CLIMATE WISE

Wise Rules for Industrial Efficiency

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

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

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- Michael R. Muller, Director, Office of Industrial Productivity & Energy Assessment, Rutgers University.
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- George M. Wheeler, Director, Industrial Assessment Center, Oregon State University.

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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 preveprtot5,ba11.3b97 0 T :0 TDbspecifi9, Climagas emisss 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 c0.025 Tw(Wise Rules)1ise Rule8SDr air compressor efficiency measures were 0.4 percent of total *facility* energy use, or an average 300 MMBtu annual reduction in each facility'

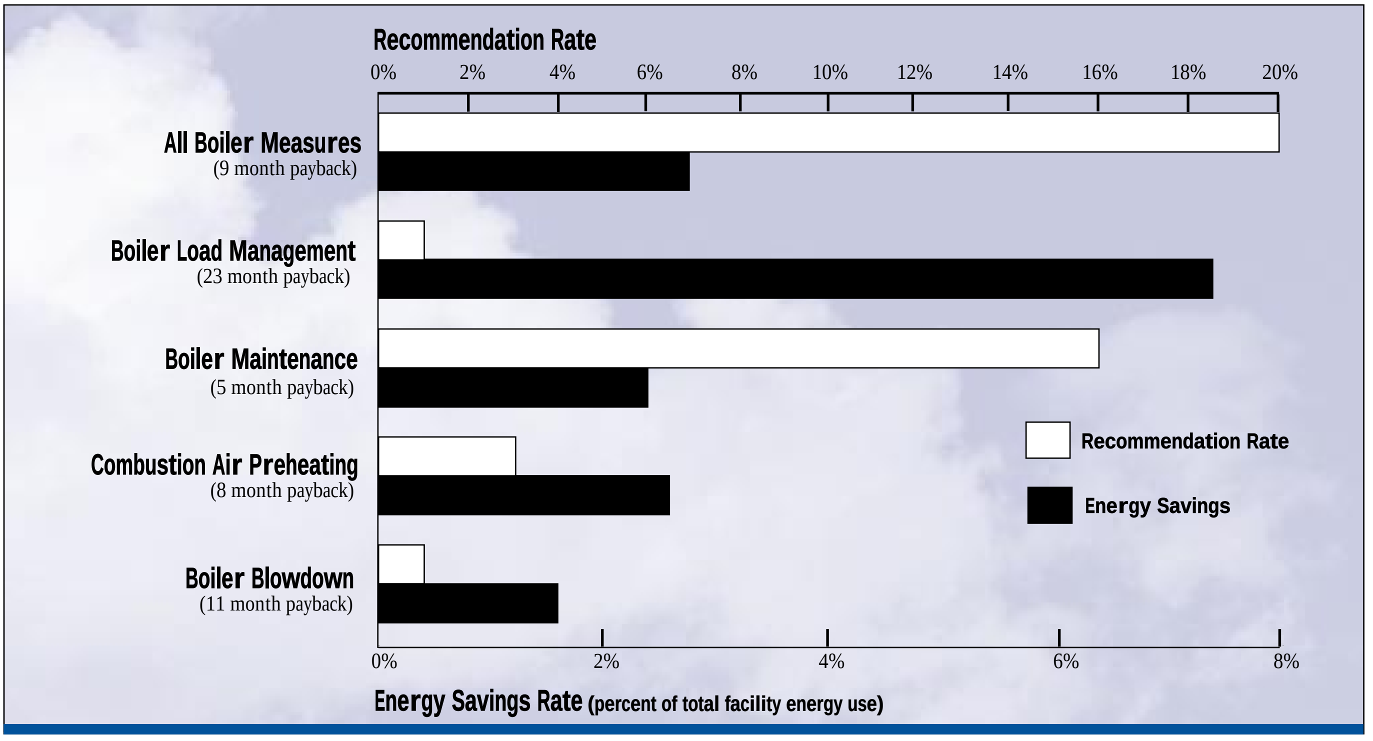
2. Boilers

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 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]

Bur

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

[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]

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.

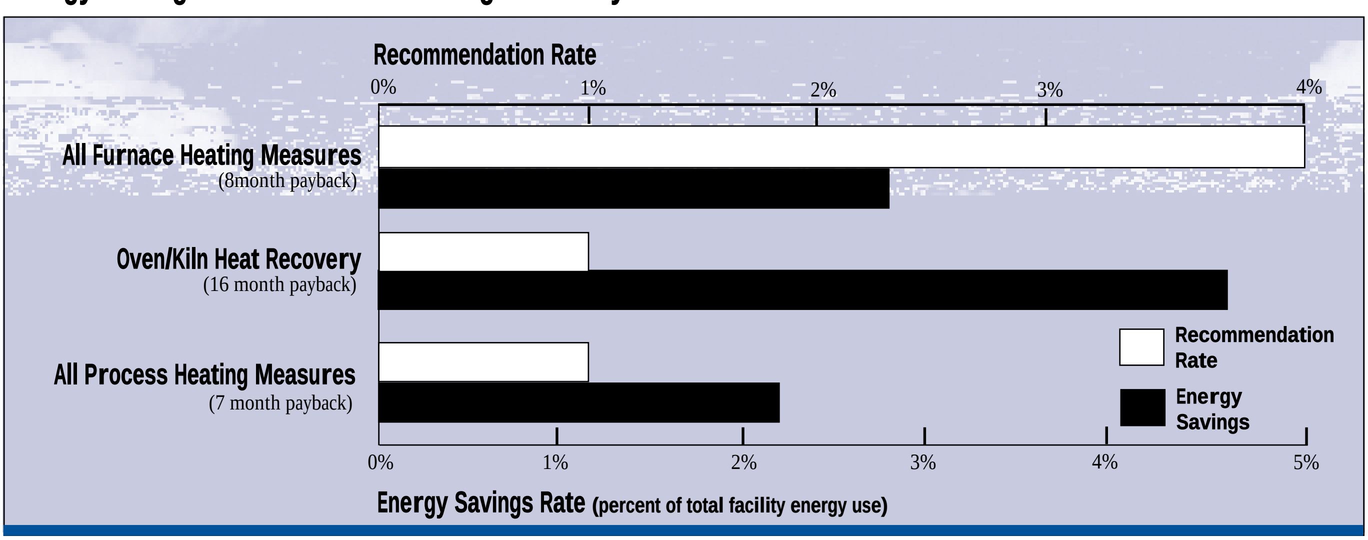
4. Process Heating

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 measur[illegible] -1(m1(. 0 T77 surw6 0d.19inmfo.109 0-172 reW(peratur)Tj9

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



Process Heating Wise Rule 1

Proper heat containment can save about 2% of a

Direct Heating

Direct heating is generally more efficient than indirect heating

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)

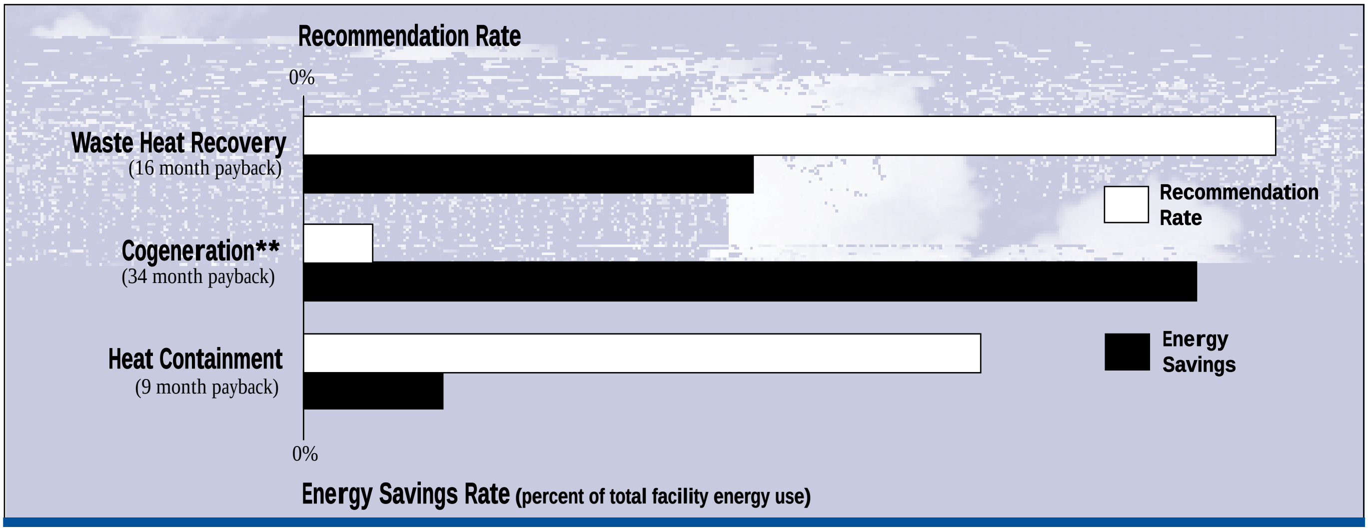
Source references for each Wise Rule are included in the chapter notes.

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*



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 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. Ide1

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.

Several compressed air system efficiency measures may be of interest to Climate Wise Partners, including using cooler intake air

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 W

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
381. 0 0 14 53.69 28n4 TDtr(er)Tj0.647 0 TD-0.00 8.5 58.c((inch9,500er yea14)			

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 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.

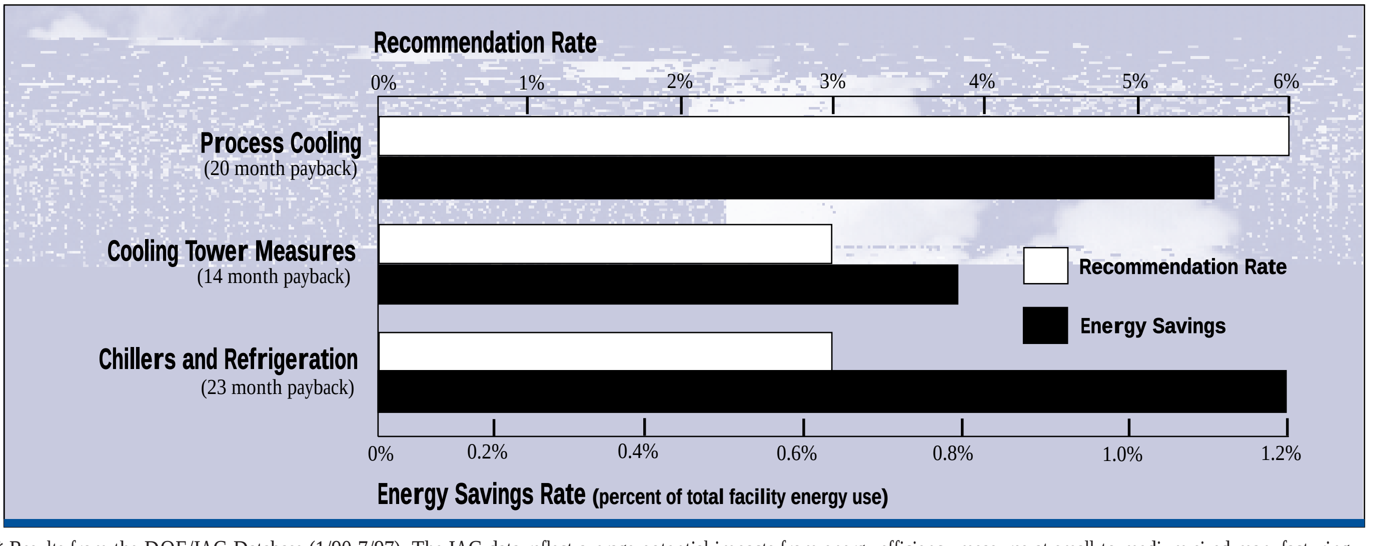
Energy Efficient Chillers and Refrigeration Units

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.)

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.

Table A-1: SIC Code Definitions

SIC Code	Classification
20	Food and Kindred Products
21	Tobacco*
22	Textile Mill Products
23	Apparel and O

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 Pr					

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 69 0 TD(ocessse 511.5.5%)Tj(aste)44/F13 1 41 Tf5.171 0 TD(3%)Tj9.188 0 TD(5.2%)T58.283 0 TD(3,700)Tj0Tj9.188TD(19,600)Tj98.186 0 TD(7,600)Tj6.87ver	7%	5.2%	3,700	19,600	13,600	17

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.

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	7%	2.7%	7,400	13,000	21,000	8

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

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	21%	1.4%	100	450	900	6

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: Primar

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	18%	2.8%	1,000	2,600	6,100	5

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. Manup

Appendix B

Conversion Factors and Emission Coefficients

This appendix provides the necessary information to calculate CO_2 emissions reductions from energy efficiency measures. Omissio2i4dTD-0.016 Tc(nce y1 TD(2378 0 0 1j10.u563.52v78 0 078831.043 T 0 1610.u56))Tjari(nce y1 TD(2378 0 0 1j10.

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	
	P CO_2 U I V / M	P CO_2 M//I B
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

Geo. TDT.4bio/F17 Tm-
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State	CO_2 Emission Factors		
	W	/MW	/MW
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

Boiler Wise Rule 7W

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 ev

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 dr

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 compr

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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