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Climate Wise

Wise Rules for Industrial Efficiency

A Tool Kit for Estimating Energy Savings and Greenhouse Gas Emissions Reductions

CLIMATE WISE

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For more information on the Climate Wise Program, call the *Wise Line* at 1-800-459-WISE.

Climate Wise would like to thank the following people for their assistance and input:

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1. Introduction

The Climate Wise Program

Climate Wise is a partnership initiative sponsored by the U.S. EPA, with technical support from the U.S. DOE, designed to stimulate the voluntary reduction of greenhouse gas emissions among participating manufacturing companies. Climate Wise hopes to spur innovation by encouraging broad goals, providing technical assistance, and allowing organizations to identify the most cost-effective ways to reduce greenhouse gas emissions. Climate Wise currently has more than 400 partners, representing about 12 percent of U.S. industrial energy use. As part of their Climate Wise commitment, partner companies across the country develop comprehensive Action Plans that describe their energy efficiency and pollution prevention goals, the specific actions undertaken to achieve these goals, the time frame for implementing commitments, and estimates of the impacts on energy, costs, and emissions from these actions. To date, Climate Wise Partner companies have submitted Action Plans detailing more than 1,000 individual actions to reduce greenhouse gas emissions and prevent pollution. About half of these actions pertain to energy efficiency measures in industrial operations such as: boiler and steam systems, compressed air systems, energy management operations, motor systems, process heating, and process improvements. Partner companies also pursue non-process energy efficiency measures such as lighting, HVAC, and building shell improvements, as well as water conservation, recycling, pollution prevention and educational outreach.

Overview

The *Wise Rules for Industrial Efficiency* – "Wise Rules Tool Kit" – was developed to help partners make the most of their Climate Wise participation and generate interest and commitment in support of energy efficiency and pollution prevention efforts. It provides Climate Wise Partners with simple rules for estimating energy savings and greenhouse gas emissions reductions from a wide range of industrial energy efficiency measures, based on a large number of resources. Information on typical cost savings and paybacks are also provided. The Wise Rules focus on six process energy end-uses including boilers, steam systems, process heating, waste heat recovery and cogeneration, compressed air systems, and process cooling. Six chapters describe energy efficiency measures and provide Wise Rules on typical energy and cost savings for each of these major process end-uses. This information can help your company identify and evaluate alternative energy efficiency activities. It can also help you to develop your Climate Wise Action Plan — your statement of commitment under your Climate Wise Participation Agreement.

Climate Wise will update this document periodically as we gather new information on industrial energy efficiency measures. We welcome your feedback and input on the Wise Rules Tool Kit, including other rules that you have found useful and would like to share, or requests for new Wise Rules for specific end-uses. Please phone in your comments to the *Wise Line* at 1-800-459-WISE, fax them to 703-934-3968, send them via electronic mail to: WiseLine@ICFKaiser.com, or mail them to:

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Information Sources

The Wise Rules Tool Kit is a compilation of some of the best information available on industrial energy efficiency. These rules are based on energy efficiency research and engineering principles, the experience of Climate Wise Partners, and government sources such as the U.S. Department of Energy's Industrial Assessment Center (DOE/IAC) energy audit database. These resources provide a wealth of energy efficiency and other information in the manufacturing sector, including energy, cost, and operating data.

The Wise Rules capture broad categories of efficiency improvements such as "air compressor efficiency measures" and more detailed actions such as "optimize boiler air-to-fuel ratio." The Wise Rules also provide multiple perspectives on efficiency opportunities by expressing energy savings as a percent of a particular end-use's energy consumption (e.g., optimizing air-to-fuel ratio can reduce boiler fuel use by two to 20 percent), as a percent of a facility's total energy use (e.g., steam trap maintenance can reduce a facility's total energy use by 3.4 percent), or per unit change in a physical parameter (e.g., for every one psi decrease in air compressor pressure, energy use is reduced by 0.7 percent). To make them as useful as possible, the Wise Rules are presented in a variety of formats, including graphs, bullets, and tables. In addition, we have provided a handy reference guide to identify energy efficiency opportunities for specific manufacturing sectors (see Appendix A).

The DOE/IAC energy audit database was an important source of information for the Tool Kit. The database contains information from industrial energy assessments conducted at small-to-medium sized manufacturing facilities by teams of faculty and students from accredited engineering schools in 30 universities across the country. The Wise Rules Tool Kit includes information on the expected impacts from approximately 27,000 specific improvements and upgrades from 4,300 detailed facility audits conducted between 1990 and 1997. The majority of the auditors' recommendations had relatively short (1 to 2 year) payback periods and were expected to be implemented within two years of the audit.

The impacts from broad categories of efficiency recommendations in the DOE/IAC audits are summarized in **Introduction Table 1**. For example, boiler efficiency measures were recommended during 20 percent of the 4,300 audits and were expected to save on average 2.8 percent of a *facility's* total energy use, or an average of 2,600 MMBtu per year. The average cost of implementing boiler efficiency measures was expected to be $5,300 with average first-year savings of $7,200 for an expected average simple payback of nine months. Compressed air efficiency measures were recommended during 68 percent of the audits. The average savings from

Introduction Table 1: Summary of Efficiency Measures from the DOE/IAC Database*

End Use	Recommendation Rate (% of audited facilities)	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost	Average Cost Savings	Average Simple Payback (months)
Boilers	20%	2.8%	2,600	$ 5,300	$ 7,200	9
Steam Systems	13%	2.0%	2,400	$ 3,300	$ 7,100	6
Furnaces & Ovens	4%	2.8%	2,500	$ 5,500	$ 8,100	8
Process Heating	1%	2.2%	3,600	$ 7,500	$ 12,200	7
Heat Containment	22%	1.5%	1,100	$ 1,100	$ 5,100	9
Heat Recovery	26%	4.6%	3,700	$ 16,500	$ 12,500	16
Cogeneration**	3%	9.1%	31,000	$667,500	$233,600	34
Air Compressors	68%	0.4%	300	$ 1,600	$ 4,300	5
Process Cooling	6%	1.1%	1,000	$ 18,900	$ 11,200	20

* Based on DOE/IAC estimates at audits of 4,300 manufacturing companies (1/90-7/97). Savings may not be additive.

**Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricty.

Definition of Terms: The recommendation rate is equal to the number of *facilities* receiving a particular recommendation (e.g., repair steam leaks) divided by the total number of facilities audited (≈4,300). Average percent energy savings are defined as the average reduction in a *facility's* total energy use from a specific recommendation. Average annual energy and cost savings reflect first year savings. Cost savings are primarily based on energy cost savings, but also may include other cost savings. The average simple payback is the average implementation cost divided by average annual cost savings, times 12 (months per year).

air compressor efficiency measures were 0.4 percent of total *facility* energy use, or an average 300 MMBtu annual reduction in each facility's energy use. The average cost of implementing compressed air efficiency measures was expected to be $1,600 with average first-year cost savings of $4,300 for an average simple payback of five months. Similar rules developed for a range of other broad actions as well as more detailed measures are presented in the body of the Wise Rules Tool Kit. The estimated audit impacts for specific industry sectors are presented in Appendix A.

Using the Tool Kit

The Wise Rules were developed to help you take full advantage of your participation in the Climate Wise Program. As you begin to develop your Climate Wise Action Plan, the Wise Rules can help you and your Climate Wise team generate ideas for energy savings opportunities in your facilities. The Tool Kit provides a quick scan of measures along a number of dimensions, including potential energy savings, implementation costs, energy costs savings, and payback. Use the Wise Rules, along with information on the processes in your operations, to screen a broad range of efficiency measures and to eliminate less attractive options based on your company's key criteria. The Tool Kit provides background information on all of the Wise Rules so that Climate Wise Partners will have a better understanding of how and when to use them. We have also provided references to the primary data source for every Wise Rule so that partners can learn more if they desire. Appendix D of the Tool Kit contains a summary of key references and resources.

Once measures have been identified, you can use the Wise Rules to estimate project-level energy savings and CO_2 emissions reductions to be reported on your Climate Wise Action Plan. While you will want to refine these estimates over time and track actual results for completed projects, the Wise Rules can serve as place-holders until your experience provides you with better, site-specific data. You may also find that you want to develop your own rules based on your engineering analyses and metered data. In this way you can tailor Wise Rules for processes specific to your company or based on your company's operations, energy prices, and other factors.

The Tool Kit also provides information required to calculate CO_2 emissions reductions, as required in your Climate Wise Action Plan. CO_2 emission factors provided in Appendix B of the Tool Kit can be used with the energy savings estimates based on the Wise Rules to estimate total emissions reductions from your actions.

It is important to keep in mind a number of points when using the Wise Rules:

- The Tool Kit provides savings estimates for many important efficiency measures, but it is not a exhaustive list of industrial efficiency opportunities. A number of processes and end-uses are not included here that may offer savings to your company (e.g., lighting and motors). There may also be attractive measures — including pollution prevention measures — applicable to your specific processes and operations that your company should consider. Moreover, many of the Wise Rules reflect efficiency recommendations with relatively short (1 to 2 year) payback periods. Your company's payback requirement may be longer for some types of projects. When identifying energy efficiency and pollution prevention opportunities, it is important not to limit your actions to those measures included here.
- The Wise Rules can provide simple savings estimates but they cannot take the place of detailed engineering analyses based on site-specific data and operating parameters. The Wise Rules are based on typical experience and general engineering observations from a number of sources. The energy audit data reflect the energy and cost savings estimates (not actual experience) across many industry groups, over several years and across many parts of the country. Be sure to consider your company's unique circumstances when applying Wise Rules. For many projects, more detailed analysis will be desirable.
- Some Wise Rules may be only applicable under specific operating conditions (e.g., only to equipment of a certain size or within a specific temperature range). Some efficiency measures for the same or related end-uses may interact, such that the total energy savings from completing two measures may be less (or more) than the sum of the two measures' individual impacts. Because Wise Rules are drawn from a variety of sources, savings estimates may not be comparable, even when the energy efficiency measures are similar. For example, some Wise Rules express savings for an energy efficiency measure on the basis of specific *equipment* energy consumption, while others are expressed as a percent of a *facility's* total energy savings. Such rules may not be comparable,

because they may assume different specific measures, implementation levels, or contributions of the end use to total facility energy-use.

- All Wise Rules are expressed as "energy savings" to allow easy comparison across measures. However, many of the key references and resources are based on efficiency impacts — a closely related measure.
- A comprehensive analysis of efficiency opportunities should also examine secondary impacts of savings measures. These include impacts on operations, maintenance, productivity, and the environment. For example, changes in boiler operating parameters may have secondary effects on emissions of nitrogen oxides, particulates, or carbon monoxide. These may all be important decision criteria for your company.
- Energy savings estimates based on the Wise Rules cannot take the place of measuring the results of implemented projects. For some projects, you may want to implement energy tracking and/or metering systems to evaluate the success of your Climate Wise efforts and the return on your investments. This information can later be used to develop Wise Rules for your company.

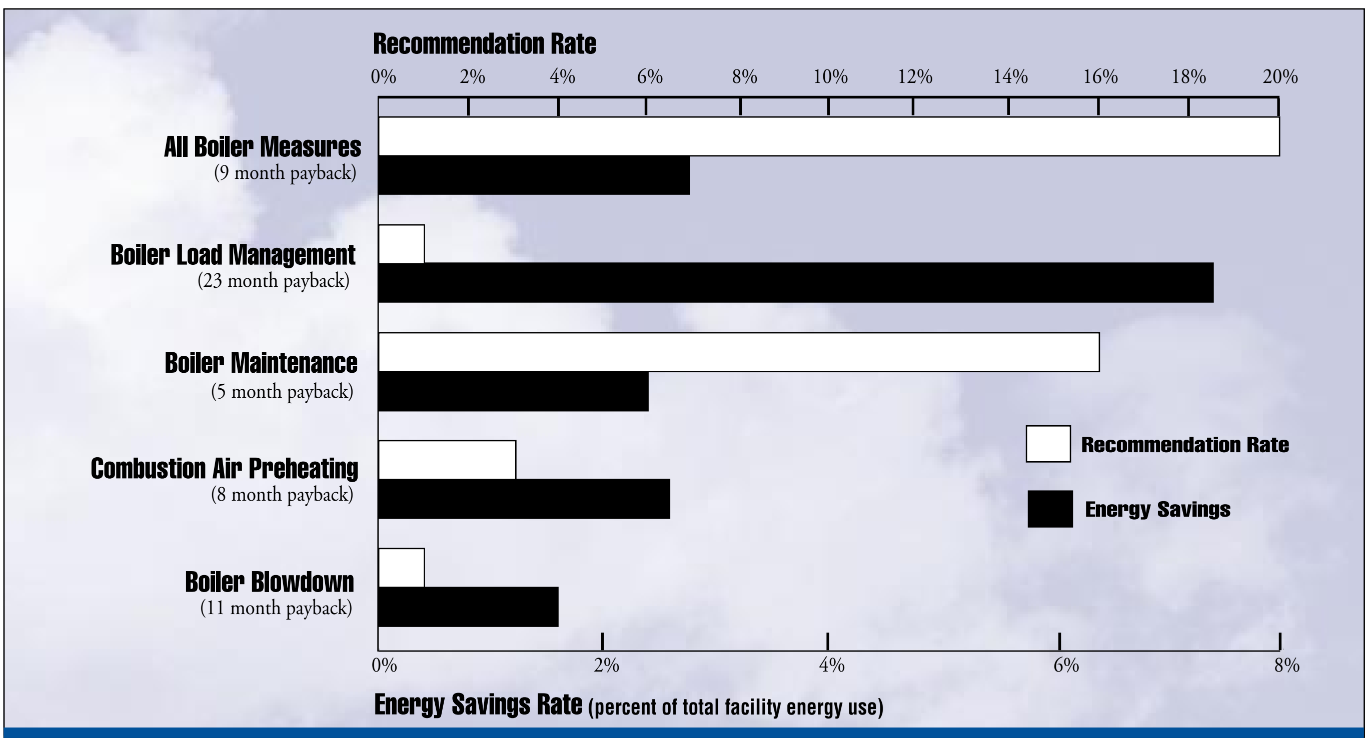
2. Boilers

Introduction

Boilers are one of the most important energy uses in manufacturing, typically comprising more than a third of total manufacturing energy demand. A boiler generates hot water or steam, typically from the combustion of coal, oil, or natural gas. A network of pipes delivers steam (or hot water) to provide heat for a variety of process and heating applications. Once the heat has been extracted from the water or steam, another network of pipes returns the condensed water back to the boiler where it is cyclically reheated. There are several different types of boilers including natural draft, forced draft, hot water or steam, and fire tube or water tube. The typical boiler used in small-to-medium sized industrial operations is a forced draft steam boiler at 120-150 psi and approximately 150 hp (equivalent to 5 MMBtu/hr).[1] Large industrial boilers can exceed 7,500 hp (250 MMBtu/hr). Typical boiler efficiencies range from about 70 to 85 percent depending on fuel type, configuration, and heat recovery capability.[2]

Several boiler efficiency measures may be of interest to Climate Wise Partners: boiler load management, burner replacement, upgraded instrumentation, tune-up and air/fuel ratio optimization, stack heat loss prevention, waste heat recovery, and blowdown control. **Boiler Figure 1** illustrates the potential energy savings from boiler efficiency measures based on IAC audit recommendations. Boiler efficiency measures with an average savings of about three percent of facility energy use, and a simple payback of nine months were recommended at 20 percent of the 4,300 facilities audited. Boiler load management measures have a relatively high

Boiler Figure 1
Energy Savings from Boiler Efficiency Measures*



* Results from the DOE/IAC Database (1/90-7/97). The IAC data reflect average potential impacts from energy efficiency measures at small-to-medium sized manufacturing facilities across all sectors and regions of the country. Most IAC audit recommendations are expected to be implemented within two years and typically have a one-to-two year payback period. (See Chapter 1.)

expected energy savings, eight percent of total energy use, but these measures were only recommended at one percent of facilities audited and have a payback of about two years. Boiler maintenance measure were recommended at 16 percent of facilities audited with average energy savings of two percent and simple payback time of only five months. **Boiler Table 1**, at the end of this chapter, summarizes the Wise Rules presented in this chapter, along with cost savings estimates, where available.

Boiler Load Management

One of the most basic energy saving measures is effective boiler load management — properly sizing the boiler to meet the steam load. A good example of this is replacing a large boiler with several smaller ones, allowing for high efficiency operation during light and full load periods. The relationship between boiler efficiency and firing rate is non-linear. Therefore, in order to maximize overall efficiency, a boiler's output can be matched to load, based on its design and specifications.[3]

Boiler Wise Rule 1

Effective boiler load management techniques, such as operating on high fire settings or installing smaller boilers, can save over 7% of a typical *facility's* total energy use with an average simple payback of less than 2 years.[4]

Boiler Wise Rule 2

Load management measures, including optimal matching of boiler size and boiler load, can save as much as 50% of a *boiler's* fuel use.[5]

Tune-Up and Air/Fuel Ratio Optimization

Periodic measurement of flue gas oxygen, carbon monoxide, opacity, and temperature provides the fundamental data required for a boiler tune-up. It is useful to have the following instruments on hand to best manage boiler operation: stack thermometers, fuel meters, make-up feedwater meters, oxygen analyzers, run-time recorders, energy output meters, and return condensate thermometers.[6] A typical tune-up might include a reduction of excess air (and thereby excess oxygen, O_2), boiler tube cleaning, and re-calibration of boiler controls. Maintaining a proper air-to-fuel ratio is very important for optimizing fuel combustion efficiency. In a "lean" mix (high air-to-fuel ratio), heat will be lost to the excess air, while in a "rich" mix (low air-to-fuel ratio), unburned fuel will be emitted with the exhaust gases. Each fuel type and firing method has an optimal air/fuel ratio. For example, optimum excess air for a pulverized coal boiler is 15 to 20 percent (3 to 3.5 percent excess O_2), and optimum excess air for a forced draft gas boiler is 5 to 10 percent (1 to 2 percent excess O_2).[7] The air/fuel ratio should be set to the manufacturer's recommendations. Because it is difficult to reach and maintain optimal values in most boilers, actual excess air levels may need to be set higher than optimal.[8] When boilers are operating at low loads, excess-air requirements may be greater than the optimal levels and efficiency may be lower.[9] Manual or automatic oxygen trim can ensure that the proper air/fuel mixture ratio is maintained.[10] Secondary impacts of boiler efficiency measures should be considered when evaluating a project. For example, adjustments of air/fuel ratio and other operating parameters may affect emissions of nitrogen oxides, particulates, or carbon monoxide.

Boiler Wise Rule 3

An upgraded boiler maintenance program including optimizing air-to-fuel ratio, burner maintenance, and tube cleaning, can save about 2% of a *facility's* total energy use with an average simple payback of 5 months.[11]

Boiler Wise Rule 4

A comprehensive tune-up with precision testing equipment to detect and correct excess air losses, smoking, unburned fuel losses, sooting, and high stack temperatures, can result in *boiler* fuel savings of 2% to 20%.[12]

Boiler Wise Rule 5

A 3% decrease in flue gas O_2 typically produces *boiler* fuel savings of 2%.[13]

Boiler Wise Rule 6

Using over fire draft control systems to control excess air can save 2% to 10% of a *boiler's* fuel use with typical equipment costs of $1,500.[14]

Boiler Wise Rule 7

Using a characterizable fuel valve to match the air/fuel ratios across the load range can save 2% to 12% of a *boiler's* fuel use at relatively low cost.[15]

Burner Replacement

The method by which fuel is delivered to the burner affects boiler efficiency. Fuel atomization can add flexibility in fuel choice and can improve low load operation. Atomizers suspend fine droplets of fuel on a cone of air or steam allowing better control of fuel delivery.[16]

Boiler Wise Rule 8

Converting to air or steam atomizing burners from conventional burners can reduce *boiler* fuel use by 2% to 8%.[17]

Stack Heat Losses and Waste Heat Recovery

Stack heat losses are usually the largest single energy loss in boiler operations. Key measures that minimize stack heat losses are air/fuel ratio optimization (see above), and stack gas heat recovery for pre-heating combustion air or boiler feedwater (see Chapter 5).[18] Heat recovery may increase boiler-operating temperature, which may have secondary effects of increasing nitrogen oxide emissions. To maximize boiler efficiency and prevent flue gas condensation, stack temperature should be 50°F to 100°F above the water temperature.[19]

Boiler Wise Rule 9

Every 40°F reduction in *net* stack temperature (outlet temperature minus inlet combustion air temperature) is estimated to save 1% to 2% of a *boiler's* fuel use.[20]

Boiler Wise Rule 10

Stack dampers prevent heat from being pulled up the stack and can save 5% to 20% of a *boiler's* fuel use.[21]

Boiler Wise Rule 11

Direct contact condensation heat recovery can save 8% to 20% of a *boiler's* fuel use, but costs may be relatively high.[22]

Boiler Wise Rule 12

Preheating combustion inlet air can save about 3% of a *facility's* total energy use with an average simple payback of 8 months.[23]

Blowdown Control and Waste Heat Recovery

Dissolved and suspended solids in boiler feedwater can deposit on heat transfer surfaces and reduce boiler efficiency. Boiler manufacturers usually establish a maximum acceptable concentration of dissolved solids. To maintain low concentration levels, boiler water is periodically diluted in a process called "blowdown" during which boiler water is drained off and new water is added.[24] Heat losses during blowdown are often overlooked because they are hard to measure and facility personnel may not fully understand the water chemistry. Hot water drained to the sewer and excess heat vented to the atmosphere contains unused energy.[25] Warming make-up feedwater with blowdown waste heat can minimize heat losses. Replacing manual blowdown valves with analyzing equipment and automatic valves can also reduce blowdown losses.

Boiler Wise Rule 13

Minimizing energy loss from boiler blowdown can save about 2% of a *facility's* total energy use with an average simple payback of less than 1 year.[26]

Boiler Wise Rule 14

Removing a 1/32 inch deposit on boiler heat transfer surfaces can decrease a *boiler's* fuel use by 2%; removal of a 1/8 inch deposit can decrease boiler fuel use by over 8%.[27, 28]

Boiler Wise Rule 15

Blowdown heat recovery is a proven technology that can reduce a *boiler's* fuel use by 2% to 5%.[29]

Boiler Wise Rule 16

For every 11°F that the entering feedwater temperature is increased, the *boiler's* fuel use is reduced by 1%.[30]

Boiler Wise Rule 17

Changing from manual blowdown control to automatic adjustment can reduce a *boiler's* energy use by 2% to 3% and reduce blowdown water losses by up to 20%.[31]

Summary of Wise Rules for Boiler Systems

Use the Wise Rules in **Boiler Table 1** (next page) to identify and estimate potential energy saving from boiler efficiency measures. In selecting alternative efficiency options and eliminating less attractive measures, consider the potential costs, savings, payback times and any secondary effects. When using the Wise Rules, remember that several of the measures may overlap, or complement each other (e.g., tune-up and flue gas O_2 reduction) and energy savings rates of overlapping measures may not be additive. In addition, multiple Wise Rules may address the same measure from different perspectives. For example **Boiler Wise Rule 1** expresses savings from boiler load management as a percent of the *boiler's* energy use, while **Boiler Wise Rule 2** expresses savings as a percent of the *facility's* total energy use. Specific Wise Rules may not be comparable with each other because they rely on different sources with different assumptions.

Adjust the Wise Rules in **Boiler Table 1** to match your circumstances. For example, you may want to scale the gross fuel cost savings to match your boiler size. To calculate savings for a 10 MMBtu/hr natural gas boiler, multiply gross fuel cost savings by a factor of ten. This scaling is applicable only to gross fuel cost savings expressed per MMBtu/hr, e.g., Rule 2, but not Rule 1 in **Boiler Table 1**. Implementation costs may not scale in a linear manner. Similarly, you can adjust the savings numbers on the basis of your fuel prices and operating hours. For example, if your boiler uses coal at a price of $1.50/MMBtu, divide the cost savings values in **Boiler Table 1** by the per MMBtu price of natural gas, e.g., $2.30, and multiply by $1.50.

Boiler System Notes

1 Rutgers University, Office of Industrial Productivity and Energy Assessment, *Modern Industrial Assessments: A Training Manual*, Version 1.0b, December 1995, p. 5-1.

2 O'Callaghan, P., *Energy Management*, McGraw-Hill, England, 1993, p. 198.

3 Taplin, H.R., *Boiler Plant and Distribution System Optimization Manual*, Fairmont Press, 1991, p. 122.

4 DOE/IAC Industrial Assessment Database, July 1997.

5 Taplin, p. 122.

6 Taplin, p. 129.

7 Turner, W.C., *Energy Management Handbook*, 3rd Edition, Fairmont Press, 1997, p. 90.

8 Rutgers, p. 5-12.

9 Turner, p. 90.

10 Garay, P.N., *Handbook of Industrial Power and Steam Systems*, Fairmont Press, 1995, p. 211.

11 DOE/IAC Database.

12 Taplin, p. 134.

13 3M Company, "Rules of Thumb: Quick Methods of Evaluating Energy Reduction Opportunities," 1992, p. 8.

14 Taplin, p. 141.

15 Taplin, p. 140.

16 Taplin, p. 153.

17 Taplin, p. 153.

18 Taplin, pp. 11-18.

19 Rutgers, p. 5-12.

20 Garay, p. 219; Taplin, p. 15; Rutgers, p. 5-2.

21 Taplin, p. 15.

22 Taplin, p. 166.

23 DOE/IAC Database.

24 Garay, p. 271.

25 Taplin, p. 13.

26 DOE/IAC Database.

27 Garay, p. 271.

28 Rutgers, p. 5-10.

29 Taplin, p. 160.

30 Taplin, p. 33.

31 Taplin, p. 161; Turner, p. 109.

Boiler Table 1: Summary of Boiler Efficiency Measures

Source	Measure (IAC recommendation rate)	Average Energy Savings[a]	Average Annual Cost Savings Savings per MMBtu/hr and (Payback)
	All Efficiency Improvements		
	Implement typical efficiency improvements, which may include many or all of the measures below (20%)	2.8% of total *facility* energy use[b]	$7,200 (9 months)[b]
	Boiler Load Management		
Rule 1	Operate on high fire setting or install smaller boilers (1%)	7.4% of total *facility* energy use[b]	$19,900 (23 months)[b]
Rule 2	Optimize boiler size and boiler load	2% to 50%	$230 to $5,750[c]
	Tune-Up and Air/Fuel Ratio Optimization		
Rule 3	Implement boiler maintenance (air/fuel ratio optimization, burner maintenance, boiler tube cleaning) (16%)	2.4% of total *facility* energy use[c]	$2,460 (5 months)[b]
Rule 4	Implement comprehensive tune-up	2% to 20%	$230 to $2,300[c]
Rule 5	Decrease flue gas O_2	2% per 3% decrease in O_2	$230[c]
Rule 6	Utilize over fire draft control	2% to 10%	$230 to $1,400[c]
Rule 7	Utilize characterizable fuel valve	2% to 12%	$230 to $1,400[c]
	Burner Replacement		
Rule 8	Convert to atomizing burners	2% to 8%	$230 to $920[c]
	Stack Losses and Waste Heat Recovery		
Rule 9	Reduce *net* stack temperature	1% to 2% per 40°F reduction	$140 to $230[c]
Rule 10	Utilize stack dampers	5% to 20%	$580 to $2,300[c]
Rule 11	Direct contact condensation heat recovery	8% to 20%	$920 to $2,300[c]
Rule 12	Preheat combustion air (3%)	2.6% of total *facility* energy use[b]	$5,200 (8 months)[b]
	Blowdown Control and Heat Recovery		
Rule 13	Minimize boiler blow down (1%)	1.6% of total *facility* energy[b]	$8,500 (11 months)[b]
Rule 14	Remove deposits from heat transfer surfaces	2% for 1/32 inch deposit, 8% for a 1/8 inch deposit	$230 to $920[c]
Rule 15	Utilize blowdown heat recovery	2% to 5%	$230 to $580[c]
Rule 16	Preheat boiler feedwater	1% per 11°F increase	$140[c]
Rule 17	Utilize automatic blowdown control	2% to 20%	$230 to $2,300[c]

Source references for each Wise Rule are included in the chapter notes.

[a] Percent of boiler energy use, unless noted.
[b] Energy savings are expressed as a percent of total facility energy use. Cost savings (fuel, O&M, etc.) are expressed in dollars, *not* in dollars per MMBtu/hr of boiler size.
[c] Based on a natural gas boiler with 80% efficiency, operating 5,000 hrs/yr, with a gas price of ≈$2.30/MMBtu. These are gross fuel cost savings only and do not include capital, maintenance, or other costs or savings.

3. Steam Systems

Introduction

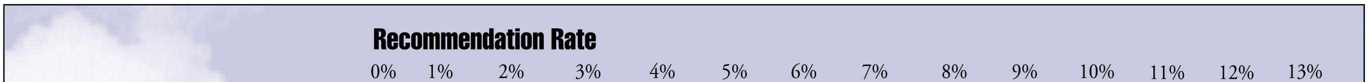
Steam system efficiency improvements are a logical complement to boiler efficiency measures. Useful energy escapes from steam distribution systems from malfunctioning steam traps, steam leaks, and via radiative losses from steam lines, condensate lines, and storage tanks. Each of these areas presents opportunities for energy savings.

Steam system efficiency measures that may be of interest to Climate Wise Partners include: steam trap maintenance, repairing steam leaks, insulation, condensate measures, and vapor recompression. **Steam Figure 1** illustrates the potential energy savings from steam system efficiency measures based on specific recommendations in the DOE/IAC database. Steam system efficiency measures were recommended at 13 percent of the 4,300 facilities audited with an average anticipated savings of two percent of a facility's total energy use and a simple payback of six months. Improved steam line insulation was recommended at seven percent of the facilities audited with an expected average savings of one percent of the facility's total energy use and a simple payback of ten months. **Steam Table 2**, at the end of this chapter, summarizes the Wise Rules presented in this chapter, along with cost savings estimates, where available.

Maintenance of Steam Traps

Steam traps hold steam in the coil until the steam releases its heat energy and condenses. Steam trap operation can be checked by comparing the temperature on each side of the trap. In properly

Steam Figure 1
Energy Savings from Steam System Efficiency Measures*



* Results from the DOE/IAC Database (1/90-7/97). The IAC data reflect average potential impacts from energy efficiency measures at small-to-medium sized manufacturing facilities across all sectors and regions of the country. Most IAC audit recommendations are expected to be implemented within two years and typically have a one-to-two year payback period. (See Chapter 1.)

functioning steam traps, there will be a large temperature difference between the two sides of the trap and no steam downstream of the trap. Malfunctioning steam traps waste steam and result in higher boiler fuel consumption.[1] Typically, 15 to 60 percent of the steam traps in a plant may be malfunctioning and wasting large amounts of energy.[2]

Steam Wise Rule 1

An effective steam trap maintenance program can save 3% of a *facility's* total energy use with an average simple payback of 2 months.[3]

Steam Wise Rule 2

An effective steam trap maintenance program can reduce a *boiler's* fuel use by 10% to 20%.[4]

Reducing Leaks

Repairing leaks in steam pipes, condensate return lines, and fittings can yield significant energy and cost savings. Steam leaks increase boiler fuel use because additional steam must be generated to make up for the wasted steam. Leaky condensate return lines increase make-up water requirements and increase boiler fuel use because more energy is required to heat the cooler, make-up boiler feedwater than would be required to heat the returned condensate. Actual savings will depend on boiler efficiency, steam pressure, and annual operating hours.[5]

Steam Wise Rule 3

Repairing steam system leaks can save 1% of a *facility's* total energy use with an average simple payback of 3 months.[6]

Steam Wise Rule 4

A single high-pressure steam leak (125 psi) can result in energy losses costing from $660 to $2,200 per year (8,760 hrs). A single low-pressure steam leak (15 psi) can result in energy losses costing $130 to $480 per year (8,760 hrs).[7]

Reducing Heat Losses

Often boiler and steam system insulation is removed to make repairs and is not replaced. Uninsulated surfaces in boiler and steam systems can reach 450°F. Such high temperatures can threaten employee safety and can pose a fire hazard, as well as waste significant amounts of energy.

Steam Table 1
Annual Costs of Heat Loss per 100 feet of Uninsulated Steam Pipe[8]

Steam Pressure	Cost per 100 ft of pipe per year (8,760 hr)
25 psi	$1,600
50 psi	$1,900
75 psi	$2,100
100 psi	$2,300

Steam Wise Rule 5

Insulating steam lines can save 1% of a *facility's* total energy use with an average simple payback of 10 months.[9]

Vapor Recompression

When there is a need for low pressure steam, vapor recompression can double the pressure of vented steam using only a fraction of the energy required to generate the steam in a boiler.[10]

Steam Wise Rule 6

Vapor recompression saves 90% to 95% of the energy needed to raise the steam to the same pressure in a boiler.[11]

Condensate

A number of measures can be implemented to reduce heat losses from condensate — the water that forms after steam has been used. Increasing the amount of condensate returned to the boiler saves energy because it eliminates the need to heat cold make-up water. Insulating steam lines, condensate lines and tanks, will prevent unnecessary heat loss through the system. Collecting high-pressure condensate after flash steam formation can provide low-pressure steam for other purposes.

Steam Wise Rule 7

Measures to reduce heat loss from condensate in a steam system can save over 1% of a *facility's* total energy use with an average simple payback of 8 months.[12]

Summary of Wise Rules for Steam Systems

Use the Wise Rules in **Steam Table 2** (next page) to identify and estimate potential energy saving from steam system efficiency measures. When identifying attractive options and eliminating weak ones, consider potential costs, savings, payback periods and any secondary effects. When using the Wise Rules, remember that some measures may interact or complement each other (e.g., steam trap maintenance and steam pipe insulation) and energy savings rates may not be additive. Multiple Wise Rules may address the same efficiency measure from different perspectives. For example, Steam Rules 1 and 2 express savings from steam trap maintenance as (1) a percent of a *facility's* total energy use, and (2) as a percent of *boiler* energy use.

Steam System Notes

1 Rutgers University Office of Industrial Productivity and Energy Assessment, *Modern Industrial Assessments: A Training Manual*, Version 1.0b, December 1995, p. 5-19.

2 Turner, W.C., *Energy Management Handbook*, 3rd Edition, Fairmont Press, 1997, p. 149.

3 DOE/IAC Industrial Assessment Database, July 1997.

4 Taplin, H.R., *Boiler Plant and Distribution System Optimization Manual*, Fairmont Press, 1991, p. 276.

5 Rutgers, p. 5-17.

6 DOE/IAC Database.

7 Rutgers University OIPEA, "Useful Rules of Thumb for Resource Conservation and Pollution Prevention," March 1996, #1 and #2.

8 Rutgers, "Useful Rules of Thumb,"#8.

9 DOE/IAC Database.

10 Bonneville Power Administration (BPA), Washington State Energy Office, Electric Ideas Clearinghouse, "Vapor Recompression," July 1992, p. 1.

11 BPA, p. 1.

12 DOE/IAC Database.

Steam Table 2: Summary of Steam System Efficiency Measures

Source	Measure (IAC recommendation rate)	Average Energy Savings	Average Annual Cost Savings (payback)
	All Efficiency Improvements		
	Implement typical efficiency improvements, which may include many or all of the measures below (13%)	2% of total *facility* energy use	$7,100 (6 months)
	Steam Trap Maintenance		
Rule 1	Implement steam trap maintenance program (1%)	3.4% of total *facility* energy use	$17,400 (2 months)
Rule 2	Implement steam trap maintenance program	10% to 20% of boiler fuel use	10% to 20% of boiler fuel costs
	Leak Repair		
Rule 3	Repair steam leaks (2%)	1.0% of total *facility* energy use	$6,100 (3 months)
Rule 4	Repair high pressure leaks (125 psi) Repair low pressure leaks (15 psi)		$660 to $2,200 per leak $130 to $480 per leak
	Insulation		
Table 1	Insulate steam lines (7%)		$1,600 to $2,300 per 100 feet
Rule 5	Improve steam line insulation	1.0% of total *facility* energy use	$2,800 (10 months)
	Other Measures		
Rule 6	Recompress low pressure steam	90% to 95% of energy needed to raise the steam in a boiler	
Rule 7	Reduce heat loss from condensate (4%)	1.3% of total *facility* energy use	$6,700 (8 months)

Source references for each Wise Rule are included in the chapter notes.

4. Process Heating

Introduction

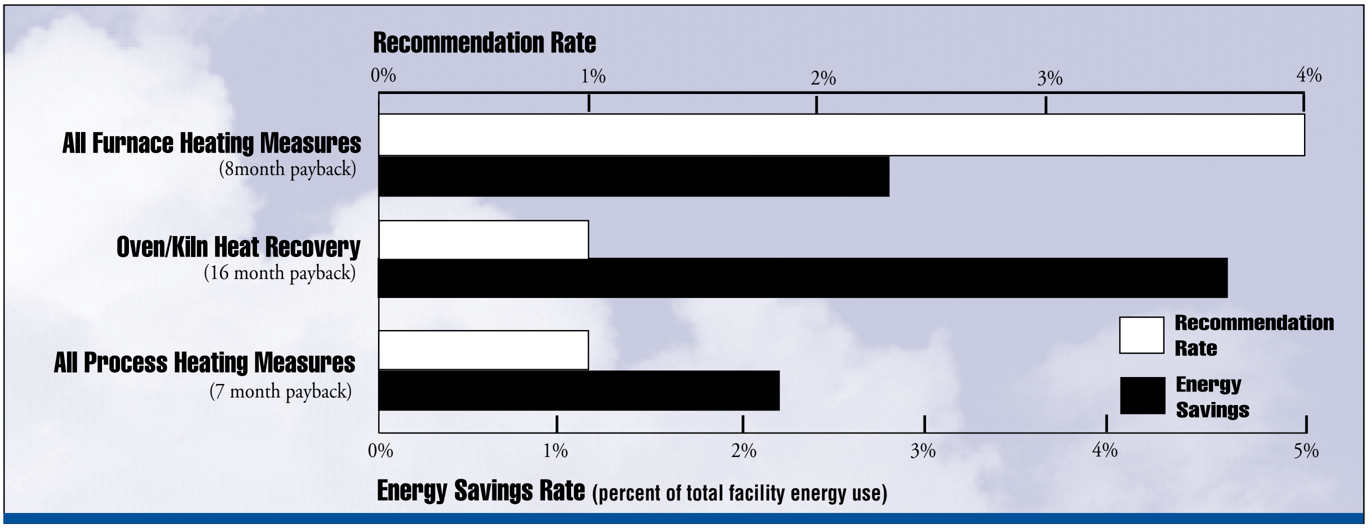
Industrial companies use furnaces, ovens, and kilns to raise the temperature of a raw material or intermediate product as part of a manufacturing process. Important process heating efficiency measures include: insulation, combustion air control, burner adjustment, automatic stack dampers, waste heat recovery, temperature optimization, use of minimum safe ventilation, immersion heating, and enhanced sensitivity of temperature control and cutoff. Minimizing equipment heat-up time can also save energy. For example, many ovens need only 15 to 60 minutes to heat up,[1] but, in practice, may "warm up" for an unnecessarily long period of time. The remainder of this chapter provides additional information on heat containment, process heating and direct heating.

Process Heating Figure 1 illustrates the potential energy savings from heating efficiency measures based on IAC audit recommendations. Furnace efficiency measures were recommended at four percent of the facilities audited with estimated average savings of three percent of the average facility's total energy use and a simple payback of eight months. Heat recovery from ovens, kilns, and other equipment was recommended during only one percent of the audits with estimated energy savings of almost five percent and average simple payback of 16 months. **Process Heating Table 1**, at the end of this chapter, summarizes the Wise Rules presented in this chapter, along with cost savings estimates, where available.

Insulation and Heat Containment

Heat loss can cause major reductions in process heating efficiency. Heat containment measures include insulation of bare equipment and open tanks, isolating hot or cold equipment from air conditioned areas, and reducing infiltration into hot or cold process equipment. New refractory fiber material, with low thermal conductivity and heat storage, can produce significant improvements in efficiency with minimal detriment to the work environment. Typical applications include furnace covers, installing fiber liner between the standard refractory lining and the shell wall, or installing ceramic fiber linings over the present refractory liner. Replacing standard refractory linings with vacuum-formed refractory fiber insulation can also improve efficiency.[2]

Process Heating Figure 1
Energy Savings from Process Heating Efficiency Measures*



* Results from the DOE/IAC Database (1/90-7/97). The IAC data reflect average potential impacts from energy efficiency measures at small-to-medium sized manufacturing facilities across all sectors and regions of the country. Most IAC audit recommendations are expected to be implemented within two years and typically have a one-to-two year payback period. (See Chapter 1.)

Process Heating Wise Rule 1

Proper heat containment can save about 2% of a *facility's* total energy use with an average simple payback of 9 months.[3]

Process Heating Wise Rule 2

Insulating a furnace with refractory fiber liners can improve the *thermal* efficiency of the heating process by up to 50%.[4]

Combustion Air Control

Maintaining a proper air-to-fuel ratio is very important for optimizing fuel combustion efficiency in process heating. In a "lean" mix (high air-to-fuel ratio), heat will be lost to the excess air, while in a "rich" mix (low air-to-fuel ratio), unburned fuel will be emitted with the exhaust gases. Aspirators can help maintain a proper air-to-fuel ratio for premix burners systems, while ratio-regulating systems can do this for nozzle mix burners.[5] Automatic burner control is also an effective strategy for optimizing the air-to-fuel ratio. Control systems technologies include programmable logic controllers, direct stack temperature monitors, and intelligent high-level computer controllers.[6] Be sure to consider potential secondary impacts from adjustments of air/fuel ratio or other operating parameters, such as changes in emissions of nitrogen oxides, particulates, and carbon monoxide.

Process Waste Heat Recovery

Exhaust gas heat losses are another source of process efficiency loss. Heat recovery systems can recapture this heat and reintroduce it into processing heat or other end-uses. A recuperator extracts heat from furnace waste gases to preheat incoming combustion air. A regenerator uses porous ceramic beds for waste gas heat recovery and short-term heat storage.[7] Chapter 5, "Waste Heat Recovery and Cogeneration," describes additional waste heat recovery measures.

Process Heating Wise Rule 3

Recovering waste heat from furnaces, ovens, kilns, and other equipment can save 5% of a typical *facility's* total energy use with an average simple payback of 16 months.[8]

Process Heating Wise Rule 4

Recovering waste heat through a recuperator can reduce a *kiln's* energy use by up to 30%; regenerators can save up to 50%.[9,10]

Specific Process Heat Applications

Energy savings opportunities available in some sectors may be more broadly applicable. For example, in the lumber industry, air-drying lumber before putting it in the kiln can reduce kiln energy use. Using variable speed controls to reduce kiln fan power after the water has been driven off can significantly reduce kiln energy use without affecting drying time or product quality.[11] In the cement industry, advanced control systems such as automated controls and expert systems have shown significant energy savings. Optimizing heat transfer conditions in the clinker cooler through better distribution of clinker and air can also result in substantial energy savings.

Process Heating Wise Rule 5

Each percent of moisture removed by air drying lumber reduces the *kiln's* energy use by 50 to 85 Btu per board foot.[12]

Process Heating Wise Rule 6

Variable fan speed control in the lumber industry can reduce dry kiln airflow by 20% and reduce the *kiln's* energy used during surface drying by as much as 50%.[13]

Process Heating Wise Rule 7

Installing expert systems for kiln secondary control can reduce a *cement kiln's* energy use by up to 3%.[14]

Process Heating Wise Rule 8

New clinker cooler technologies that optimize heat transfer conditions can reduce a *cement kiln's* energy use by up to 6%.[15]

Direct Heating

Direct heating is generally more efficient than indirect heating because heat transfer losses from equipment and transfer media are eliminated. Examples of direct heating technologies include direct firing (generally with natural gas), infrared, microwave, and dielectric heating. Direct heating also provides other operational benefits including faster drying times, reduced maintenance, easier installation, more precise temperature control, more uniform heating, and increased output.[16]

Process Heating Wise Rule 9

Direct firing with natural gas in place of indirect steam heating has the potential to save 33% to 45% of *process heating* energy use. Payback times may range from a few months to 6 years.[17]

Process Heating Wise Rule 10

Direct electric heating (infrared, microwave, or dielectric) can reduce *process heating* energy use by up to 80% with typical payback periods of 1 to 3 years.[18]

Summary of Wise Rules for Process Heating

Use the Wise Rules in **Process Heating Table 1** (next page) to identify and estimate potential energy savings from process heating efficiency measures. When evaluating alternatives and eliminating options, consider the potential costs, energy savings, payback time, and any secondary effects. When using the Wise Rules, remember several of the measures may overlap or complement each other and energy savings rates from overlapping measures may not be additive. In addition, multiple Wise Rules may express savings for similar measures from different perspectives. For example, some express energy savings in terms of a typical facility's *total* energy use, while others are expressed in terms of an end use's energy consumption.

Process Heating Notes

1 3M Company, "Laboratory Operations Energy Efficiency Guidelines," Feb. 1994.

2 Rutgers University Office of Industrial Productivity and Energy Assessment, *Modern Industrial Assessments: A Training Manual*, Version 1.0b, December 1995, p. 5-36.

3 DOE/IAC Industrial Assessment Database, July 1997.

4 Rutgers, p. 5-37.

5 Rutgers, p. 5-34.

6 Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), "Learning from Experiences with Process Heating in the Metals Industry," Analyses Series No. 11, 1990.

7 CADDET, 1990.

8 DOE/IAC Database.

9 Bonneville Power Administration (BPA), Washington State Energy Office, Electric Ideas Clearinghouse, "Dry Kiln Retrofit/Replacement," October 1991.

10 CADDET, 1990.

11 BPA, "Dry Kiln Retrofit/Replacement."

12 Bonneville Power Administration (BPA), Washington State Energy Office, Electric Ideas Clearinghouse, "Optimizing Dry Kiln Operation," October 1991.

13 BPA, "Dry Kiln Retrofit/Replacement."

14 ICF Kaiser Consulting Group estimate based on cement industry data.

15 ICF Kaiser Consulting Group estimate based on cement industry data.

16 Mercer, A., *Learning from Experience with Industrial Drying Technologies,* Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), 1994.

17 Mercer, pp. 25-38.

18 Mercer, pp. 39-54.

Process Heating Table 1: Summary of Process Heating Efficiency Measures

Source	Measure (IAC recommendation rate)	Average Energy Savings	Average Annual Cost Savings (payback)
	All Efficiency Improvements		
	Implement typical efficiency improvements, which may include many or all of the measures below (4%)	2.8% of total *facility* energy use	$8,100 (8 months)
	Insulation and Heat Containment		
Rule 1	Improve heat containment (22%)	1.5% of total *facility* energy use	$5,100 (9 months)
Rule 2	Install fiber insulation	50% improvement in *thermal* efficiency	
	Process Heating Waste Heat Recovery		
Rule 3	Recover furnace, oven, and kiln waste heat (1%)	4.6% of total *facility* energy use	$13,000 (16 months)
Rule 4	Recover heat from kilns	30% to 50% reduction in *kiln* energy use	
	Specific Process Heating Applications		
Rule 5	Air dry lumber	50 to 85 Btu *per board foot* for each 1% moisture removed	
Rule 6	Install variable speed drives (VSD) for dry kiln airflow	up to 50% of *kiln* energy use	
Rule 7	Install expert systems for secondary kiln controls	up to 3% of *cement kiln* energy use	
Rule 8	Optimize heat transfer conditions	up to 6% of *cement kiln* energy use	
	Direct Heating		
Rule 9	Use direct firing with natural gas in place of indirect heating	33% to 45% of the energy requirement	(few months to 6 years)
Rule 10	Use direct electric heating in place of indirect heating	80% of *heating* energy use	(1 to 3 years)

Source references for each Wise Rule are included in the chapter notes.

5. Waste Heat Recovery and Cogeneration

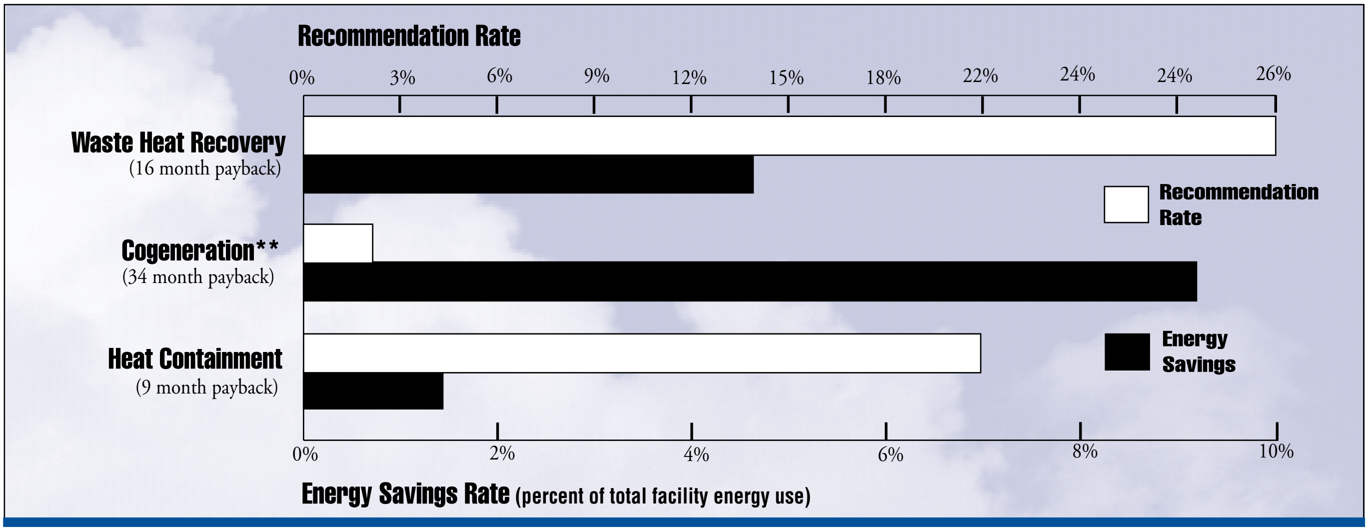
Introduction

Heat exchangers recover useful energy that would ordinarily be lost. Generally, a heated gas or liquid leaving a process passes through a heat exchanger to preheat another gas or liquid entering a process or an HVAC system. Cogeneration takes heat recovery a step further by recovering heat that would normally be wasted in the process of power generation and steam production. Cogeneration systems can reach efficiencies that can triple, or even quadruple, conventional power and steam generation. **Heat Recovery/Cogen Figure 1** illustrates the potential energy savings from heat recovery and cogeneration measures based on IAC audit recommendations. Waste heat recovery measures were recommended at 26 percent of the 4,300 IAC audits conducted from 1990 through mid-1997 and were estimated to save almost five percent of the average facility's total energy use with a simple payback of 16 months. Cogeneration was recommended at fewer facilities (three percent), but the average expected energy savings were much higher (nine percent of the facility's energy use, including fuel inputs at off-site powerplants for purchased electricity) and the payback was about three years. **Heat Recovery/Cogen Table 2**, at the end of this chapter, summarizes the Wise Rules presented in this chapter, along with cost savings estimates, where available.

Waste Heat Recovery

Heat recovery is often a viable retrofit option for existing equipment. Ventilation and exhaust from process heating or combustion equipment are some common sources of potentially recoverable energy. Heat recovery is beneficial only if the heat can be used elsewhere and if it is available when it is needed. Typical applications of waste heat include process heating, combustion air preheating, boiler feedwater preheating, and space heating.[1] Be sure to consider any secondary effects from adjustments of combustion parameters, such as emissions of nitrogen oxides, particulates, and carbon monoxide.

Heat Recovery/Cogen Figure 1
Energy Savings from Heat Recovery and Cogeneration Efficiency Measures*



* Results from the DOE/IAC Database (1/90-7/97). The IAC data reflect average potential impacts from energy efficiency measures at small-to-medium sized manufacturing facilities across all sectors and regions of the country. Most IAC audit recommendations are expected to be implemented within two years and typically have a one-to-two year payback period. (See Chapter 1.)

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity. Off-site power generation is assumed to have a heat rate of about 10,000 Btu/kWh. Savings are calculated by dividing total energy savings, including powerplant inputs, by total facilityenergy use.

Heat Recovery/Cogen Wise Rule 1

Recovering waste heat can reduce a typical *facility's* total energy use by about 5% with an average simple payback of 16 months.[2]

Heat Recovery/Cogen Wise Rule 2

Reducing *net* stack temperature (outlet temperature minus inlet combustion air temperature) by 40°F is estimated to reduce the *boiler's* fuel use by 1% to 2%.[3]

Heat Recovery/Cogen Wise Rule 3

Preheating furnace combustion air with recovered waste heat can save up to 50% of the *furnace's* energy use. **Heat Recovery/Cogen Table 1** summarizes typical fuel savings for a natural gas furnace.[4]

Air-to-air heat exchangers transfer heat from a hot air stream to a cold one. Using air-to-air heat exchangers to preheat ventilation air in the winter or for precooling in the summer can add to the air distribution system's pressure losses and may require larger ventilation fans.[6] In heat pipes, hot and cold air streams flow in opposite directions. Heat pipes typically are used in the range of 150°F to 850°F and recover between 60 and 80 percent of the heat from the exhaust air stream. Heat wheels are porous disks with high heat capacity that rotate between a cold-gas duct and a hot-gas duct. They can recover from 70 to 90 percent of the heat from the exhaust air stream. Glass fiber ceramic heat wheels can be used at temperatures up to 2,000°F.[7] Economizers are used primarily to preheat boiler feedwater with flue gas waste heat. The boiler feedwater flows through the economizer and is heated by the hot exhaust gases from the boiler. The higher the waste gas temperature, the greater the possible energy savings. Economizers can be used at gas temperatures up to 1,800°F.[8]

Heat Recovery/Cogen Table 1
Fuel Savings from Preheating Combustion Air[5]

Furnace Outlet Temperature	Combustion Air 400°F	600°F	Preheat Temperature 800°F	1000°F	1200°F
2600°F	22%	30%	37%	43%	48%
2400°F	18%	26%	33%	38%	43%
2200°F	16%	23%	29%	34%	39%
2000°F	14%	20%	26%	31%	36%
1800°F	13%	19%	24%	29%	33%
1600°F	11%	17%	22%	26%	30%
1400°F	10%	16%	20%	25%	28%

Based on a natural gas furnace with 10% excess air.

Heat Recovery/Cogen Wise Rule 4

Using an economizer to capture flue gas waste heat and preheat boiler feedwater can reduce a *boiler's* fuel use by up to 5%.[9]

Heat exchanger efficiency is directly proportional to the surface area that separates the heated and cooled fluids. If heat exchanger surfaces become fouled with films, deposits, or corrosion, exchanger efficiency suffers. If heavy fouling is expected, contaminated streams may need to be filtered, or the design may need to be modified to include different materials or to allow easy access to surfaces for frequent cleaning.[10]

Heat Recovery/Cogen Wise Rule 5

Removing a 1/32 inch deposit on *boiler's* heat transfer surfaces can reduce a *boiler's* energy use by 2%; removing a 1/8 inch deposit can reduce a boiler's energy use by over 8%.[11,12]

Cogeneration

Cogeneration is the simultaneous production of electric power and thermal energy from a single fuel. In a typical configuration, an industrial boiler is replaced by a gas turbine. The turbine is used to generate electricity, and the waste heat is used to generate steam in a heat recovery steam generator (or HRSG). Other cogeneration configurations combine boilers and steam turbines, or gas turbines and steam turbines (combined cycle units). Two emerging technologies that are applicable to cogeneration are the use of fuel cells and the Kalina cycle — a vapor heat engine cycle using an ammonia-water working fluid.[13]

Cogeneration is often a more efficient way of providing electricity and process heat than producing them independently given the overall efficiency gain, as well as a potential fuel shift. Average efficiencies for traditional cogeneration systems can range from 70 percent to more than 80 percent.[14] Cogeneration makes most sense in facilities where steam and electrical demand are balanced with the typical output of the cogeneration unit.

There are generally economies of scale involved with cogeneration systems, with larger units having lower costs (per installed kW) and higher efficiencies. Average-sized cogeneration units range from 10 to 50 MW, though units as small as 3 MW can be cost-effective.[15] Cogeneration economics depend on system utilization.[16] Therefore, it is important to closely match the system's output to the facility's steam and electrical load. When electricity production is in excess of on-site consumption needs, it can typically be sold to others and should be accounted for when evaluating the feasibility and economics of cogeneration. It is a good idea to examine the steam load prior to assessing electrical needs in evaluating a potential cogeneration project. Be sure to consider any secondary impacts from new combustion equipment such as nitrogen oxide emissions from gas turbines.

Heat Recovery/Cogen Wise Rule 6

Gas turbines with heat recovery equipment typically cost from $600 to $1,000/kW. Larger gas turbines may be available for half the cost per kW.[17]

Heat Recovery/Cogen Wise Rule 7

A typical cogeneration project may reduce *primary* energy consumption (including fuel inputs at off-site powerplants for purchased electricity) for steam and electricity generation by 10% to 15%.[18]

Heat Recovery/Cogen Wise Rule 8

Cogeneration systems can save about 9% of a typical *facility's* primary fuel inputs for on-site energy use (i.e., including fuel savings at off-site powerplants for purchased electricity) with an average simple payback of 34 months.[19] (Savings are calculated by dividing total energy savings, including powerplant inputs, by total facility energy use.)

Summary of Wise Rules for Waste Heat Recovery and Cogeneration

Use the Wise Rules in **Heat Recovery/Cogen Table 2** (next page) to identify and estimate potential energy saving from heat recovery and cogeneration. Consider potential costs, savings, payback time, and any secondary effects in order to analyze different efficiency alternatives and eliminate less attractive options. When using the Wise Rules, remember that several of the measures may interact or complement each other and energy savings rates may not be additive.

Waste Heat Recovery and Cogeneration Notes

1 Rutgers University Office of Industrial Productivity and Energy Assessment, *Modern Industrial Assessments: A Training Manual*, Version 1.0b, December 1995, pp. 5-21 and 5-22.

2 DOE/IAC Industrial Assessment Database, July 1997.

3 Garay, P.N., *Handbook of Industrial Power and Steam Systems*, Fairmont Press, 1995, p. 219; Taplin, H.R., *Boiler Plant and Distribution System Optimization Manual*, Fairmont Press, 1991, p. 15; Rutgers, p. 5-2.

4 Rutgers, p. 5-21.

5 Rutgers, p. 5-21.

6 Bonneville Power Administration (BPA), Washington State Energy Office, Electric Ideas Clearinghouse, "Exhaust Air Heat Recovery Systems," May 1992, p. 1.

7 Rutgers, p. 5-23.

8 Rutgers, p. 5-22.

9 O'Callaghan, P., *Energy Management*, McGraw-Hill, England, 1993, p. 198.

10 Turner, W.C., *Energy Management Handbook*, 3rd Edition, Fairmont Press, 1997, pp. 207-208.

11 Garay, p. 271.

12 Rutgers, p. 5-10.

13 Orlando, J.A., *Cogeneration Design Guide*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1996, pp. 62-63.

14 Stromberg, Jan, *Gas-Turbine-Based CHP in Industry*, Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CAD DET), 1993, p. 6.

15 McIntire, Margaret E., "Trigen Dispersed Energy Services for the Mid-Sized Industrial and Commercial Market," *Nineteenth National Industrial Energy Technology Conference Proceedings*, 1997, pp. 117-124.

16 Payne, F.W., *Cogeneration Management Reference Guide*, Fairmont Press, Inc., 1997, p. 6.

17 Rutgers, p. 5-40.

18 ICF Kaiser Consulting Group estimate.

19 DOE/IAC database. Off-site power generation is assumed to have a heat rate of about 10,000 Btu/kWh.

Heat Recovery/Cogen Table 2: Summary of Heat Recovery and Cogeneration Efficiency Measures

Source	Measure (IAC recommendation rate)	Average Energy Savings*	Average Annual Cost Savings (payback)
	Waste Heat Recovery		
Rule 1	Recover waste heat (26%)	4.6% of total *facility* energy use	$12,500 (16 months)
Rule 2	Reduce stack waste heat losses	1% to 2% per 40°F reduction	
Rule 3	Preheat furnace combustion air	Up to 50%	
Rule 4	Preheat boiler feedwater	up to 5% of *boiler* energy use	
Rule 5	Clean heat exchangers	2% for 1/32 inch deposit, 8% for a 1/8 inch deposit	
	Cogeneration		
Rule 6	Install gas turbine cogeneration	Capital Cost: $600-$1,000/kW	
Rule 7	Install cogeneration system	10% to 15% of *primary* energy consumption	
Rule 8	Install cogeneration system (3%)	9.1% of total *facility* energy use**	$233,600 (34 months)

Source references for each Wise Rule are included in the chapter notes.

* Percent of equipment energy use, unless noted.

** Cogeneration energy savings are based on *primary* fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity. Off-site power generation is assumed to have a heat rate of about 10,000 Btu/kWh. Savings are calculated by dividing total energy savings, including powerplant inputs, by total facility energy use.

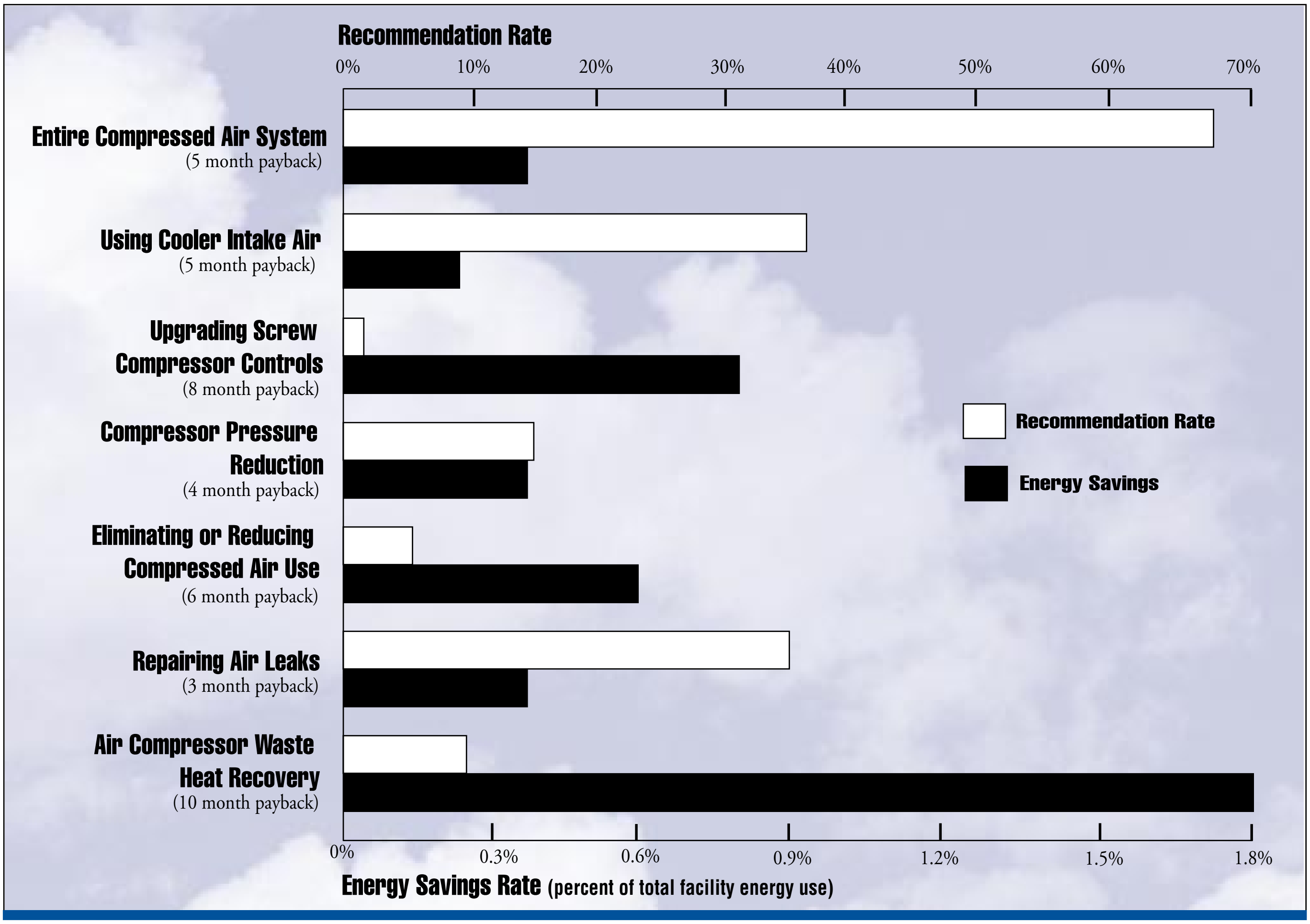
6. Compressed Air Systems

Introduction

Compressed air is used to power tools and machines, to regulate HVAC systems, and for drying or cleaning various items. The two main types of air compressors are reciprocating compressors and screw compressors. Screw compressors generally use more energy than reciprocating compressors, especially when they are oversized. Compressor energy use is a function of many variables including compressor type, part-load efficiency, and control mechanisms.[1]

Several compressed air system efficiency measures may be of interest to Climate Wise Partners, including using cooler intake air, optimizing load, reducing pressure, eliminating or reducing air use, repairing leaks, recovering waste heat, replacing filters, and cleaning coolers. Typical energy savings for these types of air compressor measures are illustrated in **Compressed Air Figure 1,** based on specific recommendations in the DOE/IAC database. Air compressor efficiency measures can be made at most facilities and were

Compressed Air Figure 1
Energy Savings from Air Compressor Efficiency Measures*



* Results from the DOE/IAC Database (1/90-7/97). The IAC data reflect average potential impacts from energy efficiency measures at small-to-medium sized manufacturing facilities across all sectors and regions of the country. Most IAC audit recommendations are expected to be implemented within two years and typically have a one-to-two year payback period. (See Chapter 1.)

recommended at 68 percent of the 4,300 IAC audits conducted from 1990 to mid-1997. Using cooler intake air and repairing air leaks were recommended at more than a third of facilities audited. Average expected savings are relatively small — less than a half percent of a facility's total energy use. However, these measures tend to have relatively short payback periods (about 5 months) and reduce electricity use, a relatively expensive energy source with high CO_2 emission rates in many regions. Some measures have higher impacts. For example, air compressor waste heat recovery can reduce facility energy use by almost two percent. **Compressed Air Table 2**, at the end of this chapter, summarizes the Wise Rules presented in this chapter, along with cost savings estimates, where available.

The range of compressor efficiency measures is broad. Air compressor energy use may represent 5 to 15 percent of a typical facility's energy use, depending upon process needs.

Compressed Air Wise Rule 1

Efficiency improvements can reduce *compressed air system* energy use by 20% to 50%.[2]

Compressed Air Wise Rule 2

Efficiency improvements to compressed air systems can save approximately one-half percent of a *facility's* total energy use.[3]

Use Cooler Intake Air

The amount of energy required to compress air is a function of the intake air temperature, with warm air requiring more energy to compress than cool air. There is a potential for energy savings when cooler air, typically from outside, is used in place of warmer compressor room air. Often piping can be installed to supply cooler outside air to the compressor intake. Energy and cost savings for this measure will depend on compressor size, load factor, and the number of hours of operation.[4]

Compressed Air Wise Rule 3

Using cooler intake air for compressors can reduce *compressed air system* energy use by 1% per 5°F reduction in intake air temperature.[5] The payback period for this measure is usually less than two years.[6]

Compressed Air Wise Rule 4

Using cooler intake air for compressors can save almost one-half percent of a *facility's* total energy use with an average simple payback of 5 months.[7]

Match Compressor with Load Requirement

Matching the compressor size with load can result in significant energy savings. Because air compressors can consume 16 to 100 percent of full load power at low loads, it is a good idea to optimize compressor loading to minimize operation at low output levels.[8] This optimization can be achieved with unloading controls, automatic shutdown timers, and manual or automatic compressor sequencing. Unloading controls cost about $500 to install at the factory and about $1,000 to retrofit; automatic on/off timers cost about $300 to install. You might also consider purchasing a small compressor for smaller loads to avoid low-load operation of a large compressor.[9]

Compressed Air Wise Rule 5

Installing or adjusting unloading controls can reduce *compressed air system* energy use by about 10%.[10]

Compressed Air Wise Rule 6

Upgrading controls on screw air compressors can reduce a *facility's* total energy use by about 1% with an average simple payback of 8 months.[11]

Reduce Compressor Air Pressure

Air is often compressed to a higher pressure than required by the process equipment. Lowering air pressure reduces compressor demand and energy use. Be sure to determine the minimum required pressure before implementing this measure. Consider reducing compressor operating pressure if it is higher than 10 psi above that required by the process equipment (except with long delivery lines or high pressure drops).[12] Energy savings depend on the compressor type, power rating, load factor, use factor, horsepower reduction factor, and the proposed pressure change.[13]

Compressed Air Wise Rule 7

Reducing air compressor pressure can reduce a *facility's* total energy use by about one-half percent with an average simple payback of 4 months.[14]

Compressed Air Wise Rule 8

Reducing air compressor pressure by 2 psi can reduce *compressor* energy use by 1% (at 100 psi).[15]

Reduce or Eliminate Compressed Air Use

In some facilities, compressed air use can be reduced or eliminated entirely. Less expensive alternatives may exist for processes such as cooling, agitating liquids, or moving products. In addition, some air-powered tools (e.g., grinders) can be replaced by high frequency electric tools. Reducing compressed air use may result in an existing compressor operating at reduced load and lower efficiency. If the reductions are significant, you may need to re-optimize loading sequence or controls, or change to a smaller compressor.

Compressed Air Wise Rule 9

Eliminating or reducing compressed air usage for certain activities can reduce a *facility's* total energy use by more than one-half percent, with an average simple payback of 6 months.[16]

Compressed Air Table 1
Energy Losses and Cost Impacts of Compressed Air System Leaks[24]

Hole Diameter (inches)	Leak Rate (cubic feet/min.)	Energy Loss (kWh per year)	Cost of Wasted Energy (dollars per year)
1/64"	0.5	635	$20
1/32"	1.8	2,500	$90
1/16"	7.2	10,800	$350
1/8"	29.0	43,800	$1,500
1/4"	115.8	174,100	$5,900
3/8"	260.6	392,000	$13,200

Based on a 115 psi system with 8,520 hours of compressor operation. Electricity price is assumed to be $0.034 per kWh.

Eliminate Air Leaks

Compressed air distribution system leaks along piping, around valves, fittings, flanges, hoses, traps, and filters can result in significant energy losses in manufacturing facilities. Typical leakage rates range from two to 20 percent of system capacity. In poorly maintained systems, leakage rates can be as high as 40 percent.[17] The cost of compressed air leaks increases exponentially as the size of the hole increases. **Compressed Air Table 1** presents average energy losses for air leaks of various sizes. Leaks are often audible when the system is pressurized but equipment is not running (e.g., during breaks or after hours). Where you suspect a slow leak, use a soapy water solution or an ultrasonic detector to pinpoint its location.[18] When repairing compressed air leaks, it is important to consider the effect on compressor loading. If the reductions are significant, you may need to re-optimize loading sequence or controls.

Compressed Air Wise Rule 10

Repairing air leaks can reduce *compressed air system* energy use by 30% or more.[19]

Compressed Air Wise Rule 11

Repairing air leaks can reduce a *facility's* total energy use by about one-half percent, with an average simple payback of 3 months.[20]

Compressed Air Wise Rule 12

It takes approximately 2.5 to 5.0 kWh to compress 1,000 ft^3 of air to 100 psi.[21,22] Each psi reduction in compressed air loss from the distribution system (at 100 psi), reduces the *compressor's* energy use by more than one-half percent.[23]

Recover Waste Heat

Sixty to 90 percent of the energy of compression is available as heat that can be recovered.[25] Recovered waste heat may be used for space heating or to supply heat to a manufacturing process. The amount of heat energy that can be recovered depends on compressor characteristics and use factor. Waste heat recovery will be most cost-effective when the compressor is located near the process in which the heat is to be used.[26] Air compressors 100 hp and larger are often cooled with water from a cooling tower. The temperature of the water leaving the compressor cooling coils may be high enough that heat can be extracted and applied elsewhere.

For example, boiler feedwater could be preheated by the compressor cooling water.

Compressed Air Wise Rule 13

Air compressor waste heat recovery can reduce a *facility's* total energy use by about 2% with an average simple payback of 10 months.[27]

Filters and Coolers

Compressed air system efficiency suffers as compressed air system filters and coolers become soiled. When filters are obstructed with pipeline contaminants, significant pressure drops can develop, requiring an increase in compressor discharge pressure. As a result of the pressure increase, air leaks will become more costly.[28]

Compressed Air Wise Rule 14

For every 1 psi increase in air compressor pressure gained by periodic filter changes, *air compressor* energy use is reduced by about one-half percent.[29] Changing dryer filters at 8 or 10 psi drop per filter can eliminate this waste.

Compressed Air Wise Rule 15

For every 11°F decrease in air compressor working temperature, gained by careful maintenance of intercoolers, *air compressor* energy use will decreased by 1%.[30]

Summary of Wise Rules for Compressed Air Systems

Use the Wise Rules in **Compressed Air Table 2** (next page) to identify and estimate potential energy saving from air compressor efficiency measures. When evaluating efficiency options, consider potential costs, savings, payback and any secondary effects. While some of the measures in **Compressed Air Table 2** yield modest potential savings as a percent of total facility energy use, the cost and CO_2 savings can be significant because most air compressors are driven by electricity. When using the Wise Rules, remember that several of the measures may overlap or complement each other and energy savings rates may not be additive. In addition, Wise Rules for similar measures are addressed from different perspectives. Some are stated in terms of the *air compressor's* energy use, others in terms of a *facility's* total energy use, or as a function of a physical parameter (e.g., change in energy use with a change in pressure).

Compressed Air Notes

1 Talbott, E.M., *Compressed Air Systems: A Guidebook on Energy and Cost Savings,* 2nd Edition, Fairmont Press, 1992, p. 160.

2 Oregon State University, AIRMaster Compressed Air System Audit and Analysis Software, "How to Take a Self-Guided Tour of Your Compressed Air System," 1996 revised in 1997, p. 2. (Self-Guided Tour)

3 DOE/IAC Industrial Assessment Database, July 1997.

4 Rutgers University, Office of Industrial Productivity & Energy Assessment (OIPEA), *Modern Industrial Assessments: A Training Manual,* Version 1.0b, 1995, p. 6-28.

5 Oregon State University, Self-Guided Tour, p. 5.

6 Rutgers, p. 6-28.

7 DOE/IAC Database.

8 Oregon State University, AIRMaster Compressed Air System Audit and Analysis Software Version 1.4, "Analysis Methodology Manual for AIRMaster," 1996 revised in 1997, p. 32.

9 Oregon State University, AIRMaster Compressed Air System Audit and Analysis Software, "Case Studies: Compressed Air System Audits Using AIRMaster," 1996 revised in 1997 pp. 20-21.

10 Oregon State University, AIRMaster Case Studies, p. 12.

11 DOE/IAC Database.

12 Rutgers, p. 6-17.

13 Rutgers, p. 6-17.

14 DOE/IAC Database.

15 Oregon State University, Self-Guided Tour, p. 8.

16 DOE/IAC Database.

17 Talbott, E.M., p. 112.

18 Oregon State University, Self-Guided Tour, p. 8.

19 Oregon State University, Self-Guided Tour, p. 8.

20 DOE/IAC Database.

21 ICF Kaiser Consulting Group estimate based on Talbott, p. 77; 3M, "Compressed Air Optimization," 1994, p. 9.

22 Bonneville Power Administration, *Industrial Compressed Air System Energy Efficiency Guidebook,* 1996, p. 2-2 and p. 4-5.

23 Talbott, p. 93.

24 Rutgers, p. 6-22.

25 Talbott, p. 91.

26 Rutgers, p. 6-16.

27 DOE/IAC Database.

28 Oregon State University, Self-Guided Tour, p. 9.

29 3M, "Compressed Air Optimization," 1994, p. 9.

30 3M, p. 9.

Compressed Air Table 2: Summary of Compressed Air Efficiency Measures

Source	Measure (IAC recommendation rate)	Average Energy Savings*	Average Annual Cost Savings (payback)
	All Efficiency Improvements		
Rule 1	Implement typical efficiency improvements, which may include many or all of the measures below	20% to 50%	
Rule 2	Implement typical efficiency improvements, which may include many or all of the measures below (68%)	0.4% of total *facility* energy use	$4,300 (5 months)
	Use Cooler Outside Air		
Rule 3	Use cooler air for intakes	1% per 5°F reduction	less than 2 years
Rule 4	Use cooler air for intakes (37%)	0.2% of total *facility* energy use	$1,400 (5 months)
	Optimize Load		
Rule 5	Install or adjust unloading controls	10%	
Rule 6	Upgrade screw compressor controls (1%)	0.8% of total *facility* energy use	$7,900 (10 months)
	Reduce Compressor Air Pressure		
Rule 7	Reduce compressor pressure (15%)	0.4% of total *facility* energy use	$2,800 (4 months)
Rule 8	Reduce compressor pressure	1% per 2 psi reduction**	
	Eliminate /Reduce Compressed Air Use		
Rule 9	Eliminate/reduce some uses of air (5%)	0.6% of total *facility* energy use	$7,300 (6 months)
	Eliminate Air Leaks		
Rule 10	Repair air leaks	30% or more	
Rule 11	Repair air leaks (36%)	0.4% of total *facility* energy use	$3,900 (3 months)
Rule 12	Reduce air leaks in distribution system	0.7% decrease in compressor energy use per 1 psi loss reduction**	
Table 1	Repair 1/16" leak	7,560 kWh per leak per yr	$360/yr
	Recover Waste Heat		
Rule 13	Recover waste heat from compressors (8%)	1.8% of total *facility* energy use	$2,700 (10 months)
	Change Filters and Clean Coolers		
Rule 14	Change dryer filters at 8 to 10 psi drop	0.5% per avoided 1 psi drop in pressure	
Rule 15	Clean intercoolers to reduce compressor working temperature	1% per 11°F reduction	

Source references for each Wise Rule are included in the chapter notes.

* Percent of compressed air system energy use, unless noted.

** Based on compressed air system pressure of approximately 100 psi.

7. Process Cooling

Introduction

Many manufacturing processes require that materials or components be cooled to lower temperatures. Chillers, heat pumps and other refrigeration equipment used as heat sinks for a variety of industrial processes. Efficiency measures for process cooling include using cooling tower water in place of refrigeration or chilling, modifying the refrigeration system to operate at a lower pressure, increasing chilled water temperatures, and using variable speed drives (VSDs).

Process Cooling Figure 1 illustrates the potential energy savings from process cooling efficiency measures based on specific recommendations in the DOE/IAC database. Process cooling measures were recommended during six percent of the IAC audits with estimated savings of about one percent of a facility's total energy use and a simple payback of 20 months. Cooling tower measures were recommended at three percent of audited facilities, with estimated energy savings of almost one percent and a 14 month simple payback. **Process Cooling Table 2**, at the end of this chapter, summarizes the Wise Rules presented in this chapter, along with cost savings estimates, where available.

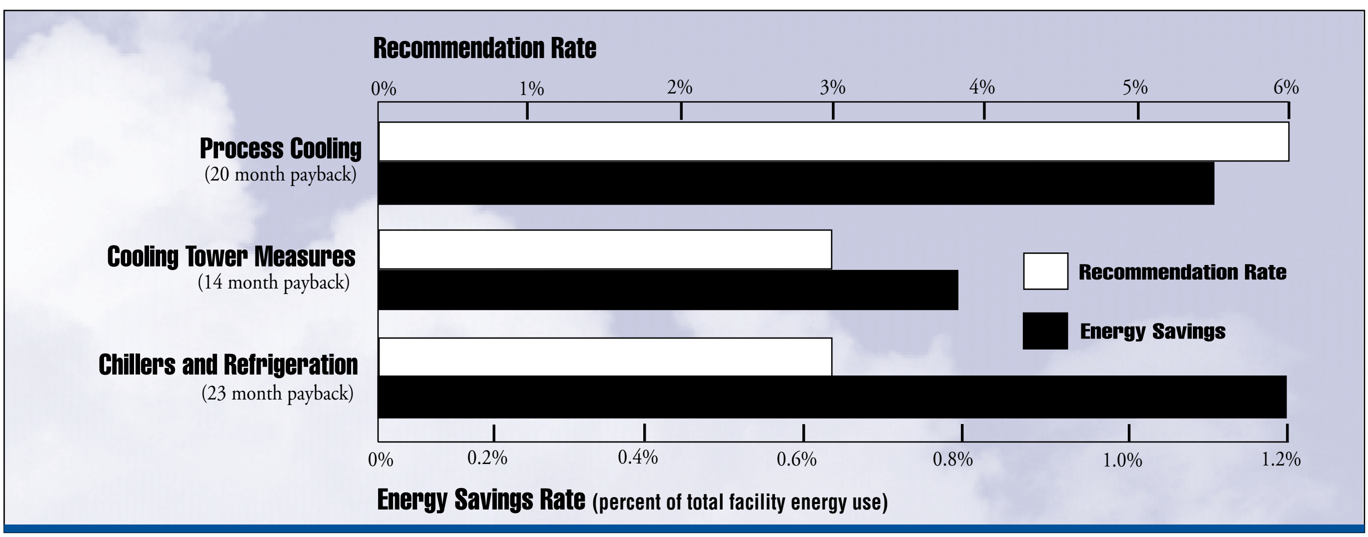
Energy Efficient Chillers and Refrigeration Units

There are several energy efficiency options available when installing new chilling equipment. For example, oversizing condenser water supply pipes can reduce head pressure and pumping requirements. Evaporative cooled chillers consume considerably less energy per ton of cooling capacity then water- and air-cooled chillers. Using high efficiency compressors can also reduce chiller energy use.

Process Cooling Wise Rule 1

Installing energy efficient chillers and refrigeration systems can save about 1% of a *facility's* total energy use with an average simple payback of 23 months.[1]

Process Cooling Figure 1
Energy Savings from Process Cooling Efficiency Measures*



* Results from the DOE/IAC Database (1/90-7/97). The IAC data reflect average potential impacts from energy efficiency measures at small-to-medium sized manufacturing facilities across all sectors and regions of the country. Most IAC audit recommendations are expected to be implemented within two years and typically have a one-to-two year payback period. (See Chapter 1.)

Cooling Tower Water

Using cooling tower water in place of a chiller can dramatically reduce cooling energy use when the outside temperature is low enough to achieve the required process temperature. This method of cooling is referred as "free cooling" because the chiller is not used.

Process Cooling Wise Rule 2

"Free cooling" with cooling tower water can reduce a *facility's* total energy use by about 1% with an average simple payback of 14 months.[2]

Process Cooling Wise Rule 3

Free cooling can reduce *cooling system* energy use by as much as 40% depending on location and load profile.[3]

Refrigeration and Chillers

Reducing the cooling load is a direct approach to cutting chiller energy use. A cooling system audit may identify opportunities for improving insulation and eliminating unnecessary heat sources. Raising the chilled water set temperature can also reduce chiller energy use. By monitoring the minimum requirements on the chilled water temperature, the chiller can be reset appropriately to meet the demands of the system without wasting energy. Refrigerant subcooling decreases the load on the compressor and reduces chiller energy use. Oversizing or continuous operation of cooling towers can lower condenser cooling water temperature and reduce cooling system energy use. Careful system maintenance and removal of non-condensable fluids can lower operating pressure and save energy.

Procees Cooling Table 1

Energy Savings from Increasing Chilled Water Temperature[5]

Chiller Type	Energy Savings (Energy Savings per 1°F Increase in Temperature)
Screw Compressor	2.5%
Centrifugal Compressor	1.7%
Reciprocating Compressor	1.2%
Absorption Chiller	0.6%

Process Cooling Wise Rule 4

Increasing chilled water temperature by 1°F reduces *chiller* energy use by 0.6% to 2.5%.[4] (See **Process Cooling Table 1** for data on specific chiller types.)

Process Cooling Wise Rule 5

Reducing condenser pressure by 10 psi can decrease *refrigeration system* energy use per ton of refrigeration (kW/ton) by about 6%.[6]

Process Cooling Wise Rule 6

For each 1°F decrease in condenser cooling water temperature, until optimal water temperature is reached, there is a decrease in *chiller* energy use by up to 3.5%.[7]

Freezing

The freezing process in a manufacturing facility can be made more efficient by reducing heat loss through the use of improved insulation (such as air locks) and by freezing products in batches rather than continuously.

Process Cooling Wise Rule 7

Eliminating heat losses from leaks and improper defrosting can reduce *refrigeration system* energy use by 10% to 20%.[8]

Process Cooling Wise Rule 8

Freezing products in batches rather than continuously can reduce *freezing process* energy use by up to 20%.[9]

Variable Speed Drives

The application of variable speed drives (VSD) can reduce energy use when cooling loads vary over time. VSDs can be applied to the compressor within the chiller or, in some situations, utilized in chilled water distribution.

Process Cooling Wise Rule 9

Installing variable speed drives in place of constant speed systems can reduce *cooling system* energy use by 30% to 50%, depending on load profile.[10]

Summary of Wise Rules for Process Cooling Systems

Process Cooling Table 2 (next page) summarizes Process Cooling Wise Rules contained in this chapter. These Wise Rules can be used to identify and estimate potential energy saving from boiler efficiency measures. When evaluating options, consider potential costs, savings, payback times, and any secondary impacts. When using the Wise Rules, remember that several of the measures may overlap or complement each other and energy savings rates may not be additive. In addition, multiple Wise Rules may express savings for similar measures from different perspectives: in terms of a facility's total energy use, an end-use's or process' energy use, or as a function of a physical parameter such as temperature.

Process Cooling Notes

1 DOE/IAC Industrial Assessment Database, July 1997.

2 DOE/IAC Database.

3 ICF Kaiser Consulting Group estimate based on D. Murphy, "Cooling Towers Used for Free Cooling," *ASHRAE Journal*, June 1991, pp. 16-26.

4 Clevenger, L. and J. Hassel, "Case Study: From Jump Start to High Gear – How DuPont is Cutting Costs by Boosting Energy Efficiency," *Pollution Prevention Review*, Summer 1994, p. 304.

5 Clevenger and Hassel, p. 304.

6 Bonneville Power Administration (BPA), Washington State Energy Office, Electric Ideas Clearinghouse, "Improving Industrial Refrigeration Energy Efficiency," October 1991, p. 3.

7 Bonneville Power Administration (BPA), Washington State Energy Office, Electric Ideas Clearinghouse, "Optimizing Cooling Tower Performance," November 1991, p. 1.

8 Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), Newsletter No. 4 December 1996, p. 16.

9 CADDET, p. 16.

10 York International, "HVAC&R Engineering Update: Examining Part-Load Performance Gives You the Full Story on Chiller Efficiency," 1994.

Process Cooling Table 2: Summary of Process Cooling Efficiency Measures

Source	Measure (IAC recommendation rate)	Average Energy Savings	Average Annual Cost Savings and (Payback)
	Implement typical efficiency improvements, which may include many or all of the measures below (6%)	1.1% of total *facility* energy use	$11,200 (20 months)
Rule 1	Install energy efficient chillers and refrigeration units (3%)	1.2% of total *facility* energy use	$11,200 (23 months)
	Cooling Towers		
Rule 2	Use cooling tower to replace chiller for free cooling (3%)	0.8% of total *facility* energy use	$11,000 (14 months)
Rule 3	Use free cooling	up to 40% of *cooling system* energy	
	Refrigeration and Chillers		
Rule 4	Increase chilled water temperature	0.6% to 2.5% reduction in energy input per 1°F increase	
Rule 5	Reduce condenser pressure	6% decrease in *refrigeration* energy use per ton for each 10 psi reduction	
Rule 6	Decrease condenser working temperature	3.5% reduction in *chiller* energy for each 1°F decrease	
	Freezing		
Rule 7	Reduce heat loss and improper defrosting	10% to 20% decrease in *freezer* energy use	
Rule 8	Use continuous freezing	20% decrease in *freezer* energy use	
Rule 9	Install variable speed drives	30% to 50% reduction in *cooling* energy use	

Source references for each Wise Rule are included in the chapter notes.

Appendix A

Sector-Specific Energy Potential

In this appendix, we present examples of sector-specific savings from the DOE IAC database. The IAC audit database contains information on the expected impacts from energy efficiency measures recommended at small-to-medium sized manufacturing facilities. IAC audits typically recommend measures with short (one to two year) payback periods. The energy and cost savings represent averages across industry groups, years, and regions.

"Average percent energy savings" are defined as the average reduction in a *facility's* total energy use resulting from the implementation of a specific recommendation. For example, a typical facility in the food industry (SIC 20) could expect to save about six percent of their total facility energy use by implementing the measures recommended during an IAC audit (refer to **Table A-2**). The average simple payback period is defined as the amount of time it takes to recover initial investment costs through energy savings.

Table A-1 provides the definition of the Standard Industrial Classification (SIC) codes for manufacturing industries.

Table A-1: SIC Code Definitions

SIC Code	Classification
20	Food and Kindred Products
21	Tobacco*
22	Textile Mill Products
23	Apparel and Other Textile Products
24	Lumber and Wood Products
25	Furniture and Fixtures
26	Paper and Allied Products
27	Printing and Publishing
28	Chemicals and Allied Products
29	Petroleum and Coal Products
30	Rubber and Misc. Plastics Products
31	Leather and Leather Products
32	Stone, Clay and Glass Products
33	Primary Metal Industries
34	Fabricated Metal Industries
35	Industrial Machinery and Equipment
36	Electronic and Other Electric Equipment
37	Transportation Equipment
38	Instruments and Related Products
39	Misc. Manufacturing Industries

*Only three IAC audits were conducted for SIC 21 (1/91-7/97).

Table A-2: Average Impacts of All Energy Efficiency Measures Recommended by IAC Audits, by Sector*

SIC Code & Manufacturing Classification	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
20 Food and Kindred Products	6.2%	4,400	78,000	41,000	23
21 Tobacco**	4.4%	8,800	85,000	52,000	19
22 Textile Mill Products	6.8%	8,300	103,000	64,000	19
23 Apparel and Other Textile Products	8.8%	1,700	22,000	21,000	13
24 Lumber and Wood Products	4.7%	7,600	86,000	56,000	19
25 Furniture and Fixtures	12.3%	3,700	47,000	29,000	20
26 Paper and Allied Products	8.5%	7,900	65,000	51,000	15
27 Printing and Publishing	7.1%	1,800	42,000	26,000	20
28 Chemicals and Allied Products	5.7%	6,200	66,000	37,000	21
29 Petroleum and Coal Products	13.4%	16,400	189,000	80,000	28
30 Rubber and Misc. Plastics Products	4.2%	2,500	43,000	35,000	15
31 Leather and Leather Products	4.0%	1,300	25,000	18,000	16
32 Stone, Clay and Glass Products	5.2%	16,800	183,000	98,000	22
33 Primary Metal Industries	7.0%	5,700	57,000	46,000	15
34 Fabricated Metal Industries	7.2%	2,900	33,000	27,000	14
35 Industrial Machinery and Equipment	5.9%	2,200	31,000	25,000	15
36 Electronic and Other Electric Equipment	8.5%	3,200	51,000	39,000	16
37 Transportation Equipment	7.3%	2,600	38,000	30,000	15
38 Instruments and Related Products	8.8%	2,300	41,000	32,000	15
39 Misc. Manufacturing Industries	9.7%	2,300	30,000	24,000	15

* Based on DOE/IAC estimates at audits of 4,300 manufacturing companies (1/90-7/97). Savings may not be additive.

** Only three IAC audits were conducted for Tobacco companies (SIC 21).

Table A-3: Food and Kindred Products Sector*(SIC 20)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Miscellaneous Heat Recovery	1%	21.2%	18,500	144,300	54,800	32
Steam Operations	2%	8.2%	4,800	400	11,400	0
Cogeneration**	5%	5.5%	7,100	705,900	229,000	37
Boiler Hardware	3%	5.5%	2,000	15,200	7,600	24
Other Process Waste Heat Recovery	7%	5.2%	3,700	19,600	13,600	17
Heat Recovery from Equipment	15%	4.5%	2,700	15,600	10,000	19
Chillers and Refrigeration	12%	3.2%	1,900	26,300	15,200	21
Flue Gas Recuperation	8%	2.9%	2,300	11,700	7,100	20
Boiler Maintenance	36%	2.3%	2,000	1,200	5,600	3
Steam Condensate	9%	2.3%	1,300	3,100	6,900	5
Thermal System Insulation	23%	2.2%	1,700	4,200	3,400	15
Steam Leaks and Insulation	20%	0.9%	900	1,600	3,200	6
Motor Hardware	62%	0.6%	470	11,300	6,300	22
Air Compressor Operations	35%	0.5%	300	1,400	3,600	5
Lighting Hardware	75%	0.4%	250	5,800	4,200	17

* Calculations based on IAC estimates at audits of 527 companies in SIC 20 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Table A-4: Textile Mill Products*(SIC 22)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Cogeneration**	3%	16.0%	9,700	211,000	111,000	23
Steam Operations	2%	7.7%	15,400	9,000	42,000	3
Heat Recovery from Equipment	10%	5.6%	4,700	11,000	15,000	9
Other Process Waste Heat Recovery	13%	4.1%	5,500	22,000	19,000	14
Boiler Hardware	5%	3.4%	6,000	60,000	21,000	34
Steam Condensate	10%	2.6%	4,200	16,000	14,000	13
Flue Gas Recuperation	13%	2.2%	4,900	19,000	14,000	16
Boiler Maintenance	27%	1.8%	2,500	15,000	13,000	14
Thermal System Insulation	26%	1.3%	1,200	4,000	5,000	10
Steam Leaks and Insulation	22%	0.8%	1,300	1,000	4,000	4
Lighting Hardware	77%	0.7%	850	38,000	13,000	35
Motor Hardware	64%	0.5%	700	26,700	9,200	34
Air Compressor Operations	49%	0.5%	600	3,000	7,000	5
Air Compressor Hardware	36%	0.5%	500	2,000	5,000	5
Motor Operations	49%	0.4%	600	11,000	7,000	18

* Calculations based on IAC estimates at audits of 144 companies in SIC 22 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Table A-5: Apparel and Other Textile Products* (SIC 23)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Miscellaneous Cooling	1%	46.2%	4,000	240,000	84,600	34
Space Conditioning Controls	19%	8.3%	600	2,200	4,500	6
Flue Gas Recuperation	4%	6.7%	650	5,600	3,300	20
Building Envelope Infiltration	4%	5.3%	450	1,200	2,500	6
Air Circulation Hardware	12%	4.9%	750	4,200	10,300	5
Space Conditioning Operation	15%	4.3%	700	3,200	8,600	4
Other Process Waste Heat Recovery	5%	3.5%	350	1,700	2,100	9
Heat Recovery from Equipment	19%	3.0%	350	2,000	1,400	17
Lighting Operation	21%	2.9%	400	8,200	7,600	13
Thermal System Insulation	15%	2.7%	1,700	3,600	6,800	6
Lighting Hardware	81%	1.7%	300	10,300	5,800	21
Steam Leaks and Insulation	16%	1.6%	600	950	1,700	7
Boiler Maintenance	21%	1.2%	400	1,300	2,000	7
Motor Hardware	35%	0.7%	150	6,700	2,500	33
Air Compressor Operations	51%	0.5%	100	350	1,600	2

* Calculations based on IAC estimates at audits of 113 companies in SIC 23 (1/90 - 7/97). Savings may not be additive.

Table A-6: Lumber and Wood Products* (SIC 24)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Air Circulation Hardware	1%	11.0%	1,000	11,900	4,800	30
Heating/Cooling Hardware	4%	8.0%	800	6,600	5,100	15
Boiler Maintenance	14%	7.0%	13,100	2,900	18,100	2
Boiler Operation	3%	4.8%	27,700	9,700	19,800	6
Cogeneration**	6%	4.6%	41,700	680,000	297,000	27
Heat Recovery from Equipment	10%	2.0%	700	8,100	2,700	36
Steam Leaks and Insulation	11%	1.7%	4,800	3,000	5,800	6
Space Conditioning Controls	7%	1.4%	350	1,000	2,600	5
Thermal System Insulation	9%	0.8%	1,900	4,600	3,300	17
Air Compressor Operations	63%	0.3%	650	5,800	8,400	8
Motor Hardware	74%	0.2%	450	17,000	7,000	29
Motor Operations	55%	0.2%	250	7,100	3,700	23

* Calculations based on IAC estimates at audits of 213 companies in SIC 24 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Table A-7: Furniture and Fixtures* (SIC 25)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Cogeneration**	5%	17.4%	17,400	402,900	117,000	41
Boiler Hardware	2%	14.1%	15,600	2,300	38,700	1
General Ventilation	8%	7.7%	3,000	19,800	10,800	22
Other Process Waste Heat Recovery	5%	7.7%	3,400	11,700	12,500	11
Heat Recovery from Equipment	21%	6.4%	1,800	4,700	6,200	9
Thermal System Insulation	11%	5.8%	2,500	14,000	7,400	23
Space Conditioning Operation	16%	3.8%	700	4,100	5,000	10
Space Conditioning Controls	11%	3.8%	500	2,100	3,100	8
Boiler Maintenance	9%	3.4%	800	1,000	1,500	9
Building Envelope Infiltration	15%	2.9%	750	5,400	2,800	23
Air Circulation Hardware	10%	2.8%	550	6,500	3,500	22
Equipment Use Reduction	18%	2.1%	500	450	4,400	1
Lighting Hardware	77%	1.0%	200	7,500	4,500	20
Air Compressor Operations	60%	0.7%	250	950	3,400	3
Motor Hardware	50%	0.5%	150	7,000	3,800	22

* Calculations based on IAC estimates at audits of 109 companies in SIC 25 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Table A-8: Paper and Allied Products* (SIC 26)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Mechanical System Design	1%	43.1%	62,500	219,400	161,000	16
Flue Gas-Other Uses	2%	19.2%	33,700	69,800	98,200	9
Cogeneration**	4%	11.0%	29,500	400,100	275,900	17
Other Process Waste Heat Recovery	6%	7.5%	15,900	72,700	39,200	22
Steam Trap Management	3%	7.0%	4,400	2,300	21,000	1
Heating/Cooling Hardware	4%	4.7%	1,200	35,200	9,900	43
Miscellaneous Building Envelope	4%	4.6%	2,400	19,700	6,500	36
Boiler Operation	7%	2.9%	2,300	3,000	8,200	4
Building Envelope Infiltration	12%	2.5%	1,100	13,900	4,300	39
Heat Recovery from Equipment	15%	1.9%	2,500	10,300	7,600	16
Space Conditioning Controls	10%	1.9%	850	2,500	4,300	7
Boiler Maintenance	25%	1.2%	1,900	4,200	6,100	8
Lighting Hardware	78%	0.5%	350	9,700	6,900	17
Air Compressor Operations	39%	0.5%	300	1,100	4,600	3
Motor Hardware	61%	0.4%	450	14,600	8,200	21

* Calculations based on IAC estimates at audits of 226 companies in SIC 26 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Table A-9: Printing and Publishing* (SIC 27)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Heating/Cooling Hardware	7%	5.6%	450	26,700	9,600	33
Flue Gas Recuperation	3%	4.2%	2,000	15,600	8,300	23
Space Conditioning Controls	19%	4.0%	850	4,100	4,500	11
Heat Recovery from Equipment	16%	3.5%	1,000	5,600	5,200	13
Boiler Hardware	4%	3.2%	800	12,200	4,300	34
Air Circulation Hardware	7%	2.9%	400	4,900	2,300	25
Miscellaneous Building Envelope	10%	2.4%	800	16,000	5,000	37
Space Conditioning Operation	25%	2.2%	300	3,000	2,900	13
Equipment Use Reduction	12%	1.7%	600	46,100	4,700	118
Motor Hardware	42%	1.3%	300	6,900	5,400	15
Lighting Hardware	79%	1.0%	300	9,200	5,400	20
Building Envelope Infiltration	15%	1.0%	250	1,100	1,300	11
Air Compressor Operations	45%	0.8%	250	1,000	4,000	3
Motor Operations	31%	0.5%	150	2,700	2,300	14
Lighting Controls	31%	0.4%	120	1,200	1,700	9

* Calculations based on IAC estimates at audits of 182 companies in SIC 27 (1/90 - 7/97). Savings may not be additive.

Table A-10: Chemicals and Allied Products* (SIC 28)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Cogeneration**	4%	18.6%	11,400	772,000	147,900	63
General Ventilation	1%	9.9%	900	1,500	3,700	5
Boiler Hardware	1%	9.9%	20,500	125,000	73,900	20
Flue Gas Recuperation	9%	5.1%	8,000	27,900	22,200	15
Heating/Cooling Hardware	5%	3.9%	1,900	56,300	19,600	34
Other Process Waste Heat Recovery	7%	2.7%	7,400	13,000	21,000	8
Boiler Maintenance	23%	2.2%	2,500	1,200	6,800	2
Space Conditioning Operation	9%	2.2%	800	2,400	8,400	3
Heat Recovery from Equipment	10%	1.9%	1,200	4,400	4,800	11
Steam Leaks and Insulation	17%	1.6%	4,600	2,300	8,800	3
Equipment Use Reduction	12%	1.5%	950	1,500	4,400	4
Air Compressor Operations	37%	0.8%	400	450	5,400	1
Motor Hardware	62%	0.5%	450	15,000	6,000	30
Lighting Hardware	75%	0.3%	200	7,200	4,200	21
Motor Operations	34%	0.3%	500	1,700	2,700	8

* Calculations based on IAC estimates at audits of 191 companies in SIC 28 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Table A-11: Petroleum and Coal Products* (SIC 29)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Cogeneration**	3%	23.6%	262,200	4,815,000	1,247,700	46
Furnace Operations	3%	19.6%	9,500	4,000	23,700	2
Other Equipment Hardware	3%	10.1%	16,000	47,900	46,000	13
Furnace Hardware	3%	8.8%	950	0	3,800	0
Space Conditioning Controls	3%	8.1%	2,000	400	7,000	1
Flue Gas Recuperation	15%	7.8%	9,200	40,900	36,100	14
Boiler Hardware	6%	7.4%	2,300	11,000	6,400	21
Flue Gas-Other Uses	6%	5.3%	8,700	12,000	30,900	5
Heat Recovery from Equipment	6%	3.8%	15,300	117,900	44,400	32
Thermal System Insulation	65%	3.7%	3,900	8,100	18,400	5
Steam Trap Management	6%	3.6%	3,300	4,700	9,500	6
Boiler Operation	12%	3.0%	2,300	6,700	7,500	11
Boiler Maintenance	21%	2.5%	2,900	3,300	9,500	4
Furnace Maintenance	12%	1.7%	600	750	1,600	6
Steam Leaks and Insulation	32%	0.9%	1,200	1,400	6,200	3

* Calculations based on IAC estimates at audits of 34 companies in SIC 29 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Table A-12: Rubber and Misc. Plastics Products* (SIC 30)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Flue Gas Recuperation	4%	8.3%	8,000	19,800	20,600	12
Other Process Waste Heat Recovery	3%	5.0%	2,300	24,200	11.600	25
Other Equipment Hardware	7%	2.4%	650	20,100	11,300	21
Heating/Cooling Hardware	7%	2.3%	800	20,300	9,200	26
Boiler Maintenance	11%	2.2%	1,700	3,000	6,300	6
Heat Recovery from Equipment	10%	2.2%	1,100	5,100	4,900	12
Equipment Use Reduction	13%	2.1%	650	2,600	8,200	4
Space Conditioning Operation	10%	2.0%	800	3,100	5,800	6
Equipment Automation	13%	1.7%	450	2,800	7,400	5
Air Circulation Hardware	10%	1.7%	650	6,900	4,300	19
Space Conditioning Controls	12%	1.6%	500	1,300	3,700	4
Thermal System Insulation	33%	0.8%	500	3,000	6,300	6
Lighting Hardware	74%	0.5%	300	7,200	5,100	17
Motor Hardware	59%	0.5%	400	15,200	6,800	27
Air Compressor Operations	42%	0.4%	250	1,300	4,500	3

* Calculations based on IAC estimates at audits of 440 companies in SIC 30 (1/90 - 7/97). Savings may not be additive.

Table A-13: Leather and Leather Products* (SIC 31)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Thermal System Infiltration	6%	7.3%	750	2,100	4,800	5
Steam Maintenance	3%	5.9%	700	200	2,400	1
Steam Trap Management	6%	5.7%	1,400	1,700	4,500	5
Heating/Cooling Hardware	9%	5.3%	100	19,100	3,000	77
Space Conditioning Operation	15%	3.8%	500	5,300	2,500	25
Lighting Level	12%	2.3%	250	700	3,400	2
Steam Leaks and Insulation	21%	1.8%	1,200	1,600	4,100	5
Boiler Maintenance	21%	1.8%	1,100	2,500	3,400	9
Heat Recovery from Equipment	21%	1.4%	100	450	900	6
Lighting Hardware	61%	0.9%	300	18,100	7,700	28
Lighting Controls	18%	0.7%	200	1,000	1,700	7
Thermal System Insulation	27%	0.6%	300	2,500	1,600	19
Air Compressor Operations	52%	0.5%	200	850	4,300	2
Air Compressor Hardware	58%	0.3%	70	600	1,400	5
Motor Hardware	39%	0.3%	200	7,700	5,000	18

* Calculations based on IAC estimates at audits of 33 companies in SIC 31 (1/90 - 7/97). Savings may not be additive.

Table A-14: Stone, Clay and Glass Products* (SIC 32)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Miscellaneous Heat Recovery	1%	38.8%	7,400	32,300	36,900	11
Thermal System Isolation	1%	23.7%	600	6,000	3,800	19
Cogeneration**	7%	10.2%	123,800	1,447,400	464,000	37
General Operations Maintenance	1%	5.3%	1,000	6,000	4,600	15
Flue Gas-Other Uses	6%	4.2%	27,700	46,100	65,800	8
Flue Gas Recuperation	9%	4.1%	14,800	54,300	33,400	19
Thermal System Insulation	22%	2.4%	5,000	7,200	15,500	6
Heat Recovery from Equipment	12%	2.3%	3,600	5,100	10,200	6
Boiler Maintenance	11%	2.2%	2,300	1,000	8,900	1
Other Equipment Hardware	9%	2.2%	5,000	153,800	89,700	21
Other Process Waste Heat Recovery	6%	2.2%	6,300	23,500	19,000	15
Building Envelope Infiltration	8%	1.4%	4,700	1,800	10,600	2
Boiler Operation	4%	1.4%	2,600	3,400	7,600	5
Motor Hardware	70%	0.3%	1,100	30,800	15,000	25
Air Compr essor Operations	56%	0.3%	850	3,200	9,800	4

* Calculations based on IAC estimates at audits of 151 companies in SIC 32 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Table A-15: Primary Metal Industries* (SIC 33)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Cogeneration**	2%	12.1%	8,100	473,600	112,000	51
Boiler Operation	4%	7.0%	6,300	13,000	18,100	9
Furnace Operations	3%	6.9%	11,500	2,900	26,400	1
Space Conditioning Operation	4%	6.8%	3,300	18,700	8,900	25
Flue Gas-Other Uses	8%	6.2%	10,700	106,400	52,400	24
Furnace Maintenance	3%	6.2%	4,100	7,200	15,700	6
Flue Gas Recuperation	14%	5.9%	6,000	20,600	17,800	14
Building Envelope Infiltration	6%	3.7%	1,600	10,600	6,200	21
Heat Recovery from Equipment	12%	2.8%	1,600	8,500	6,800	15
Boiler Maintenance	10%	2.0%	1,400	1,600	5,500	3
Thermal System Insulation	24%	1.7%	1,400	2,500	6,400	5
Equipment Use Reduction	11%	1.7%	2,000	1,100	7,600	2
Motor Hardware	62%	0.6%	500	11,000	7,000	20
Air Compressor Operations	45%	0.6%	450	2,300	6,600	4
Lighting Hardware	70%	0.3%	250	6,000	3,800	19

* Calculations based on IAC estimates at audits of 263 companies in SIC 33 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Table A-16: Fabricated Metal Industries* (SIC 34)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Cogeneration**	2%	15.2%	13,000	323,000	121,000	32
Flue Gas-Other Uses	4%	8.2%	6,800	19,300	21,400	11
Heating/Cooling Hardware	7%	4.5%	950	20,100	5,300	46
Flue Gas Recuperation	5%	4.1%	4,200	20,700	11,000	23
Air Circulation Hardware	8%	2.6%	800	5,400	4,500	14
Miscellaneous Building Envelope	7%	2.6%	1,100	17,100	5,400	38
Heat Recovery from Equipment	16%	2.5%	900	3,700	3,800	12
Boiler Maintenance	12%	2.5%	1,500	1,400	4,600	4
Space Conditioning Operation	9%	2.1%	700	1,500	3,800	5
Building Envelope Infiltration	15%	2.0%	700	2,800	3,000	11
Thermal System Insulation	21%	1.8%	800	3,800	3,800	12
Space Conditioning Controls	14%	1.5%	600	1,500	3,500	5
Air Compressor Operations	55%	0.6%	250	890	4,300	2
Lighting Hardware	75%	0.5%	200	6,700	4,800	17
Motor Hardware	54%	0.5%	200	6,600	3,900	20

* Calculations based on IAC estimates at audits of 570 companies in SIC 34 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Table A-17: Industrial Machinery and Equipment* (SIC 35)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Building Envelope Infiltration	15%	4.3%	1,000	3,200	3,300	12
General Ventilation	7%	4.1%	900	2,800	4,300	8
Air Circulation Hardware	9%	4.0%	750	6,600	4,200	19
Space Conditioning Operation	15%	3.8%	900	3,100	6,000	6
Heating/Cooling Hardware	8%	3.8%	700	35,000	12,600	33
Space Conditioning Controls	13%	3.6%	750	1,700	3,800	5
Miscellaneous Building Envelope	6%	3.2%	1,000	22,500	4,900	55
Other Equipment Hardware	7%	3.0%	400	6,500	5,600	14
Equipment Use Reduction	15%	2.8%	750	900	4,200	3
Heat Recovery from Equipment	21%	1.8%	600	3,200	2,800	14
Boiler Maintenance	10%	1.7%	600	1,000	2,300	5
Lighting Level	12%	1.4%	400	1,200	5,700	2
Lighting Hardware	82%	0.7%	250	9,800	5,000	23
Air Compressor Operations	55%	0.6%	250	1,000	3,700	3
Motor Hardware	47%	0.6%	150	5,900	2,800	25

* Calculations based on IAC estimates at audits of 438 companies in SIC 35 (1/90 - 7/97). Savings may not be additive.

Table A-18: Electronic and Other Electric Equipment* (SIC 36)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Humidity Control	1%	31.2%	16,000	143,400	97,000	18
Cogeneration**	1%	22.1%	47,000	286,800	303,600	11
Heating/Cooling Hardware	8%	6.2%	2,000	40,200	20,500	24
Heat Recovery from Equipment	20%	3.5%	1,000	6,400	5,400	14
Space Conditioning Controls	17%	3.4%	1,000	4,000	8,400	6
Other Process Waste Heat Recovery	5%	3.1%	2,300	17,400	11,900	18
Space Conditioning Operation	14%	2.9%	850	8,300	7,800	13
Air Circulation Hardware	8%	2.8%	650	6,200	7,400	10
Other Equipment Hardware	7%	2.6%	600	19,200	7,700	30
Miscellaneous Building Envelope	6%	2.6%	550	15,300	5,100	36
Building Envelope Infiltration	9%	2.4%	600	2,500	5,300	6
Thermal System Insulation	20%	1.2%	500	2,400	4,600	6
Lighting Hardware	77%	1.1%	400	15,100	8,000	23
Motor Hardware	55%	0.7%	250	9,100	5,000	22
Air Compressor Operations	43%	0.6%	200	1,300	3,600	4

* Calculations based on IAC estimates at audits of 287 companies in SIC 36 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Table A-19: Transportation Equipment* (SIC 37)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Flue Gas Recuperation	3%	8.4%	7,000	20,000	19,800	12
Miscellaneous Building Envelope	5%	7.0%	1,000	9,700	4,600	25
Heating/Cooling Hardware	11%	5.8%	1,000	17,000	12,400	17
Space Conditioning Operation	12%	3.7%	1,000	3,000	6,200	6
Space Conditioning Controls	18%	2.8%	1,000	2,600	6,100	5
Building Envelope Infiltration	9%	2.8%	850	2,600	4,200	7
Heat Recovery from Equipment	21%	2.7%	1,000	7,100	4,000	22
Boiler Maintenance	9%	2.4%	2,000	1,200	5,100	3
Equipment Automation	14%	1.8%	400	2,000	3,200	7
Lighting Level	15%	1.2%	350	3,300	6,200	6
Air Compressor Operations	64%	1.0%	300	1,000	4,700	3
Lighting Hardware	79%	0.9%	300	11,200	5,400	25
Motor Hardware	56%	0.8%	300	8,400	4,300	23
Motor Operations	31%	0.6%	250	2,800	3,100	11
Air Compressor Hardware	39%	0.4%	150	1,200	2,200	7

* Calculations based on IAC estimates at audits of 214 companies in SIC 37 (1/90 - 7/97). Savings may not be additive.

Table A-20: Instruments and Related Products* (SIC 38)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Solar Loading	2%	10.3%	550	4,900	4,100	14
Other Equipment Hardware	5%	9.3%	1,000	60,600	26,600	27
Other Process Waste Heat Recovery	5%	6.7%	4,000	13,400	19,000	8
Space Conditioning Operation	14%	5.3%	600	3,100	7,800	5
Heat Recovery from Equipment	13%	4.7%	1,000	5,200	5,600	11
General Ventilation	4%	4.6%	900	8,000	4,700	20
Equipment Use Reduction	14%	3.7%	700	600	4,400	2
Heating/Cooling Hardware	7%	2.6%	450	40,400	12,400	39
Lighting Hardware	83%	2.2%	450	18,900	10,300	22
Equipment Automation	19%	2.1%	400	2,900	3,900	9
Building Envelope Infiltration	13%	1.7%	450	1,500	5,100	3
Thermal System Insulation	20%	1.1%	350	1,700	2,400	5
Motor Hardware	57%	0.9%	250	9,400	4,400	25
Air Compressor Operations	40%	0.7%	100	350	2,100	2
Lighting Controls	34%	0.6%	150	1,700	2,400	8

* Calculations based on IAC estimates at audits of 95 companies in SIC 38 (1/90 - 7/97). Savings may not be additive.

Table A-21: Misc. Manufacturing Industries* (SIC 39)

Measure	Recommendation Rate	Average Annual Energy Savings (% of total *facility* energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost (dollars)	Average Annual Cost Savings (dollars)	Average Simple Payback (months)
Alternate Fossil Fuel Switching	1%	25.5%	2,000	21,700	29,000	9
Boiler Operation	3%	24.0%	7,000	15,100	5,900	31
Cogeneration**	1%	15.9%	8,000	165,000	54,000	37
Heating/Cooling Hardware	5%	10.3%	1,000	58,400	14,100	50
Solar Loading	4%	10.3%	700	13,900	4,400	38
Heat Recovery from Equipment	12%	7.0%	2,000	4,800	11,500	5
Flue Gas Recuperation	5%	6.2%	4,000	8,200	12,300	8
Boiler Maintenance	19%	5.6%	1,000	1,200	4,400	3
Miscellaneous Building Envelope	8%	4.6%	800	19,000	6,000	38
Space Conditioning Operation	13%	3.9%	600	1,700	3,000	7
Space Conditioning Controls	13%	2.7%	1,000	2,800	7,800	4
Lighting Hardware	88%	1.0%	250	8,000	4,600	21
Air Compressor Operations	48%	0.9%	150	950	3,100	4
Motor Hardware	45%	0.7%	100	4,300	2,200	24
Air Compressor Hardware	41%	0.5%	100	800	1,100	9

* Calculations based on IAC estimates at audits of 75 companies in SIC 39 (1/90 - 7/97). Savings may not be additive.

** Cogeneration energy savings are based on primary fuel savings from electricity generation, including fuel inputs at off-site powerplants for purchased electricity.

Appendix B

Conversion Factors and Emission Coefficients

This appendix provides the necessary information to calculate CO_2 emissions reductions from energy efficiency measures. Once you have qualified project impacts (using Wise Rules, metered data, and/or engineering estimates), simply multiply the energy savings by the appropriate CO_2 emission coefficient. Use **Table B-2** to calculate CO_2 emission reductions from fuel savings and use **Table B-3** to calculate CO_2 emissions reductions from electricity savings. CO_2 emissions from electricity generation are a function of powerplant efficiency and fuel use. The CO_2 emission coefficients in **Table B-3** are average values that reflect the mix of powerplants in each state. Feel free to use your own site-specific information on fuel carbon content or purchased electricity CO_2 emissions in place of the averages presented here.

Example 1: Boiler Fuel Savings

Consider a boiler tune-up that is estimated to save 1,000 MMBtu of natural gas per year. Multiply the 1,000 MMBtu savings by the CO_2 emission coefficient for natural gas, 117.08 pounds CO_2 per MMBtu (**Table B-2**) to calculate annual savings of 117,080 pounds of CO_2. To express the greenhouse gas emissions reduction in metric tons of carbon, multiply the pounds of CO_2 saved by 1.237×10^{-4} (**Table B-1**) to yield 14.5 metric tons of carbon.

Example 2: Air Compressor Electricity Savings

Consider a manufacturing facility in Florida that implements compressed air system efficiency improvements that result in annual savings of 100 MWh. Multiply the 100 MWh savings by the CO_2 emission factor for electricity generated in Florida, 0.587 metric tons CO_2 per MWh (**Table B-3**), to calculate annual savings of 58.7 metric tons of CO_2. To express the greenhouse gas emissions reduction in metric tons of carbon, multiply the metric tons of CO_2 saved by 0.2727 (**Table B-1**) to yield 16.0 metric tons of carbon.

Table B-1: Helpful Conversion Factors

To Convert	To	Multiply By
Tons	**Pounds**	2000
Tons	**Metric Tons**	0.9072
MMBtu	**Btu**	10^6
kWh	**Wh**	10^3
MWh	**kWh**	10^3
kWh	**Btu**	3413
Quads (quadrillion Btu)	**Btu**	10^{15}
Quads (quadrillion Btu)	**kWh**	2.93×10^{11}
Therms	**Btu**	10^5
Horsepower (hp)	**kW**	0.746
Btu	**Joule (J)**	1055
kWh	**Joule (J)**	3600
Carbon (mass units)	**Carbon Dioxide** (mass units)	3.667
Carbon Dioxide (mass units)	**Carbon** (mass units)	0.2727
Carbon (metric tons)	**Carbon Dioxide** (tons)	4.042
Carbon Dioxide (pounds)	**Carbon** (metric tons)	1.237×10^{-4}

Table B-2: Emission Coefficients by Fuel Type

Fuel	Emission Coefficients: Pounds CO_2 per Unit Volume or Mass	Emission Coefficients: Pounds CO_2 per Million Btu
Petroleum Products		
Aviation Gasoline	18.355 per gallon 770.916 per barrel	152.717
Distillate Fuel (No. 1, No. 2, No. 4 Fuel Oil and Diesel)	22.384 per gallon 940.109 per barrel	161.386
Jet Fuel	21.439 per gallon 900.420 per barrel	159.690
Kerosene	21.537 per gallon 904.565 per barrel	159.535
Liquefied Petroleum Gases (LPG)	12.200 per gallon 512.415 per barrel	138.846
Motor Gasoline	19.641 per gallon 824.939 per barrel	157.041
Residual Fuel (No. 6 Fuel Oil)	26.033 per gallon 1,093.384 per barrel	173.906
Natural Gas and Other Gaseous Fuels		
Methane	116.376 per 1000 ft^3	115.258
Flare Gas	133.759 per 1000 ft^3	120.721
Natural Gas (Pipeline)	120.593 per 1000 ft^3	117.080
Propane	12.669 per gallon 532.085 per barrel	139.178
Electricity	Varies depending on fuel used to generate electricity*	
Coal		
Anthracite	3852.156 per ton	227.400
Bituminous	4921.862 per ton	205.300
Subbituminous	3723.952 per ton	212.700
Lignite	2733.857 per ton	215.400
Renewable Sources		
Geothermal Energy	0	0
Wind	0	0
Photovoltaic and Solar Thermal	0	0
Hydropower	0	0
Wood and Wood Waste**	3814 per ton	221.943
Municipal Solid Waste**	1999 per ton	199.854
Nuclear	0	0

Source: DOE/EIA, *Form EIA-1605 Voluntary Reporting of Greenhouse Gases, Instructions*, 1997, Appendix B.
*For average electric power emission coefficients by state, see Table B-3.
**Fuel cycle emissions are likely to be less than the direct emissions because all or part of the fuel is renewable. These biofuels contain carbon that is part of the natural carbon balance and that will not add to atmospheric concentrations of carbon dioxide.

Table B-3: Electricity CO_2 Emission Factors by State

State	CO_2 Emission Factors lbs/kWh	short tons/MWh	metric tons/MWh
New England Region			
Connecticut	0.715	0.358	0.324
Maine	0.966	0.483	0.438
Massachusetts	1.459	0.729	0.662
New Hampshire	0.852	0.426	0.386
Rhode Island	1.091	0.546	0.495
Vermont	0.159	0.080	0.072
Mid Atlantic Region			
New Jersey	0.774	0.387	0.351
New York	1.036	0.518	0.470
Pennsylvania	1.286	0.643	0.583
East-North Central Region			
Illinois	0.866	0.433	0.393
Indiana	2.171	1.086	0.985
Michigan	1.576	0.788	0.715
Ohio	1.807	0.904	0.820
Wisconsin	1.343	0.671	0.609
West-North Central Region			
Iowa	1.686	0.843	0.765
Kansas	1.703	0.852	0.773
Minnesota	1.627	0.814	0.738
Missouri	1.783	0.891	0.809
Nebraska	1.288	0.644	0.580
North Dakota	2.303	1.151	1.045
South Dakota	0.912	0.456	0.410
South Atlantic Region			
Delaware	1.855	0.928	0.842
District of Columbia	2.649	1.324	1.192
Florida	1.294	0.647	0.587
Georgia	1.220	0.610	0.553
Maryland	1.356	0.678	0.615
North Carolina	1.350	0.675	0.612
South Carolina	0.688	0.344	0.312
Virginia	1.107	0.554	0.502
West Virginia	2.005	1.003	0.909

State	CO_2 Emission Factors lbs/kWh	short tons/MWh	metric tons/MWh
East-South Central Region			
Alabama	1.369	0.684	0.621
Kentucky	1.930	0.965	0.869
Mississippi	1.075	0.537	0.487
Tennessee	1.335	0.668	0.606
West-South Central Region			
Arkansas	1.286	0.643	0.584
Louisiana	1.388	0.694	0.629
Oklahoma	1.672	0.836	0.758
Texas	1.552	0.776	0.704
Mountain Region			
Arizona	0.798	0.399	0.362
Colorado	2.001	1.000	0.908
Idaho	0.269	0.134	0.122
Montana	1.553	0.777	0.704
Nevada	1.875	0.937	0.850
New Mexico	1.405	0.703	0.637
Utah	1.990	0.995	0.903
Wyoming	2.194	1.097	0.995
Pacific Region Contiguous			
California	0.756	0.378	0.343
Oregon	0.235	0.118	0.107
Washington	0.306	0.153	0.139
Pacific Region Non-Contiguous			
Alaska	0.031	0.016	0.014
Hawaii			
U.S. Average	1.291	0.646	0.586

Source: DOE/EIA, *Form EIA-1605 Voluntary Reporting of Greenhouse Gases, Instructions*, 1997, Appendix C.

Appendix C

Summary of Wise Rules

Boilers

Boiler Wise Rule 1

Effective boiler load management techniques, such as operating on high fire settings or installing smaller boilers, can save over 7% of a typical *facility's* total energy use with an average simple payback of less than 2 years.

Boiler Wise Rule 2

Load management measures, including optimal matching of boiler size and boiler load, can save as much as 50% of a *boiler's* fuel use.

Boiler Wise Rule 3

An upgraded boiler maintenance program including optimizing air-to-fuel ratio, burner maintenance, and tube cleaning, can save about 2% of a *facility's* total energy use with an average simple payback of 5 months.

Boiler Wise Rule 4

A comprehensive tune-up with precision testing equipment to detect and correct excess air losses, smoking, unburned fuel losses, sooting, and high stack temperatures, can result in *boiler* fuel savings of 2% to 20%.

Boiler Wise Rule 5

A 3% decrease in flue gas O_2 typically produces *boiler* fuel savings of 2%.

Boiler Wise Rule 6

Using over fire draft control systems to control excess air can save 2% to 10% of a *boiler's* fuel use with typical equipment costs of $1,500.

Boiler Wise Rule 7

Using a characterizable fuel valve to match the air/fuel ratios across the load range can save 2% to 12% of a *boiler's* fuel use at relatively low cost.

Boiler Wise Rule 8

Converting to air or steam atomizing burners from conventional burners can reduce *boiler* fuel use by 2% to 8%.

Boiler Wise Rule 9

Every 40°F reduction in *net* stack temperature (outlet temperature minus inlet combustion air temperature) is estimated to save 1% to 2% of a *boiler's* fuel use.

Boiler Wise Rule 10

Stack dampers prevent heat from being pulled up the stack and can save 5% to 20% of a *boiler's* fuel use.

Boiler Wise Rule 11

Direct contact condensation heat recovery can save 8% to 20% of a *boiler's* fuel use, but costs may be relatively high.

Boiler Wise Rule 12

Preheating combustion inlet air can save about 3% of a *facility's* total energy use with an average simple payback of 8 months.

Boiler Wise Rule 13

Minimizing energy loss from boiler blowdown can save about 2% of a *facility's* total energy use with an average simple payback of less than 1 year.[26]

Boiler Wise Rule 14

Removing a 1/32 inch deposit on boiler heat transfer surfaces can decrease a *boiler's* fuel use by 2%; removal of a 1/8 inch deposit can decrease boiler fuel use by over 8%.

Boiler Wise Rule 15

Blowdown heat recovery is a proven technology that can reduce a *boiler's* fuel use by 2% to 5%.

Boiler Wise Rule 16

For every 11°F that the entering feedwater temperature is increased, the *boiler's* fuel use is reduced by 1%.

Boiler Wise Rule 17

Changing from manual blowdown control to automatic adjustment can reduce a *boiler's* energy use by 2% to 3% and reduce blowdown water losses by up to 20%.

Steam Systems

Steam Wise Rule 1

An effective steam trap maintenance program can save 3% of a *facility's* total energy use with an average simple payback of 2 months.

Steam Wise Rule 2

An effective steam trap maintenance program can reduce a *boiler's* fuel use by 10% to 20%.

Steam Wise Rule 3

Repairing steam system leaks can save 1% of a *facility's* total energy use with an average simple payback of 3 months.

Steam Wise Rule 4

A single high-pressure steam leak (125 psi) can result in energy losses costing from $660 to $2,200 per year (8,760 hrs). A single low-pressure steam leak (15 psi) can result in energy losses costing $130 to $480 per year (8,760 hrs).

Steam Wise Rule 5

Insulating steam lines can save 1% of a *facility's* total energy use with an average simple payback of 10 months.

Steam Wise Rule 6

Vapor recompression saves 90% to 95% of the energy needed to raise the steam to the same pressure in a boiler.

Steam Wise Rule 7

Measures to reduce heat loss from condensate in a steam system can save over 1% of a *facility's* total energy use with an average simple payback of 8 months.

Process Heating

Process Heating Wise Rule 1

Proper heat containment can save about 2% of a *facility's* total energy use with an average simple payback of 9 months.

Process Heating Wise Rule 2

Insulating a furnace with refractory fiber liners can improve the *thermal* efficiency of the heating process by up to 50%.

Process Heating Wise Rule 3

Recovering waste heat from furnaces, ovens, kilns, and other equipment can save 5% of a typical *facility's* total energy use with an average simple payback of 16 months.

Process Heating Wise Rule 4

Recovering waste heat through a recuperator can reduce a *kiln's* energy use by up to 30%; regenerators can save up to 50%.

Process Heating Wise Rule 5

Each percent of moisture removed by air drying lumber reduces the *kiln's* energy use by 50 to 85 Btu per board foot.

Process Heating Wise Rule 6

Variable fan speed control in the lumber industry can reduce dry kiln airflow by 20% and reduce the *kiln's* energy used during surface drying by as much as 50%.

Process Heating Wise Rule 7

Installing expert systems for kiln secondary control can reduce a *cement kiln's* energy use by up to 3%.[14]

Process Heating Wise Rule 8

New clinker cooler technologies that optimize heat transfer conditions can reduce a *cement kiln's* energy use by up to 6%.

Process Heating Wise Rule 9

Direct firing with natural gas in place of indirect steam heating has the potential to save 33% to 45% of *process heating* energy use. Payback times may range from a few months to 6 years.

Process Heating Wise Rule 10

Direct electric heating (infrared, microwave, or dielectric) can reduce *process heating* energy use by up to 80% with typical payback periods of 1 to 3 years.

Waste Heat Recovery and Cogeneration

Heat Recovery/Cogen Wise Rule 1

Recovering waste heat can reduce a typical *facility's* total energy use by about 5% with an average simple payback of 16 months.

Heat Recovery/Cogen Wise Rule 2

Reducing *net* stack temperature (outlet temperature minus inlet combustion air temperature) by 40°F is estimated to reduce the *boiler's* fuel use by 1% to 2%.

Heat Recovery/Cogen Wise Rule 3

Preheating furnace combustion air with recovered waste heat can save up to 50% of the *furnace's* energy use. **Heat Recovery/Cogen Table 1** summarizes typical fuel savings for a natural gas furnace.

Heat Recovery/Cogen Wise Rule 4

Using an economizer to capture flue gas waste heat and preheat boiler feedwater can reduce a *boiler's* fuel use by up to 5%.

Heat Recovery/Cogen Wise Rule 5

Removing a 1/32 inch deposit on *boiler's* heat transfer surfaces can reduce a *boiler's* energy use by 2%; removing a 1/8 inch deposit can reduce a boiler's energy use by over 8%.

Heat Recovery/Cogen Wise Rule 6

Gas turbines with heat recovery equipment typically cost from $600 to $1,000/kW. Larger gas turbines may be available for half the cost per kW.

Heat Recovery/Cogen Wise Rule 7

A typical cogeneration project may reduce *primary* energy consumption (including fuel inputs at off-site powerplants for purchased electricity) for steam and electricity generation by 10% to 15%.

Heat Recovery/Cogen Wise Rule 8

Cogeneration systems can save about 9% of a typical *facility's* primary fuel inputs for on-site energy use (i.e., including fuel savings at off-site powerplants for purchased electricity) with an average simple payback of 34 months.[19] (Savings are calculated by dividing total energy savings, including powerplant inputs, by total facility energy use.)

Compressed Air Systems

Compressed Air Wise Rule 1

Efficiency improvements can reduce *compressed air system* energy use by 20 to 50%.[2]

Compressed Air Wise Rule 2

Efficiency improvements to compressed air systems can save approximately one-half percent of a *facility's* total energy use.

Compressed Air Wise Rule 3

Using cooler intake air for compressors can reduce *compressed air system* energy use by 1% per 5°F reduction in intake air temperature.[5] The payback period for this measure is usually less than two years.

Compressed Air Wise Rule 4

Using cooler intake air for compressors can save almost one-half percent of a *facility's* total energy use with an average simple payback of 5 months.

Compressed Air Wise Rule 5

Installing or adjusting unloading controls can reduce *compressed air system* energy use by about 10%.

Compressed Air Wise Rule 6

Upgrading controls on screw air compressors can reduce a *facility's* total energy use by about 1% with an average simple payback of 8 months.

Compressed Air Wise Rule 7

Reducing air compressor pressure can reduce a *facility's* total energy use by about one-half percent with an average simple payback of 4 months.

Compressed Air Wise Rule 8

Reducing air compressor pressure by 2 psi can reduce *compressor* energy use by 1% (at 100 psi).

Compressed Air Wise Rule 9

Eliminating or reducing compressed air usage for certain activities can reduce a *facility's* total energy use by more than one-half percent, with an average simple payback of 6 months.[16]

Compressed Air Wise Rule 10

Repairing air leaks can reduce *compressed air system* energy use by 30% or more.

Compressed Air Wise Rule 11

Repairing air leaks can reduce a *facility's* total energy use by about one-half percent, with an average simple payback of 3 months.

Compressed Air Wise Rule 12

It takes approximately 2.5 to 5.0 kWh to compress 1,000 ft^3 of air to 100 psi.[21,22] Each psi reduction in compressed air loss from the distribution system (at 100 psi), reduces the *compressor's* energy use by more than one-half percent.

Compressed Air Wise Rule 13

Air compressor waste heat recovery can reduce a facility's total energy use by about 1.8% with an average simple payback of 10 months.

Compressed Air Wise Rule 14

For every 1 psi increase in air compressor pressure gained by periodic filter changes, air compressor energy use is reduced by about 0.5%. Changing dryer filters at 8 or 10 psi drop per filter can eliminate this waste.

Compressed Air Wise Rule 15

For every 11°F decrease in air compressor working temperature, gained by careful maintenance of intercoolers, air compressor energy use will decreased by 1%.

Process Cooling

Process Cooling Wise Rule 1

Installing energy efficient chillers and refrigeration systems can save 1.2% of a facility's total energy use with an average simple payback of 23 months.

Process Cooling Wise Rule 2

"Free cooling" with cooling tower water can reduce a facility's total energy use by about 1 percent with an average simple payback of 14 months.

Process Cooling Wise Rule 3

Free cooling can reduce cooling system energy use by as much as 40% depending on location and load profile.

Process Cooling Wise Rule 4

Increasing chilled water temperature by 1°F reduces *chiller* energy use by 0.6% to 2.5%.[4] (See **Process Cooling Table 1** for data on specific chiller types.)

Process Cooling Wise Rule 5

Reducing condenser pressure by 10 psi can decrease *refrigeration system* energy use per ton of refrigeration (kW/ton) by about 6%.

Process Cooling Wise Rule 6

For each 1°F decrease in condenser cooling water temperature, until optimal water temperature is reached, there is a decrease in *chiller* energy use by up to 3.5%.

Process Cooling Wise Rule 7

Eliminating heat losses from leaks and improper defrosting can reduce refrigeration system energy use by 10% to 20%.

Process Cooling Wise Rule 8

Freezing products in batches rather than continuously can reduce freezing process energy use by up to 20%.

Process Cooling Wise Rule 9

Installing variable speed drives in place of constant speed systems can reduce cooling system energy use by 30% to 50%, depending on load profile.

Appendix D

Key References

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Key Resources

- For assistance in preparing your Climate Wise Action Plan or your Voluntary Greenhouse Gas Emissions Report (Form EIA-1605), call the Climate Wise *Wise Line* at 1-800-459-WISE.
- For information on the U.S. EPA Energy Star Programs, call 1-888-STAR-YES.
- For information on the U.S. EPA Waste Wise Program, call 1-800-EPA-WISE.
- For information on U.S. DOE Industrial Assessment Centers, call 1-800-DOE-EREC.
- For information on the U.S. DOE Motor Challenge Program, call 1-800-862-2086.
- For information on the U.S. DOE Compressed Air Challenge, call 1-800-559-4776.