WISE RULES: SUCCESSFUL ENERGY EFFICIENCY OPPORTUNITIES IN MANUFACTURING

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1. INTRODUCTION

1.1 Background

Energy managers at many industrial companies have expressed an interest in being able to estimate potential energy and cost savings in their facilities. As an increasing number of industrial companies embark upon energy efficiency programs, the need for screening tools or "Wise Rules" to help estimate program impacts has become apparent. For end-uses such as lighting and motors, energy savings estimates are well documented and broadly available. There is less readily accessible summary information for other industrial energy end-uses such as boilers, steam systems and compressed air systems.

The Climate Wise program has prepared a handbook of rules and measures for estimating the energy, costs and greenhouse gas emissions impacts of alternative efficiency measures targeting major industrial equipment. This paper summarizes information from the Climate Wise Technical Tool Kit. In this paper we discuss how we developed the Wise Rules and present excerpts from key chapters of the Tool Kit. We are also interested in generating feedback on the estimates presented. We invite comment on the Wise Rules and on their usefulness to industry.

The Climate Wise Technical Tool Kit includes information on the following end-uses: boilers, steam systems, furnaces, process heating, waste heat recovery, cogeneration, compressed air systems, and process cooling. In this paper we present a summary of the Wise Rules for boilers, steam systems, and compressed air systems.

1.2 The Climate Wise Program

Climate Wise is a partnership initiative between EPA, DOE and industry designed to stimulate voluntary reduction of greenhouse gas emissions by recognizing organizations that commit to significantly reduce their emissions. 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 Partners receive public recognition for their efforts. Climate Wise Partners include over 300 companies that range from small to large and span most of the manufacturing SIC groups (20-39). At present, Climate Wise member companies represent approximately 10 percent of U.S. (non-feedstock) manufacturing energy use.

Climate Wise Partners follow a well-defined path toward setting goals, achieving emissions reductions, and reporting results. Before joining the program, potential Partners meet with Climate Wise representatives to discuss their emissions reduction opportunities and goals. Six months after signing their "Partnership Agreement," Partners submit an "Action Plan" detailing their Climate Wise commitments. The savings numbers listed in Climate Wise Action Plans reflect partners' preliminary estimates of their achievements. After a full year of program participation, Climate Wise Partners report their actual achievements in some detail under the Voluntary Reporting of Greenhouse Gases Program.

Climate Wise expects that its Partners will use these Wise Rules to identify savings opportunities, screen efficiency measures, and eliminate weak options. The Wise Rules can be used to estimate energy savings directly, and the accompanying text provides helpful background information and energy savings tips. Partners can calculate CO_2 emissions reductions based on estimated energy savings and CO_2 emission factors available from the U.S. Department of Energy.[1] After examining the Wise Rules and conducting an initial screening, Climate Wise Partners can develop more thorough estimates for their Action Plans based on site-specific engineering and economic analyses. Partners may choose to develop their own Wise Rules based on their project results as reported under the Voluntary Reporting of Greenhouse Gases Program.

2. WISE RULES

2.1 Applying Wise Rules

Wise Rules can be powerful tools for estimating the impacts of energy efficiency measures. The Climate Wise Technical Tool Kit is a compilation of some of the best available industrial energy efficiency data available from government, academic, and industry sources. Key data sources include the DOE's Industrial Assessment Center (IAC) Program database, the Bonneville Power Administration, engineering texts, and estimates from individual industrial companies. Below we highlight some of the key strengths of Wise Rules and the Tool Kit.

- Wise Rules can provide guidance on identifying energy savings opportunities and on the potential magnitude of the savings.
- The Tool Kit summarize savings rules from information sources that may be unfamiliar to Climate Wise Partners and consolidates them in one place.
- The Tool Kit provides background information and references for each of the Wise Rules so that readers will have a better understanding of how and when to use them and where to look for more detailed information.
- The Tool Kit taps the vast experience of the U.S. Department of Energy Industrial Assessment Centers and presents key information from the IAC database in a readily accessible format.
- Where possible, the Tool Kit presents a range of potential savings for specific efficiency measures to highlight that actual savings vary from site to site.
- Implementation costs and energy savings may vary widely based on location, internal labor costs, contractor costs, fuel prices and electricity prices.

2.2 Wise Rules by Broad End-Use Categories

The remainder of this paper highlights the information provided in the Technical Tool Kit. This includes (1) industry-wide and sector-specific estimates of energy savings, cost savings and simple paybacks from typical industrial efficiency measures, and (2) detailed information and Wise Rules on very specific measures targeting industrial end uses. This paper focuses on boilers, steam, and air compressors although the Tool Kit also covers waste heat recovery, cogeneration, process heating and process cooling.

These estimates of energy savings from a range of efficiency measures in the manufacturing sector were developed from the Department of Energy's Industrial Assessment Center (DOE/IAC) Database. DOE/IAC audit data was used to develop energy, cost, and payback estimates for broad categories such as boilers, steam systems, and compressed air systems. Embodied in these estimates are more detailed operations, hardware and maintenance measures such as boiler air/fuel ratio optimization and air leak repairs. Since partners may be implementing several measures, it is useful to present these higher level estimates. The structure of the IAC database, where measures are categorized at a very detailed level but can be aggregated up, facilitated this exercise. In Table 2-1 we present average savings for a broad range of industrial efficiency measures in the DOE/IAC database. These values are averaged across all facilities audited from 1990-1996.[2]

The DOE/IAC database contains information from industrial energy assessments conducted for <u>small to medium sized manufacturing facilities</u>. The audits are performed by teams of faculty and students from accredited engineering schools in 30 universities across the country. The DOE/IAC energy savings estimates reflect the expected impacts of a number of specific improvements and upgrades based on the detailed facility audits. The majority of the auditors' recommendations focus on measures with short (1-2 year) payback periods and are expected to be implemented within two years of the audit. The Wise Rules in this report are based on the roughly 4,000 audits conducted and 18,000 efficiency measures recommended since 1990. To develop the Wise Rules, the energy and cost savings estimates from the DOE/IAC database are averaged across industry groups, years and regions. Averaging across the entire database captures the broad experience of many manufacturing facilities and condenses a great deal of information into a few key measures. Savings estimates vary from facility to facility and actual savings vary from audit estimates.

Table 2-1 Summary of Efficiency Measures from the DOE/IAC Database

Measure	Recommendation Rate	Average Annual Energy Savings (% of total facility energy use)	Average Annual Energy Savings (MMBtu)	Average Implementation Cost	Average Annual Cost Savings	Average Simple Payback (months)
Boilers	21%	2.9%	2,600	$5,300	$7,300	9
Steam Systems	14%	2.1%	2,400	$3,400	$7,100	6
Furnaces & Ovens	4%	3.3%	2,900	$5,300	$8,600	7
Process Heating	1%	2.3%	3,700	$8,000	$12,400	8
Heat Recovery	26%	4.6%	3,700	$16,600	$12,300	16
Cogeneration	3%	8.7%	30,200	$686,400	$272,500	30
Heat Containment	23%	1.5%	1,200	$3,900	$5,200	9
Air Compressors	67%	0.4%	300	$1,700	$4,400	5
Process Cooling	7%	1.1%	1,000	$21,000	$11,200	23

Results from the DOE/IAC Database: average across all facilities audited 1990-1996. Savings may not be additive.

The recommendation rate represents how frequently a category of efficiency measures was recommended. For example, boiler efficiency measures were recommended in 21 percent of the approximately 4,000 facilities audited from 1990 to 1996, but cogeneration was only recommended in 3 percent of facilities audited. 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, in Table 2-1 a typical facility in the IAC database could expect to save about 2.9% of their total facility energy use by implementing boiler efficiency measures. If boilers represent 50% of a typical facility's energy use, then the estimate of *boiler* energy savings would be 5.8 percent (0.029 ÷ 0.5). The average absolute energy savings (MMBtu) represents the average facility energy savings for efficiency measures in a category. The average implementation cost includes average capital and labor costs for all measures in a category. Individual implementation costs for specific measures may vary widely between different industries and regions of the country. The average annual cost savings are primarily based on fuel cost savings, but also may include other cost savings. The average simple payback period is defined as the amount of time (in months) it takes to recover initial investment costs from energy savings.

2.3 Industry-Specific Wise Rules

The DOE/IAC database also contains the Standard Industrial Classification (SIC) code for each facility audited and can be used to highlight efficiency opportunities in specific industries. The energy savings potential, recommendation rate and payback period can vary considerably across industry groups. We used the database to develop industry-specific energy and cost savings estimates. Below we present industry-specific data from DOE/IAC audits for boiler, steam, and compressed air efficiency measures. Partners can use this information to examine the opportunities identified at other companies in their industry.

The impacts from boiler efficiency recommendations in the DOE/IAC database are summarized in Table 2-2. The average savings across all industries (SIC 20-39) from boiler operations, hardware and maintenance measures was 2.9 percent of total facility energy use with an average simple payback of 9 months. Partners can use this information to estimate industry-specific savings on a facility level or an end-use level.[3] For example, boiler efficiency measures at a food processing plant (SIC 20) might reduce total facility energy use by 2.5 percent. If boilers represent 50% of the facility's energy use, then the estimate of boiler energy savings would double to 5.0 percent. Boiler efficiency measures recommended in the DOE/IAC audits had the largest relative impact in the lumber and wood products industry (SIC 24), but were most frequently recommended in the food industry (SIC 20).

Table 2-2 Sector-Specific Savings Estimates from Boiler Efficiency Measures in the IAC Database

SIC	Industry	Recommendation Rate (%)	Average Energy Savings (% of total facility energy use)	Average Energy Savings Annual (MMBtu)	Average Implementation Costs	Average Annual Cost Savings	Average Simple Payback (months)
20	Food	45%	2.5%	2,030	$3,040	$6,010	6
22	Textile Mill Products	37%	2.3%	2,970	$21,600	$13,810	19
23	Apparel & Textile Products	26%	2.9%	1,080	$2,080	$3,920	6
24	Lumber & Wood Products	16%	6.2%	18,220	$7,190	$23,100	4
26	Paper	33%	2.3%	3,510	$13,510	$10,070	16
28	Chemicals	30%	2.7%	3,000	$6,020	$9,030	8
30	Rubber and Plastics	14%	2.1%	1,520	$3,880	$6,220	7
33	Primary Metals	13%	4.1%	3,040	$5,310	$9,930	6
34	Fabricated Metals	16%	2.5%	1,460	$1,970	$4,740	5
35	Machinery and Equipment	13%	1.7%	550	$2,400	$2,200	13
36	Electronics	13%	0.9%	660	$1,960	$2,710	9
20-39	**Average Across Industries**	**21%**	**2.9%**	**2,630**	**$5,340**	**$7,260**	**9**

Source: DOE/IAC Database 1990-1996. Includes boiler operations, hardware, and maintenance.

As indicated in Table 2-3, the average savings across all industries (SIC 20-39) from measures such as steam trap replacement, leak repair, insulation, and improved operations was 2.1 percent of total facility energy use with an average simple payback of 6 months. At a fabricated metals plant (SIC 34), system efficiency measures might reduce total facility energy use by 3.0 percent. Steam system efficiency measures recommended in the DOE/IAC audits had the largest relative impact in the fabricated metals industry (SIC 34), but were most frequently recommended in the textile mill products industry (SIC 22).

Table 2-3 Sector-Specific Savings Estimates from Steam System Efficiency Measures in the IAC Database

SIC	Industry	Recommendation Rate (%)	Average Energy Savings (% of total facility energy use)	Average Energy Savings Annual (MMBtu)	Average Implementation Costs	Average Annual Cost Savings	Average Simple Payback (months)
20	Food	27%	1.7%	1,540	$2,600	$5,530	6
22	Textile Mill Products	32%	1.6%	2,480	$6,890	$7,940	10
23	Apparel & Textile Products	26%	1.7%	620	$990	$1,950	6
24	Lumber & Wood Products	15%	1.5%	3,930	$2,940	$5,480	6
26	Paper	25%	1.3%	2,220	$3,870	$8,020	6
28	Chemicals	26%	2.7%	7,170	$3,370	$13,550	3
30	Rubber and Plastics	10%	2.4%	1,850	$2,860	$9,190	4
34	Fabricated Metals	8%	3.0%	1,800	$2,610	$5,510	6
20-39	Average Across Industries	**14%**	**2.1%**	**2,420**	**$3,350**	**$7,120**	**6**

Source: DOE/IAC Database 1990-1996. Includes traps, condensate, leaks, insulation, and operations.

As indicated in Table 2-4, the average savings across all industries (SIC 20-39) from compressor operations, hardware and maintenance measures was 0.4 percent of total facility energy use with an average simple payback of 5 months. Compressed air system efficiency measures recommended in the DOE/IAC audits had the largest relative impact in the transportation equipment industry (SIC 37), but were most frequently recommended in the leather products industry (SIC 31).

Table 2-4 Sector-Specific Savings Estimates from Compressed Air Efficiency Measures in the IAC Database

SIC	Industry	Recommendation Rate (%)	Average Energy Savings (% of total facility energy use)	Average Energy Savings Annual (kWh)	Average Implementation Costs	Average Annual Cost Savings	Average Simple Payback (months)
20	Food	58%	0.3%	70,300	$1,240	$3,220	5
22	Textile Mill Products	69%	0.7%	208,000	$3,330	$7,980	5
23	Apparel and Textile Products	67%	0.5%	32,200	$500	$1,800	3
24	Lumber and Wood Products	71%	0.4%	181,700	$5,720	$8,240	8
25	Furniture and Fixtures	74%	0.7%	64,500	$1,300	$3,270	5
26	Paper	68%	0.3%	67,400	$1,270	$3,610	4
27	Printing and Publishing	66%	0.7%	61,500	$1,300	$3,440	5
28	Chemicals	60%	0.3%	93,800	$680	$4,220	2
30	Rubber and Plastics	65%	0.4%	79,100	$1,420	$4,300	4
31	Leather Products	87%	0.4%	46,900	$930	$3,680	3
32	Stone, Clay & Glass	70%	0.3%	237,300	$3,010	$9,220	4
33	Primary Metals	65%	0.6%	111,300	$3,400	$6,030	7
34	Fabricated Metals	75%	0.6%	73,300	$1,180	$4,300	3
35	Machinery and Equipment	72%	0.5%	55,700	$940	$3,080	4
36	Electronics	67%	0.6%	58,600	$1,370	$3,220	5
37	Transportation Equipment	77%	1.1%	99,600	$1,440	$5,100	3
38	Related Instrument Products	66%	0.6%	38,100	$690	$1,990	4
39	Misc. Manufacturing	69%	0.8%	46,900	$1,130	$2,620	5
20-39	**Average Across Industries**	**68%**	**0.4%**	**87,900**	**$1,680**	**$4,370**	**5**

Results from the DOE/IAC Database 1990-1996. Includes operations and hardware.

2.4 Detailed Wise Rules for Boilers, Steam, and Compressed Air

In addition to providing broad end-use energy savings information, the Technical Tool Kit provides information on very specific measures targeting these end uses. These allow partners to evaluate specific activities aimed at improving their major end uses. Detailed efficiency measures include boiler load management, steam line insulation, and compressed air leak repair.

These Wise Rules were developed from information sources including the DOE/IAC database, the Rutgers University Office of Industrial Productivity and Energy Assessment, the Association of Energy Engineers and the Bonneville Power Administration, the Energy Efficiency and Renewable Energy Clearinghouse/Network (EREC/EREN), the Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), and Climate Wise Partners' own estimates (see references at end). These data sources are quite comprehensive and may be new to many Climate Wise Partners. We have extracted core information from these materials to provide Climate Wise Partners with ready-to-use Wise Rules. Thorough references are included to direct Partners to the original sources for more detailed treatment of the issues.

In the following sections we present excerpts from the Technical Tool Kit for Boilers, Steam Systems, and Compressed Air Systems. These summaries include key Wise Rules and sample discussions.

2.4.1 Boilers

Boilers consume about one third of industrial energy use in the United States. There are many opportunities for improving boiler efficiency and reducing boiler energy use: boiler load management, burner replacement, proper instrumentation, tune-up and air/fuel ratio optimization, stack loss prevention, waste heat recovery, and blowdown control. Wise Rules on typical energy savings for each of these measures are summarized in Table 2-5. The table also includes sample fuel cost savings data for a natural gas boiler. These cost savings are presented on a normalized per MMBtu basis as discussed below.

Table 2-5 Summary of Energy and Cost Savings for Boiler Efficiency Measures from a Variety of Data Sources

Measure	Average Energy Savings (% of boiler energy use, unless noted)	Sample Data[a] Annual Fuel Cost Savings[b] (per MMBtu/hr of boiler capacity, unless noted)
BOILER LOAD MANAGEMENT		
Optimize boiler size and boiler load	2% to 50%	$230 to $5,750
Operate on high fire setting (may include installing smaller boilers)	7.6% of total facility energy use[c]	$19,900 (2 year payback) (total dollars, not on a per MMBtu/hr basis)[c]
BURNER REPLACEMENT		
Converting to Atomizing Burners	2% to 8%	$230 to $920
PROPER INSTRUMENTATION		
Improve Instrumentation	Up to 25%	Up to $2,900
TUNE-UP AND AIR/FUEL RATIO OPTIMIZATION		
Comprehensive Tune-Up	2% to 20%	$230 to $2,300
Decrease Flue Gas O_2 by 3%	2%	$230
Over Fire Draft Control	2% to 10%	$230 to $1,400
Characterizable Fuel Valve	2% to 12%	$230 to $1,400
Boiler maintenance (air/fuel ratio optimization, burner maintenance, boiler tube cleaning)	2.5% of total facility energy use[c]	$2,460 (5 month payback) (total dollars, not on a per MMBtu/hr basis)[c]
STACK LOSSES AND WASTE HEAT RECOVERY		
Reduce Stack Temperature by 40 °F	1% to 2%	$140 to $230
Stack Dampers	5% to 20%	$580 to $2,300
Direct Contact Condensation Heat Recovery	8% to 20%	$920 to $2,300
Removal of 1/32" to 1/8" Deposit From Heat Transfer Surfaces	2% to 8%	$230 to $920
Pre-Heating Combustion Air	2.8% of total facility energy use[c]	$5,200 (8 month payback) (total dollars, not on a per MMBtu/hr basis)[c]
BLOWDOWN CONTROL AND HEAT RECOVERY		
Blowdown Heat Recovery	2% to 5%	$230 to $580
Increase in Boiler Feed Water by 11° F	1%	$140
Automatic Blowdown Control	2% to 20%	$230 to $2,300

a) Based on a natural gas boiler with 80% efficiency, operating 5,000 hrs/yr, with a gas price of ≈$2.30/MMBtu.
b) Gross fuel savings only, does not include capital, maintenance or other costs (savings).
c) Energy savings are as a percent of total facility energy use. Cost savings are in dollars, not in dollars per MMBtu/hr of boiler size.

The Technical Tool Kit provides a brief overview of the efficiency measures considered. Following is a discussion of boiler tune-up and air/fuel ratio optimization measures and associated Wise Rules.

Boiler Tune-Up and Air/Fuel Ratio Optimization

Use the following instruments allows plant engineers to properly monitor and adjust boiler operating conditions: stack thermometers, fuel meters, make-up feed water meters, oxygen analyzers, run-time recorders, energy output metering (steam flow, Btu output), and return condensate thermometers.[3] Periodic measurement of flue gas oxygen, carbon monoxide, opacity, and temperature provides the fundamental data for a boiler tune-up. A typical tune-up might include a reduction of excess air (and excess oxygen, O_2), boiler tube cleaning, and re-calibration of boiler controls.

- *A good tune-up with precision testing equipment can detect and correct excess air losses, smoking, unburned fuel losses, sooting, and high stack temperatures, and result in boiler fuel savings of 2% to 20%.*[4]

Each fuel type and firing method has an optimal air/fuel ratio. For example, optimum excess air for a pulverized coal boiler is 15 - 20% (3 - 3.5% excess O_2), and optimum excess air for a forced draft gas boiler is 5 - 10% (1 - 2% excess O_2).[5] The air/fuel ratio should be adjusted 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.[6] Manual or automatic oxygen trim can insure that the proper air/fuel mixture ratio is maintained.[7]

- *A 3% decrease in flue gas O_2 typically produces a 2% increase in boiler efficiency.*[8]
- *Using over fire draft control systems to control excess air can result in boiler fuel savings ranging from 2% to 10% (with typical equipment costs around $1,500).*[9]

When boilers are operating at low loads excess-air requirements may be greater than the optimal levels and efficiency may be lower.[10]

- *Using a characterizable fuel valve to match the air/fuel ratios across the load range can lead to fuel savings ranging from 2% to 12% at low cost.*[11]

The Wise Rules also include DOE/IAC data on specific efficiency measures. For example, air/fuel ratio optimization was recommended at 16 percent of facilities audited. The average energy savings across all industry sectors was 2,100 MMBtu or 2.4 percent of annual facility energy use. The average implementation cost for these measures was $5,600 with a simple payback period of three months.

For most of the measures in Table 2-5, the cost savings can be scaled to different boiler sizes. For example, for a 10 MMBtu/hr natural gas boiler, simply multiply the cost savings in Table 2-5 by ten. The cost savings from high-fire boiler operation and boiler maintenance are from IAC data base and expressed in dollars, <u>not</u> in dollars per MMBtu/hr of boiler size. The savings numbers in Table 2-5 can also be adjusted on the basis of fuel prices and operating hours.

2.4.2 Steam Systems

Steam system efficiency improvements are a logical complement to boiler efficiency measures. Useful energy is lost in steam systems from steam leaks, malfunctioning steam traps, and poorly insulated pipes and components. Each of these areas presents opportunities for energy savings.

In addition to broad measures of steam system energy efficiency potential, energy and cost savings the Tool Kit presents Wise Rules for specific steam system actions including: steam trap maintenance, repairing steam leaks, insulation, condensate measures, and vapor recompression. Wise Rules on typical energy savings for each of these measures are presented below and summarized in Table 2-6.

Table 2-6 Summary of Energy and Cost Savings for Steam System Efficiency Measures from a Variety of Data Sources

Measure	Average Energy Savings	Average Annual Cost Savings
STEAM TRAP MAINTENANCE		
Repair or replace steam traps	3.8% of facility energy use	$18,300 (2 mo. payback)*
LEAK REPAIR		
Repair high pressure (125 psi) leaks		$660 - $2,200 per leak
Repair low pressure (15 psi) leaks		$130 - $480 per leak
Repairing steam leaks	0.9% of facility energy use	$6,050 (3 mo. payback)*
IMPROVED INSULATION		
Insulate steam pipes		$1,600 - $2,300 per 100 ft
" " "	1.0% of facility energy use	$2,900 (10 mo. payback)*
VAPOR RECOMPRESSION		
Recompression of vented steam	90-95% of energy needed to raise the steam in a boiler	
CONDENSATE MEASURES		
Increase condensate return, insulation	3.8% of facility energy use	$18,277 (2 month payback)*

* Average facility savings.

The Technical Tool Kit provides a brief overview of the efficiency measures considered. Following is a discussion of steam leak repair and insulation measures and associated Wise Rules.

<u>Repairing Steam Leaks</u>
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 make-up water is cooler than condensate return water and more energy is required to heat the boiler feedwater. Savings will depend on factors such as boiler efficiency, annual operating hours, and boiler pressure.[12]

- *The cost of high pressure steam leaks (125 psi) can range from $660 to $2,200 per leak per year (8,760 hrs). The cost of low pressure steam leaks (15 psi) can range from $130 to $480 per leak per year (8,760 hrs).*[13]

Steam leak repair was recommended at two percent of the DOE/IAC facilities audited. The average energy savings across all industry sectors was 2,200 MMBtu or 0.9 percent of annual facility energy use. The average implementation cost for these measures was $6,100 with a simple payback period of three months.

<u>Improved Insulation</u>
Often insulation is removed to make repairs and is not replaced. Uninsulated surfaces in boiler and steam systems can reach 450 °F. These high temperatures can threaten employee safety and can be fire hazards.

Table 2-7 Annual Costs of Heat Loss per 100 feet of Uninsulated Steam Pipe[14]

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

2.4.3 Compressed Air Systems

Compressed air is used to power tools and machines, to regulate HVAC systems, and for drying or cleaning various items. The two main types 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 mechanism.[15]

We have identified several compressed air system efficiency measures that may be of interest to Climate Wise partners: use of outside air for intakes, load optimization, pressure reduction, eliminate or reduce air use, leak repair, waste heat recovery, filter replacement, and cooler cleaning. Wise Rules on typical energy savings for each of these measures are presented below and summarized in Table 2-8. While the savings rate as a percent of total facility energy use is modest relative to other some measures savings, the cost savings can be significant because air compressors are generally driven by electricity.

Table 2-8 Summary of Energy and Cost Savings for Compressed Air Efficiency Measures from a Variety of Data Sources

Measure	Average Energy Savings (% of compressed air system energy use, unless noted)	Average Annual Cost Savings
ALL EFFICIENCY IMPROVEMENTS		
(Includes all measures below)	20% to 50%	
OUTSIDE AIR		
Use outside air for intakes	1% per 5 °F reduction	less than 2 years
Cooler air intake	0.2% of facility energy use	$1,400 (5 mo. payback)
LOAD OPTIMIZATION		
Install or adjust unloading controls	10%	
Upgrade screw compressor controls	1.0% of facility energy use	$8,950 (10 mo. payback)
REDUCE COMPRESSOR AIR PRESSURE		
Reduce compressor pressure	1% per 2 psi reduction	
	0.4% of facility energy use	$2,900 (4 mo. payback)
ELIMINATE /REDUCE COMPRESSED AIR USE		
Eliminate/reduce some uses of air	0.6% of facility energy use	$7,050 (6 mo. payback)
ELIMINATE AIR LEAKS		
Repair air leaks	30% or more	
" " "	0.4% of facility energy use	$4,000 (3 mo. payback)
Repair 1/16" leak (115 psi)	7,561 kWh per leak per yr	$362/yr
Repair 1/8" leak (115 psi)	30,687 kWh per leak per yr	$1,472/yr
WASTE HEAT RECOVERY		
Recover waste heat from compressors	1.8% of facility energy use	$2,700 (10 mo. payback)
Recover heat from cooling water to heat boiler feedwater	1% per 11°F	
FILTERS AND COOLERS		
Change dryer filters at 8-10 psi drop	4-5%	
Clean intercoolers	1% per 11°F improvement	

Eliminate Air Leaks

Compressed air distribution system leaks along piping, around valves, fittings, flanges, hoses, traps, and filters can result in significant energy costs in manufacturing facilities. Typical leakage rates range from 2% to 20% of system capacity. In poorly maintained systems, leakage can be as high as 40%.[16] When equipment is not running but the system is pressurized (lunch break, after hours) leaks can be located by listening. Where you suspect a slow leak use a soapy water solution or an ultrasonic detector to pinpoint leaks.[17] 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.

- *Repairing air leaks can reduce compressed air system energy use by 30% or more.*[18]

The cost of compressed air leaks increases exponentially as the size of the hole increases.

Table 2-9 Energy and Cost Losses Due to Compressed Air Leaks (115 psi)[19]

Hole Diameter	Leak Rate (ft^3/min)	Energy Loss/yr (kWh)*	Cost of Wasted Energy/yr
1/64"	0.4	440	$22
1/32"	1.3	1,780	$85
1/16"	5.0	7,560	$360
1/8"	20.3	30,690	$1,470
1/4"	81.1	121,860	$5,850
3/8"	182.4	274,400	$13,200

* Based on 8,520 hours of compressor operation.

Compressed air leak repair measures were recommended at 36 percent of the DOE/IAC facilities audited. The average energy savings across all industry sectors was 82,000 kWh or 0.4 percent of annual facility energy use. The average implementation cost for these measures was $4,100 with a simple payback period of three months.

2.5 Additional Comments on the Use of Wise Rules

Wise Rules can be powerful tools for estimating the impacts of energy efficiency measures. One of the primary strengths of the Climate Wise Technical Tool Kit is that it offers a brief summary of a broad number of data sources. It is important, however, to recognize that Wise Rules do have some limitations and they should be applied prudently. Below we list key caveats to consider when applying Wise Rules.

- The Wise Rules are typical values based on averages and general engineering analyses. Wise Rules do not take the place of detailed engineering analysis based on site-specific data and operating parameters. Be sure to consider your company's unique circumstances when applying Wise Rules.
- Exercise caution when using two or more Wise Rules for the same or related end uses—the total energy savings from completing two measures may be less than the sum of the two measures' individual impacts. In addition, it may not make sense to implement certain efficiency measures together for technical or economic reasons.
- The savings numbers in the IAC database are based on auditors' engineering estimates and not on measured results.
- The energy and cost savings estimates from the IAC database are averages across industry groups, across several years and across many parts of the country. Individual measured savings will vary depending on each company's specific characteristics.

3. CALCULATING CO_2 EMISSIONS REDUCTIONS

By joining Climate Wise, Partners make a commitment to reduce their greenhouse gas emissions. Therefore, it is important that Partners estimate the impact of their energy efficiency actions on greenhouse gas emissions. Calculating carbon dioxide (CO_2) emissions savings from energy efficiency projects is simple. Energy savings in MMBtu is multiplied by a CO_2 emissions coefficient expressed in pounds per MMBtu. CO_2 emissions factors for common primary fuels are presented in Table 3-1. If an efficiency project saves 1,000 MMBtu of natural gas CO_2 emissions will be reduced 1,171 pounds. Savings 1,000 MMBtu of subbituminous coal will result in even greater CO_2 savings, 2,127 pounds. These values can be easily converted to short tons or metric tons of CO_2 or carbon.

Table 3-1 CO_2 Emission Coefficients for Selected Fuels[20]

Fuel	Emission Coefficients	
	Pounds CO_2, per Unit Volume or Mass	Pounds CO_2 per Million Btu
Distillate Fuel	22.4 per gallon	161.4
Motor Gasoline	19.6 per gallon	157.0
Residual Fuel	26.0 per gallon	173.9
Natural Gas	120.6 per 1000 ft^3	117.1
Bituminous Coal	4,921.9 per ton	205.3
Subbituminous Coal	3,724.0 per ton	212.7

CO_2 emissions from electricity depend on the fuel type used to generate the electricity, Table 3-2. Partners may not know their utility company's fuel mix. The DOE provides default values based on state averages. These rates reflect the average mix of fuels used in the state and the average efficiency of the generating equipment. A company in Florida that reduces its electricity use by 10,000 kWh will reduce its CO_2 emissions by 12,940 lbs (6.47 tons or 5.87 tonnes).

Table 3-2 Electricity CO_2 Emission Factors for Selected States[21]

State	CO_2 Emission Factors		
	lbs/kWh	short tons/MWh	metric tons/MWh
California	0.756	0.378	0.343
Colorado	2.001	1.000	0.908
Florida	1.294	0.647	0.587
Illinois	0.866	0.433	0.393
Massachusetts	1.459	0.729	0.662
New York	0.774	0.387	0.351
Ohio	1.807	0.904	0.820
Texas	1.552	0.776	0.704

4. CONCLUSIONS

These Wise Rules provide industrial companies with order-of-magnitude estimates of the savings available from a broad class of industrial efficiency measures. This paper presents a sample of the information in the Climate Wise Technical Tool Kit. We welcome your comments on industrial energy efficiency savings rules in general, or on these Wise Rules in specific. Please call the Climate Wise *Wise Line* at 1-800-459-WISE or send e-mail to WiseLine@ICFKaiser.com.

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[20] DOE/EIA, 1996, Appendix B.

[21] DOE/EIA, 1996, Appendix C.