BOILER SELECTION CONSIDERATIONS

CONTENTS

ILLUSTRATIONS

TABLES

Perhaps no other piece of equipment is more important to a facility than the boiler. Proper boiler selection, to meet the needs of the application, is a critical factor in the design of any steam or hot water system.

This section provides information to consider when selecting a boiler. This information is divided into three main subsections:

1. Boiler Types

Typical boiler types are defined, including: firetube, firebox, industrial watertube, and commercial watertube boilers. General information is provided on the differences in boiler types (sizes, ranges, pressures, etc.). For more detailed information on boiler products, refer to the specific boiler product section.

2. Boiler Selection

Provides information on codes and standards; when to use steam or hot water boilers; defines load requirements; defines the number of boilers needed; discusses performance issues; and addresses special requirements.

3. Payback Analysis

There are many factors that affect the decision to purchase a particular piece of boiler room equipment. This section addresses economic considerations only, and provides a procedure that can be applied to individual equipment selection or evaluation of alternative systems.

Definitions

To assist with understanding information in this section, it will be necessary to understand the following definitions.

Boiler horsepower (BHP) is a measure of boiler energy output. One boiler horsepower (from and at 212 °F):

- BHP = 34.5 lbs/hr
- BHP = 33,472 Btu/hr
- BHP = 9.8 kW
- BHP should not be confused with other horsepower measurements.

Boiler Trim: Accessories added to the boiler, such as auxiliary low water cutoff, special tappings, special gas trains, etc.

Btu: Amount of energy required to raise one pound of water one °F.

Input: Total amount of fuel input to the burner in Btu/hr.

Output: Total amount of energy released from a steam or hot water boiler measured in boiler horsepower, lbs/hr of steam, or Btu/hr.

BOILER TYPES

The boilers discussed in this book are packaged boilers. This concept has been around for more than 60 years. The packaged boiler originated with Cleaver-Brooks, when a pre-engineered assembly was supplied to a customer to eliminate his need to purchase separate components, and then try to make them work together. The packaged boiler has proven to be a successful concept - with more than 150,000 Cleaver-Brooks units around the world.

There are many types of packaged boilers available. Table 1 compares common boiler types and their features.

The following is an overview of different types of boilers.

Scotch Marine - The Classic Firetube Boiler

The Scotch Marine style of boiler has become so popular in the last 40 years that it frequently is referred to simply as “a firetube boiler.” Firetube boilers are available for low or high pressure steam, or for hot water applications. Firetube boilers are typically used for applications ranging from 15 to 1500 horsepower. A firetube boiler is a cylindrical vessel, with the flame in the furnace and the combustion gases inside the tubes. The furnace and tubes are within a larger vessel, which contains the water and steam.

The firetube construction provides some characteristics that differentiate it from other boiler types. Because of its vessel size, the firetube contains a large amount of water, allowing it to respond to load changes with minimum variation in steam pressure.

Steam pressure in a firetube boiler is generally limited to approximately 350 psig.

Table 1. Common Boiler Types

	CAST IRON	MEMBRANE WATERTUBE	ELECTRIC	FIREBOX	FIRETUBE	FLEXIBLE WATERTUBE	INDUSTRIAL WATERTUBE	VERTICAL FIRETUBE
Efficiency	Low	Medium	High	Medium	High	Medium	Medium	Low/Medium
Floor Space Required	Low	Very Low	Very Low	Medium	Medium/ High	Low	High	Very Low
Maintenance	Medium/High	Medium	Medium/High	Low	Low	Medium	High	Low
Initial Cost	Medium	Low/Medium	High	Low	Medium/ High	Low/Medium	High	Low
No. of Options Available	Low	Medium	Medium	Low/Medium	High	Medium	High	Low
Pressure Range	HW/LPS	HW/LPS HPS to 600 psig	HW/LPS HPS to 900 PSIG	HW/LPS	HW/LPS HPS to 350 psig	HW/LPS	High Temp HW HPS to 900 psig	HW/LPS HPS to 150 psig
Typical Sizes	To 200 hp	To 250 hp	To 300 hp	To 300 hp	To 1500 hp	To 250 hp		To 100 hp
Typical Applications	Heating/ Process	Heating/ Process	Heating/ Process	Heating	Heating/ Process	Heating	Process	Heating/ Process
Comments	Field Erectable					Field Erectable		

To achieve higher pressure, it would be necessary to use very thick shell and tube sheet material. For this reason, a watertube boiler is generally used if pressure above 350 psig design is needed.

Firetube boilers are usually built similar to a shell and tube heat exchanger. A large quantity of tubes results in more heating surface per boiler horsepower, which greatly improves heat transfer and efficiency.

Firetube boilers are rated in boiler horsepower (BHP), which should not be confused with other horsepower measurements.

The furnace and the banks of tubes are used to transfer heat to the water. Combustion occurs within the furnace and the flue gases are routed through the tubes to the stack outlet. Firetube boilers are available in two, three and four pass designs. A single “pass” is defined as the area where combustion gases travel the length of the boiler. Generally, boiler efficiencies increase with the number of passes.

Firetube boilers are available in either dryback or wetback design. In the dryback boiler, a refractory-lined chamber, outside of the vessel, is used to direct the combustion gases from the furnace to the tube banks. Easy access to all internal areas of the boiler including tubes, burner, furnace, and refractory, is available from either end of the boiler. This makes maintenance easier and reduces associated costs.

The wetback boiler design has a water cooled turn around chamber used to direct the flue gases from the furnace to the tube banks. The wetback design requires less refractory maintenance; however, internal pressure vessel maintenance, such as cleaning, is more difficult and costly. In addition, the wetback design is more prone to water side sludge buildup, because of the restricted flow areas near the turn around chamber.

Firebox boilers

The firebox boiler uses similar tube attachment techniques as the firetube boiler. Its combustion chamber is not round, like the firetube’s cylindrical furnace. The firebox boiler is typically manufactured to low pressure steam or hot water applications. The firebox boiler is a compact, economical unit and serves as a good fit for seasonal use and when efficiency is not the driving factor. Sizes range from 12 to 337 horsepower.

Commercial Watertube Boilers

Commercial watertube boilers typically produce steam or hot water for commercial, or modest-size applications. There are a wide variety of types, sizes, capacities, and design pressures available. Commercial watertube boilers can be membrane type, straight tube, modular, etc. They can be either atmospherically fired or utilize power burners.

Industrial Watertube Boilers

The industrial watertube boiler typically produces steam or hot water primarily for industrial process applications, and is used less frequently for heating applications. In the watertube design, tubes contain steam and/or water and the products of combustion pass around the tubes. Typically, watertube designs consist of multiple drums. A steam drum (upper) and mud drums (lower) are connected by the tubes, which form both the convection section and the furnace area.

Packaged industrial watertube boilers are typically rated in pounds of steam per hour output at operating conditions and range from 10,000 to 134,000 lbs/hr.

Industrial watertube boilers are noted for their fast steaming capability. Steam is generated very rapidly because of the relatively low water content. This allows them to respond quickly to changing load demands.

The industrial watertube boiler design makes it capable of generating either saturated or superheated steam. When applications dictate superheated steam usage, large or fluctuating steam loads, or high pressures (greater than 350 psig), an industrial watertube boiler should be considered.

Flexible Watertube (Bent Tube) Boilers

Flexible watertube boilers are a common type of boiler used for heating applications because of their resistance to thermal shock. Flexible watertube boilers are available in size ranges from 2 to 9 MMBtu/hr input. Flexible watertube boilers are available for low pressure steam or hot water applications. Field erectable packages are also available.

Membrane Watertube Boilers

The membrane watertube boiler is available for low or high pressure steam or hot water applications. High outputs are available in a compact design and should be considered where space is limited. Sizes range from 34 to 143 horsepower.

Electric Boilers

Electric boilers are noted for being clean, quiet, easy to install, and compact. Because there are no combustion considerations, an electric boiler has minimal complexity (no fuels or fuel handling equipment) with easily replaceable heating elements.

An electric boiler may be the perfect alternative to supply low or high pressure steam or hot water where the customer is restricted by emission regulations. In areas where the cost of electric power is minimal, the electric boiler could be the best choice. Sizes range from 9 kW to 3,375 kW output.

Table 2. Considerations for Selecting a Boiler

REQUIREMENT OR APPLICATION	BOILER SELECTION								
	FIRETUBE	WATERTUBE	CAST IRON	ELECTRIC	COMMERCIAL WATERTUBE	OHIO SPECIAL	FIREBOX	VERTICAL	FLEXTUBE
High Efficiency	X			X					
Space Factor				X	X			X	
Emissions Factor	X[A]	X[A]		X					
Low Cost			X		X		X	X	
Low Operating Cost	X	X			X				
Boiler Operator Factor						X			
Low Maintenance	X			X			X	X	
High Turndown	X	X		X					
Field Erectable			X						X
Fuel Limitations	X	X		X					
Low Usage, No Stack				X					
High Pressure, Over 350 psig, or Superheat		X			X				

A. With Flue Gas Recirculation/ Model CB (LE) Option.

BOILER SELECTION

Six criteria should be considered when selecting a boiler to meet the application needs. The criteria are:

1. Codes and standards requirements
2. Steam or Hot Water
3. Boiler load
4. Number of boilers
5. Performance considerations
6. Special considerations

Codes and Standards

There are a number of codes and standards, laws, and regulations covering boilers and related equipment that should be considered when designing a system. Regulatory requirements are dictated by a variety of sources and are all focused primarily on safety. For more information on how the various rules affect boiler selection and operation, you may want to contact your local Cleaver-Brooks authorized representative. Here are some key rules to consider:

- The boiler industry is tightly regulated by the American Society of Mechanical Engineers (ASME) and the ASME Codes, which governs boiler design, inspection, and quality assurance. The boiler's pressure vessel must have an ASME stamp. (Deaerators, economizers, and other pressure vessels must also be ASME stamped).
- The insurance company insuring the facility or boiler may dictate additional requirements. Boiler manufacturers provide special boiler trim according to the requirements of the major insurance companies. Special boiler trim items usually pertain to added safety controls.

Some industries, such as food processing, brewing, or pharmaceuticals, may also have additional regulations that have an impact on the boiler and the boiler room.

- A UL, ULC, cUL, CSA or CGA listing, or Canadian Registration Number (CRN) may be required. State, local, or provincial authorities may require data on the boiler controls or basic design criteria.
- Most areas have established a maximum temperature at which water can be discharged to the sewer. In this case, a blowdown separator aftercooler is required.
- Most state, local or provincial authorities require a permit to install and/or operate a boiler. Additional restrictions may apply in non-attainment areas where air quality does not meet the national ambient air quality standards and emission regulations are more stringent.
- For all new boilers with inputs over 10 MMBtu/hr, U.S. Federal emission standards apply, including permitting and reporting procedures.
- Limits on fuel sulfur content are frequently set at 0.5% maximum.
- A full-time boiler operator may be required. Operator requirement depends on the boiler's size, pressure, heating surface or volume of water. Boilers can be selected which minimize the requirements, either by falling under the requirements and being exempt or with special equipment that gives the operator more freedom in the facility.
- Most states or provinces require an annual boiler inspection. There may be other requirements on piping as well.

Before beginning the selection process, refer to Table 2, which shows multiple considerations for selecting a packaged boiler.

Steam or Hot Water

Now that you have a general overview of the types of boilers and code and standards requirements, it's time to look at the facility's application in order to see how the boiler will be used. Keep in mind, the primary purpose of the boiler is to supply energy to the facility's operations - for heat, manufacturing process, laundry, kitchen, etc. The nature of the facility's operation will dictate whether a steam or hot water boiler should be used.

Hot water is commonly used in heating applications with the boiler supplying water to the system at 180 °F to 220 °F. The operating pressure for hot water heating systems usually is 30 psig to 125 psig. Under these conditions, there is a wide range of hot water boiler products available. If system requirements are for hot water of more than 240 °F, a high temperature water boiler should be considered.

Steam boilers are designed for low pressure or high pressure applications. Low pressure boilers are limited to 15 psig design, and are typically used for heating applications. High pressure boilers are typically used for process loads and can have an operating pressure of 75 to 700 psig. Most steam boiler systems require saturated steam.

Steam and hot water boilers are defined according to design pressure and operating pressure. Design pressure is the maximum pressure used in the design of the boiler for the purpose of calculating the minimum permissible thickness or physical characteristics of the pressure vessel parts of the boiler. Typically, the safety valves are set at or below design pressure. Operating pressure is the pressure of the boiler at which it normally operates. The operating pressure usually is maintained at a suitable level below the setting of the pressure relieving valve(s) to prevent their frequent opening during normal operation.

Some steam applications may require superheated steam. It should be noted that superheated steam has a high enthalpy, so there is more energy per pound of steam and higher (drier) steam quality. One example of an application where superheated steam may be required is with a steam turbine. The turbine's blades require very dry steam because the moisture can destroy the blades. When very high pressure or superheated steam is required, an industrial watertube boiler should be selected.

System Load

In addition to the system load considerations provided in this section, many excellent reference manuals are available to help further define specific load details and characteristics. For more information, refer to the ABMA Firetube Engineering Guide, the ASHRAE Handbook, or contact your local Cleaver-Brooks authorized representative.

System load is measured in either Btus or pounds of steam (at a specific pressure and temperature). When discussing the system load, we will include references to both steam and hot water. However, not all situations or criteria apply to both. It would be nearly impossible to size and select a boiler(s) without knowing the system load requirements. Knowing the system load provides the following information:

The boiler(s) capacity, taken from the maximum system load requirement.

The boiler(s) turndown, taken from the minimum system load requirement.

Conditions for maximum efficiency, taken from the average system load requirement.

Determining the total system load requires an understanding of the type(s) of load in the system. There are three types of loads: heating, process, and combination.

Table 3. Load Demand Matrix

	MINIMUM	WEIGHTED AVERAGE	MAXIMUM
Heating Load 1			
Heating Load 2			
Heating Load 3			
Total Heating Load			
Process Load 1			
Process Load 2			
Process Load 3			
Total Process Load			
Instantaneous Load			
Total Load			

Utilize a load demand matrix to analyze each load and determine minimum, average, and maximum load requirements.

Heating Load

A heating load is typically low pressure steam or hot water, and is relatively simple to define because there is not a great deal of instantaneous changes to the load. And, once a heating load is computed, the number can easily be transferred into the equipment size requirements. A heating load is used to maintain building heat. Cooling loads, using steam to run an absorption chiller, also are included when computing a heating load. Characteristics of a heating load include large seasonal variations but small instantaneous demand changes. The boiler should be sized for the worst possible weather conditions, which means that true capacity is rarely reached.

Process Load

A process load is usually a high pressure steam load. A process load pertains to manufacturing operations, where heat from steam or hot water is used in the process. A process load is further defined as either continuous or batch. In a continuous load, the demand is fairly constant - such as in a heating load. The batch load is characterized by short-term demands. The batch load is a key issue when selecting equipment, because a batch-type process load can have a very large instantaneous demand that can be several times larger than the rating of the boiler. For example, based on its size, a heating coil can consume a large amount of steam simply to fill and pressurize the coil. When designing a boiler room for a process load with instantaneous demand, a more careful boiler selection process should take place.

Combination Load

Many facilities have a mixture of loads - different types of process loads and combinations of heating and process loads. The information just given on heating and process loads should be taken into consideration when dealing with a combination load.

Defining Load Variations

Loads vary and a power plant must be capable of handling the minimum load, the maximum load, and any load variations. Boiler selection is often dictated by the variation in load demand, rather than by the total quantity of steam or hot water required.

There are three basic types of load variations: seasonal, daily, and instantaneous.

Seasonal Variations. For a heating system, seasonal variations can mean no demand in the summer, light demand in the fall and spring, and heavy demand in the winter. Manufacturing operations often have seasonal variations, because the demand for production may vary. When selecting boiler equipment, the minimum and maximum load for each season should be determined.

Daily Variation. Daily variation can occur due to variations in the work hours, or the heat required at various times of the day or weekend. Minimum and maximum seasonal variations mentioned earlier may already reflect these changes if they occur daily. If not, the minimum and maximum daily loads should be included.

The seasonal and daily variations define the size of the load that the boiler(s) must handle. Seasonal and daily variations also help define the number of boilers and turndown requirements.

Instantaneous Demand. Instantaneous demand is a sudden peak load change that is usually of short duration. These types of loads are sometimes hidden. Many machines or processes are rated in pounds of steam per hour or Btu/hr as running loads, under balanced operating conditions, and there is no recognition given to "cold startup," "peak" or "pickup loads." The instantaneous load demand is important to consider when selecting a boiler to ensure that these load variations are taken into account. If the instantaneous demand is not included in the system load calculations, the boiler(s) may be undersized.

System Load Summary

The load demand matrix shown in Table 3 can be used as a work sheet in determining the minimum, maximum, and average system loads.

Load Tracking

Load tracking is the ability of a boiler to respond to changes in steam or hot water demand. Most often associated with process loads, load tracking focuses on the boiler's ability to supply a constant volume of steam at the required pressure.

The ability of the boiler to track a variable load depends on the boiler type, burner turndown capability, feedwater valve control, and combustion control design. If the analysis of the load shows highly variable load conditions, a more complex control package may be necessary. This type of control is achieved with sophisticated boiler management systems.

If the application has instantaneous load demands, whereby a large volume of steam is required for a short period of time, a boiler with a large energy storage reserve, such as a firetube, should be considered. If the application dictates large variances in load demand, where the load swings frequently for long periods of time, the best choice is probably a watertube type boiler, because it contains less water and can respond to the variances more rapidly.

In all cases, operation of the burner should be taken into account in selecting a boiler(s) to meet system demand. The burner will require proper operating controls that can accurately sense the varying demands and be capable of the turndown requirements. The boiler feedwater valve and control design are also critical if load swings are expected.

Number of Boilers

Back-Up Boilers

When selecting the boiler(s), consideration should be given to back-up equipment to accommodate future expansion, emergency repairs, and maintenance. There are a number of considerations for a backup boiler.

Type of Load

Heating systems and non-critical loads that do not result in a sudden loss of production generally have little or no backup. While this is not recommended, it is still common practice. These types of applications rely on the ability to make repairs quickly to reduce downtime. The risk involved in having no backup is a total loss of heat when the boiler is not in service.

When process or heating loads use multiple boilers during peak times, and one boiler during most other times, the availability of an additional boiler to provide full backup during maximum demand should be considered.

In applications with critical steam or hot water requirements, laws or codes may require a backup. Even if laws or codes do not require a backup, there are many cases where the operation cannot tolerate downtime. For example, a hotel uses hot water 24 hours a day, seven days a week. During periods of maintenance or in an emergency, a backup boiler is required.

Downtime

Another way to determine whether a backup boiler is a wise decision is to compute the cost of downtime to the owner or the user, as shown in the following three examples:

> A chemical company manufactures dry cell battery compound in a batch process. The process temperature must be maintained within 2 degrees. The boiler shuts down on a flame failure. They have 20 minutes to recover steam or the batch is scrap. The value of the product is $250,000.
>
> A Midwestern insurance company building has comfort heat supplied by one boiler. There are over 2000 workers in the building. The boiler shuts down due to a failed gas valve. Outside, it's 11°F. Inside, the temperature continues to drop and, at 1:30 in the afternoon, all 2,000 workers are sent home.
>
> A meat processing company makes its entire packaged ham line in a Southern plant. It operates 24 hours a day, every day. A single boiler provides heat for curing, sterilizing, and cleaning. The boiler goes down due to a lack of feedwater. Each hour of steam loss results in four hours of lost production.

Boiler Turndown

Boiler turndown is the ratio between full boiler output and the boiler output when operating at low fire. Typical boiler turndown is 4:1. For example, a 400 horsepower boiler, with a 4:1 turndown burner, will modulate down to 100 horsepower before cycling off. The same boiler with a 10:1 turndown burner will modulate down to 40 horsepower.

The ability of the burner to turn down reduces frequent on and off cycling. Fully modulating burners are typically designed to operate down to 25% of rated capacity. At a load that is 20% of the rated capacity, the boiler will turn off and cycle frequently.

A boiler operating at low load conditions can cycle as frequently as 12 times per hour, or 288 times per day. With each cycle, pre- and post-purge air flow removes heat from the boiler and sends it out the stack. The energy loss can be eliminated by keeping the boiler on at low firing rates. Every time the boiler cycles off, it must go through a specific start-up sequence for safety assurance. It requires about one to two minutes to place the boiler back on line. And, if there's a sudden load demand, the start-up sequence cannot be accelerated. Keeping the boiler on line assures the quickest response to load changes. Frequent cycling also accelerates wear of boiler components. Maintenance increases and, more importantly, the chance of component failure increases.

As discussed earlier, boiler(s) capacity requirement determined by many different

*Table 4. Typical Firetube Boiler Fuel Consumption Rates - NO. 6 Oil (gal/hr)**

AVERAGE OUTPUT	BOILER EFFICIENCY					
	86%	**84%**	**82%**	**80%**	**78%**	**76%**
BHP						
100	26	27	27	28	29	29
200	52	53	54	56	57	59
300	78	80	82	84	86	88
400	104	106	109	112	114	117
500	130	133	136	140	143	147
600	156	159	163	168	172	176
700	182	186	191	196	200	206
800	208	213	218	224	229	235
900	234	239	245	252	257	264
1000	260	266	272	280	286	294

* Based on 150,000 Btu/gallon.

*Table 5. Typical Firetube Boiler Fuel Consumption Rates - No. 2 Oil (gal/hr)**

AVERAGE OUTPUT	BOILER EFFICIENCY					
	86%	**84%**	**82%**	**80%**	**78%**	**76%**
BHP						
100	28	28	29	30	31	31
200	56	57	58	60	61	63
300	83	85	87	90	92	94
400	111	114	117	120	123	126
500	139	142	146	149	153	157
600	167	171	175	179	184	189
700	195	199	204	209	215	220
800	222	228	233	239	245	252
900	250	256	262	269	276	283
1000	278	285	292	299	307	315

* Based on 140,000 Btu/gallon.

types of load variations in the system. Boiler over-sizing occurs when future expansion and safety factors are added to assure that the boiler is large enough for the application. If the boiler is oversized, the ability of the boiler to handle minimum loads without cycling is reduced. Therefore, capacity and turndown should be considered together for proper boiler selection to meet overall system load requirements.

Table 6. Typical Firetube Boiler Fuel Consumption Rates - Natural Gas (MM/Btu/hr)

AVERAGE OUTPUT	BOILER EFFICIENCY					
	86%	84%	82%	80%	78%	76%
BHP						
100	3.89	3.99	4.08	4.18	4.29	4.41
200	7.78	7.98	8.16	8.36	8.58	8.82
300	11.67	11.97	12.24	12.54	12.87	13.23
400	15.56	15.96	16.32	16.72	17.16	17.64
500	19.45	19.95	20.40	20.90	21.45	22.05
600	23.34	23.94	24.48	25.08	25.74	26.46
700	27.23	27.93	28.56	29.26	30.03	30.87
800	31.12	31.92	32.64	33.44	34.32	35.28
900	35.01	35.91	36.72	37.62	38.61	39.69
1000	38.90	39.90	40.80	41.80	42.90	44.10

Performance Considerations

Three important considerations pertain to fuels, emissions, and efficiency. All three have important impact on boiler performance, and can affect long-term boiler operating costs.

Fuels

Remember, from an operating perspective, fuel costs typically account for approximately 10% of a facility's total operating budget. Therefore, fuel is an important consideration. Normally, the fuels of choice are natural gas, propane, or light oil. Increasingly stringent emission standards have greatly reduced the use of heavy oil and solid fuels such as coal and wood. Of the fossil fuels, natural gas burns cleanest and leaves less residue; therefore less maintenance is required.

It can be advantageous to supply a boiler with a combination burner that can burn two fuels independently - for example, oil or natural gas. A combination burner allows the customer to take advantage of "peak time" rates, which substantially reduces the costs of a therm of gas when operating "off peak" by merely switching to the back up fuel. Dual fuel capability also is beneficial if the primary fuel supply must be shut down for safety or maintenance reasons.

Some waste streams can be used as fuel in the boiler. In addition to reducing fuel costs, firing an alternate fuel in a boiler can greatly reduce disposal costs. Waste streams are typically used in combination with standard fuels to ensure safe operation and to provide additional operating flexibility.

Emissions

Emission standards for boilers have become very stringent in many areas, because of the new clean air regulations. The ability of the boiler to meet emission regulations depends on the type of boiler and burner options.

Efficiency

Efficiency is used in the measure of economic performance of any piece of equipment. In the boiler industry, there are four common definitions of efficiency, but only one true measurement. Following are the definitions and how to measure efficiency.

Combustion Efficiency

Combustion efficiency is the effectiveness of the burner only and relates to its ability to completely burn the fuel. The boiler has little bearing on combustion efficiency. A well- designed burner will operate with as little as 15 to 20% excess air, while converting all combustibles in the fuel to thermal energy.

Thermal Efficiency

Thermal efficiency is the effectiveness of the heat transfer in a boiler. It does not take into account boiler radiation and convection losses - for example, from the boiler shell, water column piping, etc.

Boiler Efficiency

The term “boiler efficiency” is often substituted for combustion or thermal efficiency. True boiler efficiency is the measure of fuel-to-steam efficiency.

Fuel-to-Steam Efficiency

Cleaver-Brooks guaranteed boiler efficiencies are fuel-to- steam efficiencies.

Fuel-to-steam efficiency is the correct definition to use when determining boiler efficiency. Fuel-to-steam efficiency is calculated using either of two methods, as prescribed by the ASME Power Test Code, PTC 4.1. The first method is input-output. This is the ratio of Btu output divided by Btu input x 100.

The second method is heat balance. This method considers stack temperature and losses, excess air levels, and radiation and convection losses. Therefore, the heat balance calculation for fuel-to-steam efficiency is 100 minus the total percent stack loss and minus the percent radiation and convection losses.

Stack Temperature and Losses

Stack temperature is the temperature of the combustion gases (dry and water vapor) leaving the boiler. A well-designed boiler removes as much heat as possible from the combustion gases. Thus, lower stack temperature represents more effective heat transfer and lower heat loss up the stack. The stack temperature reflects the energy that did not transfer from the fuel to steam or hot water. Stack temperature is a visible indicator of boiler efficiency. Any time efficiency is guaranteed, predicted stack temperatures should be verified.

Stack loss is a measure of the amount of heat carried away by dry flue gases (unused heat) and the moisture loss (product of combustion), based on the fuel analysis of the specific fuel being used, moisture in the combustion air, etc.

Excess Air

Excess air provides safe operation above stoichiometric conditions. A burner is typically set up with 15 to 20% excess air. Higher excess air levels result in fuel being used to heat the air instead of transferring it to usable energy, increasing stack losses.

Radiation and Convection Losses

Radiation and convection losses will vary with boiler type, size, and operating pressure. The losses are typically considered constant in Btu/hr, but become a larger percentage loss as the firing rate decreases.

Boiler design factors that also impact efficiencies of the boiler are heating surface, flue gas passes, and design of the boiler and burner package.

Heating Surface

Heating surface is one criterion used when comparing boilers. Boilers with higher heating surface per boiler horsepower tend to be more efficient and operate with less thermal stress. Many packaged boilers are offered with five square feet of heating surface per boiler horsepower as an optimum design for peak efficiency.

Flue Gas Passes

The number of passes that the flue gas travels before exiting the boiler is also a good criterion when comparing boilers. As the flue gas travels through the boiler it cools and, therefore, changes volume. Multiple pass boilers increase efficiency because the passes are designed to maximize flue gas velocities as the flue gas cools.

Integral Boiler/Burner Package

Ultimately, the performance of the boiler is based on the ability of the burner, the boiler, and the controls to work together. When specifying performance, efficiency, emissions, turndown, capacity, and excess air all must be evaluated together. The efficiency of the boiler is based, in part, on the burner being capable of operating at optimum excess air levels. Burners not properly designed will produce CO or soot at these excess air levels, foul the boiler, and substantially reduce efficiency. In addition to the boiler and burner, the controls included on the boiler (flame safeguard, oxygen trim, etc.) can enhance efficiency and reduce overall operating costs for the customer. A true packaged boiler design includes the burner, boiler, and controls as a single, engineered unit.

Special Considerations

Replacement Boilers

If the boiler is to be placed in an existing facility, there are a number of considerations:

- Floor space required.
- Total space requirements.
- Access space for maintenance.
- Size and characteristics of the boiler to be replaced, including location of existing piping, the boiler stack and utilities.
- Boiler weight limitations.
- With little or no access to the boiler room, some bent-tube type boilers can be carried into the boiler room in sections or pieces and easily assembled, with no welding required.
- Electric boilers should also be considered, especially since they do not require a stack.
- Vertical firetube boilers have a small floor space requirement.

PAYBACK ANALYSIS

There are many factors that affect the decision to purchase a particular piece of boiler room equipment. This subsection addresses some of the economic considerations in the decision process. The procedure presented can be applied to equipment selection and the economic evaluation of alternative systems.

The effect of a single piece of equipment can be a significant part of the overall transfer of energy from the fuel burned to the thermal energy of the steam or hot water delivered. The performance of equipment, such as the boiler, stack gas recovery systems (economizers), condensate recovery systems (deaerators, etc.), oxygen trim systems, and blowdown heat recovery systems, should be considered. Efficiency gains from each piece of equipment need to be evaluated individually in the context of the overall system to determine the incremental fuel cost savings.

Savings from efficiency gains are used to evaluate the payback potential of the equipment. Payback simply refers to the time period that will elapse before the cumulative cost savings will equal the incremental capital cost of the equipment selected.

In summary, this section provides a procedure and a set of tables and figures to assist in assessing the economic justification of purchasing higher performance equipment or additional energy savings equipment (e.g., economizers, oxygen trim controls, etc.). This procedure may also be used to evaluate the operating cost impact of different system configurations.

The tables and figures provided are not unique to Cleaver- Brooks products. Therefore, the procedures may be applied to any thermal energy consuming system. Before proceeding, product related information (e.g., efficiency and fuel consumption rates) should be obtained for each specific product.

Having defined a basic system configuration, and having identified equipment that would yield incremental performance improvement (and investment), the payback analysis sequence is straight forward and can be summarized as follows:

1. Estimate boiler fuel consumption rate.
2. Estimate annual fuel use.
3. Estimate annual fuel cost.
4. Determine potential incremental efficiency improvement.
5. Estimate potential annual fuel savings.
6. Determine the payback period for the investment.
7. Refine the analysis.

The remainder of this section outlines the step-by-step procedure to be used in conjunction with the figures and tables.

Remember, the lowest cost product is not necessarily the most economic choice. In fact, most often it is not the best choice!

Step 1: Boiler Fuel Consumption Rate

Use Table 4,Table 5, andTable 6 to compare the fuel consumption rates of two boiler configurations with different fuel-to-steam efficiency or, as a base fuel rate for a given boiler configuration. Find the appropriate boiler size and the efficiency on the table to find the associated fuel consumption.

Step 2: Annual Fuel Usage

Multiply the hourly fuel consumption rates by the annual hours of operation to determine the annual fuel usage rate.

Step 3: Annual Fuel Cost

Figure 1 and Figure 2 are used to determine annual fuel cost for natural gas based on annual gas use (billion Btu/yr) and gas cost ($/MMBtu). Figure 2 provides a more detailed graph for lower gas usage applications. Save the annual fuel cost value for Step 5.

(Note that the figures referenced in this discussion are located at the end of this section.)

Figure 3 and Figure 4 are used to determine annual fuel cost for oil fuels based on annual oil use (thousand gal/yr) and oil cost ($/gal). Figure 4 provides a more detailed graph for lower oil usage application. Save the annual fuel cost value for Step 5.

Step 4: Incremental Efficiency Improvement

If an improvement is being added to a boiler (economizer, oxygen trim, etc.) that is designed to improve the efficiency of the boiler by “x” percent (incremental efficiency gain). Use Figure 4 to take the base system efficiency (bottom) and the incremental efficiency gain (right side) to determine the actual improvement in the system efficiency to be used for the cost savings in Step 5.

Step 5: Annual Fuel Savings

Use Figure 6 to determine the annual fuel savings based on the annual fuel cost and system efficiency improvement (right side of graph). Figure 7 provides for a more detailed graph for lower fuel cost applications.

Step 6: Payback Period

The payback period is the years required to recover the capital investment. To determine payback simply divide the capital cost of the equipment by the annual savings.

To determine the amount of capital available based on a known payback period, multiply the annual savings by the payback period required.

Step 7: Refine the Analysis

It should be recognized that the tools provided herein are intended to provide a quick mechanism to focus on an appropriate equipment configuration and scope. The graphs provided should permit you to quickly identify candidate equipment options that economically qualify and, therefore, merit more serious evaluation.

Additional economic issues (maintenance, necessity of equipment, etc.) should be considered by final conclusions are reached.

Contact your local Cleaver-Brooks authorized representative for additional information.

Example

Consider the following payback analysis example. Assume that a project requires a three-year payback for any incremental capital investment. Also assume that an 800 hp firetube boiler firing No. 2 oil and operating at 85% efficiency has a cost of $1/gal. Assume the average load is 50% of rated capacity for the anticipated 5000 hours per year of operation. The questions are:

What is the yearly savings attributable to adding an oxygen trim control system designed to improve efficiency 1.3% to the boiler?

How much capital may be allocated to purchase this equipment and fall within the three-year payback guideline?

Step 1: Estimate Boiler Fuel Consumption Rate

Using Figure 4, an average output of 400 hp at 85% efficiency will use approximately 112.5 gal/hr (interpolated between 86% at 111 gal/hr and 84% at 114 gal/hr) of No. 2 fuel oil.

Step 2: Estimate Annual Fuel Use

112.5 gal/hr x 5000 hr/yr = 562,500 gal/yr annual fuel consumption or approximately 560,000 gal/yr

Step 3: Estimate Annual Fuel Cost

Refer to Figure 5 and find the intersection of 560,000 gal/yr (bottom scale) and the $1.40/ gal fuel price line (right scale). Looking to the left, the annual fuel cost (left scale) is shown to be $784,000.

Step 4: Determine Potential Incremental Efficiency Improvement

Based on an average efficiency improvement attributable to the trim control of 1.3% for No. 2 oil. Refer to Figure 3and find the intersection of the boiler system base efficiency of (85%) and the 1.3% incremental efficiency gain curve (right scale). Referring to the left scale, the system efficiency improvement is shown to be 1.6%.

Step 5: Estimate Potential Annual Fuel Savings

Refer to Figure 7and find the intersection of $784,000 annual fuel cost (bottom scale) and the 1.6% system efficiency improvement (right scale) identified in Step 4. Looking across to the left scale, annual savings are shown to be approximately $12,000.

Step 6: Determine the Payback Period for the investment (or the Allowable Incremental Capital)

Multiply $12,000 times the three years required to get $36,000.

Step 7: Refine the Analysis

If there are other economic factors to be considered as a result of adding oxygen trim controls, add these savings (or costs) to the $12,000 annual fuel savings determined in Step 5. Then repeat Step 6 with the combined savings figure.

Assuming there are no other economic factors to be considered, the analysis has shown that the project payback criteria can be met provided the installed oxygen trim control will cost no more than $36,000. Clearly, purchase of the added control in this example would be a good investment. The equipment purchase cost would be recouped in less than three years and the customer would enjoy $12,000 annual savings thereafter that will grow with fuel price increases and escalation.

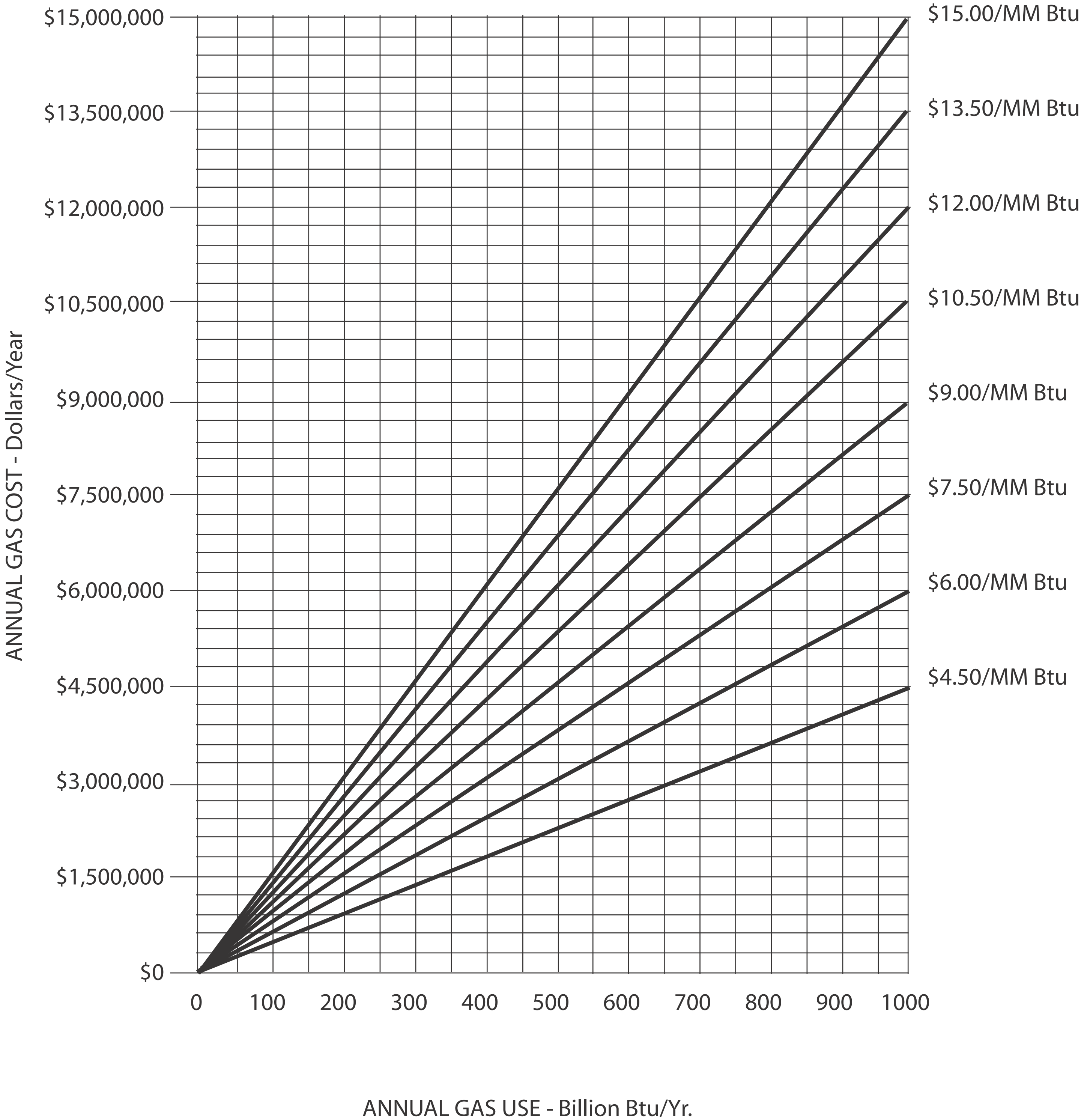

Figure 1. Annual Gas Cost as a Function of Gas Use and Unit Price

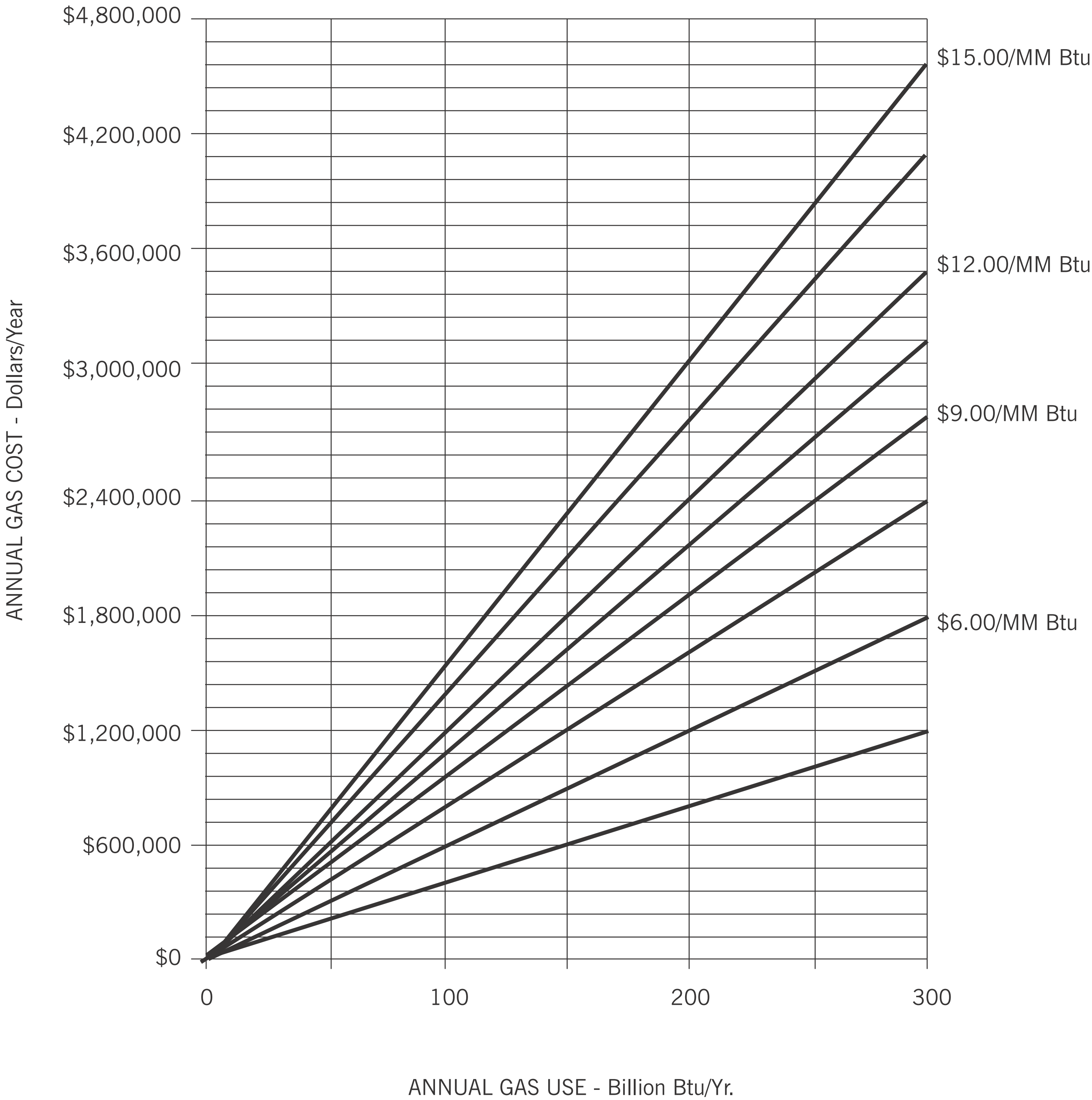

Figure 2. Annual Gas Cost as a Function of Gas Use and Unit Price (Expansion of Figure 1)

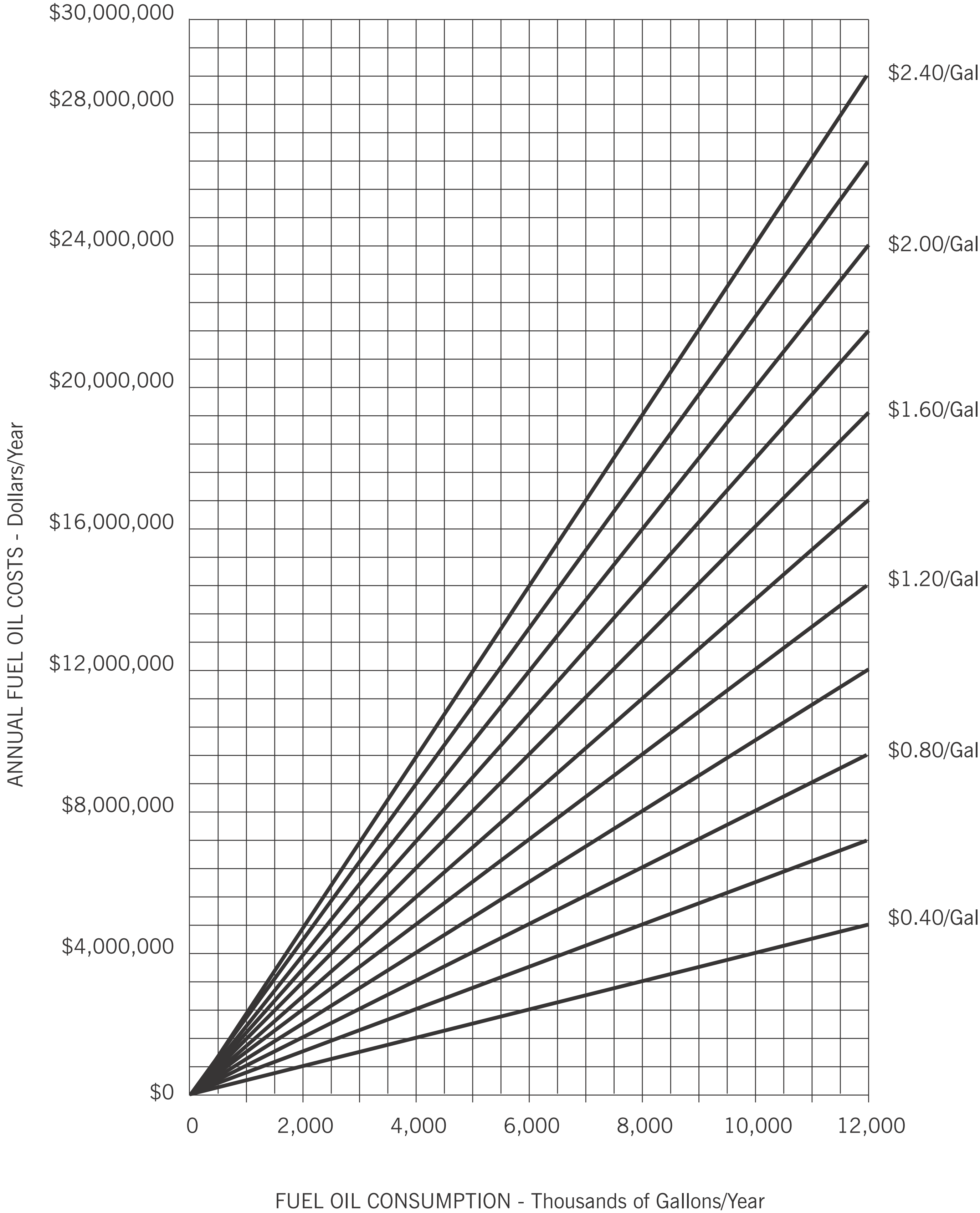

Figure 3. Annual Fuel Oil Cost as a Function of Fuel Oil Use and Unit Price

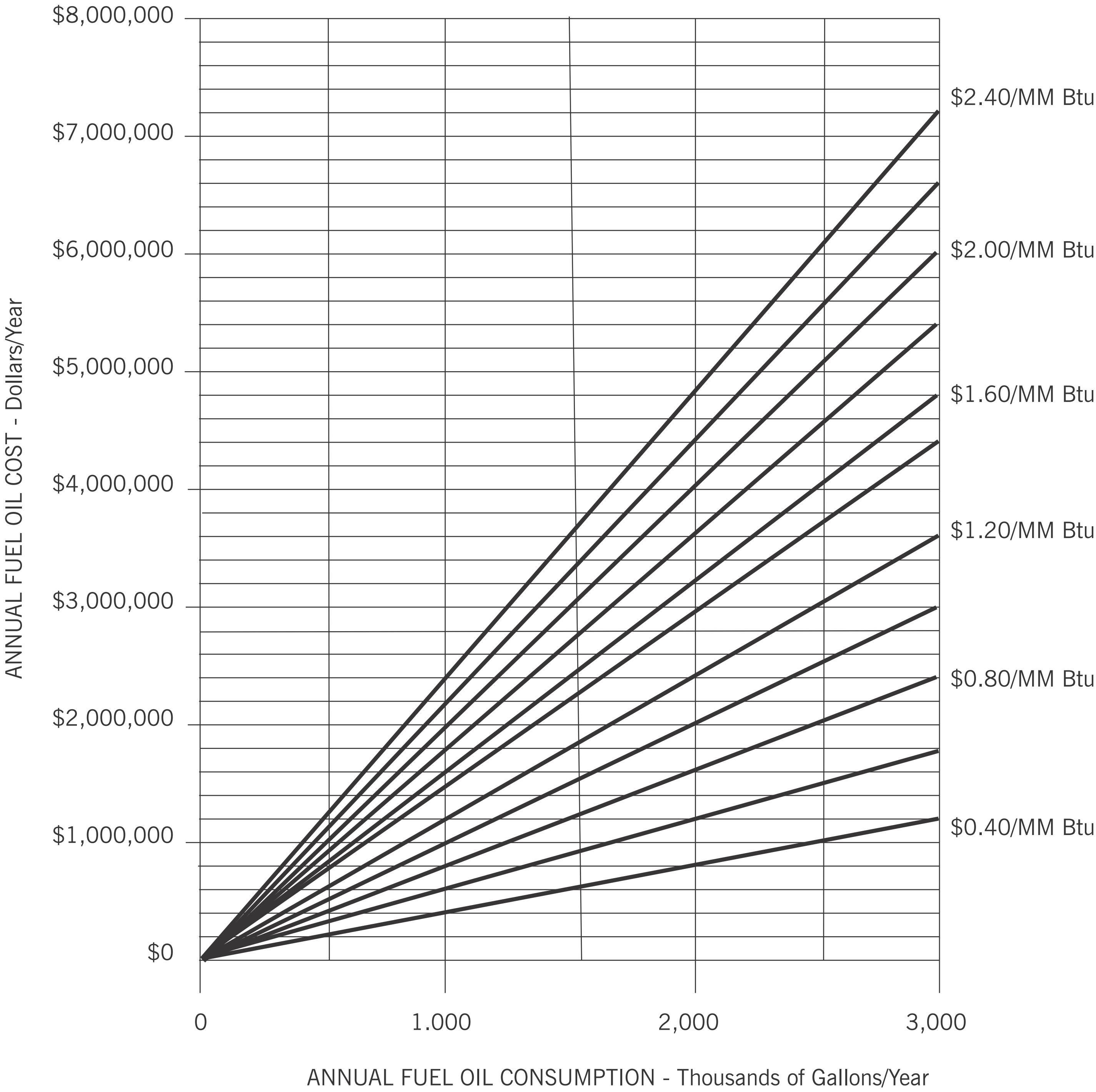

Figure 4. Annual Fuel Oil Cost as a Function of Fuel Oil Use and Unit Price (Expansion of Figure 3)

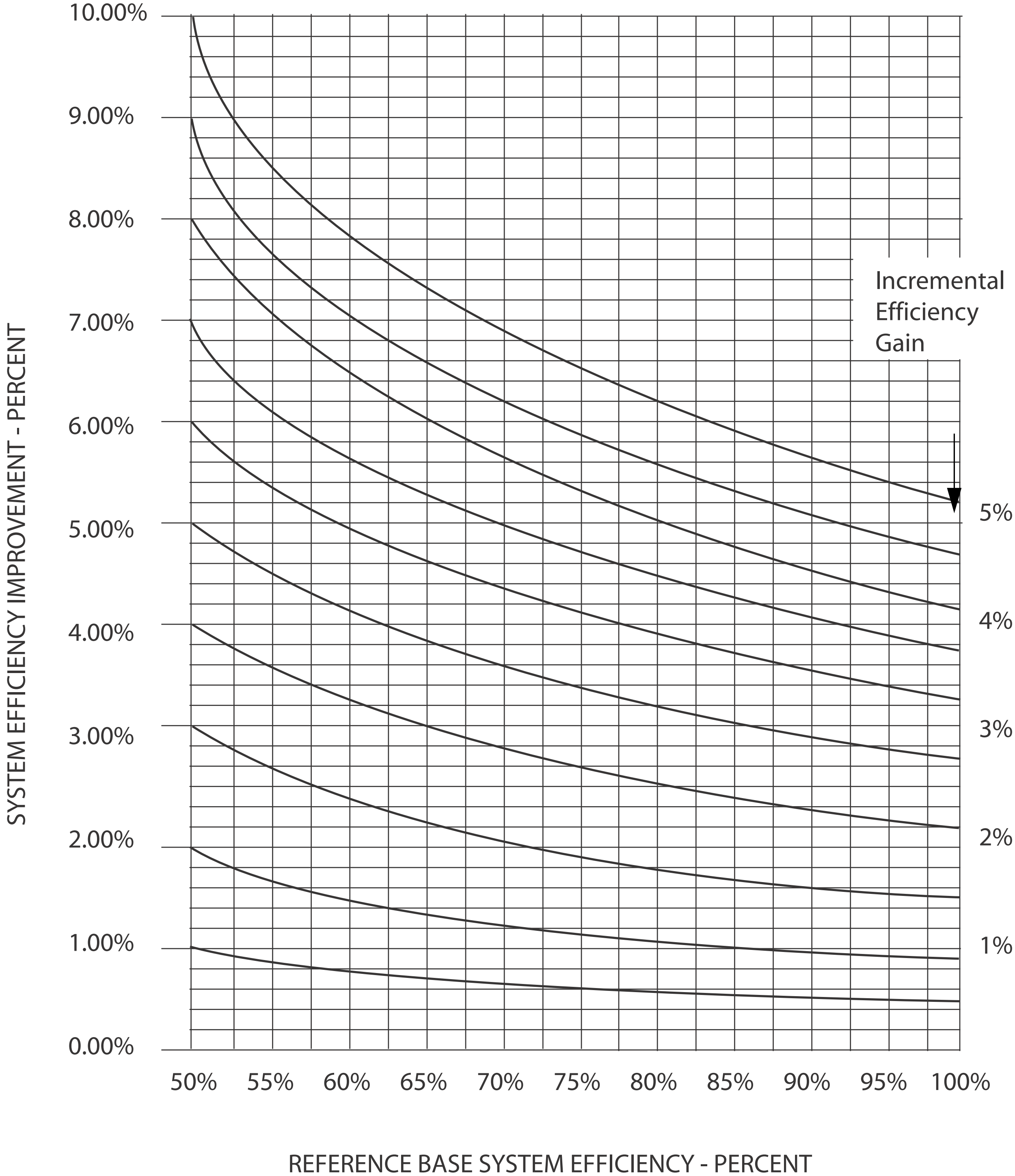

Figure 5. System Efficiency Improvement as a Function of Incremental Component Efficiency Gain

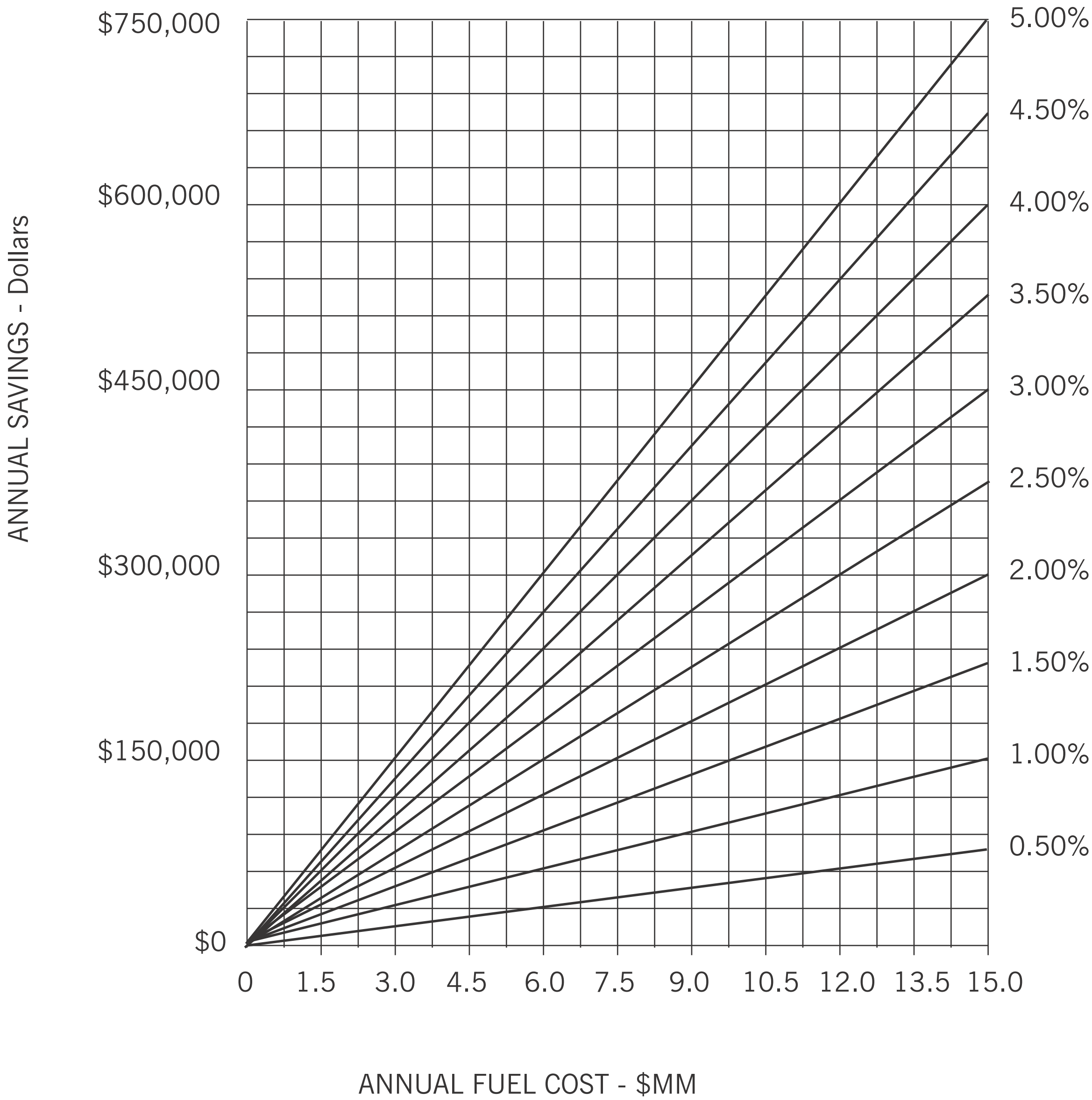

Figure 6. Annual Savings as a Function of Annual Fuel Cost and System Efficiency Improvement

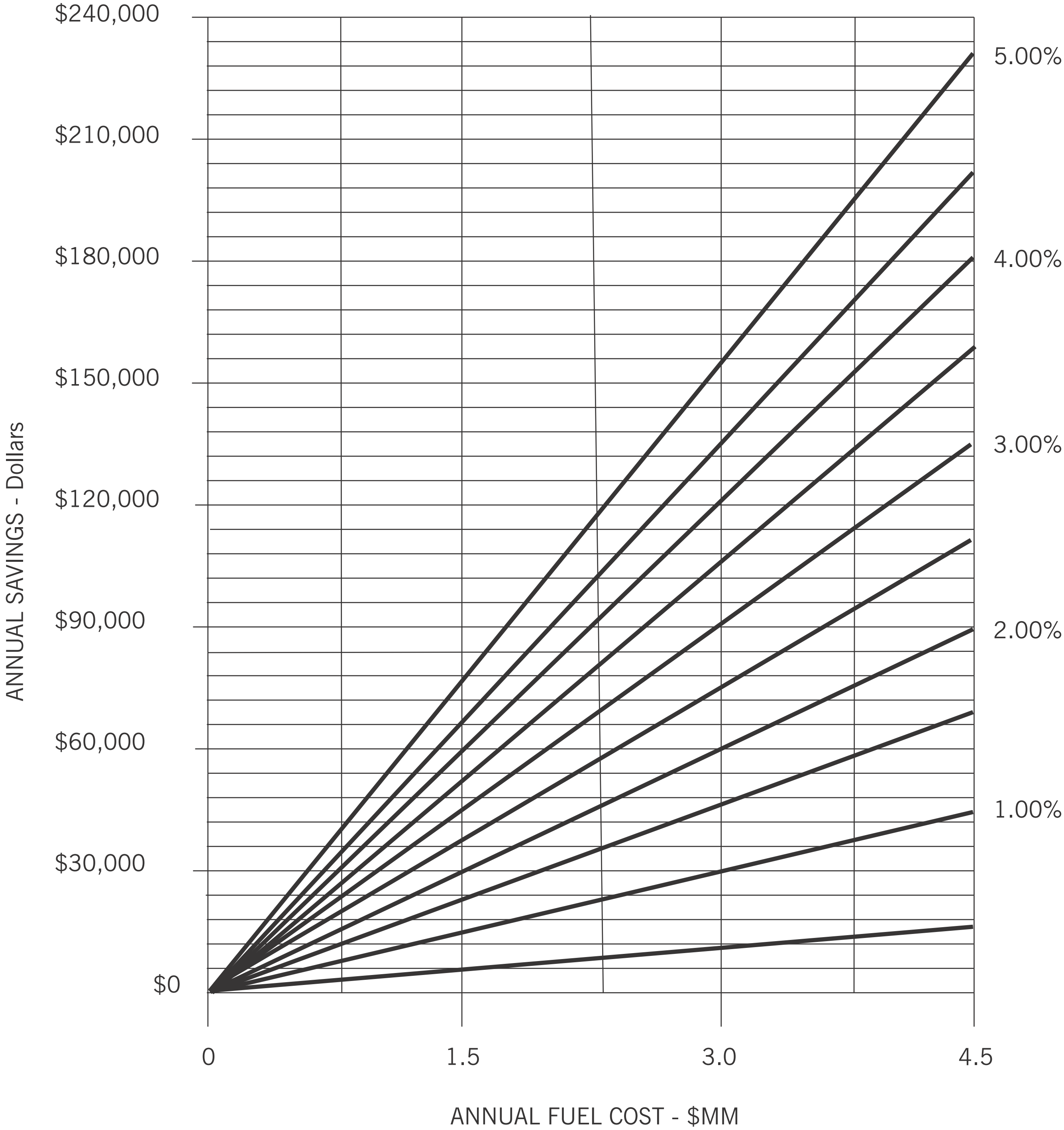

Figure 7. Annual Savings as a Function of Annual Fuel Cost and System Efficiency Improvement (Expansion of Figure 6)