Guideline

Gas Furnaces

Southern California Gas Company

New Buildings Institute

Advanced Design Guideline Series

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CHAPTER 1: PREFACE

These Guidelines have been developed by the New Buildings Institute in cooperation with Southern California Gas Company to assist program planners, evaluators and designers make informed decision on the cost-effectiveness of energy saving measures. This guideline deals specifically with gas furnaces. These guidelines are intended to be a step toward a comprehensive approach to design specifications.

This Design Guideline is based on careful evaluation and analysis of high efficiency gas furnaces to determine when the measure is appropriate, how it is best implemented, how cost effective it is, and how its energy savings are described. These Guidelines describe efficiency measures that are more advanced than standard practice, yet still cost effective in all, or select markets. Design Guidelines are used by individuals and organizations interested in making buildings more energy efficient. They provide the technical basis for defining efficiency measures used in individual building projects, in voluntary energy efficiency programs, and in market transformation programs.

It should be remembered that this Guideline document deals primarily with the comparison of a single efficiency measure and its baseline. This means that the analysis assumes that all other features of the building are fixed. This is done primarily for clarity of the analysis, and allows one to focus on the advantages and economics of the single measure.

In reality, most new building design situations involve multiple energy efficiency options. The cost effectiveness of one measure is often influenced by other measures. For example, increases in building envelope insulation can often reduce HVAC loads enough to reduce the sizing requirements for the heating and cooling equipment. It is not uncommon for the cost savings from smaller equipment to offset increased insulation costs.

It is beyond the scope of this Guideline to attempt to address the interactions between measures, especially because these interactions can cover a huge range of options depending on the climate, the local energy costs, the building, and its systems. Nevertheless, the New Buildings Institute recommends that building designers give careful consideration to measure interactions and to integrated systems design. This Guideline can provide the starting point by providing insight into the performance of one measure.

CHAPTER 2: DESCRIPTION

Warm air furnaces are designed to heat air to approximately 130°F for space conditioning. This warm air is distributed to zones requiring heating via a supply fan and duct work. This kind of heating is called forced air heating as contrasted with hydronic, or radiant heating systems. Warm air heating in many commercial buildings is provided by the furnace section of unitary heating and cooling equipment (rooftop units). As is discussed in this report, premium efficiency furnaces are not available in unitary equipment, thus most of our comparisons revolve around the furnace type that currently is manufactured with high efficiency options – the stand-alone furnace.

Stand-alone furnace sizes are typically 40 kBtu/h to 140 kBtu/h. They are typically designed for residential use. However, these furnaces are often used in commercial environments and multiple units can be used to provide greater capacity.

Furnaces are designed for several different fuels, including various types of fuel gas, various grades of fuel oil, and electricity. A furnace is typically designed for only one fuel type and cannot burn other fuels. Some furnace designs can be adapted to burn gas, LPG, oil or coal. Other designs allow for burner conversion for different fuels.

This guideline covers gas furnaces only, since gas is certainly the most prevalent fuel used in furnaces in the United States.

A. Heating Efficiency

The overall efficiency of the furnace is gross output energy divided by input energy. The overall efficiency is affected by four basic factors:

Combustion efficiency

Standby losses

Cycling losses

Heat transfer

Combustion Efficiency, or Thermal Efficiency, is output energy minus stack loss energy, divided by input energy, and describes how well the furnace is able to burn the fuel and transfer this heat.

Standby Losses can include the following:

exterior surface losses

interior surface losses

standing pilot losses

Exterior surface losses are the losses of heat via radiation and convection from the surface of the furnace. These losses are typically small (0.5% or less). Interior surface losses are the largest heat loss mechanism for natural draft gas furnaces. When the furnace is cycling on and off, there is air movement over the heat transfer surfaces even when the furnace is off. Air movement is induced by a combination of stack and wind velocity effects. These losses can be reduced by using a stack damper. Furnaces with fan assisted combustion have less off-cycle losses because the higher pressure drop through the furnace limits airflow when the fan is off. Interior surface losses on forced draft furnaces result from the “purge cycle” - emptying the combustion chamber of gases before initiating firing.

A standing pilot can consume as much as 2,000 Btu/hr. This form of heat loss is being eliminated by the widespread replacement of standing pilots with electronic ignition. With an electronic ignitions, a spark or hot surface igniter lights an intermittent pilot light, which in turn lights the gas burner. The 1996 ASHRAE Systems Handbook reports a 16% energy savings from replacing a natural draft furnace and standing pilot with a fan assisted furnace and electronic ignition.

Cycling Losses occur during periods of non-uniform operation. When a furnace is first cycled on, the interior surfaces of the furnace are cooler and steady-state combustion conditions are not developed. Some of the fuel will not be completely burned under these non-equilibrium conditions, temporarily resulting in lower combustion efficiency.

Heat transfer from the hot combustion gases to the cooler heat exchange surface results from radiation and convection. Convection can be enhanced by increasing turbulence via the shape of combustion gas passages or the addition of inserts such as turbulators. Heat transfer can also be increased by increasing the size of the heat exchange surface through the use of additional fins on the gas side of the heat exchanger.

B. Furnace Types

Gas-fired furnaces use a natural-draft or a fan-assisted combustion system.

The minimum allowable thermal efficiency for central furnaces is 80%. Natural-draft and fan-assisted combustion furnaces typically have an 80% thermal

efficiency. Condensing furnaces have efficiencies over 90%. Most furnace manufacturers have either 80% efficient furnaces or condensing furnaces, with little product in between.

Natural Draft Furnace

Natural draft furnaces rely on buoyancy forces to induce air into the combustion chamber and combustion gases out of the flue. Natural draft furnaces are fairly simple with few moving parts and thus easy to maintain.

Fan-Assisted Combustion Furnace

Many furnaces now incorporate fan-assisted combustion into their design to improve efficiency. Fan-assisted combustion furnaces use a blower to force or induce the combustion products through the furnace. The blower may be located either upstream or downstream from the heat exchanger.

With the upstream configuration, as shown in Figure 1, the fan blows the combustion air into the heat exchanger. This type of furnace is also called forced draft, power burner, power combustion and pressure fired furnace.

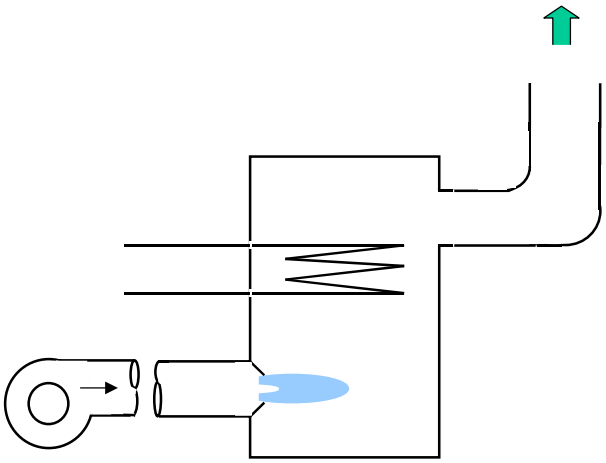


Figure 1. Upstream Fan-Assisted Combustion Furnace

A downstream configuration has the blower on the exhaust side of the heat exchanger. These systems are known as induced draft and power vent furnaces.

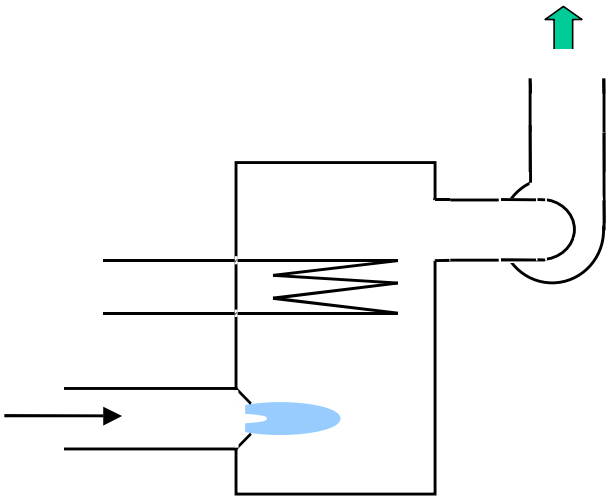


Figure 2 - Downstream Fan-Assisted Combustion Furnace

The efficiency of standard forced draft furnaces, can be increased by adding extra passes to the combustion heat exchanger. The number of passes and increased efficiency are limited by the amount of heat that can be extracted. It is critical not to remove so much heat as to condense the flue gases.

Direct Vent Furnace

Direct vent furnaces, also called sealed combustion furnaces, draw combustion air directly from outside through a venting system. Sealed combustion is a way to prevent furnaces from inducing infiltration into a building and to more carefully control the combustion process. Direct vent furnaces may have either natural-draft or fan-assisted combustion. An added advantage is that the threat of carbon monoxide poisoning of occupants is mostly eliminated. Direct vent systems are well suited for combustion air pre-heating; the combustion intake air is drawn in through an outer pipe that surrounds the flue duct. On a standard furnace, a pre-heater can save as much as 9% of annual heating energy.

Condensing Furnace

Condensing furnaces differ from conventional furnaces in that they recover waste heat from their exhaust gases that would otherwise be lost to the atmosphere. This is achieved through the use of an enlarged heat exchanger surface, which extracts sensible heat and, under certain conditions, extracts the latent heat from the water vapor which is generated during combustion.

Condensing furnaces have the following advantages:

- More efficient than conventional furnaces
- Up to 15% reduction in fuel costs
- Production of less CO_2, sulfur and nitrogen oxides.

The principal component of natural gas is methane (CH_4). The difference between Methane's Higher Heating Value (Gross Caloric Value) of 23,875 Btu/lb and its Lower Heating Value (Net Caloric Value) of 21,495 is the 2,380 Btu/lb (10%) of contained in the latent heat of vaporization. This latent heat content is not released again unless the combustion gas is condensed. Thus, condensing furnaces are approximately 10% more efficient than efficient non-condensing furnaces.

Condensing furnaces have an acidic (pH around 3.8) condensate that requires disposal. In most areas, this condensate can be sent to a drain or discharged outside untreated. Sometimes treatment is required. This can be as simple as draining the condensate through limestone gravel before sending it down the drain. Sometimes the type of drain is specified - allowing condensate in cast iron and plastic drains but not in galvanized drains. If the trap is only serving the condensate load, a trap primer, a device to keep the trap full of water, will likely be required. Other jurisdictions can have more stringent requirements, checking with your local building department is recommended.

Pulse Combustion Furnace

One form of condensing furnace is the "pulse combustion" furnace. Pulse combustors have the following advantages:

- Reduces energy costs by operating at high efficiency with low standby losses
- Low nitrogen oxide emissions
- Combustion air fan energy consumption is virtually eliminated.

The combustion process for a pulse combustion furnace is unlike all the other types of furnaces in that during firing the combustion is not a continuous equilibrium reaction but burns of discrete "charges" of gas/air mixtures in rapid succession, similar to the firing process in an automobile engine.

A combustion fan, used only for initial charge, draws in both air and gas, which mix and are then ignited by a spark. The combustion of the fuel air mixture creates pressure waves at sonic velocity, which drives the flow of combustion gases out of the combustion chamber, and across the heat transfer surfaces to the end of the exit pipe.

The cooling and momentum of the combustion gases creates suction in the combustion chamber, which draws in a fresh charge of air and gas. Because of the resonant design of the combustion chamber and the exit pipe, when the pressure wave reaches the end of the exit pipe it is partially reflected back toward the combustion chamber where the new charge of air and gas is ignited by residual heat.

The turbulent flow in pulse furnaces produces high heat transfer rates compared to furnaces that have a "smoother" or laminar airflow, which creates an insulating air layer (boundary layer) between the hot combustion gas and the heat exchanger surface.

Lennox is currently the only furnace manufacturer using pulse combustion for condensing furnaces. The other manufacturers are using an extended heat transfer surface to extract the latent heat. In some models, the condensing furnace is the same as the standard furnace with an additional secondary heat exchanger. Most of the condensing furnaces use an induced draft combustion air fan, which maintains a negative pressure on the furnace heat exchanger where as the Pulse system exerts positive and negative pressures on the heat exchanger.

C. Furnace Venting

When comparing the costs of condensing and non-condensing gas furnaces, the costs of removing the stack gases should be considered. The combustion gases from a condensing furnace are cooler than non-condensing furnaces but contain corrosive condensate.

Venting Categories

ANSI/AGA *Standard* Z21.47 classifies central furnaces venting systems as shown in Figure 3. They are categorized by vent pressure, temperature above dew point, and steady-state efficiency. Essentially the venting systems are categorized by the vent pressure, and whether they are condensing or not. Category II and IV typically uses PVC pipe. Category I and III venting will typically use double wall metal pipe.

Different jurisdictions will have different furnace venting requirements. Therefore, familiarity with local requirements is important before designing a space heating system.

Category	Vent Pressure	Temperature above dew-point	Steady State Efficiency
I	non-positive	≥ 140°F	< 83%
II	non-positive	< 140°F	> 83%
III	positive	≥ 140°F	< 83%
IV	positive	< 140°F	> 83%

Figure 3. Furnace Categories

Automatic Vent Dampers

Natural draft furnaces rely on buoyancy forces to draw in combustion air and to exhaust combustion gases. However, when the furnace is not firing, these same buoyancy effects are removing heat from the furnace heat exchanger and increasing building exfiltration. Use of a draft damper reduces these losses by closing the flue when the furnace is not firing. Fan assisted furnaces do not need draft dampers because their combustion passages are more resistive to the free flow of air.

D. Limitations

Most of the condensing furnaces currently available are primarily suited for the residential market. This creates a market barrier to greater use of condensing furnaces in commercial air-conditioned buildings.

In many commercial buildings that use furnaces for heating, the furnace is a section in a unitary packaged unit (roof top unit). There are no cooling/gas heating packaged units with a high efficiency heating option. Typical packaged rooftop units have furnace combustion efficiencies around 80%. The high-efficiency designation of unitary equipment applies strictly to cooling efficiency.

Carrier Corp. is currently involved with initial testing of a packaged HVAC unit with a condensing furnace. Whether this goes to market depends on cost and expected market share.

The popularity of rooftop units is primarily due to simplifications for designers, owners and maintenance staff. Packaged rooftop units are designed and manufactured so that the equipment units are properly matched, safety and code concerns are addressed, installation is less labor intensive and repair is simplified. The current alternative to rooftop units for commercial buildings with both cooling and heating loads is a furnace with a split system cooling coil.

Thus we do not think gas energy savings alone will induce construction specifiers to call for a condensing furnace with a split system cooling coil. If cost-effectiveness of condensing furnaces exceed program criteria, an appropriate target for a market transformation program promoting condensing furnaces would be to induce the manufacturers of rooftop units to offer a condensing furnace option to their product line of rooftop units.

Energy codes may have driven out any product differentiation on the lower end of the market and any further non-condensing efficiency improvements may have a similar cost as the condensing furnace while providing less energy savings.

CHAPTER 3: HISTORY AND STATUS

A. Efficiency Ratings

Because there are many ways to characterize the efficiency of furnaces, it has become necessary to establish consistent, published measurements. There are various definitions of efficiency including

- Steady-State Efficiency, and
- Annual Fuel Utilization Efficiency

Steady-state efficiency is the furnace efficiency under equilibrium conditions.

Annual fuel utilization efficiency (AFUE) represents the part-load efficiency at the average outdoor temperature and load of a furnace installed in the United States. This value is useful for comparing different furnaces, but is not meant to represent actual efficiency. Federal law requires manufacturers of furnaces to use AFUE as determined using the isolated combustion system method to rate efficiency.

The AFUE of a furnace may be improved by using:

- combustion air pre-heater.
- flue damper
- intermittent ignition device (electronic ignition)

The table in Figure 4 gives AFUE values for different furnace types[1].

Type of Gas Furnace	AFUE,%	
	Indoor	ICS*
Natural-draft with intermittent ignition and auto vent damper	78.0	**68.5**
Fan-assisted combustion with standing pilot or intermittent ignition	80.0	78.0
Same as above, except with improved heat transfer	82.0	80.0
Direct vent, fan-assisted combustion, and intermittent ignition	80.0	78.0
Fan-assisted combustion (induced-draft)	80.0	78.0
Condensing	93.0+	91.0+

*Isolated combustion system.

Figure 4 – Typical AFUE values

B. Energy Efficiency Standards

Different minimum efficiencies are required for different furnace types and sizes. Small furnaces are rated according to AFUE, while large units are rated by thermal efficiency. The table in Figure 5 summarizes minimum furnace efficiency levels, in either E_t, thermal efficiency or E_c, combustion efficiency. The current efficiency levels are from the ASHRAE/IESNA 90.1 energy code. The proposed efficiencies for Jan. 2001 are from the revised 90.1 code designated ASHRAE/IESNA 90.1R. The table shows that changes in furnace thermal efficiency are not likely to be mandated by energy codes. However the proposed efficiency standards reduce the standby losses on the larger furnaces.

[1] P. 28.6, 1996 ASHRAE Systems and Equipment Handbook

Size (Input Rating)	Current Efficiency	Proposed Efficiency as of Jan. 2001
<225 MBH	AFUE ≥78% or E_t ≥80%	AFUE ≥78% or E_t ≥80%
>225 MBH	E_t ≥80% max cap. E_t ≥78% at min. cap.	E_c ≥80% Intermittent ignition, Flue damper or power venting, SL≤0.75%

Figure 5 – Warm Air Gas Furnace Minimum Efficiency Requirements

C. Other Standards

The following list summarizes other important standards that apply to central gas furnaces installed in the United States:

- ANSI/AGA Z21.47-93 - *Gas Fired Central Furnaces*
- ANSI/AGA Z21.64-90 - *Direct-Vent Central Furnaces*
- ANSI/AGA Z21.66-88 - *Automatic Vent Damper Devices for Use with Gas-Fired Appliances*
- ANSI/AGA Z21.47-93 *Gas Fired Central Furnaces*
- ANSIZ223.1-1996/NFPA 54 *National Fuel Gas Code*
- ANSI/ASHRAE 103-1993 - *Method of Testing for Annual Fuel Utilization Efficiency Residential Central Furnaces and Boilers*
- 10CFR430Appendix N - *Uniform Test Method for Measuring the Energy Consumption of Furnaces*

D. Condensing Furnace Manufacturers

This section provides information on several manufacturers of condensing furnaces. The standard designation that manufacturers use for system capacity is "MBH," which means the same thing as "kBtu"; thousands of Btus per hour.

Bryant

Bryant has at least two lines of condensing furnaces, the Plus 90i or the Model 355 MAV with an AFUE of 96% and the Plus 90 or model 340 MAV. These units come in sizes with input ratings from 40 MBH to 120 MBH.

Heil

Heil offers 4 lines of condensing furnaces all with input gas ratings having a range of models from 50 MBH to 125 MBH. The highest efficiency model, NTVM, has an AFUE of 94%. The NTPM and NTGM lines have AFUE's of 92% and the NTCG models have a 90% AFUE.

Lennox

Lennox manufactures both pulse and fan-assisted combustion condensing furnaces. The Pulse 21 and 21V are the pulse combustion lines and offer models up to 140 kBtu/h input rating. The Elite 90 and Dimension lines are condensing, but not pulse.

Thermopride

Thermopride offers condensing and non-condensing furnaces. The condensing furnaces, the CHB-50 to CHB-125 have gas input ratings of 50 MBH to 125 MBH and seasonal efficiencies (AFUE) of approximately 93%.

Trane

Trane carries two lines of similar condensing furnaces the XV90 furnace has a variable speed blower while the XE 90 has a multi-speed blower. The XV90 offers furnaces from 56 MBH to 111 MBH output ratings with a a seasonal efficiency (isolated combustion system AFUE) of 93%. The XE model ranges from 37 MBH to 111 MBH output rating and have a slightly lower efficiency AFUE = 92%.

CHAPTER 4: ANALYSIS

A. Overview

A high thermal efficiency level of 90% was compared to the base efficiency of 80%. The 90% efficiency represents a condensing furnace. Efficiency ratings for condensing furnaces range from 87% to 95%. The 90% efficiency rating was selected as a conservative basis for estimating savings.

This analysis is structured to provide "typical" values that can be used as a screening tool during schematic design of a building or as guidance on equipment efficiency issues for voluntary programs or market transformation programs. The results of a detailed energy and rates analysis, for six building types in ten cities, have been distilled down to a series of graphs.

The selected cities and buildings are representative of the range of climates and building occupancies where warm air ducted furnaces would be used. The economic analysis is of course dependent upon gas rates. The results are graphed for a range of gas rates. Building descriptions and city specific utility rates are provided in the Appendix.

Both energy savings and cost-effectiveness were calculated. The energy savings metric is presented in two ways:

- Annual energy cost savings ($/yr)
- Normalized energy cost savings ($/yr per MBH capacity)

The normalized graphs, in the following chapter, allow the user to expand these results to different size equipment.

The cost-effectiveness metric is the Savings to Investment Ratio (SIR), which is the Life Cycle Cost (LCC) savings divided by the incremental measure cost. The measure is assumed to be cost-effective if the SIR is greater than 1.0.

B. Energy Savings

The high efficiency furnace measure was analyzed for the six (6) building types shown in Figure 6. The range of capacities represents the variation in heating load for the cities analyzed.

Bldg. Type	Size (Sq Ft)	Capacity (MBH)
Medium Office	49,000	640 - 905
Sit-down Restaurant	9,060	1,275 - 1,828
Fast Food Restaurant	2,000	325 – 525
Medical Clinic	49,000	738 - 969
Small Retail	9,600	483 - 779
School	50,000	2,275 – 3,339

Figure 6 - Building Type and Size

Annual heating loads were calculated for each building type from a detailed energy simulation using DOE-2.1E. The models provide comprehensive data on energy use and savings. The building models were modified for each location to be compliant with the applicable building energy code.

The cities were selected for varying HDD (heating degree days) as shown in Figure 7. The graphs in the following chapter present the energy savings for each of these cities for a range of marginal gas prices. The graph legend corresponds to the abbreviations for each of the cities, as shown in the table.

City	HDD_{65}
Miami (Mia)	200
San Diego (SD)	1256
Phoenix (Phnx)	1350
Los Angeles (LA)	1458
Riverside (River)	1861
Fort Worth (FW)	2304
Atlanta (Atl)	2991
San Francisco (SF)	3016
Washington D.C. (DC)	4707
Chicago (Chic)	6536

Figure 7 - Cities used for Heating Analysis

The graphs present the annual energy cost savings versus the marginal cost of gas, in dollars per therm. The marginal gas cost, which provides the incremental energy cost, is calculated as energy cost savings, in dollars, divided by energy savings in therms. The marginal cost accounts for varying gas rates that may apply based on total usage.

To make best use of these graphs it is important to understand what was not included in the analysis as well as what was. Maintenance issues could affect the economic efficiency of gas furnaces in a split system versus packaged system configuration. However, there are too many variables and the additional complication would not have increased the clarity or accuracy of the analysis. The economic effects of maintenance contingencies within one configuration are likely insignificant with high efficiency furnaces versus the base case.

Another basic assumption in this analysis is that the cost effectiveness comparison of options is being made at the time of new construction. In a retrofit application, existing supply, venting or distribution equipment can significantly shift the incremental cost of condensing furnaces versus standard efficiency furnaces.

C. Cost Effectiveness

Cost effectiveness is based on the calculation of the Savings to Investment Ratio (SIR), which is defined as the Life Cycle Cost (LCC) savings, in dollars, divided by the incremental measure cost per unit capacity, in dollars per MBH capacity, as shown in the following equation:

$$SIR = \frac{LCC\ Savings}{Incremental\ Cost}$$

The SIR uses an investment model over the life of the equipment rather than the simplistic and short range perspective of simple payback.

The LCC savings describe the present worth of the energy cost savings over the life of the investment. If the LCC savings are greater than the incremental cost, then the SIR will be greater than one and the measure is assumed to be cost effective.

Savings to Investment Ratios (SIR's) indicate the cost effectiveness of the equipment selection depending upon several factors including:

- building type,
- equipment,
- climate,
- utility rate, and
- scalar ratio.

The scalar ratio is a single term that combines discount rate, period of analysis, and fuel escalation. A scalar ratio is a mathematical simplification of life cycle costing (LCC) analysis. The first year savings are multiplied by the scalar to arrive at the life cycle savings. In technical terms, the scalar ratio represents the series present worth multiplier. A more detailed description of the scalar ratio is provided in the Appendix.

Different scalars have been used to evaluate the cost-effectiveness based on different economic assumptions. Typical values of the scalar are in the 8 to 16 range. This approach has the virtue that different life cycle costing criteria, and different scalars may be applied to the results.

CHAPTER 5: DESIGN ANALYSIS GRAPHS

A. Using the Furnace Graphs

The following pages contain families of graphs that describe the performance of high efficiency furnaces in a variety of cities and building types. As described in Chapter 4, these graphs were developed from DOE-2.1E runs for representative prototype buildings using the actual utility rate structures currently published for each of the cities. The graphs can save the reader a great deal of analysis work, and can provide good information about when and where high efficiency furnaces can be cost effective.

Each of the lines on the graphs represents the energy savings potential of the prototype building in one of the ten cities studied. Markers on each line indicate the current local gas rate for each of the cities selected. By following the line on the graph the results can be extrapolated to different gas rates.

Annual Energy Cost Savings Graphs

The top graph in Figure 8 is typical of the annual energy cost savings graphs. This particular one is for the medium office building prototype.

The horizontal x-axis of this graph is the marginal cost of gas, in dollars per therm. Marginal cost is the cost charged, under the local utility rate structure, for those therms that are saved by the higher efficiency furnace, and so it does not include the utility basic service charges or other charges that are common to both scenarios.

The vertical y-axis shows the annual energy cost savings, in dollars per year, between the 80% base efficiency case and the 90% efficient condensing furnace.

For example, Los Angeles is represented by a hollow circle marker. In this example, the prototype medium office building in Los Angeles has a marginal gas cost of approximately $0.53 per therm, and a high efficiency condensing furnace would save approximately $200/year compared to a base efficiency furnace.

The slope of the line represents the rate of change in annual energy cost savings for each increment or decrement in the marginal cost of gas. In the Los Angeles example, if gas were to increase to $0.60 per therm, the cost savings would increase to approximately $230 per year.

The cases shown on this graph can also be used to estimate savings for other cities with comparable climates. For example, the Chicago line would also be reasonably representative of Milwaukee, Detroit or Omaha. The gas costs in these other locations may be different than Chicago, but by entering the graph at the x-axis value that represents the costs in the other location, an estimate of the savings can be obtained.

Normalized Energy Cost Graphs

The bottom graph in Figure 8 is typical of the normalized energy cost graphs. Unlike the annual energy savings cost graphs, which are specific to the furnace sizes of the prototype buildings in each city, these have been normalized to show annual dollar savings per unit of furnace capacity, in thousands of Btus per hour (MBH). This makes them a bit more abstract, but also makes them more universal. These graphs can be used to estimate the furnace savings for different size furnaces and buildings for different building types.

For example, a 90% efficiency furnace installed in a medium office in Los Angeles, with a marginal gas cost of about $0.53 per therm, would save about $0.27 of gas costs per year per MBH of furnace capacity. A 1,000 MBH capacity furnace would save about $0.27 x 1,000 = $270 per year in energy costs compared to a heating system with an 80% efficient furnace. A building in a climate similar to Los Angeles, but with a marginal cost of $0.60 per therm, would save about $0.31/yr per MBH capacity. For a 1,000 MBH heating system, this would translate to $0.31 x 1,000 = $310 per year in cost savings. For a building with a larger heating load and therefore a larger heating system, 3,000 MBH, the savings would be $0.31 x 3,000 = $930 per year.

The city lines higher up on the graph indicate locations of higher furnace loads and hence higher savings potential. Because of the upward slope of the lines, savings increase as the marginal cost increases. As with the previous set of graphs, the markers on each line show the actual marginal cost and savings for the cities.

Cost Effectiveness Graphs

This section presents the cost effectiveness, or SIR, graphs developed for various gas rates and locations.

The graphs in Figure 15 are typical of the savings-to-investment ratio (SIR) graphs. These graphs describe the cost effectiveness of high efficiency furnaces on a life cycle costing basis.

The SIR is used as the figure of merit for cost effectiveness, as described in Chapter 4. It is the ratio of the life cycle cost (LCC) savings to the incremental first cost of a high efficiency furnace, as shown in the following equation:

$$SIR = \frac{LCC\ Savings}{Incremental\ Cost}$$

If the LCC savings are greater than the incremental cost, then the SIR will be greater than one and the investment is a sound one. Thus, any point on the graph that is above the 1.00 point on the vertical axis is a good investment.

Calculating the LCC savings can seem complicated to anybody unfamiliar with present worth analysis principles. It involves several variables, including the lifetime of the investment, the rate of increase in energy costs, and the rate of economic inflation. These factors have been combined into a single numeric parameter called the scalar ratio, or "scalar," as described in Chapter 4.

For each of the SIR graphs, particular scalar and incremental equipment values are used. Figure 15 presents the SIR graphs for a medium office with an incremental equipment cost of $7.50/MBH. Three graphs are presented in this figure, for scalars of 8, 12, and 16.

Each graph enables one to quickly determine the cities where the high efficiency furnace is currently cost effective. If the marker for the city is above the 1.00 SIR line, it's cost effective. If the marker is not quite over the 1.00 line, then one can see how much of an increase in marginal gas cost would be needed to bring it over the line.

For example, if one was examining a furnace installation, using a scalar of 12, in a medium office in Los Angeles, the SIR would be 0.49, which is not cost effective.

As with the previous graphs, one can also apply these graphs to other cities by selecting one of the ten cities whose climate conditions are most similar and moving to the point on the line that corresponds to the gas costs in the other city.

These graphs can be adjusted for different incremental equipment costs. For example, the graphs in Figure 15 are based on an incremental cost of $7.50/MBH. This value is the denominator of the SIR values plotted on the graphs. If the incremental cost for an installation were instead $15/MB, assuming a scalar of 12, then the SIR value from the graph would be adjusted to reflect the new cost. In this example, an SIR value of 0.43 from the graph would be multiplied by 7.5/15 to arrive at an adjusted SIR of 0.21. If, instead, the incremental cost was $2.50/MBH, the adjustment factor would be 7.5/2.5, for an adjusted SIR of 1.29. The adjustment factor will always have a numerator of 7.5 and a denominator of the new incremental equipment cost, in dollars per MBH capacity, as shown in the following equation:

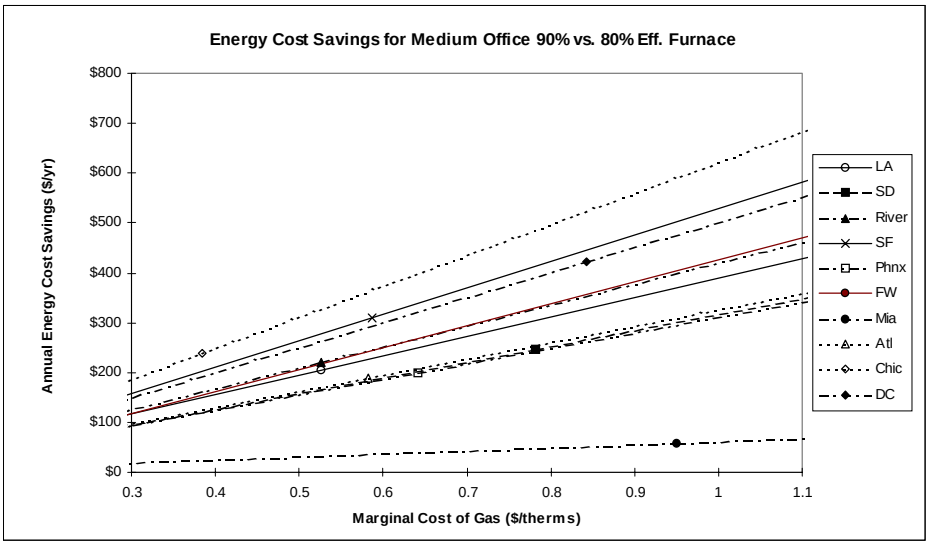
$$SIR_{Actual} = SIR_{graph} \times \frac{Cost_{graph}}{Cost_{Actual}}$$

The following pages contain the full set of graphs describing high efficiency furnaces and their applicability in different building types and cities, with different energy and equipment costs, and different economic criteria.

B. Energy Cost Savings Graphs

90% Efficient, Condensing Furnaces

The following charts show the savings associated with the 90% efficient furnace compared to a standard 80% efficient furnace, by building type. Efficiency ratings for condensing furnaces range from 87% to 96%. The 90% efficiency rating was selected as a conservative basis for estimating savings. Actual savings will vary based on the actual efficiency. As a general rule, the increase in savings will be proportional to the increase in efficiency.



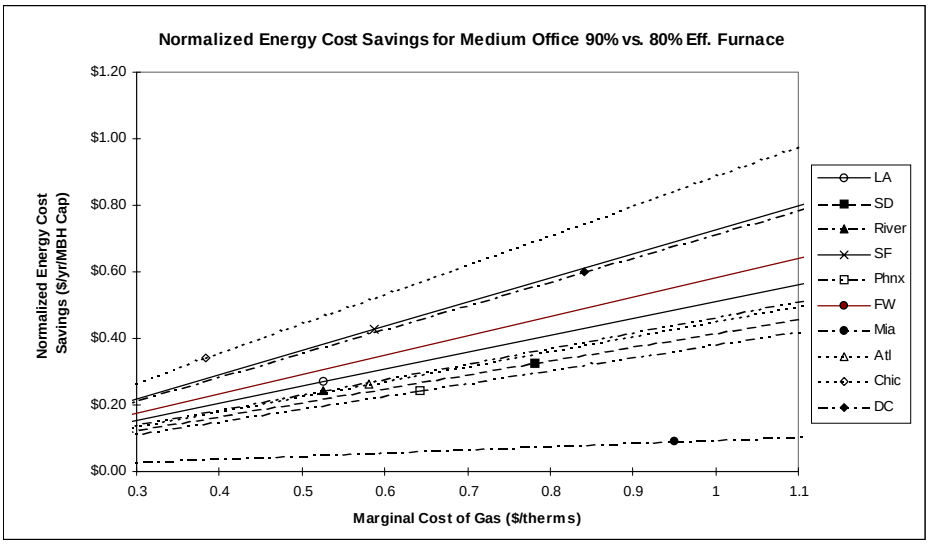
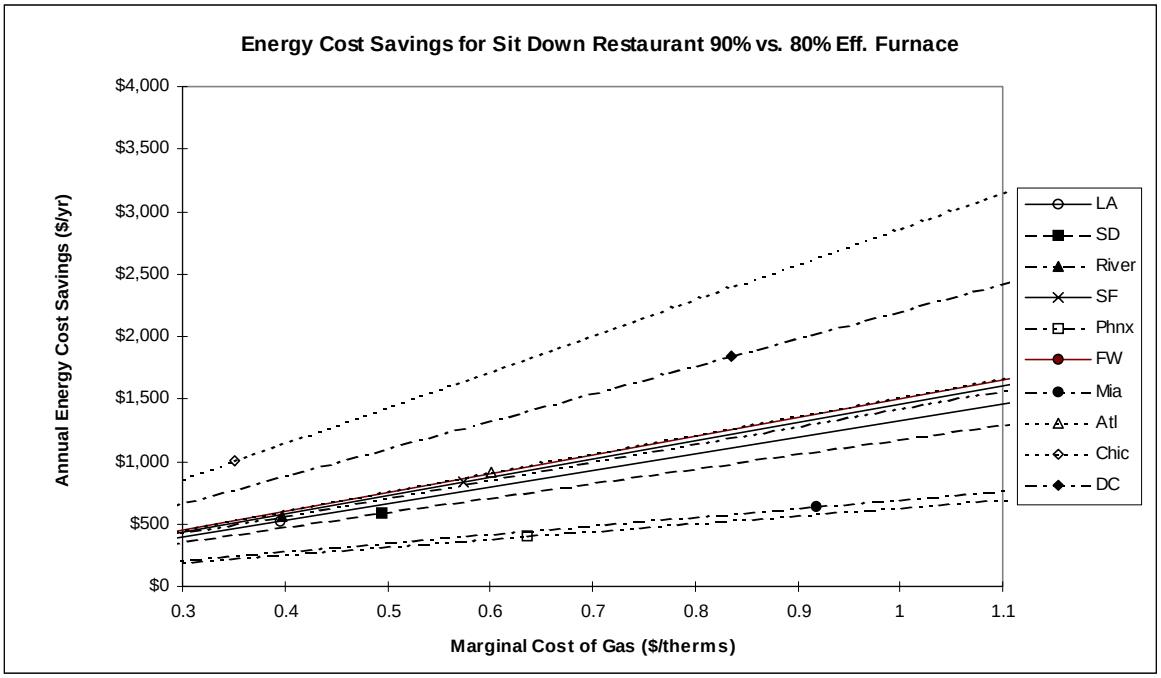


Figure 8 - Energy Savings for Medium Office, 80% vs. 90% Efficient Furnace



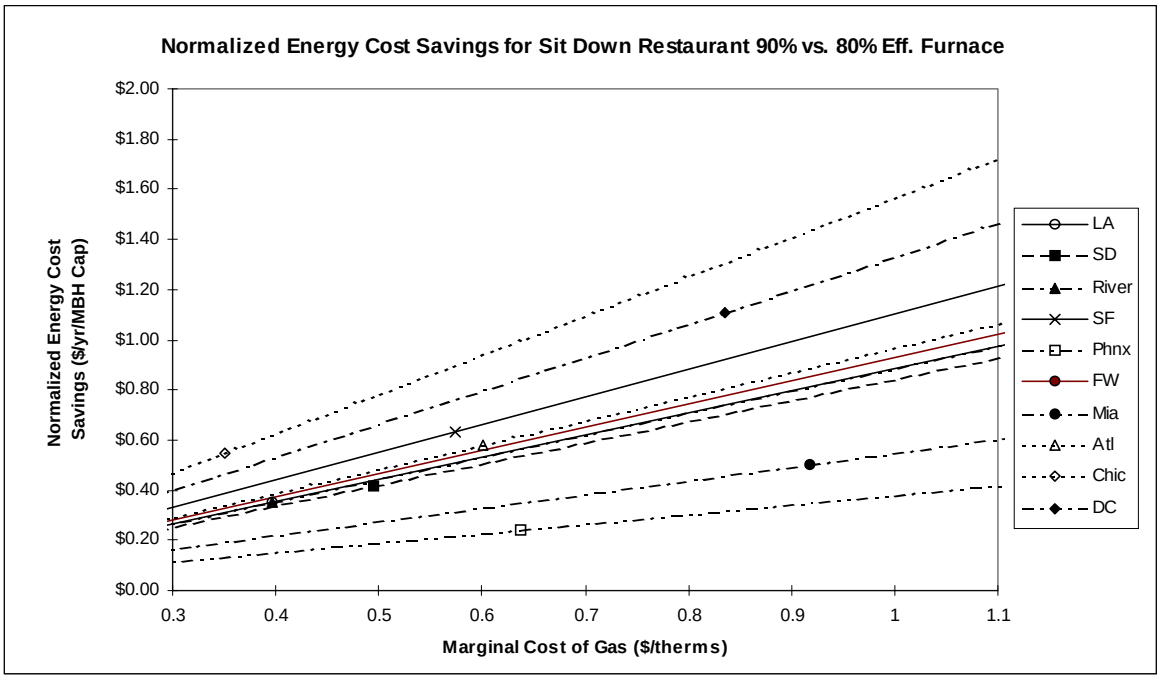
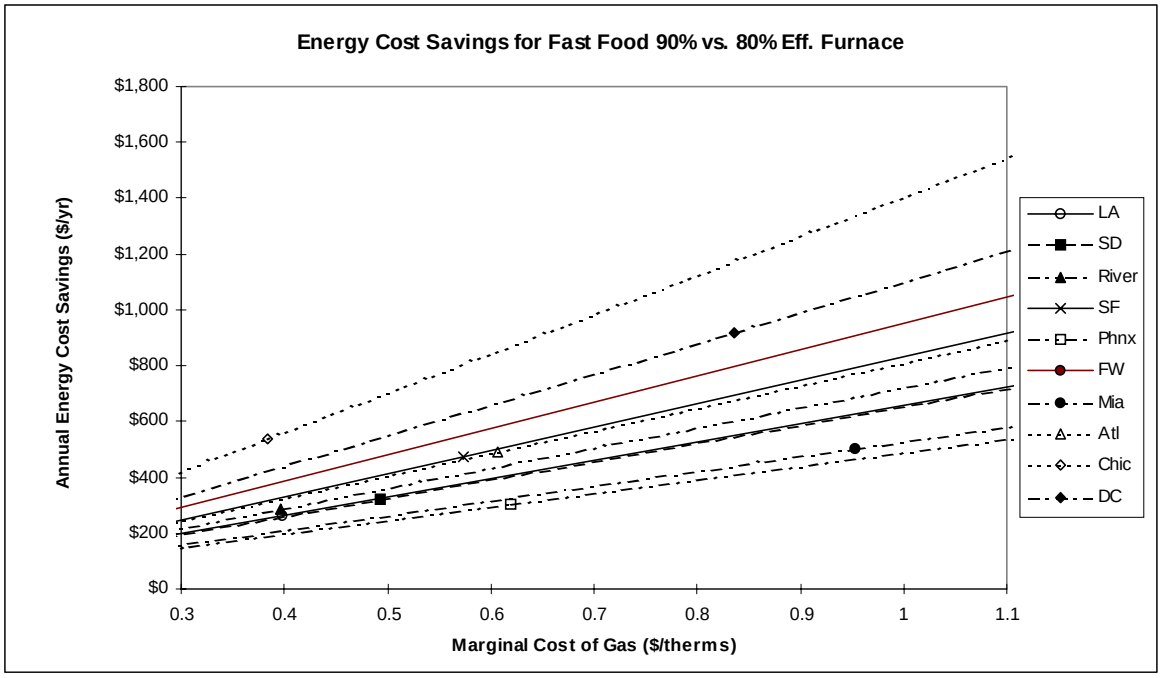


Figure 9 - Energy Savings for Sit Down Restaurant, 80% vs. 90% Efficient Furnace



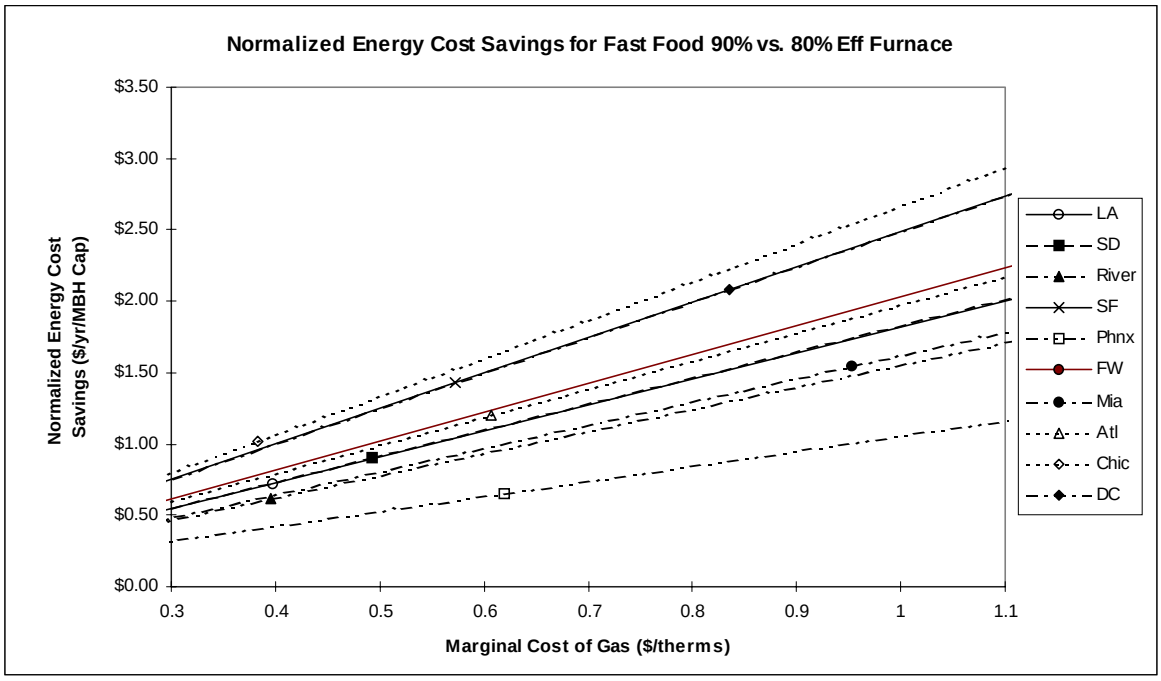
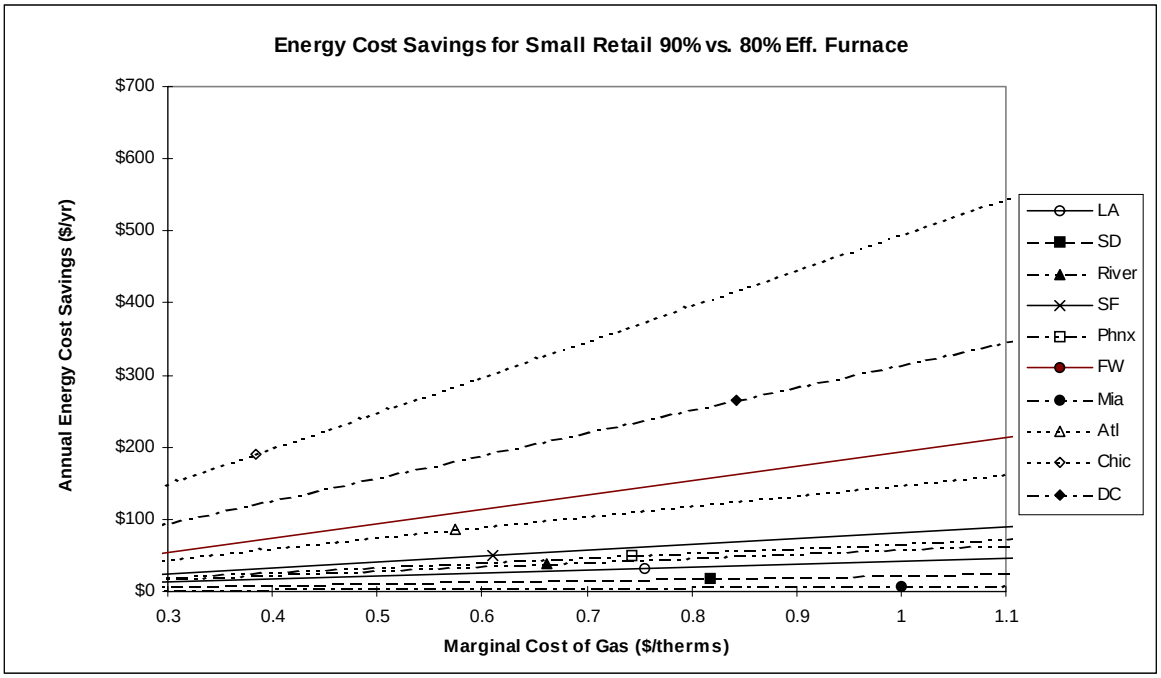


Figure 10 - Energy Savings for Fast Food Restaurant, 80% vs. 90% Efficient Furnace



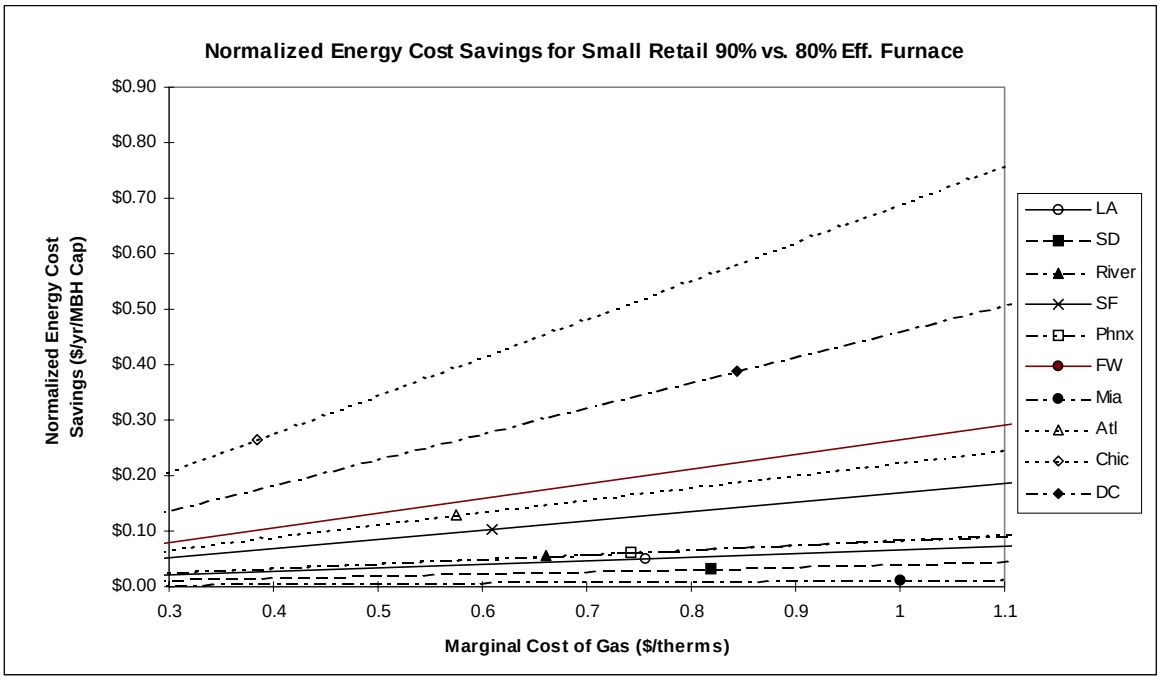
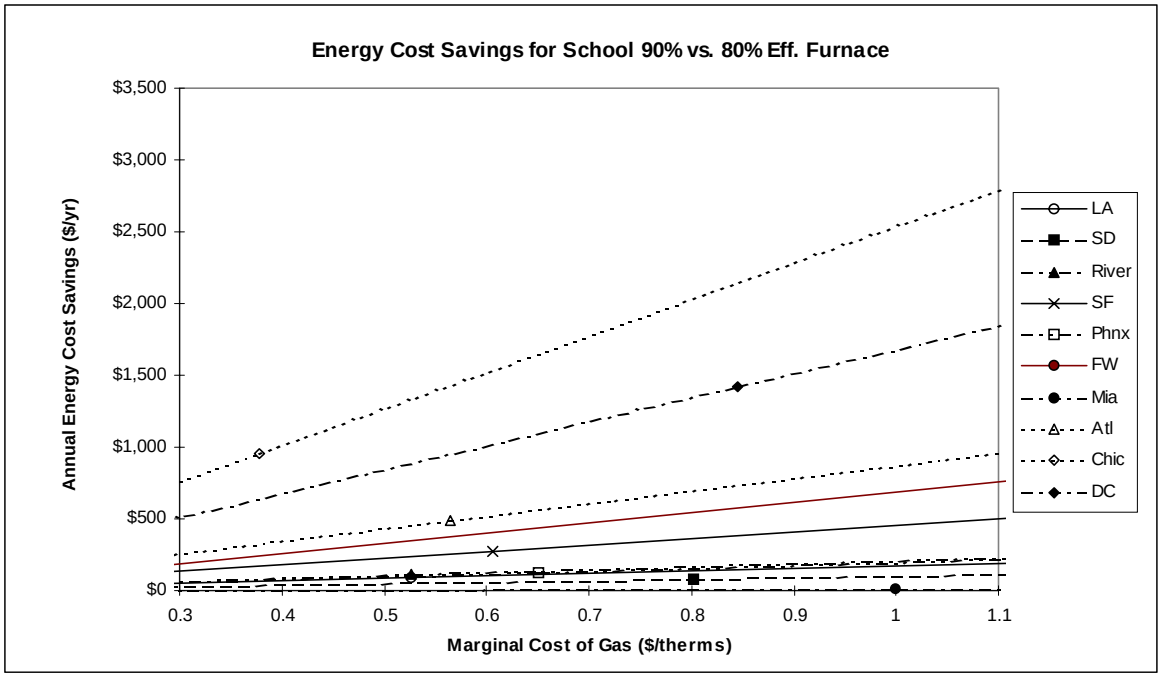


Figure 11 - Energy Savings for Small Retail, 80% vs. 90% Efficient Furnace



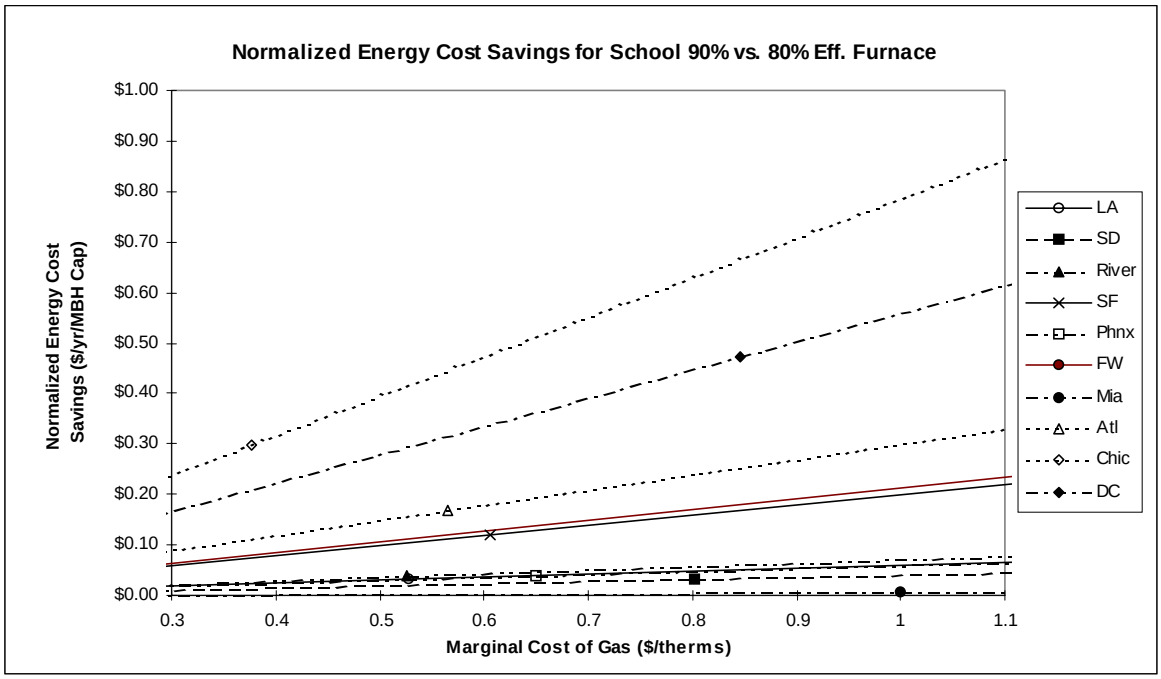
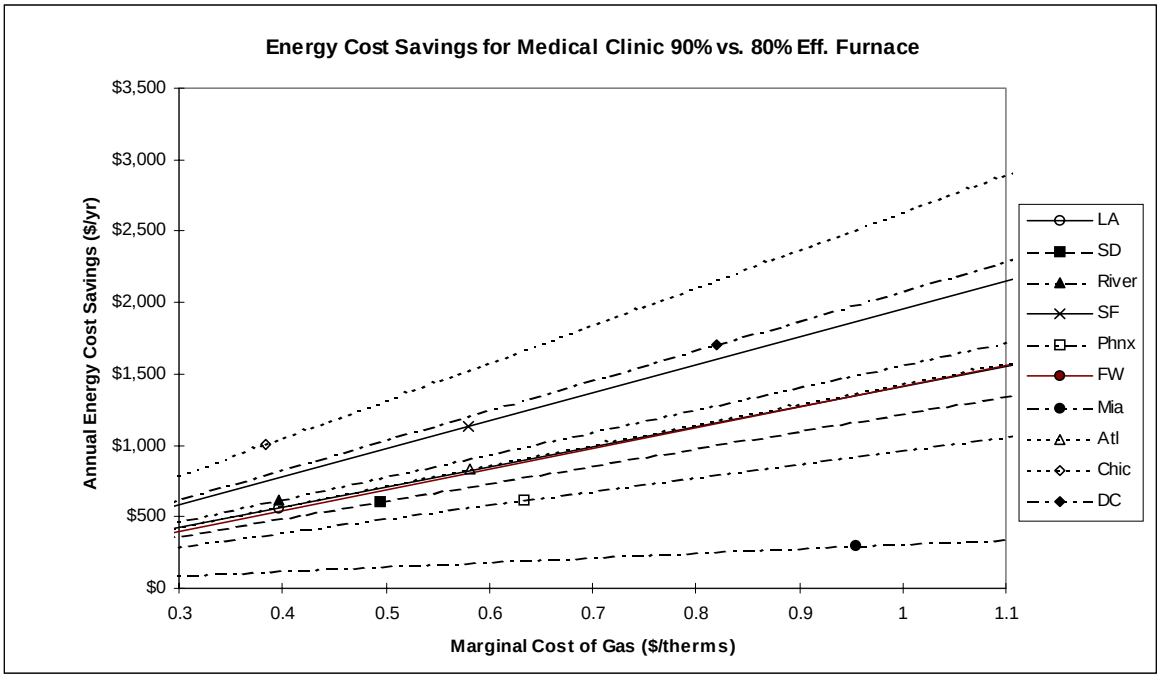


Figure 12 - Energy Savings for School, 80% vs. 90% Efficient Furnace



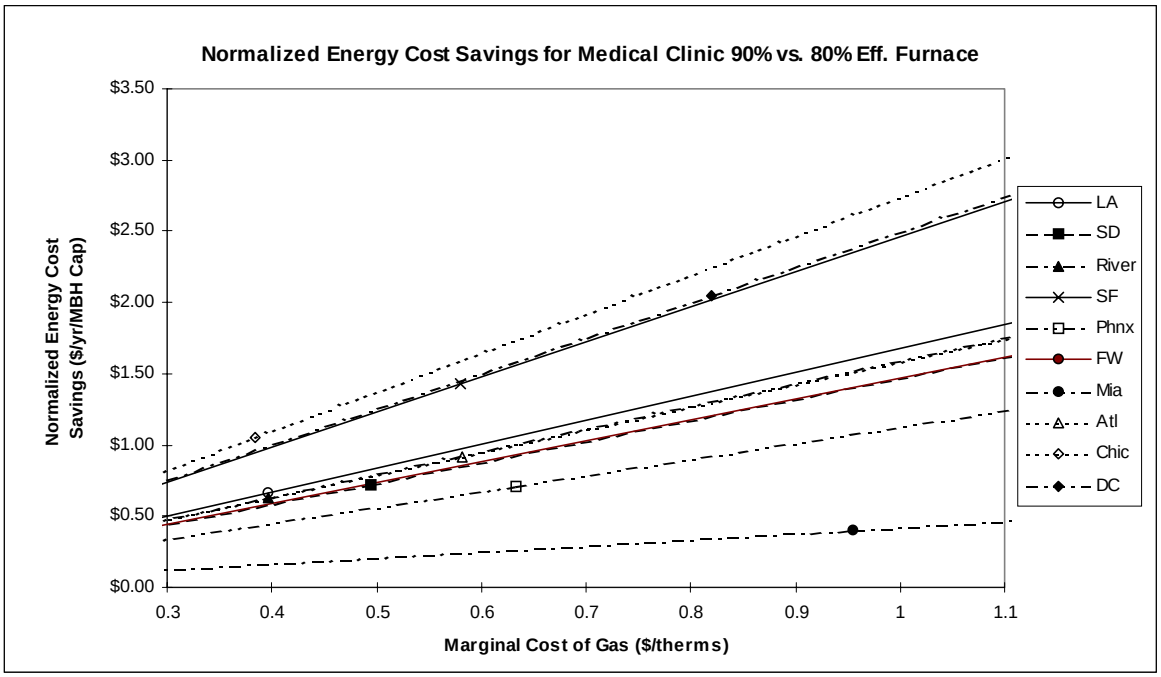


Figure 13 - Energy Savings for Medical Clinic, 80% vs. 90% Efficient Furnace

C. Cost Effectiveness Graphs

90% Efficient, Condensing Furnaces

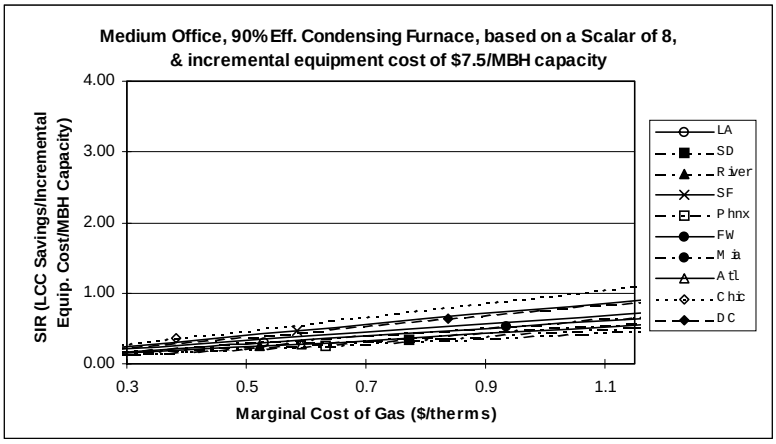
The following graphs show the SIR for a condensing furnace (90%) compared to a standard 80% efficient furnace, using an incremental equipment cost of $2.50/MBH furnace capacity, for an 8, 12 and 16 scalar, respectively.

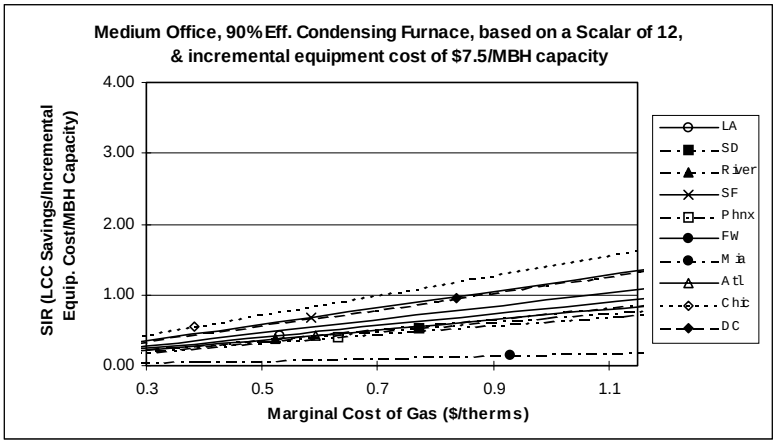
Bldg. Type	Location	Marg. Gas Rate	Scalar		
			8	12	16
Medium Office	Los Angeles	0.53	0.29	0.43	0.57
	San Diego	0.77	0.35	0.52	0.69
	Riverside	0.52	0.26	0.39	0.52
	San Francisco	0.59	0.46	0.68	0.91
	Phoenix	0.63	0.26	0.39	0.52
	Fort Worth	0.17	0.11	0.16	0.21
	Miami	0.93	0.10	0.14	0.19
	Atlanta	0.59	0.28	0.42	0.56
	Chicago	0.38	0.36	0.54	0.73
	Baltimore (Wash D.C.)	0.84	0.64	0.96	1.28
Sit Down Restaurant	Los Angeles	0.39	0.37	0.56	1.12
	San Diego	0.50	0.44	0.67	1.33
	Riverside	0.39	0.37	0.56	1.12
	San Francisco	0.58	0.68	1.01	2.03
	Phoenix	0.63	0.26	0.39	0.78
	Fort Worth	0.17	0.20	0.30	0.59
	Miami	0.93	0.54	0.81	1.61
	Atlanta	0.58	0.62	0.93	1.86
	Chicago	0.35	0.59	0.88	1.76
	Baltimore (Wash D.C.)	0.84	1.18	1.78	3.55
Fast Food Restaurant	Los Angeles	0.40	0.77	1.16	1.54
	San Diego	0.49	0.96	1.44	1.93
	Riverside	0.39	0.65	0.98	1.31
	San Francisco	0.58	1.52	2.28	3.04
	Phoenix	0.62	0.70	1.05	1.40
	Fort Worth	0.21	0.46	0.69	0.92
	Miami	0.95	1.65	2.47	3.29
	Atlanta	0.60	1.28	1.92	2.56
	Chicago	0.38	1.09	1.64	2.18
	Baltimore (Wash D.C.)	0.83	2.22	3.33	4.44

Figure 14 - SIR for 90% vs. 80% Furnace

Bldg. Type	Location	Marg. Gas Rate	Scalar		
			8	12	16
Small Retail	Los Angeles	0.75	0.05	0.08	0.11
	San Diego	0.75	0.04	0.05	0.07
	Riverside	0.64	0.06	0.09	0.12
	San Francisco	0.63	0.11	0.17	0.22
	Phoenix	0.75	0.07	0.10	0.13
	Fort Worth	0.16	0.05	0.07	0.10
	Miami	1.00	0.01	0.02	0.02
	Atlanta	0.57	0.14	0.21	0.27
	Chicago	0.38	0.28	0.42	0.56
	Baltimore (Wash D.C.)	0.85	0.41	0.62	0.83
School	Los Angeles	0.55	0.03	0.05	0.07
	San Diego	0.79	0.03	0.05	0.07
	Riverside	0.54	0.04	0.06	0.08
	San Francisco	0.61	0.13	0.19	0.26
	Phoenix	0.63	0.04	0.06	0.08
	Fort Worth	0.16	0.04	0.06	0.08
	Miami	1.00	0.01	0.01	0.01
	Atlanta	0.57	0.18	0.27	0.36
	Chicago	0.38	0.32	0.47	0.63
	Baltimore (Wash D.C.)	0.85	0.50	0.75	1.01
Medical Clinic	Los Angeles	0.40	0.71	1.06	1.42
	San Diego	0.49	0.77	1.16	1.55
	Riverside	0.40	0.67	1.01	1.35
	San Francisco	0.58	1.52	2.28	3.04
	Phoenix	0.63	0.76	1.14	1.52
	Fort Worth	0.18	0.28	0.42	0.57
	Miami	0.96	0.43	0.64	0.85
	Atlanta	0.58	0.98	1.47	1.96
	Chicago	0.38	1.12	1.68	2.24
	Baltimore (Wash D.C.)	0.82	2.18	3.27	4.36

Figure 14 (continued) - SIR for 90% vs. 80% Furnace





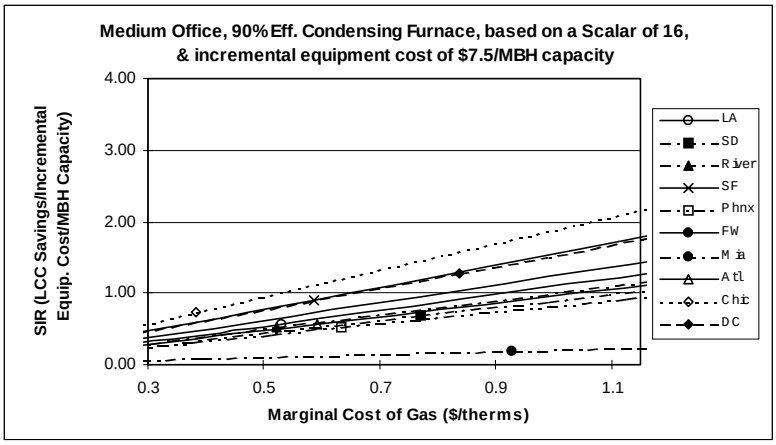
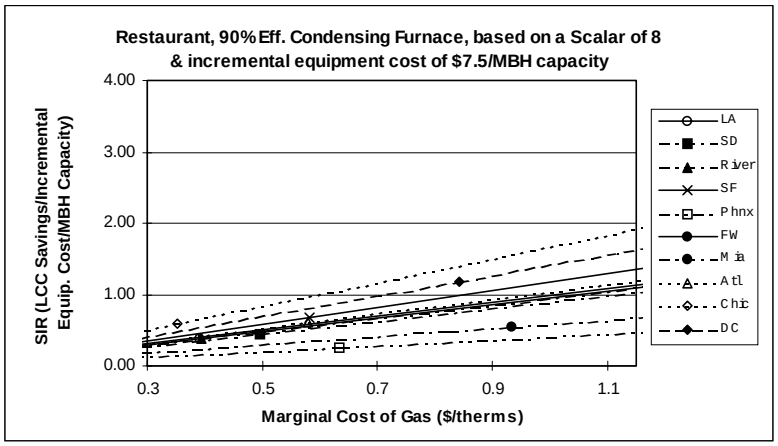
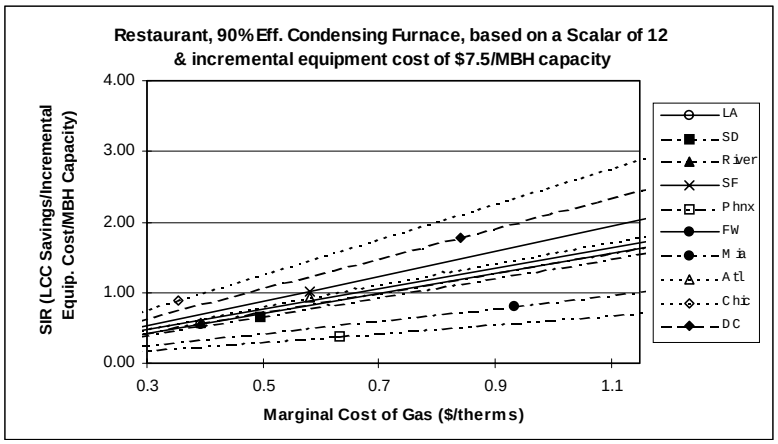


Figure 15 - Savings to Investment Ratio for Medium Office, 80% vs. 90% Efficient Furnace





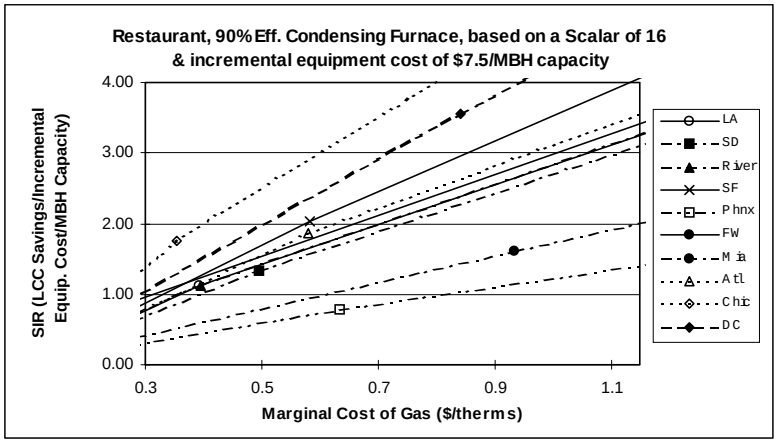
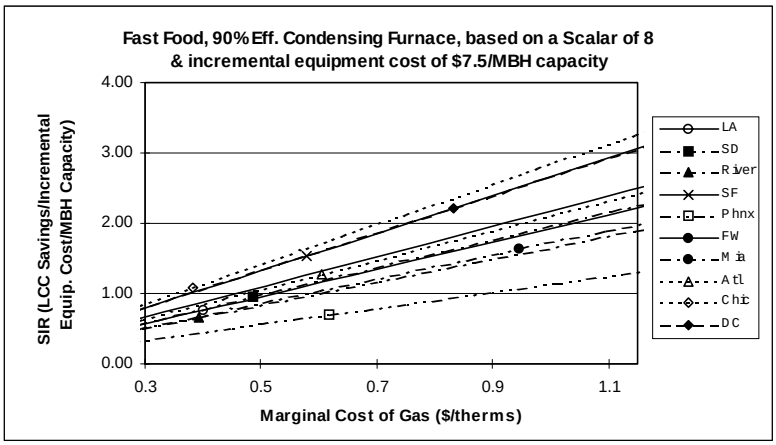
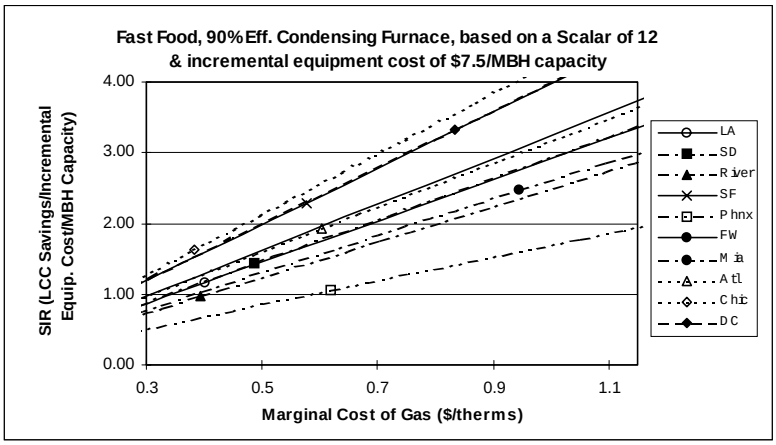


Figure 16 - Savings to Investment Ratio for Sit Down Restaurant, 80% vs. 90% Efficient Furnace





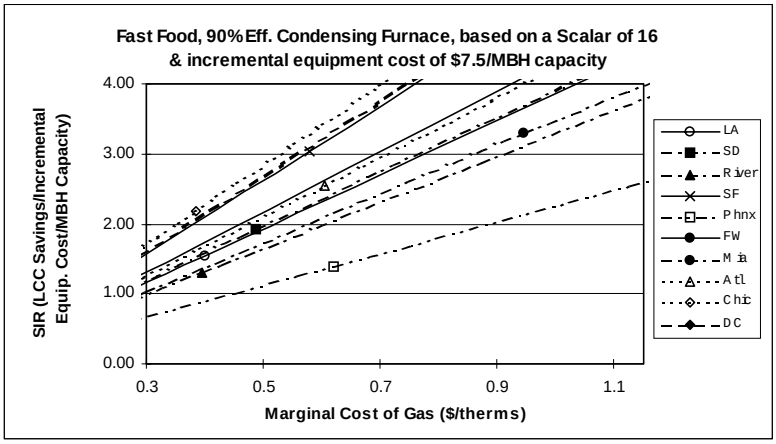
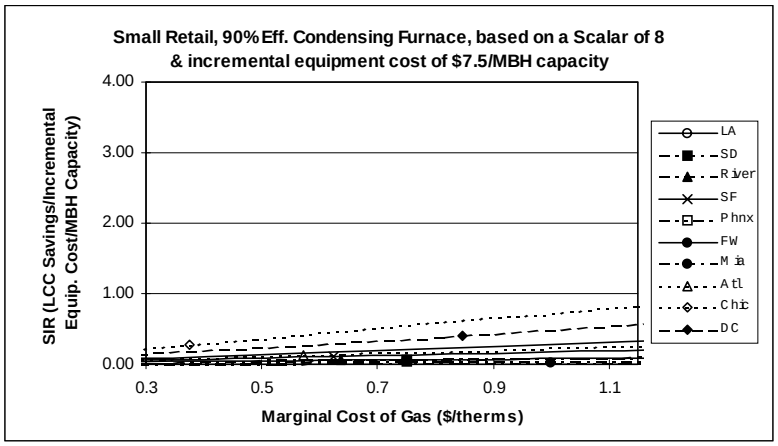
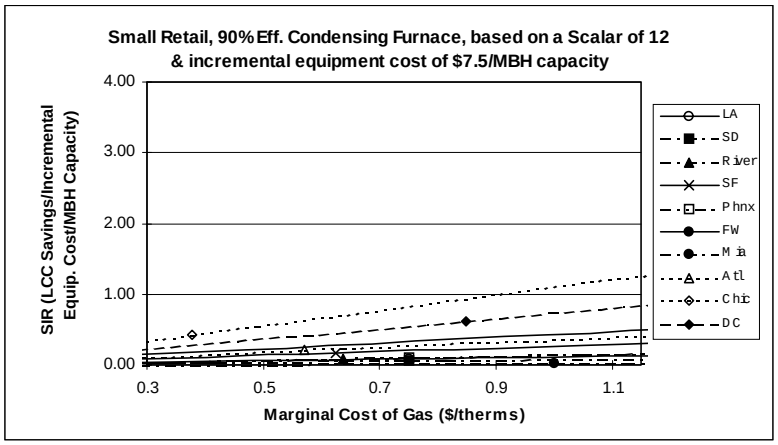


Figure 17 - Savings to Investment Ratio for Fast Food Restaurant, 80% vs. 90% Efficient Furnace





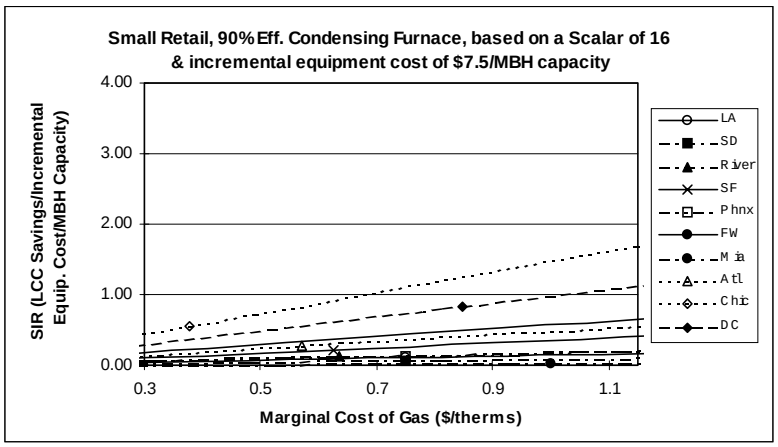
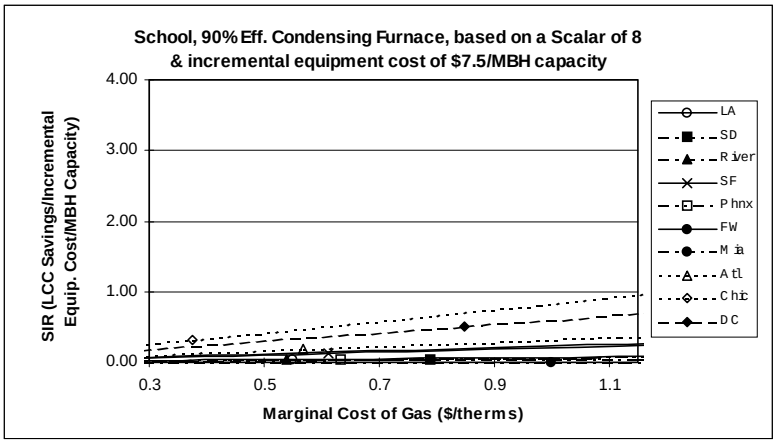
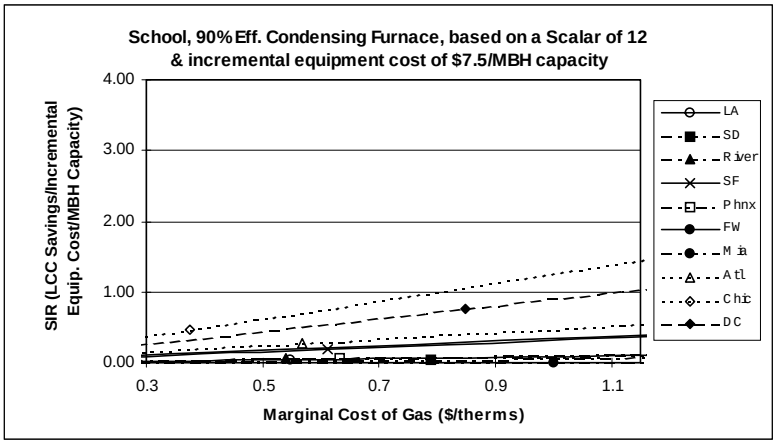


Figure 18 - Savings to Investment Ratio for Small Retail, 80% vs. 90% Efficient Furnace





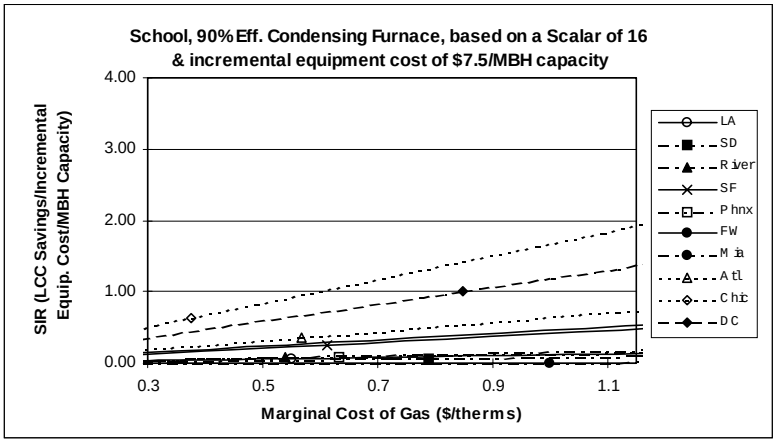
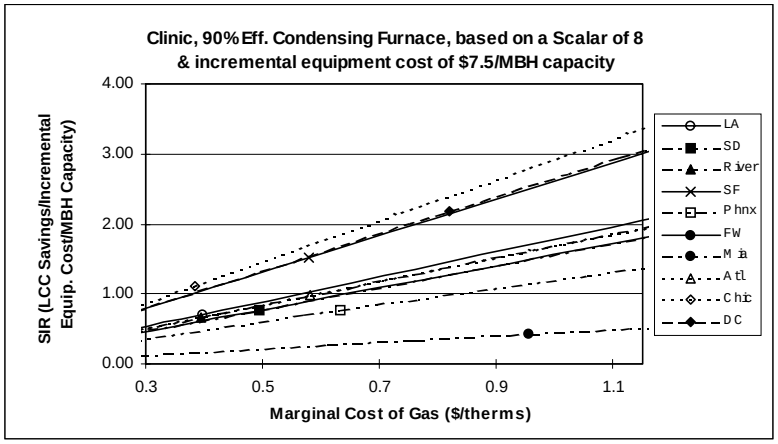


Figure 19 - Savings to Investment Ratio for School, 80% vs. 90% Efficient Furnace



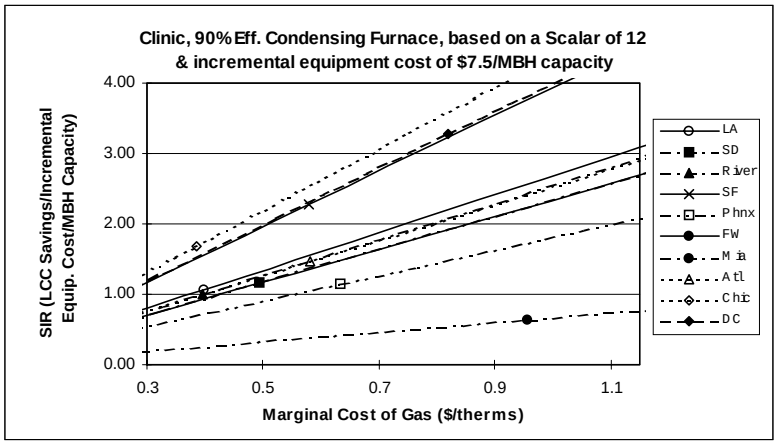


Figure 20 - Savings to Investment Ratio for, Medical Clinic 80% vs. 90% Efficient Furnace

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CHAPTER 7: APPENDIX

A. Building Type Descriptions

1. **Medium Office Building**
   This building is a 49,000 sq. ft., 3-story structure made of precast exterior concrete panels. The glass is 36% of the wall area on all sides and is vertical. (The original building had sloped glass on the lower level. - is this comment of any significance, other than historical interest?) Occupancy is 330 people, 5 days a week plus half-day on Saturday, none on Sundays or holidays. The HVAC system has three powered induction units serving each floor separately, with variable-air-volume (VAV) air handling units on the roof. The chiller is DX air cooled and the heating is by a gas-fired hot water generator.

2. **Large Office Building**
   This structure is a hexagonal shaped 38-story office building with 18,000 sq. ft. per floor (total of 684,000 sq. ft.). Construction is steel frame with limestone cladding. The glass area on the SE and NW sides is about 50%, with the other four sides having 15% glass. The building is occupied from 8AM to 6PM weekdays, 10% occupied during the same hours on Saturday and unoccupied Sundays and holidays. The HVAC systems are split into a core VAV system and a perimeter VAV system with reheat coils for the perimeter only. The chillers are centrifugal and heating is supplied by gas-fired hot water generators.

3. **Retail Store**
   The retail store is a high quality department store located in a shopping mall. It is a 2-story masonry structure of 164,200 sq. ft. with 82% of the floor area devoted to merchandising and office and 18% devoted to storage and stock preparation. There is very little glass except for entry doors. External loads from the three sides of the building in thermal contact with the rest of the mall, are neglected. Operating hours are 10AM to 10PM, 6 days a week and 10AM to 6PM Sundays and holidays. The HVAC systems are constant volume variable temperature (CVVT) served by centrifugal chillers and gas-fired hot water generators.

4. **Strip Retail**
   The strip store is a typical 9,600 sq. ft. end unit of a street mall with one portion of one side connected to another store. It is a slab-on-grade building of wood frame construction with display windows on the west and south walls. The west windows are shaded by a canopy, but on the south side there is no shading. The glazing on the west and south exposures is about 35% of the wall area. The store is open for business 10AM to 10PM, 6 days a week and from 10AM to 6PM on Sundays and holidays. The HVAC system is a rooftop packaged VAV unit with DX air cooled condensing unit. The heating is by a gas-fired hot water generator.

5. **Hospital**
   The building is a 4-story, 272,200 sq. ft., 348-bed hospital. It is of face brick construction. There are multiple types of HVAC systems such as dual duct, 4-pipe induction, reheat constant volume, 4-pipe fan coil and CVVT. These units are all served by hermetic centrifugal chillers and gas-fired hot water generators.

6. **Junior High School**
   The junior high school is a 50,000 sq. ft. building with combination auditorium/recreation space, multi-purpose rooms, and classrooms. The classroom section is 2-stories high. Walls are constructed of face brick and stucco. The building is modeled with CVVT units with centrifugal chiller and gas-fired heaters.

7. **Hotel**
   This 350 room hotel is a medium size convention-type facility with 10 floors totaling 315,000 sq. ft. The space utilization divides as follows: 65% guest rooms, 30% public areas such as lobby, restaurants and meeting rooms, and 5% service area. The building is 70% glass on the west, 50% on the east and less than 10% on the south and north. Construction is of reinforced concrete. The HVAC system is a mix of VAV and CVVT in the public areas, with 4-pipe fan coil units in the guest rooms and CVVT for makeup air units supplying ventilation air to the corridors for guest room bathrooms.

8. **Full Service Restaurant**
   This full service restaurant is open from 7AM to 12 midnight all days including holidays. The building is a 1-story brick structure with 9,060 sq. ft. of floor space with a main dining area for 240 people and a lounge area for 60 people. The HVAC system includes a multi-zone unit serving the public areas and a CVVT unit serving the kitchen area. Makeup air requirements are about 65% of the total supply air. The primary cooling is provided by two reciprocating chillers with air cooled condensers. Heating is from two hot water generators.

9. **Fast Food Restaurant**
   The fast food restaurant is atypical major chain design with food preparation, food storage and food service and dining areas. The restaurant is a single floor, 2,000 square foot building with wood frame construction, brick veneer, and a built-up roof. The restaurant has 4 five-ton DX packaged rooftop units with 150,000 Btuh input gas heating each. Windows are present on the north, south, and west walls. Floor-to-roof height is 12 feet. Maximum occupancy is 81 persons. Typical periods of occupancy are from 5AM to midnight, 7 days per week.

B. Summary of Utility Rates

Summary of Gas Utility Rates Used

City	Utility	Rate Name	Rate Type	Minimum (Therms/Mo)	Maximum (Therms/Mo)
Chicago	NiCor	4	General Service	0	No Limit
Washington DC	Washington Gas Light	2	General Service	0	No Limit
Dallas/Ft. Worth	Lone Star Gas	General Service	General Service	0	No Limit
Los Angeles City	So. Cal. Gas	GN-10	General Service	0	<20800
		GN-20	General Service	20800	No Limit
		G-AC	Air Conditioning	0	No Limit
Riverside	So. Cal. Gas	GN-10	General Service	0	<20800
		GN-20	General Service	20800	No Limit
		G-AC	Air Conditioning	0	No Limit
San Diego	San Diego G & E	GN-1	General Service	0	<20800
		GN-2	General Service	20800	No Limit
San Francisco	Pacific G & E	G-NR1	General Service	0	<20800
		G-NR2	General Service	20800	No Limit
Atlanta	Atlanta Gas Light	G-11	General Service	0	<2000 th/day
		G-11 AC	Air Conditioning	0	<2000 th/day
		G-12	Heating Only	0	<2000 th/day
		G-13 LLF	General Service	0	<5000 th/day
		G-13 AC LLF	Air Conditioning	0	<5000 th/day
Phoenix	Southwest Gas	CG-25 Small	General Service	0	600
		CG-25 Medium	General Service	>600	15000
		CG-25 Large	General Service	>15000	No Limit
		CG-40	Air Conditioning	0	No Limit
Miami	Peoples Gas	SGS	General Service	0	108
		GS	General Service	>108	2708
		GSLV-1	General Service	>2708	54166
		GSLV-2	General Service	>54166	No Limit
		Rider LE	Air Conditioning	0	No Limit

C. Scalar Ratio and SIR

Throughout the Guidelines, the terms scalar ratio and SIR (savings to investment ratio) are used to describe the economic analysis of measures. A scalar ratio is a mathematical simplification of life cycle costing (LCC) analysis. An SIR compares the life cycle savings to the initial investment. An LCC analysis is preferable to a simple payback analysis, because it enables a more realistic assessment of all the costs and savings to be expected over the life of an investment. While LCC analysis can be quite complicated and difficult to understand, a scalar ratio and an SIR are relatively simple to use. This discussion explains their meaning and derivation, and provides some guidance on how to use them in better understanding the analysis graphs in these Guidelines.

Scalar Ratios Simplified

In technical terms, the scalar ratio represents the series present worth multiplier. This can be understood by assuming a simple situation: an initial investment in an energy efficiency measure, followed by a series of annual energy savings realized during the lifetime of the measure. The annual energy costs are assumed to escalate at a steady rate over the years and an annual maintenance cost, when included, is assumed to escalate at a different steady rate. Once the included costs and savings are laid out over the life of the investment, each year's net savings is discounted back to present dollars, and the resulting present worth values are summed to arrive at the life cycle energy savings. This number is then divided by the net savings for the first year, to obtain the scalar ratio. Once the scalar ratio is determined, it can be applied to other investment scenarios that share the same economic rates of energy cost and maintenance cost escalation. One simply calculates the first year's energy savings and multiplies it by the scalar ratio to obtain the net present worth of the savings.

The process of discounting these future dollars back to present dollars is a straightforward calculation (most spreadsheets have built-in present worth functions). The present worth of a future dollar earned (or saved) is a function of the number of years in the future that the dollar is earned, and of the discount rate. The discount rate may be thought of as the interest rate one would earn if the first cost dollars were put into a reliable investment, or as the minimum rate of return one demands from investments. If the investment is a good one, the present worth of the discounted savings will exceed the cost of the investment. If the present worth of savings does not exceed the investment cost, then the investment will not provide the minimum rate of return and could be better spent on another investment.

Of course, in the case where the net cost of the higher efficiency equipment is lower than that of the base case equipment, <u>any</u> positive present worth of energy savings indicates a sound investment. In some cases more efficient equipment allows downsizing of other equipment in the building, such as the electrical load center and service drop. These savings can be significant enough to offset the incremental cost of the more efficient equipment, resulting in a lower overall first cost. To be conservative, in the development of these Guidelines, we have ignored these potential related savings.

Likewise, maintenance costs were not included because there are too many variables and the additional complication would not have increased the clarity or accuracy of the analysis.

Figure 21 shows a simple spreadsheet illustrating how this basic scenario would be calculated. In the example, the first year's savings are $1,051. The annual energy savings escalate at 4% per year, and the annual maintenance costs escalate at 2% per year. If you simply add up these costs after five years, you will expect to save $5,734. The discounted present worth is calculated using the spreadsheet's net present value (NPV) function using the string of annual totals and the discount rate. If the discount rate is 15%, these savings have a present worth of $3,799, which is 3.6 times the first year's savings (scalar ratio = 3.6). If the initial investment to achieve these savings was less than $3,799, then it meets the investment criteria and will provide a rate of return greater than 15%. On the other hand, if the discount rate is 3%, the present worth of the savings is $5,239 and the scalar ratio is 5.0. Investors with high discount rates have higher expectations for their returns on investment, and are therefore less willing to invest in efficiency measures that have lower savings. On the other hand, public agencies and most individuals have lower discount rates and accept lower rates of return in exchange for reliable returns. A discount rate of 3% in this example yields a scalar ratio of 5.0 and indicates that a substantially higher initial investment of $5,239 could be justified.

Year:	1	2	3	4	5
Energy Savings (escalated 4%/yr);	$1,200	$1,248	$1,298	$1,350	$1,404
Maint. costs (escalated 2%/yr):	($150)	($153)	($156)	($159)	($162)
Annual totals:	$1,051	$1,097	$1,145	$1,195	$1,246
			(Sum of Annual totals:		$5,734)
Discounted Present Worth: (15% discount rate)	$3,799	/ $1,051 = Scalar:	3.6		
Discounted Present Worth: (3% discount rate)	$5,239	/ $1,051 = Scalar:	5.0		

Figure 21 - Example Present Worth Calculation

Selecting a Scalar Ratio

To use the cost-effectiveness analysis graphs in this Guideline, one must select a scalar ratio by deciding on the economic conditions for their efficiency investments. The example discussed here has been rather simplistic, and the five-year analysis period is quite short for most energy efficiency measures. In selecting a scalar, users should decide on at least the following:

- Period of Analysis - This is the number of years the energy efficiency investment is expected to provide savings. Some users will have a long-term perspective, and will choose a period of analysis that approaches the expected life of the measure. For long life measures, such as building insulation, the period of analysis may be thirty years or more. For mechanical system measures, the period may be fifteen years. Other users may choose a shorter analysis period because they are interested in their personal costs and benefits and are not expecting to hold the property for a long time. Public policy agencies setting energy codes may choose a societal perspective, based on the principle that building investments impinge on the environment and the economy for a longer period of time, and so may select a long period of analysis.
- Discount Rate - This is the real rate of return that would be expected from an assured investment. A rate of return offered by an investment instrument is the investment's nominal interest rate and must be adjusted, by the loss in real value that inflation causes, to arrive at the real interest rate. Nominal discount rates must likewise be adjusted for inflation to find the real discount rate. In order to simplify the analysis, we assumed a zero inflation rate, which then makes the nominal and real discount rates the same. As discussed in the example above, different kinds of people may have different expectations. A lower end interest rate (and discount rate) might be the rate of return expected from savings account or a money market fund (2% - 4%). An upper end might be the rate of return that an aggressive investor expects to produce with his money (10% - 20%), although it is difficult to argue that this represents an "assured investment." Another way to think of the real discount rate is the real rate of return that competing investments must provide in order to change the choice of investments that the organization makes.

The table in Figure 22 shows a range of typical scalars. It presents the resulting scalars for 8, 15 and 30-year study periods, discount rates ranging from 0% to 15% and escalation rates ranging from 0% to 6%.

Savings to Investment Ratios (SIRs)

An extension of the present worth and scalar concepts is the *Savings to Investment Ratio (SIR)*. As indicated above, one is interested in both the incremental first cost of an investment (how much more it costs than the base case) and in the present worth of its cost savings. The SIR provides a simple way to compare the two: divide the present worth of the savings by the incremental first cost (or its present worth if the investment extends over time). If this ratio is greater than one, then the discounted savings are greater than the first cost, and the return on investment will be greater than the discount rate. The cost-effectiveness analysis graphs presented in this Guideline use the SIR on the vertical axis. Thus any points on the curves that lie above an SIR value of one are deemed to be cost effective.

Advanced Economic Analysis

The economic analysis could be more elaborate than the examples discussed here, of course, and could account for more factors. For example, there could be other maintenance costs that recur every few years, the energy cost escalation factors could be non-linear, or the tax deductions for the operating and maintenance costs could be included. In addition, the first costs could be spread out over the years as loan payments and interest cost deductions. All of these costs would be discounted back to present dollar values and summed to arrive at the net present value, which compares the life cycle costs to the life cycle savings[1].

Analysis for different purposes will include both different types of inputs as well as varying levels for the input types chosen. For example, while a commercial building owner is likely to be interested in the economic impacts within a relatively short time frame, e.g., 8-10 years, a state energy office is likely to be more concerned with the societal economic impacts over a much longer term, like 30 years for residential energy codes. A business owner, who is looking at energy efficiency investments relative to other business uses of her capital, might also feel that a discount rate of 15% reflects her value for future energy savings. On the other hand, an energy efficiency program planner or energy code developer could justify a 0% discount rate as representative of the future value of resource savings.

The table in Figure 23 provides guidance on selecting between the range of potential scalars.

A more comprehensive economic analysis might also consider measure interactions and analyze the impacts of numerous building elements as a system. For example, increasing the level of roof insulation can lead to the ability to downsize the cooling equipment. Selection of a gas chiller could potentially allow the downsizing of the electric service drop and load center for the building. The analysis in this Guideline did not include such synergies because of the complication of identifying situations in which the additional savings could be expected.

Appendix section A described the base case buildings that were used in the analysis for these Guidelines. A more comprehensive, targeted analysis would begin with an examination of these building descriptions to determine whether they are representative of the location of interest. The building design can greatly increase or decrease the cost effectiveness of various measures. For example, a base case office building with effective daylighting, reducing internal gains from lighting systems, and high performance glazing on the south, east and west, may have a small enough cooling load that high efficiency equipment will be less cost effective.

Finally, it is assumed in this analysis that a decision about the cost effectiveness of options is being made at the time of new construction. For program designers focusing on retrofit applications of these technologies, additional first costs will need to be included. This is less of an issue when the change-out is due to equipment failure and replacement is required. In the case of replacements for equipment that is still functioning, the incremental first cost will be the full cost of the new equipment minus the salvage value of the equipment removed. Obviously, the energy savings must be of much greater value to justify replacing equipment before the end of its useful life.

As this discussion illustrates, a thorough economic analysis of energy efficiency investments can require considerable thought and calculation. The scalar and SIR approach used throughout these Guidelines provide a convenient method for simplifying the economic analysis task. For many purposes, this will be sufficient, provided the decision-makers who will be relying on this analysis understand its limitations.

[1] For a more in-depth description, see *Plant Engineers and Managers Guide to Energy Conservation*, by Albert Thumann, Fairmont Press, Lilburn, GA 1989.

	Scalars for 8 year period				Scalars for 15 year period				Scalars for 30 year period			
	Escalation rates				Escalation rates				Escalation rates			
Discount Rates	**0%**	**2%**	4%	**6%**	**0%**	**2%**	**4%**	**6%**	**0%**	**2%**	**4%**	**6%**
0%	8.0	8.8	9.6	10.5	15.0	17.6	20.8	24.7	30.0	41.4	58.3	83.8
3%	7.0	7.7	8.4	9.1	11.9	13.9	16.2	19.0	19.6	25.9	35.0	48.3
5%	6.5	7.0	7.7	8.4	10.4	12.0	13.9	16.2	15.4	19.8	26.0	34.9
7%	6.0	6.5	7.1	7.7	9.1	10.4	12.0	13.9	12.4	15.5	19.9	26.0
9%	5.5	6.0	6.5	7.1	8.1	9.2	10.5	12.1	10.3	12.6	15.7	20.0
11%	5.1	5.6	6.0	6.5	7.2	8.1	9.3	10.6	8.7	10.4	12.8	15.9
13%	4.8	5.2	5.6	6.1	6.5	7.3	8.2	9.3	7.5	8.8	10.6	12.9
15%	4.5	4.8	5.2	5.6	5.8	6.5	7.4	8.3	6.6	7.6	9.0	10.8

Figure 22 - Range of Typical Scalars

INPUT	IF INPUT:	THEN SCALAR TENDS TO:
Measure Life	Increases	Increase
Discount Rate	Increases	Decrease
Energy Cost Escalation Rate	Increases	Increase
Maintenance Escalation Rate	Increases	Decrease
Inflation Rate	Increases	Decrease
Mortgage Interest Rate	Increases	Decrease
Tax Advantage	Increases	Increase

Figure 23 - Variable Effects on Scalar