Mid	1	1	1	0	0	0	0	0	1	4
	Low	0	0	0	1	0	1	0	0	0	7
4	Top	0	0	0	0	0	0	0	0	0	0
	Mid	0	1	0	1	0	1	0	0	1	4
	Low	1	0	1	0	1	0	1	1	0	4
5	Top	0	1	1	0	1	0	1	1	1	6
	Mid	1	0	0	0	0	0	0	0	0	1
	Low	0	0	0	1	0	1	0	0	0	7
6	Top	0	1	0	0	0	0	1	1	1	4
	Mid	1	0	1	1	1	1	0	0	0	5
	Low	0	0	0	0	0	0	0	0	0	9
7	Top	0	1	1	0	1	0	0	0	1	4
	Mid	0	0	0	0	0	0	1	0	0	1
	Low	1	0	0	1	0	1	0	1	0	5
8	Top	1	0	0	1	0	1	0	0	0	3
	Mid	0	0	0	0	1	0	1	1	0	3
	Low	0	1	1	0	0	0	0	0	1	6
9	Top	0	0	1	0	0	0	0	0	0	1
	Mid	0	1	0	1	0	1	0	0	1	4
	Low	1	0	0	0	1	0	1	1	0	5

Top & Mid Equipment System Highest Score = 9 = System #6

Table 9.1.6 - Top & Mid Equipment System that meets all the Perspective Requirements for Los Angeles

Summary of the "best" equipment systems that meet all the selection perspective requirements

Top Equipment Systems

Selection Format	Madison	Los Angeles	Atlanta	New York
Top				
1st Choice	#5	#5	#5	#5
2nd Choice	#6	#6	#6	#6
Top & Middle				
1st Choice	#2	#6	#6	#3
2nd Choice	#5 #6 #7	#3 #5	#3 #5	#2 #5 #6 #7

Table 9.2.1 - Summary of the "best" equipment systems that meet all the selection perspective requirements for all four Cities

Chapter 10 - Conclusions and Recommendations

A number of conclusions can be drawn from this research and analysis. The most obvious is that the selection of a heating/air conditioning/water heating system for a apartment/office building is <u>not</u> a easy task! There is a wide range of equipment (nine systems were selected for this study) out in the market place and each manufacturer claims their product to be the right choice for many reasons; low cost, high reliability, high energy efficiency, ease of installation, and so on.

A "poor" selection can have serious ramifications on the tenant, owner, utility company serving the facility, the energy regulatory agency responsible for energy management and use in the state, and on the environment.

This study analyzed nine equipment systems from nine different selection perspectives. The analysis determined the "best" system selections for each of the nine equipment perspectives for four different city locations in the United States, representing four regions (north, south, east and west). This allows a individual who is in the position of needing to select a equipment system for a apartment /

office facility to use this study to determine his selection perspective(s) and the "best" equipment per that perspective(s). The ranking of the equipment systems per each selection perspective for the four cities; New York, Atlanta, Los Angeles and Madison are shown in Tables 7.10 to 7.13 (New York, Atlanta and Los Angeles) and in Table 5.0.1 (Madison). This information is summarized for all perspectives for all four cities in Table 7.14. These Tables summarize the total of all the research of this study.

The top rated equipment systems for the nine perspectives for all four cities are:

Building Owners Perspective (Lowest Equipment Cost):

System #1: Baseboard electric space heating, low efficiency electric water heater and a low efficiency air conditioner.

Tenant Perspective (Lowest Annual Fuel Cost):

System #5: High efficiency gas furnace, high efficiency gas water heater and a high efficiency air conditioner (for Madison and New York).

System #7: Low efficiency central building electric water loop heat pump space heating and air conditioning system with a low efficiency gas water heater (for Los Angeles and Atlanta).

Utility-Needs Capacity Perspective (Lowest KW):

System #9: High efficiency integrated electric heat pump that supplies space and water heating and air conditioning.

Electric Utility-Profit Oriented (Highest KWH Use):

System #1: Baseboard electric space heating, low efficiency electric water heater and a low efficiency air conditioner.

Gas Utility-Profit Oriented (Highest Therm Use):

System #3: Low efficiency gas furnace, low efficiency gas water heater and a low efficiency air conditioner.

Combined Utility-Profit Oriented (Highest KWH Use):

System #1: Baseboard electric space heating, low efficiency electric water heater and a low efficiency air conditioner.

Regulatory Agency Perspective (Lowest LCC, Lowest Annual Energy Cost and Lowest KW):

System #5: High efficiency gas furnace, high efficiency gas water heater and a high efficiency air conditioner

Bennevolent Dictator Perspective (Lowest LCC):

System #6: High efficiency gas water heater for space heating and water heating with a high efficiency air conditioner.

Total Resource Perspective (Lowest Resource Energy Used):

System #7: Central water loop heat pump system and low efficiency water heater.

As stated in Chapter 8, once the "best" equipment system has been selected for the appropriate selection perspective, that equipment systems total resource energy use should be reviewed for its impact on society (the environment). If the equipment selection has a detrimental effect (high resource energy use) then the individual should consider an equipment system that is not so detrimental (uses less total resource energy) to the environment.

Chapter 9 goes one step further to determine the equipment system that "best" meets the requirements of all the nine selection perspectives. Two analysis methods are used and a couple of clear winners do surface. One test determines which system ranks as one of the top three selections for each selection perspective. System #5 (The high efficiency gas furnace, high efficiency gas water heater and the high efficiency air conditioning system) ranked as the top three selections for a total of six of the nine selection perspectives. The second choice was system #6 (The high efficiency gas water heater used for space and domestic water heating and a high efficiency air conditioner) which ranked in the top three selections for four out of the nine perspectives.

If one is looking to select the "best" all around equipment system , then systems #5 and #6 are the choices.

System #5, is the most efficient system with the lowest first year energy costs, was ranked third in Life Cycle Costs, ranked sixth in equipment first costs and is ranked first in lowest total resources used.

System #6, was ranked second in first year energy costs, first in Life Cycle Costs, fourth in equipment first costs and second in lowest total resource energy used.

Again, in conclusion it is recommended that for the individual who has the responsibility to select a space heating, air conditioning and water heating system for a apartment / office facility that he/she use the selection perspective Tables 5.0.1 or Tables 7.10 - 7.13.

For the generalist who is interested in the theoretically "best" system that meets all the selection perspectives then Tables 9.1.1 to 9.2.6 are appropriate.

10.1-Recommendations for Further Study

This study is quite encompassing in investigating the full range of equipment systems available at the time of the study and in considering all potential selection perspectives possible. Two areas for potential future study are:

First, additional cities could be modeled to determine if additional locations change the equipment rankings.

Second, this analysis could be performed on specific pieces of equipment (eg. a high efficiency air conditioner) rather than a total heating/cooling/water heating system to determine the "best" specific pieces of equipment for each city location. A "best" system could then be assembled for each city.

These two recommendations for further study would expand the usefulness of this study for other locations in the United States and it would allow a individual to assemble the "best" system for each specific city for the appropriate perspective(s).

Appendix A

Input and Output data for the FLOAD software.

-Input Data
-Sample Equipment Input Data
-Output Data

```
03-30-1991
BASE APARTMENT
ELECTRIC BB
ELECTRIC DHW

** BASIC BUILDING **
1  CITY LOCATION................   127
2  REFERENCE ANGLE WRT SOUTH.....   130          DEG
3  HEATED AIR VOLUME.............   9000         FT3
4  CONSTR QUAL (0 TO 3 OR NEG)...   2
5  NUMBER OF EXTERIOR WALLS......   1
6  SET ALL EXTERIOR WALL R-VALUES   16.4         FT2-HR-F/BTU
7  SET ALL WINDOW DAY R-VALUES...   2.2          FT2-HR-F/BTU
8  SET ALL WINDOW NIGHT R-VALUES.   2.2          FT2-HR-F/BTU
9  STORAGE CAP (0 TO 3 OR NEG)...   1
10 OUTPUT 1=SUMMARY TO 4=DETAILED   3
11 GRAPHIC OUTPUT? 1=Y 2=N.......   1

** WALL 1 **
1  ORIENTATION WRT TO REFERENCE..   0            DEG
2  GROSS WALL AREA...............   450          FT2
3  EXTERIOR WALL R-VALUE.........   16.4         FT2-HR-F/BTU
4  WINDOW AREA...................   48           FT2
5  WINDOW DAYTIME R-VALUE........   2.2          FT2-HR-F/BTU
6  WINDOW NIGHTTIME R-VALUE......   2.2          FT2-HR-F/BTU
7  WINDOW SHADING COEFFICIENT....   .5
8  DOOR AREA.....................   48           FT2
9  DOOR R-VALUE..................   2.2          FT2-HR-F/BTU
10 WINDOW TILT FROM HORIZONTAL...   90           DEG
11 WALL SOLAR ABSORPTIVITY.......   .4

** ROOF-FLOOR-BASEMENT-GARAGE **
1  TOTAL CEILING AREA............   1000         FT2
2  CEILING R-VALUE...............   26.3         FT2-HR-F/BTU
3  1=SLAB,2=CRAWLSP,3=FULL,4=COMB   3
4  TYPE 1:DUCTS IN SLAB? 1=Y 2=N.   2
5  TYPE 1:PERIMETER OF SLAB......   63           FT
6  TYPE 1:R-VALUE OF EDGE INSUL..   5            FT2-HR-F/BTU
7  TYPE 2:FLOOR AREA OVER CRAWL..   0            FT2
8  TYPE 2:FLOOR R-VALUE..........   2            FT2-HR-F/BTU
9  TYPE 3:BASEMT HEATED? 1=Y 2=N.   1
10 TYPE 3:FLOOR AREA OVER BASEMT.   0            FT2
11 TYPE 3:BUILDING FLOOR R-VALUE.   12           FT2-HR-F/BTU
12 TYPE 3:BASEMENT WALL AREA.....   0            FT2
13 TYPE 3:BSMT INSUL WALL R-VALUE   0            FT2-HR-F/BTU
14 NUMBER OF CAR GARAGE (0 TO 3).   0
15 WALL AREA COMMON TO GARAGE....   188          FT2
16 R-VAL OF WALL COMMON TO GARAGE   19           FT2-HR-F/BTU
17 FLOOR AREA COMMON TO GARAGE...   480          FT2
18 R-VAL OF FLOOR COMMON TO GAR..   12           FT2-HR-F/BTU
19 R-VAL OF GARAGE EXTERIOR WALLS   2            FT2-HR-F/BTU
20 DUCTS IN UNHEATED SPC 1=Y 2=N.   2
21 PITCHED ROOF ATTIC? 1=Y 2=N...   2
22 ROOF SOLAR ABSORPTIVITY.......   .4

** INTERNAL SPACE **
1  ANNUAL ELECTRICAL CONSUMPTION.   2700         KW-HR
2  AVERAGE NUMBER OF OCCUPANTS...   2
3  HEATING LOAD CALC (1=Y 2=N)...   1
4    DAYTIME THERMOSTAT SETTING..   72           F
5    NIGHTTIME THERMOSTAT SETTING   68           F
6    EQUIPMENT FILE NAME........ ELECBB
7  COOLING LOAD CALC (1=Y 2=N)...   1
```

8	DAYTIME THERMOSTAT SETTING..	78	F
9	NIGHTTIME THERMOSTAT SETTING	78	F
10	ROOM RELATIVE HUMIDITY......	40	%
11	VENTILATION (1=Y 2=N).......	2	
12	MOISTURE GENERATION.........	.25	LBM/HR
13	EQUIPMENT FILE NAME.........	STDAC	
14	HOURS FOR NIGHT SETTING.......	8	HOURS
15	ALLOWABLE TEMPERATURE SWING...	9	F
16	VENTILATION HX EFFECTIVENESS..	0	%
17	VENTILATION HX FLOWRATE.......	0	CFM
18	DHW CALCULATION (1=Y 2=N).....	1	
19	DHW LOSS TO SPACE (1=Y 2=N).	1	
20	DHW(1=EL;2=NG;3=OIL;4=OTHER)	1	
21	WATER HEATER EFFICIENCY.....	90	%
22	AVERAGE DAILY HOT WATER USE.	30	GALLONS
23	HOT WATER SET TEMPERATURE...	140	F
24	R-VALUE OF TANK INSULATION..	3.4	FT2-HR-F/BTU
25	HOT WATER TANK VOLUME.......	40	GALLONS

** ECONOMICS **

1	ECON ANALYSIS DETAIL (0 TO 4).	2	
2	COST (ABOVE BASE).............	0	$
3	PRICE OF ELECTRICITY..........	.075	$/KW-HR
4	ANNUAL % INCREASE IN ELEC.....	5	%
5	PRICE OF NATURAL GAS..........	.636	$/100 FT3
6	ANNUAL % INCREASE IN NAT. GAS.	2	%
7	PRICE OF FUEL OIL.............	.9	$/GALLON
8	ANNUAL % INCREASE IN FUEL OIL.	10	%
9	PRICE OF OTHER FUEL...........	.5	$/MMBTU
10	ANNUAL % INCREASE IN OTHER....	10	%
11	PERIOD OF ECONOMIC ANALYSIS...	20	YEARS
12	% DOWN PAYMENT................	100	%
13	ANNUAL MORTGAGE INTEREST RATE.	10	%
14	TERM OF MORTGAGE..............	20	YEARS
15	ANNUAL MARKET DISCOUNT RATE...	8	%
16	% EXTRA INSUR & MAINT - YEAR 1	1	%
17	ANNUAL % INCREASE IN I & M....	5	%
18	FEDERAL/STATE INCOME TAX RATE.	45	%
19	TRUE PROPERTY TAX RATE........	1.33	%
20	ANNUAL % INCREASE IN PROP TAX.	5	%
21	% RESALE VALUE................	0	%
22	% CREDIT RATE IN TIER 1.......	20	%
23	MAXIMUM INVESTMENT IN TIER 1..	0	$
24	% CREDIT RATE IN TIER 2.......	0	%
25	MAXIMUM INVESTMENT IN TIER 2..	0	$
26	INCOME PRODUCING BLDG? 1=Y 2=N	1	
27	COMMERCIAL DEPRECIATION YEARS.	35	YEARS
28	0=NONE;1=ST;2=DEC BAL;3=SOYD..	1	

```
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*            608-836-3420              *
****************************************
MADISON          WI            03-30-1991
```

BASE APARTMENT
ELECTRIC BB
ELECTRIC DHW

EQUIPMENT FILE TITLES

HEATING: Electric Baseboard(ELECBB)
COOLING: TYPICAL ELECTRIC AIR CONDITIONER(8.5-SEER)(STDAC)

*** HEATING ENERGY (MMBTU) ***

ALL WALLS

MONTH	WALL	WINDOW	DOOR	SOLAR
JAN	0.86	0.87	0.87	0.13
FEB	0.73	0.74	0.74	0.18
MAR	0.65	0.66	0.66	0.31
APR	0.39	0.40	0.40	0.40
MAY	0.24	0.24	0.24	0.55
JUN	0.09	0.09	0.09	0.61
JUL	0.05	0.05	0.05	0.62
AUG	0.06	0.06	0.06	0.51
SEP	0.17	0.18	0.18	0.35
OCT	0.34	0.34	0.34	0.23
NOV	0.56	0.57	0.57	0.13
DEC	0.78	0.79	0.79	0.10
YR	4.92	4.98	4.98	4.13

MONTH	ROOF	BSMT	INFIL	GARAGE
JAN	1.52	0.00	2.69	0.00
FEB	1.29	0.00	2.21	0.00
MAR	1.14	0.00	1.80	0.00
APR	0.69	0.00	0.92	0.00
MAY	0.42	0.00	0.47	0.00
JUN	0.16	0.00	0.14	0.00
JUL	0.08	0.00	0.07	0.00
AUG	0.11	0.00	0.09	0.00
SEP	0.31	0.00	0.32	0.00
OCT	0.59	0.00	0.73	0.00
NOV	0.98	0.00	1.47	0.00
DEC	1.38	0.00	2.34	0.00
YR	8.67	0.00	13.25	0.00

MONTH	(ENV)	GAIN	EXCESS	AUX
JAN	6.82	1.65	0.03	5.20
FEB	5.70	1.60	0.03	4.14
MAR	4.90	1.93	0.05	3.03
APR	2.80	2.01	0.13	0.93
MAY	1.61	2.26	0.65	0.00
JUN	0.57	2.30	1.73	0.00
JUL	0.28	2.36	2.07	0.00
AUG	0.38	2.22	1.84	0.00
SEP	1.15	1.94	0.79	0.00
OCT	2.34	1.82	0.18	0.70
NOV	4.15	1.61	0.06	2.60
DEC	6.08	1.61	0.04	4.51
YR	36.80	23.29	7.60	21.10

*** COOLING ENERGY (MMBTU) ***

ALL WALLS

MONTH	WALL	WINDOW	DOOR	SOLAR
JAN	0.00	0.00	0.00	0.13
FEB	0.00	0.00	0.00	0.18
MAR	0.00	0.00	0.00	0.31
APR	0.00	0.00	0.00	0.40
MAY	0.00	0.00	0.00	0.55
JUN	0.00	0.00	0.00	0.61
JUL	0.00	0.00	0.00	0.62
AUG	0.00	0.00	0.00	0.51
SEP	0.00	0.00	0.00	0.35
OCT	0.00	0.00	0.00	0.23
NOV	0.00	0.00	0.00	0.13
DEC	0.00	0.00	0.00	0.10
YR	0.00	0.00	0.00	4.13

MONTH	ROOF	BSMT	INFIL	GARAGE
JAN	0.00	0.00	0.00	0.00
FEB	0.00	0.00	0.00	0.00
MAR	0.00	0.00	0.00	0.00
APR	0.00	0.00	0.00	0.00
MAY	0.00	0.00	0.00	0.00
JUN	0.00	0.00	0.00	0.00
JUL	0.00	0.00	0.00	0.00
AUG	0.00	0.00	0.00	0.00
SEP	0.00	0.00	0.00	0.00
OCT	0.00	0.00	0.00	0.00
NOV	0.00	0.00	0.00	0.00
DEC	0.00	0.00	0.00	0.00
YR	0.00	0.00	0.00	0.00

MONTH	ENV	GAIN	LATENT	A/C
JAN	0.00	1.65	0.00	0.00
FEB	0.00	1.60	0.00	0.00
MAR	0.00	1.93	0.00	0.00
APR	0.00	2.01	0.00	0.00
MAY	0.00	2.26	0.21	0.61
JUN	0.00	2.30	0.53	1.73
JUL	0.00	2.36	0.81	2.42
AUG	0.00	2.22	0.75	2.09
SEP	0.00	1.94	0.29	0.74
OCT	0.00	1.82	0.00	0.05
NOV	0.00	1.61	0.00	0.00
DEC	0.00	1.61	0.00	0.00
YR	0.00	23.29	2.58	7.64

*** DESIGN VALUES ***

DESIGN HEATING LOAD = 15400 BTU/HR
LOSS/(AREA-DD) = 3.7 BTU/FT2-F-DAY
DESIGN COOLING LOAD = 8000 BTU/HR

*** PURCHASED ENERGY (MMBTU) ***

HEATING MONTH	AUX	DEL	SHORT	PURCH
JAN	5.20	5.20	0.00	5.20
FEB	4.14	4.14	0.00	4.14
MAR	3.03	3.03	0.00	3.03
APR	0.93	0.93	0.00	0.93
MAY	0.00	0.00	0.00	0.00
JUN	0.00	0.00	0.00	0.00
JUL	0.00	0.00	0.00	0.00
AUG	0.00	0.00	0.00	0.00
SEP	0.00	0.00	0.00	0.00
OCT	0.70	0.70	0.00	0.70
NOV	2.60	2.60	0.00	2.60
DEC	4.51	4.51	0.00	4.51
YR	21.10	21.10	0.00	21.10

*** PURCHASED ENERGY (MMBTU) ***

COOLING MONTH	A/C	DEL	SHORT	PURCH
JAN	0.00	0.00	0.00	0.00
FEB	0.00	0.00	0.00	0.00
MAR	0.00	0.00	0.00	0.00
APR	0.00	0.00	0.00	0.00
MAY	0.61	0.61	0.00	0.30
JUN	1.73	1.73	0.00	0.85
JUL	2.42	2.42	0.00	1.19
AUG	2.09	2.09	0.00	1.03
SEP	0.74	0.74	0.00	0.37
OCT	0.05	0.05	0.00	0.02
NOV	0.00	0.00	0.00	0.00
DEC	0.00	0.00	0.00	0.00
YR	7.64	7.64	0.00	3.76

*** ECONOMICS ***

FIRST YEAR UTILITY COSTS

HOT WATER ELECTRICITY	$ 290
ELECTRIC UTILITIES	$ 203
HEATING ELECTRICITY	$ 464
COOLING ELECTRICITY	$ 83
TOTAL UTILITIES	$ 1039

LIFE CYCLE COSTS

HOT WATER ELECTRICITY	$ 2294
ELECTRIC UTILITIES	$ 1599
HEATING ELECTRICITY	$ 3662
COOLING ELECTRICITY	$ 652
EQUIPMENT	$ 0
TOTAL	$ 8207

```
***              HEATING              ***

              ENVELOPE LOSSES

   WALLS !*********
  WINDOW !*********
   DOORS !*********
    ROOF !****************
    BSMT !
   INFIL !************************
  GARAGE !
         !------------!------------!
         0            7           14
                    MMBTU


              HEATING ENERGY

     JAN !*************************
     FEB !********************
     MAR !***************
     APR !*****
     MAY !
     JUN !
     JUL !
     AUG !
     SEP !
     OCT !****
     NOV !*************
     DEC !**********************
         !------------!------------!
         0           2.6          5.2
                    MMBTU


                  SUMMARY

   (ENV) !*************************
    GAIN !****************
    (XS) !*****
   HTG E !**************
         !------------!------------!
         0           19           38
                    MMBTU
```

***　　COOLING　　***

```
            COOLING ENERGY

 JAN !
 FEB !
 MAR !
 APR !
 MAY !*******
 JUN !******************
 JUL !**************************
 AUG !**********************
 SEP !********
 OCT !
 NOV !
 DEC !
     !-------------!-------------!
     0            1.2           2.4
                 MMBTU
```

```
              SUMMARY

   ENV !
  GAIN !*************************
   LAT !***
 CLG E !********
       !-------------!-------------!
       0             12            24
                   MMBTU
```

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***************************************
```

HEATPUMP-HEATING(FOR APARTMENT)

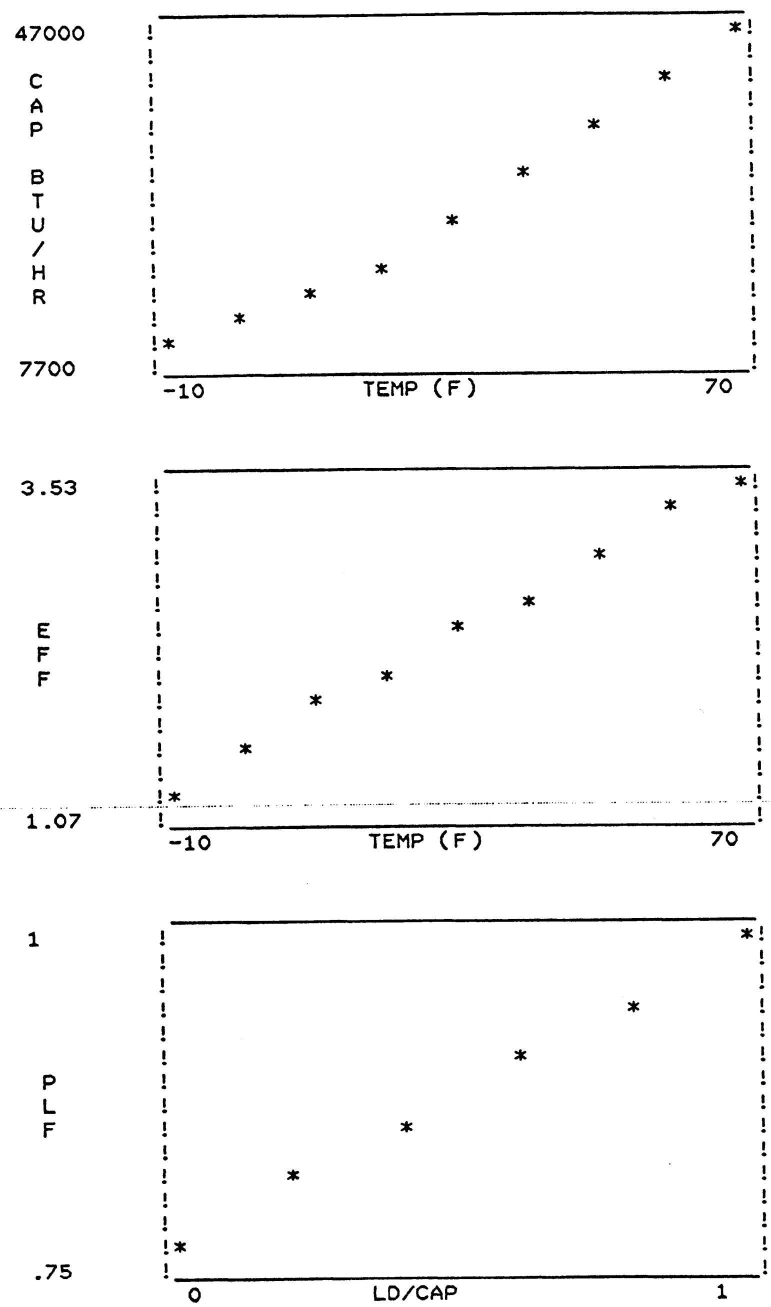
CAP (BTU/HR)	TEMP (F)
7700	-10.0
11300	0.0
14800	10.0
17500	20.0
22500	30.0
28200	40.0
34000	50.0
40000	60.0
47000	70.0

Strip heater capacity: 65000 (BTU/HR)

EFF	TEMP (F)
1.07	-10.0
1.44	0.0
1.74	10.0
1.97	20.0
2.36	30.0
2.58	40.0
2.93	50.0
3.25	60.0
3.53	70.0

PLF	LD/CAP
0.75	0.00
0.80	0.20
0.85	0.40
0.90	0.60
0.95	0.80
1.00	1.00

HEATPUMP-HEATING(FOR APARTMENT)



Appendix B

Monthly heating, cooling, and water heating loads for the base apartment located in the cities of Los Angeles, Atlanta and New York.

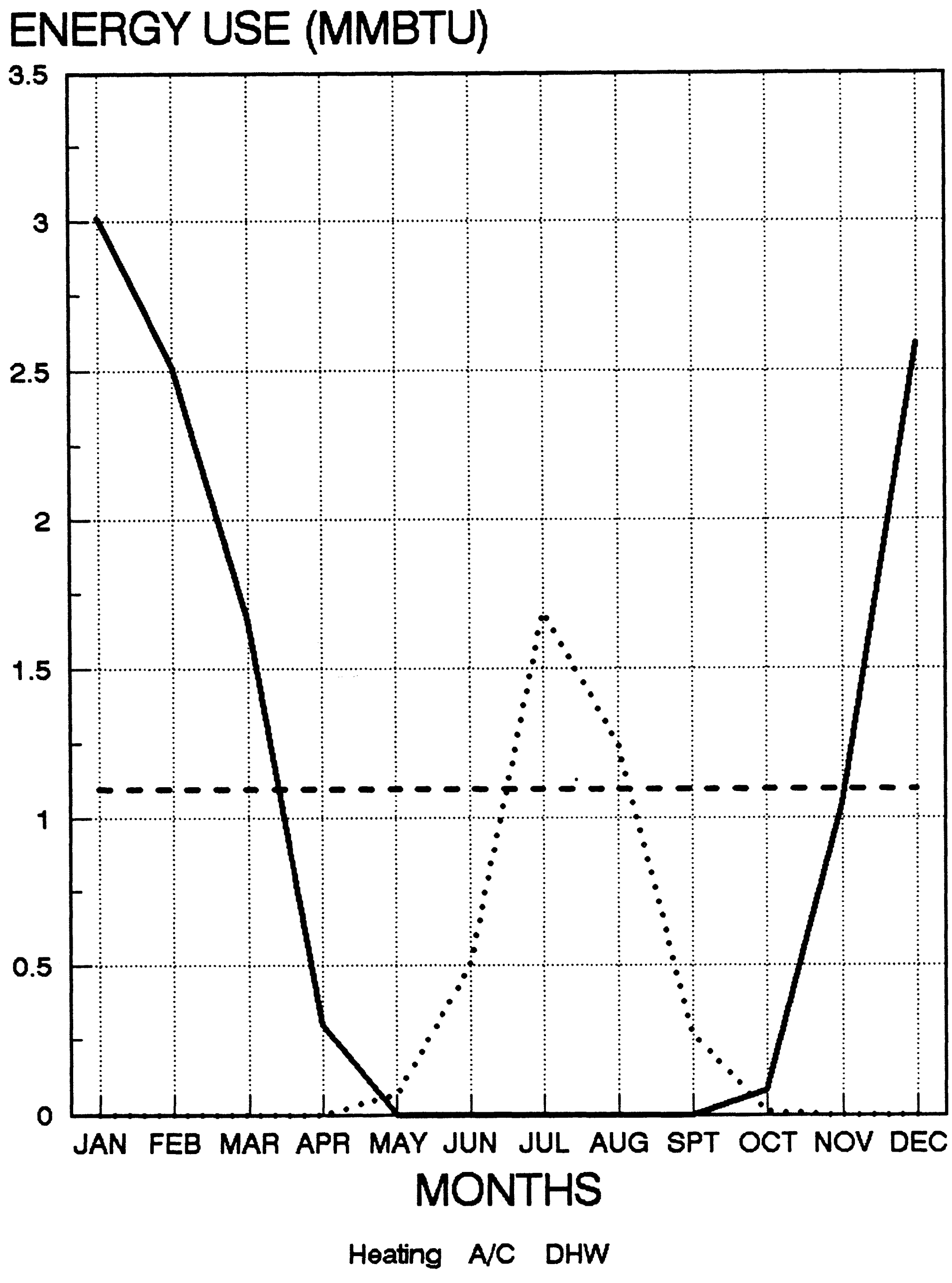


Figure 1-Monthly Heating,Cooling and Water Heating Energy Loads for the Base Apartment for New York,New York

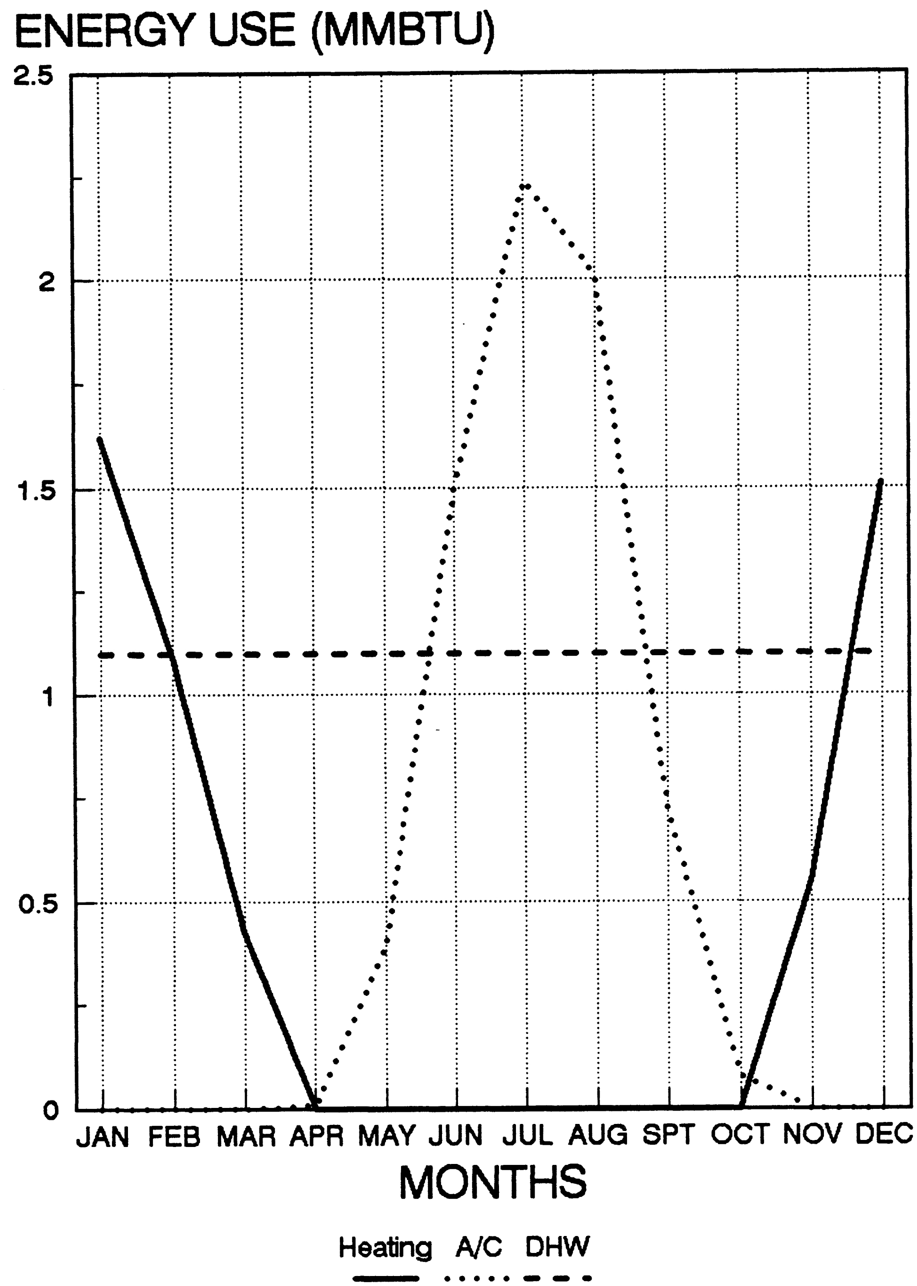


Figure 2-Monthly Heating,Cooling and Water Heating Energy Loads for the Base Apartment for Atlanta,Georgia

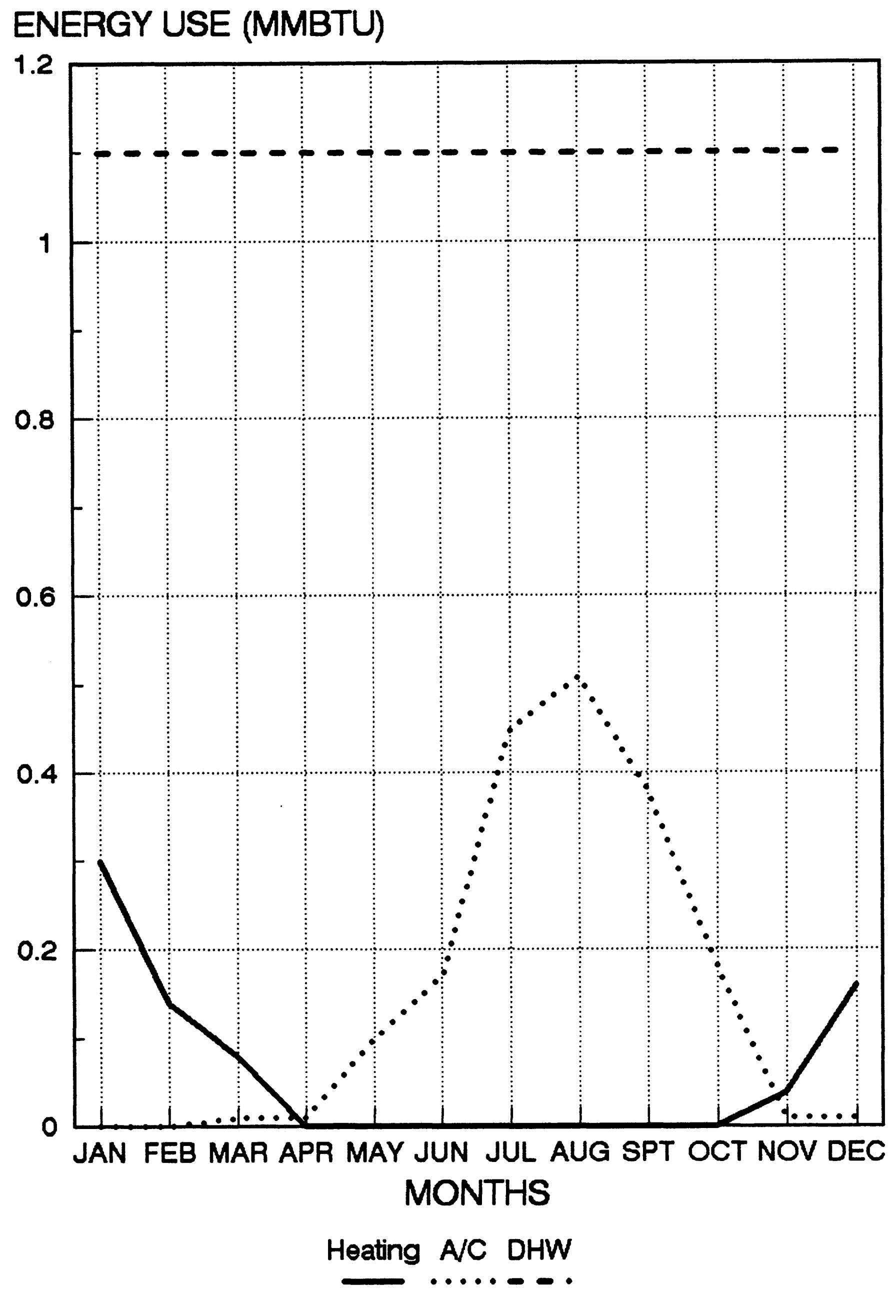


Figure 3-Monthly Heating,Cooling and
Water Heating Energy Loads for the
Base Apartment for Los Angeles,Califonia

Appendix C

Equipment Specifications

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Number 1

EQUIPMENT TYPE: Electric baseboard heating unit

MANUFACTURER: TPI Electric Baseboard

MODEL NUMBER: CC2d25

HEATING CAPACITY: 17,066 BTUH

EQUIPMENT SUPPLIES: (X)Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $242

ESTIMATED EQUIPMENT INSTALLATION COSTS: $150

RATED EFFICIENCY: 100%

TECHNICAL INFORMATION REFERENCES:
Grainger Catolog Page 1642F

OTHER SPECIFICATIONS:
240" sections @ 250 watts per foot

Electric baseboard space heating equipment specifications.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in System Number 3

EQUIPMENT TYPE: Low efficiency gas furnace space heating unit

MANUFACTURER: Carrier Corporation

MODEL NUMBER: 58GSC030-BB

HEATING CAPACITY: 31,000 BTUH

EQUIPMENT SUPPLIES: (X)Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $900

ESTIMATED EQUIPMENT INSTALLATION COSTS: $400

RATED EFFICIENCY: 77% AFUE

TECHNICAL INFORMATION REFERENCES:
Gas Appliance Manufacturers Association (GAMA) Consumer's Directory of Certified Efficiency Ratings For Residential Heating and Water Heating Equipment. March, 1990. Page 25.

OTHER SPECIFICATIONS:
Electronic Ignition

Low efficiency gas furnace space heating equipment specifications

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in System Number 4

EQUIPMENT TYPE: Low efficiency heat pump for space heating and cooling.

MANUFACTURER: Trane Company

MODEL NUMBER: WeatherTron TWJ712

HEATING CAPACITY: 17,400 BTUH

COOLING CAPACITY: 18,100 BTUH

EQUIPMENT SUPPLIES: (X)Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $1500

ESTIMATED EQUIPMENT INSTALLATION COSTS: $2300

RATED EFFICIENCY: HSPF = 6.35, SEER = 8.00

TECHNICAL INFORMATION REFERENCES:
Trane WeatherTron Heat Pump Specification Manual for Model TWJ712. Page 6.

OTHER SPECIFICATIONS:
All ratings were @670 CFM fan Speed.

Low efficiency heat pump space heating and cooling equipment specifications.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in System Number 5

EQUIPMENT TYPE: High efficiency gas furnace space heating unit.

MANUFACTURER: Carrier Corporation

MODEL NUMBER: Weathermaker SX 58SXA040-FG

HEATING CAPACITY: 40,000 BTUH

EQUIPMENT SUPPLIES: (X)Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $1200

ESTIMATED EQUIPMENT INSTALLATION COSTS: $450

RATED EFFICIENCY: AFUE = 94%

TECHNICAL INFORMATION REFERENCES:
Gas Appliance Manufacturers Association (GAMA) Consumer's Directory of Certified Efficiency Ratings For Residential Heating and Water Heating Equipment. March, 1990. Page 26.

OTHER SPECIFICATIONS:
1. Electric Ignition
2. Power Combustion
3. Condensing Type
4. Direct Vent

High efficiency gas furnace space heating equipment specifications.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in System Number 5

EQUIPMENT TYPE: High efficiency Natural Gas Water Heater for Space and Water Heating.

MANUFACTURER: Appolo HydroHeat & Cooling

MODEL NUMBER: VB2012-1 (Air Handler), A5-40-40.0NART (Water Heater).

HEATING CAPACITY: 30,400 BTUH (Water Heater), 20,000 BTUH (Air Handler).

EQUIPMENT SUPPLIES: (X)Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $1555

ESTIMATED EQUIPMENT INSTALLATION COSTS: $562

RATED EFFICIENCY: Energy Factor = 0.57 (Water Heater)
Annual Space Heating Efficiency = 87%

TECHNICAL INFORMATION REFERENCES:

Gas Appliance Manufacturers Association (GAMA) Consumer's Directory of Certified Efficiency Ratings For Residential Heating and Water Heating Equipment. March, 1990. Page 118.

Apollo HydroHeat Technical Reference Manual.

OTHER SPECIFICATIONS:

The Air Conditioning unit is the same unit specified for the other systems in this report.

High efficiency gas water heater for space and water heating equipment specifications.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in system number 8

EQUIPMENT TYPE: Low efficiency central building gas boiler space heating unit.

MANUFACTURER: Burnham Company

MODEL NUMBER: P210W

HEATING CAPACITY: 285,000 BTUH (Total System)

EQUIPMENT SUPPLIES: ( )Single Building Unit
(X)Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $13,700 (Total)

ESTIMATED EQUIPMENT INSTALLATION COSTS: (See Above)

RATED EFFICIENCY: AFUE = 82%

TECHNICAL INFORMATION REFERENCES:

OTHER SPECIFICATIONS:

Low efficiency central building gas boiler space heating equipment specifications.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in System Number 7

EQUIPMENT TYPE: Low Efficiency Central Building Electric Water Loop Heat Pump System.

MANUFACTURER: Carrier Corporation

MODEL NUMBER: 50 QEV-QXV0184

HEATING CAPACITY: 23,000 BTUH

COOLING CAPACITY: 18,000 BTUH

EQUIPMENT SUPPLIES: ( )Single Building Unit
(X)Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $6500 per unit

ESTIMATED EQUIPMENT INSTALLATION COSTS: Included Above

RATED EFFICIENCY: Seasonal COP (Heating) = 1.02, COP (Heating) = 3.6.

Seasonal COP (Cooling) = 1.10, EER (Cooling) = 11.0

TECHNICAL INFORMATION REFERENCES:
American Refrigeration Institute (ARI) Directory of Certified Unitary Water Source Heat Pumps. July, 1991. Page WSHP-4.

OTHER SPECIFICATIONS:

Low efficiency central building electric water loop heat pump space heating and air conditioning equipment specifications.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in System Number 9.

EQUIPMENT TYPE: Electric Integrated Heat Pump for Space Heating, Water Heating and Air Conditioning.

MANUFACTURER: Carrier Corporation

MODEL NUMBER: HydroTech 2000

HEATING CAPACITY: 25,800 BTUH

COOLING CAPACITY: 24,000 BTUH

EQUIPMENT SUPPLIES: (X)Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $5400

ESTIMATED EQUIPMENT INSTALLATION COSTS: $1600

RATED EFFICIENCY: SEER = 13.35, HSPF = 8.75

TECHNICAL INFORMATION REFERENCES:

American Refrigeration Institute (ARI) Directory of Certified Unitary Air Source Heat Pumps. July, 1991. Page ASHP-20.

Carrier HydroTech 2000 Specification Manual.

OTHER SPECIFICATIONS:

Outdoor Unit: 38QE92430
Indoor Unit: 38QE02430+40QE02430

High efficiency integrated electric heat pump for space and water heating and air conditioning equipment specifications.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in Systems #3 and #7.

EQUIPMENT TYPE: Low Efficiency Gas Water Heater.

MANUFACTURER: Rudd Water Heater Company.

MODEL NUMBER: RLP40P (Rudd Pacemaker)

FIRST HOUR RATING: 65 Gallons

EQUIPMENT SUPPLIES: (X)Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $245

ESTIMATED EQUIPMENT INSTALLATION COSTS: $112

RATED EFFICIENCY: Energy Factor = 0.52

TECHNICAL INFORMATION REFERENCES:
Gas Appliance Manufacturers Association (GAMA) Consumer's Directory of Certified Efficiency Ratings For Residential Heating and Water Heating Equipment. March, 1990. Page 137.

OTHER SPECIFICATIONS:
40 Gallon Storage Volume

Low efficiency gas water heater equipment specifications.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in System # 5.

EQUIPMENT TYPE: High Efficiency Gas Water Heater.

MANUFACTURER: Rudd Water Heater Company.

MODEL NUMBER: PT-40-1N (Tri-Power Energy Miser)

FIRST HOUR RATING: 71 Gallons

EQUIPMENT SUPPLIES: (X)Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $355

ESTIMATED EQUIPMENT INSTALLATION COSTS: $112

RATED EFFICIENCY: Energy Factor = 0.62

TECHNICAL INFORMATION REFERENCES:
Gas Appliance Manufacturers Association (GAMA) Consumer's Directory of Certified Efficiency Ratings For Residential Heating and Water Heating Equipment. March, 1990. Page 138.

OTHER SPECIFICATIONS:
39 Gallon Storage Volume

High efficiency gas water heater equipment specifications.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in Systems #1, #2, #4, and #8.

EQUIPMENT TYPE: Low Efficiency Electric Water Heater.

MANUFACTURER: Rudd Water Heater Company.

MODEL NUMBER: PLI40

FIRST HOUR RATING: 43 Gallons

EQUIPMENT SUPPLIES: (X)Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $327

ESTIMATED EQUIPMENT INSTALLATION COSTS: $112

RATED EFFICIENCY: Energy Rating = 0.85

TECHNICAL INFORMATION REFERENCES:

Gas Appliance Manufacturers Association (GAMA) Consumer's Directory of Certified Efficiency Ratings For Residential Heating and Water Heating Equipment. March, 1990. Page 164.

OTHER SPECIFICATIONS:
40 Gallon Storage Volume

Low efficiency electric water heater equipment specifications.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in Systems #1, #2, #3 and #8.

EQUIPMENT TYPE: Low Efficiency Air Conditioner

MANUFACTURER: Carrier Corporation.

MODEL NUMBER: 38TGO1830-28RD (Tech 2000)

COOLING CAPACITY: 17,500 BTUH

EQUIPMENT SUPPLIES: (X)Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $522

ESTIMATED EQUIPMENT INSTALLATION COSTS: $50

RATED EFFICIENCY: SEER = 8.5

TECHNICAL INFORMATION REFERENCES:

American Refrigeration Institute (ARI) Directory of Certified Unitary Air Conditioners. July, 1991. Page AC-86.

OTHER SPECIFICATIONS:

Low efficiency air conditioner equipment specifications.

EQUIPMENT SPECIFICATIONS

SYSTEM NUMBER: Used in Systems #5 and #6.

EQUIPMENT TYPE: High Efficiency Air Conditioner.

MANUFACTURER: Carrier Corporation.

MODEL NUMBER: 38TM01830DL-28RD (Tech 2000 TM)

COOLING CAPACITY: 17,200 BTUH

EQUIPMENT SUPPLIES: (X)Single Building Unit
( )Multiple Building Units

ESTIMATED EQUIPMENT COSTS: $800

ESTIMATED EQUIPMENT INSTALLATION COSTS: $400

RATED EFFICIENCY: SEER = 10.0

TECHNICAL INFORMATION REFERENCES:

American Refrigeration Institute (ARI) Directory of Certified Unitary Air Conditioners. July, 1991. Page AC-75.

OTHER SPECIFICATIONS:

High efficiency air conditioning equipment specifications.

APPENDIX D: Contractor Quotation Form

Please provide equipment and installation costs for the equipment listed. The project is a apartment or office building consisting of 12 units, each 1000 square feet of floor space and having a heating load of 15,400 btu's per hour and a cooling load of 8,000 btu's per hour. State building energy construction standards are followed.

Equipment: Systems 1-9 as listed on Table 3.2 were listed here for each of the three HVAC contractors to bid on.

	Heating Equipment	Water Heating Equipment	Cooling Equipment
Manufacturer:	________	________	________
Model Number:	________	________	________
Efficiency Rating:	________	________	________
Equipment Cost:	________	________	________
Installation Cost:	________	________	________

Additional Factors:______________________________

Contractors Name:______________________________

Contractors Address:______________________________

Contractors Phone Number:______________________________

Date:__________________

Appendix E

Calculating the Total Resource Energy Used by the Nine Equipment Systems.

Calculations of the Total Resource Energy Used for Equipment Systems #1 through #9.

Total Resource Energy Calculations for System #1

Electric Baseboard Space Heating

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
21.13	30%	100%[1]	70.43

Electric Water Heater (Low Efficiency)

On-Site End-Use (MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
15.57	30%	85%[2]	51.90

Electric Air Conditioner (Low Efficiency)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
3.78	30%	249%[3]	12.60

Electric Utilities (Lights, Appliances, Etc.)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
9.24	30%	100%	30.80

Total Resource Energy Used for System # 1

On-Site End-Use Energy(MMBTU)	Total Resource Energy Used (MMBTU)
47.35	165.73

Total Resource Energy Calculations for System #2

Low Efficiency Gas Furnace Space Heating

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
27.70	95%	77%[4]	29.16

Electric Water Heater (Low Efficiency)

On-Site End-Use (MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
15.57	30%	85%	51.90

Electric Air Conditioner (Low Efficiency)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
3.78	30%	249%	12.60

Electric Utilities (Lights, Appliances, Etc.)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
9.24	30%	100%	30.80

Total Resource Energy Used for System # 2

On-Site End-Use Energy(MMBTU)	Total Resource Energy Used (MMBTU)
56.29	124.46

Total Resource Energy Calculations for System #3

Low Efficiency Gas Furnace Space Heating

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
27.70	95%	77%	29.16

Gas Water Heater (Low Efficiency)

On-Site End-Use (MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
19.81	95%	52%	20.85

Electric Air Conditioner (Low Efficiency)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
3.78	30%	249%	12.60

Electric Utilities (Lights, Appliances, Etc.)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
9.24	30%	100%	30.80

Total Resource Energy Used for System # 3

On-Site End-Use Energy(MMBTU)	Total Resource Energy Used (MMBTU)
60.53	93.41

Total Resource Energy Calculations for System #4

Low Efficiency Heat Pump Space Heating

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
12.52	30%	186%	41.73

Electric Water Heater (Low Efficiency)

On-Site End-Use (MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
15.57	30%	85%	51.90

Electric Heat Pump Air Conditioner (Low Efficiency)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
2.87	30%	234%	9.57

Electric Utilities (Lights, Appliances, Etc.)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
9.24	30%	100%	30.80

Total Resource Energy Used for System # 4

On-Site End-Use Energy(MMBTU)	Total Resource Energy Used (MMBTU)
37.83	134.00

Total Resource Energy Calculations for System #5

High Efficiency Gas Furnace Space Heating

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
22.64	95%	94%[8]	23.83

Gas Water Heater (High Efficiency)

On-Site End-Use (MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
19.02	95%	62%[9]	20.02

Electric Air Conditioner (High Efficiency)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
3.14	30%	293%[10]	10.47

Electric Utilities (Lights, Appliances, Etc.)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
9.24	30%	100%	30.80

Total Resource Energy Used for System # 5

On-Site End-Use Energy(MMBTU)	Total Resource Energy Used (MMBTU)
54.04	83.12

Total Resource Energy Calculations for System #6

High Efficiency Gas Water Heater Space Heating

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
25.94	95%	87%[11]	27.31

Gas Water Heater (Standard Efficiency)

On-Site End-Use (MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
13.68	95%	87%[12]	14.40

Add-On Electric Air Conditioner (High Efficiency)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
3.14	30%	293%	10.47

Electric Utilities (Lights, Appliances, Etc.)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
9.24	30%	100%	30.80

Total Resource Energy Used for System # 6

On-Site End-Use Energy(MMBTU)	Total Resource Energy Used (MMBTU)
52.00	83.98

Total Resource Energy Calculations for System #7

Low Efficiency Water Loop Heat Pump Space Heating

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
8.48	30%	102%[13]	28.27

Gas Water Heater (Low Efficiency)

On-Site End-Use (MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
19.81	95%	52%	20.85

Water Loop Heat Pump Air Conditioner (Low Efficiency)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
2.69	30%	110%[14]	8.97

Electric Utilities (Lights, Appliances, Etc.)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
9.24	30%	100%	30.80

Total Resource Energy Used for System # 7

On-Site End-Use Energy(MMBTU)	Total Resource Energy Used (MMBTU)
40.22	88.89

Total Resource Energy Calculations for System #8

Low Efficiency Gas Central Boiler Space Heating

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment[15]	Total Resource Energy Used (MMBTU)
47.48	95%	82%	49.98

Electric Water Heater (Low Efficiency)

On-Site End-Use (MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
15.57	30%	85%	51.90

Electric Air Conditioner (Low Efficiency)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
3.78	30%	249%	12.60

Electric Utilities (Lights, Appliances, Etc.)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
9.24	30%	100%	30.80

Total Resource Energy Used for System # 8

On-Site End-Use Energy(MMBTU)	Total Resource Energy Used (MMBTU)
76.07	145.28

Total Resource Energy Calculations for System #9

High Efficiency Heat Pump Space Heating

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
8.20	30%	256%[16]	27.33

Heat Pump Water Heater (High Efficiency)

On-Site End-Use (MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
11.88	30%	256%	39.60

Heat Pump Air Conditioner (High Efficiency)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
2.0	30%	391%	6.67

Electric Utilities (Lights, Appliances, Etc.)

On-Site End-Use Energy(MMBTU)	% of energy Delivered to the Site	Seasonal Efficiency of the Equipment	Total Resource Energy Used (MMBTU)
9.24	30%	100%	30.80

Total Resource Energy Used for System # 9

On-Site End-Use Energy(MMBTU)	Total Resource Energy Used (MMBTU)
31.32	104.40

[1]Electric baseboard space heating equipment is considered 100% efficient.

[2] Electric water heater seasonal efficiency is measured by the energy factor for the equipment. This is the overall efficiency rating of the water heater. Reference the 1990 Consumer's Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment from GAMA (Gas Research Manufacturers Association). This unit selected has a ER (Efficiency Ratio) of 85%.

[3] The low efficiency air conditioner has a SEER of 8.5. The SPF (seasonal performance factor) is the total cooling performance over the entire cooling season. The SEER (8.5)/3.413=2.49=SPF. Reference ARI (Air Conditioning and Refrigeration Institute Directory of Certified Unitary Air Conditioners and Air Source Heat Pumps.

[4] The low efficiency gas furnace efficiency is measured by the AFUE (annual fuel utilization efficiency). Reference the 1990 Consumers Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment GAMA (Gas Appliance Manufacturers Association). This low efficiency furnace has a 77% AFUE.

[5] The gas water heater efficiency is measured by the Energy Factor. The low efficiency gas unit has a energy factor of 0.52. The reference is the same as in footnote #2.

[6] The low efficiency heat pump has a HSPF (heating seasonal performance factor) of 6.35. This is the total heat delivered to the space divided by the total electrical energy required to run the heat pump. Then 6.35/3.413=1.86=SPF (seasonal performance factor). Reference ARI (Air Conditioning and Refrigeration Institute Directory of Certified Unitary Air Conditioning and Air Source Heat Pumps. Also reference Trane weathertron heat pump manual for model TWJ712.

[7] The low efficiency heat pump has a SEER of 8.00. Then 8.00/3.413=2.34=SPF. Reference is the same as footnote #6.

[8] The high efficiency gas furnace has a AFUE of 94%. Reference is the same as footnote #4.

[9] The high efficiency gas water heater has as EF of 0.62. Reference is the same as footnote #5.

[10] The high efficiency air conditioner has a SEER of 10.0. The 10.0/3.413=2.93=SPF. Reference is the same as footnote #3.

[11] This gas fired water heater is used for space heating and domestic water heating. The annual space heating efficiency (ASHE) is

$$\frac{Er}{1-(77)\ (8.25)\ (S)\ (v)\ (Q\ in)}$$

Er=Recovery Efficiency
S=Standby Losses
V=Storage Volume
Qin=Btu/h input to water heater

This is a formula developed in ASHRAE standard 124, Appendix A, pages 38, 39 and 40 for combined space heating and water heating appliances. Reference the Appollo HydroHeating and Cooling Manual-The Inside Story, page 5. The ASHE=87%.

[12] Same as footnote #11.

[13] The water loop heat pump for space heating can not use a HSPF because it is using water from a supply loop maintained at 60-70 degrees and is not affected by outside temperatures. The seasonal COP for the water loop heat pump is 1.02 (average). Reference EPRI (Electric Power Research Institute) Water Loop Heat Pump Systems: Assessment Study, page 5-1, Table 5-1.

[14] The water loop heat pump in the cooling mode uses loop water at 70-90 degrees and its seasonal COP is 1.10. The reference is the same as footnote #13.

[15] The central gas boiler has a AFUE of 82%. Reference same as in footnote #4.

[16] The high efficiency heat pump (Carrier Hydrotech 2000) has a SEER of 13.35. So 13.35/3.413=3.91=SPF. The HSPF is 8.75. Then 8.75/3.413=2.56=SPF (heating). This same value will be used for the heat pump water heater unit. Reference the Carrier Hydrotech 2000 specifications manual and the ARI reference from footnote #6.

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