Guideline

Absorption Chillers

Southern California Gas Company

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CHAPTER 1: PREFACE

These Advanced Design Guidelines have been developed by the New Buildings Institute in cooperation with Southern California Gas Company to assist designers, program planners, and evaluators to make informed decisions on the cost-effectiveness of energy saving measures. There are two basic types of gas chillers: absorption systems and gas engine driven chiller systems. This Guideline deals specifically with gas absorption systems. These Guidelines are intended to be a step toward a comprehensive approach to design specifications, which encompass the full range of efficiency options for a building.

This Advanced Design Guideline is based on careful evaluation and analysis of gas absorption cooling to determine when it 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

Absorption chillers differ from the more prevalent compression chillers in that the cooling effect is driven by heat energy, rather than mechanical energy. The simplest absorption machines are residential refrigerators, with a gas flame at the bottom, ice cubes at the top and no electricity involved. An absorption chiller is larger and more complicated, but the basic principle is the same.

The absorption chiller cycle is shown in Figure 1. The evaporator allows the refrigerant to evaporate and to be absorbed by the absorbent, a process that extracts heat from the building. The combined fluids then go to the generator, which is heated by the gas or steam, driving the refrigerant back out of the absorbent. The refrigerant then goes to the condenser to be cooled back down to a liquid, while the absorbent is pumped back to the absorber. The cooled refrigerant is released through an expansion valve into the evaporator, and the cycle repeats.

Absorption chillers are either lithium bromide-water ($LiBr/H_2O$) or ammonia-water equipment. The $LiBr/H_2O$ system uses lithium bromide as the absorber and water as the refrigerant. The ammonia-water system uses water as the absorber and ammonia as the refrigerant.

A. Applications

The primary variable that drives the economics of gas absorption cooling is the electric demand charge. Ideal candidates for gas absorption applications are those where the peak demand charge is high. Since cooling is generally the primary cause of sharp spikes in a building's electric load profile, it is advantageous to investigate alternatives that can reduce this peak. Gas cooling minimizes or flattens the electric peaks in a building's electric load.

The absorption cooling system should be operated to maximize electric peak-shaving in areas with high demand charges or extended ratchet electricity rates. Hybrid systems, which use an electric chiller for base load, and the gas engine-driven chiller for peak load, are an attractive option in regions with high electric costs.

Gas absorption chillers can be economically installed as a cooling only system, or as part of an integrated cooling and heating facility. In many parts of the country, the cost difference between electricity and natural gas is sufficient to justify absorption chillers. Additional cost savings can be realized through the use of heat recovery.

In summary, good applications for absorption chillers

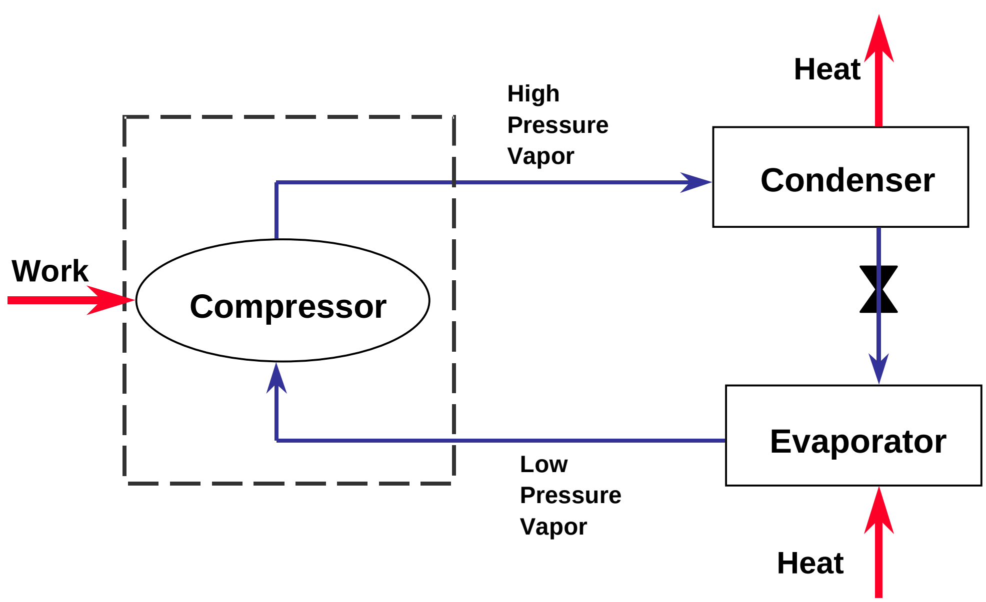


Figure 1 - Simple Absorption Cycle Diagram

have the following characteristics:

- High demand charges
- Coincident need for air conditioning and heating
- Maintenance and service requirements are acceptable to building owner

B. Types

Absorption chillers are generally classified as direct- or indirect-fired, and as single, double - or triple-effect. In direct-fired units, the heat source can be gas or some other fuel that is burned in the unit. Indirect-fired units use steam or some other transfer fluid that brings in heat from a separate source, such as a boiler or heat recovered from an industrial process. Hybrid systems, which are relatively common with absorption chillers, combine gas systems and electric systems for load optimization and flexibility.

Single Effect

The single-effect "cycle" refers to the transfer of fluids through the four major components of the refrigeration machine - evaporator, absorber, generator and condenser, as shown in the Pressure-Temperature diagram in Figure 2.

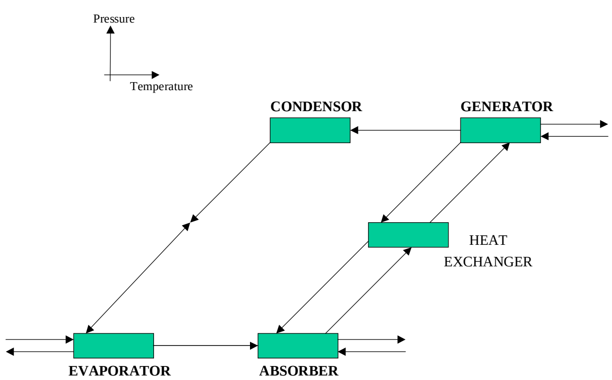


Figure 2 - Single-Effect Absorption Refrigeration Cycle

Single-effect LiBr/H_2O absorption chillers use low pressure steam or hot water as the heat source. The water is able to evaporate and extract heat in the evaporator because the system is under a partial vacuum. The thermal efficiency of single-effect absorption systems is low. Although the technology is sound, the low efficiency has inhibited the cost competitiveness of single-effect systems. Most new single-effect machines are installed in applications where waste heat is readily available. Single-effect chillers can be used to produce chilled water for air conditioning and for cooling process water, and are available in capacities from 7.5 to 1,500 tons.

Double Effect

The desire for higher efficiencies in absorption chillers led to the development of double-effect LiBr/H_2O systems. The double-effect chiller differs from the single-effect in that there are two condensers and two generators to allow for more refrigerant boil-off from the absorbent solution. Figure 3 shows the double effect absorption cycle on a Pressure-Temperature diagram. The higher temperature generator uses the externally-supplied steam to boil the refrigerant from the weak absorbent. The refrigerant vapor from the high temperature generator is condensed and the heat produced is used to provide heat to the low temperature generator.

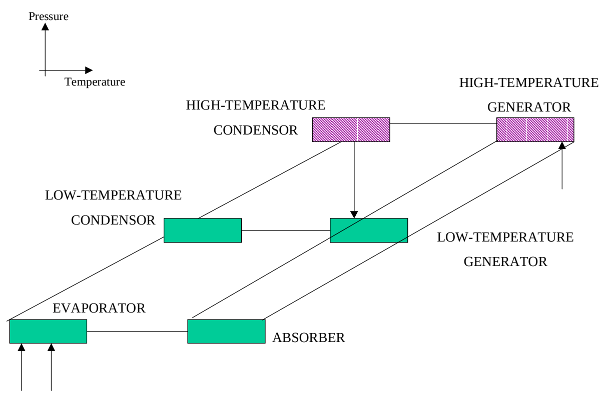


Figure 3 - Double-Effect Absorption Refrigeration Cycle

These systems use gas-fired combustors or high pressure steam as the heat source. Double-effect absorption chillers are used for air-conditioning and process cooling in regions where the cost of electricity is high relative to natural gas. Double-effect absorption chillers are also used in applications where high pressure steam, such as district heating, is readily available. Although the double-effect machines are more efficient than single-effect machines, they have a higher initial manufacturing cost. There are special materials considerations, because of increased corrosion rates (higher operating temperatures than single-effect machines), larger heat exchanger surface areas, and more complicated control systems.

Triple Effect

The triple-effect cycles are the next logical improvement over the double-effect. Triple-effect absorption chillers are under development, as the next step in the evolution of absorption technology. Figure 4 shows the triple effect absorption cycle on a Pressure-Temperature diagram. The refrigerant vapor from the high and medium temperature generators is condensed and the heat is used to provide heat to the next lower temperature generator. The refrigerant from all three condensers flows to an evaporator where it absorbs more heat.

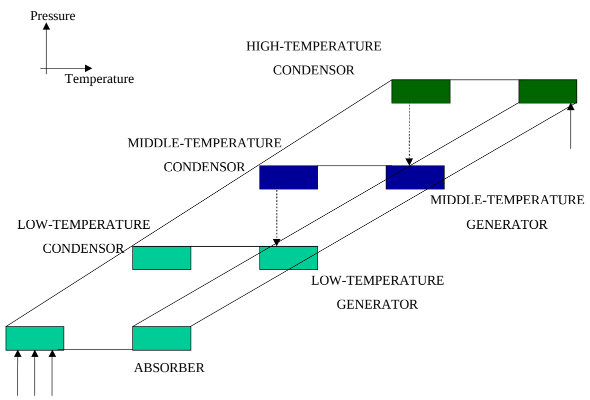


Figure 4 - Triple-Effect Absorption Cycle

Two different triple-effect absorption chiller cycles are capable of substantial performance improvements over equivalent double-effect cycles. One uses two condensers and two absorbers to achieve the triple effect. A second, the double condenser coupled (DCC) triple-effect, uses three condensers as well as a third condenser subcooler.

Triple-effect systems offer the possibility of thermal efficiencies equal to those of electrical chillers. The cost, however, will be higher, so system cost-effectiveness will need to be evaluated on a case-by-case basis. The higher efficiency levels would open wider markets for absorption chillers.

Hybrid Systems

Hybrid systems capture the best of both gas and electric usage by installing an absorption system in parallel with an electric vapor compression system. In a typical hybrid system, the electricity-driven chiller takes advantage of the lowest time-of-use costs during off-peak hours. The absorption chiller is used as the primary source during the on-peak hours, with the vapor compression chiller used for the remainder of the load, as needed. The specifics of any hybrid system design depend on the nature of the cooling load, and the characteristics of the local gas and electric rates, but there are many applications where a hybrid system is advantageous. This is especially true for large facilities with sophisticated energy management personnel who can optimize system performance and energy costs.

The hybrid plant crystallizes the concept of a system design that maximizes the flexibility of "time dependent" energy selection. The use of absorption chillers eliminates the high incremental cost of electricity. The hybrid approach will play a larger role in cooling options as utility rate structures continue to be more variable.

C. Efficiencies

Efficiencies of absorption chillers are described in terms of coefficient of performance (COP), which is defined as the refrigeration effect, divided by the net heat input (in comparable units such as kBtu).

Single-effect absorption chillers have COPs of approximately 0.6-0.8 out of an ideal 1.0. Since the COPs are less than one, the single-effect chillers are normally used in applications that recover waste heat such as waste steam from power plants or boilers.

Double-effect absorption chillers have COPs of approximately 1.0 out of an ideal 2.0. While not yet commercially available, prototype triple effect absorption chillers have calculated COPs from 1.4 to 1.6.

The COP metric is also applied to electric chillers. However, since COP is based on site energy, it is not good for comparing gas and electric chiller efficiencies.

A better metric is the Resource COP, which accounts for the source to site efficiency of the fuel, accounting for electricity generation and transmission losses. Figure 5 shows typical values for both electric chillers and absorption chillers.

Chiller	Site COP	Source -to-Site Factor	Resource COP
Electric	2.0 - 6.1	0.27	0.54 - 1.65
Absorption	0.65 - 1.2	0.91	0.59 - 1.1

Figure 5 - Site vs. Resource COP

D. Benefits

The primary energy benefit of gas cooling systems is reduction in operating costs by avoiding peak electric demand charges and time-of-day rates. The use of gas absorption chillers eliminates the high incremental cost of electric cooling.

The restructuring of the electric utility industry adds significant complexity and uncertainty to the HVAC design and operation. The key is operational flexibility. Gas cooling systems eliminate some of the variability associated with electric rate structures, while a hybrid system maximizes the flexibility of an “all- energy ” plant.

Natural gas cooling systems have greater resource efficiency than similar electric systems. Typical electricity generation and distribution results in an approximately 65% - 75% loss in the initial energy resource of the fuel. In contrast, only about 5% to 10% of the fuel resource is lost with a gas system. Additionally, electricity costs per Btu are typically three to four times the cost per Btu for electricity, so the cost of a unit of output (refrigeration) can often be lower with an absorption unit.

Utilizing waste heat that would otherwise be unused greatly increases the cost-effectiveness of the systems, compared to consuming gas directly.

Gas absorption systems have several non-energy benefits over conventional electric systems including:

- Elimination of the use of CFC and HCFC refrigerants
- Quiet, vibration-free operation
- Lower pressure systems with no large rotating components
- High reliability
- Low maintenance

The contribution that gas cooling technologies can make to the goal of improved emissions is substantial. Natural gas-powered air-conditioning equipment offers substantial advantages to the environment in regard to CFCs and HCFCs, because they are not used in the absorption cycle. Legislative activities are focused on pushing the nation toward energy-efficient technologies that reduce harmful emissions. While gas-fired chillers produce emissions at the site, combustion efficiencies can be high and harmful emissions comparatively low for a well-operated absorption unit.

A direct-fired absorption system can supply hot water in addition to chilled water if:

- equipped with an auxiliary heat exchanger
- the hot water circuit of the auxiliary heat exchanger includes the necessary control devices.

If the equipment is to provide heating as well as cooling, then a true comparison of equipment cost and annual maintenance costs between an electric and gas system must consider the electric centrifugal chiller plus a boiler. The results of such a comparison should show the direct-fired absorption chiller annualized costs, including maintenance, operating, and first costs, to be less than or roughly equal to those of an electric chiller and boiler.

E. Limitations

Cost is the primary constraint on the widespread adoption of absorption chiller systems. The low thermal efficiency of single-effect absorption systems has made them non-competitive except in situations with readily available free waste heat. Even double effect systems are not cost-effective in many applications. Although absorption chillers can be quite economical in the right situation, their exact economics must be worked out on a project-by-project basis.

Absorption systems also require greater pump energy than electric chillers. The size of condenser water pumps is generally a function of the flow rate per unit cooling capacity. Cooling technologies with lower COPs typically require a significantly higher condenser water flow rate than those technologies with higher COPs, therefore requiring larger pumps. Similarly, absorption chillers require larger cooling tower capacity than electric chillers, due to the larger volume of water.

CHAPTER 3: HISTORY AND STATUS

A. History

Absorption cycles have been used in air-conditioning applications for over 50 years. Ammonia-water absorption equipment was found to be well suited for large capacity industrial applications that required low temperatures for process cooling. In the late 1950s the first working double-effect lithium bromide - water absorption chiller was built. Lithium bromide-water absorption equipment is currently used to produce chilled water for space cooling and can also be used to produce hot water for space heating and process heating.

In the 1960s the natural gas industry was very effective in promoting this alternative to electric-driven cooling. Absorption cooling and gas absorption chillers were successfully marketed on the basis of lower operating costs, and better system performance. Counteracting this, innovations in compressors, electric motors, and controls increased the performance and decreased the cost of electric cooling systems. Additionally, and perhaps more importantly, the gas crunch of the seventies curtailed gas cooling promotion and forced prospective buyers to remain with conventional electric systems.

Since 1987 when the Montreal Protocol first came into existence many issues surrounding electric cooling including the use of CFC refrigerants and electric utility rates, have become increasingly complicated. Coincident with these electric cooling issues, gas costs have remained relatively stable while the technology itself has improved.

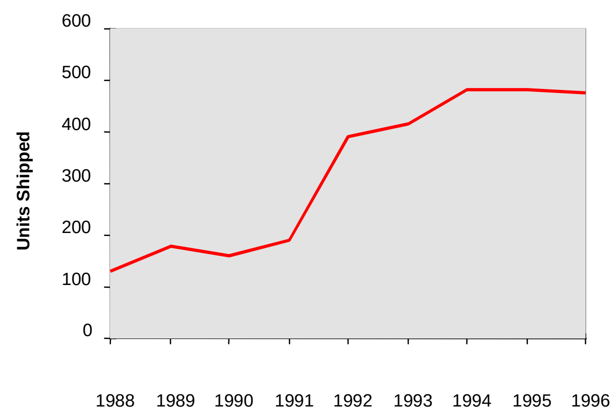
Since 1995 several factors have helped the absorption cooling market including: the opening of large natural gas equipment manufacturing plants in the United States, major developments in equipment financing and performance contracting.

A basic three-condenser-three-generator triple-effect cycle was patented in 1985. An alternate triple-effect cycle, the double-condenser coupled (DCC) cycle, was patented in 1993. As of the end of 1997, two U.S. manufacturers were conducting research and development (R&D) programs aimed at producing triple-effect absorption chillers. York International has partnered with DOE in a cost-shared program to build a triple-effect absorption chiller utilizing the DCC cycle. Field testing is expected next year, with commercialization expected in 2000 or 2001. The Trane Company, has conducted research to develop a triple-effect chiller utilizing a dual loop cycle. The goal of these large commercial chiller "programs" is to produce a triple-effect chiller that improves cooling efficiency by 30 to 50 percent, compared to double-effect absorption chillers currently on the market. Estimates for the price premium over a double-effect chiller range from 25 to 30 percent.

B. Current Market Share

The two basic types of gas chillers are absorption systems and gas engine chiller systems. The potential for the gas chillers is attractive in regions with high electric demand charges.

Natural gas equipment accounts for 8 to 10 percent of the market for larger chillers. This number is expected to grow, however, as a result of rising electric rates and the increased efficiency, reliability, and accessibility of gas equipment. Figure 6 shows the gas absorption cooling market conditions from 1988 to 1996.



Source: AGCC

Figure 6 - Gas Absorption Cooling Market Conditions

C. Standards and Ratings

Currently there are no state or federal standards that regulate gas absorption cooling systems. However, there are several metrics that are used to define absorption chiller efficiency, including:

- COP
- IPLV
- APLV

Coefficient of Performance (COP)

The performance of gas cooling equipment is usually rated in terms of COP, defined as the cooling output, or refrigeration effect, in Btu, divided by the energy input, in Btu. This same metric is applied to electric chillers, but since it is based on site energy, it is not good for comparing gas and electric chiller efficiencies.

Gas absorption chillers, as well as electric chillers, are rated to Air Conditioning and Refrigeration Institute ARI-550-92 conditions as listed below:

Chilled Water Conditions:

- 44ºF chilled water supply temperature
- 54ºF chilled water return temperature
- 2.4 gpm/ton chilled water flow

Water Cooled Condensers:

- 85ºF condenser water supply temperature
- 95ºF condenser water return temperature
- 3.0 gpm/ton condenser water flow

Air Cooled Condensers:

- 95ºF air supply temperature
- 20ºF temperature differential between air supply and condensing refrigerant
- 2ºF refrigeration system loss to the condenser

Integrated Part Load Value (IPLV)

Another measurement of chiller efficiency is Integrated Part Load Value, IPLV. IPLV is an industry standard for calculating an annual COP based on a typical load profile and the part load characteristics of chillers. It was originally conceived as part of ANSI/ASHRAE Standard 90.1 (*Standard for Energy Efficient Design of New Nonresidential and High-Rise Residential Buildings*) in response to a need for directly comparing manufacturers' part load data. The method assumes that the chiller operates at a specific part load for a specific number of hours during the year. According to the following equation:

$$\text{IPLV} = \frac{1}{\frac{0.17}{A} + \frac{0.39}{B} + \frac{0.33}{C} + \frac{0.11}{D}}$$

Figure 7 provides the assumption and appropriate values for the equation.

Chiller Load (%)	Chilled Water Return Temp (ºF)	Mfgr. Rated COP	Part Load Hours (%)
100	85	A	17
75	78.75	B	39
50	72.5	C	33
25	66.25	D	11

Figure 7 - IPVL Calculation Assumptions

COP ratings A, B, C and D at each part load condition are obtained from the chiller manufacturer and should be derived from actual chiller tests. Note that the calculation allows for a 2.5ºF reduction in the entering cooling water temperature for every 10% drop in cooling load. A lower entering cooling water temperature corresponds to part load (reduced) cooling demand, that results from a drop in ambient temperature.

Although IPLV is a useful way to compare different manufacturers' chiller models, it probably doesn't represent actual operating conditions. For applications where cooling load is not significantly affected by ambient temperature conditions, (e.g., when cooling load is dominated by internal gains) this estimate of part load performance may not provide accurate results. Chiller performance should be modeled to actual building load profiles tailored to site-specific ambient conditions.

Applied Part Load Value (APLV)

The Applied Part Load Value, APLV is calculated using the same IPLV formula, except that actual chilled and condenser water temperatures and flow rates are used. The advantage of using the APLV over the IPLV, is that this rating more closely approximates actual operating conditions imposed on the chiller. The disadvantage is the additional performance data that needs to be collected.

D. Economics/Cost Effectiveness

The economics of gas-fueled cooling systems vs. electric chillers are driven by the additional investment cost and several factors influencing operating cost, including:

- relative costs of the electricity and gas, and their billing structures,
- relative performance characteristics,
- operating characteristics, and
- relative maintenance costs.

The first three factors are discussed in the following sections and combined to produce estimates of Annual Energy Savings. Annual operating savings include an energy component and a comparison of O&M costs.

Energy Rates and Billing Structure

Energy rates and billing structure have a major impact on economic evaluations of gas versus electric cooling equipment. Energy rates include:

- Electric demand, $/kW
- Electric energy, ¢/kWh
- Gas energy rate, $/MMBtu (or therms)

It is essential that the complete utility rates and rate structures are used for an accurate economic analysis. Utility rate structures may include one or more of the following:

Block Rates - The electric block rates may be in terms of kWh, with different rates for various levels of energy consumption. It may also be stated in kWh per kW of demand. In this case the kWh rate is a function of demand. A lower demand typically results in a large allowed amount of kWh at a lower rate. A high demand results in a smaller amount of kWh before the higher rate kicks in. Typically, although not always, the unit price per kWh increases as demand increases.

Time-of Use Rates - the electric rate may vary depending on the time of day. The time-of-use rate is typically described in terms of on-peak and off-peak, and sometimes partial peak.

Ratchets - the electric rate may include a demand ratchet, which allows for a variation on how the demand kW is defined.

Seasons - some utilities have different summer and winter rates.

Taxes - applicable taxes and franchise fees, which can be over 10% in many areas.

Special Rates - for gas cooling equipment or special load-management electric rates are sometimes available.

Using average electric and gas costs is rarely adequate to capture the cost of operating cooling equipment, especially when the rate structure includes demand charges or declining blocks. The marginal electric price for cooling has a larger demand component relative to usage, which drives up the unit price. The details of the actual electric rates must be considered in the total analysis of chiller system operating costs.

Performance Characteristics

When comparing gas and electric cooling options there are several equipment performance characteristics that must be considered:

- Electric chiller seasonal COP and peak load COP,
- Gas cooling equipment seasonal COP,
- Gas and electric differential auxiliary power requirements, seasonal and peak, and,
- Gas and electric differential O&M cost requirements, $/ton hour.

Miscellaneous electric loads from pumps should be included in the calculation of annual savings.

Operating Characteristics

Operating schedules for building types vary. For example, HVAC equipment for office buildings generally are operated approximately 10 –12 hours per day, five days per week. Equipment in hospitals will operate near full load for much of the day and at reduced, but still significant load for the remainder of the day. The descriptions of the building types used in the analysis, provided in the appendix, include the assumed operating schedules.

Annual energy savings need to be large enough to overcome higher initial costs and potentially higher maintenance costs for gas-engine driven chillers to be cost-effective. Annual energy savings will be a function of the operating schedule. An operating schedule that has a significant number of hours where the equipment runs at part load, favors gas engine-driven chillers because of their excellent part load performance. However, operating schedules that require equipment to run at full load for relatively few hours and not at all for most hours will result in too little annual energy savings to realize an acceptable payback for most business' requirements.

Estimating Annual Energy Savings

To estimate annual energy savings, the performance characteristics of each chiller alternative must be carefully compared.

The customary approach to analyzing chiller economics has been to employ "equivalent full load hour" methodology. Equivalent Full Load Hours (EFLH) are defined as the total cooling load supplied over the cooling load duration (ton/hours) divided by the cooling equipment capacity (tons). Part load operation is modified to obtain the equivalent of running at full load. While this method does not reflect the efficiency of part load operation, it does simplify economic comparison.

Since the economics of gas cooling are highly dependent on operating hours, accurate analysis requires a detailed building simulation. A comprehensive analysis should be done with an hourly simulation model, such as DOE-2, HAP, or TRACE, which predicts when, where and how much cooling is required for the building.

The current publicly available version of DOE-2.1E contains performance simulation modules for:

- direct-fired absorption chillers,
- natural gas absorption chillers, and
- gas absorption air conditioners and heat pumps.

E. Sizes

Commercially proven absorption cooling systems, ranging in size from 3 to 1,700 tons are widely available. These systems come as stand-alone chillers or as chillers with integral heating systems. The following sections provide manufacturer specific information and examples of installations.

F. Equipment Manufacturers

There are several manufacturers of absorption chillers, including:

- Robur Single-Effect, 3 to 25 ton
- Yazaki LiBr Double-Effect, 20 to 100 ton
- McQuay LiBr Double-Effect, 20 to 100 ton
- Carrier Absorption Chillers, 100 to 1,700 ton
- Trane Absorption Chillers, 100 to 2,000 ton
- McQuay Absorption Chillers, 100 to 1,500 ton
- York Absorption Chillers, 100 to 1,500 ton
- Dunham-Bush, 100 to 1,400 tons

G. Equipment Installations

Gas absorption cooling equipment is available for commercial facilities including hotels, office buildings, warehouses, supermarkets, retail outlets and institutions including hospitals, nursing homes, and schools. Following are several examples of gas absorption chiller installations:

AT&T Office Building, St. Louis, Missouri

The 421,000 sq. ft. office building and 255,000 sq. ft. warehouse facility existing equipment consisted of three York steam absorbers and a York reciprocating chiller.

In the early 1990s, a 1,000-ton Hitachi* ParaFlowTM direct-fired absorption chiller, a 600-ton York HCFC-123 electric centrifugal chiller and a BAC plate-and-frame 300-ton heat exchanger for use as a water economizer were installed.

"The combined maintenance and energy savings of $237,000 per year exceeded our expectations," says Vince Behan, senior plant engineer.

FERC Office Building, Washington, D. C.

The 868,000 sq. ft. Federal Energy Regulatory Commission (FERC) office building, which opened in 1995, has office space, a health club and a 200 seat restaurant.

A 1,000 ton direct fired absorption chiller was put into a hybrid plant with an electric chiller to cool the facility. Other features affecting the decision to install the system were low maintenance and reduced use of CFC refrigerants. The estimated savings are approximately $40,000 to $50,000 per year or about 3% to 5% of annual utility costs.

Walter and Lois Curtis Middle School, Allen, Texas

In 1994 the new 186,681 sq. ft. middle school was constructed. Two 100 ton York direct-fired double-effect absorption chillers were installed. The system provides all of the school's cooling and part of the heating.

The operating savings were great enough to convince the school district to install gas cooling in a new 400,000 sq. ft. high school then under construction.

Greene Hospital, San Diego, California

One 400 ton McQuay direct-fired double-effect absorption chiller was installed during an expansion project in 1993 to provide cooling to 300,000 sq. ft. The use of the absorption chiller allowed the hospital to avoid the cost of upgrading its electric service.

"Using a natural gas-powered chiller is how we reduce our electric load," says Bob Diehl, acting vice president for Scripps Health. "We would've had to buy additional electric equipment in order to satisfy an electric load increase and upgrade. By using the natural gas-powered chiller we are saving 35 percent per year in energy costs. That translates into a yearly savings of $25,000."

Philadelphia Convention Center

Completed in 1993, this 1.3 million square foot, $523 million dollar state-of-the-art facility chose to install two 1,500 ton and two 1,000 ton direct fired absorption chiller heaters for all the building's heating and cooling needs. The units provide all the heating and cooling, so no boilers were required, which reduced space requirements by 40%. They were also selected because of quiet operation.

CHAPTER 4: DESIGN ANALYSIS

A. Overview

Gas absorption chillers were compared to the following chiller options:

- Standard efficiency electric screw or centrifugal
- High efficiency electric screw or centrifugal
- Indirect-fired single effect absorption

The 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 energy code bodies. The results of a detailed energy and rates analysis, for seven building types in ten cities, have been distilled down to a series of graphs.

The cities and buildings are representative of the range of climates and building occupancies where gas cooling options would be used. The list of cities, sorted by Cooling Degree Day (CDD) is provided in Figure 8. Information on building type and size are provided in Figure 9. The economic analysis is of course dependent upon gas and electric rates. Building descriptions and city specific utility rates are provided in the Appendix.

The results are graphed for various gas rates and various electric rates. Due to the complexities of the interactions between fuel type usage and utility rates, it was not possible to develop "typical" gas-to-electric cost results. These graphs can be used, as will be shown by example in the following chapter, to determine relative increase in gas consumption and relative decrease in electric consumption, when comparing a gas chiller to an electric chiller. The results of separate fuel type analysis can then be combined to provide a complete picture of the savings opportunities.

City	CDD_{50}
San Francisco	2,883
Chicago	2,941
Washington DC	3,734
Los Angeles	4,777
Atlanta	5,038
San Diego	5,223
Riverside	5,295
Fort Worth	6,557
Phoenix	8,425
Miami	9,474

Figure 8 - Cities used for Cooling Analysis

Figure 9 shows the building types included in the analysis, along with the building size in square feet, and the cooling equipment size in tons. The range of equipment sizes represents the variation in cooling load for the cities analyzed. The sizing of the cooling plant follows ASHRAE 90.1R ECB guidelines with a 20 % oversizing margin.

Type	Size (Sq Ft)	Cooling (tons)*
Medium Office	49,000	100 - 143
Large Office	160,000	408 - 573
Hospital	272,000	384 - 519
Hotel	315,000	645 - 891
Out-Patient Clinic	49,000	90 - 111
Secondary School	50,000	90 - 205
Large Retail	164,000	165 - 393

*Cooling plant capacity includes 20% additional oversizing

Figure 9 - Building Type and Size

As shown in Figure 10, the type of electric equipment, either screw or centrifugal, used as a comparison, was dependent on the size. Figure 13 shows the standard and high efficiencies assumed for the various types of chillers.

Size (tons)	Type
100 - 300	Screw
>300 - 600	Screw
>600	Centrifugal

Figure 10 - Cooling Equipment Type Based on Size

Because of the complexities and "individual" nature of hybrid systems, results of any hybrid systems analysis cannot be generalized. They were therefore intentionally not included in this analysis. However, if the results indicate that a gas absorption chiller is cost-effective, or even marginally not cost-effective, a hybrid system under the same conditions, will typically be cost-effective.

B. Energy Savings

Energy savings were calculated using detailed DOE-2.1E building simulation models. The models provide comprehensive data on energy use and savings. The modeling included a complete comparison of system components, including auxiliary equipment such as cooling towers, fans and pumps.

The graphs in the following chapter present the energy savings for each of the cities for a range of marginal gas and electrical prices. The graphs present the annual energy cost savings, in dollars per year, versus the marginal cost of gas, in dollars per therm, or the marginal cost of electricity in dollars per kWh. The marginal energy cost, gas or electric, is calculated as energy cost savings, in dollars, divided by energy savings in therms or kWh. The marginal cost accounts for varying rates that may apply based on total usage.

C. Cost Effectiveness

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

Specific equipment cost information is provided in the Appendix. Additional first costs for absorption systems were applied to the cost-effectiveness model, including:

- additional cooling tower capacity adds$20-$25/ton
- additional boiler capacity adds $50-$150/ton

Another element of the first cost for gas absorption chillers is the potential savings from interactions with other building elements. For example, installing a gas absorption chiller may reduce the building's electric load enough to allow for downsizing of the electric service drop and load center. These savings could be significant, but are not included due to the variability between installations.

A scalar ratio is a mathematical simplification of life cycle costing (LCC) analysis. The scalar ratio is a single term that combines discount rate, period of analysis, fuel escalation and other factors. 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.

Equipment Type & Size	Standard Efficiency		High Efficiency	
	COP	kW/ton	COP	kW/ton
Electric Screw, <150 tons	3.8	0.93	4.45	0.79
Electric Screw, =>150 to 300	4.2	0.84	4.90	0.72
Electric Centrifugal, >300	5.2	0.68	6.01	0.58
Single Effect Absorption			0.60	5.86
Double Effect Absorption			1.00	3.51

Reference: ASHRAE 90.1R "Minimum Efficiency" and "Efficiency as of Jan, 2000"

Figure 11 - Cooling Equipment Efficiencies

CHAPTER 5: DESIGN ANALYSIS GRAPHS

A. Using the Graphs

The following pages contain families of graphs that describe the performance of gas absorption chillers in a variety of cities and building types. As described in Chapter 4, these graphs were developed from DOE-2.1E runs done 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 gas absorption chillers 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 current local gas and electric rates for each city. By following the line on the graph, the results can be extrapolated to different utility rates.

Annual Energy Cost Savings Graphs

Two sets of energy cost savings are calculated for each building type. One is for a range of marginal gas costs and a fixed marginal electric cost. The other is for a range of marginal electric costs based on a fixed marginal gas cost.

The top graph in Figure 12 is typical of the annual energy cost savings vs. marginal gas cost graphs. The bottom graph is for the same conditions showing the energy cost savings vs. marginal electric costs. These particular results are for the medium office building prototype. The comparison is between a gas absorption chiller and a standard efficiency electric screw chiller.

The horizontal x-axis of these graphs is the marginal cost of gas, in dollars per therm, or the marginal cost of electricity, in dollars per kWh. Marginal electric costs are the costs charged, under the local utility rate structure, for the kilo-Watt/hours that are saved by the use of the gas absorption chiller. For the case of gas rates, marginal cost represents the costs charged per therm for the increase in gas consumption. The marginal cost does not include the utility basic service charges or other charges that are common to both equipment scenarios.

The vertical y-axis shows the annual energy cost savings, in dollars per year, between the base equipment and the gas absorption chiller.

As shown on the top graph, as gas prices increase, the energy savings associated with an absorption chiller decrease. Conversely, as electric prices increase, savings from the absorption chiller increase, as shown in the bottom graph.

For example, as shown in Figure 20, Chicago is represented by a solid diamond marker. In this example, the prototype large office building in Chicago has a marginal gas cost of approximately $0.37 per therm, and a marginal electric cost of approximately $0.11 kWh. The gas absorption chiller would save approximately $8,900/year compared to a high efficiency screw chiller.

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 energy. In the Chicago example, if gas were to increase to $0.45 per therm, a 20% increase, the energy cost savings would decrease to approximately $5,500 per year. Conversely, if the electric rate increased to $0.20, the savings would increase to $26,500 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 or 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.

Cost Effectiveness Graphs

This section presents the cost effectiveness graphs developed for various utility rates and locations.

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, 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.

The graphs in Figure 34 are typical of the “savings-to-investment ratio (SIR) as a function of marginal gas costs” graphs for scalars of 8, 12 and 16. Figure 35 is an example of “SIR as a function of marginal electric costs” graphs. For each of the SIR graphs, particular scalar and incremental equipment values are used. The top graph in Figure 34 is for a scalar of 8, and the incremental equipment cost is $380/ton of chiller capacity. There are different sets of graphs for each of the different building types studied.

Each graph enables one to quickly determine the cities where gas absorption chiller 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 a decrease in marginal gas cost, or an increase in marginal electricity cost, would be needed to bring it over the line. 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 that line, which corresponds to the gas or electric costs in the other city.

For example, if one were comparing a gas absorption chiller to a high efficiency electric chiller for a large office for a scalar of 12, in a city whose climate was similar to Phoenix (marked with an X in Figure 51), with similar electric rates, but with a marginal gas cost of $0.35 per therm, the SIR would be greater than 1.00, which is cost effective.

These graphs can be adjusted for different incremental equipment costs. For example, the SIR for a scalar of 8 for Chicago, shown in the graph in Figure 35, is based on an incremental cost of $380/ton. This value is the denominator of the SIR values plotted on this graph. If the incremental cost for a particular installation was instead $450/ton, then the SIR value from the graph would be adjusted to reflect the new cost. In this case, an SIR value of 1.00 from the graph would be multiplied by 380/450 to arrive at an adjusted SIR of 0.84. If, instead, the incremental cost was $300/ton, the adjustment factor would be 380/300, for an adjusted SIR of 1.27, which makes the gas option cost effective. For this particular comparison, the adjustment factor will always have a numerator of 380 and a denominator of the new incremental equipment cost, in dollars per ton capacity, as shown in the following equation:

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

Further review of the Cost-Effectiveness, or SIR graphs, shows that for a medium office, (see Figure 35) an absorption chiller compared to a standard efficiency electric chiller is cost-effective based on a scalar of 8 for Chicago, Atlanta, Washington D.C., Los Angeles, Riverside, Phoenix, and San Diego. The gas option is not cost-effective in Fort Worth, Miami, and San Francisco. Using a scalar of 12, gas cooling becomes cost-effective in Fort Worth, while a scalar of 16 also makes it cost effective in San Francisco. The cost-effectiveness results can be obtained from either the gas or the electric based graphs.

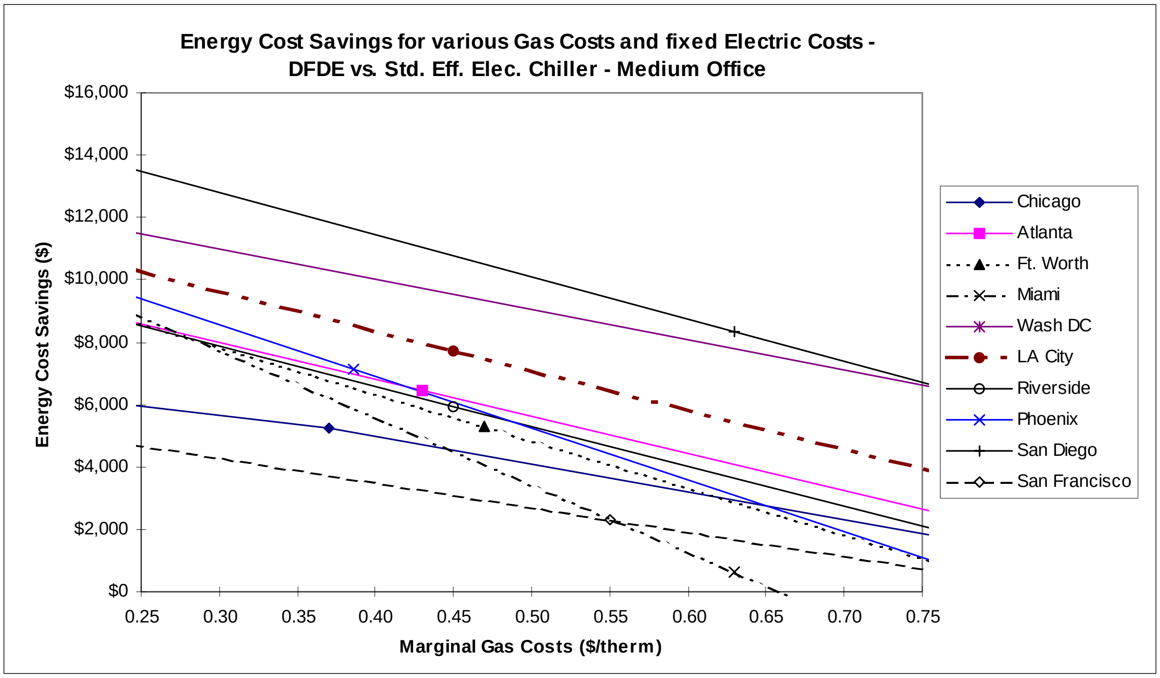
The following pages contain the full set of graphs comparing gas absorption chillers to other cooling options. For each comparison there are different energy and equipment costs, and different economic criteria. The abbreviation DFDE in the graphs stands for a direct- fired double-effect absorption chiller.

Some of the graphs have no, or almost no, savings curves on them, while others are missing curves (or markers) for one or more cities. In these cases, the energy savings are so great that the curves are literally off the scale. For example, in Figure 36, the graph for SIR comparing gas engine driven chillers to standard efficiency chillers with a scalar of 16, shows curves for six cities. None of them have markers on the curve, therefore this technology can assumed to be cost effective at marginal gas rates above $0.80/therm in all locations. An exception to this is the result for Miami. Gas rates are high enough, and electric rates low enough, that there are no energy savings for this technology for most building types. The SIR is a negative number, and the marker for Miami is below the x-axis of the graph.

In any case where the marker for a city does not appear on the line, the SIR value can be found on the table which precedes the graphs in the following sections.

B. Energy Savings Graphs

Direct Fired Double Effect (DFDE) Absorption Chiller vs. Standard Efficiency Electric Chiller



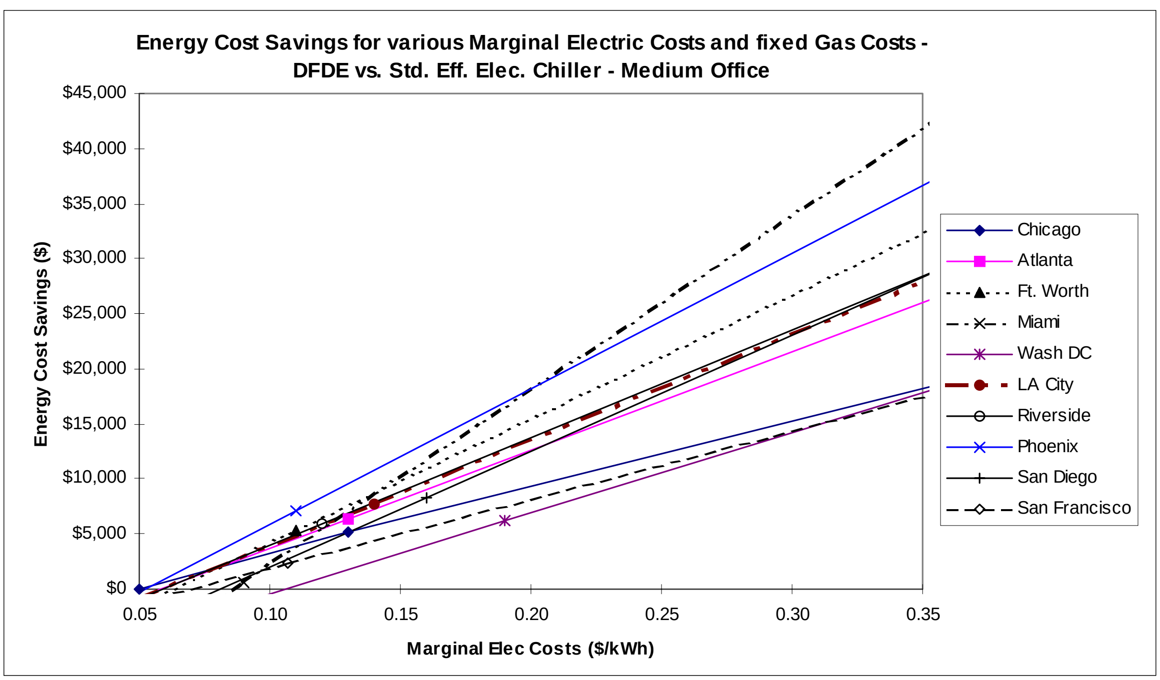
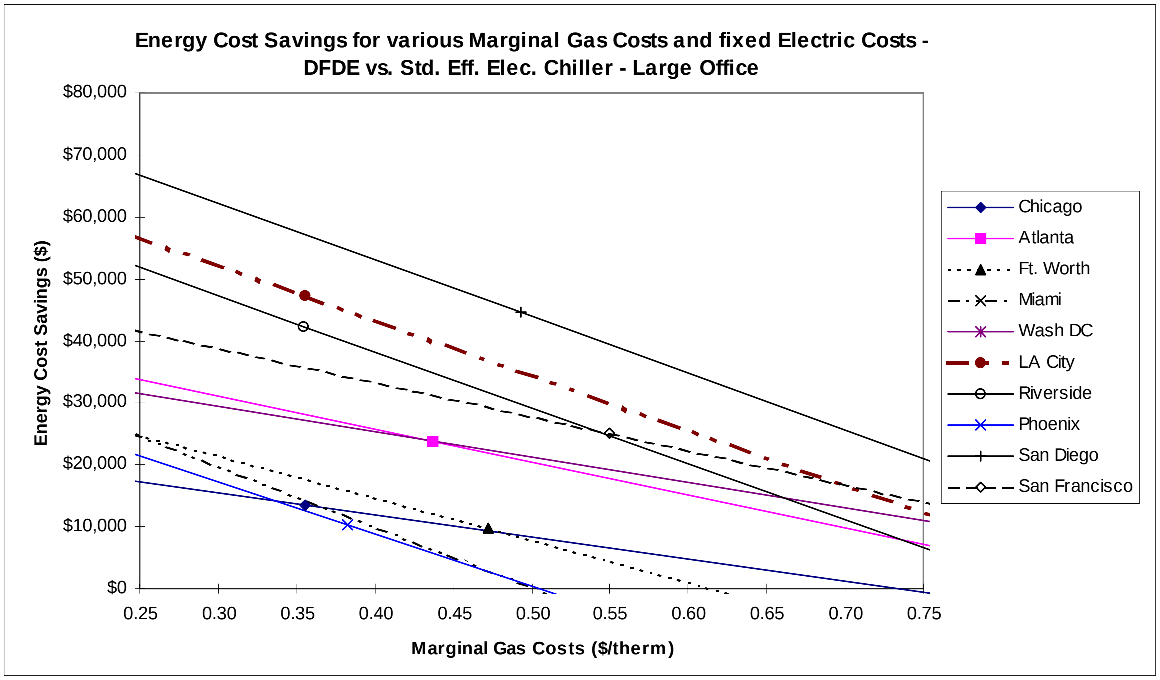


Figure 12 - Energy Cost Savings for Absorption Chiller vs. Standard Efficiency Chiller for Medium Office



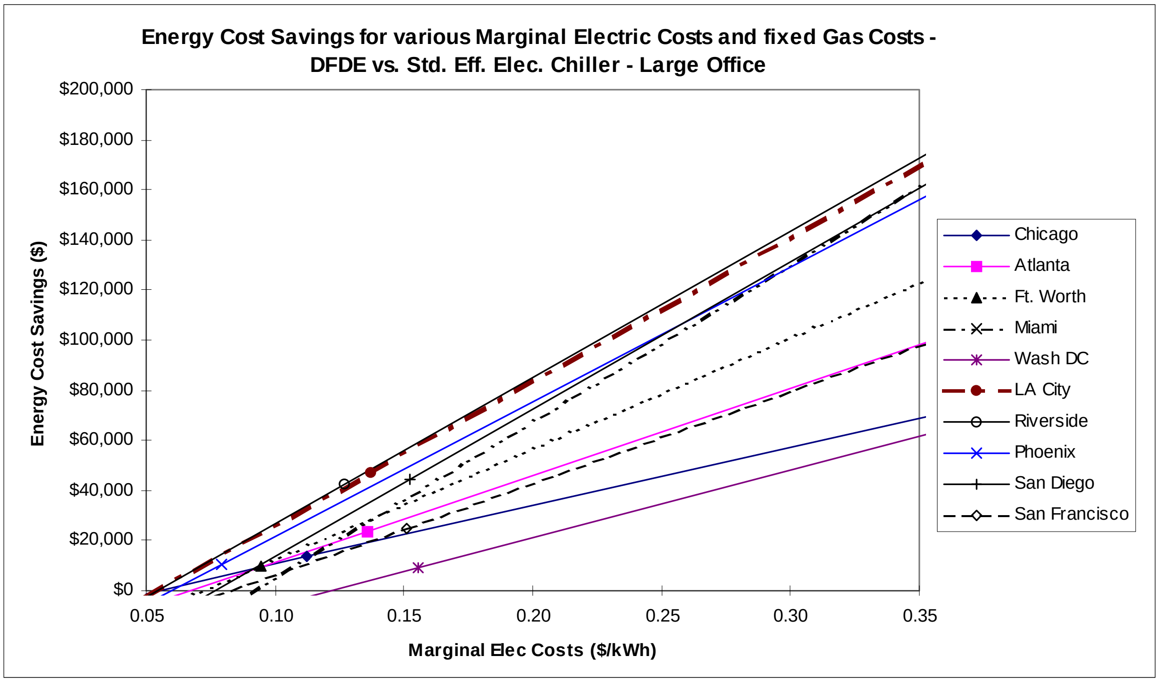
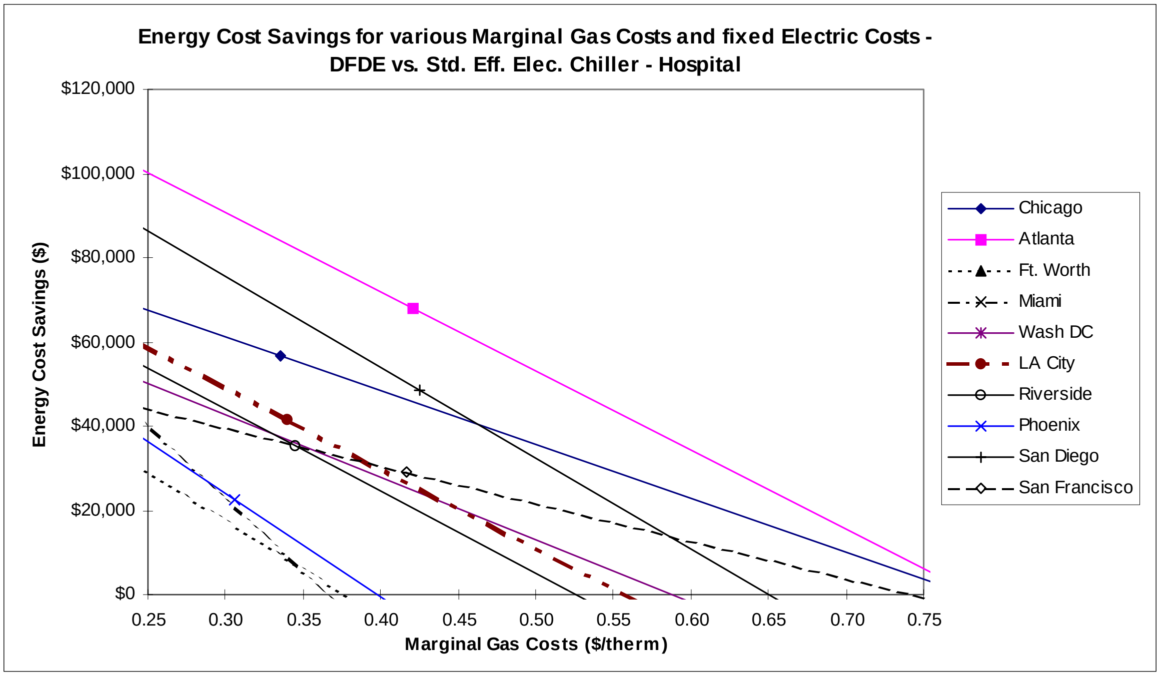


Figure 13 - Energy Cost Savings for Absorption Chiller vs. Standard Efficiency Chiller for Large Office



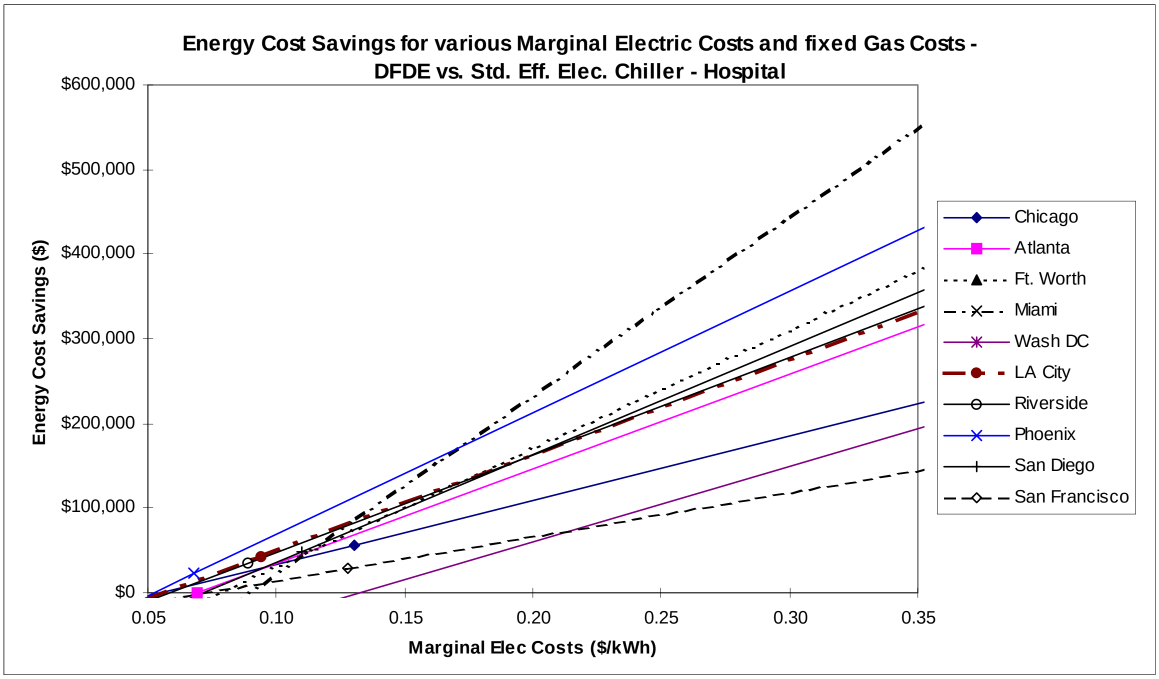
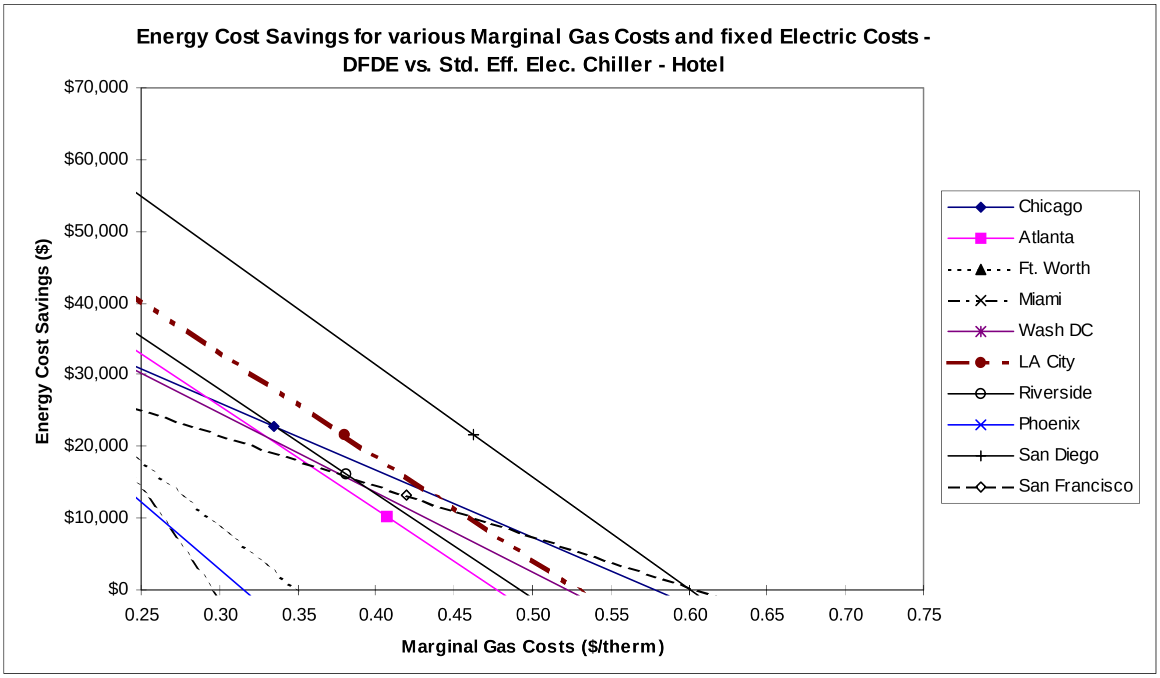


Figure 14 - Energy Cost Savings for Absorption Chiller vs. Standard Efficiency Chiller for Hospital



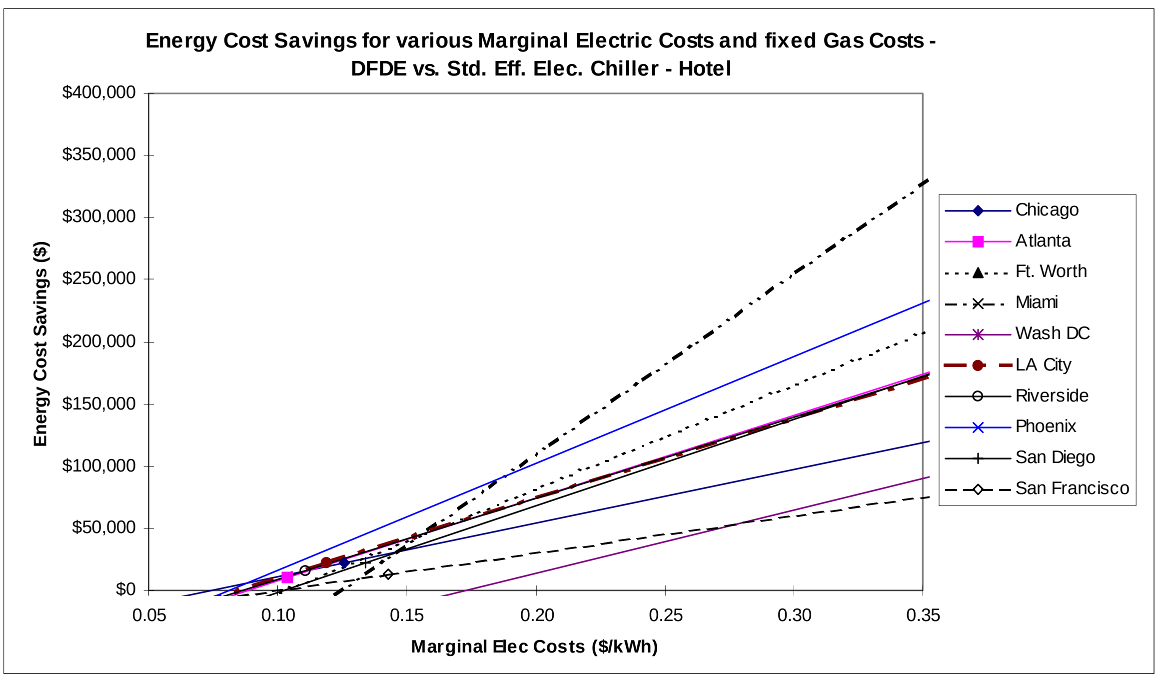
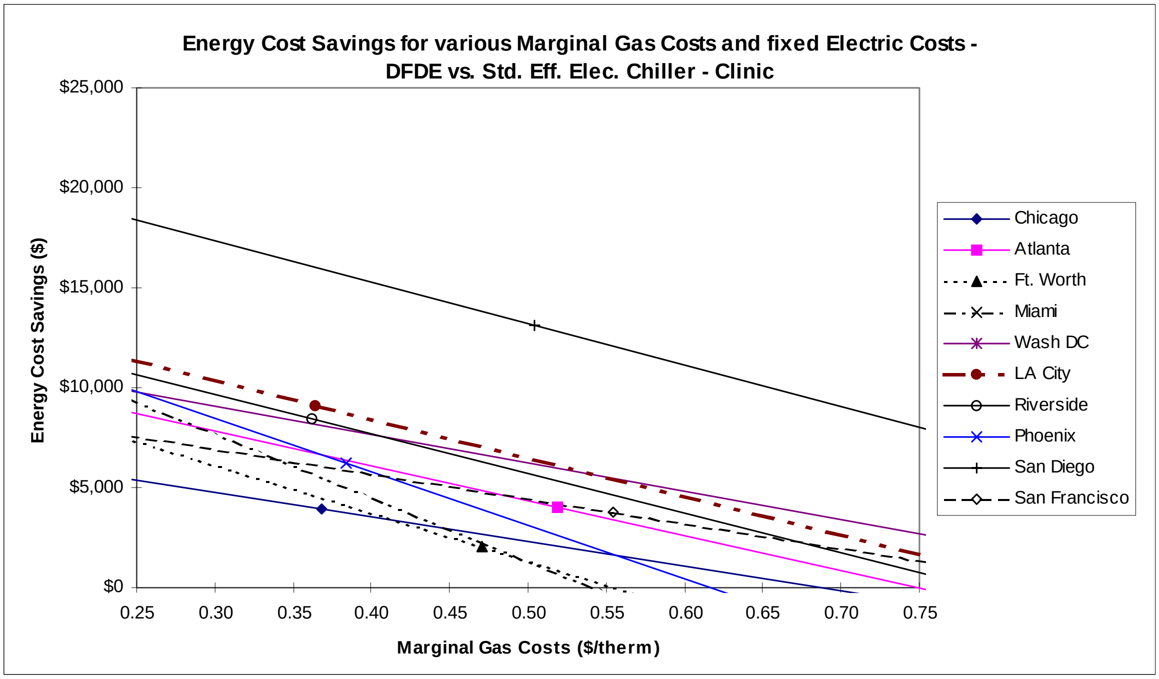


Figure 15 - Energy Cost Savings for Absorption Chiller vs. Standard Efficiency Chiller for Hotel



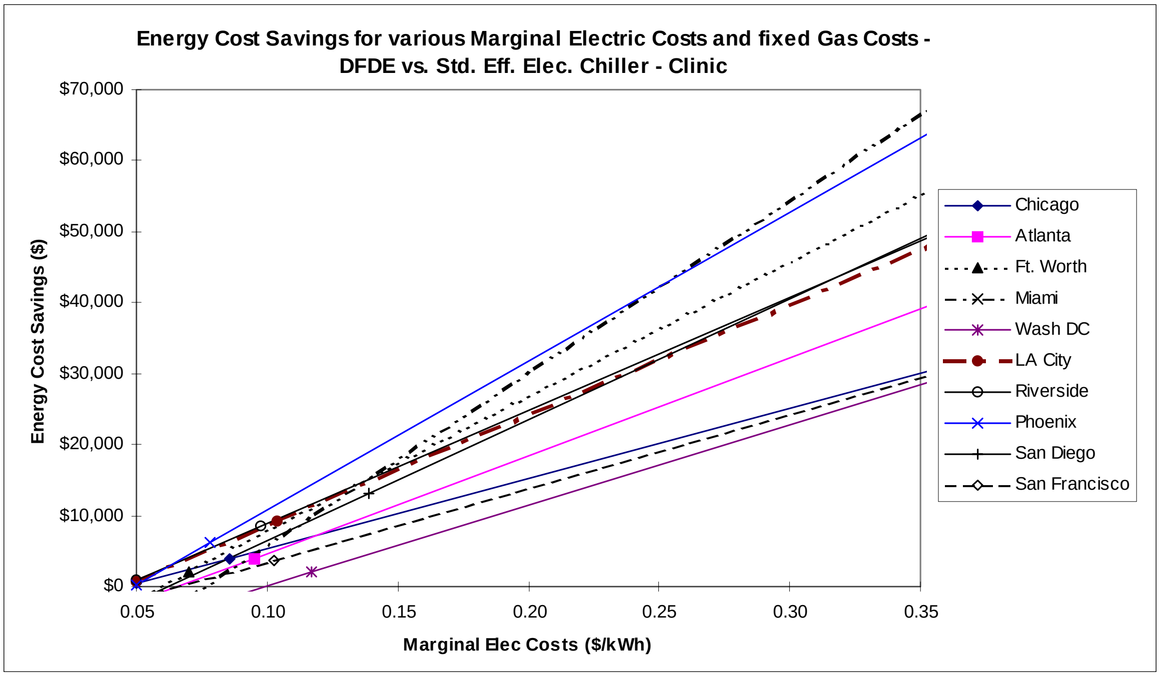
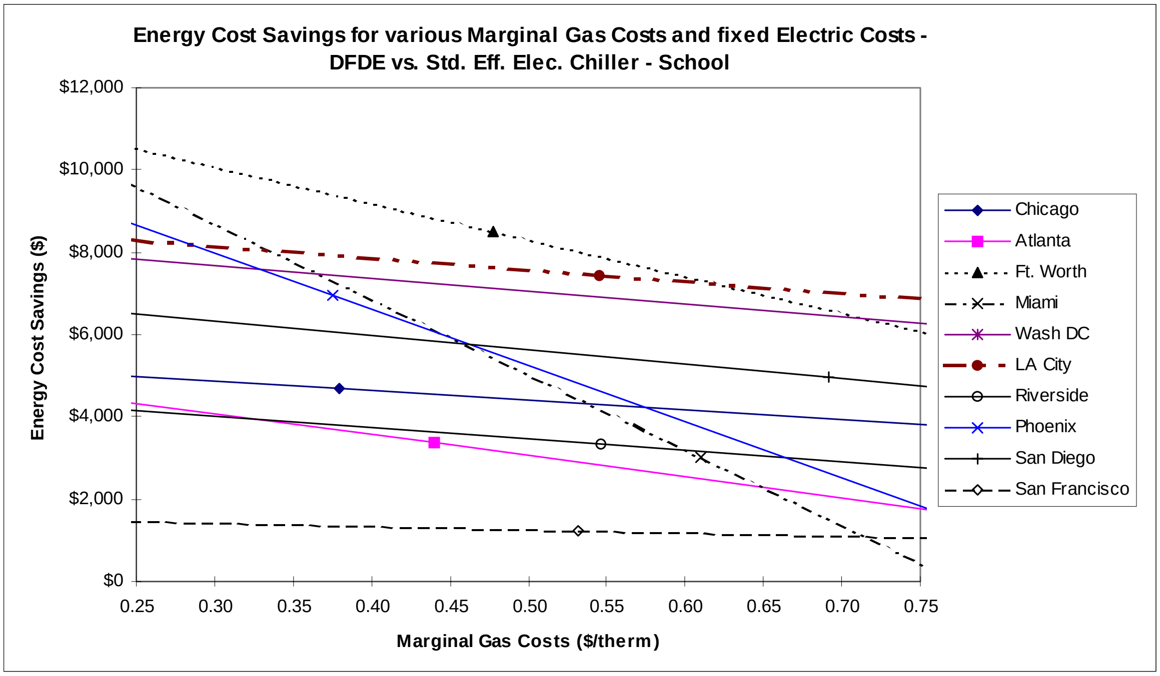


Figure 16 - Energy Cost Savings for Absorption Chiller vs. Standard Efficiency Chiller for Clinic



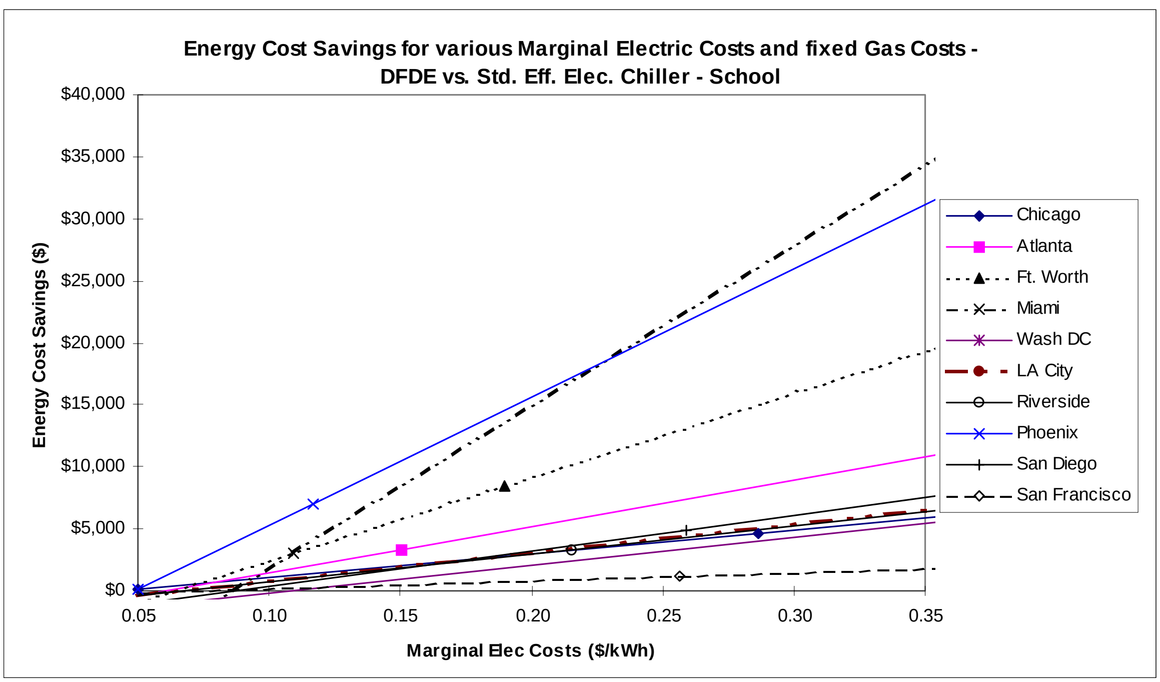
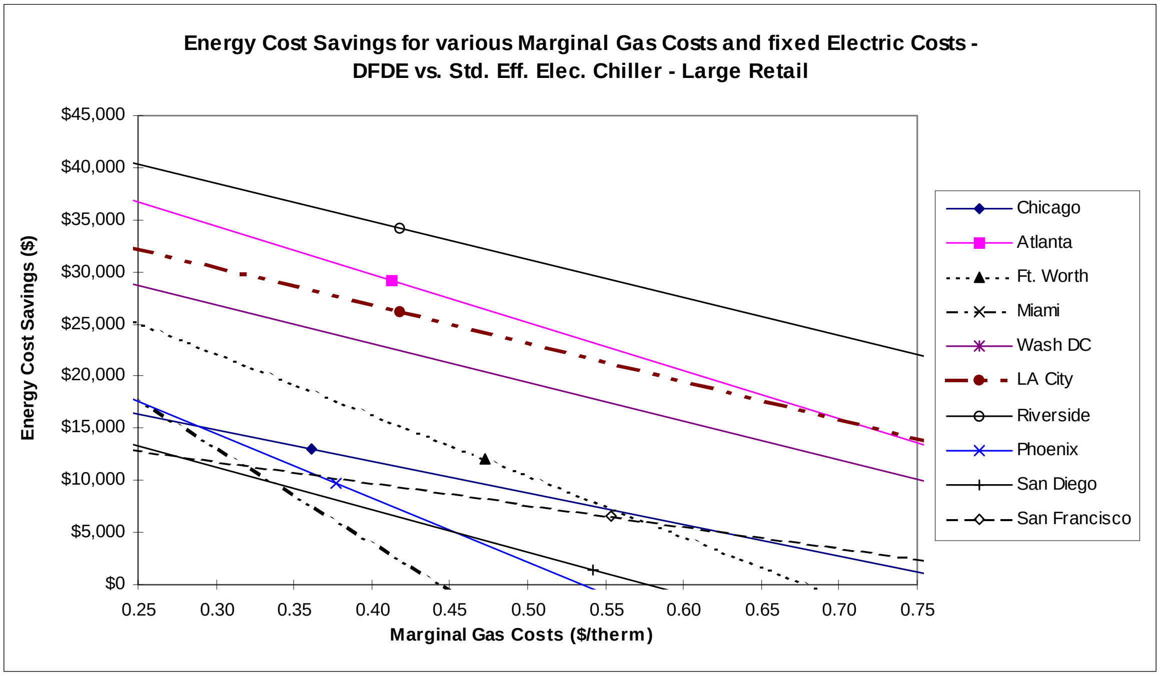


Figure 17 - Energy Cost Savings for Absorption Chiller vs. Standard Efficiency Chiller for School



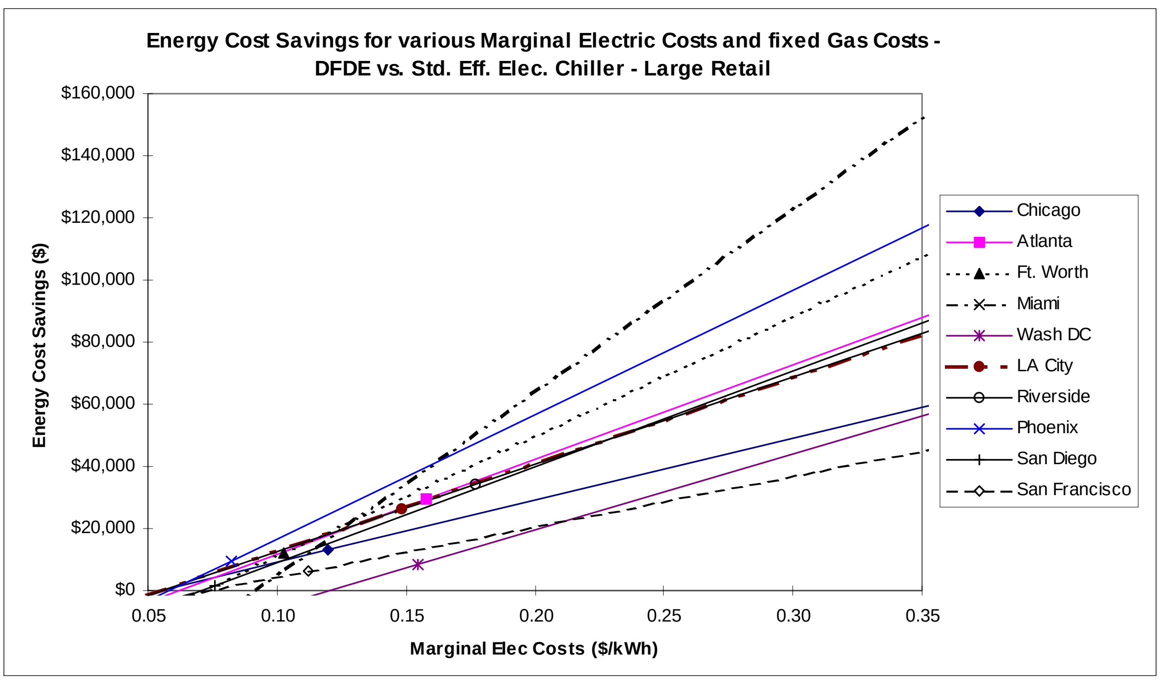
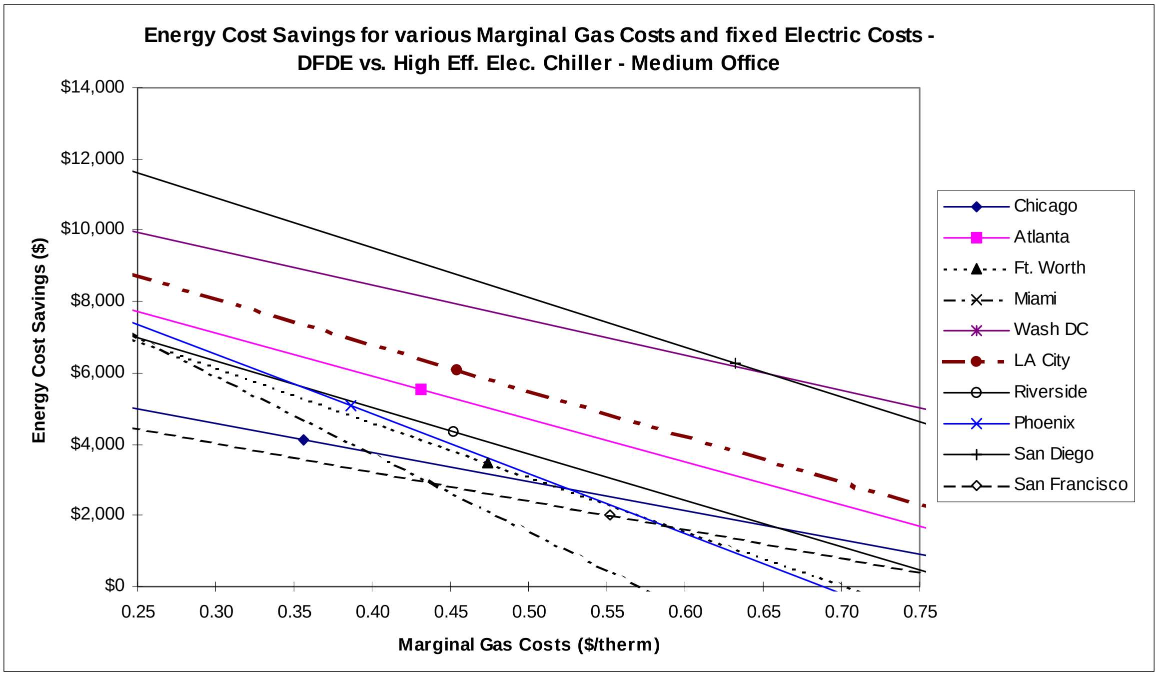


Figure 18 - Energy Cost Savings for Absorption Chiller vs. Standard Efficiency Chiller for Large Retail

Direct Fired Double Effect (DFDE) Absorption Chiller vs. High Efficiency Electric Chiller



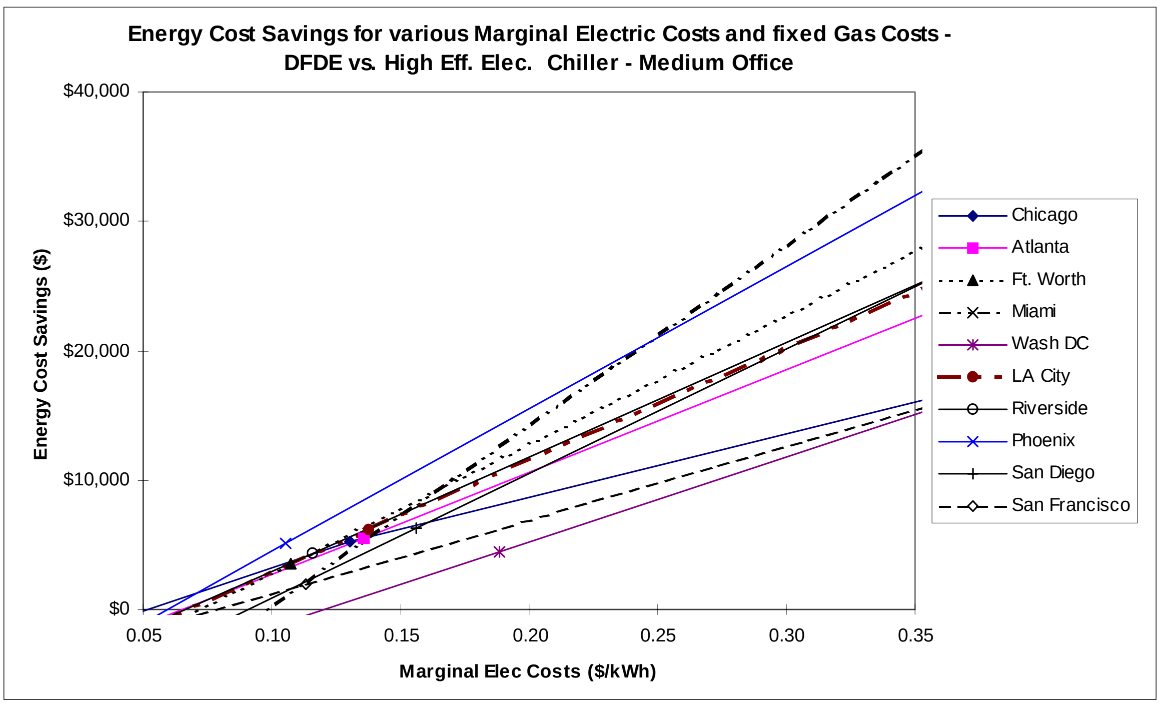
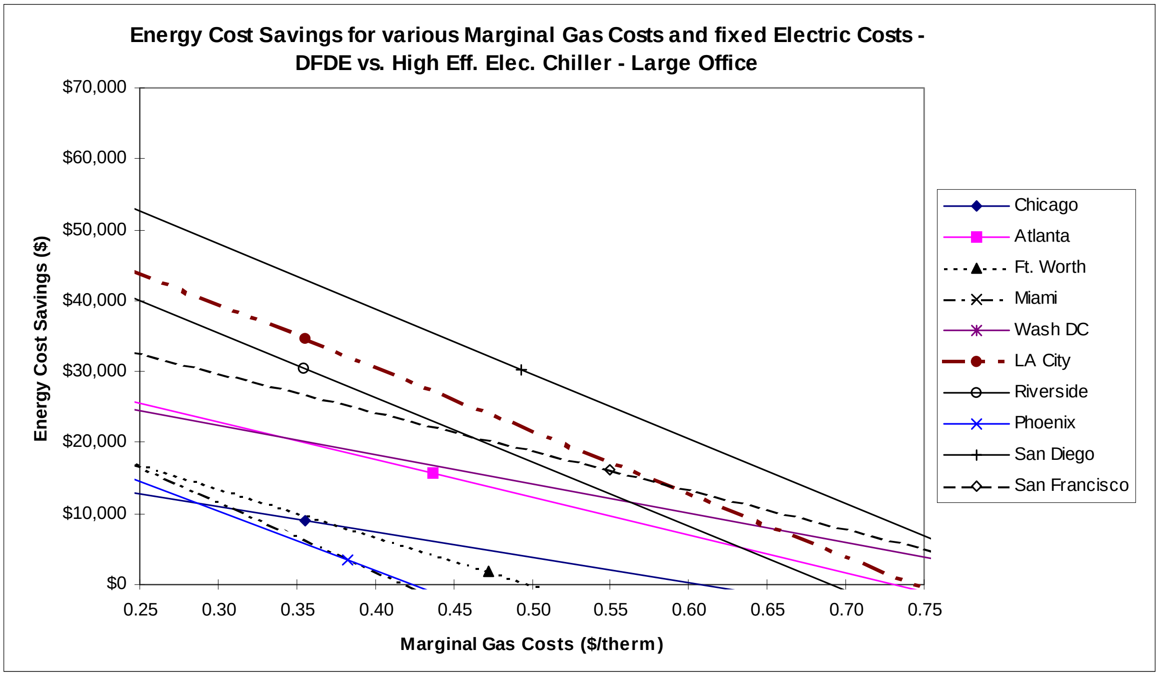


Figure 19 - Energy Cost Savings for Absorption Chiller vs. High Efficiency Chiller for Medium Office



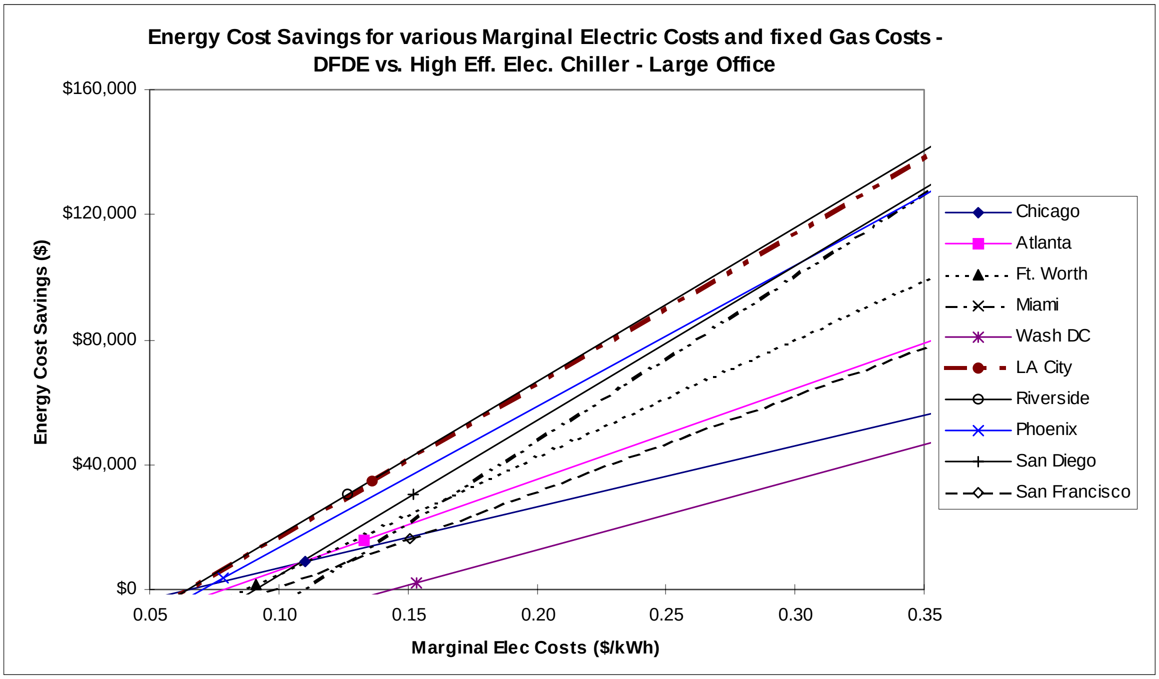
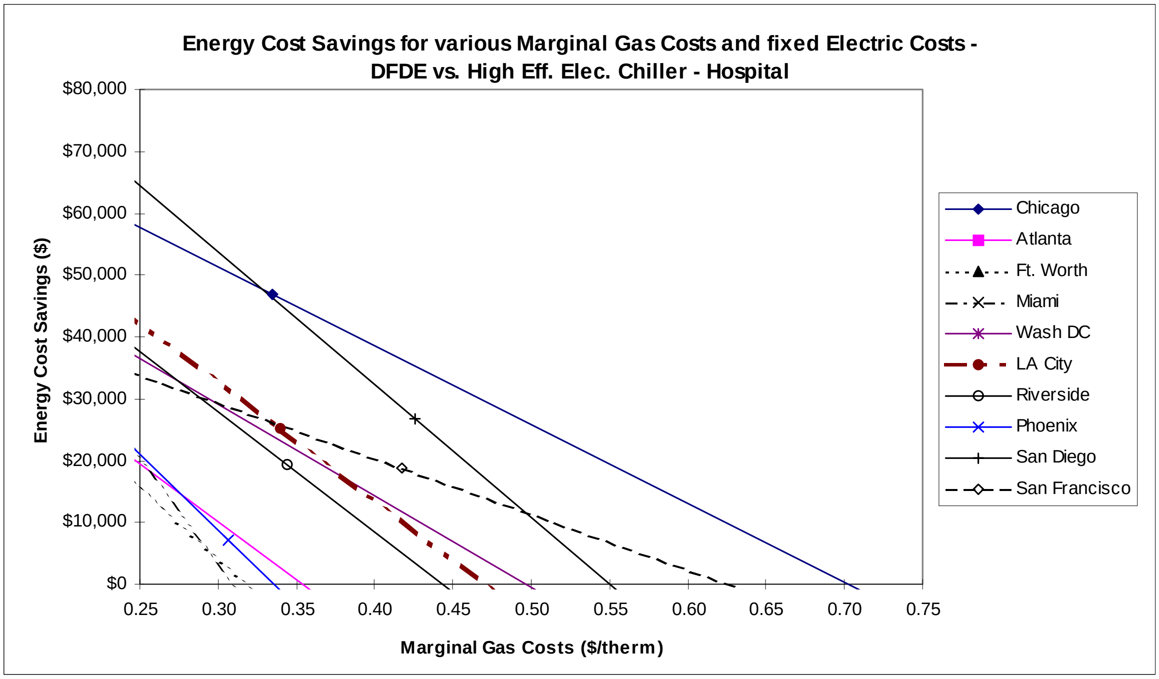


Figure 20 - Energy Cost Savings for Absorption Chiller vs. High Efficiency Chiller for Large Office



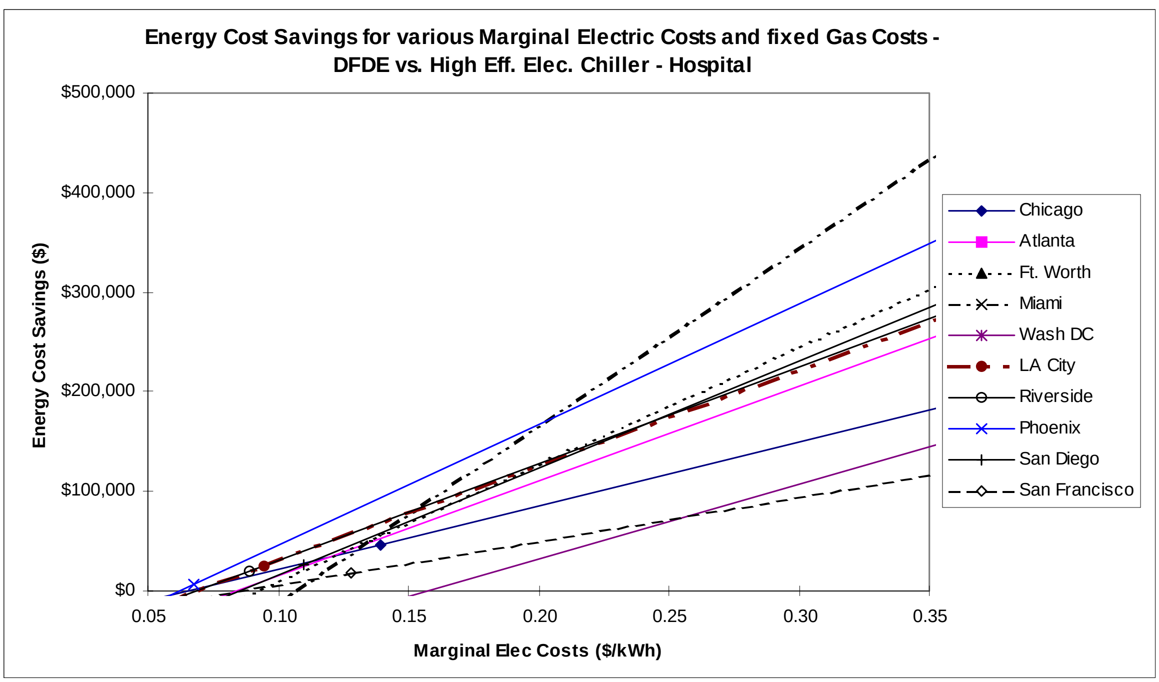
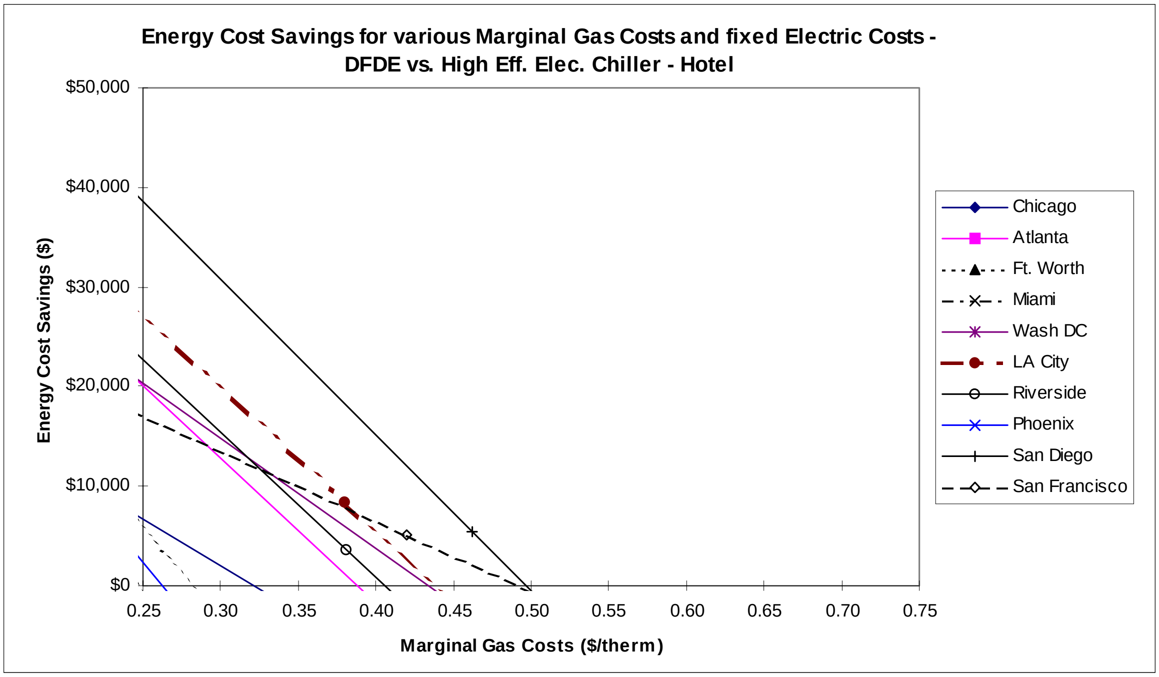


Figure 21 - Energy Cost Savings for Absorption Chiller vs. High Efficiency Chiller for Hospital



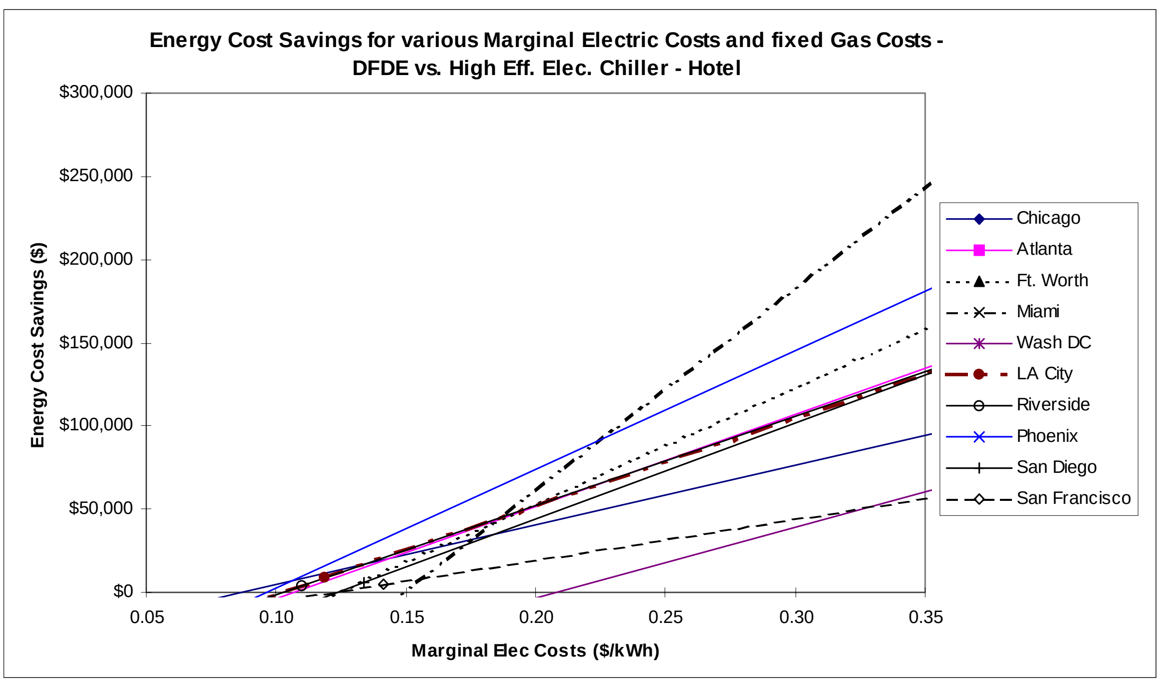
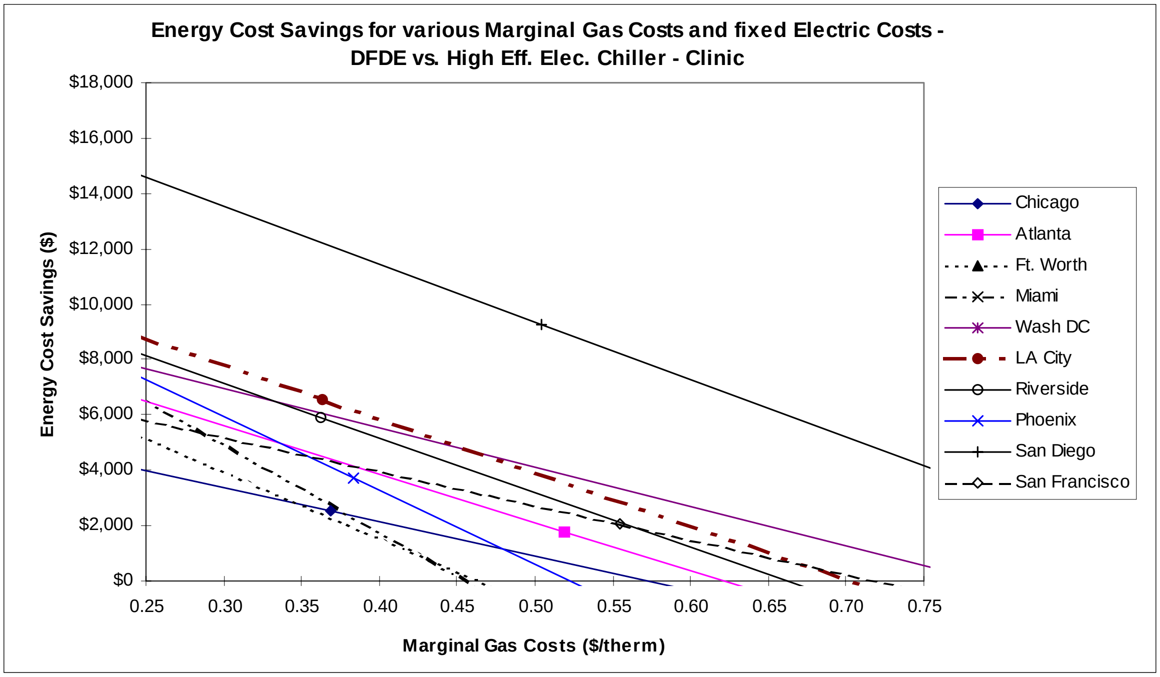


Figure 22 - Energy Cost Savings for Absorption Chiller vs. High Efficiency Chiller for Hotel



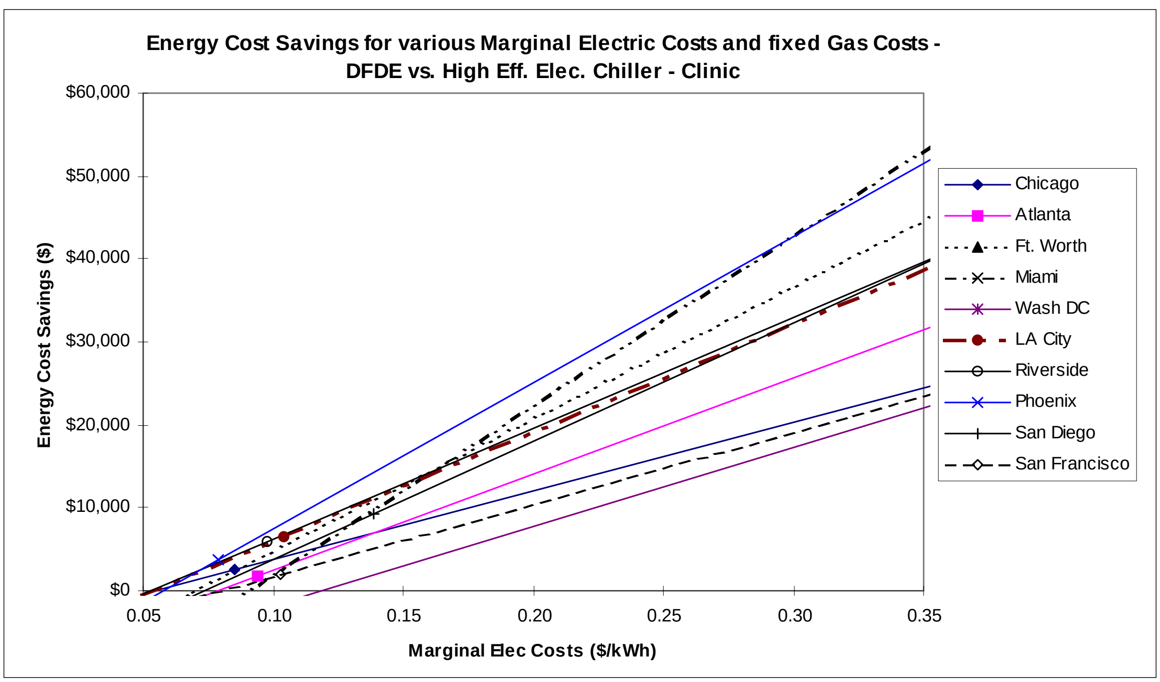
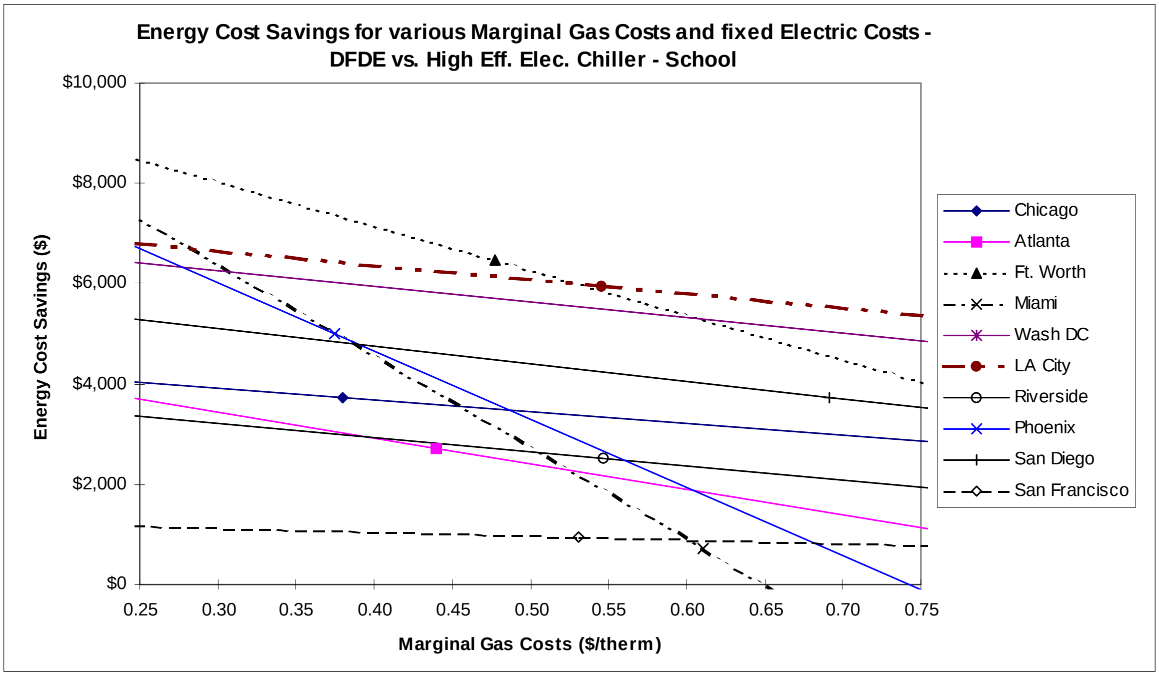


Figure 23 - Energy Cost Savings for Absorption Chiller vs. High Efficiency Chiller for Clinic



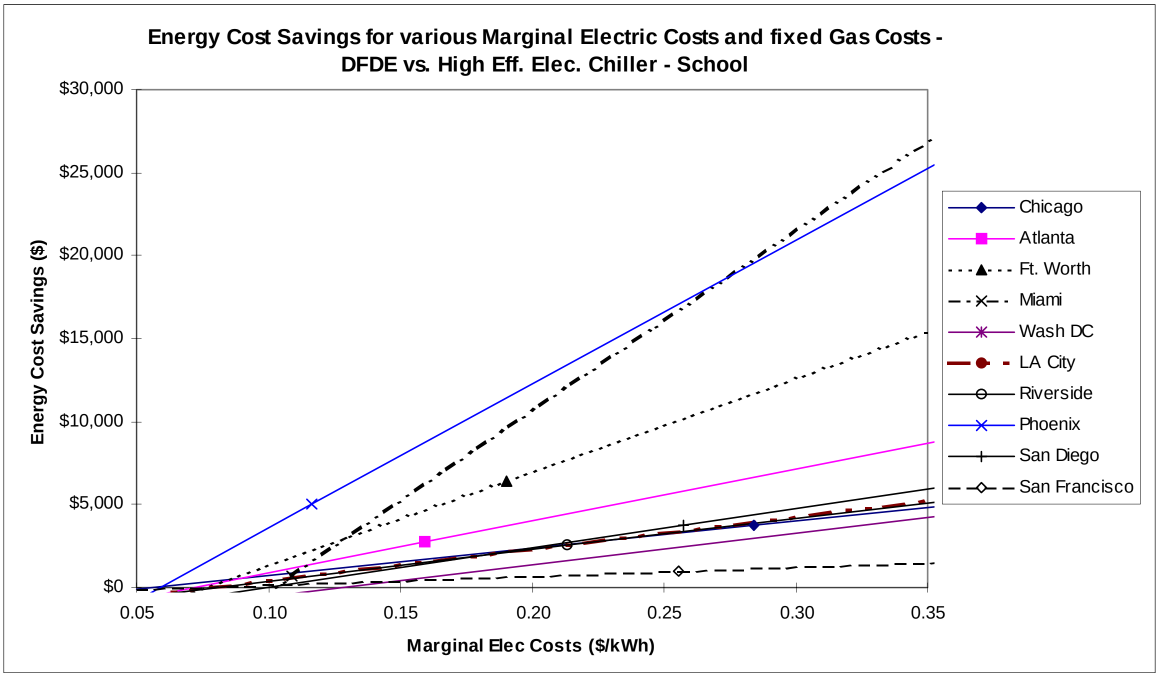
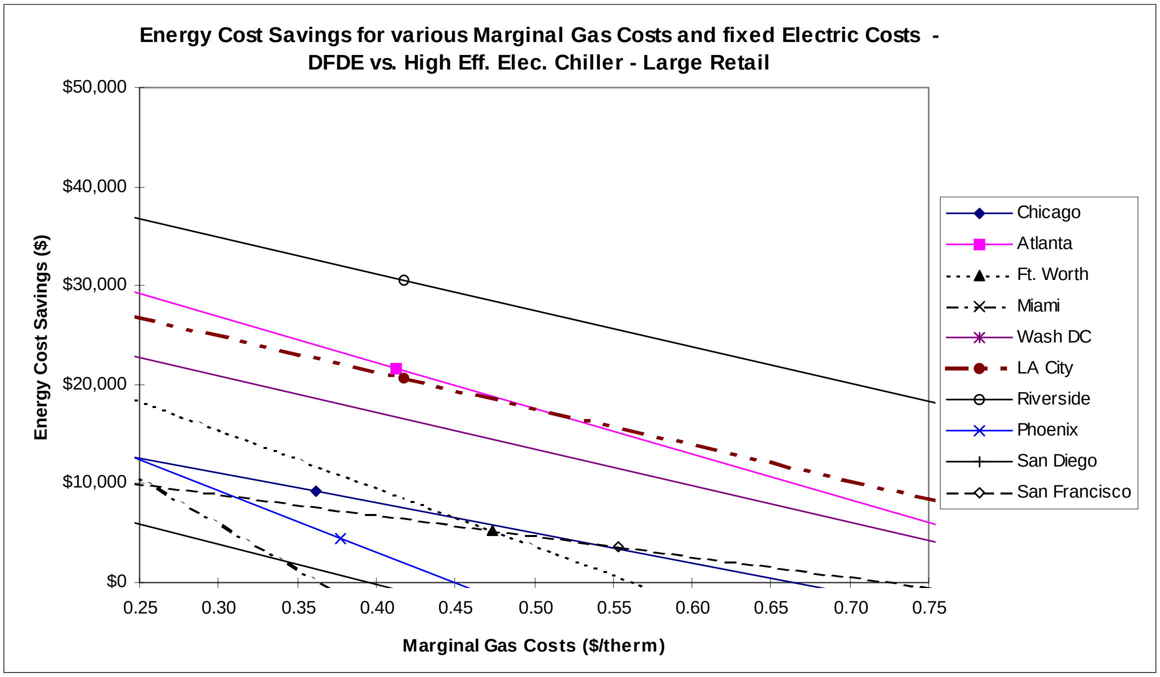


Figure 24 - Energy Cost Savings for Absorption Chiller vs. High Efficiency Chiller for School



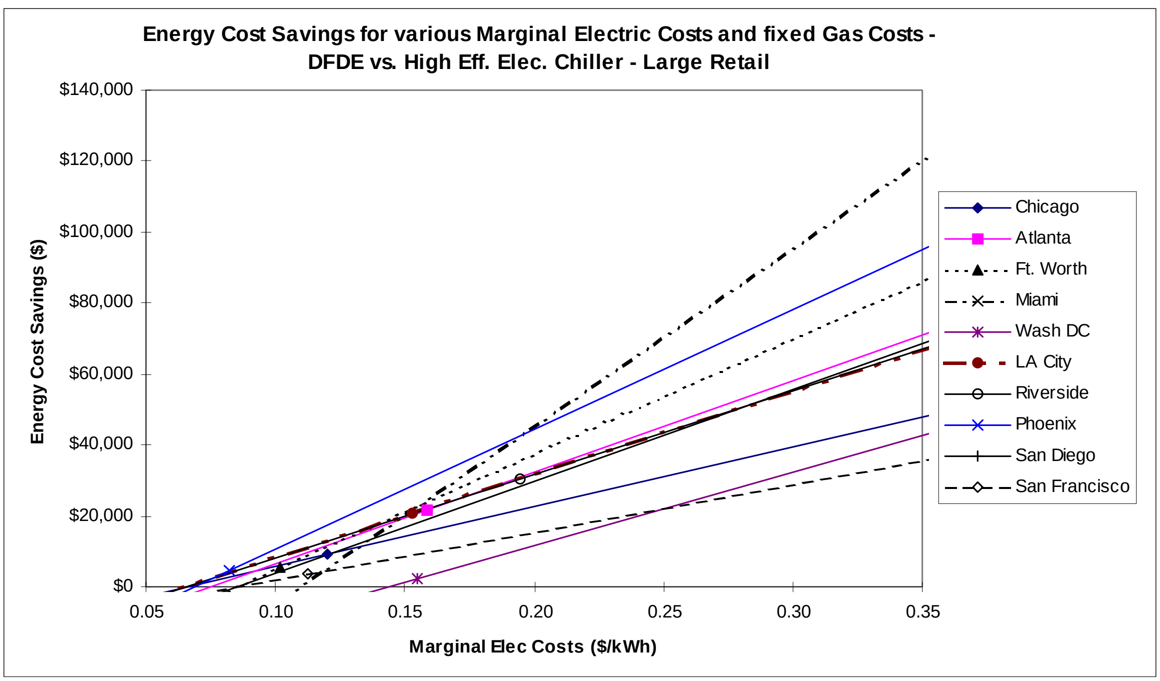


Figure 25 - Energy Cost Savings for Absorption Chiller vs. High Efficiency Chiller for Large Retail

Double vs. Single Effect Absorption Chiller

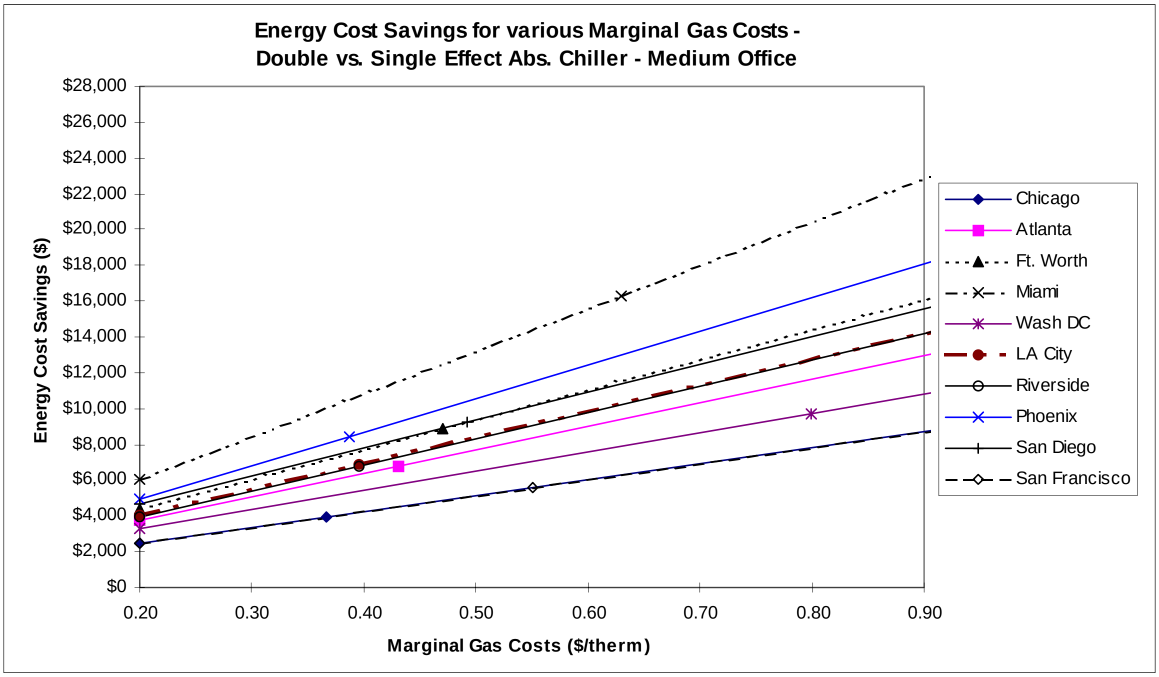


Figure 26 - Energy Cost Savings for Double vs Single Effect Absorption Chiller for Medium Office

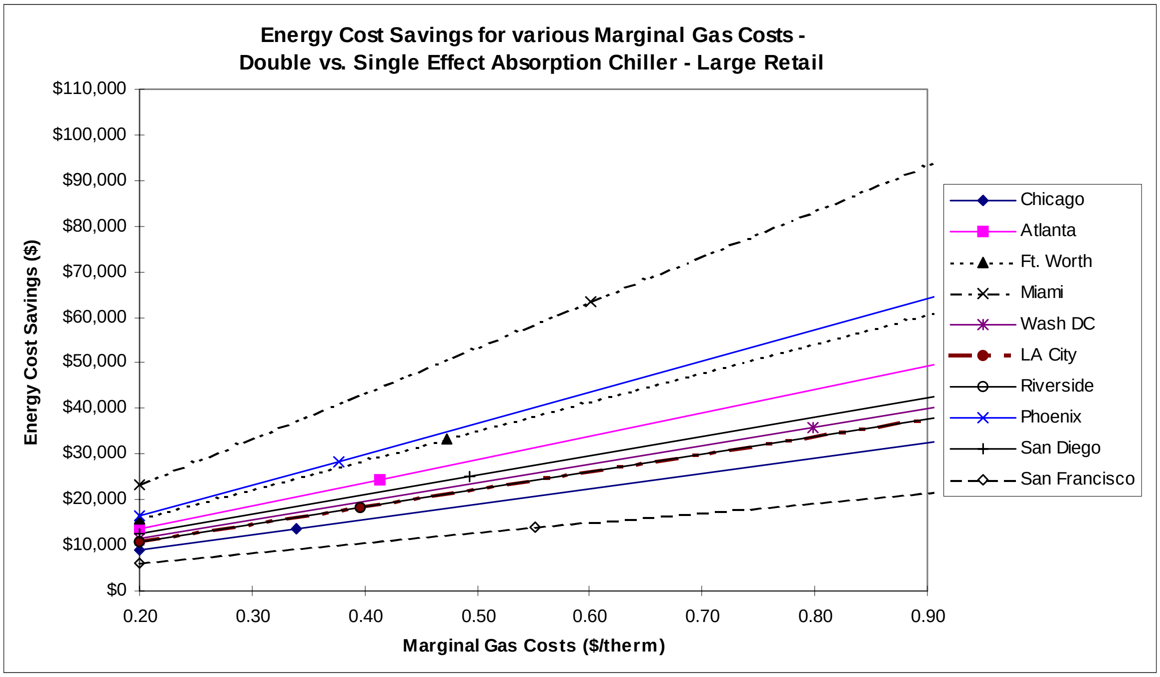


Figure 27 - Energy Cost Savings for Double vs Single Effect Absorption Chiller for Large Office

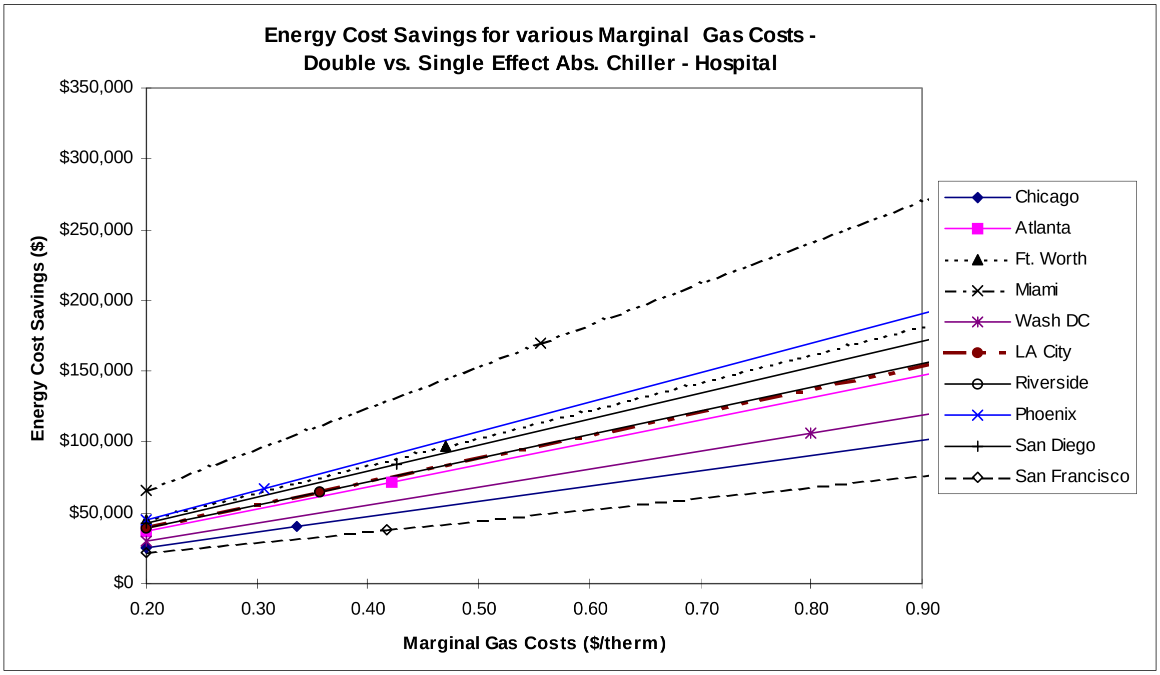


Figure 28 - Energy Cost Savings for Double vs Single Effect Absorption Chiller for Hospital

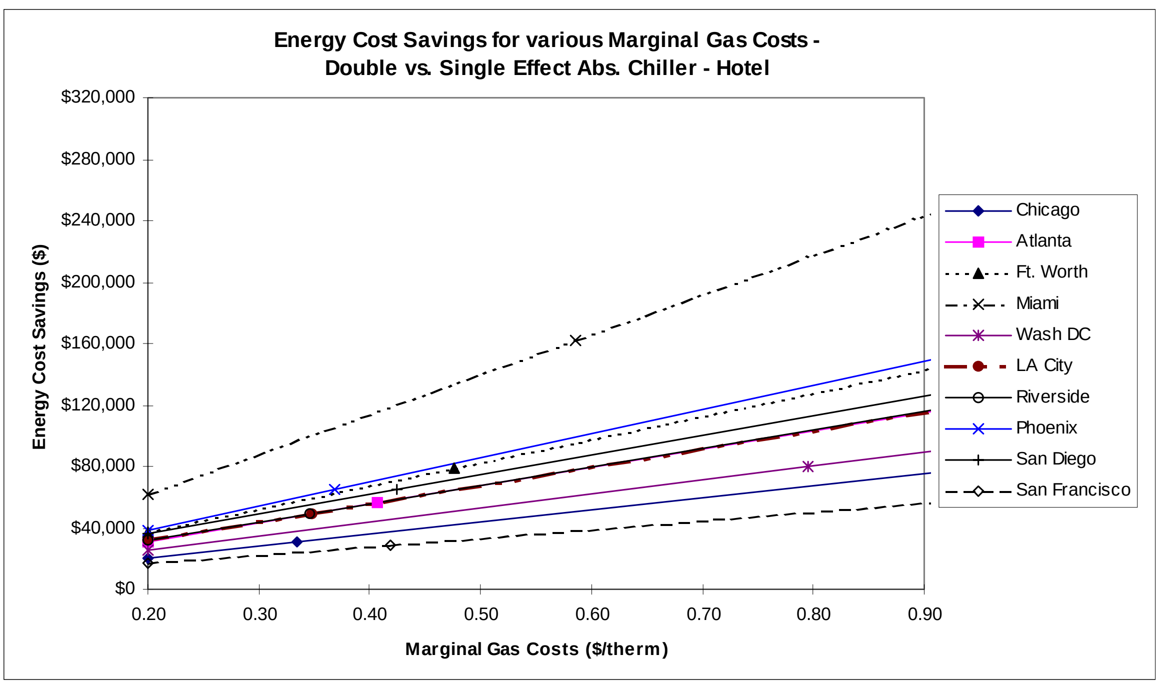


Figure 29 - Energy Cost Savings for Double vs Single Effect Absorption Chiller for Hotel

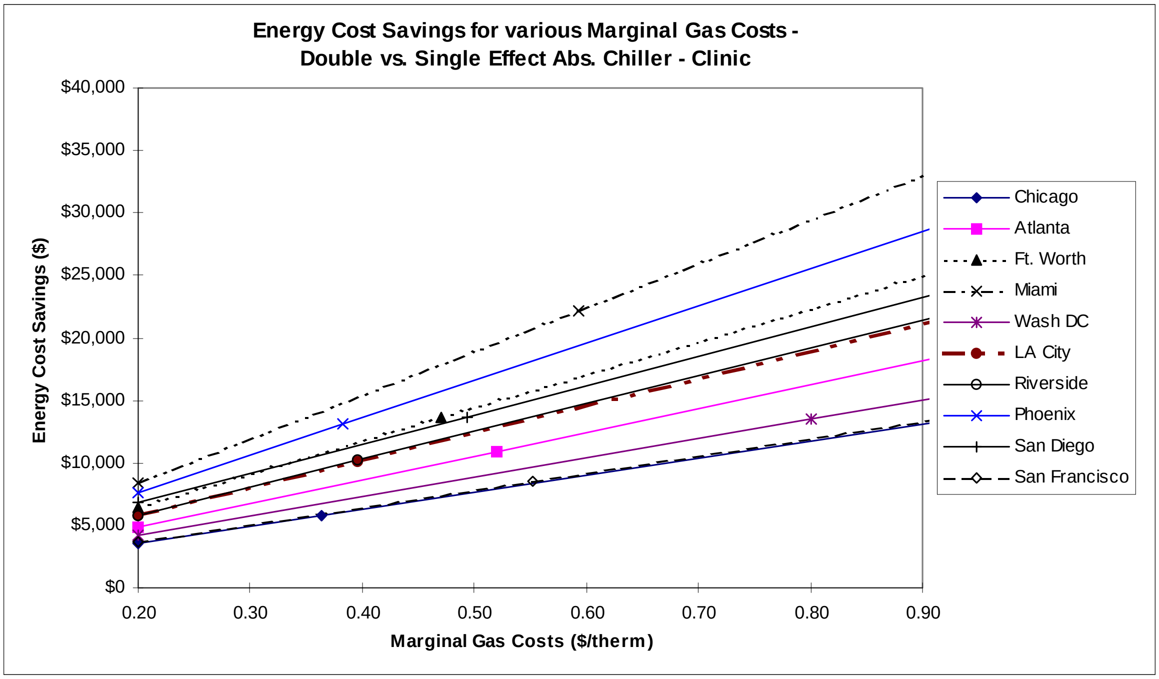


Figure 30 - Energy Cost Savings Double vs Single Effect Absorption Chiller for Clinic

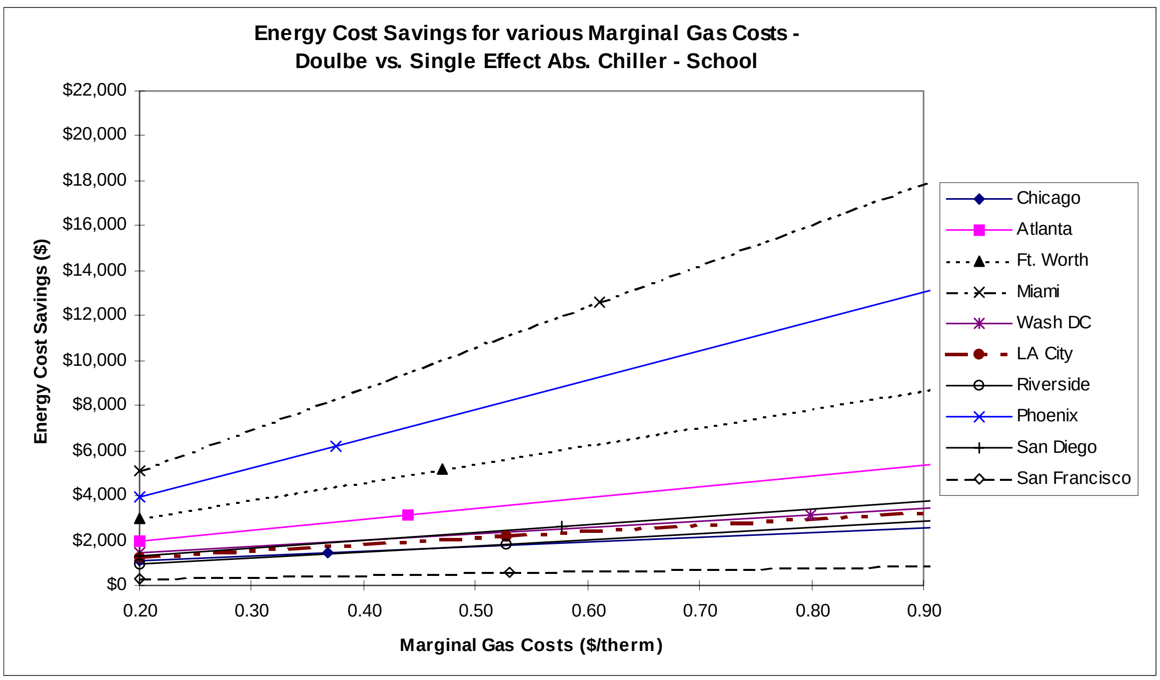


Figure 31 - Energy Cost Savings Double vs Single Effect Absorption Chiller for School

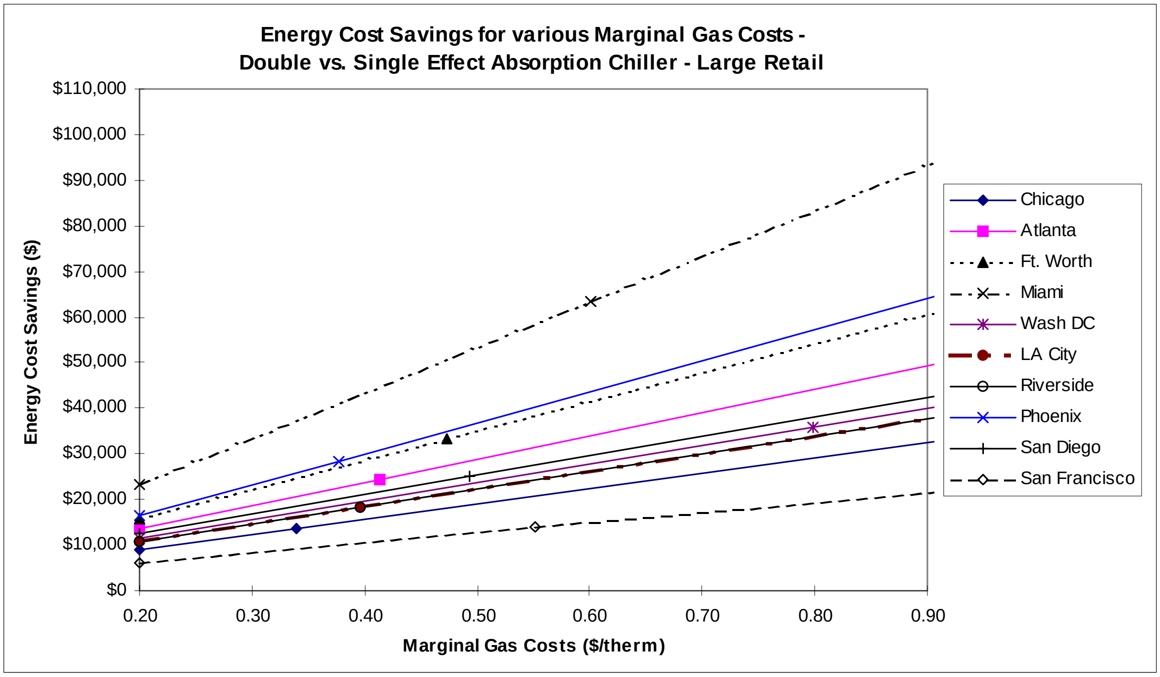


Figure 32 - Energy Cost Savings for Double vs Single Effect Absorption Chiller for Large Retail

C. Cost Effectiveness Graphs

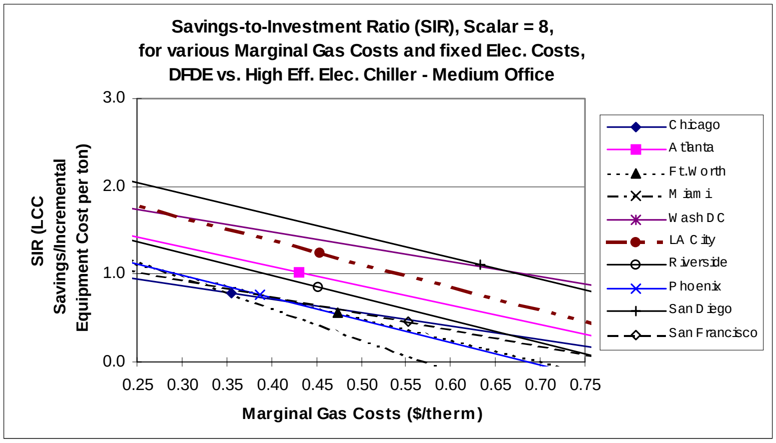
Direct Fired Double Effect (DFDE) Absorption vs. Standard Efficiency Electric Chiller

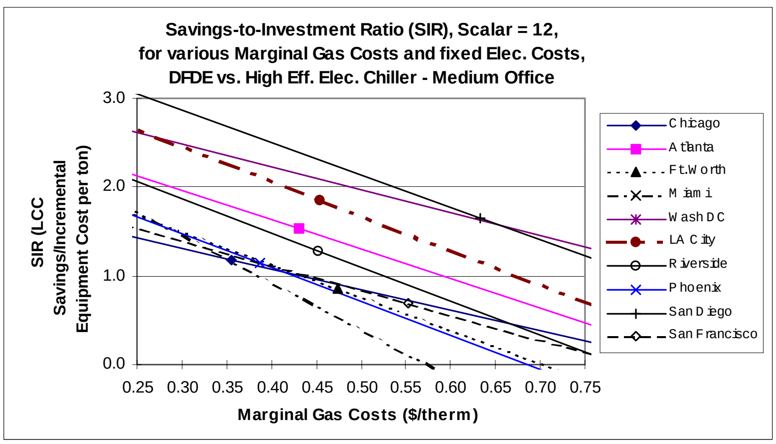
Bldg. Type	Location	Marg. Utility Rate		Scalar		
		Gas Rate	Elec.Rate	8	12	16
Medium Office	Chicago	0.37	0.13	1.00	1.50	2.00
	Atlanta	0.43	0.13	1.18	1.77	2.36
	Ft. Worth	0.47	0.11	0.86	1.29	1.72
	Miami	0.63	0.09	0.10	0.15	0.20
	Washington DC	0.80	0.19	1.08	1.62	2.16
	LA City	0.45	0.14	1.57	2.35	3.14
	Riverside	0.45	0.12	1.17	1.75	2.34
	Phoenix	0.39	0.11	1.08	1.62	2.17
	San Diego	0.63	0.16	1.46	2.19	2.92
	San Francisco	0.55	0.11	0.54	0.80	1.07
Large Office	Chicago	0.36	0.11	2.56	3.84	5.12
	Atlanta	0.44	0.14	4.36	6.54	8.72
	Ft. Worth	0.47	0.09	1.57	2.35	3.14
	Miami	0.60	0.08	-1.55	-2.32	-3.09
	Washington DC	0.80	0.16	1.56	2.34	3.12
	LA City	0.35	0.14	9.57	14.36	19.14
	Riverside	0.35	0.13	8.32	12.48	16.65
	Phoenix	0.38	0.08	1.56	2.34	3.12
	San Diego	0.49	0.15	7.82	11.73	15.64
	San Francisco	0.55	0.15	5.79	8.69	11.58
Hospital	Chicago	0.34	0.11	10.80	16.20	21.60
	Atlanta	0.42	0.14	12.48	18.71	24.95
	Ft. Worth	0.47	0.09	-3.53	-5.30	-7.06
	Miami	0.56	0.08	-10.87	-16.31	-21.74
	Washington DC	0.80	0.16	-5.49	-8.23	-10.97
	LA City	0.34	0.14	8.45	12.67	16.90
	Riverside	0.34	0.13	6.91	10.36	13.81
	Phoenix	0.31	0.08	3.40	5.09	6.79
	San Diego	0.43	0.15	8.52	12.78	17.04
	San Francisco	0.42	0.15	6.73	10.10	13.47

Figure 33 - SIR for DFDE vs. Std. Eff. Electric Chillers

Bldg. Type	Location	Marg. Utility Rate Gas Rate	Elec.Rate	Scalar 8	12	16
Hotel	Chicago	0.34	0.13	4.36	6.53	8.71
	Atlanta	0.41	0.10	1.88	2.82	3.76
	Ft. Worth	0.48	0.08	-3.73	-5.59	-7.45
	Miami	0.59	0.06	-14.80	-22.20	-29.60
	Washington DC	0.80	0.11	-5.30	-7.95	-10.61
	LA City	0.38	0.12	4.40	6.59	8.79
	Riverside	0.38	0.11	3.20	4.79	6.39
	Phoenix	0.37	0.07	-1.53	-2.29	-3.05
	San Diego	0.46	0.13	3.82	5.73	7.64
	San Francisco	0.42	0.14	3.04	4.56	6.08
Medical Clinic	Chicago	0.37	0.09	0.75	1.12	1.50
	Atlanta	0.52	0.09	0.73	1.10	1.47
	Ft. Worth	0.47	0.07	0.33	0.50	0.66
	Miami	0.59	0.07	-0.27	-0.41	-0.54
	Washington DC	0.80	0.12	0.35	0.52	0.69
	LA City	0.36	0.10	1.85	2.78	3.70
	Riverside	0.36	0.10	1.65	2.48	3.30
	Phoenix	0.38	0.08	0.94	1.41	1.88
	San Diego	0.50	0.14	2.30	3.45	4.60
	San Francisco	0.55	0.10	0.87	1.31	1.75
School	Chicago	0.38	0.29	0.89	1.34	1.78
	Atlanta	0.44	0.15	0.62	0.92	1.23
	Ft. Worth	0.48	0.19	1.39	2.08	2.77
	Miami	0.61	0.11	0.49	0.74	0.99
	Washington DC	0.80	0.38	1.08	1.61	2.15
	LA City	0.55	0.39	1.51	2.26	3.01
	Riverside	0.55	0.22	0.65	0.98	1.31
	Phoenix	0.37	0.12	1.05	1.58	2.11
	San Diego	0.69	0.26	0.87	1.30	1.74
	San Francisco	0.53	0.26	0.28	0.43	0.57
Large Retail	Chicago	0.36	0.12	2.48	3.72	4.96
	Atlanta	0.41	0.16	5.36	8.04	10.72
	Ft. Worth	0.47	0.10	1.96	2.94	3.92
	Miami	0.60	0.07	-2.35	-3.52	-4.69
	Washington DC	0.80	0.15	1.47	2.20	2.94
	LA City	0.42	0.15	5.30	7.94	10.59
	Riverside	0.42	0.18	6.73	10.09	13.46
	Phoenix	0.38	0.08	1.47	2.20	2.94
	San Diego	0.54	0.08	0.26	0.39	0.52
	San Francisco	0.55	0.11	1.50	2.26	3.01

Figure 33 (continued) – SIR for DFDE vs. Std. Eff. Electric Chillers





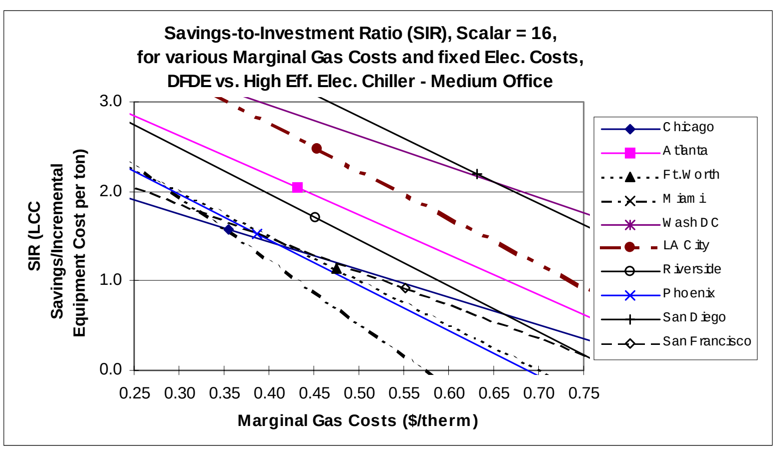


Figure 34 - SIR for various marginal gas costs for Medium Office, DFDE vs. Std. Eff. Chiller

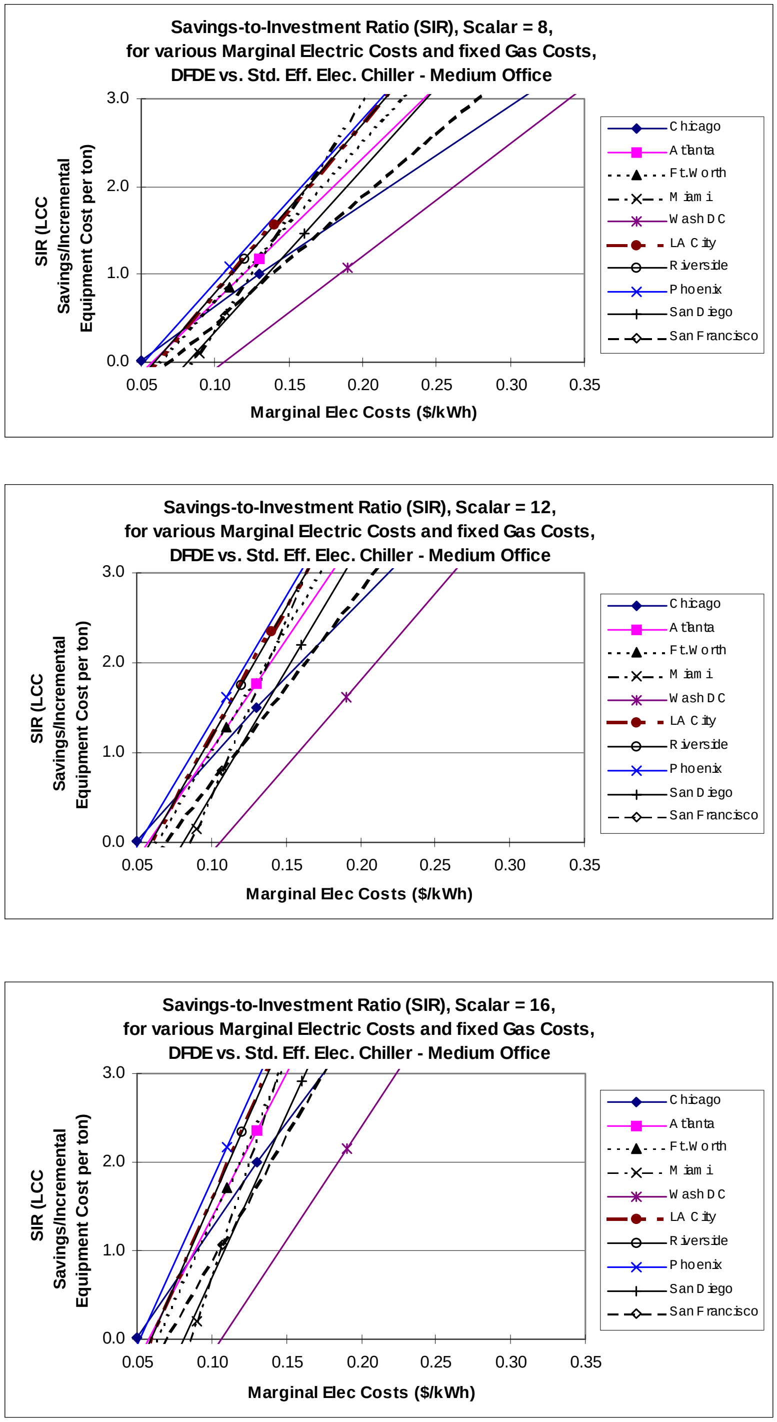
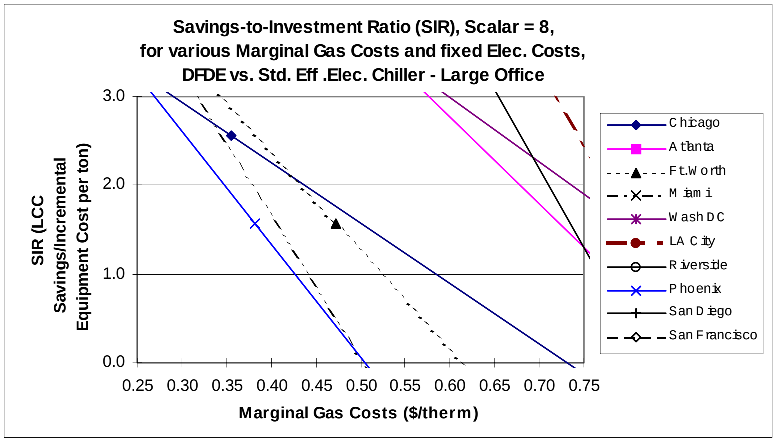
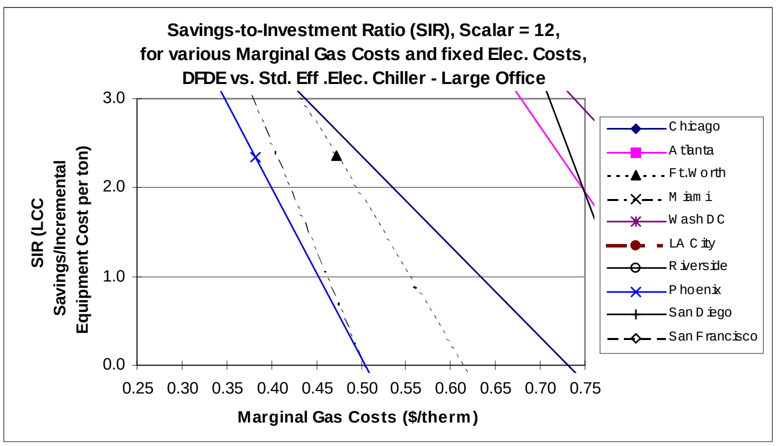


Figure 35 - SIR for various marginal electric costs for Medium Office, DFDE vs. Std. Eff. Chiller





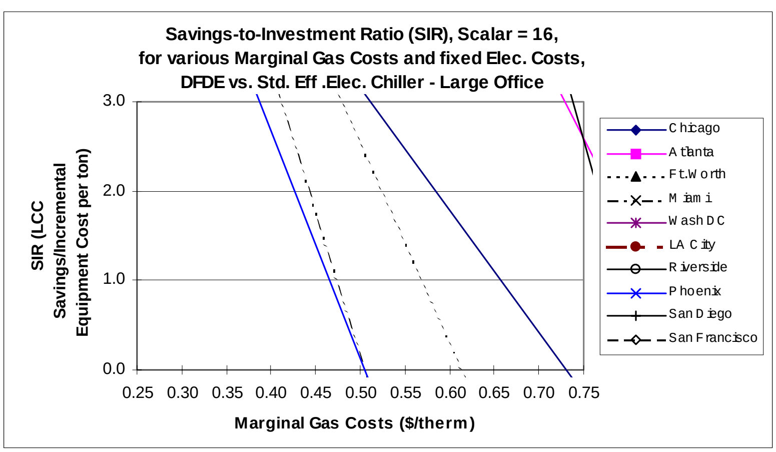
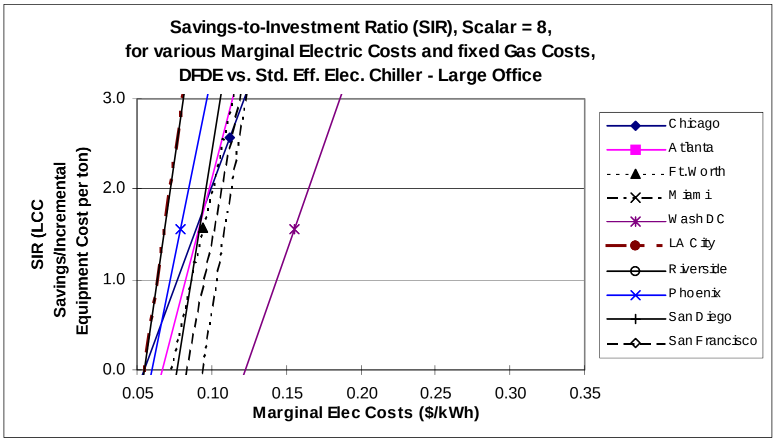
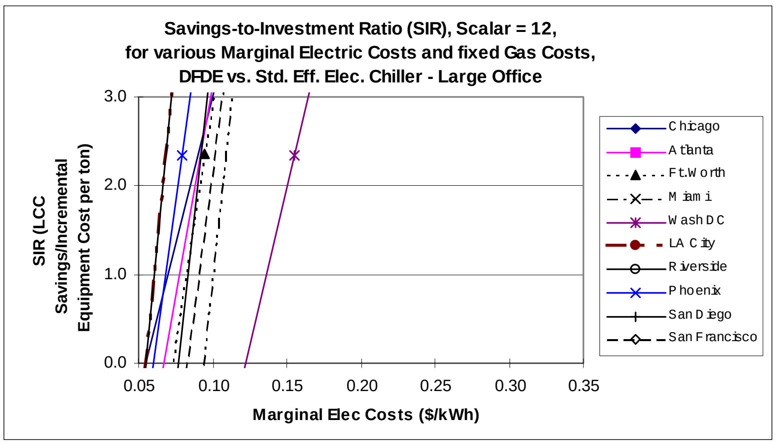


Figure 36 - SIR for various marginal gas costs for Large Office, DFDE vs. Std. Eff. Chiller





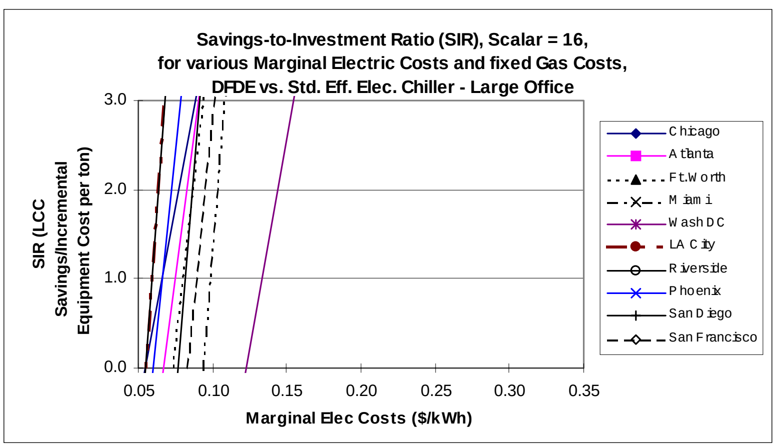
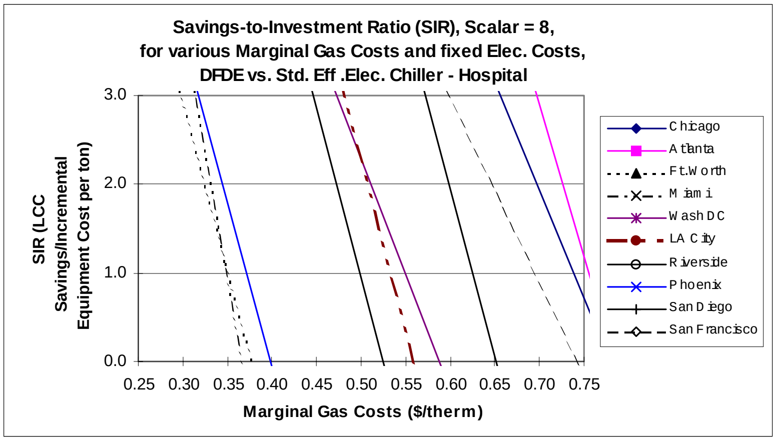
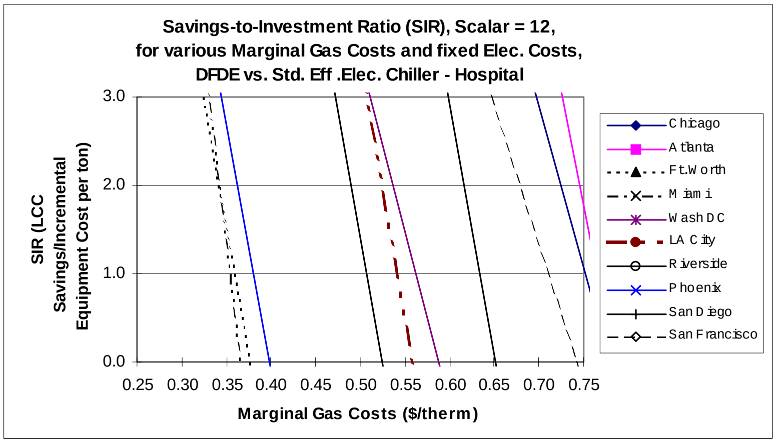


Figure 37 - SIR for various marginal electric costs for Large Office, DFDE vs. Std. Eff. Chiller





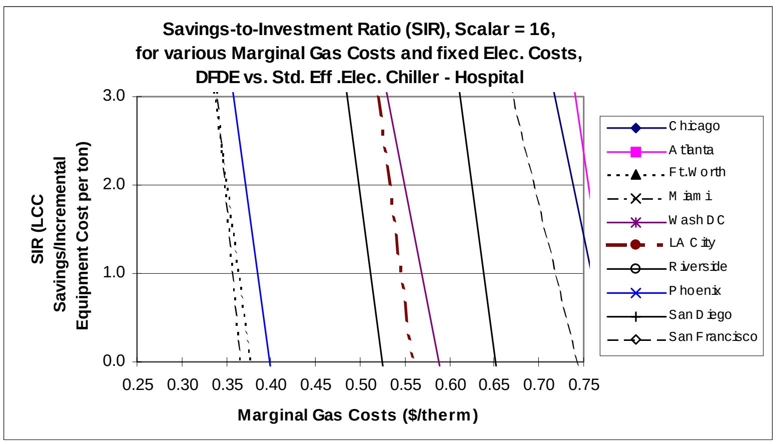
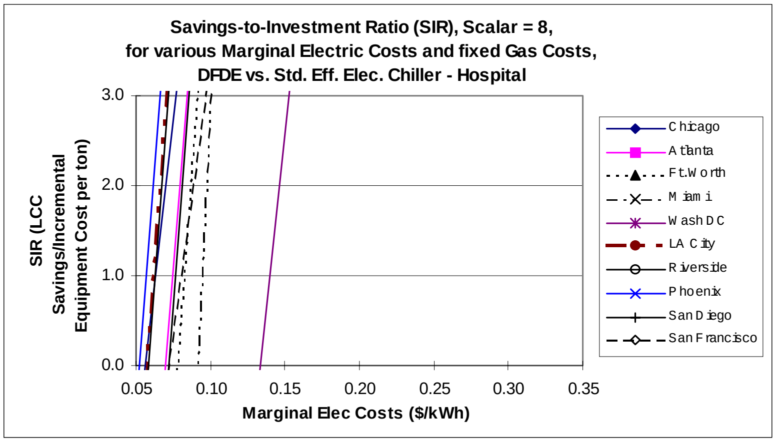
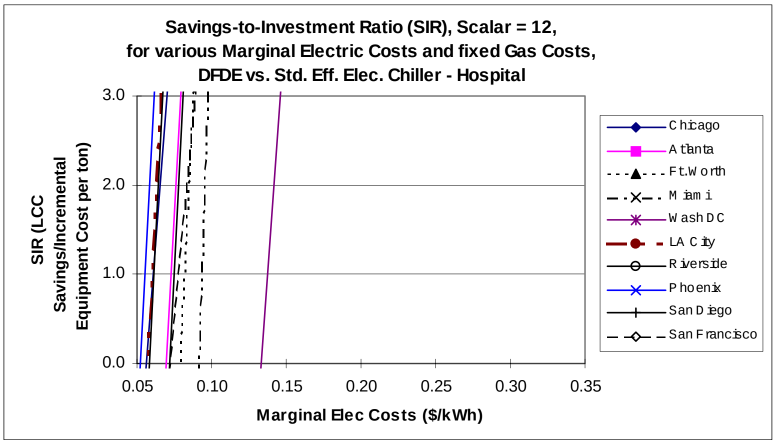


Figure 38 - SIR for various marginal gas costs for Hospital, DFDE vs. Std. Eff. Chiller





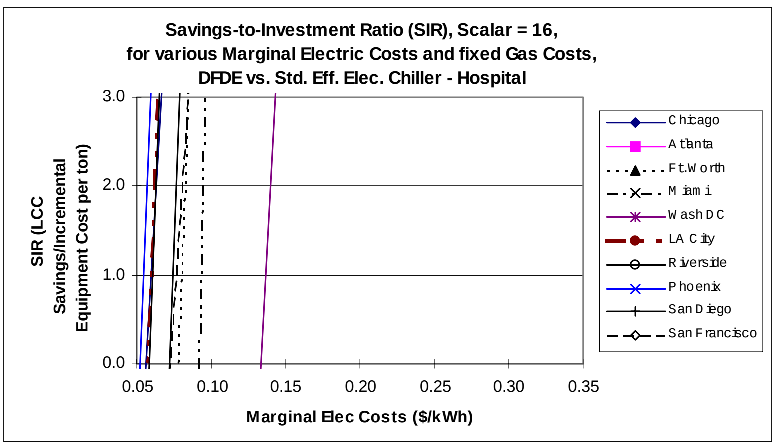
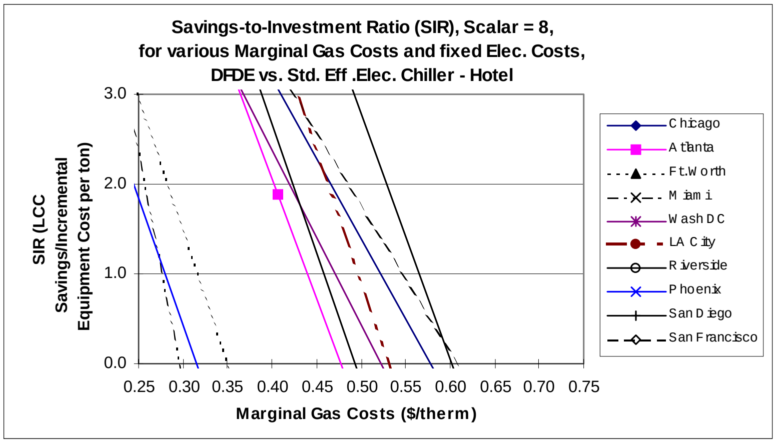
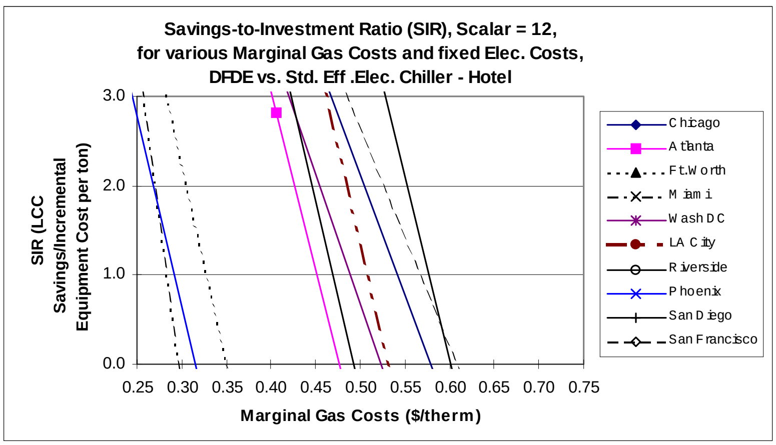


Figure 39 - SIR for various marginal electric costs for Hospital, DFDE vs. Std. Eff. Chiller





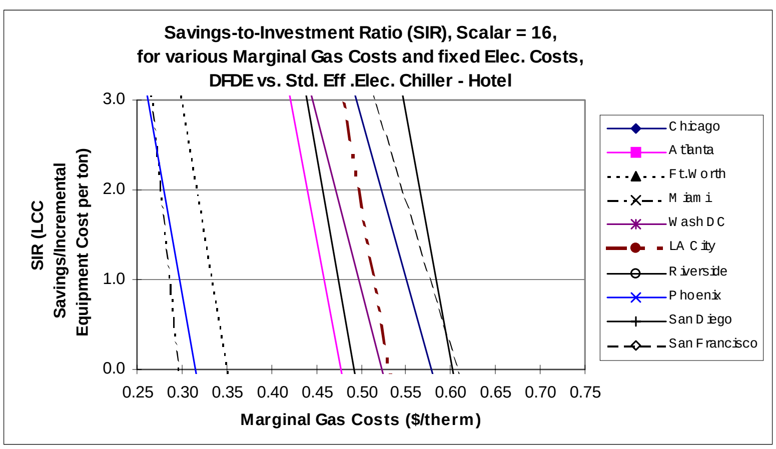
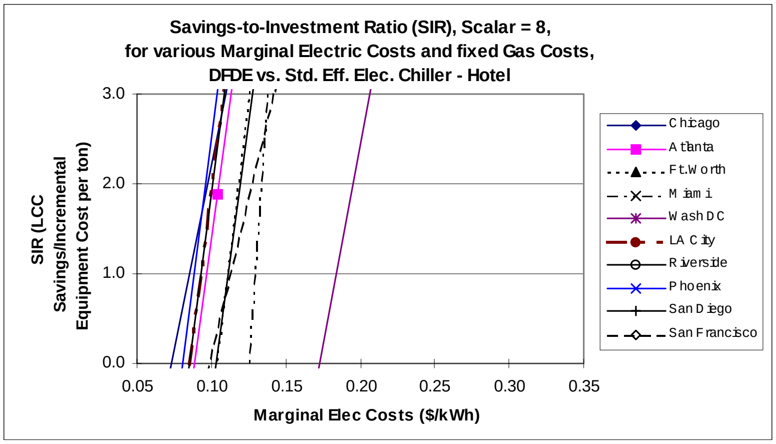
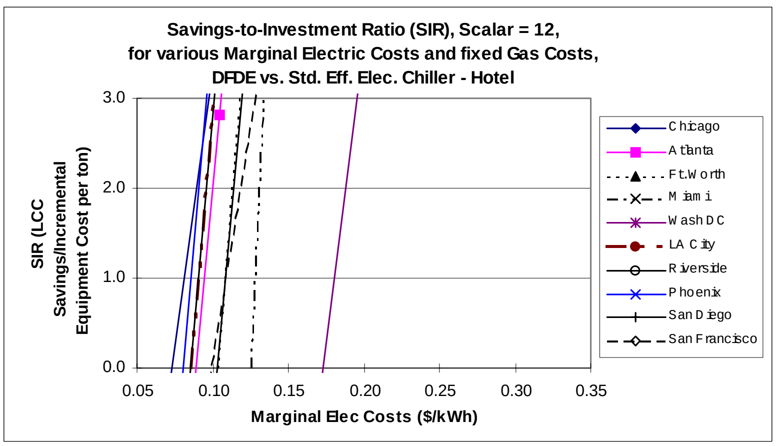


Figure 40 - SIR for various marginal gas costs for Hotel, DFDE vs. Std. Eff. Chiller





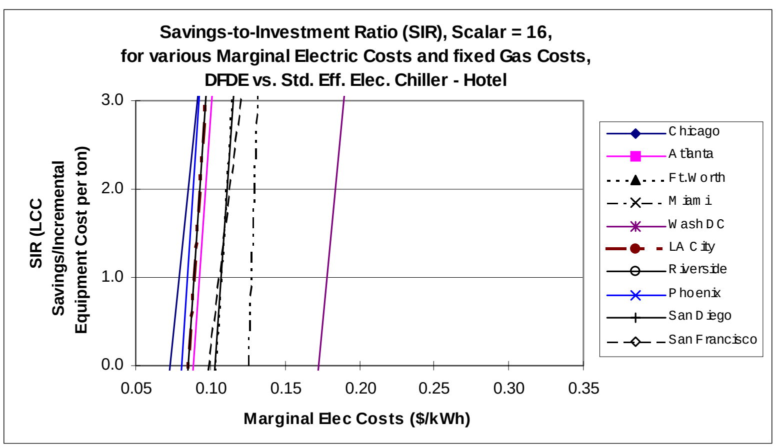


Figure 41 - SIR for various marginal electric costs for Hotel, DFDE vs. Std. Eff. Chiller

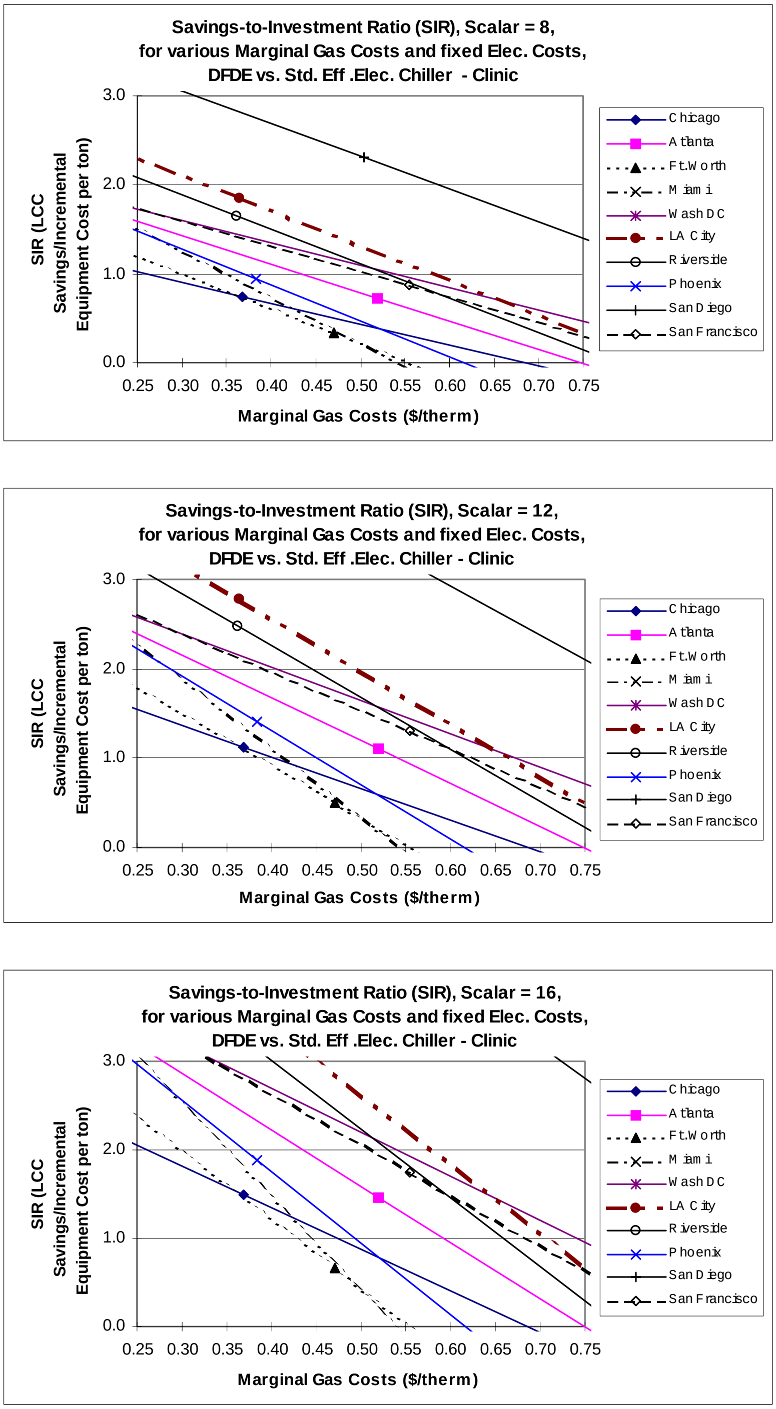


Figure 42 - SIR for various marginal gas costs for Clinic, DFDE vs. Std. Eff. Chiller

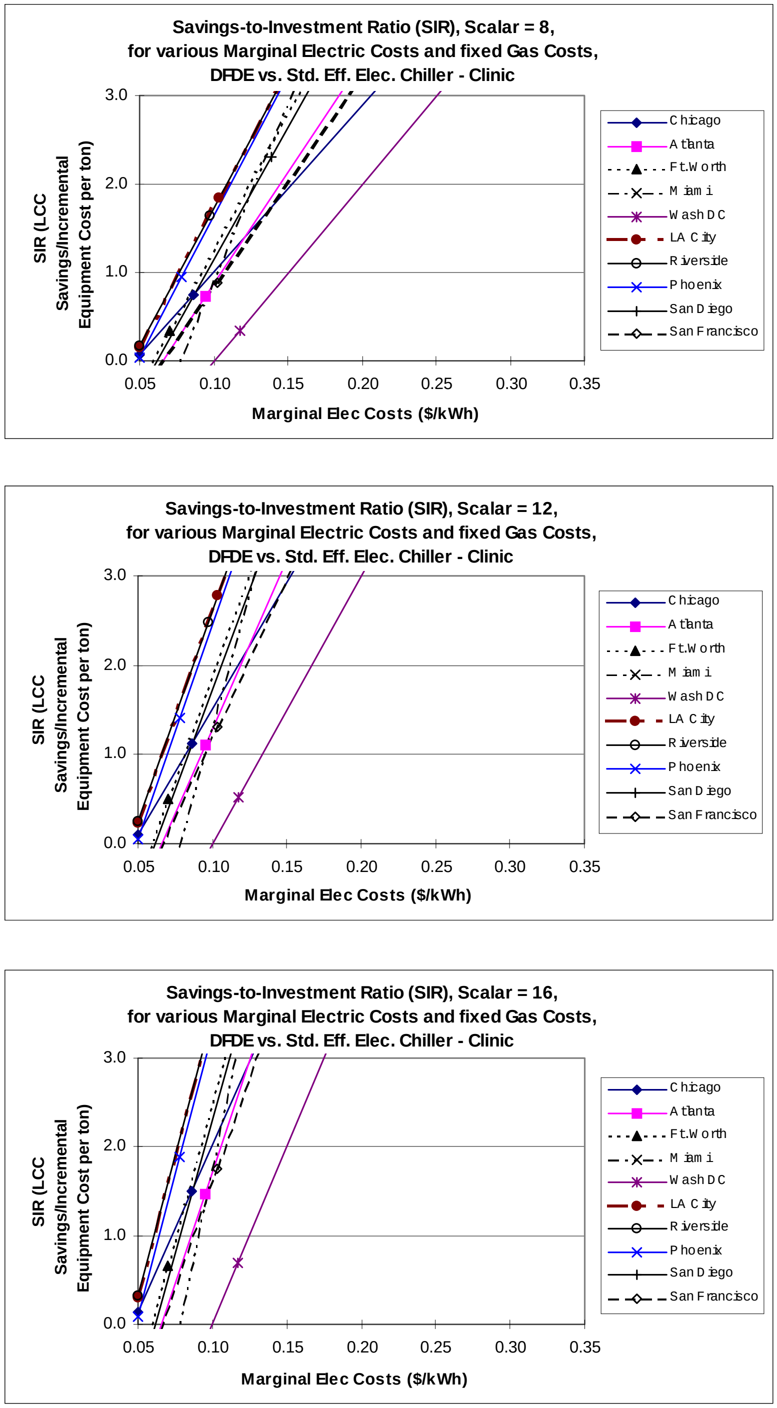


Figure 43 - SIR for various marginal electric costs for Clinic, DFDE vs. Std. Eff. Chiller

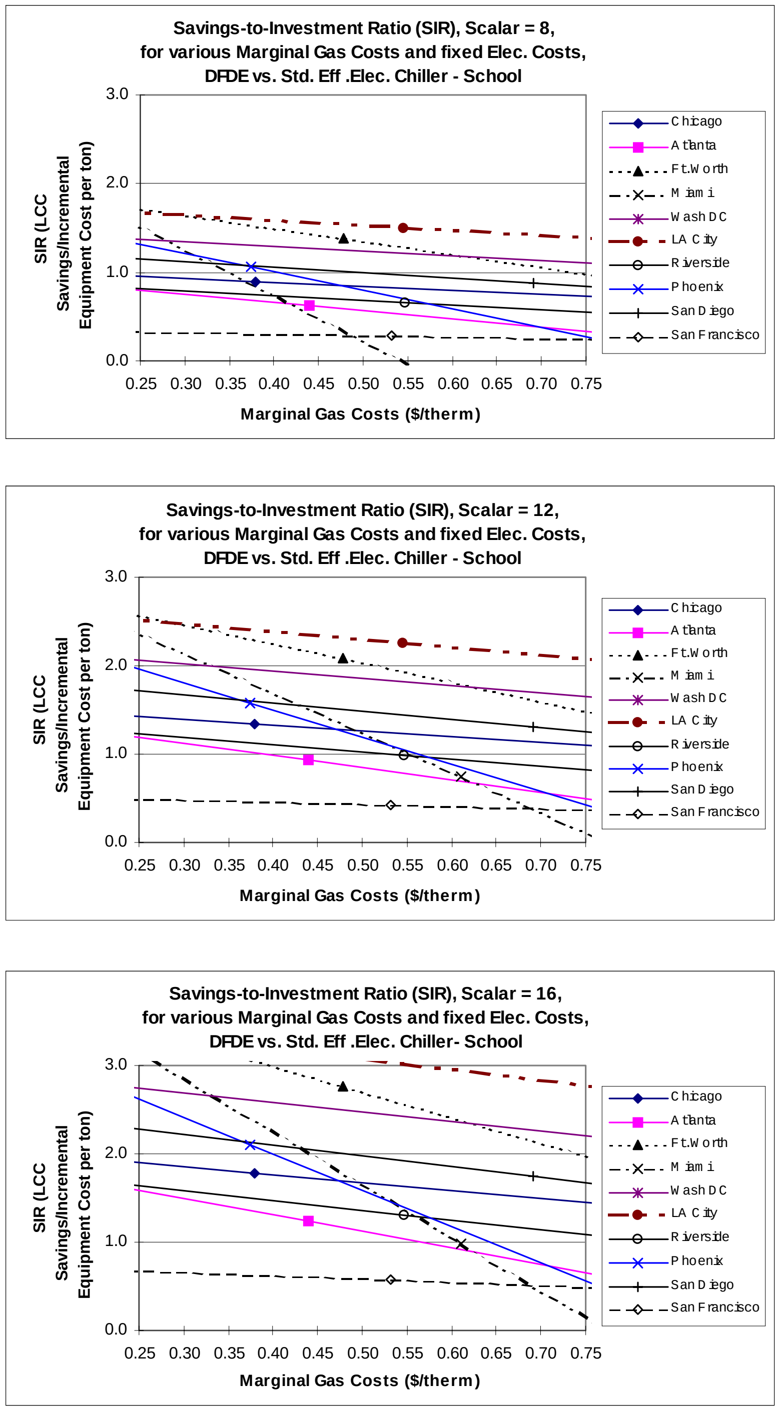
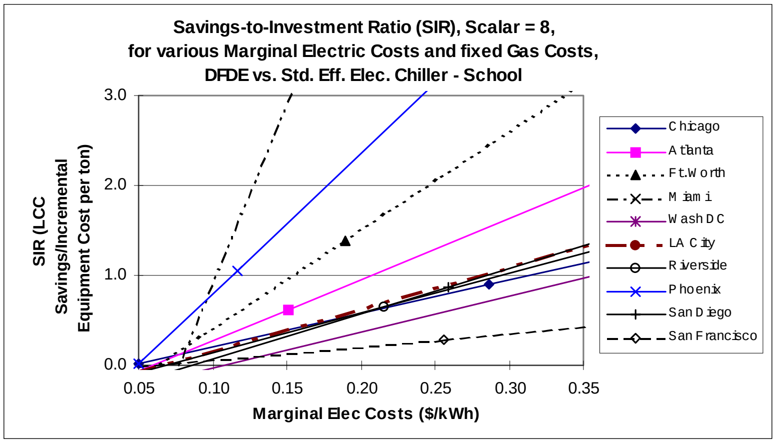
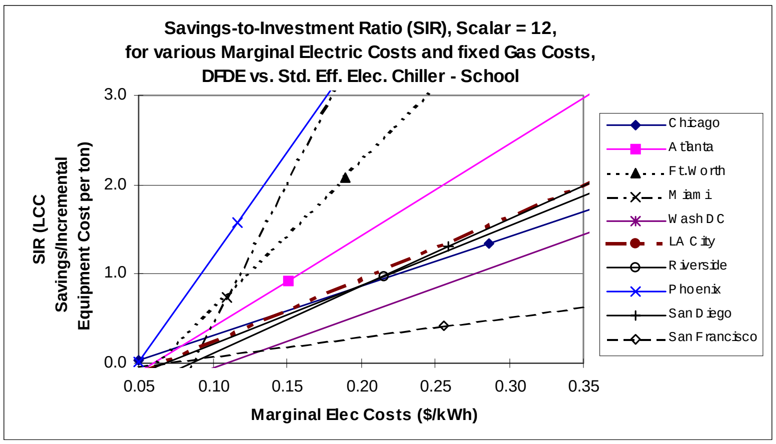


Figure 44 - SIR for various marginal gas costs for School, DFDE vs. Std. Eff. Chiller





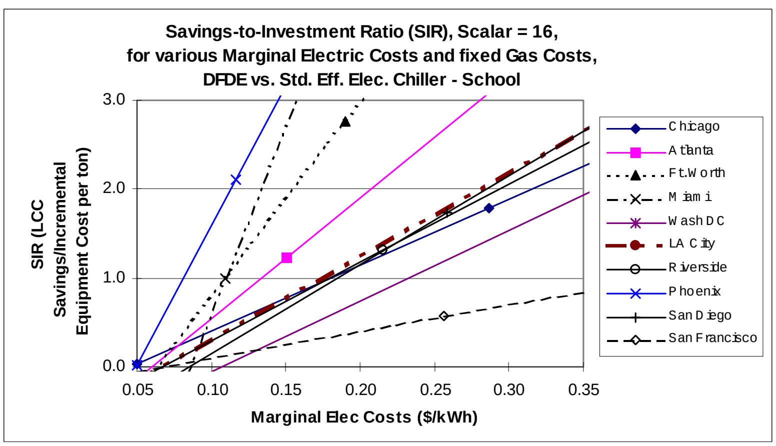


Figure 45 - SIR for various marginal electric costs for School, DFDE vs. Std. Eff. Chiller

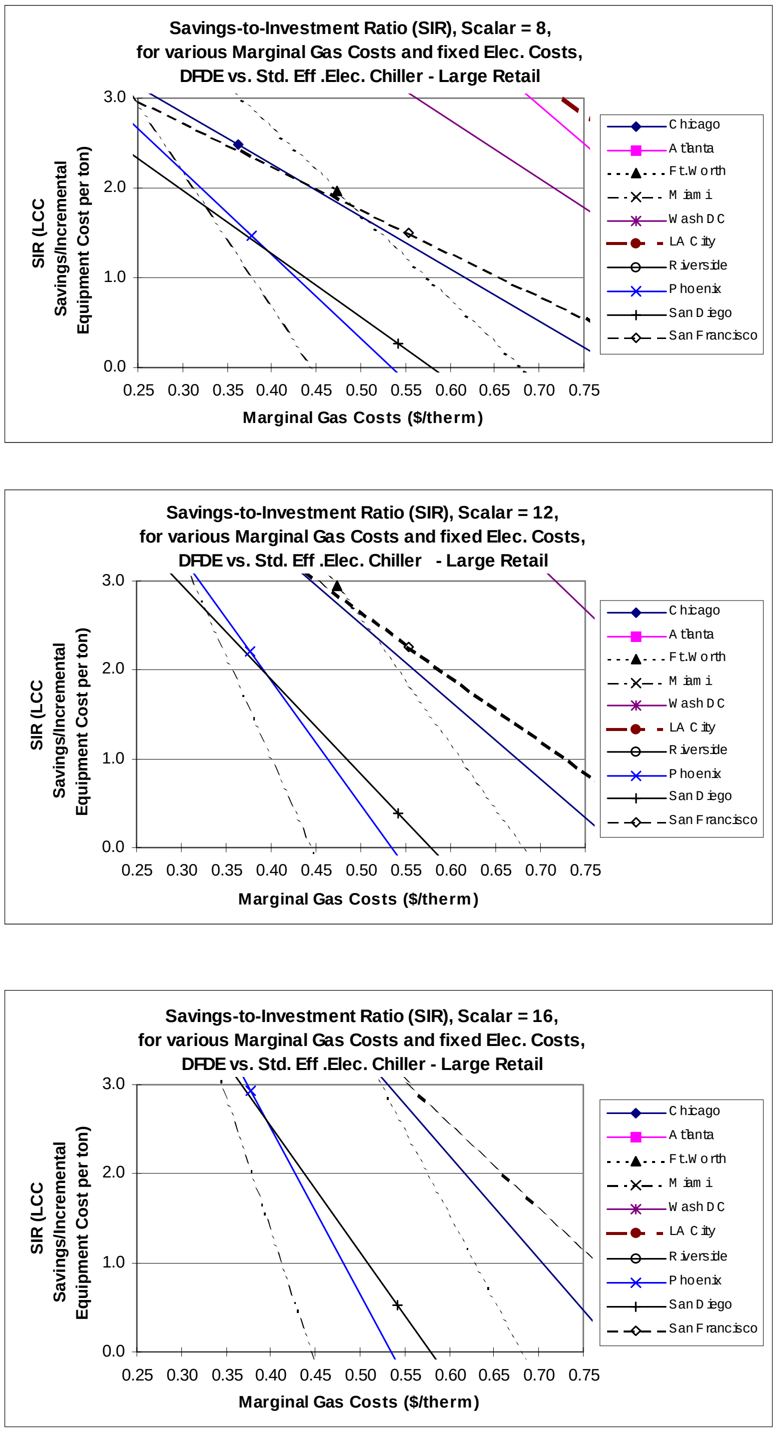


Figure 46 - SIR for various marginal gas costs for Large Retail, DFDE vs. Std. Eff. Chiller

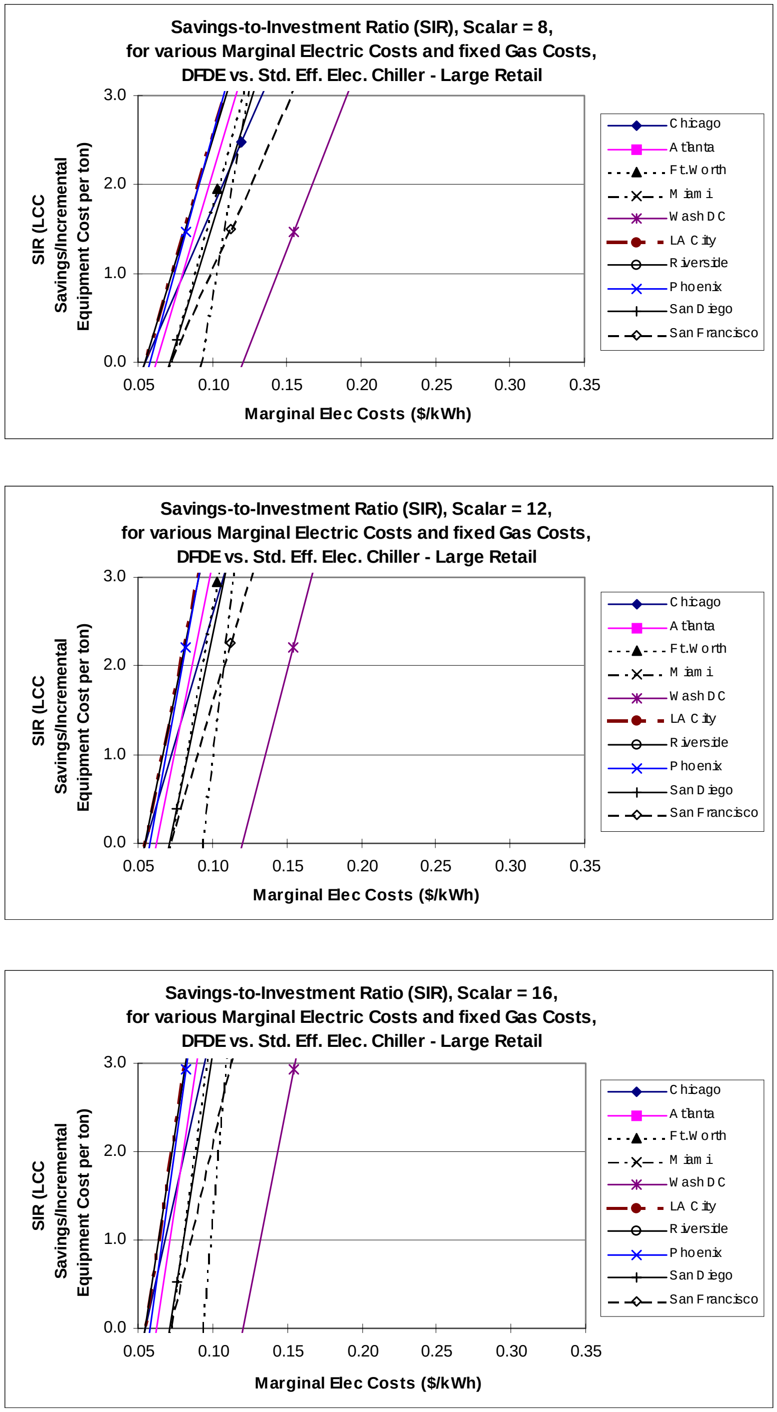


Figure 47 - SIR for various marginal electric costs for Large Retail, DFDE vs. Std. Eff. Chiller

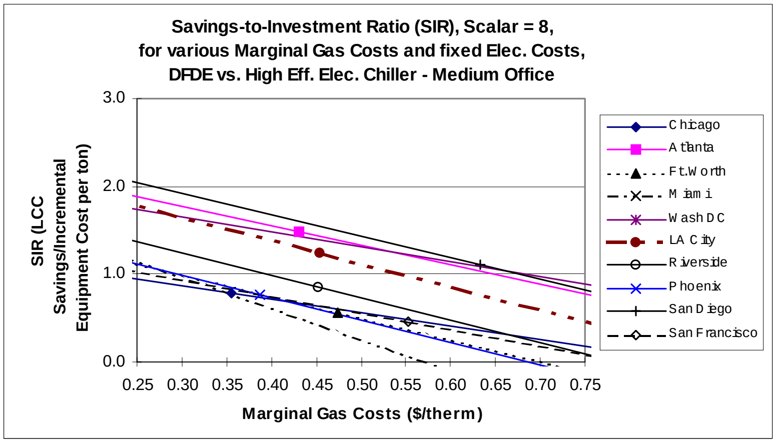
Direct Fired Double Effect (DFDE) Absorption Chiller vs. High Efficiency Electric Chiller

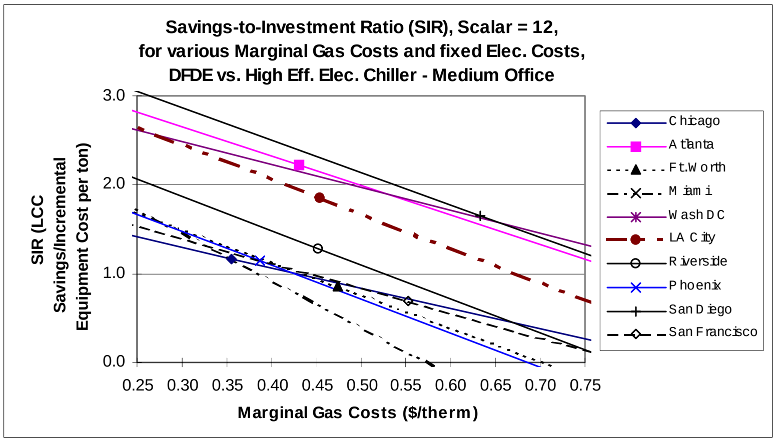
Bldg. Type	Location	Marg. Utility Rate		Scalar		
		Gas Rate	Elec.Rate	8	12	16
Medium Office	Chicago	0.36	0.13	0.79	1.18	1.58
	Atlanta	0.43	0.14	1.02	1.53	2.04
	Ft. Worth	0.47	0.11	0.57	0.85	1.14
	Miami	0.63	0.09	-0.20	-0.31	-0.41
	Washington DC	0.80	0.19	0.79	1.19	1.59
	LA City	0.45	0.14	1.24	1.86	2.48
	Riverside	0.45	0.12	0.86	1.28	1.71
	Phoenix	0.39	0.11	0.77	1.15	1.53
	San Diego	0.63	0.16	1.10	1.65	2.20
	San Francisco	0.55	0.11	0.46	0.70	0.93
Large Office	Chicago	0.36	0.11	1.70	2.55	3.40
	Atlanta	0.44	0.13	2.88	4.31	5.75
	Ft. Worth	0.47	0.09	0.29	0.44	0.58
	Miami	0.60	0.08	-2.88	-4.32	-5.76
	Washington DC	0.80	0.15	0.33	0.50	0.66
	LA City	0.35	0.14	7.01	10.52	14.03
	Riverside	0.35	0.13	5.99	8.98	11.97
	Phoenix	0.38	0.08	0.52	0.78	1.04
	San Diego	0.49	0.15	5.33	8.00	10.66
	San Francisco	0.55	0.15	3.74	5.61	7.48
Hospital	Chicago	0.34	0.14	8.93	13.39	17.86
	Atlanta	0.42	0.07	-2.27	-3.41	-4.54
	Ft. Worth	0.47	0.06	-5.74	-8.61	-11.48
	Miami	0.56	0.06	-14.11	-21.16	-28.21
	Washington DC	0.80	0.10	-7.87	-11.80	-15.73
	LA City	0.34	0.09	5.09	7.64	10.19
	Riverside	0.34	0.09	3.79	5.68	7.58
	Phoenix	0.31	0.07	1.10	1.65	2.19
	San Diego	0.43	0.11	4.69	7.04	9.38
	San Francisco	0.42	0.13	4.35	6.52	8.70

Figure 48 - SIR for DFDE vs. High Eff. Electric Chillers

Bldg. Type	Location	Marg. Utility Rate		Scalar		
		Gas Rate	Elec.Rate	8	12	16
Hotel	Chicago	0.34	0.08	-0.24	-0.36	-0.48
	Atlanta	0.41	0.10	-0.50	-0.74	-0.99
	Ft. Worth	0.48	0.07	-5.73	-8.60	-11.47
	Miami	0.59	0.06	-17.29	-25.94	-34.58
	Washington DC	0.80	0.11	-7.04	-10.57	-14.09
	LA City	0.38	0.12	1.70	2.55	3.40
	Riverside	0.38	0.11	0.71	1.07	1.42
	Phoenix	0.37	0.07	-3.03	-4.55	-6.07
	San Diego	0.46	0.13	0.96	1.43	1.91
	San Francisco	0.42	0.14	1.19	1.78	2.38
Medical Clinic	Chicago	0.37	0.09	0.48	0.72	0.97
	Atlanta	0.52	0.09	0.33	0.49	0.66
	Ft. Worth	0.47	0.07	-0.03	-0.04	-0.06
	Miami	0.59	0.07	-0.72	-1.08	-1.44
	Washington DC	0.80	0.12	-0.04	-0.05	-0.07
	LA City	0.36	0.10	1.33	1.99	2.65
	Riverside	0.36	0.10	1.16	1.75	2.33
	Phoenix	0.38	0.08	0.56	0.85	1.13
	San Diego	0.50	0.14	1.63	2.45	3.26
	San Francisco	0.55	0.10	0.48	0.71	0.95
School	Chicago	0.38	0.28	0.71	1.07	1.42
	Atlanta	0.44	0.16	0.50	0.75	1.00
	Ft. Worth	0.48	0.19	1.05	1.58	2.10
	Miami	0.61	0.11	0.12	0.18	0.24
	Washington DC	0.80	0.38	0.83	1.24	1.65
	LA City	0.55	0.39	1.21	1.81	2.42
	Riverside	0.55	0.21	0.49	0.74	0.99
	Phoenix	0.37	0.12	0.76	1.14	1.52
	San Diego	0.69	0.26	0.66	0.98	1.31
	San Francisco	0.53	0.26	0.22	0.33	0.44
Large Retail	Chicago	0.36	0.12	1.75	2.63	3.51
	Atlanta	0.41	0.16	3.98	5.97	7.96
	Ft. Worth	0.47	0.10	0.87	1.30	1.73
	Miami	0.60	0.07	-3.54	-5.31	-7.08
	Washington DC	0.80	0.15	0.42	0.63	0.84
	LA City	0.42	0.15	4.18	6.26	8.35
	Riverside	0.42	0.19	6.00	9.00	12.00
	Phoenix	0.38	0.08	0.68	1.03	1.37
	San Diego	0.54	0.06	-1.03	-1.55	-2.07
	San Francisco	0.55	0.11	0.83	1.24	1.66

Figure 48 (continued) - SIR for DFDE vs. High Eff. Electric Chillers





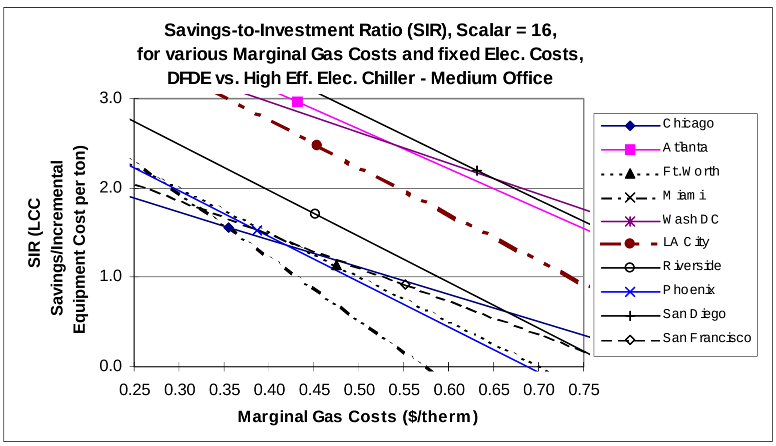
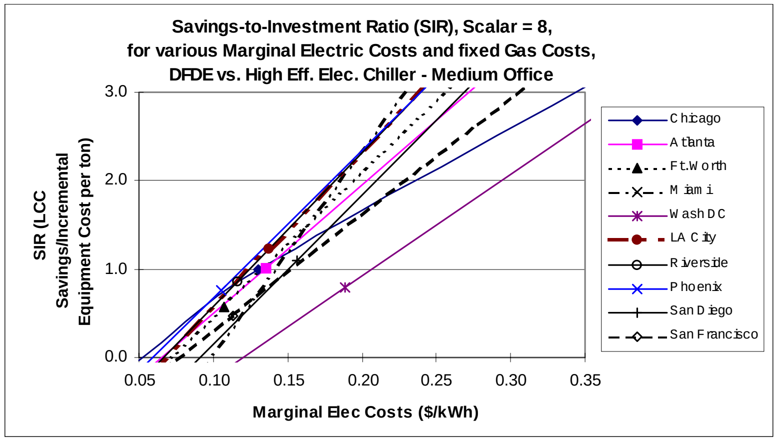
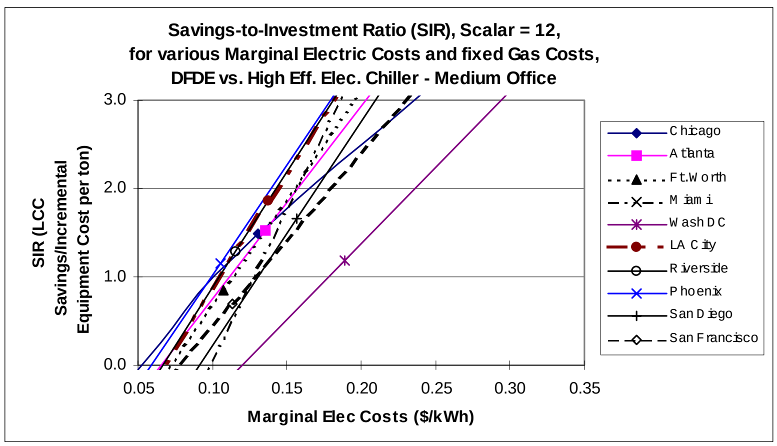


Figure 49 - SIR for various marginal gas costs for Medium Office, DFDE vs. High Eff. Chiller





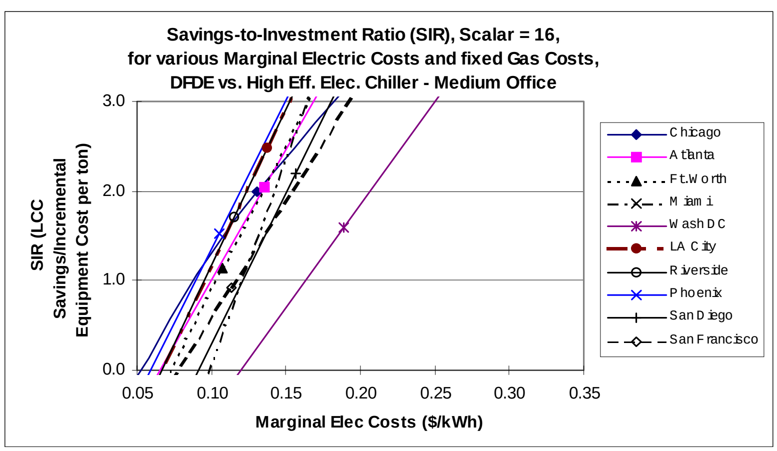
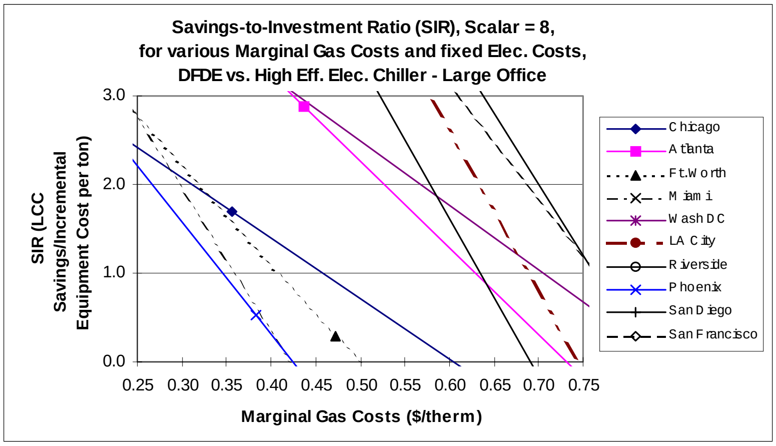
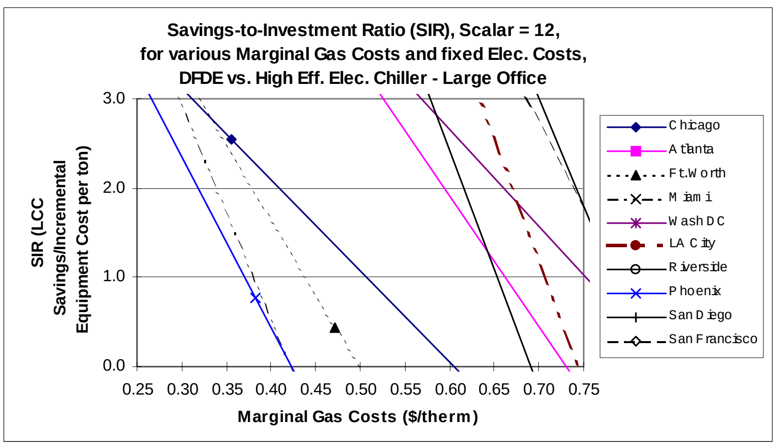


Figure 50 - SIR for various marginal electric costs for Medium Office, DFDE vs. High Eff. Chiller





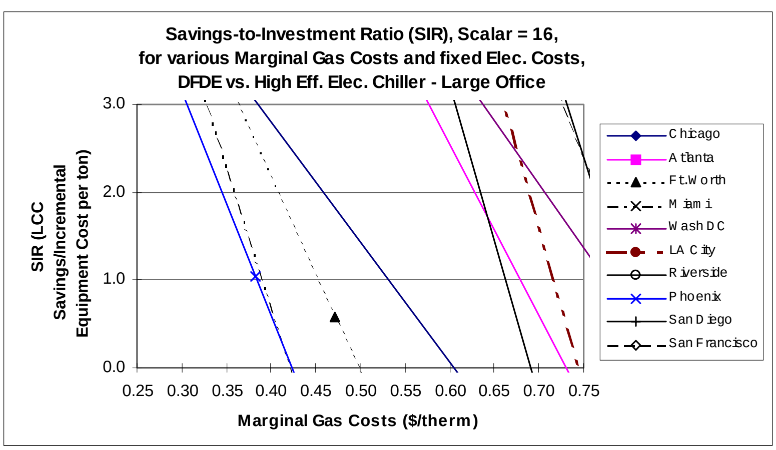
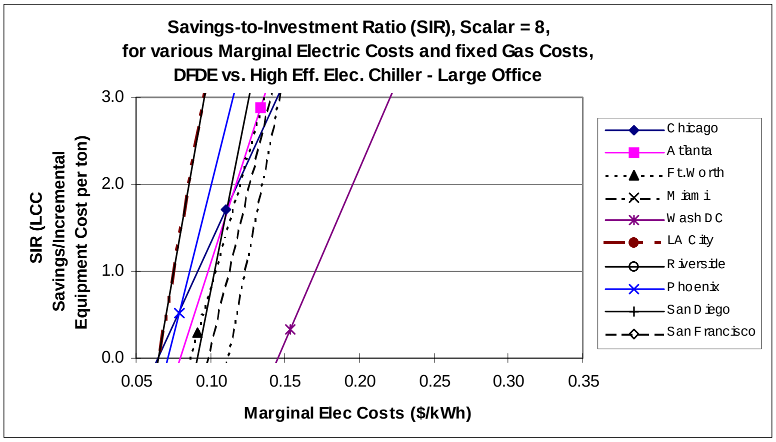
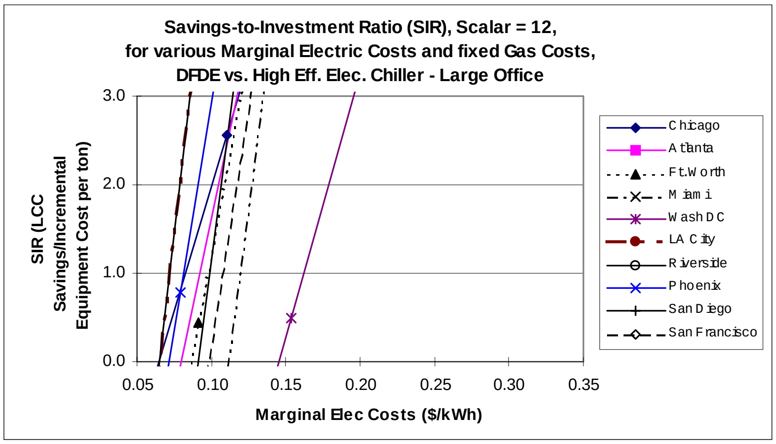


Figure 51 - SIR for various marginal gas costs for Large Office, DFDE vs. High Eff. Chiller





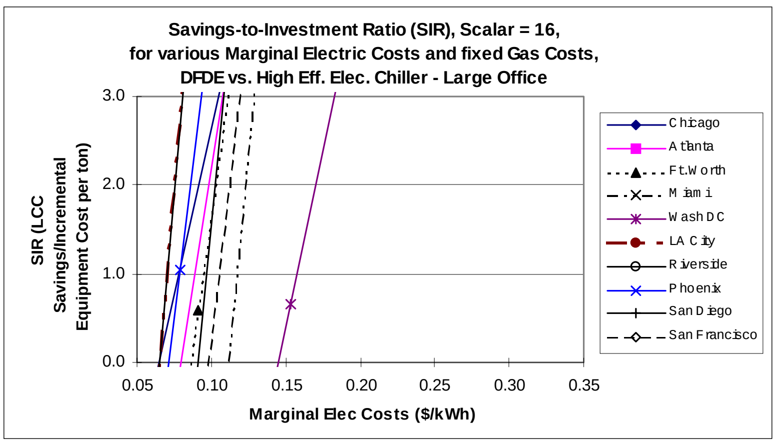
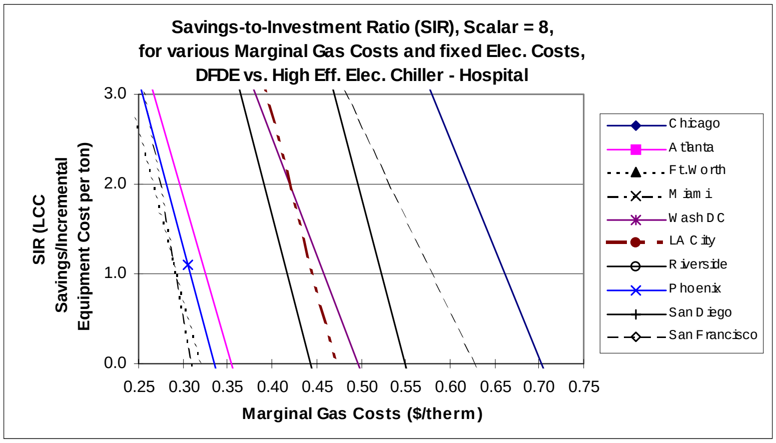
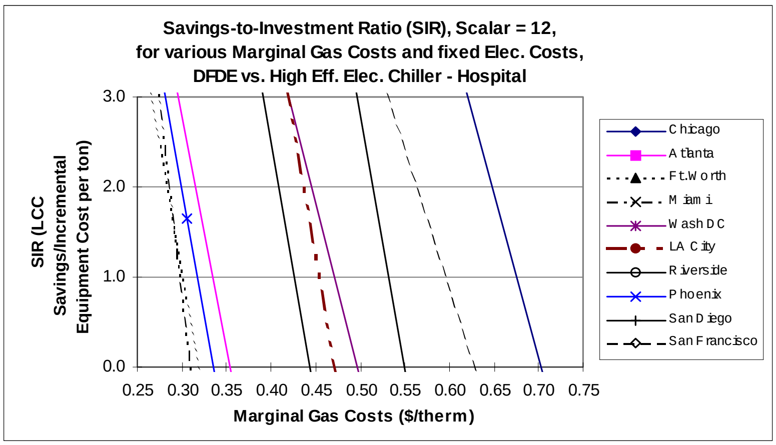


Figure 52 - SIR for various marginal electric costs for Large Office, DFDE vs. High Eff. Chiller





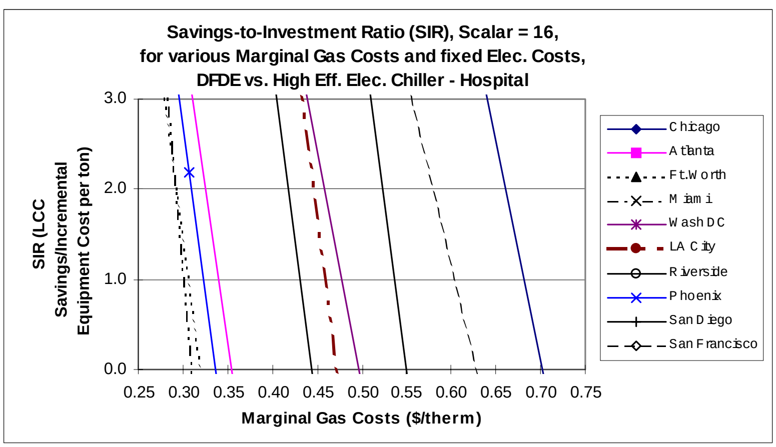
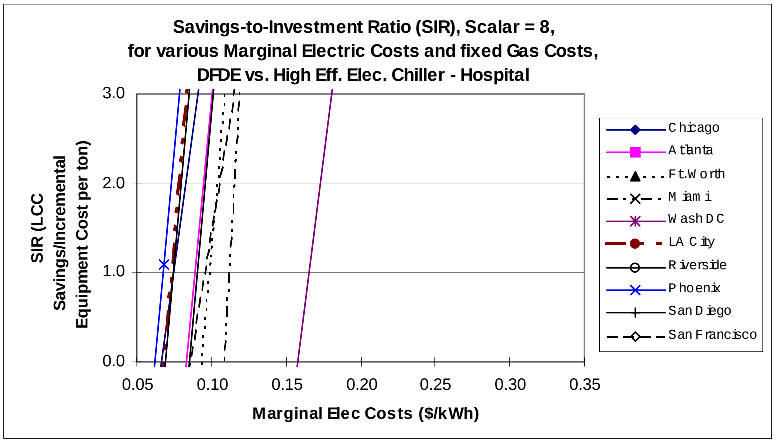
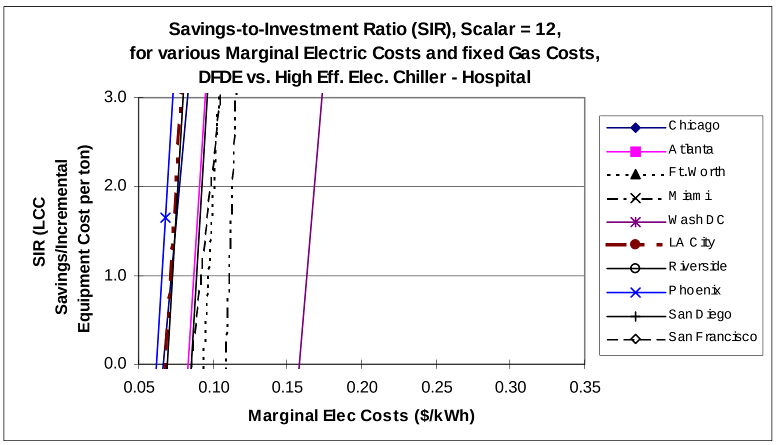


Figure 53 - SIR for various marginal gas costs for Hospital, DFDE vs. High Eff. Chiller





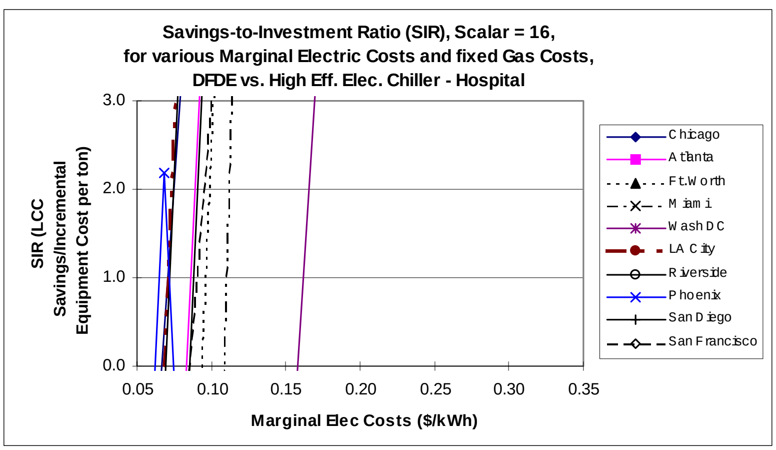
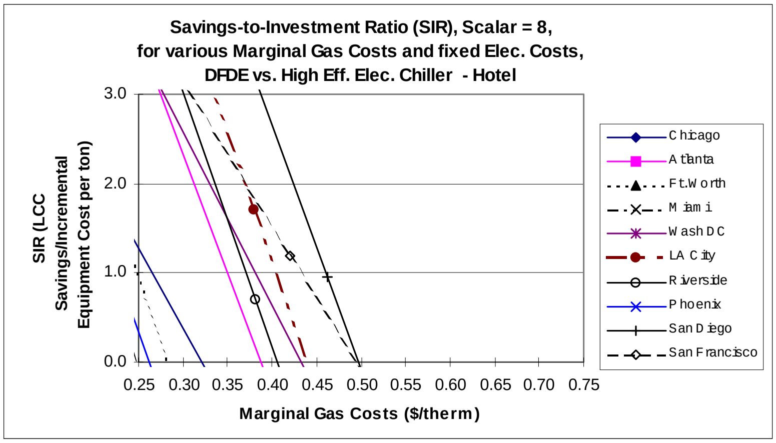
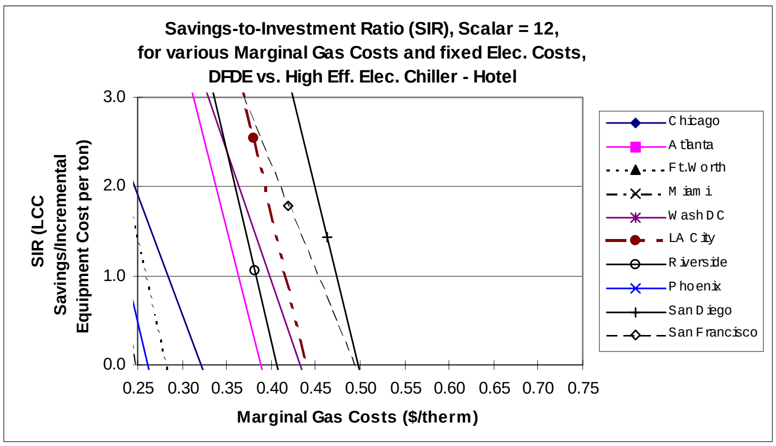


Figure 54 - SIR for various marginal electric costs for Hospital, DFDE vs. High Eff. Chiller





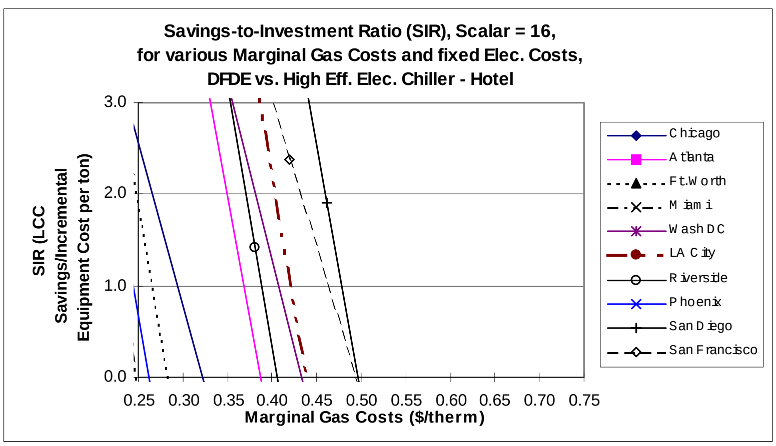


Figure 55 - SIR for various marginal gas costs for Hotel, DFDE vs. High Eff. Chiller

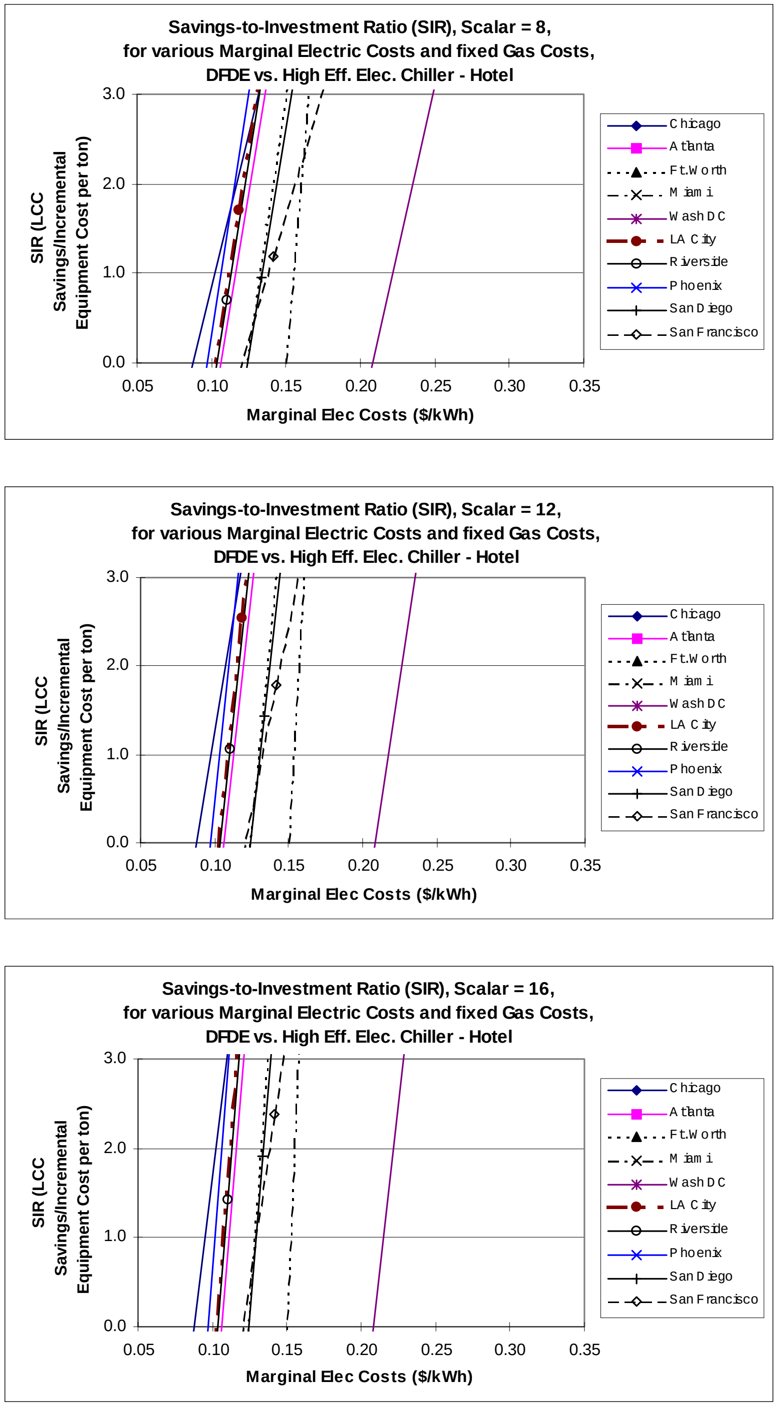
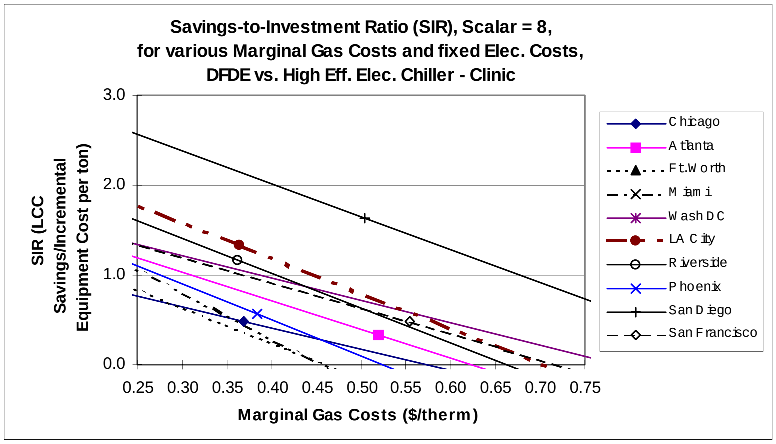
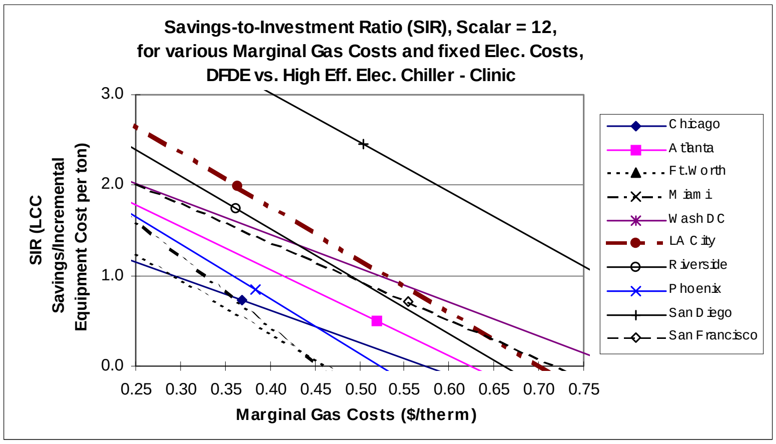


Figure 56 - SIR for various marginal electric costs for Hotel, DFDE vs. High Eff. Chiller





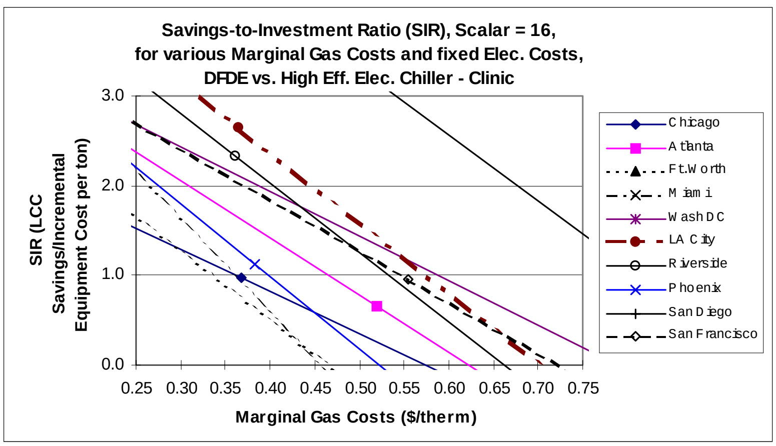


Figure 57 - SIR for various marginal gas costs for Clinic, DFDE vs. High Eff. Chiller

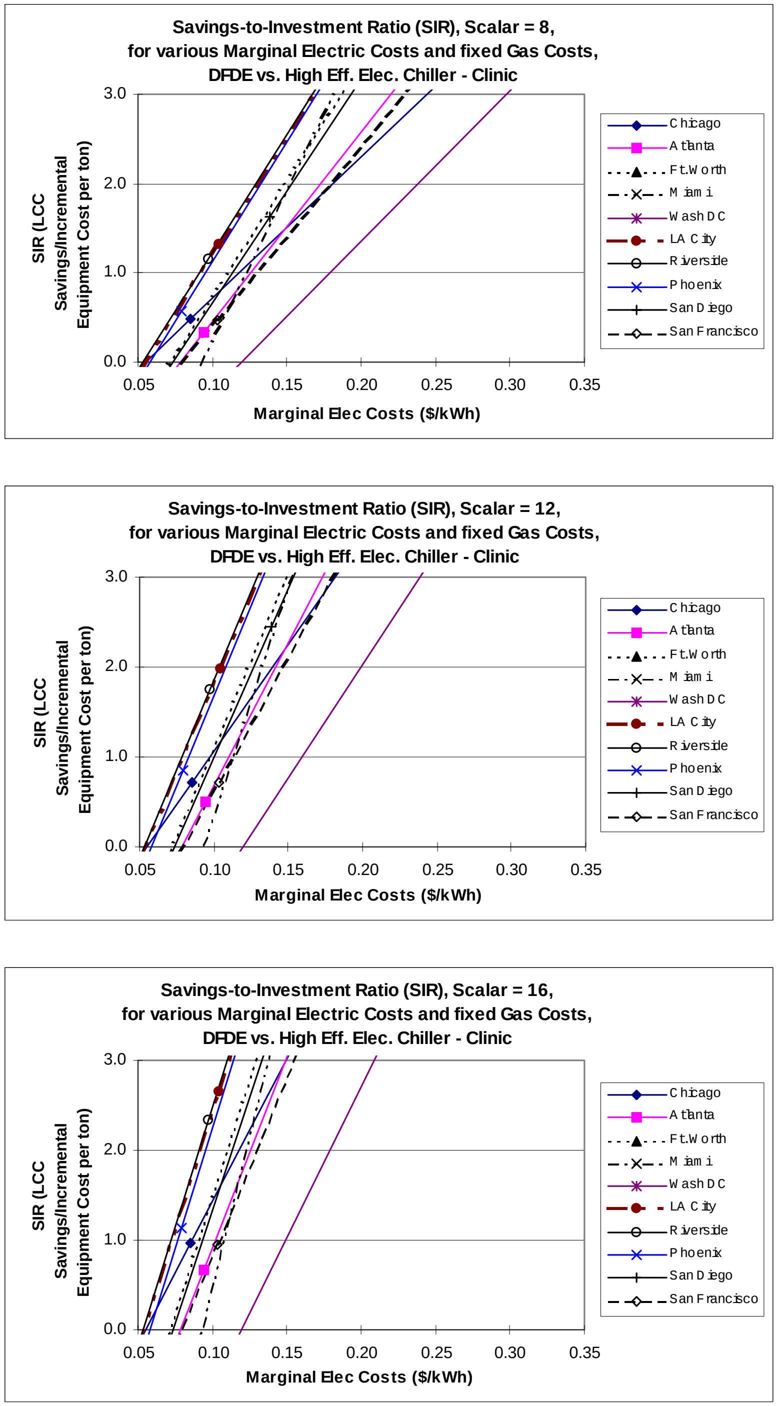
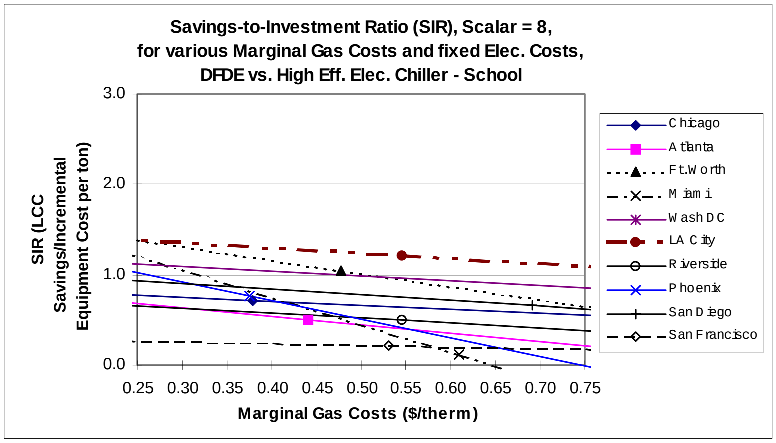
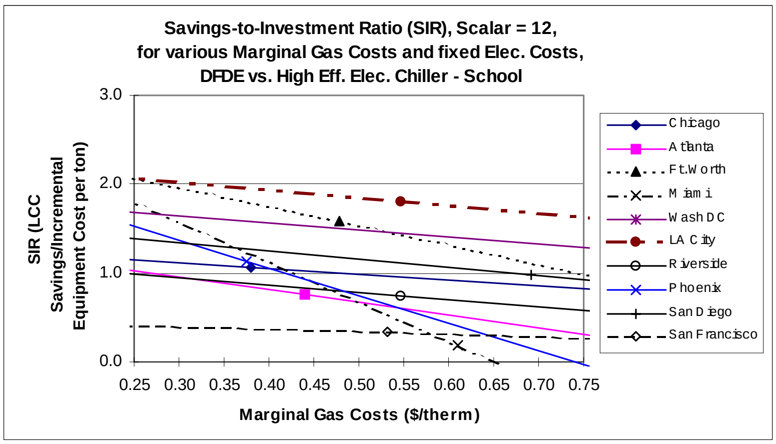


Figure 58 - SIR for various marginal electric costs for Clinic, DFDE vs. High Eff. Chiller





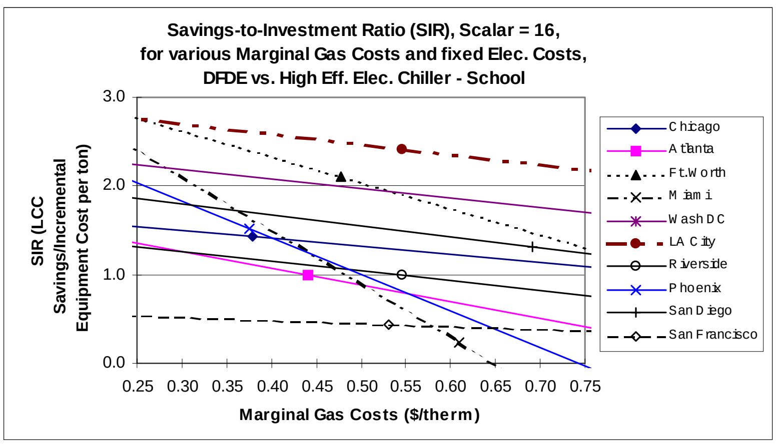
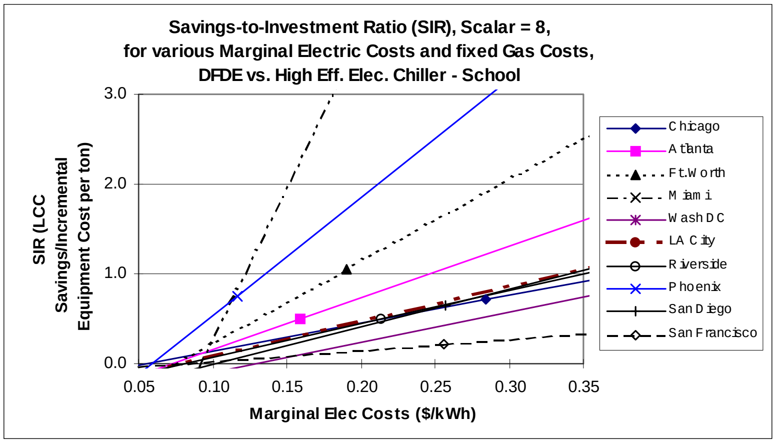
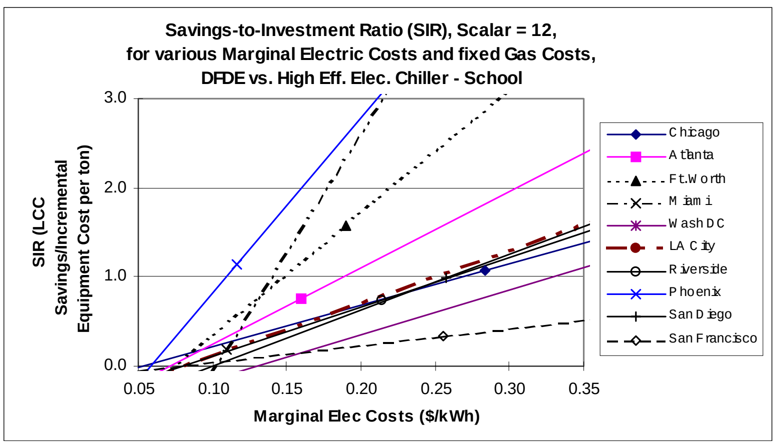


Figure 59 - SIR for various marginal gas costs for School, DFDE vs. High Eff. Chiller





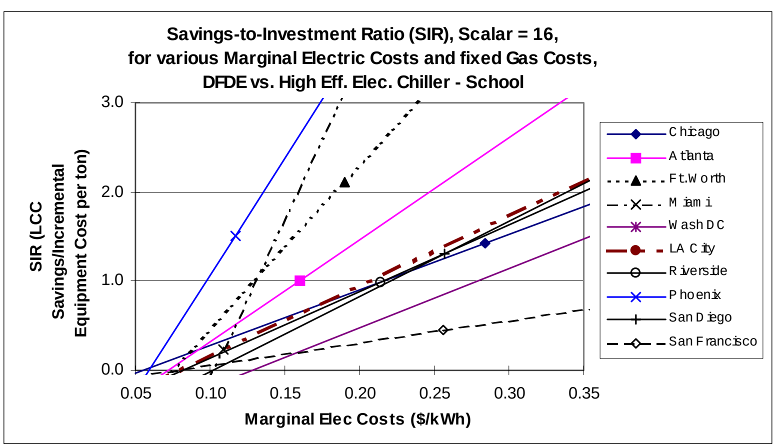
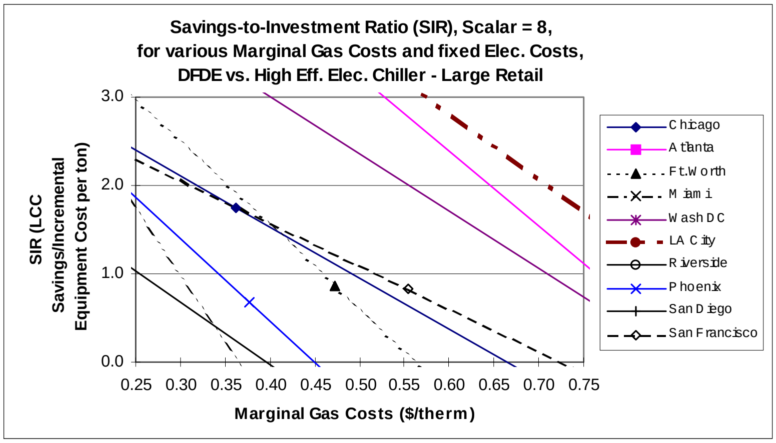
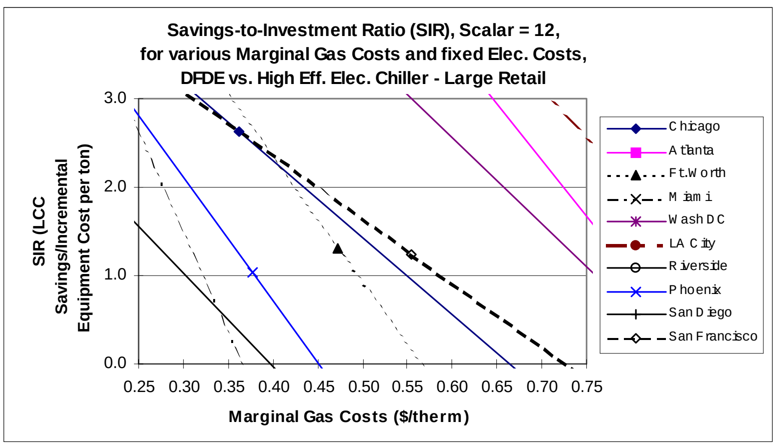


Figure 60 - SIR for various marginal electric costs for School, DFDE vs. High Eff. Chiller





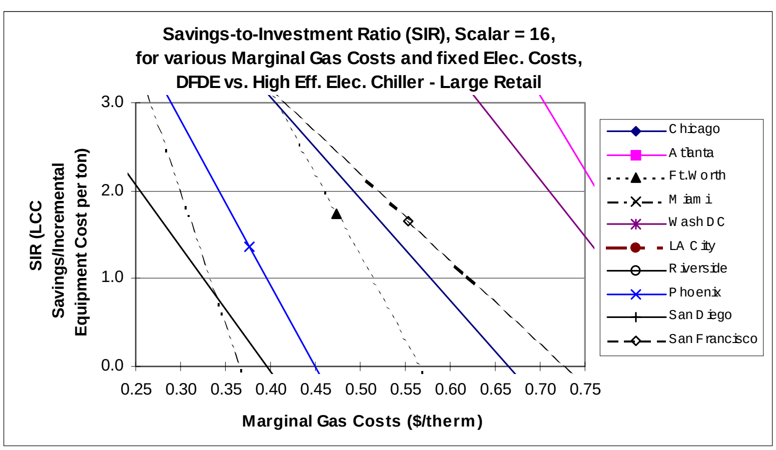


Figure 61 - SIR for various marginal gas costs for Large Retail, DFDE vs. High Eff. Chiller

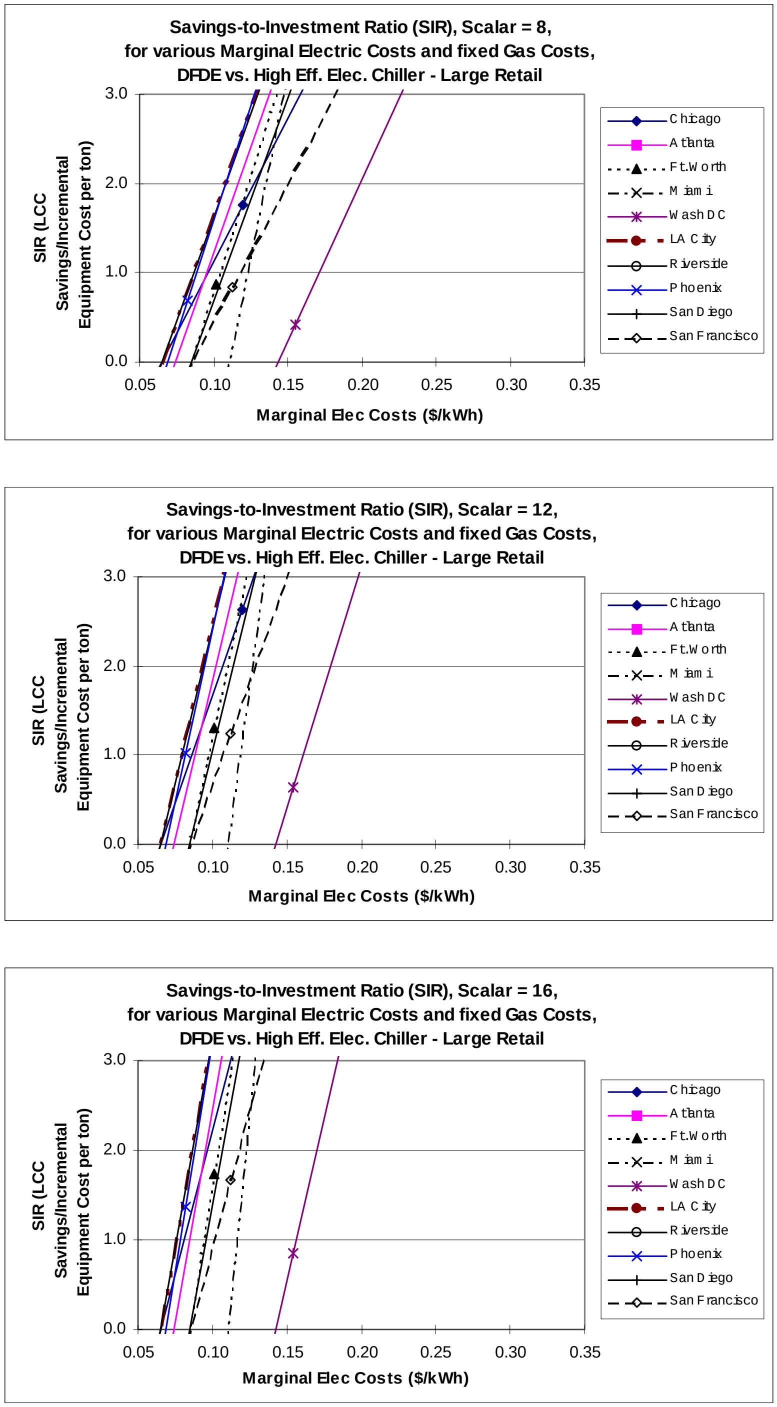


Figure 62 - SIR for various marginal electric costs for Large Retail, DFDE vs. High Eff. Chiller

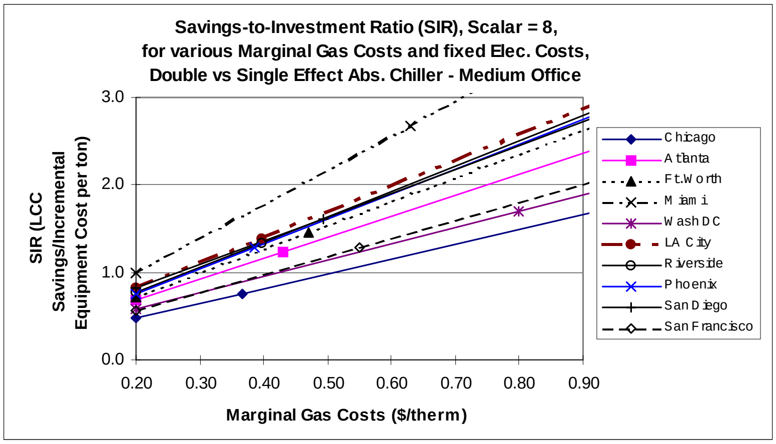
Double vs. Single Effect Absorption Chiller

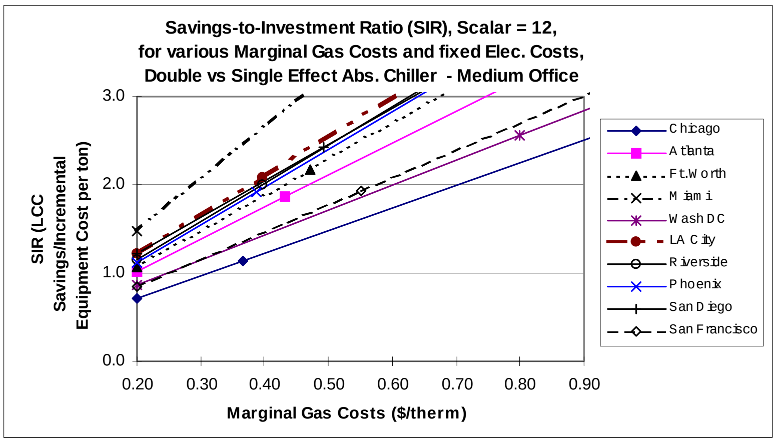
Bldg. Type	Location	Marg. Gas Rate	Scalar		
			8	12	16
Medium Office	Chicago	0.37	0.76	1.14	1.52
	Atlanta	0.43	1.24	1.86	2.48
	Ft. Worth	0.47	1.45	2.18	2.90
	Miami	0.63	2.68	4.02	5.36
	Washington DC	0.80	1.70	2.56	3.41
	LA City	0.40	1.39	2.09	2.79
	Riverside	0.40	1.34	2.01	2.68
	Phoenix	0.39	1.28	1.92	2.56
	San Diego	0.49	1.62	2.43	3.24
	San Francisco	0.55	1.29	1.93	2.58
Large Office	Chicago	0.20	1.89	2.84	3.78
	Atlanta	0.20	2.45	3.67	4.90
	Ft. Worth	0.20	2.95	4.43	5.91
	Miami	0.20	4.18	6.27	8.36
	Washington DC	0.20	2.20	3.30	4.40
	LA City	0.20	5.14	7.72	10.29
	Riverside	0.20	5.02	7.53	10.04
	Phoenix	0.20	3.46	5.18	6.91
	San Diego	0.20	4.89	7.34	9.79
	San Francisco	0.20	4.06	6.08	8.11
Hospital	Chicago	0.34	7.66	11.49	15.32
	Atlanta	0.42	13.15	19.72	26.30
	Ft. Worth	0.47	15.87	23.80	31.74
	Miami	0.56	27.84	41.76	55.67
	Washington DC	0.80	18.59	27.89	37.19
	LA City	0.36	13.07	19.60	26.14
	Riverside	0.36	12.82	19.23	25.64
	Phoenix	0.31	10.21	15.32	20.43
	San Diego	0.43	14.76	22.13	29.51
	San Francisco	0.42	8.92	13.38	17.84

Figure 63 - SIR for Double vs. Single Effect Absorption Chillers

Bldg. Type	Location	Marg. Gas Rate	Scalar		
			8	12	16
Hotel	Chicago	0.33	5.94	8.91	11.88
	Atlanta	0.41	10.29	15.44	20.58
	Ft. Worth	0.48	12.80	19.20	25.60
	Miami	0.59	26.58	39.87	53.16
	Washington DC	0.80	14.02	21.03	28.04
	LA City	0.35	10.00	15.00	20.00
	Riverside	0.35	9.71	14.57	19.43
	Phoenix	0.37	9.83	14.74	19.65
	San Diego	0.42	11.42	17.13	22.84
	San Francisco	0.42	6.76	10.15	13.53
Medical Clinic	Chicago	0.36	1.09	1.64	2.19
	Atlanta	0.52	2.01	3.01	4.02
	Ft. Worth	0.47	2.22	3.32	4.43
	Miami	0.59	3.65	5.47	7.30
	Washington DC	0.80	2.37	3.56	4.74
	LA City	0.40	2.03	3.05	4.07
	Riverside	0.40	2.00	3.00	4.00
	Phoenix	0.38	1.98	2.97	3.96
	San Diego	0.49	2.40	3.60	4.80
	San Francisco	0.55	1.97	2.95	3.94
School	Chicago	0.37	0.27	0.41	0.54
	Atlanta	0.44	0.58	0.87	1.16
	Ft. Worth	0.47	0.84	1.26	1.68
	Miami	0.61	2.07	3.10	4.14
	Washington DC	0.80	0.55	0.83	1.10
	LA City	0.53	0.44	0.66	0.88
	Riverside	0.53	0.36	0.54	0.72
	Phoenix	0.37	0.94	1.41	1.87
	San Diego	0.58	0.46	0.69	0.92
	San Francisco	0.53	0.13	0.20	0.27
Large Retail	Chicago	0.34	2.62	3.93	5.23
	Atlanta	0.41	4.50	6.75	8.99
	Ft. Worth	0.47	5.41	8.11	10.82
	Miami	0.60	10.39	15.58	20.78
	Washington DC	0.80	6.31	9.46	12.62
	LA City	0.40	3.71	5.57	7.42
	Riverside	0.40	3.57	5.36	7.15
	Phoenix	0.38	4.31	6.47	8.62
	San Diego	0.49	4.40	6.60	8.80
	San Francisco	0.55	3.20	4.80	6.41

Figure 63 (continued) - SIR for Double vs. Single Effect Absorption Chillers





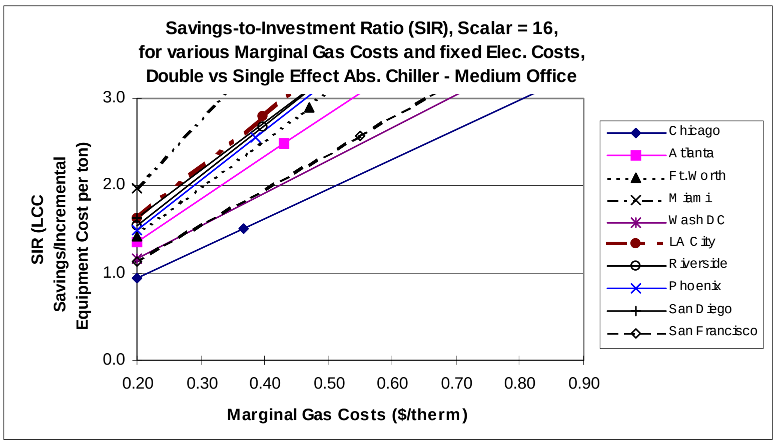
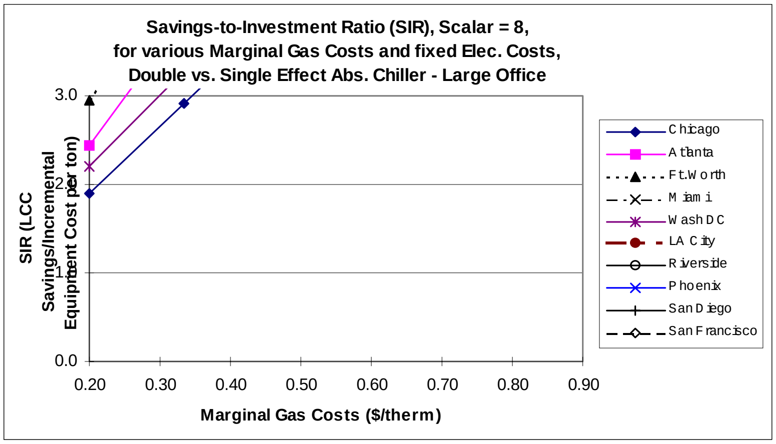
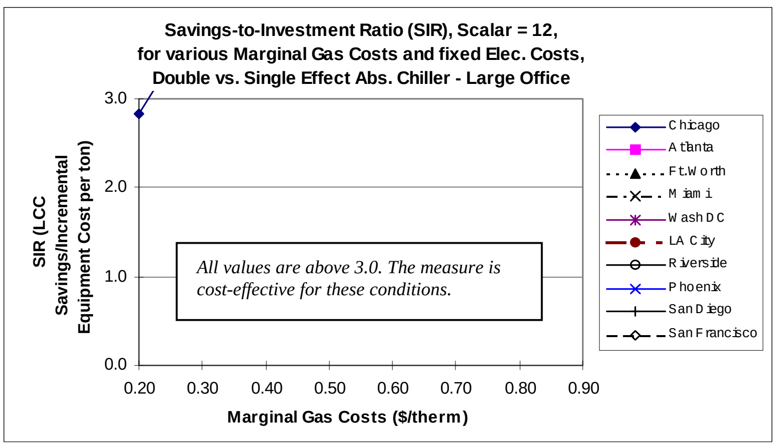


Figure 64 - SIR for various marginal gas costs for Medium Office, Double vs. Single Effect Absorption Chiller





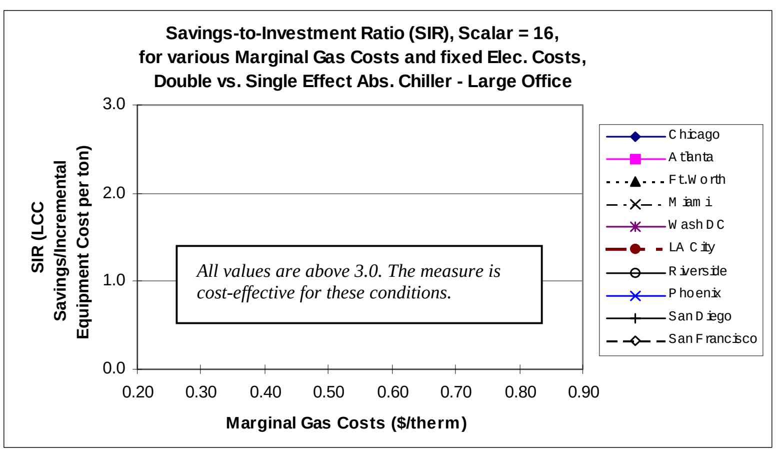
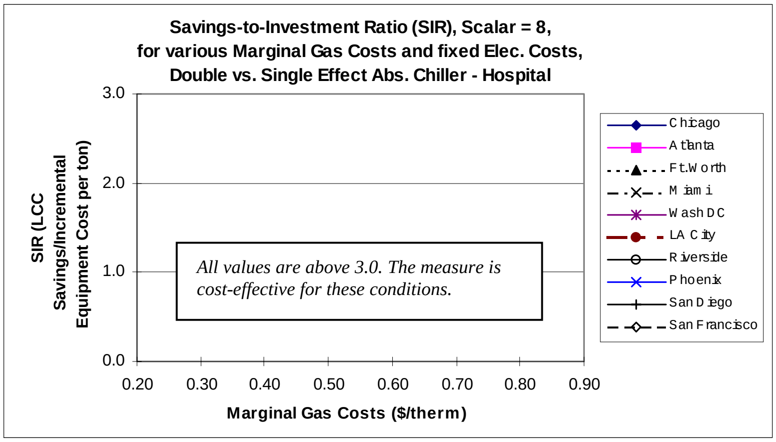
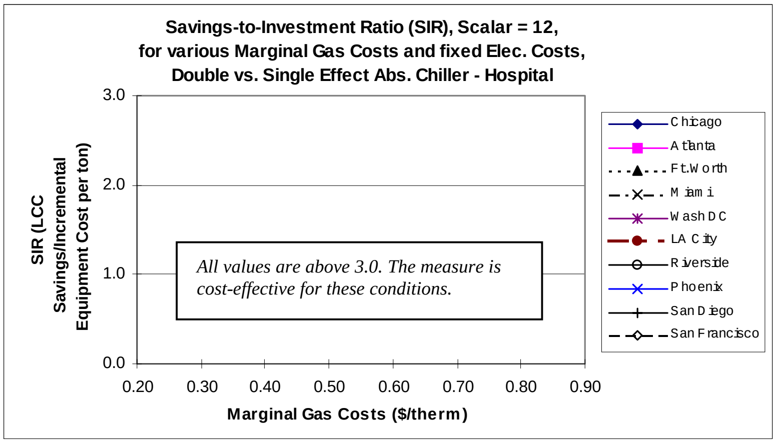


Figure 65 - SIR for various marginal gas costs for Large Office, Double vs. Single Effect Absorption Chiller





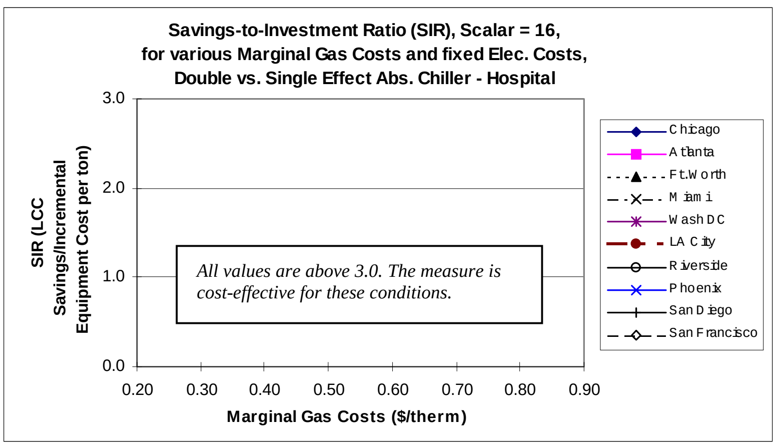
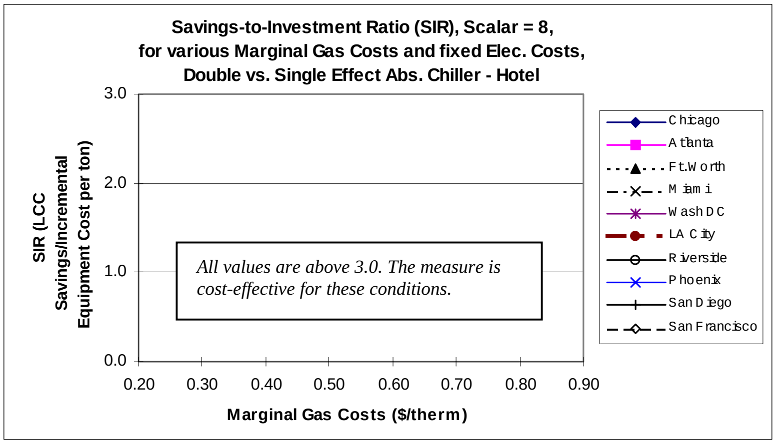
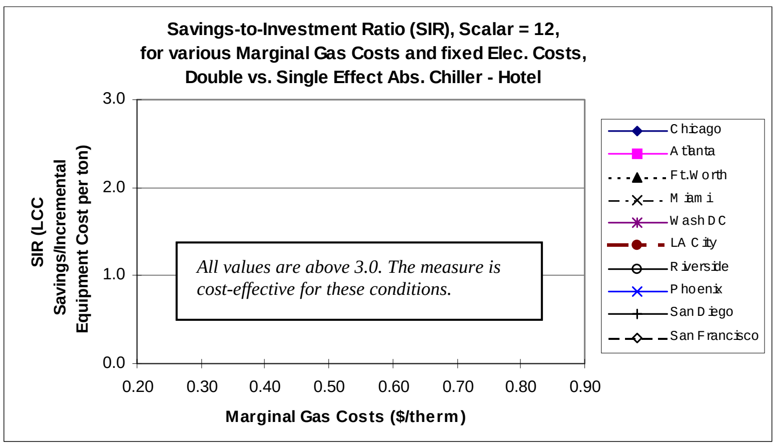


Figure 66 - SIR for various marginal gas costs for Hospital, Double vs. Single Effect Absorption Chiller





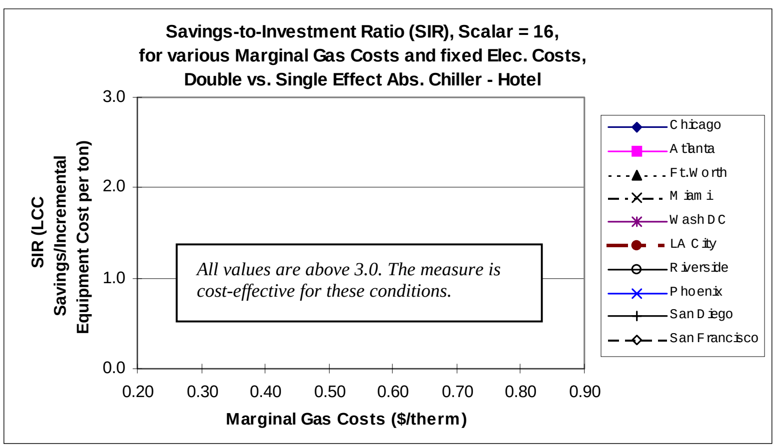
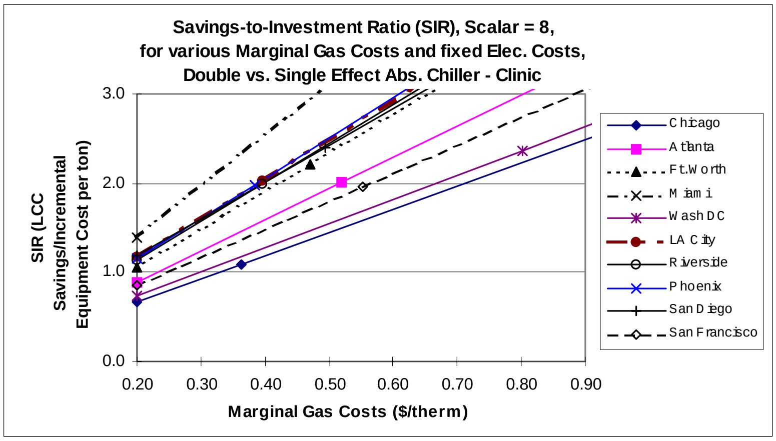
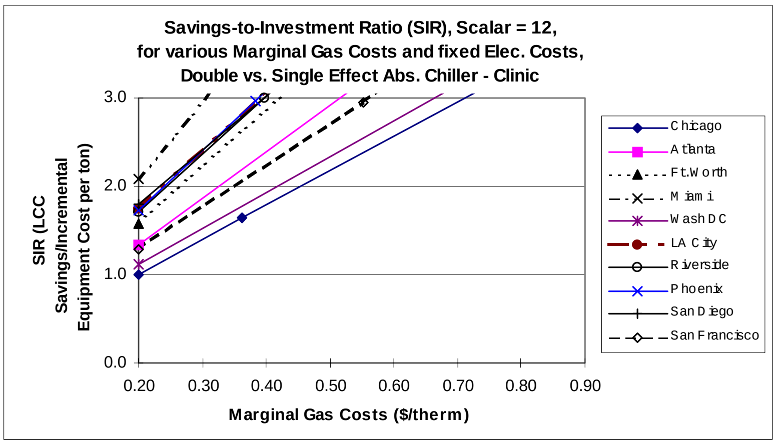


Figure 67 - SIR for various marginal gas costs for Hotel, Double vs. Single Effect Absorption Chiller





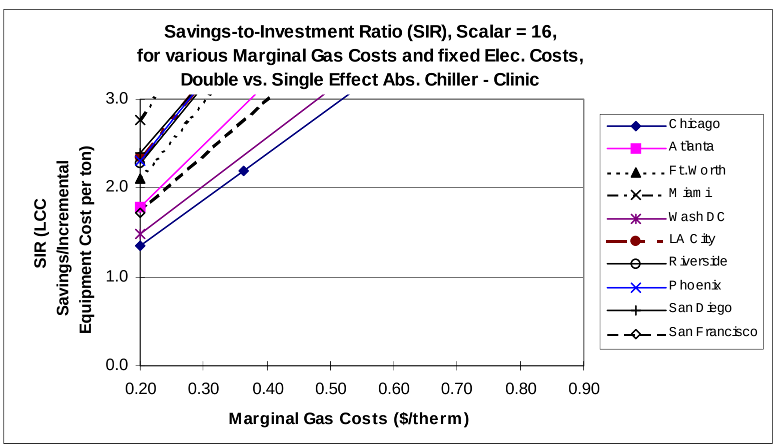
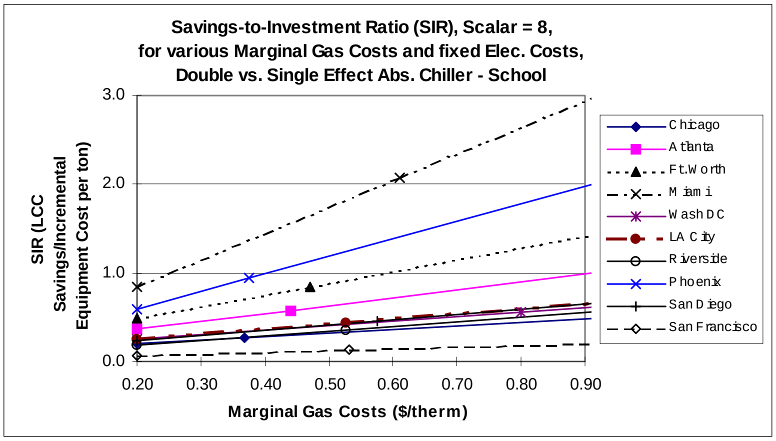
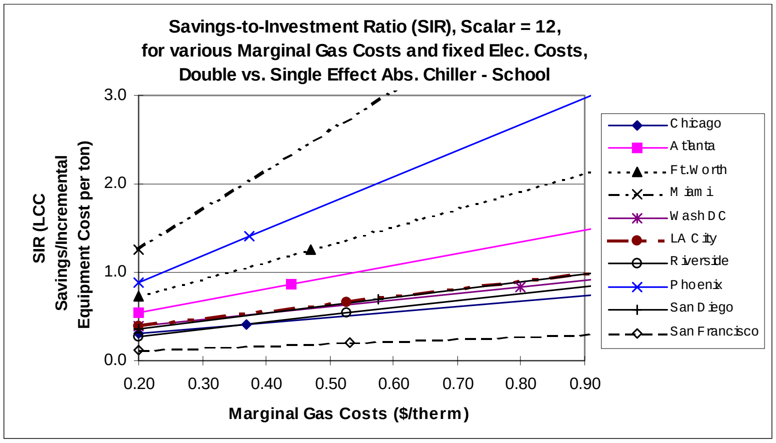


Figure 68 - SIR for various marginal gas costs for Clinic, Double vs. Single Effect Absorption Chiller





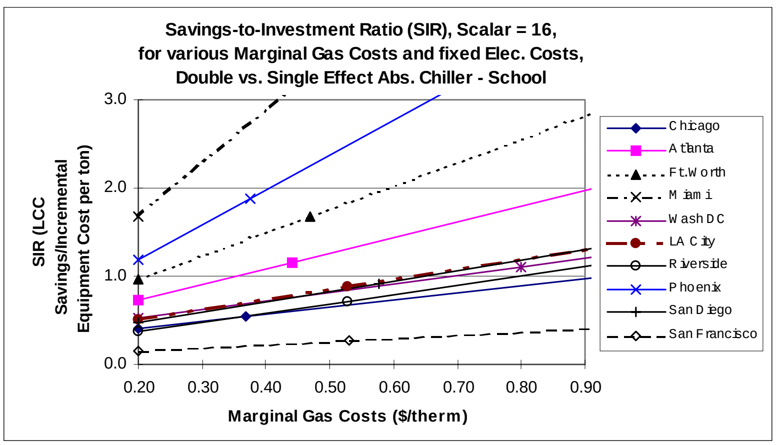
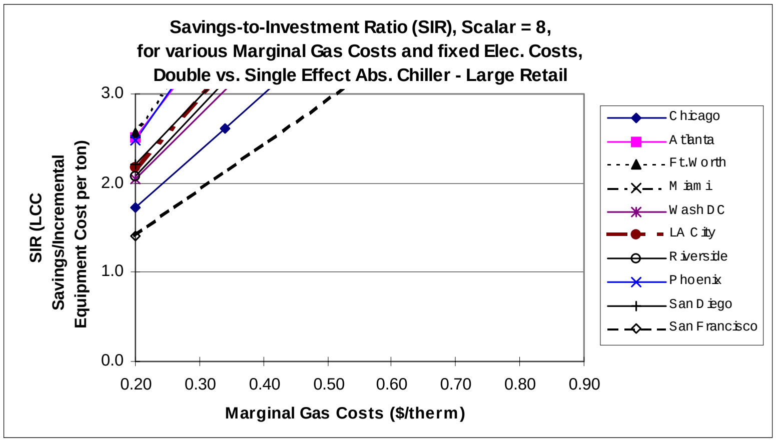
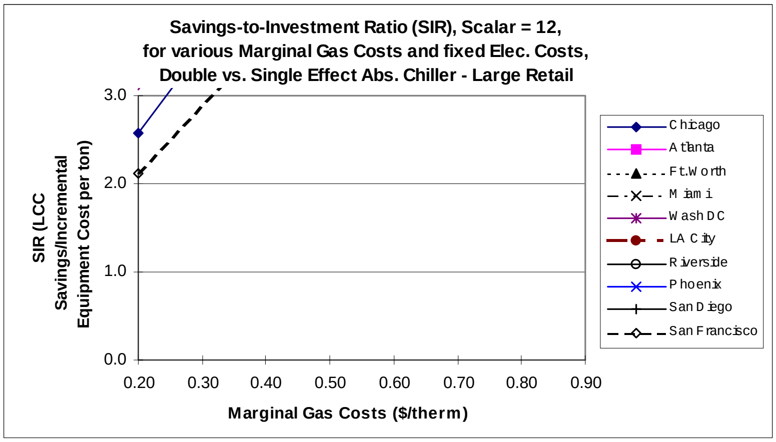


Figure 69 - SIR for various marginal gas costs for School, Double vs. Single Effect Absorption Chiller





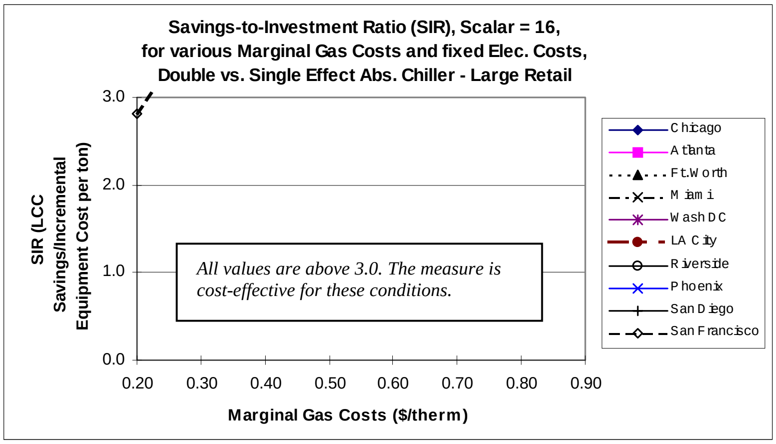


Figure 70 - SIR for various marginal gas costs for Large Retail, Double vs. Single Effect Absorption Chiller

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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)	Summer (¢/therm)
Chicago	NiCor	4	General Service	0	No Limit	33
Washington DC	Washington Gas Light	2	General Service	0	No Limit	79
Dallas/Ft. Worth	Lone Star Gas	General Service	General Service	0	No Limit	48
Los Angeles City	So. Cal. Gas	GN-10	General Service	0	<20800	34-51
		GN-20	General Service	20800	No Limit	34-48
		G-AC	Air Conditioning	0	No Limit	38
Riverside	So. Cal. Gas	GN-10	General Service	0	<20800	34-51
		GN-20	General Service	20800	No Limit	34-48
		G-AC	Air Conditioning	0	No Limit	38
San Diego	San Diego G & E	GN-1	General Service	0	<20800	49
		GN-2	General Service	20800	No Limit	42
San Francisco	Pacific G & E	G-NR1	General Service	0	<20800	53
		G-NR2	General Service	20800	No Limit	41
Atlanta	Atlanta Gas Light	G-11	General Service	0	<2000 th/day	78
		G-11 AC	Air Conditioning	0	<2000 th/day	36
		G-12	Heating Only	0	<2000 th/day	82
		G-13 LLF	General Service	0	<5000 th/day	74
		G-13 AC LLF	Air Conditioning	0	<5000 th/day	36
Phoenix	Southwest Gas	CG-25 Small	General Service	0	600	62
		CG-25 Medium	General Service	>600	15000	53
		CG-25 Large	General Service	>15000	No Limit	34
		CG-40	Air Conditioning	0	No Limit	32
Miami	Peoples Gas	SGS	General Service	0	108	85
		GS	General Service	>108	2708	73
		GSLV-1	General Service	>2708	54166	70
		GSLV-2	General Service	>54166	No Limit	63
		Rider LE	Air Conditioning	0	No Limit	40% of above

Summary of Electric Utility Rates Used

City	Utility	Rate Name	Rate Type	Min Demand (kW)	Max Demand (kW)	Summer On Peak (¢/kWh)	Summer On-Peak ($/kW)
Chicago	ComEd	6	Non TOU	0	<1000	3	14
		6L	TOU	1000	<10000	5	16
Washington DC	Potomac Electric	GS-Non Demand	Non TOU	0	<25	12	0
		GS-Demand	Non TOU	25	<100	8	12
		GT	TOU	100	No Limit	6	24
Dallas/Ft. Worth	Texas Utilities	GS	Non TOU	10	No Limit	5	14
Los Angeles City	LA Dept W & P	A-1 (Rate A)	Non TOU	0	<30	10	3
		A-2 (Rate A)	Non TOU	30	<500	5	18
		A-3 (Rate C)	TOU	500	No Limit	8	14
Riverside	So. Cal. Edison	GS-2	Non TOU	20	<500	4	25
		TOU-8	TOU	500	No Limit	9	24
San Diego	San Diego G & E	A (No Demand)	Non TOU	0	<20	14	0
		AD (Demand Metered)	Non TOU	20	500	9	10
		AL-TOU	TOU	>500	No Limit	9	27
San Francisco	Pacific G & E	A-10	Non TOU	0	<500	9	7
		E-19S	TOU	500	<1000	9	17
		E-20S	TOU	1000	No Limit	9	17
Atlanta	Georgia Power	PLS-2	Non TOU	0	<30	9-10	16
		PLM-2	Non TOU	30	<500	6-10	18
		PLL-2	Non TOU	500	No Limit	6-10	18
Phoenix	Arizona Pub Serv	E-32	Non TOU	0	No Limit	8	6
Miami	Florida P & L	GSD-1	Non TOU	20	<500	5	9
		GSLD-1	Non TOU	500	<2000	4	9
		GSLD-2	Non TOU	2000	No Limit	4	9

C. Equipment First Cost

	Size (tons)	Cost ($/ton)
Electric Screw	100-350	360
Hi Eff. Electric Screw	100-350	414
SE Steam Absorption	100-350	510
DE Direct-Fired Absorption	100-350	740
Engine-Driven Screw	100-350	700
Electric Centrifugal	350-450	259
Hi Eff. Electric Centrifugal	350-450	349
SE Steam Absorption	350-450	264
DE Direct-Fired Absorption	350-450	627
Engine-Driven Centrifugal	350-450	528
Boiler		$11 per 1000 Btuh
Cooling Tower		$55 per AC ton

Notes:

1) Chiller costs from 1997 manufacturer's data, FOB price plus 20%

2) 15% cost premium for high efficiency electric screw chiller versus standard screw chiller per ASHRAE 90.1 cost analysis.

3) 35% cost premium for high efficiency electric centrifugal chiller versus standard centrifugal chiller per ASHRAE 90.1 cost analysis.

4) Boiler and cooling tower cost from Means.

D. 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 71 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 71 - 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 72 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 73 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.

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[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 72 - 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 73 - Variable Effects on Scalar