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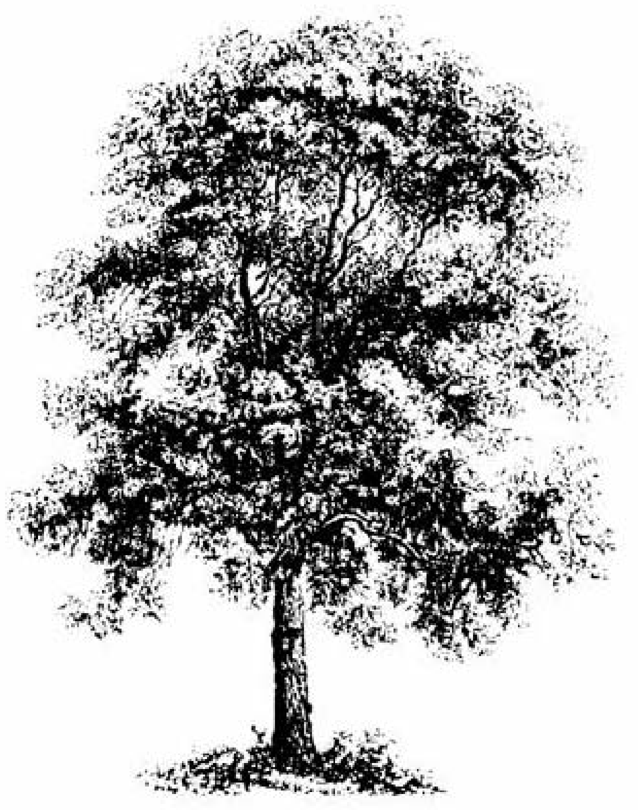

Essentials of Industrial Assessments

A Training Manual

Version 3.0

Sponsored by:

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Preface to the First Edition

The assessment of energy consumption practices and conservation opportunities for industrial clients has always been tied to the cost of energy resources. Beginning with the oil embargo in the seventies, interest in efficient running of industrial operations has risen with manufacturing cost to the point where the current study of resource use has broadened into the waste minimization / pollution prevention and productivity arenas. The old energy audit allowed directly focused insight into energy applications while the new industrial assessment includes all industrial methodologies at the local manufacturing plant. The energy auditor now finds skills sharpened for the energy side of the business inadequate for the entire process although intuitive observations from energy auditors, which have led to excursions into industrial assessment recommendations in the past, make the transition from energy auditing to industrial assessing a logical and natural one. Precisely that which previously made the energy audit worth the initial investment by the manufacturing concern now makes the full industrial assessment attractive.

But what exactly makes the industrial assessment pay for the client? Analysis of the assessment client's satisfaction indicates several reasons. First, fresh "eyes" and insights into operations commonplace to management commonly bring questionable but normal practice into question. Assessors bring a high degree of sophistication into the manufacturing plant, recommendations are based on firm engineering background after questioning the client as to needs and concerns and precise measurement of existing conditions. Implementation costs are economically analyzed against savings for complete impact projections then explained to management in plain, common language. Finally, the industrial assessor takes pride in the work bringing strong desire to see the plant implement and adopt concepts and ideas presented in the assessment report.

Essentials of Industrial Assessments: A Training Manual, grew from the desires of the United States Department of Energy's Office of Industrial Technology and the United States Environmental Protection Agency's Risk Reduction Engineering Laboratory to consolidate into a single tome information about industrial assessments presently located in the public domain. This information derived principally from industrial energy conservation and waste minimization / pollution prevention training courses and information agencies sponsored by the Federal Government and to a lesser extent State sponsored research and training material.

This single sourcing of scattered instructions allowed for collapse of many differing ideas of what exactly an industrial assessment may cover. Meshing thought processes and works from multiple backgrounds and disciplines proved to be monumental in its complexities. This first edition therefore represents the "first pass" at the task. Gathering public domain material, arranging the work in a coherent fashion, and indexing the final document took the better part of a year. This investment of time and effort has yielded a compiled product representative of a firm foundation in industrial assessment.

Essentials of Industrial Assessments: A Training Manual leads the professional though the assessment proves form client selection and assessment methodology to client reporting. In between, there ensues an explanation of energy form definitions to production then transportation, consumption by systems and finally conservation recommendations. Analysis of waste follows with the study of material waste types, generation, and reduction practices along with pollution prevention background. Preparation of the industrial assessor would be incomplete if not sprinkled liberally with the requisite tools and while energy measurement devices do not transmit well over the internet, what does are numerous examples of time-tested recommendations and the insight of years of experience.

Essentials of Industrial Assessments: A Training Manual portends to be different from other, similar works in a few ways: energy and waste assessments combined into the industrial assessment, indexing of the manual for easy reference, but most of all its changeability and availability. As the Internet and World Wide Web have flourished in recent years, so has the ability to transfer documents from computer to computer, State to State, or even Country to Country almost instantly and at a fraction of the cost of printing and distributing. *Essentials of Industrial Assessments: A Training Manual* will be published for public consumption on World Wide Web at the address **http://oipea-www.rutgers.edu**. Some copies undoubtedly will be printed and mailed though traditional means; however, unless the reader has access to the Internet, the most unique feature of *Essentials of Industrial Assessments: A Training Manual* will be foregone.

To what the World Wide Webmaster will identify as instantaneous access to continuous updating, the “lining document” was born and is alive and well and living in cyberspace. The living document has no singular form, thus living documents are subject to change. Living documents do not sit on the shelf fathering dust, the living document is erased as soon as current usage dictates or the reader)or listener) finishes as electronic documents from the “cyber press” download easily for temporary storage on local computer systems for performance via an audio interpreter for the hearing impaired. When the need arises, the industrial assessor or the other interested party can access the web site and fetch the latest version of the document for a fresh examination. Living documents cannot perish – they only get better with age.

Of final note, this first edition of *Essentials of Industrial Assessments: A Training Manual* will be followed shortly by the second edition. It is gratifying to note that while those responsible for compiling this work realize the need to get the manual into he eager hands of industrial assessors they do not feel comfortable about the readability and up-to-the-minute nature of this 300+ page document. Some chapters are slated for updating while others will be fleshed out with summary thoughts explored and expanded. Industrial assessment technology will be re-examined for state of the art forms the subsequent and future editions. Productivity enhancements loom largely as the next area of concentration for this manual and certainly will merit a full section in the next volume. Future editions will be brought online immediately upon completion of even minor revisions. Industrial assessors can query the experts on any topic relating to resource conservation by sending email to **oipea@camp.rutgers.edu** as the message will be addressed to OIPEA staff and forwarded to the list moderator for attention. We encourage participation in this open forum.

We at OIPEA gratefully acknowledge our sponsors: The Industrial Assessment Center Program Manager Charles Glaser and Marsha Quinn at DOE's Office of Industrial Technology, and Emma Lou George at EPA's Pollution Research Branch for their support, patience and understanding as we "tried to do it right". We also thank all those who have made this work possible through their contributions to Essentials of Industrial Assessments, particularly Dr. Richard Jendrucko of the University of Tennessee, Dr. Byron Winn of Colorado State University and all the Directors, Assistant Directors and students of the current and previous Industrial Assessment Centers. Finally, Ted Hones, Mark Hopkins, and the others at the Alliance To Save Energy deserve praise for their untiring efforts to promote industrial assessments and the education and support of the frontline industrial assessors.

Disclaimer

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Table of Contents

1 INTRODUCTION

Modern Industrial Assessments: A Training Manual represents the effort made by the United States' Department of Energy to provide technical training to a range of potential end users interested in performing industrial assessments at small to medium-sized manufacturing plants and the effort of course instructor's to provide the best training methods and materials to these industrial assessors. Industrial assessments, as discussed in this manual, refer to detailed reviews of existing operations with an eye to improving productivity in any of a number of ways.

In this fashion the focus of this manual becomes "re-engineering", the currently popular buzzword interpreted as meaning increased efficiency in the use of resources and just as the industrial assessor seeks to re-engineer a client's manufacturing processes, this manual increases the efficiency of the assessment instructor by combining materials produced over decades in an attempt to organize, assemble and index the collection. Although some of the material and most of the organization methodologies were produced from scratch or updated from existing sources, much of the manual's content was assembled utilizing the work of other professionals in the assessment field and to those who have come before us, we gratefully acknowledge their contributions to this work. In particular, we wish to acknowledge the work of Professor Jendrucko at the University of Tennessee and his staff along with Professor Byron Winn of Colorado State University for contributing much to this document. The Preface to the First Edition introduced this manual as a living document and all engineering libraries contain many references to money saving industrial techniques already out of date as the "latest" book goes to press. Certainly many the ideas contained within this manual will stand the test of time, but when desirable, the structure allows continuous updating.

This section focuses on industrial energy use. As shown in the figure below, industrial sector energy needs accounts for more than 36% of national consumption at a cost of $99.7 billion in 1991. According to the Alliance To Save Energy, the energy savings potential resulting from increased energy efficiency has been estimated at 11-13% over the next two decades and this manual should be used as a tool in the battle for energy efficiency. Source: Energy Information Administration Annual Energy Review 1993

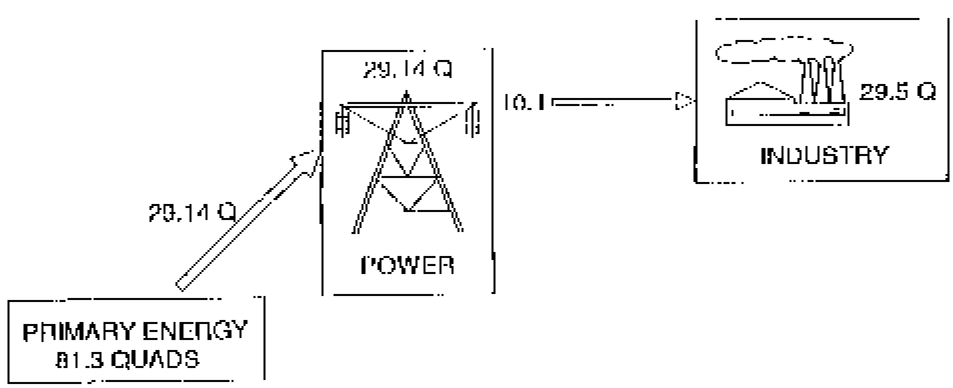


Figure 1.1: US Energy Use

1.1. ENERGY

All nations, particularly those with a strong industrial base, transform energy of one form into another for the benefit of Society. Thus a shared governmental enterprise that spends money wisely while improving the efficiency and minimizing the environmental impact of energy transformation is a simple goal perhaps, but not one without inherent difficulties. Limited resources such as oil reserves or coal deposits illustrate an obvious obstacle overcome chiefly through importation mechanisms but influenced directly by strategic resource allocation requirements. Luckily, not all activities, even essentials such as illumination, require the same amount of energy and different opportunities for resource conservation exist both in the type of energy usage and the industries in which usage occurs. The following pictures from the U.S. Dept. of Energy's Energy Information Agency show a typical profile of energy usage for different activities within buildings and the energy intensity of various industries.

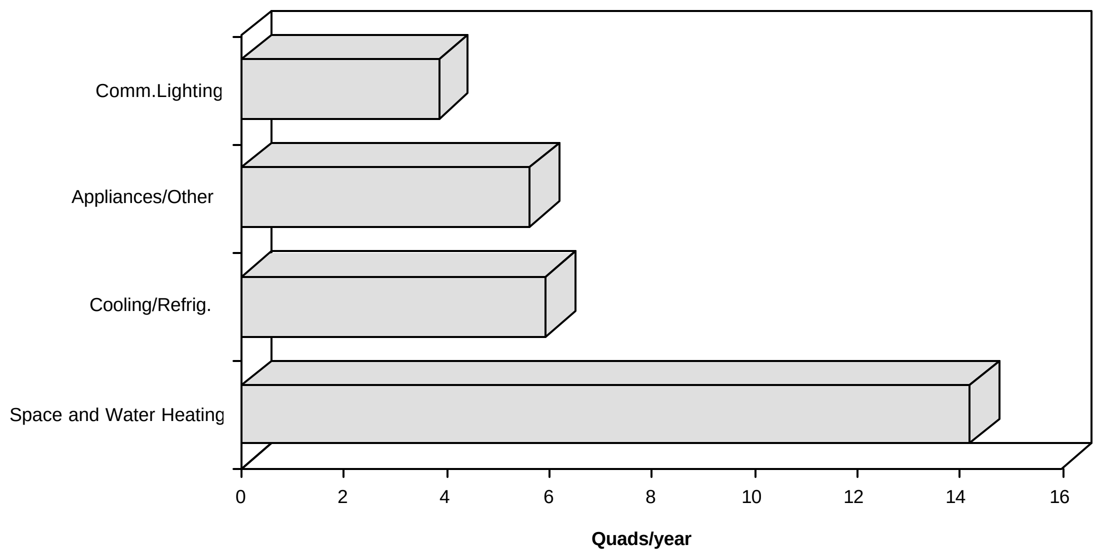


Figure 1.2: Building Energy Use

From these generalities the greatest opportunities for energy conservation occur in the chemical and primary metals industries. Assessments of the energy usage in such plants with recommendations for conservation together constitute one valid strategy for demand-side energy management (DSM). Cutting usage by the consumer decreases the demand on the energy providers as their consumer base increases. Thus, aggressive utility DSM programs may abrogate the need for creation of new power generation plants. Energy conservation on the facility scale translates directly to resource preservation and decreased environmental stress on the larger scale. With the forthcoming deregulation of energy providers, demand side services will become increasingly more important as consumers shop for value added services accompanied by competitive pricing in the energy markets.

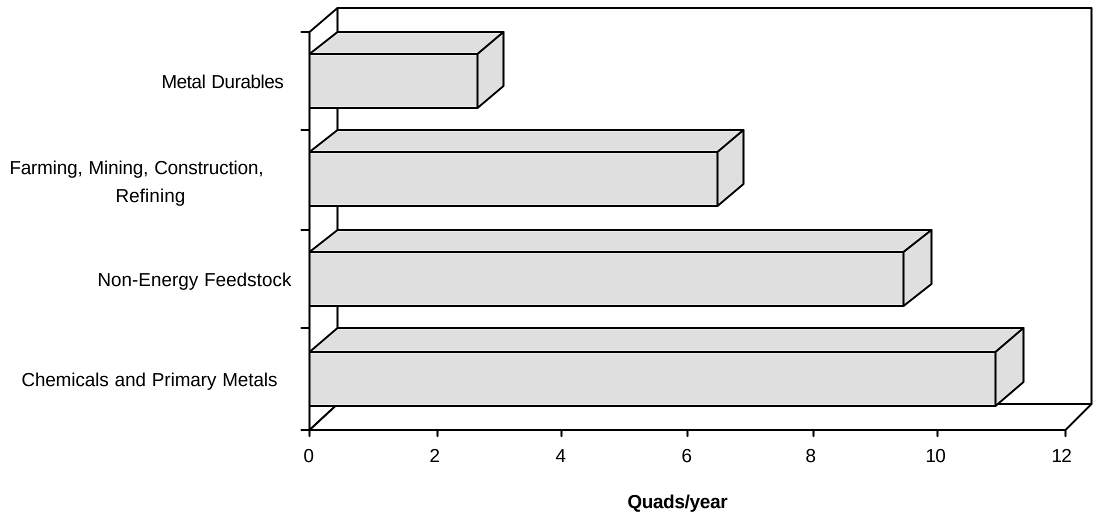


Figure 1.3: Industrial Energy Use

Energy conservation, waste minimization, pollution prevention and productivity enhancement all represent areas investigated during the industrial assessment. Energy conservation strategy research and development since the oil embargo years has enriched the possibilities of use reduction methodology's application to the small and medium sized industrial manufacturer. The Figure 1.4:"Load Shape Changes" on page 4 from Clark W. Gellings presentation to the EEI shows examples of typical load variations resulting from some conservation strategies. An extension of this approach follows the graphic keys with descriptions of a variety of systems typically employed in most of today's manufacturing plants. As can be seen, in some cases more than one approach is available and in the case of demand controls and heat pumps three load shape changes apply. The following and last page of Gellings' summary shows some expected simple payback periods. Paybacks are derived from division of the money saved annually after implementing the recommendation by its associated implementation cost. An important piece of information, presentation of the payback to the assessed industrial client becomes an essential stratagem used in gaining project approval. The role of payback in industrial decision making by small to medium sized manufacturers for whom the window of competitive opportunity is quite small cannot be over-emphasized. The industrial assessor must sell the manufacturer on the recommendation's possibilities before short-term profits can be routed into operational budgets.

The following abbreviations are used in the summary:

PC - peak clipping
VF - valley filling
LS - load shifting
SC - strategic conservation
SG - strategic growth
FLS - flexible load shape

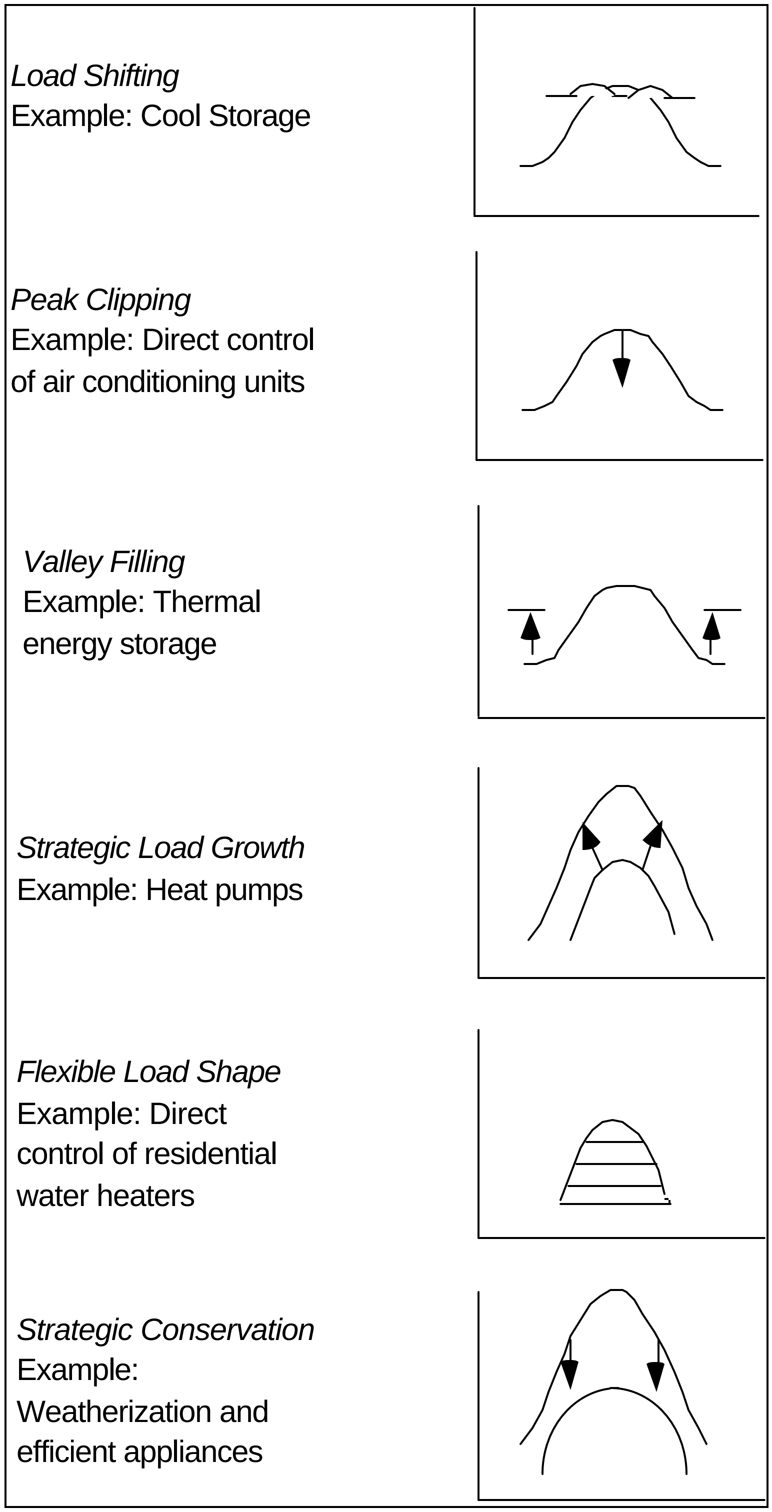


Figure 1.4: Load Shape Changes

Demand-Side Management Strategies:
Industrial Measures

	PC	VF	LS	SC	SG	FLS
Cooling Systems						
1. Condenser Water Temperature Reset				x		
2. Chilled Water Supply Temperature Reset				x		
3. Hot-Gas Defrost				x		
4. Two-Speed Motors on Cooling Tower Fan				x		
Heating Systems						
5. Destratification Fans				x		
6. Comfort Radiant Heating Systems				x		
7. Process Radiant Heating Systems				x		
8. Quartz Radiant Heating Systems				x		
Boilers						
9. Combustion Air Blowers Variable Frequency Drives	x					
10. Air/Fuel Ratio Reset				x		
11. Turbulators				x		
12. High-Pressure Condensate Return System				x		
13. Steam Trap Repair				x		
14. Steam Leak Repair				x		
Air Compressors						
15. Outside Air Usage	x			x		
16. Leakage Reduction	x			x		
17. Cooling Water Heat Recovery				x		
18. Waste Heat Recovery				x		
19. Pressure Reduction	x			x		
20. Screw Compressor Controls				x		
21. Compressor Replacement	x			x		
22. Low-Pressure Blowers	x			x		

	PC	VF	LS	SC	SG	FLS
Insulation						
23. Steam Leaks and Hot Water Pipes				x		
24. Chilled Water Pipes				x		
25. Hot Tanks				x		
26. Cold Tanks				x		
27. Injection Mold Barrels				x		
28. Dock Doors				x		
Industrial Process Heat Recovery						
29. Industrial Process Heat Exchangers	x			x		
30. Waste Heat Recovery Boilers	x			x		
31. Cogeneration	x	x				
32. Industrial Process Heat Pumps		x	x	x		
Solar Energy						
33. Solar Industrial Process Heating	x			x		
34. Once-Through Solar Heated Ventilation and Process Air				x		
35. Solar Photocatalytic Water Detoxification				x		
Electric Use Shifting and Controls						
36. Demand Controls	x	x	x			
37. Interruptible and Curtailable Service	x					x
38. Power Factor	x					

PC = peak clipping; VF = valley filling; LS = load shifting; SC = strategic conservation; SG = strategic growth; FLS = flexible load shape

Paybacks[1] for Demand-Side Management Strategies: Industrial Measures

	<2	2-5	6-10	>10
Cooling Systems				
1. Condenser Water Temperature Reset	x			
2. Chilled Water Supply Temperature Reset	x			
3. Hot-Gas Defrost		x		
4. Two-Speed Motors on Cooling Tower Fan	x			
Heating Systems				
5. Destratification Fans	x			
6. Comfort Radiant Heating Systems	x			
7. Process Radiant Heating Systems	x			
8. Quartz Radiant Heating Systems		x		
Boilers				
9. Combustion Air Blowers Variable Frequency Drives		x		
10. Air/Fuel Ratio Reset	x			
11. Turbulators	x			
12. High-Pressure Condensate Return System		x		
13. Steam Trap Repair	x			
14. Steam Leak Repair	x			
Air Compressors				
15. Outside Air Usage	x			
16. Leakage Reduction	x			
17. Cooling Water Heat Recovery	x			
18. Waste Heat Recovery	x			
19. Pressure Reduction	x			
20. Screw Compressor Controls	x			
21. Compressor Replacement	x			
22. Low-Pressure Blowers	x			
Insulation				
23. Steam Leaks and Hot Water Pipes	x			

	<2	2-5	6-10	>10
24. Chilled Water Pipes	x			
25. Hot Tanks	x			
26. Cold Tanks	x			
27. Injection Mold Barrels	x			
28. Dock Doors	x			
Industrial Process Heat Recovery				
29. Industrial Process Heat Exchangers		x		
30. Waste Heat Recovery Boilers				x
31. Cogeneration		x		
32. Industrial Process Heat Pumps	x	x		
Solar Energy				
33. Solar Industrial Process Heating		x	x	x
34. Once-Through Solar Heated Ventilation and Process Air		x		
35. Solar Photocatalytic Water Detoxification		x	x	x
Electric Use Shifting and Controls				
36. Demand Controls		x		

PC = peak clipping; VF = valley filling; LS = load shifting; SC = strategic conservation; SG = strategic growth; FLS = flexible load shape

1 Paybacks will vary based on climate, fuel costs, system characteristics, implementation cost by geographical area, and other factors.

x - The payback falls in the category indicated

Industrial assessments such as those practiced by the universities participating in the U.S. Department of Energy's Industrial Assessment Center Program typically begin long before the facility is visited by representatives of the Center. Compiled from over 8,000 assessments and containing and 57,000 recommendations, the IAC program data base is available to public and may be accessed via the internet's World Wide Web (W3) at the address or uniform resource locator (URL) http://oipea-www.rutgers.edu, downloaded to any computer and analyzed with any data base program recognizing files with a .dbf extension.

Relational form from assessments to recommendations in a one to many manner, study of manufacturing environments through the data base allows assessment of previous recommendations: typical and innovative ideas, dollar savings, energy and resource conservation, implementation likelihood.

Average cost savings broken down by recommendation type provides a good representation of the potential before on site evaluation. Expressed in this case averaged over the entire data set, this can be further broken down (in most cases) by four-digit standard industrial code as a pre-assessment tool.

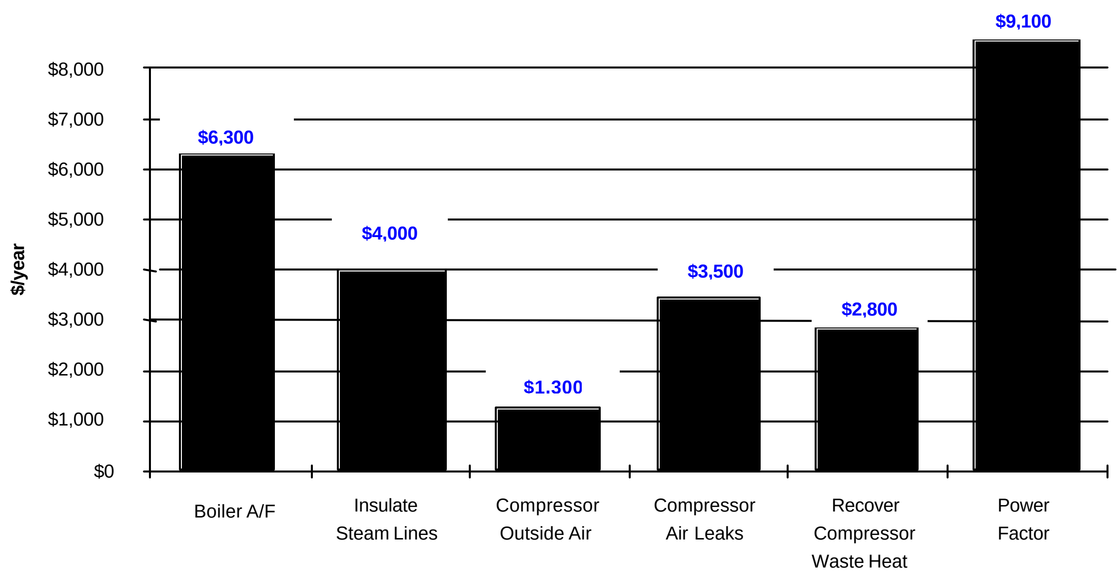


Figure 1.5: Average Cost Savings for IAC Recommendations – 1

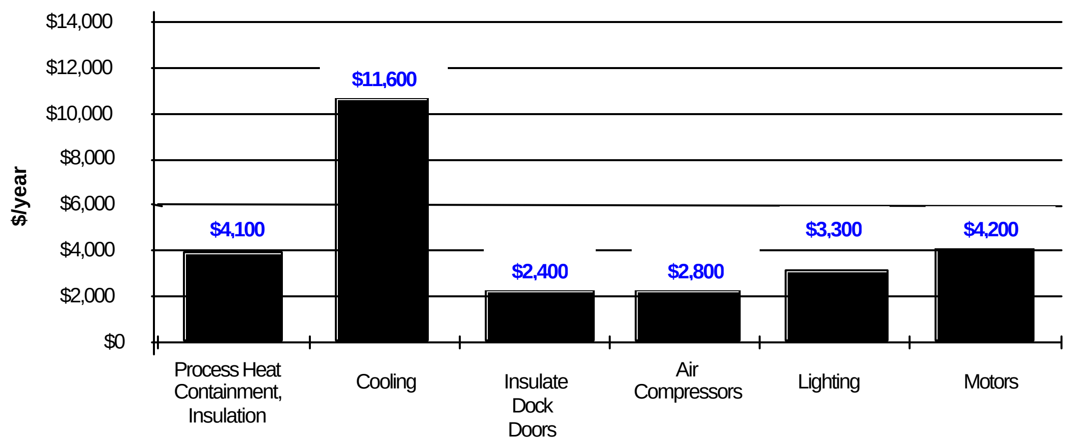


Figure 1.6: Average Cost Savings for IAC Recommendations – 2

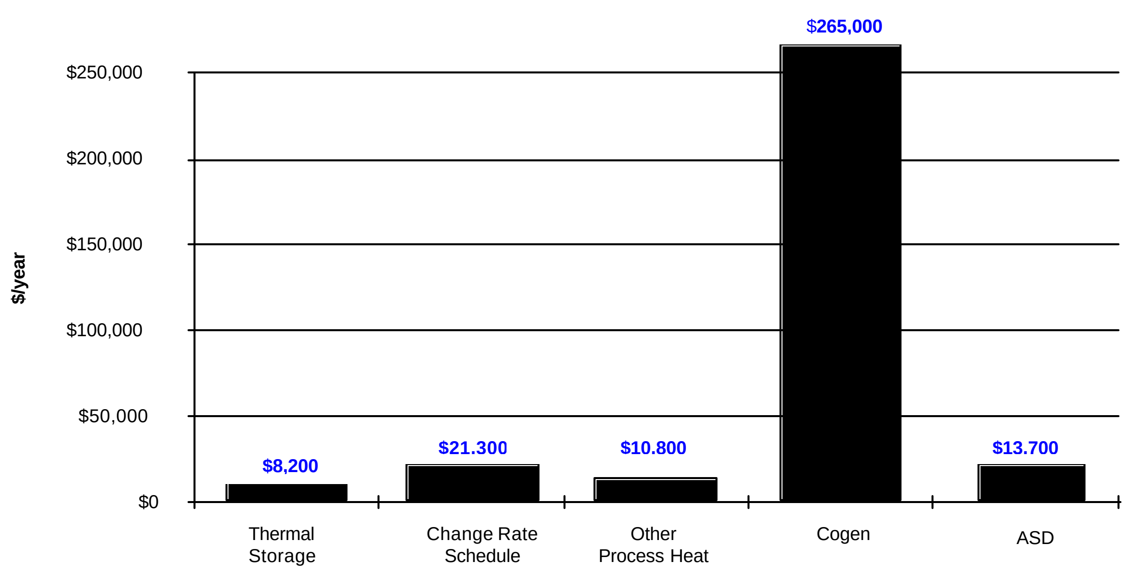


Figure 1.7: Average Cost Savings for IAC Recommendations – 3

1.1.1. Building Energy Summary

When comparing an industrial plant to an office building the common denominator found relates to certain energy costs. Each facility must provide working conditions for the people inside the buildings adequate for the intended product output including heating and/or cooling of the inside air and providing light. However, manufacturing plants incur other energy demands concerning equipment not typically operated in the office environment - motors, conveyor systems, compressors, chillers, ovens and other production components.

On the other hand, the office operates some devices like telecommunication equipment, computers, printers and monitors which although not unique to support functions such as information transfer and data tracking and increasingly located on the manufacturing floor connected to the production line or robotic applications, are found in such quantity as to be a major contributor to the commercial energy demand. The following building summary gives some flavor of what typical annual energy demands for electricity and gas small to medium sized manufacturers' require.

Overall Annual Energy & Cost Summary:
Total Energy - 20,132.4 MMBtu/yr
Total Cost - 349,135.34 $/yr

ELECTRICAL SUMMARY

Month	Energy Usage (kWh)	Energy Charge ($)	Peak Demand (kW)	Demand Cost ($)	Other Costs ($)	Reactive Cost ($)	Total Elect. Cost ($)	Unit Elect. Cost ($/kWh)
Jan	250000	19185.42	584.0	7965.82	215.13	110.15	27476.52	0.078
Feb	254400	19495.87	556.4	7595.74	214.97	116.98	27423.56	0.077
Mar	246800	18979.84	552.8	7530.38	213.21	111.22	26834.65	0.077
Apr	247600	16077.64	551.6	4245.78	194.66	113.77	20631.85	0.065
May	275600	17937.39	590.8	4617.85	201.35	114.30	22870.89	0.065
Jun	313600	20365.63	633.6	4905.38	209.51	116.58	25597.10	0.065
Jul	324800	21582.86	620.0	4919.60	216.13	112.84	26831.43	0.066
Aug	316000	21050.37	620.8	4946.63	214.93	116.75	26328.68	0.067
Sep	273200	17943.95	594.0	4632.62	201.60	108.94	22887.11	0.066
Oct	260000	17058.38	574.0	4468.58	198.46	110.82	21836.24	0.066
Nov	266800	17440.93	580.8	4466.06	199.60	112.29	22218.88	0.065
Dec	237600	18308.30	581.6	7860.44	212.19	108.54	26489.47	0.077

NATURAL GAS SUMMARY

Month	Energy Usage (CCF)	Energy Usage (MMBtu)	Total Cost ($)	Unit Cost ($/MCF)
Jan	10543	906.7	4979	4.72
Feb	8116	698.0	3838	4.73
Mar	1444	124.2	700	4.85
Apr	756	65.0	376	4.97
May	791	68.0	393	4.97
Jun	558	48.0	283	5.07
Jul	816	70.2	404	4.95
Aug	2615	224.9	1251	4.78
Sep	7540	648.4	3567	4.73
Oct	12877	1107.4	6076	4.72

Nov	18244	1569.0	8588	4.71
Dec	19807	1703.4	9466	4.78

Gas Quality - 860 Btu/cf

FUEL OIL SUMMARY

Month	Usage (gallons)	Usage (MMBtu)	Cost ($)	Unit Cost ($/gal)	Tax ($)
Jan	5878	829	3804.35	0.65	11.38
Feb	3024	426	1910.83	0.63	5.72
Ma	-	-	-	-	-
Apr	-	-	-	-	-
May	-	-	-	-	-
Jun	-	-	-	-	-
Jul	-	-	-	-	-
Aug	-	-	-	-	-
Sep	-	-	-	-	-
Oct	-	-	-	-	-
Nov	3515	496	2227.86	0.63	6.66
Dec	-	-	-	-	-

Rate Summary

Prior to visiting a manufacturing facility for assessment purposes information obtained by the assessor becomes a springboard in the determination of possible conservation recommendations. The energy bills yield information that when analyzed may provide recommendations before the visit such as energy demand rescheduling, avoidance of late payment penalties, and energy ratcheting errors. Information obtained from utility billing includes (with examples):

Electrical Rate Data:
Total Energy Usage - 3,266,400 (kWh)
Total Energy Usage - 11,148,2 (MMBtu)
Total Reactive Charge - $1,353.18
Total Electricity Cost - $297,426.38
Total Other Cost - $2,491.74

Natural Gas Rate Data:
Total Energy Usage - 84107 (CCF)
Total Energy Usage - 7233.2 (MMBtu)
Usage Cost - $39921.00

Fuel Oil:
Total Energy Usage - 12,417 (gal)
Total Energy Usage - 1,751 (MMBtu)
Usage Cost - $7,943.04

Average Costs:
Electricity - 0.07 ($/kWh)
Electricity - 26.68 ($/MMBtu
Electricity - 9.81 ($/kW)
Natural Gas - 5.52 ($/MMBtu)
Fuel Oil - 4.52 ($/MMBtu)

Graphical Representation

Graphical representation of the data subsequently provides the assessor the next logical step in the energy usage analysis progression. Experience indicates clients like graphical summaries as easily read and understood indications of relative proportions. Comparison to regional and like industries, normalized usage patterns may indicate abnormalities worthy of investigation. Some examples of graphical representation of data collected for a hypothetical company is presented on the following pages.

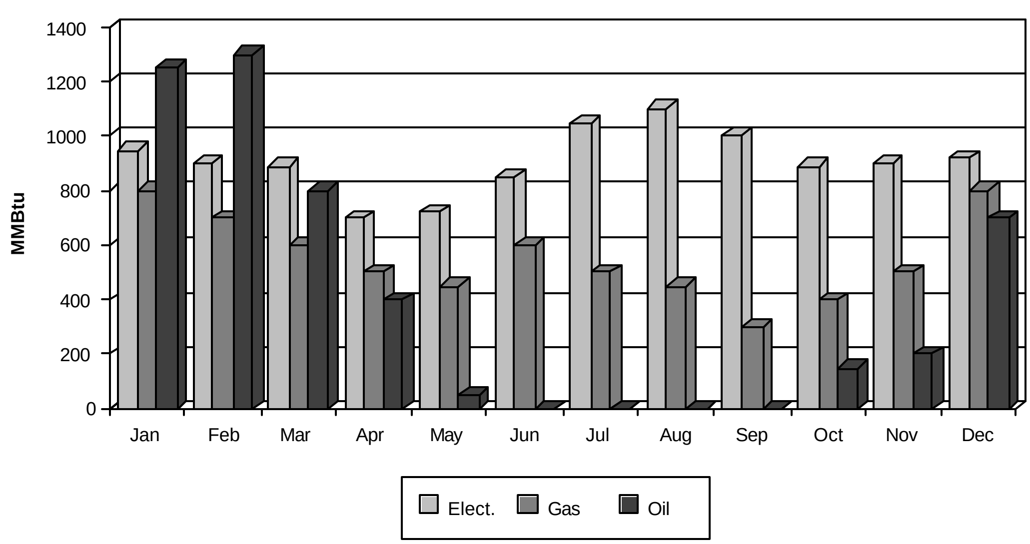


Figure 1.8: Energy Usage

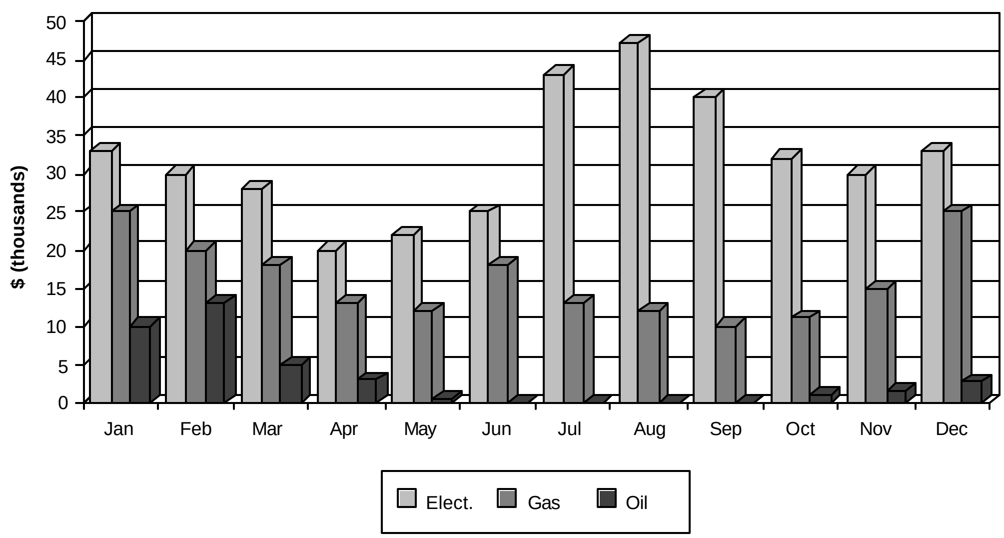


Figure 1.9: Energy Costs

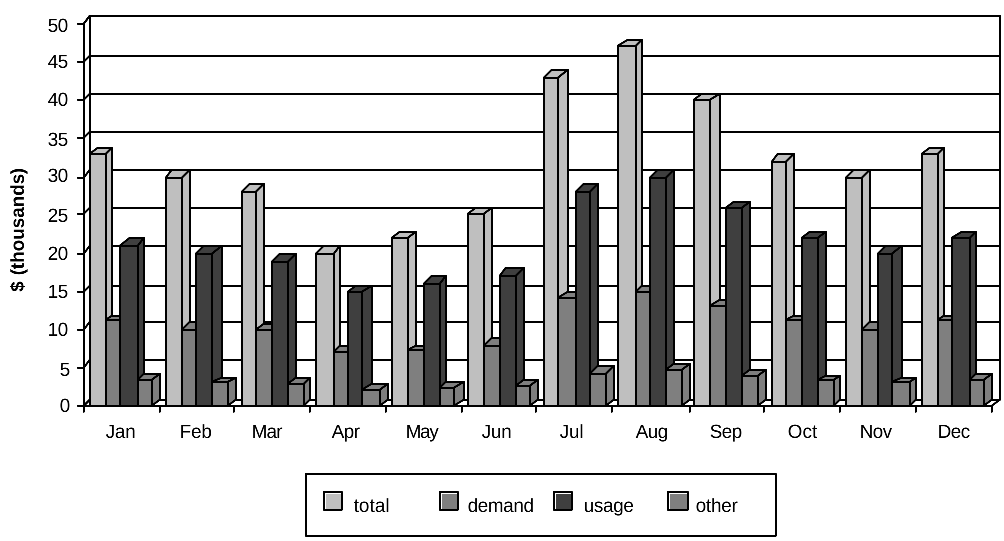


Figure 1.10: Electrical Costs

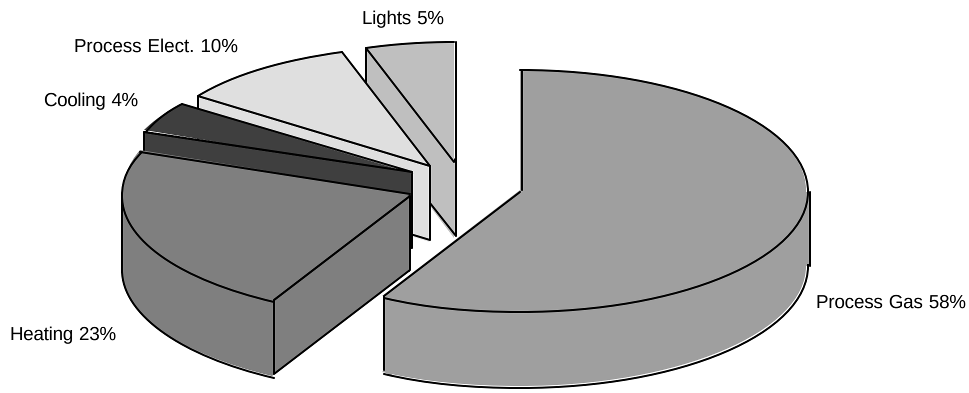


Figure 1.11: Energy Usage

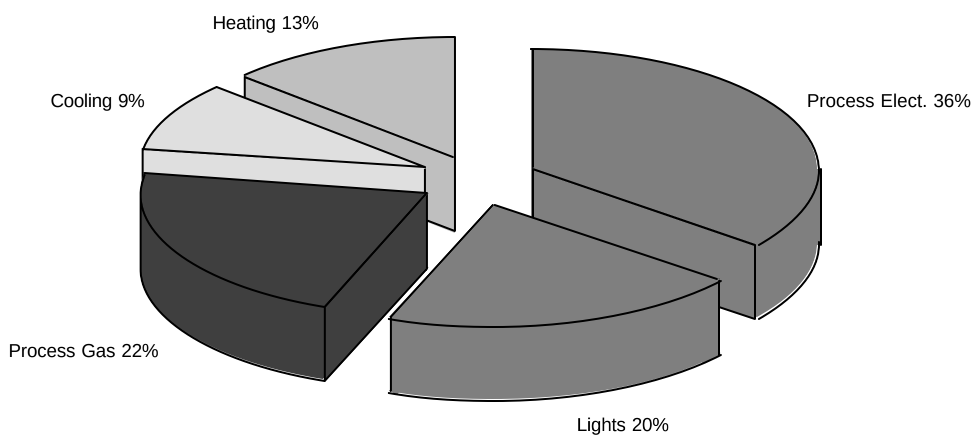


Figure 1.12: Energy Costs

REFERENCES

Clark W. Gellings, Highlights of a speech presented to the 1982 Executive Symposium of EEI Customer Service and Marketing Personnel

The Alliance To Save Energy, Getting in Gear: How energy efficiency can help smaller manufacturers compete in the global Marketplace, January 1995.

2 ENERGY AND WASTE ASSESSMENT

2.1. ASSESSMENT METHODOLOGY

There is no single approach toward performing industrial assessments. Each assessing individual will develop personalized techniques to identify potential opportunities and establish the close relationships necessary while determining the needs of the client. Upon agreement of the client's wishes, the assessment team member may then apply the professional techniques in the assessment arsenal to identify dollar saving, energy conserving, and waste minimization opportunities. The assessment does not end with the detailed calculations of the benefits of adapting these strategies, the assessment team member next pitches the ideas to the client using the written report as the gun but clear, concise logic as the ammunition. The selected material presented here outlines some basic rudimentary knowledge which every assessment team member should possess.

2.1.1. Client Selection Based on Industry Type

In the process of getting potential clients, acquisition of preliminary data and an understanding of the industrial process involved in these companies help the industrial assessment team member to get a "foot in the door". Presentations to the client may start with background data already prepared but the data primarily aids in getting the client interested. The selection of a potential client should start with looking at a compiled list of industries which traditionally use a lot of energy or historically are known to be inefficient. Some industrial processes inherently generate a substantial amount of waste and represent good assessment opportunities. Almost all companies provide supporting activities that are essential for the business that are inherently wasteful, as in the necessary evil of product packaging.

Using SIC (Standard Industrial Classification ") code enables us to group industries into certain categories and today we can present lists of potential energy or waste intensive industries.

Assessments in this publication are classified as energy assessments (EA) or industrial assessments (IA). Industrial assessments address both energy and waste issues. It would be rather unusual to provide only a waste assessment but this is not technically impossible.

1. Generally good industrial assessment candidates (waste intensive)
   SIC
   26 - Paper and allied products (with chemical processing)
   27 - Printing and publishing (with ink printing)
   28 - Chemical and allied products
   29 - Petroleum refining and related industries
   34 - Fabricated metal industries (with cleaning, surface finishing)

35 - Industrial machinery (with cleaning, surface finishing)
37 - Transportation equipment (with cleaning, surface finishing)

2. Usually sufficient waste for a successful industrial assessment
   SIC
   20 - Food and kindred products
   22 - Textile mill products (if dyeing is done)
   25 - Furniture (if finishing is done)
   30 - Rubber and miscellaneous plastic products
   31 - Leather and leather products (if tanning is done)
   36 - Electronic and electric equipment (other than assembly)

3. Energy Intensive with Frequently Doubtful Waste Profile
   SIC
   21 - Tobacco products
   23 - Apparel and other textile products
   24 - Lumber and wood products
   32 - Stone, clay, glass, and concrete products
   33 - Primary metal industries
   38 - Instruments and related products
   39 - Miscellaneous manufacturing industries (unless significant solvent use)

Waste Minimization Opportunities " Commonly Applicable to Many Plants

In this section we make an attempt to provide a list of practices which will improve or entirely convert wasteful methods of material handling. Generally speaking, not all the introduced improvements reduce the waste itself, in some cases, the financial aspect prevails.

1. Solid Landfill (Non-Hazardous) Waste:
   - ◊ Segregate (paper, cardboard, metals) and recycle
   - ◊ Compact for volume reduction disposal cost savings
   - ◊ Market wood scrap as fireplace fuel

2. Wastewater
   - ◊ Treat (filtration, precipitation, pH neutralization) and reuse in-plant processes for clean-up

3. Contaminated Liquid Cleaning Systems
   - ◊ Purify (filtration, distillation) and reuse in plant

4. Evaporative Losses of Water or Solvents
   - ◊ Modify equipment or procedures to reduce evaporative losses

5. Compressed Air Oily-Water Condensate
   ◊ Install oil/water separator to reduce disposal costs

2.1.2. Techniques for Use of Information Obtained from Plant Survey

It is beneficial to prepare for the assessment of the plant before the actual visit; this homework really pays off. Most of the work that is outlined below can be conducted over the phone, by fax, and by acquiring copies of pertinent information. Some guidelines for the plant inspection are also included.

1. Conduct an interview prior to the physical inspection; use a questionnaire

2. Follow flow of materials through plant processes

3. Control pace of plant walk-through inspection

4. Prepare material flow diagrams

5. Record questions raised while physically inspecting equipment or processes

6. Initiate discussions with equipment or process operators.

2.1.3. Types of Assessments

It is not unusual to divide all assessments into three basic categories. Energy, waste including pollution prevention (P2) and industrial (both energy and waste). Furthermore waste assessments could be performed for just regular waste or hazardous waste (obviously also for both). Industrial assessments in this text are not compliance audits . It is absolutely essential to make sure that the client understands this, otherwise cooperation dissipates along with the assessment's value.

<u>Start-up Resources - Good Places for Data</u>

EPA website for publications www.epa.gov/epahome/index.html

Pollution Prevention Assessment.
EPA, <u>Facility Pollution Prevention Guide</u>, EPA/600/R-92/088, 1992.

Industry- Specific Guides (Example)
EPA, <u>Guides to Pollution Prevention: The Fabricated Metal Products Industry</u>, EPA/625/7-90/006, 1990.

Process-Specific Guides (Example)

EPA, Guides to Cleaner Technologies Organic Coating Removal, EPA/625/R93/015, 1994.
For industrial and waste *auditing* the regulations are basically the driving force.
In the case of Industrial Assessments, other considerations might be:

- Priorities-Ozone depleting chemicals
- Cost
- Data
- Targeting

2.1.4. Benefits of Industrial Assessments

Assessment team members must realize that the major driving force is money to be saved for the company and not compliance with regulations or perceived salutary benefits. That's not to say that the assessmentor should not try to combine these two aspects; and in practice it works that way.

1. Economic Incentives

   Lowering energy bills (electricity, gas, oil, coal)
   Streamlining the process
   Finding newer and less expensive ways to manufacture

Cost savings due to lowering volume and/or toxicity of wastes can be found in the following areas:

- Disposal fees
- Generator fees/taxes
- Transportation costs
- On-site waste storage and handling
- Pre-disposal treatment
- Permitting, reporting and record keeping
- Emergency preparedness and site clean-up following accidents
- Pollution liability insurance
- Raw supply materials
- Operating and maintenance costs

2. Liabilities

   Cradle-to-grave, meaning that the polluter is forever responsible
   Waste minimization required in the 1984 Hazardous and Solid Wastes Amendments (HSWA) to the Resource Conservation and Recovery Act (RCRA)
   At present three formal statutory requirements were enacted as part of the 1984 HSWA amendments: section 3002(a)/6, section 3002(b) and section 3005(h)

3. EPCRA - Community Right-to-Know

   Emergency Reporting
   Toxic Release Inventory (TRI)

Reporting of releases
Reporting of pollution prevention

4. Waste Reduction Laws
    30 States
    Different State Requirements
        Mandatory planning - voluntary
        Implementation
        Mandatory toxins use reduction

5. Develop Benchmarks
    Energy [Btu/Ft2]
    Demand [kW/mo]
    Cost [$/Ft2]

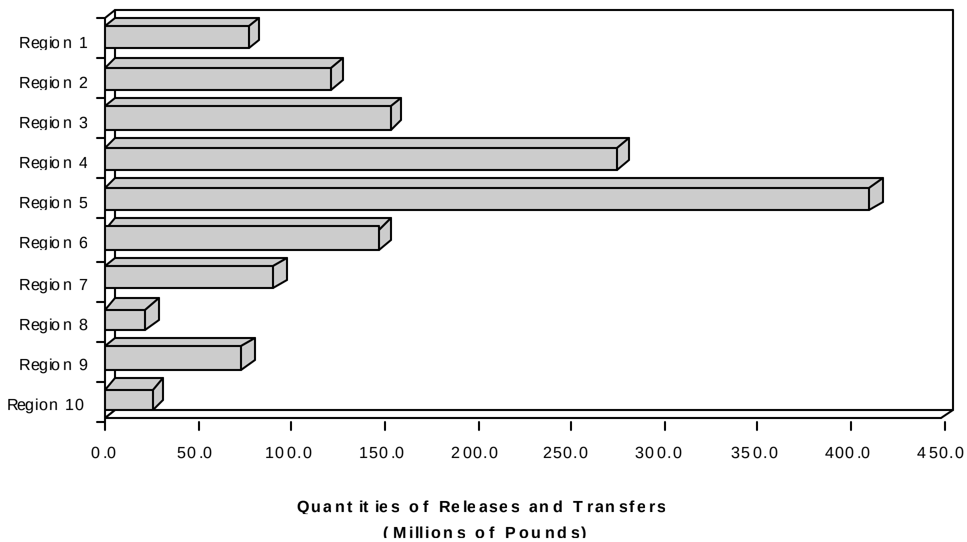


Figure 2.1: Typical Waste Release per Year in EPA Classified Regions

The picture above gives some idea of waste quantities involved in the various regions of the US. The regions were grouped by EPA.

6. Train Facility Staff
    New staff
    Overcome myths
    Introduce new technologies
    "Another set of eyes" (mental blocks)

7. Education On Billing Algorithms

8. Identify Need For Sub-Metering / Data Collection

9. Collect Input For Building Simulation

10. Improve System For Monitoring Performance

11. Confirm Proper Operation Of Equipment & Controls
    As designed
    Review as a complete system
    Confirm suspicions

12. Identify New Potential Conservation & Low Maintenance Options
    Repair
    Upgrades
    New alternatives & ideas

The US DOE's Industrial Assessment Centers, formerly Energy Analysis and Diagnostic Centers, provide technical assistance to manufacturers in reducing energy consumption and minimizing waste. The following summary shows quite clearly that the benefit of an assessment to the customer is undeniable. The numbers were compiled using the program database from the Office of Industrial Productivity and Energy Assessment at Rutgers University. The IAC database tracks energy and waste assessments performed by the major US universities under the Department of Energy (DOE) umbrella.

Summary of Energy, Cost and Environmental Savings
From Industrial Energy Conservation Assessments

Mfrs. Served	5,058
Number of Recommendations	33,980 ECOs
Total Recommended Cost Savings	$210,827,619
Implementation Rate	44%
Avg. Payback Period	1.36 years

Energy Type	Recommended Energy Savings, MMBtu/yr	Recommended Cost Savings, $/yr
Electricity	639,017	11,184,344
Natural Gas	865,927	3,750,278
Other	260,333	1,282,887
Totals	**1,765,277**	**16,217,509**

Energy Type	CO2 Emission Reductions,	CO Emission Reductions,	NOx Emission Reductions,	SO2 Emission Reductions,

	Billion lbs/yr	lbs/yr	lbs/yr	lbs/yr
Electricity	326	51,100	1,044,000	1,077,000
Natural Gas	249	72,600	290,000	1,250
Totals	575	123,700	1,334,000	1,078,250

Note: Air pollutant emission factors provided by the U.S. EPA, Office of Air and Radiation

Waste minimization / pollution prevention aspects of the industrial assessment provide implementation-worthy technical assistance to manufacturers.

Summary of Pollution Prevention and Cost Savings
From Industrial Pollution Prevention Assessments

Manufacturers Served	61
Number of Recommendations	175 WMOs
Total Recommended Cost Savings	$4,134,097
Implementation Rate	58.0%
Avg. Payback Period	1.08 years

Waste Type	Recommended Liquid Waste Reduction	Recommended Solid Waste Reduction
Hazardous Waste	931,998 gals/yr	2,016,905 lbs/yr
Nonhazardous Waste	384,774 gals/yr	31,878,822 lbs/yr
Total	1,316,772 gals/yr	33,895,727 lbs/yr

2.1.5. Assessment Structure

Each industrial different assessment's keeps the assessment team member fresh as it remains impossible to have "seen it all". However, certain tasks repeat and can be planned ahead and development of standard assessment performance methodologies remains good practice. In this section, the individual steps in the process developed from decades of experience are recalled for use as a starting point for a novice assessmentor as well as reference for the old hands.

Major Assessment Tasks

1. Introductory Meeting with Clients
   - Be flexible, solicit cooperation
   - Be friendly but firm - keep interview moving
   - Explain the program/assessment:
     Give background (be brief but thorough)
     Point out cost vs. benefits
     Brief the client on the day's activities
   - Identify any items requested but not obtained prior to the assessment
   - Ask about client's concerns
     Problem areas
     Measurements
     Needs, ideas

2. Plant Tour
   - Follow process flow
   - Ask numerous questions until acquiring full understanding
   - Take notes - if it is not written down, it did not happen
   - Make sure to ask what areas can be accessed and what is off-limits
   - Keep the assessment crew and client together
   - Try to get the tour leader to introduce you to floor supervisors, etc.
   - Afterwards, reiterate your needs and set a time to meet with the management before leaving
   - Inquire if the assessment team needs to be escorted

3. Assessment Recommendation " (AR) Idea Generation
   - Following the tour compile a list of potential ARs
   - Assign the assessment recommendations to the various team members for measurements

4. "The Rest of the Day"
   - Take measurements, collect data, and look for additional ARs. Talk with the plant personnel. Teams should compare notes for internal consistencies among the recommendations.
   - About 30 minutes prior to the scheduled meeting time, attempt to organize plans for the wrap-up meeting.
   - Have wrap-up meeting with the management. Discuss your potential ARs and answer any questions or concerns. Be sure to follow up on the manager's questions or ideas. Inquire about obtaining follow-up data. Discuss reporting requirements.
   - Sort out plans and ideas before leaving site.

2.1.6. Techniques and Tools

Since there is not a recognized unified assessment technique or universally accepted approach to the assessment, it is up to the individual assessmentor to develop his or her own. As a guideline, an example of a typical industrial assessment is provided. This section focuses on tasks which, in our view, are more difficult for an inexperienced assessmentor. Generally, waste related techniques are more difficult to develop and therefore are introduced in more detail. At the same time common sense indicates that there are a lot of commonalties between energy and waste, especially in areas which describe dealing with the client.

<u>Case Study Task Outline</u>

- Preassessment information
- Plant Visit: Waste-related objectives
- Plant visit slide presentation
- Process flow diagram
- Waste stream data
- Brainstorming
- Analysis
- Summary

Preassessment Information

Here is an example of the type of information that should be obtained prior to an industrial assessment.

Type of Products Manufactured:	Telescopic sights, mounts
Types of Wastes Generated:	Coolants, Rinse water, Metal chips
Relevant Data:	Water, Sewer, Sewer/Waste Hauling Bills; Hazardous waste; Manifests

Plant Visit: Waste-Related Objectives

When conducting the waste portion of an industrial assessment it is a good idea to make a checklist of tasks to be performed.

Identify Process Wastes
Identify Current Waste Management Practices
Look for waste-reduction opportunities
Identify key personnel for follow-up interviews

WASTE-RELATED ISSUES

Ask:

- Does this process generate waste? What is it?
- How much is generated? (weekly, yearly) Who has the data?
- How is the waste currently managed?
- What are the waste management costs? Who has the data?
- What waste reduction measures have been tried?

See:

- Raw materials and production areas
- Waste generation and accumulation areas
- Waste treatment and disposal areas

Waste Stream Data

After the waste streams have been determined, specific information is gathered for each.

- Cutting Fluid from Machining
  Amount of waste formed: 3,020 gal/yr
  Composition: 98% water, 2% concentrate
  Disposal: TSDF blends into cement
  Disposal Cost: $1,360/yr

- Rinse Water from Polishing, Salt Blackening
  Amount of waste formed: 90,400 gal/yr
  Composition: Water pH> 7.0
  Disposal: Neutralize with H_2SO_4, sewer
  Disposal Cost: $100/yr

- Metal Chips from Machining
  Amount of waste formed: unknown
  Composition: Aluminum, steel
  Disposal: Drained, collected by metal reclaimer credit
  Disposal Cost Credit

- Acetone from assembly operations
- Amount of waste 700 gal/yr
- Composition Acetone Vapor
- Disposal Evaporates to Atmosphere
- Raw Material Cost $1,890/yr

Brainstorming: Waste Reduction

After collecting all the relevant data, these waste minimization opportunities were suggested:

- Reduce volume of waste
  - Treat with acid to induce phase separation
  - Dewater by heat addition
  - Implement more aggressive coolant recycling
- Replace flood cooling with spray
- Reduce volume of waste water
  - Treat and recycle rinse water
- Replace acetone with less hazardous cleaner
  - (note: this is Pollution Prevention, not waste reduction)
  - Use Aqueous cleaner
  - Use less hazardous organic solvent

Brainstorming: Other Potential Recommendations

As with any industrial assessment, an energy analysis was also conducted. It resulted in the following Energy Conservation Opportunities.

- Compressed Air
  - Repair eight leaks
  - Reduce tank pressure
  - Use outside air: Door kept open
- Insulate heated caustic and salt blackening tanks
- Replace 81 kW electric annealing oven with gas oven
- Implement PM (Preventive Maintenance) program to reduce oil on shop floor
- Replace TCA vapor degreaser: Done January 1993

Analysis: Acid Treat Waste Cutting Fluid

Add sulfuric acid to induce separation of organic and aqueous phases. Tests indicate that pH 5.5 is optimal. Sewer aqueous phase. Dispose of organic phase in non hazardous waste oil.

Volume of spent cutting fluid = 3,020 gal/yr
Composition: 98% (v/v) water, 2% organic concentrate
Reduction in waste requiring hauling to TSDF:
Waste reduction = (3,020 gal/yr)(1.00-0.02) = 2960 gal/yr
Annual cost savings, S = ($0.45/gal)(2,960 gal/yr)
Annual Cost - [(3,020 gal/yr(1hr/bch)($25/hr)] / (200 gal/bch)
S = $955/yr

Equipment required for implementation: 200 gallon tank
Mixer
pH meter

Implementation cost:	$1,000
Payback period:	($1,000)/($955/yr) = 1.0 yr
Alternative approach:	Dewater with evaporator
Advantage:	Reduce expenditures for labor
Disadvantages:	Three - year payback period Possible air pollution problem Requires electricity

1 Summary of Assessment Recommendations

Assessment Recommendation	Annual Savings	Implementation Cost	Payback Period
1. Repair Air Leaks	**$7,730/yr**	**$800**	**0.1 yr**
2. Gas Annealing Oven	**$8,330/yr**	**$53,000**	**6.5 yr**
3. Acid Treat Spent Cutting fluid	**$955/yr**	**$1,000**	**1.0 yr**

Additional Measures Considered

It is useful to introduce all ideas, including those which might present just a relatively weak opportunity for an implementation at present time. The economic climate might change and the customer will have the basic information needed.

Replace flood cooling with spray cooling.
- Advantage: Eliminate spent cutting coolant waste stream
- Disadvantage: Higher implementation and operating costs

Replace acetone with less hazardous cleaner
- Advantage: Eliminate a source of solvent air emissions
- Disadvantage: Prolonged drying time for aqueous cleaners

2.1.7. Identification, Selection, Analysis and Write-up of ARs

1. AR Identification
   - Focus attention on the largest and most costly waste streams
   - For each waste stream generate one or more possible AR ideas;
     Use the following ideas sources:
     Consider common-sense approaches to waste reduction (e.g. simple procedural changes)

Review available waste reduction literature
Survey databases
Other sources detailed below

2. AR Selection
   - Include all simple concepts (assured technical feasibility), short payback ARs for relatively significant waste streams
   - Be cautious in selecting measures with highly doubtful technical feasibility
   - In general, select measures with paybacks less than 5 years

3. AR Analysis (See 2.1.8.4 "AR Analysis")

4. AR Write-up

(All items below should be included; the more clear the text the better)

- State current practices and observations
- Recommended action has to be clear, write in plain language
- Estimation of reduction in amount of waste
- Estimation of associated net waste management (and if relevant, energy) cost savings
- Implementation considerations

  Equipment requirements and costs
  Procedural changes
  Payback calculation
  Cautions, if any

5. Example

Develop Record Keeping Systems

- Waste Profiles
- Disposal Plans
- Manifests
- Generation and Disposal Reports
- Training Records
- Inspection Records
- Contingency Plans
- Correspondence
- Assessment Summaries

AR calculation references

<u>General</u>

Thumann, Albert, Handbook of Energy Assessments, Association of Energy Engineers, Atlanta, GA (several editions).

Industrial Market and Energy Management Guide, American Consulting Engineering Council, Research and Management Foundation, 1987.

Energy Conservation Program Guide for Industry and Commerce, NBS Handbook 115 and Supplement, U.S. Department of Commerce and Federal Administration, U.S. Government Printing Office, 1975.
Mark's Handbook of Mechanical Engineering, Baumeister (Ed.), McGraw-Hill, Eight Edition, 1978.

ASHRAE Handbooks, Fundamentals, Systems, Equipment, Application, HVAC and Refrigeration Volumes, American Society of Heating, Refrigeration and Air Conditioning Engineers.

Directory of Software for Energy Managers and Engineering, Association of Energy Engineers, Atlanta GA, 1990.

Boilers

Dyer, David and Glennon Maples, Boiler Efficiency Improvement, Boiler Efficiency Institute, Auburn, Alabama, 1981.

Steam Efficiency Improvement, Boiler Efficiency Institute

Air Compressors

Compressed Air and Gas Data, Ingersoll-Rand Company, 1982

Compressed Air Systems, A Guidebook on Energy and Cost Savings, Varigas Research, Inc., Timonium, MD 1984.

Compressed Air and Gas Handbook, Compressed Air and Gas Institute, New York, New York, Third Edition, 1961.

Sources for Implementation Cost Data

Installation and Labor Costs

Installation and labor costs are of great importance whenever one faces the responsibility of estimating pecuniary aspects of an engineering proposal. It is an indisputable fact that different companies have different overhead costs, therefore similar jobs may not necessarily cost the same. However, it is possible to estimate expenditures for standard tasks typically required in order to accomplish specific projects.

Some typical jobs, such as concrete work, masonry, thermal and moisture insulation, carpentry, plumbing, and variety of electrical installations can be estimated using cost data books. As an example see "Means Building and Construction Data" and "Dodge Unit Cost Data". These provide standard costs for a great variety of tasks commonly encountered. Prices contained in these books are those that would be incurred by a general contractor. The general contractor's overhead and markup are not included in any of the prices in these references. Caution must be exercised since no two projects are identical and conditions of work may differ considerably. Special project conditions must be reflected in the simplicity or complexity of work items. The size and scope of work have a significant impact on cost. Economies of scale can reduce costs for larger projects and unit costs can often run higher for small projects.

Since each project is an complex engineering undertaking hiring a consultant experienced in the field is encouraged before any work is to begin. The fees for such services vary from $1500 to $2000/day based on level of expertise and difficulty of the task.

1. MEANS Cost References:
    Electrical
    Mechanical
    Construction
    Man-hour Standards
    System Costs

2. Local Wholesale / Retail Supplier Catalogs:
    Grainger
    McMaster-Carr
    Ryall Electric
    Poudre Valley Air

3. Manufacturer's Representatives (Equipment Costs):
    Bell and Gossett
    ITT
    Conservawatt
    Kewanee
    Cleaver Brooks
    Marley

4. Contractors
    Sheet Metal
    HVAC / Mechanical
    Plumbing

5. Industrial Assessment Database (past assessments)

6. Manufacturer's Data / Cost Catalogs

7. Common Sense In-house Estimates

Software

1. Basic tools:

   Weather Data / Data Extraction
   - Your local Climate Center
   - In-house Energy Billing information
   - In-house Extraction Codes
   - ASHRAE Bin Data

   Billing Data
   - FASER
   - In-house Spreadsheet Program

   Simple Measure Evaluation
   - Spreadsheets / Code
   - Hand Calculations

   Building Simulation
   - Simple Buildings - Modified Bin Program
   - Complex Buildings - Consultant

   Daylighting
   - Simple - SuperLite or Equivalent
   - Complex - Consultant
2. Other assessmenting software:

   Daylighting
   - DOE-2 (LBL)
   - Controlite (LBL)
   - SuperLite (LBL)
   - Daylite (Claude Robbins)

   Billing Data Tracking
   - FASER
   - ENACT
   - Spreadsheet (Lotus, Quatro Pro, Excel, etc.)

Weather Data Manipulation

- Your Local Climate Center
- TMY Data Tapes
- Extraction Code

Database

- FoxPro
- Paradox
- DBase IV
- RBase

2.1.8. Tasks and Data for Energy and Waste Assessments

Elements of an Industrial Assessment

1. Pre-plant visit data collection and review
2. Plant visit
3. Follow-up process information and data request(s), if needed
4. Report preparation

Pre-plant Visit Data Collection and Review

1. Desirability of advance data collection
    - To prepare assessment team to efficiently address plant-specific processes and associated waste streams and energy usage
    - To "get a jump" on waste and energy consumption data collection which is often time-consuming and difficult to complete in plant.

2. Data desired
    - General description of major energy consuming and waste-generating processes
    - Identification of all major types of waste stream releases:
        a) Solid or liquid (other than water) containerized waste streams:
            Hazardous waste: type of waste, lbs (or containers)/yr shipped off site, cost of shipments.
            Non-hazardous solid (landfill) waste: principal components, lbs (or containers) shipped/yr, cost of shipments.

        b) Waste water: process yielding waste water, lbs (or gal)/yr released, sewering costs.

c) Air releases:
   Permitted: nature of release(s), lbs/yr released, cost of replacement chemicals.
   Non-regulated (e.g. water evaporation): lbs/yr, purchase cost of water.

3. Caution
- Extensive data requests (especially regulated discharges) in advance of plant visit may threaten or otherwise discourage client from continuing with assessment!

Plant Visit Activities

1. Staff Interview
   - Make sure you understand energy usage in the plant and billing schedules involved
   - Ask questions to gain a basic understanding of plant processes yielding waste and to identify point sources of waste generated in plant
   - Obtain approximate quantitative data for major waste streams (amounts and associated costs)
   - Request and review available waste data records (and energy bills if necessary)

2. Inspection of Plant Manufacturing and Support Operations
   - Clarify process details
   - Confirm point sources of waste
   - Clarify causes of waste production and energy consumption
   - Characterize waste handling/processing procedures
   - Generate preliminary AR ideas
   - List areas/processes for which additional quantitative data is needed for later analysis

3. Exit Interview
   - Present list of lacking essential data for follow-up transmittal to you
   - Clarify process details limiting feasibility of brainstormed ARs
   - Present and discuss proposed ARs

Waste Content of Client Energy/Waste Assessment Reports

Following the assessment, a report should be generated for presentation to the client. This assessment report should at least contain the following categories.

1. Disclaimer

   Information presented and recommendations made do not address or guarantee plant compliance with any environmental laws.

2. Executive Summary

   Listing of energy and waste reduction measures recommended

3. Sections Addressing Energy Consuming and Waste Generating Processes
   Energy and waste discussion in process description
   Include process flowsheets indicating point sources of waste streams

4. Section Presenting Summary of Waste Production Rates and Associated Costs

5. Listing of Measures Undertaken Previously by Plant to Manage Waste or Lower Energy Usage (Best Practices)

6. Assessment Recommendations (ARs)

AR Analysis

1. Clearly identify energy-consuming equipment and waste stream(s) associated with recommended measure (e.g. motors, raw waste water or waste water treatment system sludge)

2. Specify current energy usage or waste production rates for considered stream(s); Obtain data from:
   - Energy bills
   - Waste release records
   - Mass balancing
   - Plant personnel estimates
   - Assessment team estimates (e.g. cardboard fraction in landfill waste)

3. Estimate costs associated with waste streams of concern
   - Raw materials replacement costs
   - Estimates of administrative and handling labor costs, if any
   - Release permitting costs, if any
   - Estimates of shipping costs, if any

4. Specify reduction amount for waste stream(s) minimized; obtain reduction amounts from:
   - Case study experience (literature information)
   - Equipment vendor data
   - Estimates of assessment

5. Calculate net cost savings associated with waste reduction amounts; Consider:
   - Recurring costs associated with new waste streams produced, if any
   - New labor costs
   - Operational costs of new equipment

6. Estimate AR implementation cost (one-time capital expenses)
7. Calculate simple payback

§ *Mass Balancing Example*

Spray Painting of Automotive Sideview Mirror Housings

Basic material mass balances (on a unit time basis):

1. Paint:
   Quantity purchased - Quantity stored = Quantity used
   Quantity used = Quantity deposited on parts +
   Quantity disposed as liquid waste +
   Quantity disposed as solid waste
2. Reducer:
   Quantity purchased - Quantity stored = Quantity used
   Quantity used = Quantity evaporated in paint mixing area +
   Quantity evaporated in paint booths +
   Quantity evaporated in paint curing oven +
   Quantity evaporated in clean-up operations +
   Quantity disposed as waste (contaminated) liquid

Waste Management Component Costs

1. Hazardous Waste (solid and liquid)
   a) Raw materials replacement
   b) Administration and record keeping
   c) Materials handling
   d) Pre-treatment on-site, if any
      Chemicals (e.g. acid neutralization)
      Energy (e.g. heating, materials transfer)

2. Air Emissions (vapors and particulates)
   a) Raw materials replacement
   b) Release permitting
   c) Pre-treatment on-site if any
      Materials (e.g. baghouse filters)
      Energy (e.g. incineration)

3. Wastewater
   a) Make-up (replacement) water
   b) Release permitting

c) Pre-treatment on-site, if any
   System components (e.g. filters)
   Chemicals (e.g. pH adjustment)
   Energy (e.g. pumping)
d) Periodic effluent sampling and testing

4. Landfill Waste (Solid)
   a) Raw materials replacement (e.g. paper)
   b) Administration and record keeping
   c) Materials handling
   d) Equipment rental (e.g. dumpsters, compactors)
   e) Hauling

§ *Waste Minimization Example in Minimizing Waste of Tap Water*

<u>Current Practice and Observations</u>

It was noted that tap water was being used to cool the 60 horsepower air compressor by letting it flow freely through the compressor cooling coils. The temperature rise of the cooling water at inlet was 65°F and the exit water temperature was 85°F. The unrestricted flow results in significant waste water. The compressor oil temperature was also found to be 90°F.

<u>Recommended Action</u>

Reduce flow of cooling tap water by installing a gate valve and/or recirculate water through a small cooling tower.

The air compressor specifications indicate that the operating temperature of the oil should be maintained at approximately 150 °F. The free flow of tap water through the cooling passages is wasting water and overcooling the compressor oil.

• *A gate valve (with a hole drilled in the gate of the correct cross section to limit the flow to rate to the minimum acceptable to the manufacturer of the compressor) should be installed.*

• *The hole will guarantee that the cooling water will not be accidentally shut off*

• *The use of a valve rather than a flow restrictor will permit adjustment of the flow rate in the event of line fouling and permit periodic flushing of the line to eliminate scale.*

Additional water savings would be possible by installing a small cooling tower to reject heat from the compressor cooling water and then recirculate it through the compressor cooling lines.

<u>Anticipated Savings</u>

At full load (60 HP) approximately 20% of the energy delivered to the compressor is removed by the cooling water. The flow rate in gallons per hour for a 20°F temperature rise is given by:

$$GPH = \frac{f * HP * CF * GPP}{CP * \Delta T}$$

where:

GPH	=	Gallons of water per hour through the compressor.
HP	=	full load horsepower of the compressor
f	=	the fraction of compressor power lost to cooling water (0.2)
CF	=	the conversion factor (2,545 BTU/HP-hr)
GPP	=	Gallons of water per pound mass (0.12 gallons/lbm)
CP	=	specific heat of water (1 BTU/lbm°F)
ΔT	=	Temperature rise of water through the compressor (20°F)

$$GPH = \frac{0.2 * 60HP * 2545Btu/hr * 0.12gal/lbm}{1Btu/lbm^0F * 20^0F}$$

It is assumed that allowing the exit water temperature to rise to 145°F will maintain the compressor oil at 150°F. The flow rate can be reduced by (85°F - 65°F) / (145°F -65°F) yielding the flow rate as:

(85°F - 65°F) / (145°F- 65°F)) x 183 GPH = 46 GPH

and the cost savings as:

$$CS = L * HR * CF$$

CS	=	Cost Savings in $/yr
L	=	total water flow reduction rate (183 GPH - 46 GPH = 137 GPH)
HR	=	yearly operating time of the compressed air system (8 hours/day) x (5 days/ week) x (52 weeks/yr) = 2,080 hours/yr
CF	=	Cost of tap water consumption ($18/1000 gallons)

Thus with gate valve flow restrictor:
CS = (137 gal/hr) x (2,080 hrs/yr) x ($0.018/gallon) = $5,129/yr

Cooling tower makeup water is estimated to be no more than 10 gallons per hour for this size unit, thus the cost savings with an installed cooling tower would be:

CS = (183 GPH - 10 GPH x (2,080 hrs/yr) x ($0.018/gallon) = $6,477/yr

Total Annual Savings = $6,477

Implementation

It is estimated the cost of a flow good gate valve will be approximately $20 and it can be installed and drilled by maintenance personnel. Based on the implementation cost and reduction in cost of wasted tap water, the simple payback period for this recommendation is:

($20 implementation cost) / ($5,129/yr savings) = 1.4 days

The implementation cost with a cooling tower is considerably greater. It is estimated to be $7,500 for a five ton packaged unit which would be adequate for this application. Based on this implementation cost and reduction in cost of wasted tap water, the simple payback period for this recommendation is:

($7,500 implementation cost) / ($6,477/yr savings) = 1.2 years.

Simple Payback = 1.2 years

The relatively long payback and complexity involved with the cooling tower may make this approach undesirable. If some other requirement within the plant makes a cooling tower purchase likely this solution should be considered.

2.1.9. Load Calculations and Energy Analysis

For any system that is encountered in the field an assessmentor should perform load calculations to see energy requirements. Given the equipment and/or process demands one can draw a conclusion whether the plant is using too much energy and if that is the case, start analyzing different components for potential savings.

1. POTENTIALLY ACCURATE METHODS
   - Heat balance
   - Weighting factors

2. COMPARATIVE METHODS
   - CLTD and CLF methods
   - BIN methods
   - Modified degree day methods

3. Complicated methods
   - TETD methods
   - 65°F-based degree method

Energy Estimating Methods

<u>Heating</u>

1. Heating Degree Day, EHT

$$E_{HT} = \frac{UA * DD}{h}$$

where

E = heating energy, Btu
UA = design heat load, Btu/°F day
DD = degree days, °F day
η = furnace efficiency

2. Variable Based Degree Days (Vbdd)

   Same, except we use degree days to the base t_b, where

$$t_b = \frac{t_i - Q_{GAIN}}{UA}$$

3. Bin Method

$$E_{HT} = \sum_{BINS} E_i$$

where

E_i = BLC x (t - $t_{o,i}$)

4. Detailed Simulation Methods

<u>Cooling</u>

1. Cooling Degree Day

$$E_{CL} = \frac{24 * BLC * CDD}{COP}$$

where
COP = coefficient of performance
CDD = cooling degree days

2. Bin Method

3. Cltd/Clf Method

4. Tetd/Ta Method

5. Transfer Function Method
6. Heat Balance Method

Procedure for Building Simulation

1. GATHER DATA FROM BUILDING PLANS
   A. Determine appropriate zones
      - Perimeter vs. core
      - Wings
      - Different HVAC systems

   B. Identify wall sections, glazing types
      - i.e., Wood sheathing, 3 1/2” fiberglass insulation, 5/8” dry wall, etc.

   C. Define and size HVAC systems
      - From mechanical plans
      - Flow rates, coil ratings, sometimes controls

2. EVALUATE UTILITY BILLS (ELEC., GAS, WATER)
   A. Break out hot water energy use
      - Iterate fraction of hot water

   B. Break out HVAC use
      - Look for seasonal variation in electricity and gas usage

   C. Evaluate load factor

- Monthly usage / (peak demand x # of hours of operation in a month)

3. INTERVIEW FACILITY STAFF
   A. Obtain schedules for people, equipment, lighting, HVAC equip. control / operation
      - Setpoints and setback times
      - Outside air control (economizer)
      - Supply and exhaust fan schedules
      - Manual override of the system (typically seasonal)

4. SITE VISIT DATA COLLECTION
   A. Note day, outside weather conditions
      - compare to the mode of the system operation.

   B. Use a separate page for each zone: saves time when creating simulation input.
   C. Count lights and equipment
      - Find rating, size, etc.
      - Note how many are operating and time of survey

   D. HVAC SYSTEM OPERATION
      - Fan and coil operation (ON/OFF or variable speed)
      - Outside air damper setting (fixed position, economizer setting)
      - Note placement and setting of thermostats (setback capability)

5. CREATE SIMULATION INPUT FILE
   A. Alter file from similar building
      - Saves time

   B. Write simple input file first
      - Easier to debug
      - Start with components of zone loads

   C. Then add more schedules and complexity

   D. Compare the magnitude of the loads and the load shape with the bills

2.2. ENERGY AND WASTE INSTRUMENTATION FOR ASSESSMENTS

It is important to be able to gather all the information necessary for competent evaluation of energy usage and waste generation. Hardware designed to help data collection is available and should be used. Since manufacturers of measuring equipment constantly strive for better products it is a good practice to keep up with the latest development in the field. Then one is able to make use of state-of-the-art technology to achieve better results in his or her own work.

2.2.1. Equipment List

___1. Thermo Anemometer - *Alnor Model 8255* (Digital)

___2. Velometer - *Alnor* (Analog)

___3. *Amprobe* Ampere Meter (Digital)

___4. *Amprobe* Ampere Meter (Analog)

___5. PWF Meter

___6. Rubber Gloves

___7. Infra Red-Temp Sensor - *Kane May 500*

___8. Temperature Probes/*Flukes* Meters

___9. *Sylvania* Light Meters

___10. Combustion Analyzer - *Kane May 9003* (Silver)

___11. *Enerac* Combustion Eff. Computer - *Model 943* (Blue) and Separate Probe

___12. *Polysonics* - Ultra Sonic Flow Meter

___13. Drill and Bit from ME shop

___14. Safety Glasses, Ear Plugs

___15. Dust Masks

___16. *Amprobe Chart Recorder*

___17. Record of Previous Recommendations

___18. Tool Box (include flashlight, wire brush, rags)

___19. Preassessment Data Sheet

Number of Cases taken to site ___.

2.2.2. Product and Supplier List

Combustion Analyzer

Energy Efficiency Systems 1300 Shames Drive Westbury, NY 11590 (800) 695-3637	Enerac 2000 - $3,000 Pocket 100 - $1,500
Universal Enterprises 5500 South West Arctic Drive Beaverton, OR 97005 (503) 644-9728	KM9003 - $2,000
Goodway Tools Corporation 404 W. Avenue Stanford, CT 06902 (203) 359-4708	ORSAT and EFF-1
Bacharach, Inc. 625 Alpha Drive Pittsburgh, PA 15238 (412) 963-2000	FYRITE II - $695 No CO or Combustibles
Dwyer Instruments, Inc. Highway 212 at 12 P.O. Box 373 Michigan City, IN 46360 (219) 872-9141	
Milton Ray Company Hays-Republic Division 742 East Eighth Street Michigan City, IN 46360	
Burrell Corporation 2223 5th Avenue Pittsburgh, PA 15219	

Amp Probe

Grainger	Analog Amprobe	Digital Amprobe
4885 Paris Street	#RS3 - $100	#3A360 - $350
Denver, CO		
(303) 371-2360		

Cogeneration:

Martin Cogeneration Systems (913) 266-5784
1637 SW 42nd St.
PO Box 1698
Topeka, KS 66601

Waukesha/Dresser
Waukesha Engine Division
Dresser Industries
1000 W St. Paul Ave.
Waukesha, WI 53188

Tecogen Inc.
45 1st Ave.
PO box 9046
Waltham, MA 02254-9046

Stewart and Stevenson, Inc. (713) 457-7519
Gas Turbine Product Division
16415 Jacintoport Blvd.
Houston, TX 77015

Boilers:

Kewanee Boiler Corporation (314) 532-7755
Suite 200
16100 Chesterfield Village Parkway
Chesterfield, MO 63017

Boiler Efficiency Institute
School of Engineering
Auburn University
PO Box 2255
Auburn, AL 36830

(Steam Traps)
Yarway Corporation (312) 668-4800
PO Box 1060
Wheaton, IL 60189

Weben-Jarco Inc.
PO Box 763460
Dallas, TX 75376-3460
Uniluc Manufacturing Company Inc. (416) 851-3981
140 Hanlan Rd.
Woodbridge (Toronto) Ontario, Canada L4L3P6

Waste Heat Recovery:

Beltran Associates, Inc. (516) 921-7900
200 Oak Dr.
Syoset, NY 11791

Therma Stak
1-800-521-6676
Des Champs Labs Inc. (201) 884-1460
Z Duct Energy Recovery Systems
PO Box 440
17 Farinella Dr.
East Hanover, NJ 07936

Pumps:

ITT Bell & Gossett (708) 966-3700
8200 N. Austin Ave.
Morton Grove, IL 60053

Ingersoll Rand

Taco, Inc. (401) 942-8000
1160 Cranston St.
Cranston, RI 02920

Lighting:

Valmont Electric (217) 446-4600
Hunt Electronics
1430 E. Fairchild St.
Danville, IL 61832

The Watt Stopper, Inc. (408) 988-5331
296 Brokaw Rd.
Santa Clara, CA 95050

MagneTek Universal Manufacturing (201) 967-7600
200 Robin Rd.
Paramus, NJ 07652

Philips Lighting Company (908) 563-3000
200 Franklin Square Dr.
PO Box 6800
Somerset, NJ 08875-6800

(Light Controls)
Powerline Communications, Inc. 1-800-262-7521
123 Industrial Ave.
Williston, VT 05495

Conservolite, Inc.
PO Box 215
Oakdale, PA 15071
(412) 787-8800

General Electric

Implementation Costs/Pricing:

RS Means Company Inc. 1-800-334-3509
100 Construction Plaza
PO Box 800
Kingston, MA 02364-0800

Grainger
(Regional Numbers)

General Information:

ASHRAE Handbook of Fundamentals

HVAC:

McQuay - Perfex Inc.
13600 Industrial Park Blvd.
PO Box 1551
Minneapolis, MN 55440

(Hot Water Systems)
Weben Jarco, Inc. 1-800-527-6449
4007 Platinum Way
Dallas, TX 75237

(Evaporative Cooling)
ECCI
PO Box 29734
Dallas, TX 75229
(214) 484-0381

(Chillers)
Carrier Corporation
Syracuse, NY 13221
Trane Company
Clarksville, TN 37040

(Cooling Towers)
The Marley Cooling Tower Company
5800 Foxridge Dr.
Mission, KS 66202 (913) 362-1818

(Radiant Heaters)
Roberts - Gordon Appliance Corporation (716) 852-4400
PO Box 44
1250 William St.
Buffalo, NY 14240

Air Compressors:

Ingersoll Rand Company
5510 77 Center Dr.
PO Box 241154
Charlotte, NC 28224

Gardner-Denver Company

Motors:

GE Company
Motor Business Group
1 River Rd.
Schenectady, NY 12345
Baldor

Variable Speed Drives:

York International (717) 771-7890
Applied Systems
PO Box 1592-361P
York, PA 17405-1592

ABB Industrial Systems, Inc.
Standard Drives Division
88 Marsh Hill Rd.
Orange, CT 06477

Allen Bradley
Drives Division
Ceadarburg, WI 53012-0005

Enercon Data Corporation
7464 W. 78th St.
Minneapolis, MN 55435
(612) 829-1900

Belts:

The Gates Rubber Company (303) 744-1911
990 S. Broadway
PO box 5887
Denver, CO 80217

REFERENCES

1. Thumann, Albert, Handbook of Energy Assessments, Association of Energy Engineers, Atlanta, GA (several editions).
2. Industrial Market and Energy Management Guide, American Consulting Engineering Council, Research and Management Foundation, 1987.
3. Energy Conservation Program Guide for Industry and Commerce, NBS Handbook 115 and Supplement, U.S. Department of Commerce and Federal Administration, U.S. Government Printing Office, 1975.
4. Mark's Handbook of Mechanical Engineering, Baumeister (Ed.), McGraw-Hill, Eight Edition, 1978.
5. ASHRAE Handbooks, Fundamentals, Systems, Equipment, Application, HVAC and Refrigeration Volumes, American Society of Heating, Refrigeration and Air Conditioning Engineers.

3 EVALUATION OF ENERGY AND WASTE COSTS

3.1. FINANCIAL ANALYSIS

Financial analysis of proposed energy projects essentially "sell" the ideas to the client. In today's competitive environment, industry can ill afford starting a project with fiscal uncertainties. This section covers the basics of pre-investment financial breakdowns and performance considerations.

3.1.1. Definitions

Block: A division of billing based on usage. The total block amount of use is divided into blocks of different price per unit of use.

Btu: British thermal unit. It is the amount of energy to raise or lower one pound of water one degree Fahrenheit.

CCF: One hundred cubic feet of gas. (Typically 1 Therm = 1.02 CCF)

Celsius: A metric unit for temperature measurement.

Collector: Panels for collecting and transforming the sun's radiation

Constant: Multiplier used in computing electric meter reading.

Degree Day: The sum of the average outdoor temperature over a short time frame (day). Usually subtracted from 65 used as the heat balance temperature.

Demand: Highest amount of electricity used in a month, measured in Kilowatts (kw). Usually approximated by integrating the consumption over the highest 15-30 minute period during any one month. Power companies must have the generating capacity to meet the demands of their customers during these peak period.

Duty Cycle: Controlled interruption of a piece of equipment that is within its operating band. It is designed to reduce demand, usage and the equipment's life.

Enthalpy: A measure of the energy content of a substance, reflecting both moisture content and temperature.

Fossil Fuel: Fuel (natural gas, coal, oil etc.) coming from the earth that was formed as a result of decomposition of vegetation or animal matter.

Humidity: The ratio of water vapor within a given space to the amount of water the air can hold at that temperature and pressure (saturation).

HVAC: Heating, ventilation and air conditioning.

HVLP: High Volume Low Pressure. A type of paint gun that uses less paint.

Infiltration: Air flowing inward through a wall, window, door or a crack., associated with an equal amount of air leaving a structure (exfiltration).

Insulation: A material having a relatively high resistance to heat flow, principally used to retard the flow of heat. This ability is measured as "R" factor. The higher the factor the higher the ability to insulate.

Interruptible Service: Large users of electricity or gas who are able to turn off a portion of their use during peak periods are rewarded by lower rates.

Kilowatt: 1000 Watts, unit of power.

Kilowatt Hour: Unit of electrical power consumption. It is one kilowatt used for one hour.

LP Gas: Liquid petroleum gas. This fuel is distributed in pressurized cylinders in liquid state and by releasing it is converted into a combustible gas.

Load Scheduling: A clock programmed by the user to start and stop electric loads on selected days at particular times.

Load Shedding: A scheduled shutdown of equipment to conserve energy and reduce demand.

Lumen: A unit for quantitative measure of light.

Make-Up Air: Air forced into the area equal to the air lost through exhaust vents.

MEK Methyl Ethyl Ketone, a highly volatile solvent.

Optimum Start: The load scheduling program, when applied to heating or cooling loads, is modified to follow temperature changes outside the building.

Power Factor: Ratio between usable power supplied (kW) and reactive power (kVAR) used in inductive loads.

Ratchet:	A utility rate charged to customers based on the peak yearly demand of a facility. The rate is designed to represent the cost to the utility of constructing and maintaining enough capacity to meet that demand.
Service Charge	A fixed fee for providing service from a utility company.
Therm	A unit of heat, equivalent to 100,000 Btu.

3.1.2. Sample Calculation of Savings

Examples of calculations or approaches to a variety of problems are the best tools for learning. This methodology continues here with sample recommendations and calculations.

Energy Conservation

Energy consumption at your plant for the twelve month period from October 1993 through September 1994, consisted of:

4,303,202kWh of electricity (14,684 x 10^6 BTUs)

423,830 Therms of natural gas (42,383 x 10^6 BTUs)

This is equivalent to 57,067 million BTUs of energy. The energy costs for the period were $366,580 with unit energy costs averaging $0.059 per kW for electricity and $0.267 per Therm for natural gas.

The eight assessment recommendations related to energy described in this report, considered independently, could provide a net savings of about $167,868 each year, or about 46% of your total energy usage. However, due to the law of diminishing returns, your actual savings would be less. Our estimated costs for implementing the recommended energy conservation measures translates into an average payback of less than 3.2 years.

#	Energy Assessment Recommendation	Fuel Conserved	Energy Savings BTU x 10**6**	Annual Cost Savings	Payback (Years)
1	Insulate Steam Lines	Natural Gas	385.6	$1,041	1.3
2	Use Synthetic Lubricants	Electricity	264.4	$4,572	-
3	Install Personnel Access Door	Natural Gas	173.4	$463	1.5
4	Replace Compressors with a Gas Unit and Utilize Heat Recovery	Electricity and Natural Gas	505 334	$8,732 $890	1.2
5	Install Piggy Back Motors on Cooling Towers	Electricity	30	$513	1.7
6	Install Air Curtains	Electricity and Natural Gas	125.3 153.1	$2,166 $409	0.36
7	Install Packaged Cogeneration	None	None	$144,532	3.4
8	Install Desuperheater	Natural Gas	1,685	$4,550	2.1

Table 3.1: Energy Assessment Recommendations

Waste Minimization

The one assessment recommendation related to waste described below can save $21,760 with varying paybacks depending upon the type of implementation.

#	**Recommended Measures**	**Waste Stream Components**	**Projected Annual Reduction (gal/yr)**	**Net Cost Savings ($/yr)**	**Payback (Years)**
1	Install Water Treatment Station	Waste Water	None	$21,760	4.2-10.6*

* Depends on the manufacturer price of and features of different systems

Table 3.2: Waste Assessment Recommendation

Example of Incorporation of Waste Information in Process Description

Manufacturing Process Overview

The principal products produced in this plant are shift levers, shift fingers, remote control housings, shift towers, shift rods, clutch relief yokes, and bearing caps. Raw materials for production include several grades of steel, iron and aluminum castings, 5/8" and 2" diameter steel rods and steel tubing.

The castings arrive in cardboard boxes, approximately 75% of which are lined with plastic. Most boxes are banded with either plastic or metal bands. Plastic banding and used cardboard boxes are discarded in the municipal refuse.

To produce the assorted products, the castings are removed from the boxes and are transported by small push carts to the appropriate milling, drilling, tapping and grinding machines. The metal waste from the metalworking operations and metal banding are deposited in a designated trash container and shipped off-site for recycling. Most of the metalworking machines utilize a "wet process" with circulating coolant. Coolant in individual machines is replaced using a "Yellow Bellied Sump Sucker" when the operator of the machine concludes that the coolant is no longer effective. Oil skimmed off coolant reservoirs, along with contaminated hydraulic oil, is pumped into a waste oil containment system, and is hauled off-site in bulk on a monthly basis.

After the castings are machined to specification they are categorized into one of three groups. The first group of parts is washed in a single immersion tank and washer, then removed, allowed to air dry and placed in cardboard boxes. This parts group is subcontracted out for off-site heat treatment, then returned and put in storage or transported to the assembly area. The second group of components is washed in the same manner as the first group, allowed to air dry, then heat treated on-site using a 25kW induction heat-treater, and finally transferred to storage or an assembly areas.

Used transmissions to be remanufactured are usually received in a relatively oily and debris-contaminated condition. Therefore, complete used transmissions are initially placed in a "Storm Vulcan" washer. This high temperature, high-pressure washer thoroughly cleans the transmission exteriors before disassembly. The cleaning solution is changed twice a year, with the entire volume of cleaning solution placed in drums and disposed of as a hazardous waste. This washer produces a waste water stream on the magnitude of eight drums per year. Once the transmissions are disassembled using hand-held air tools, they are remanufactured using new gaskets, original parts in good condition, and new parts produced in the plant to replace broken or worn out parts. Some assembled transmissions are painted and then tested on one of two test stands for normal operation before crating for shipment to customers.

Breakdown of Handling Labor and Record Keeping Costs

Total estimated handling labor costs associated with all waste streams:
($6/hr)(2 workers)(8 hr/day)(5 day/wk)(52 wk/yr) ≅ $25,000/yr
Total estimated handling labor costs associated with all waste streams:
($25/hr)(1 employee)(1 hr/2 wks)(52 week/year) ≅ $ 700/yr

Total estimated handling and record keeping costs: ≅ $25,700/yr

Waste Stream	Quantity Generated Annually (lbs)	Raw Material Replacement Cost	Estimated Handling Labor and Record Keeping Costs*	Off-Site Removal Cost	Total Annual Cost
Waste wood	36,200,000	$0	$269,750	$1,128	$270,878
Toner and Washcoat Overspray	21,364	$22,880	$3,250	$0	$26,130
Toner and Washcoat VOC Evaporation	152,886	$163,730	$3,250	$0	$166,980
Lacquer Overspray	21,346	$14,300	$3,250	$0	$17,550
Lacquer VOC Evaporation	152,866	$102,300	$3,250	$0	$105,550

*Handling labor and record keeping costs have been estimated from experience with other plants

Table 3.3: Total Cost Associated with Waste Streams

Quality Technical Tools for P2

- Pareto Chart: Bar graph to Prioritize data
- Ishikawa Diagram: Cause and Effect of "Fishbone"
- Histogram: Frequency Distribution of Data
- Scatter Diagram: Groupings, Bimodality
- Check Sheet: Tabulation of Results
- Shewhart Control Chart: Analysis of Variation; Control limits
- Stratification of Data

Status	Waste Stream	% of Total Handling Labor and Record Keeping Costs*	Estimated Annual Costs
Landfilled	Waste Wooden pallets	24%	$6,168
	Waste dry glue	1%	$257
	Waste wood (pieces)	6%	$1,542
	Waste cardboard	10%	$2,570
	Paint Overspray	2%	$514
	General landfill trash	6%	$1,542
Recycled	Waste metal banding	1%	$257
Shipped off-site at no cost	Waste wood (sawdust)	50%	$12,850
	Total =	**100% =**	**$25,700**

*Percentages based on estimations by plant personnel and staff experience with other plants.

Table 3.4: Handling Labor and Record Keeping Costs Breakdown

3.1.3. Electric Bills and Rates

The structure of electric bills differ from region to region. Traditionally, utility companies have been regulated by the Public Utility Commission or Public Utility Board of a particular state of operation. Approval was needed for any rate change and was subject to reviews confirming the necessity of such change. The rates reflected the requirement to maintain a sound financial condition of a utility company and also to pay a "reasonable return" to the shareholders. De-regulation of the industry is likely to change these structures forever.

The Electric Bill Components

1. Components Of Your Electric Bill

- Customer Charge
- Demand Charge
- Energy Charge
- Reactive Demand Charge
- Sales Tax

2. What Is Included In The Customer Charge

- Fixed monthly amount
  Designed to recover:
  - Service drop - wires from transformer to connection on building.
  - Meter.
  - Billing, credit and collection and related costs.
  - Customer service - costs to encourage safe, efficient and economical use of electricity.

3. What Is Included In The Demand Charge

- Generally based on highest 15-minute integrated kW consumption. Sometimes “ratcheted” to represent highest yearly demand.

  Designed to recover:
  - Investments in generating plants.
  - Investments in transmission system - 345,000, 115,000 & 34,500 volt lines and substations.
  - Investments in distribution system - all voltages below 34,500 volts, including distribution transformer.

4. What Is Demand)?

   A. Assume: Fifty (50) - 100 watt light bulbs.
      All 50 bulbs are on at the same time.
      50 bulbs x 100 watts each = 5000 watts
   B. Total Demand (Load) on System:
      5000 watts/1000 = 5 kilowatts (5 kW)

5. What Is Included In The Energy Bill

- Price per kWh designed to recover:

  - Variable costs to generate electricity
  - Oil costs
  - Nuclear fuel costs

  Varies with voltage levels due to losses

(See Electricity section for an example of a typical electric bill.)

Load Factor is a useful method of determining if the manufacturer is utilizing their energy consuming equipment on a levelized basis, or using the equipment for a short duration, thereby paying a demand penalty. The following figures show examples of different loads, and load factor calculations.

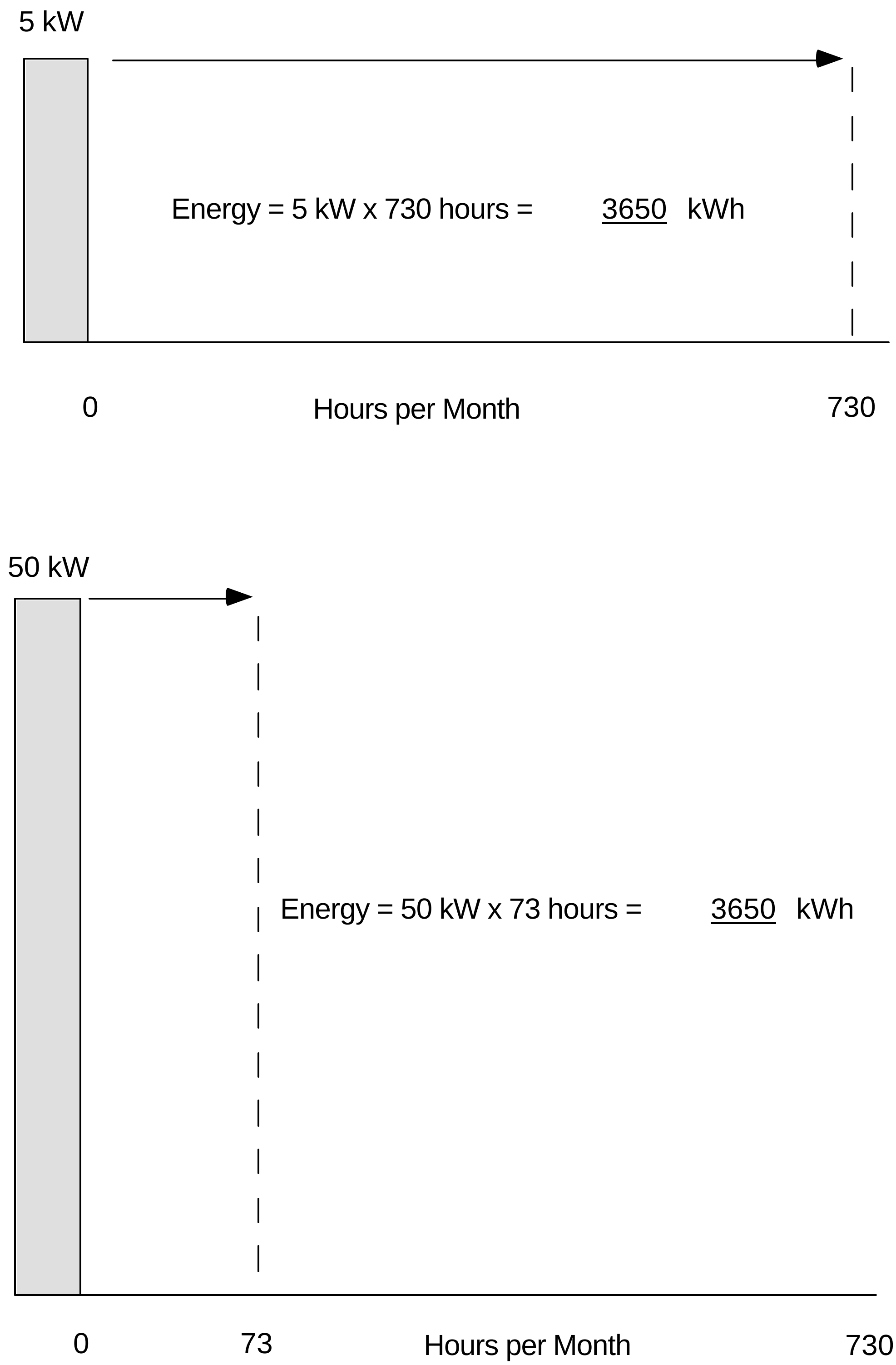


Figure 3.1: Relation of Demand (kW) to Energy (kWh)

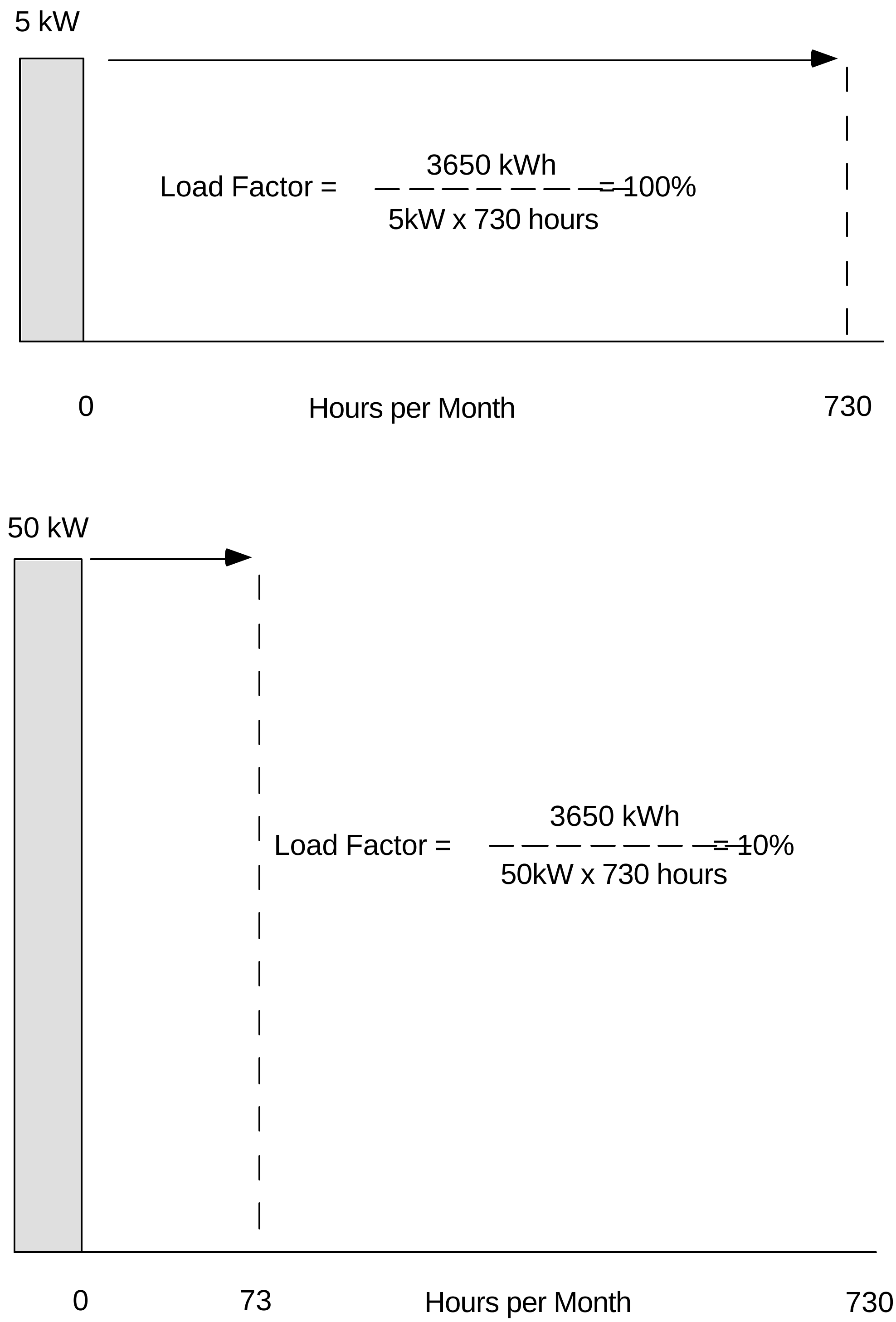
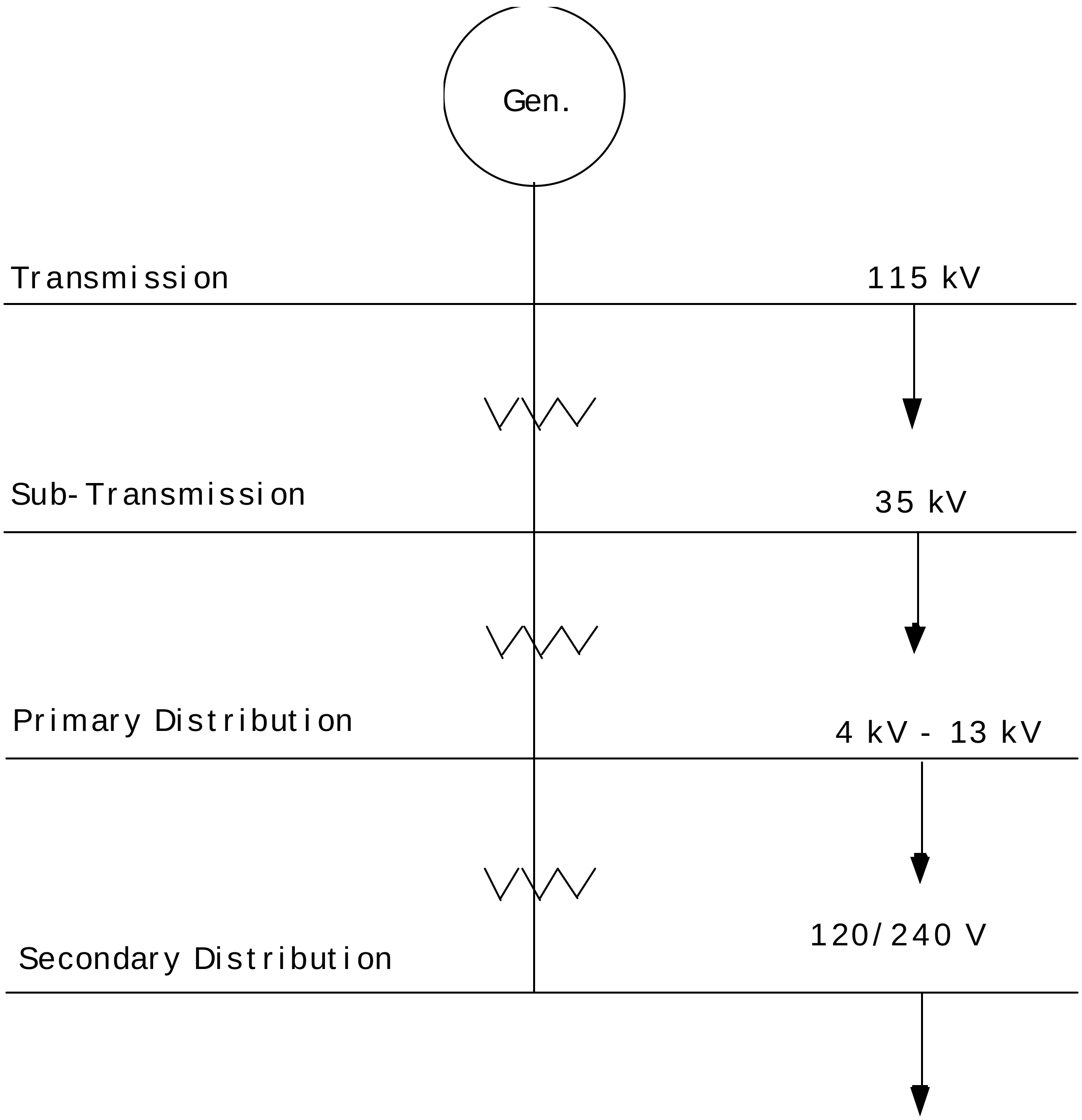


Figure 3.2: Load Factor

Load Factor = kWh used in period / (max kW x hours in period)

Elements of a Utility System



Costs vary with the voltage level.

Figure 3.3: Power Transmission

SOURCES (kWh)	1997	1973
Coal	50 %	45 %
Nuclear	18 %	5 %
Hydro	9 %	14 %
Oil	2 %	17 %
Natural Gas	8 %	18 %
Non-Utility Generators	12 %	n/a
Other	< 1 %	< 1 %
Total	100%	100%

source: Monthly Energy Report

What Is The Reactive Demand Charge?

- An amount per kVAR of reactive demand in excess of 50% of monthly demand (for example, LGS is 50% of first 1,000 kW of monthly on-peak kW demand and 25% of all additional monthly on-peak demand).
- No kVAR billing unless power factor below 90% (higher for customers with demands in excess of 1,000 kW).
- Designed to recover the difference of the cost between real power produced and apparent power consumed.

Sales Tax

- If electricity is used in a manufacturing process, customer can get an exemption for majority of sales taxes. It is advantageous for the community to have the tax incentives in order to preserve or help manufacturing in the area.

3.1.4. Examples of Gas Bills and Gas Rates

Unlike electric charges (discussed in detail in Electricity section), gas utility bills are very simple to read. In the following section a typical example of a monthly gas utility bill is introduced.

Terminology and the Bill

1. The service period on a monthly basis.

2. The rate schedule and terms used.
   Gas company rate are based on the following priority schedule:

- GN-1 is for residential and small industrial users consuming less than 100,00 cubic feet of gas per day.
- GN-2 is for industrial users consuming over 100,000 cubic feet per day and who have standby fuel capability.

3. The actual month's consumption in cubic feet of gas.
   - The billing factor is the actual heat content of the gas (can vary depending on location).
   - The final column is the amount of therms used for the month.
   - Meter units are 100 cu. ft. (i.e., example equals 3,806,000 cu. ft.).

①

Service Period	
06-18-79	07-18-79

Service Address: ____________________

②

Rates	Therms	
GN-1		
GN-2	17,667	
GN-3	22,486	
Total	40,153	$9,760.09

③

Meter Number	Meter Readings Previous	Meter Readings Present	Difference	Billing Factor	Therms
2345678	917920	955980	38060	1,055	40,153

Our hypothetical bill is interpreted as follows:

1. Gas consumption @ GN-2 rate = 17,667 therms
2. Gas consumption @ GN-3 rate = 22,486 therms
3. Total gas consumption = 40,153 therms

4. Difference in meter readings = 3,806,000 cu. ft.
5. Btu content of gas = 1,055 Btu/cu. ft.
6. Amount of therms used per month
   = (3,806,000 x 1,055) / 1000,000 = 40,153 therms

1 therm = 100,000 Btu

Actual BTUs consumed = 40,153 x 10^5 Btu

In-Plant Metering

The monthly gas bills show how many Btu's have been expended to produce a product, heat a building, etc. However, the bill does not indicate where the Btu's were used in a particular gas consuming process.

As the nation's energy requirements grow, industry can expect to pay even more for gas in future years. Plants that will remain dependent upon gas for their production processes will be placing even greater emphasis on in-house conservation efforts in order to achieve maximum production efficiency from this increasingly expensive fuel. Cost allocations within departments and fuel surcharges to customers will become commonplace. Close monitoring of allocated supplies will become a necessity in energy management.

The basic and most important tool in energy management is an energy monitoring system. Before energy can be saved, an accurate metering system must be established in the plant to determine exactly how and in what quantities energy is being used; considerable savings can be realized almost immediately from the data derived from an energy audit using in-plant metering. Gas consumption monitoring can also be advantageously used to control oven or furnace temperatures and prevent over-temperature damage.

Measuring fuel consumption alerts maintenance crews to a variety of potential problems such as:

- Leaking fuel lines.
- Faulty temperature measuring devices.
- Faulty relief valves.
- Excessive burner cycling.
- Warped furnace doors.
- Deteriorating furnace insulation.

A relatively low cost monitoring device is the "Annubar". This device is a primary flow sensor designed to produce a differential pressure that is proportional to the flow. The flo-tap annubar can be inserted and removed from operation without system shut down. It can be interfaced with secondary devices, a standard flow meter is available for rate of flow indication. It can also be used as a portable meter or permanently mounted one. Annubar connected to a differential pressure transmitter (electric or pneumatic) is used with a variety of standard secondary equipment for totaling, recording, or controlling complex systems.

3.1.5. Fuel Oil Rates

Fuel oil is supplied by a private contractor. The price is negotiated before the season or period of interest to both parties. The supplier is obligated to provide the oil to the customer for an agreed upon period (typically a year). The price is fixed for an estimated amount of consumption and provides for an adjustment if supplier's costs change during the period. The supplying company might require a minimum purchase, called "allotment", in order to maintain the required service as well as the price. It is noteworthy to point out that some customers may decide to burn more fuel than necessary for the operations just to preserve their pricing.

The normal way of calculating the average cost of oil is simply the total money spent divided by volume purchased.

In the United States three types of fuel are available. The most expensive oil is No. 2, 138 000 Btu/gallon. A little cheaper option is No. 4, 142 000 to 145 000 Btu/gallon and the cheapest is No 6, 149 690 Btu/gallon. It is important to keep in mind that the fuels are not interchangeable because the combustion equipment is designed for only one type of fuel. Different fuels also have to be handled differently, for example No. 6 fuel requires heating to flow. A very detailed information about equipment, characteristics of fuel oils and exact Btu content is available from individual suppliers.

The Fuel-Adjustment Charge

The fuel-adjustment change permits the utility companies to adjust the total cost for producing electricity due to increased fuel costs, without making a request for a rate increase.

3.2. METHODS FOR ENERGY AND WASTE

Energy or waste costs savings can be calculated in many different ways. Which is the most appropriate model sometimes depends on the level of detail desired, tax structure of the state or service charge structures of utility or waste removal company. The proper model has to be carefully selected and an assessment team member must know why a particular method was employed. If simplifications are made, they have to be justifiable.

3.2.1. Estimates of Project Costs

Cost estimates for energy or waste reduction projects do not differ much from any other cost estimates for engineering projects. The regular cost estimating procedures will prove adequate. The usual way of employing standard engineering data, using available catalogues or books (Means Construction Cost Data or Dodge Unit Cost Data for example), obtaining estimates from contractors and manufacturers or recommended consulting firms are all legitimate means for getting the information necessary to make a qualified decision about an energy or waste savings measure.

A detailed flowchart of activities involved and bill of materials required is the best starting point. The more detail provided before beginning the work the better chance for success for the whole enterprise. If the project is not well defined, flexibility must be allowed for contingencies and unexpected complications. Also, contractors can be much more specific thus more realistic with their proposals. Not negligible is the fact that the cost can by also better tracked by the customer.

One of the most important factors during the proposal process clearly lies in the ability to demonstrate the benefit of proposed changes. Characteristically, the most important revelation lies in an attractive rate of return, return on investment or simple payback period. Fiscal data gathered and presented must represent reasonable forecasts of the cause and effect relationship from implementing energy, waste or production recommendations. Accurate forecasts, however, are not easy to come by but may be reasonably defended if the typical data calculations include ratios, percentages and logically estimated values as in the case of price projections. The assessor is urged to exercise extreme caution when prognosticating fluctuations in inflation, material and labor costs while calculating implementation values. While difficult for persons new to on site industrial assessments, experience provides valuable educational lessons as confidence grows during these excursions by the engineer into the financial world.

3.2.2. Payback Periods

As with most company decisions, an energy project's feasibility will be evaluated in conjunction with its financial impact. Payback period calculation provides a quick feasibility analysis and for that reason occupies status known as "common practice". More sophisticated analysis should be employed if either greater detail requirements indicate or the assessor believes simple payback to be inadequate for decision making under particular circumstances.

Waste Minimization AR Write-Up Example for Cardboard Recycling

Current Practice and Observations

A substantial amount of corrugated cardboard is generated by packaging of incoming raw-materials, supplies, and other parts used in the manufacturing process. Cardboard waste is not currently being segregated and recycled. It is disposed with other solid waste and hauled to the municipal landfill. The estimated amount of cardboard generated at this facility is 15% of the total solid trash volume. This estimate is based on observation of the dumpsters. The annual volume of trash hauled to the landfill is about 4,000 cubic yards per year as determined from the trash bills. The bills also indicate a unit disposal cost of $2 per cubic yard.

Recommended Action

A recycling program for corrugated cardboard should be implemented. Segregate the cardboard into a separate dumpster and deliver it to a recycling center.

Anticipated Savings

The annual solid waste volume reduction and the estimated annual solid waste savings are calculated as follows:

$$SWRV = PC \times CTV$$
$$SWS = SWRV \times UCD$$

where:

SWS	=	Solid waste savings, $/yr
PC	=	percent of solid waste which is cardboard, 15% (estimated)
CTV	=	Current annual solid waste volume, 4,000 yd3/yr
UCD	=	Unit cost of solid waste disposal, 2 $/yd^3.
SWRV	=	Solid Waste Volume Reduction, yd^3/yr

$$SWRV = 0.15 \times 4{,}000\ yd^3/yr = 600\ yd^3/yr$$
$$SWS = 600\ yd^3/yr \times 2\ \$/yd^3 = \$1{,}200/yr$$

<u>Implementation</u>

The cost of recycling the cardboard is based on discussions with a waste management company. The cost to haul one 30 cubic yard dumpster to a recycling center, dump it, and return the dumpster is estimated as $165 per trip. The recycling center pays about $55 per ton of cardboard and a 30 cubic yard dumpster holds about 3 tons of cardboard if the boxes are broken down flat. The cost of hauling is thus equal to the recycle credit. The only other requirement is that plant personnel responsible for solid waste removal to the dumpster must be trained to separate out the cardboard and break down the boxes.

There is no associated implementation cost and the payback is immediate.

<u>Simple Payback = immediate</u>

3.2.3. Methods for Financing Conservation Projects

Energy conservation and pollution prevention projects, as with all projects proposed, indicate analysis requirements pertaining to cost and financial implications. Company management as a matter of course determine a set of parameters or benchmarks which have to be met for project approval. Upon passing the initial hurdle (perhaps by achieving the simple payback goals), projects move to the next tier and subjection to further scrutiny along with other plans up for adoption for ranking in order of greatest financial potential.

Capital Budget

Probably the most common form of financing conservation, minimization or prevention projects requires a charge to the company's capital budget. These projects compete equally with other pending projects for available funds. Project acceptance occurs when the defined set of financial indicators (typically financial ratios) falls in line with corporate policy. Financial return examination requires a most advantageous outlook but, if found acceptable, project funding through capital budgeting risks little more than the original principal. The best possible cash flow continues as there is no repayment of loans and no future obligation of capital. If the project fails to achieve the expected goals, the company may suffer slightly in profit/loss accounting but only for the year of the cash outlay. Subsequent years' profits remain unaffected.

Leveraged Purchase

Borrowing money = maximum risk incurred = paying later for current expenditures = corporate debt secured from banks or other financial institutions. Maximum risk because the loan security equals the financial credit of the borrower. Less than expected return requires the money be made up from corporate resources for the entire term of the debt. Indebtedness must be reported on financial statements and the company benefits from limited tax advantages as only the loan interest is tax-deductible.

Leasing

An energy or waste project can be leased instead of being purchased. The simplest way is just in the form of a rental. A lessee pays a lessor an agreed upon sum of money for the use of the project. The savings should, of course, exceed the rent and therefore the lessee experiences a positive cash flow. The leasing does not have full tax deduction.

Shared Savings

An energy service company supplies, installs and maintains the energy project for which it shares project's savings with the client. There is no cash investment on part of the buyer, no maintenance cost associated with the project and the positive cash flow is immediate. There is a tax advantage in this scenario.

3.2.4. Comprehensive Simulated Assessment

- Client Selection: Waste-Related Issues (if industrial assessment)
- Energy and Waste-Related Information and Data
- Process Flow Diagram
- Preparations for Plant Visit
- Brainstorming: Ideas, Data Needed
- Analysis

- Assessment Recommendations

Client Selection: Waste-Related Issues

Hazardous Waste:	How much is generated?
Generator Status:	What are the costs?
Current Waste	Storage
Activities:	Treatment
	Disposal
	Tracking and Reporting
In-House Expertise:	Most small plants have part-time hazardous waste part-time person
Potential for Successful	
Outcome:	Client's motivation regarding pollution prevention policy measures
	Already tried/implemented involvement with production
	Specific problems/concerns relationship with regulators,
	access to facilities, data
Educational:	Quality of learning experience

Energy and Waste Related Information and Data

Products:	Coated metal and plastic parts
Electrical and Gas Bills	app. $100,000/yr
Raw Materials:	Paints, Coating, Solvents, Reagents, Parts
Wastes:	610,000 gal/yr Waste Water
	660 gal/yr MEK (Haz)
	40 gal/yr Paint Wastes (Haz)
	1,290 lb/yr Solvent Air Emissions
	300 lb/yr Paint Booth Filters
Waste Costs:	Approximately $15,000/yr
Already Implemented:	One HVLP Paint Gun
	Flow Reducers Flowing Rinses

Preparations for Plant Visit

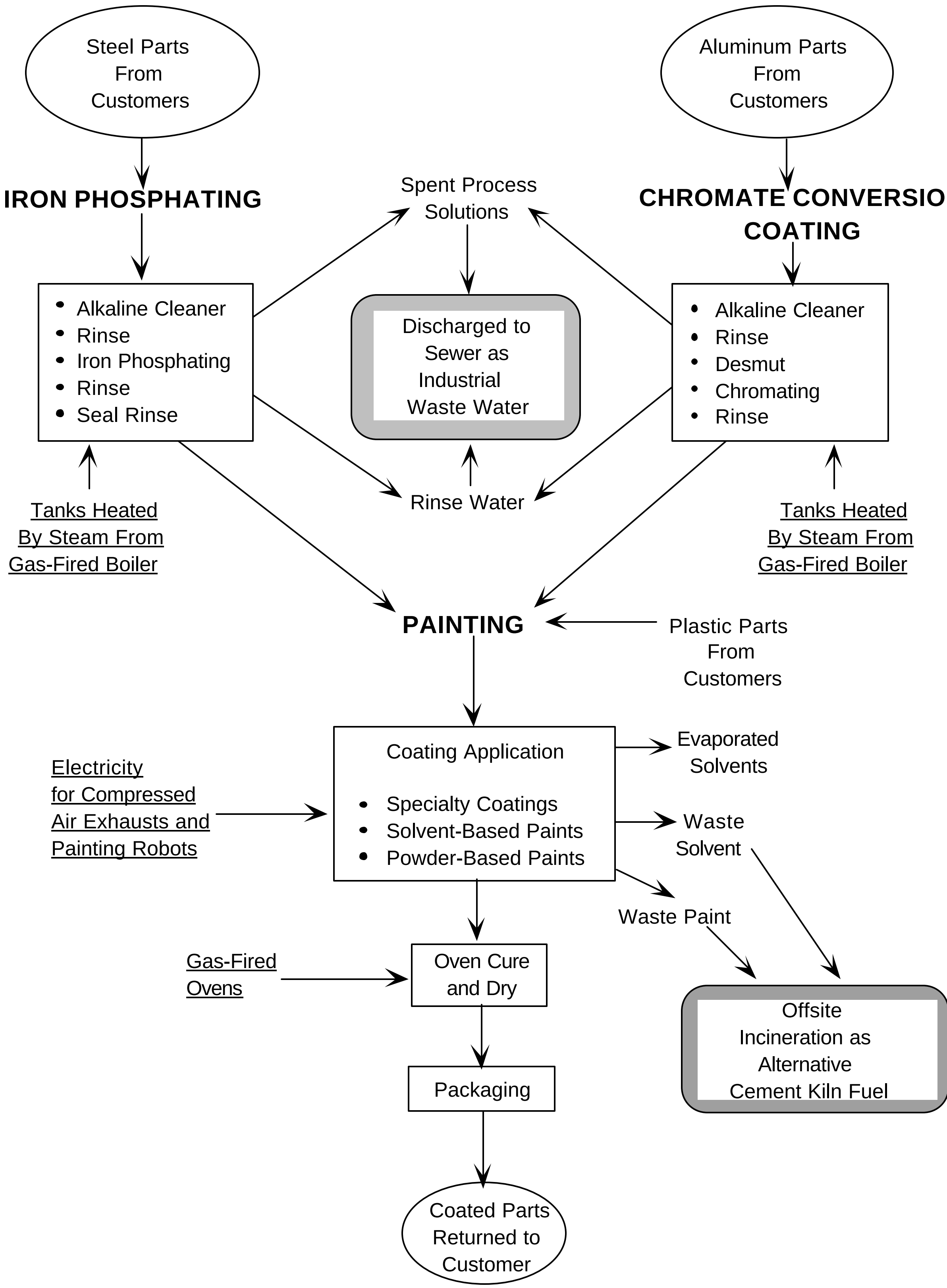
- Request: Electric bills, water and sewer bills, gas bills, hazardous waste manifests and invoices, paint and solvent purchase records POTW agreement.

- Personnel:

Personnel:	John A	Group Leader
John B	Group Leader Assistant	
	John C	Team Member
	John D	Team Member
	John E	Team Member

- Review: Paint application technology safe solvent product files iron phosphating process chromate conversion process enclosed paint gun washer file solvent recovery unit file.
- Discuss: Safety issues, equipment needs.

Process Flow Diagram



Brainstorming: Energy and Waste Reduction

IDEA	DATA
Use Energy Efficient Lights	Manufacturer's data
Insulate Steam Pipes	Calculations and manufacturer's data
Adjust Boiler Air/fuel Ratio	Measurements
HVLP Paint Guns	Paint consumption, costs
Solvent Recovery Unit	Spent solvent volume, Purchase and disposal costs
Replace MEK	Spent MEK volume, Purchase, Disposal, Replacement costs
Reduce Dragout	Observation of line operations, Estimates for dragout volumes Invoices for Reagent amounts and costs
Reduce Water Consumption	Water and sewer bills, determine locations for additional flow regulation, Interviews

Analysis of Waste Recommendations

HVLP Paint Guns

Replace five conventional paint guns with higher transfer efficiency HVLP paint guns. Paint transfer efficiency improves from 30% to 55%

PR = Reduction in paint consumed = 80 gal/yr
MR = Reduction in mixing materials consumed = 30 gal/yr
UPC = Average Paint Cost = $35.60/gal
UMC = Average Mixing Material Cost = $26.90/gal
PFS = Paint Booth Filter Savings = $1,450/yr

Savings = S = (PR)(UPC) + (MR)(UMC) + PFS

S = (80)(35.60) + (30)(16.90) + 1,450

S= $4,805/yr

Implementation Cost: $400/HVLP Paint Gun

IC = (5)(400) = $2,000 Payback = 2,000/4,805 = 0.42 yr

Solvent Recovery Unit

Distill and reuse parts cleaning solvent, MEK. The recovery factor for a commercial, 15 gal unit is 75%.

- Current waste generation and costs

  Volume spent MEK currently generated = 660 gal/yr
  PC = MEK purchase cost = $3.15/gal
  DC = Waste MEK disposal cost = $3.63 gal
  CAC = Current annual costs = (660)(3.15 + 3.63)
  CAC = $4,475

- Projected costs with solvent recovery unit

  NB = Number of batches = 660/15 = 44/yr
  CW = Cooling water required = 4,620 gal/yr
  WC = Water cost = $10/yr
  EC = Electrical cost = $40/yr
  LC = Labor cost = $550/yr
  LNC = Boiler liner cost = $132/yr
  SBDC = Still bottoms disposal cost increment = $2.91/gal
  EPC = Equipment purchase cost = $6,700
  EIC = Equipment installation cost
  WPC = Waste Profile cost

  OC = Annual operating cost = 10 + 40 + 550 + 132 +480
  OC = $1,212/yr
- Annual Savings

  S = (0.75)(4,475) - 1,212 = $2,144/yr

- Implementation Costs

IC = 6,700 + 200 + 300 = $7,200

- Simple Payback Period

P = IC/S = 7,200/2,144 = 3.4 yr

Replace MEK for Cleaning Parts

Replace MEK with a less hazardous parts cleaning solvent. The replacement is a hydrocarbon blend with lower vapor pressure and higher flash point. A dedicated parts cleaning appliance will be required. Periodic solvent addition and recharging will be needed.

- Current Waste Generation and Costs

Volume of spent MEK currently generated = 660 gal/yr
MEK purchase cost = $3.15/gal
Waste MEK disposal cost = $3.63/gal

- Projected Annual Costs

Dragout, evaporation, and annual 5 gal recharge:
(est. 0.25 gal/mo)(12 mo/yr) + 5 gal/yr = 8 gal/yr
(8 gal/yr)($19.60/yr) = $157/yr

- Raw Material Savings
RMS = (660)(3.15) - 157 = $1,922/yr

- Waste Disposal Savings
WDS = (660)(3.63) = $2,396/yr

- Total Savings

S = RMS +WDS = 1,922 + 2,396 = $4,318/yr

- Implementation

30 gal UNIT: $1,300 Freight: $150
Installation $1,200

IC = Implementation cost = 1,300 + 1,200 + 150 = $2,650
Simple Payback Period = 2,650/4,318 = 0.6 yr (7.3 mo)

Summary of Assessment Recommendations

ASSESSMENT RECOMMENDATION	**ANNUAL SAVINGS**	**IMPLEMENTATION COST**	**PAYBACK PERIOD**
1. Efficient lighting	$3,480/yr	$3,320	1.0 yr
2. Insulate steam pipes	$270	$270	1.0 yr
3. Adjust boiler a/f	$220/yr	$750	3.4 yr
ASSESSMENT RECOMMENDATION	ANNUAL SAVINGS	IMPLEMENTATION COST	PAYBACK PERIOD
4. HVLP paint guns	$4,805/yr	$2,000	0.4 yr
5. Solvent recovery unit	$2,144/yr	$7,200	3.4yr
6. Replace MEK	$4,318/yr	$1,450	0.3 yr

<u>Additional Measure Considered</u>

Install enclosed paint gun cleaning unit.

Advantage:	Reduce solvent consumption
Disadvantage:	8.3 payback period

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4 ELECTRICITY

4.1. ELECTRIC ENERGY

4.1.1. Definitions

In the following sections reference will be made to various terms; to enable a better understanding, the following identification is provided:

Ampere (Current): The ampere, the rate of flow of a unvarying electric current.

Coulomb (Quantity): The quantity of electricity conveyed by one ampere flowing for one second.

Farad (Capacitance): The farad is the electrostatic capacitance which will hold a charge at a pressure of one volt.

Joule (Energy): The joule is the energy conveyed by one watt during one second, the kilowatt hour (kWh) is one kilowatt hour flowing for one hour.

Voltage (Difference in Electrical Potential): The difference in electrical potential between two points in the circuit indicated the energy required to move charge from one point to another (1 Volt = 1 Joule/coulumb). One volt is required to produce one ampere in a resistance of one ohm. 1 kilovolt (kV) = 1,000 volts.

Volt - Ampere: The product of the rated load amperes and the rated range of regulation in kilovolts (kVA).

Watt (Power): The watt is the power generated by a steady current of one ampere at a pressure of one volt. The kilowatt (kW) = 1,000 watts. One horsepower = 746 watts.

4.1.2. Introduction

Listed below are five basic ways to reduce electric costs. Of these, only the first involves a reduction in energy consumption while the remainder detail some special situations not directly related to the quantity of electricity consumed but rather the cost of consumption.

1. Reduce Electrical Uses.
2. Power Factor Improvements.
3. Load Factor Improvements.
4. Electric Billing Verification.
5. Rate Structure Corrections.

4.1.3. Reduce Electrical Use

The detailed use of electricity will be discussed under the separate sections in this manual, but the conservation message can never be delivered too many times. Basically, electricity should be conserved, like any other resource, and not wasted, as in the simple but common example of lights or equipment consuming energy during periods when rooms remain unoccupied or production lines experience downtime. Corrective action requires cognizant, conscientious employees cooperating with energy-minded management to identify areas of waste and suggest conservation practices.

Distribution System

The electrical power distribution system, from the source to utilization points, consists of electric lines of varying sizes, switches and circuit breakers designed for maximum carrying capacity, transformers and protective equipment. As related to the total consumption at any industrial plant, this system usually involves losses of 3 percent or less. Consequently, rarely does any practical savings potential in transmission systems appear to warrant investment in conservation.

The voltage in an electric circuit will drop in proportion to the circuit resistance. Resistance varies with wire size, temperature and metallic material. Thus, as conductor losses increase, current necessary to deliver a given amount of power increases at any point in the circuit as power derives from the product of the voltage and current. This principle applies likewise to switches, circuit breakers, and protective equipment.

The question of energy conservation possibilities should be examined in relation to the individual components in the system. In the case of the transmission lines it can be shown that doubling the conductor sizes reduces resistance losses by 75 percent; however, usually savings do not justify the expense as conductor cost related to the total electric investment comes to about 10 percent. Because doubling the conductor sizes essentially doubles cost, the savings potential deserves little attention.

As previously mentioned, energy losses from switches, circuit breakers, and protective equipment also deserve minimal attention as replacement with more energy-efficient devices equalizes costs with benefits. However, in the case of defective contacts or other parts, malfunction may cause overheating and imminent failure of the part(s) causing an outage. Monitoring and inspection to diagnose abnormally high temperature operation of these items will help prevent costly power outages and subsequent downtime. Replacement with more energy efficient devices when failure occurs incrementally improves energy conservation with little or no expense over normal, less efficient practices. To sum up, the distribution system will offer few opportunities unless monitoring and replacement of parts before failure practices are observed saving on future electricity costs and preventing expensive downtime.

Transformers do represent an area of potential savings during the condition of lightly loaded equipment. Shrinking loads or incorrectly forecasted plant expansions often manifest themselves during transformer examination by the industrial assessor. Unloaded motors incur no-load losses continually, as do transformers, although newer model transformers adjust based upon loading conditions. Older transforms incur continual power losses on the basis of full-load rating, not that of the load served and the industrial assessor investigates the possibilities of redistributing existing loads to permit scrapping of under-loaded transformers. Implementation decisions must allow favorable comparison of the cost of both installing new connecting cables and disposal of existing equipment with power savings from the elimination of no-load transformer losses. For the case involving older transformers disposal cost should be compared with not removing the equipment, later removal and future growth of waste disposal costs, and the cost of emergency disposal if an explosion damages the transformer. Close examination of the materials within the transformers for hazardous and poisonous substances for inclusion in the energy conservation and pollution prevention write-up will help present the entire picture and consequence scenario to the client.

Use of Electricity in the Industry

Electrical energy use, commonly found in the following systems and operations, presents significant opportunities for exploration during the industrial assessment:

- Mixing operations
- Melting and refining metallic and non-metallic materials
- Holding molten material
- Material Transportation
- Cleaning and finishing (air compressors)
- Miscellaneous assembly equipment
- Computers and other controls
- Material handling
- Packaging operations
- Environmental controls
- Lighting
- Heating, Ventilation, and Air Conditioning

4.1.4. Power Factor

Power factor quantifies the reaction of alternating current (AC) electricity to various types of electrical loads. Inductive loads, as found in motors, drives and fluorescent lamp ballast, cause the voltage and current to shift out of phase. Electrical utilities must then supply additional power, measured in kilovolt-amps (kVA), to compensate for phase shifting. To see why, power must be examined as a combination of two individual elements. The total power requirement can be broken down into the resistive, also known as the real component, and reactive component. Useful work performance comes from the resistive component, measured in kilowatts (kW) by watt meter. The reactive component, measured in reactive kilovolt-amps (kVAR), represents current needed to produce the magnetic field for the operation of a motor, drive or other inductive device but performs no useful work, does not register on measurement equipment such as the watt meter. The reactive component significantly contributes to the undesirable heating of electrical generation and transmission equipment formulating real power losses to the utility.

Power factor derives from the ratio of real, usable power (kW), to apparent power (kVAR). During the industrial assessment recommendations toward reduction of the power factor in fact indicate reduction of reactive losses. To accomplish this goal, the industrial electricity user must increase the power factor to a value as close to unity as practical for the entire facility. The supplying utility should be consulted for the determination of the requisite amount of capacitance necessary for correction to the desired power factor. The number in the table is multiplied by the current demand (kW) to get the amount of capacitors (kVAR) needed to correct from the existing to the desired power factor. Mathematically, power factor is expressed as

$$PF = \frac{kW}{kVA}$$

Power factor can also be defined as the mathematical factor by which the apparent power is multiplied in order to obtain active power.

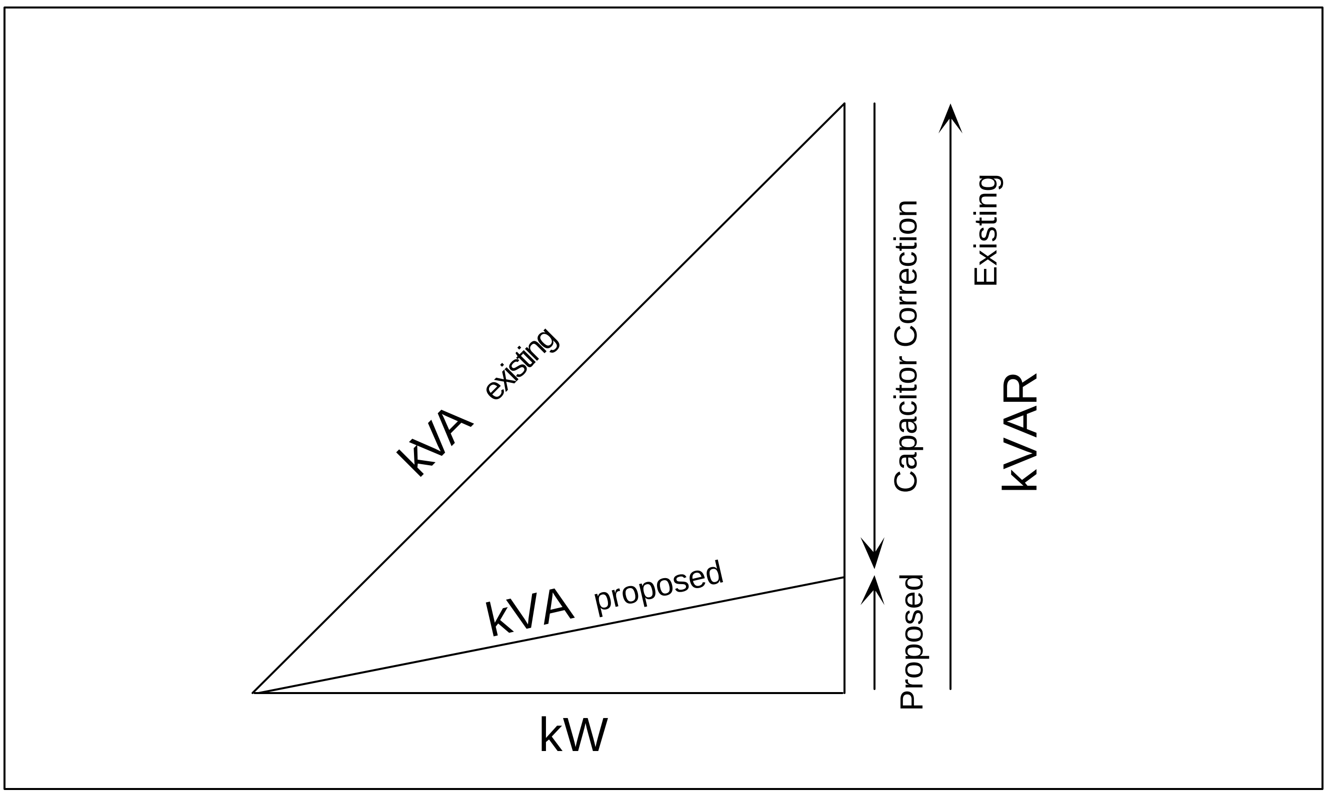


Figure 4.1: Components of Electrical Power

Example: Consider a 480 volt 3-phase system with an assumed load and instrument readings as follows: the ammeter indicates 200 amps and wattmeter reads 120 kW. The power factor of the load can be expressed as follows:

The apparent power for a 3-phase circuit is given by the expression

$$kVA = \frac{E \times I \times \sqrt{3}}{1000} = \frac{480 volts \times 20 amps \times 1.73}{1000} = 290.6 kVA$$

Therefore:

$$PF = \frac{kW}{kVA} = \frac{120}{290.6} = 41.2\%$$

From the above example it is apparent that by the decreasing power drawn from the line (kVA) the power factor can be increased.

Power Factor Improvement

Preventive measures involve selecting high-power-factor equipment. For example, when considering lighting, only high-power factor ballast should be used for fluorescent and high-intensity discharge (HID) lighting. Power factor of so-called normal-power factor ballast is notoriously low, on the order of 40 to 55 percent.

When induction motors are being selected, the manufacturer's motor data should be investigated to determine the motor power factor at full load. In the past few years, some motor manufacturers have introduced premium lines of high-efficiency, high-power-factor motors. In some cases, the savings on power factor alone can justify the premium prices charged for such motors. Motors should also be sized to operate as closely as possible to full load, because power factor of an induction motor suffers severely at light loads. Power factor decreases because the inductive component of current that provides the magnetizing force, necessary for motor operation, remain virtually constant from no load to full load, but the in-phase current component that actually delivers work varies almost directly with motor loading.

Corrective measures for poor power factor involve canceling the lagging current component with current that leads the applied voltage. This cancellation can be done with power-factor-improvement capacitors, or by using synchronous motors. Capacitors have the effect of absorbing reactive current on a one-to-one basis, because almost all of the current flowing through a capacitor leads the applied voltage by 90 degrees. A capacitor rated at 100 kilovolt-amperes capacitive (kVAC) will, therefore cancel 100 kilovolt-amperes reactive (kVAR).

Synchronous motors provide an effective method of improving power factor because they can be operated at leading power factor. Moreover, power factor of a synchronous motor to serve a load with actual power requirements of 1,000 kW, improves power factor on the load center from 80 percent to 89 percent. This improvement at the load center contributes to an improvement in overall plant power factor, thereby reducing the power factor penalty on the plant electric bill. The burden on the load center, plant distribution system, and entire electric-utility system is 400 kVA less than if an induction motor with a power factor of 85 percent were used. Power factor can be improved still more by operating the synchronous motor at leading power factor.

The Table 4.1 can be also used to determine the amount of capacitors needed to correct a power factor. The required amount of capacitors needed in (kVAR) can be determined from:

kVAR = D x CF

where

D = maximum annual demand, kW

CF = correction factor

EXISTING POWER FACTOR	**NEW POWER FACTOR**					
	1.00	0.95	0.90	0.85	0.80	0.75
0.66	1.138	0.810	0.654	0.519	0.388	0.256
0.68	1.078	0.750	0.594	0.459	0.328	0.196
0.70	1.020	0.692	0.536	0.400	0.270	0.138
0.72	0.964	0.635	0.480	0.344	0.214	0.082
0.74	0.909	0.580	0.425	0.289	0.159	0.027
0.76	0.855	0.526	0.371	0.235	0.105	
0.78	0.802	0.474	0.318	0.183	0.052	
0.80	0.750	0.421	0.266	0.130		
0.82	0.698	0.369	0.214	0.078		
0.84	0.646	0.317	0.162	0.026		
0.86	0.593	0.265	0.109			
0.88	0.540	0.211	0.055			
0.90	0.484	0.156				
0.92	0.426	0.097				
0.94	0.363	0.034				
0.96	0.292					
0.98	0.203					
0.99	0.142					

Table 4.1: Power Factor Correction

General Considerations for Power Factor Improvements

Poor power factor penalizes the user in three ways.

1. It robs the distribution system of capacity that could be used to handle the work-performing load.
2. It results in currents higher than necessary to perform a given job, thereby contributing to higher voltage drop and electrical system losses.
3. It can result in electric power billing penalties depending on the schedule terms.

A plant's power factor penalty can be determined from the monthly utility bills. The method of billing for low power factor varies widely among utilities. Often no penalty is imposed unless the power factor falls below a certain minimum, typically 85 percent to 90 percent. In other situations, a penalty is involved for any reduction below 100 percent. For this reason, each rate schedule must be studied separately to determine the potential savings involved for improving power factor.

Some equipment, such as high power factor lighting ballasts or synchronous motors, has inherent power factor improvement. With other equipment, notably induction motors, power factor is a function of the mode of operation. Operation of an induction motor below full load will significantly reduce the power factor of the motor. Therefore, motors should be operated close to full load for the best power factor. Power factor also becomes progressively lower for slower speed motors. For example, the decline in power factor below 90 percent for a 1,200-rpm motor is 1.5 times greater than for an 1,800-rpm motor; for a 900-rpm motor, the decrease is more than double that for an 1,800-rpm motor.

The use of power factor improvement capacitors is the simplest and most direct method of power factor improvement. Capacitors can be bought in blocks and combined to provide the required amount of capacitive reactance or individual capacitors can be installed at each motor. Capacitors already in use should be checked annually to ensure all units are operating. Inoperative capacitors negate the power factor improvement for which their installation was intended. Diminishing returns are realized as power factor approaches 100 percent. Generally, 95 percent (based on normal full load) is the economic break-even point in a power factor improvement program; up to this point, improvements usually show a good return on investment.

4.1.5. Electrical Demand / Load Factor Improvement

The plant's load factor should be analyzed to determine the opportunity for improvement. Load factor improvement is synonymous with demand control.

Potential Savings

The potential savings for demand limiting depends on such factors as

- The plant's profile (Variations in kW demand.)
- The availability of sheddable loads
- The rate schedule

Together these factors determine the relative importance of the demand charge to the plant's total electric bill. Controlling demand becomes more important if the schedule includes a ratchet clause that involves payment based on the highest peak occurring in the previous 12 months.

Definition

Load factor is the ratio of the average kilowatt load over a billing period to the peak demand. For example, if a facility consumed 800,000 kWh during a 30-day billing period and had a peak demand of 2,000 kW, the load factor is:

Load Factor = (800,000 kWh/720 hrs) / 2,000 kW = 0.55 or 55%

A high-load factor usually indicates that less opportunity exists for improvement because the load is already relatively constant.

System Analysis

The user will obtain the lowest electric cost by operating as close to a constant load as possible (load factor 100 percent). The closer a plant can approach this ideal situation, the lower the monthly demand charge will be. The key to a high-load factor and corresponding lower demand charge is to even out the peaks and valleys of energy consumption.

To analyze the opportunity for demand reduction, it is necessary to obtain data on the plant's demand profile. The demand profile is best obtained from the utility's record of the kW demand for each 15- or 30-minute interval. If no demand recording is made as a routine part of the billing procedure, the utility will usually install an instrument temporarily to provide the customer with this information. A plot of this data will show the extent of the peaks and valleys and indicate the potential for the limiting demand. If sharp peaks or an unusually high demand for one shift or short period occur, the opportunity for demand control should be investigated further. If the demand curve is relatively level, little opportunity exists for reducing demand charges by peak shaving. In order to level out peaks in the demand profile, it is necessary to reduce loads at these times. Consequently it is necessary to identify the various loads that could be reduced during periods of high demand. The major users of electricity will provide the most likely sources for limiting demand. Accordingly, a list of the largest users, their loads, and their operating schedules should be prepared. The smaller loads can be ignored as they will not be able to affect the demand materially. An examination of this list will often suggest which loads do contribute or are likely to peak demands. When the load pattern is not easily determined, a recording wattmeter can be installed at individual loads to provide a more detailed record of load variations.

Ways to Reduce Demand

Consideration of demand control often begins with automatic demand controllers. However, several other approaches should be considered first.

- Stagger Start-Up Loads:
  If a high-peak load is determined to result from the simultaneous start-up of several loads, such as might occur at the beginning of a shift, consideration can be given to staggering start-up of equipment to span two or more demand intervals.

- Reschedule Loads:
  Peak demands are usually established at particular times during the day shift. A review of the operating schedule may show individual loads can be rescheduled to other times or shifts to even out demand. This technique can provide significant gains at little or no cost. For example, operation of an electric oven might be rescheduled to the evening shift if the oven is not needed full-time. Another example is conducting routine testing of the fire pump during periods when peak demands are not likely to occur.

- Increase Local Plant Generation:
  When some electricity is generated by the plant, plant generation can be temporarily increased to limit demand. In some cases, any venting of excess low-pressure steam from the turbo-generator for short periods may represent a lesser penalty than the increased demand charge.

- Install Automatic Demand Control:
  After an investigation has been made of the above approaches, if an application for automatic demand control still appears to exist, a more detailed analysis of conditions should be made. The minimum peak demand that can be established will depend on the downtime that is acceptable without causing undue interference with normal operations and the available sheddable load.

To determine the extent of downtime necessary to achieve a given kW reduction, it is necessary to tabulate the size and frequency of peak demands. A sufficient number of months should be similarly studied to develop a representative profile. Seasonal or production variations may also exist although it is likely the variations in peak demands will remain relatively the same.

A suggested method of analysis is to tabulate the 10 to 20 highest peak demands occurring during a typical month in descending order, as shown in the example given in Table 4.2. In this case, limiting the demand to the lowest value shown (5,990 kW) would reduce the electrical demand by 330 kW. The monthly saving based on $9.40/kW would be $3,100, or on an annual basis, $37,200.

Date	Time	kW	kW Above 5990
May 10	10:00 a.m.	6320	330
May 24	10:30 a.m.	6220	230
May 14	11:00 a.m.	6145	155
May 5	1:30 p.m.	6095	105
May 20	2:30 p.m.	6055	65
May 15	10:30 a.m.	6025	35
May 15	10:00 a.m.	6010	20
May 8	2:00 p.m.	6000	10
May 9	2:00 p.m.	5995	5
May 13	1:30 p.m.	5995	5
May 5	2:00 p.m.	5990	--

Table 4.2: Highest Demands for Hypothetical Billing Period of May

To effect this reduction requires a total sheddable load of at least 330 kW. If additional sheddable loads are available, a greater reduction in peak demand can be considered. It should be noted that the task of eliminating a peak becomes progressively harder as the demand limit is set lower because the frequency of the peaks increases. For example, limiting the demand to 6,220 kW for a reduction of 100 kW from the peak demand requires shedding a total of 960 kW for 30 minutes over 10 separate occasions. In other words, in the second case it was necessary to shed a load almost three times longer for an equivalent reduction in demand. As further limiting of demand is attempted, progressively longer periods of equipment outage are required. A point is eventually reached where the interference with normal operation outweighs the benefits or no more sheddable loads are available.

To determine the sheddable loads, review the list of the larger electrical loads which have already been identified. These loads should be divided into two major categories.

1. Essential: Loads that are essential to maintain production or safety. Unscheduled shutdowns on these loads cannot be tolerated.

2. Nonessential or sheddable: Loads in this category can be shut down temporarily without significantly affecting operations or worker comfort. Examples of such loads are air conditioning, exhaust and intake fans, chillers and compressors, water heaters, and battery charges. Electric water heaters represent a load that can usually be shed.

The practical extent of peak shaving can now be determined based on the schedule of sheddable loads and the pattern of peak demands. The number and type of loads to be controlled will determine the type of demand controller needed. Automatic demand controllers are offered in a wide range of prices from several thousand dollars to tens of thousands of dollars. For different applications, the more sophisticated controllers may be necessary. For normal demand control, the less expensive controllers will be more than adequate.

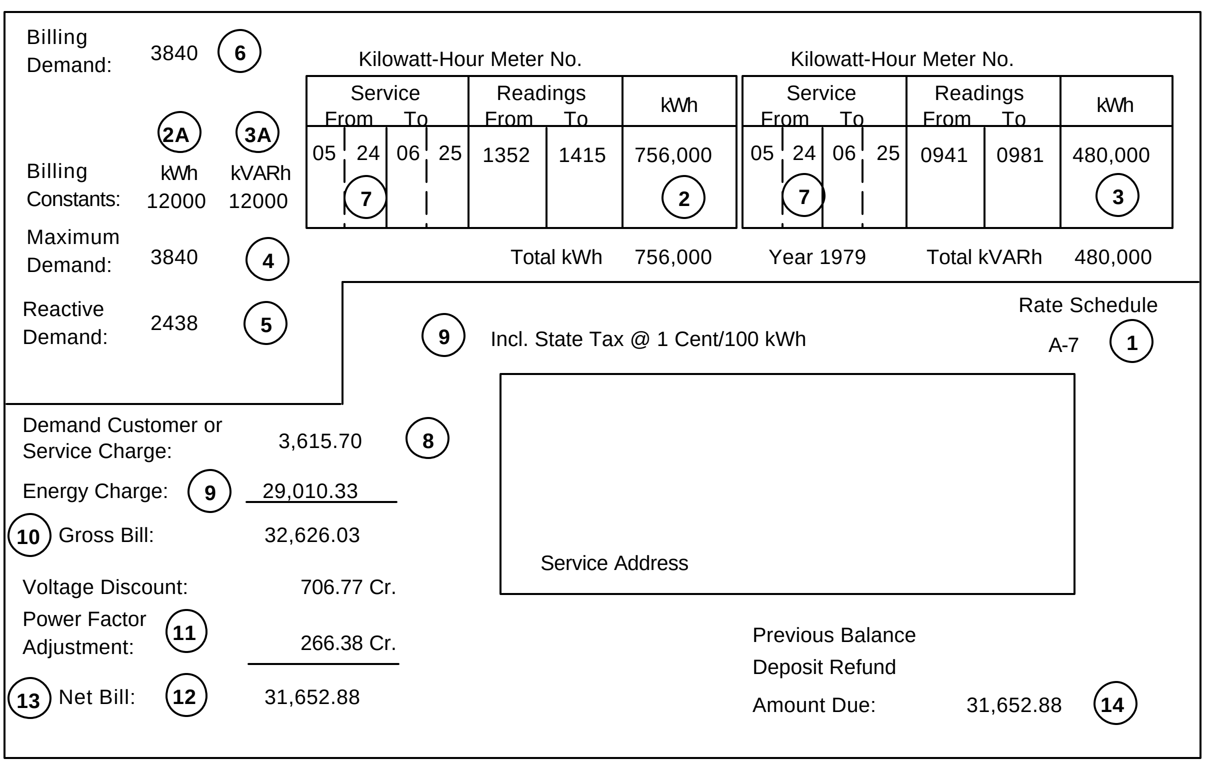
Annual savings can be calculated and compared to the costs of installing a demand control system. As part of the installation, demand controllers will require a pulse signal from the utility to synchronize the utility's demand interval with the demand controller's.

4.1.6. Reading the Bill

The cost of purchasing electrical power from utility companies is derived from four major factors; energy charge, fuel-adjustment charge, demand charge, and low power factor penalty.

Other incidental items which will affect the power charges are character of service, service voltage, and equipment charges. These are fixed charges.

Example of a Typical Electric Bill



1. The utility rate schedule A-7 is the key to analyzing the electric bill. It is normally included as part of the contract.

2. The energy used expressed in kilowatt-hours (kWh) is determined by the difference of two monthly meter readings times the billing constant (2A). The billing constants (2A) and (3A) are also described as “Meter Multipliers”. They are determined by the product of the current and potential transformer ratios installed at the particular location.

3. The reactive power used, sometimes called “wattless power”, expressed reactive kilowatt ampere hours (kVARh) is determined from a separate reactive meter similar to the kWh meter (2) above.

4. The maximum demand in kilowatts for the current month is read from a separate register on the kWh meter. The value is the largest quantity of kilowatts consumed during a time interval prescribed in the contract.

5. The reactive demand in kVAR is calculated from the formula kVAR = kW (kVARh/kWh).

6. The billing demand is the average of the maximum demand for the past 11 months and the current month’s demand. The minimum is half of the past 11-month value.

7. Date and time span of the current billing.

8. The service charge, as specified in the rate schedule, is based on the billing demand item 6 and the service charge, is also used as the minimum billing if the energy usage falls to a low value.

9. The electrical energy charge is based on the kilowatt hours used as shown in item (2). Certain adjustments are made to the energy charge determined from the meter readings as follows:

   a) Energy cost adjustment known as “ECAC” varies with the change in fuel cost to the utility.
   b) Fuel balance factor is usually a credit.
   c) Load management factor.
   d) State tax as indicated on the monthly bill.

10. The gross bill is the summation of items (8) and (9).

11. The voltage discount is available for services that are metered on the high voltage or primary side of the power company transformer. This discount is made to compensate for the utility transformer losses which are now included in item (2).

12. The power factor adjustment may be a penalty or a discount depending on the amount of reactive power, item (3), required by a plant. Power factor is defined as the ratio of the kW to kVA, sometimes stated as the ratio of “real power to the apparent power’. This value is not read directly

from the utility meters but must be calculated. A simpler method, using a hand calculator, is to solve as a right angle triangle where power factor (PF) is:

$$PF = \frac{kW}{kVA} = \frac{kWh}{RkVAh}$$

$$(kVAh)^2 = (kWh)^2 + (RkVAh)^2$$

This month's

$$PF = \frac{756000}{\sqrt{(756000)^2 + (480000)^2}} = 0.844$$

%PF = 100 x 0.844 = 84.4% Power Factor

On this rate schedule a power factor over 70.7% provides a credit; below a penalty, however, other utilities may use a different break even point - 85% is used by many.

13. City tax where applicable.

14. Net bill is the summation of all of the above charges, adjustments and credits.

4.1.7. The Energy Charge

Energy charge is based on the number of kilowatt hours (kWh) used during the billing cycle. The total kilowatt hours are multiplied by the energy charge for total energy billing. The energy charges can vary with the type of service, voltage, and energy consumption. Example energy rate schedules are as follows:

Example 1: General service schedule that is applied to electrical load demand of up to 8,000 (kWh) kilowatt hours per month. Thus a non-demand charge schedule, the cost of energy and demand are one charge.

Example 2: Rate schedule A-12 is applied to electrical load demand of 30 to 1,000 kilowatt of demand per month. This schedule has an energy charge, fuel-adjustment charge, demand charge, and low power factor penalty.

Example 3: Rate schedule A-22 is applied to electrical load demands of 1,000 to 4,000 kilowatt of demand per month. This schedule has an energy charge, fuel-adjustment charge, demand charge, and low power factor penalty. The rate schedule has a "time of day" billing rate for energy and demand for both summer and winter. The summertime hour periods are from May 1 to September 30; the energy and demand charges change between the following hours:

Peak hours - 12:30 pm to 6:30 pm = 6 hours
Partial peak hours - 8:30 am to 12:30 pm = 4 hours
Partial peak hours - 6:30 pm to 10:30 pm = 4 hours
Off peak hours - 10:30 pm to 8:30 am = 10 hours

The wintertime hour periods are from October 1 to April 30; the energy demand charges change between the following hours:

Peak hours - 4:30 pm to 8:30 pm = 4 hours
Partial peak hours - 8:30 am to 4:30 pm = 8 hours
Partial peak hours - 8:30 pm to 10:30 pm = 2 hours
Off peak hours - 10:30 pm to 8:30 am = 10 hours

Example 4: Rate schedule A-23 is applied to electrical load demands of 4,000 and above kilowatts (kW) of demand per month. All other charges and "time of day" billing hours and periods are the same as rate schedule A-22. Additional rates are available for the purchase of supply voltage of 4,500 or 12,000 volts, this schedule provides for a high voltage discount of the total energy and demand charges.

4.1.8. The Demand Charge

This charge compensates the utility company for the capital investment required to serve peak loads, even if that peak load is only used for a few hours per week or month. The demand is measured in kilowatts (kW) or kilovolt amperes (kVA). These units are directly related to the amount of energy consumed in a given time interval of the billing period. The demand periods vary with the type of energy demand; the high fluctuating demand has a short demand period which can be as short as five minutes, but generally demand periods are of 15 or 30 minutes. The period with the highest demand is the one used for billing demand charges.

> *Example*: If the demand for a plant is 70 kilowatts for the first 15-minute period, and for the next 15-minute period the demand increases to 140 kilowatts and then drops back to 70 kilowatts for the remainder of the billing period (one month), the billing demand for that month is then 140 kilowatts. This represents the interval of maximum energy demand from the utility company for the month.

Demand charges can be a significant portion of the total electric bill; in some cases, demand charges can amount to as much as 80 percent of the bill. The demand charge can be reduced by smoothing out the peaks in energy demand by rescheduling of work or through a demand control program to shed loads when a demand limit is approached. This concept is particularly important for plants using electricity for major processes such as melting.

4.1.9. Power Demand Controls

The power demand controller automatically regulates or limits operation in order to prevent set maximum demands from being exceeded. The role of such a power demand controller has been widely recognized, the “time of day” billing rates will make it far more necessary in the future. The type of controller best suited for a plant operation is that which will predetermine the demand limit and the demand interval.

The overall usage of power is constantly monitored from the power company meter, the power usage of all the controlled loads is also monitored. By having this information the controller can calculate when an overrun of the desired demand limit will occur. The controller will delay any shed action to allow time for loads to shed normally. When it is determined that it will be necessary to shed one or more loads to keep from exceeding the demand, the controller, at the last possible moment, will shed the necessary loads. This means that shedding will occur only once during a demand interval and maximum use of available power will be realized.

4.1.10. Demand Shifting

Due to the lack of availability and the increased cost of natural gas and petroleum products, industry has come to rely on electrical power as a major source of energy. The use of electrical energy has increased at a greater rate than was anticipated and therefore a critical shortage has also been created in some areas. This is particularly true during the normal working day hours. Over the past few years this condition has caused situations known as “brown-outs”, which is controlled curtailment of power.

Even with power companies doing their best to cope with the problem by building new generating stations, installing additional equipment in existing facilities, and operating all equipment at maximum capacity, they still have not been able, in some cases, to keep up with the rapid growth in the demand for electrical energy.

The demand for electrical energy is not constant, but occurs in peaks and valleys. Power companies are obligated to have enough equipment available to meet a customer’s peak demand, even though this equipment is only used during the peak periods and is not in use during most of the working day. In order to finance the equipment necessary to provide this peak demand service for industrial users, the power demand charge was created. In some localities this high demand rate is the rate which is paid for the next year, even if it is never reached again, and the price paid for power demand can be very high.

With peaks and valleys in electrical demand caused by electrical melting during the normal work day, maximum demand peaks should be controlled by sequencing the furnace's operation and maximum power input to each furnace. By applying this procedure, the revised operation would level out the peak demands and produce a flat demand profile during normal daytime melting. With this melting operation the "load factor" would be improved, thus preventing high maximum demand peaks, which are developed through operating all machines at full load at the same time.

4.2. MOTORS

Motors represent the largest single use of electricity in most plants. The function of an electric motor is to convert electrical energy into mechanical energy. In a typical three-phase AC motor, current passes through the motor windings and creates a rotating magnetic field. The magnetic field in turn causes the motor shaft to turn. Motors are designed to perform this function efficiently; the opportunity for savings with motors rests primarily in their selection and use.

4.2.1. Idle Running

The most direct power savings can be obtained by shutting off idling motors, thereby eliminating no-load losses. While the approach is simple, in practice it calls for constant supervision or automatic control. Often, no-load power consumption is considered unimportant. However, the idle no-load current is frequently about the same as the full-load current.

An example of this type of loss in textile mills occurs with sewing machine motors that are generally operated for only brief periods. Although these motors are relatively small (1/3 horsepower), several hundred may be involved at a plant. If we assume 200 motors of 1/3 horsepower are idling 90 percent of the time at 80 percent of full-load ratings:

Cost of idling = 200 motors x 1/3 hp x 80% of load x 6,000 hrs/yr x 90% idling x $0.041/hp-hr = $11,800

A switch connected to the pedal can provide automatic shutoff.

4.2.2. Efficiency at Low Load

When a motor has a greater rating than the unit it is driving requires, the motor operates at only partial load. In this state, the efficiency of the motor is reduced (see Figure 4.2). The use of oversized motors is fairly common because of the following conditions:

Personnel may not know the actual load; and, to be conservative, select a motor larger than necessary.
The designer or supplier wants to ensure his unit will have ample power; therefore, he suggests a driver that is substantially larger than the real requirements. The maximum load is rarely developed in real service. Furthermore, most integral horsepower motors can be safely operated above the full-load rating for short periods. (This problem may be magnified if there are several intermediaries.)
When a replacement is needed and a motor with the correct rating is not available, personnel install the next larger motor. Rather than replace the motor when one with the correct rating becomes available, the oversized unit continues in use.
A larger motor is selected for some unexpected increase in driven equipment load which has not materialized.
Process requirements have been reduced.
For some loads, the starting or breakaway torque requirement is substantially greater than the running torque; thus, oversizing of the motor is a frequent consequence, with penalties in the running operation.

Plant personnel should be sure none of the above procedures are contributing to the use of oversized motors and resulting in inefficient operation.

Replacement of underloaded motors with smaller motors will allow a fully loaded smaller motor to operate at a higher efficiency. This arrangement is generally most economical for larger motors, and only when they are operating at less than one-third to one-half capacity, depending on their size.

The identification of oversized motors will require taking electric measurements. The recording wattmeter is the most useful instrument for this purpose to analyze the load over a representative period of time.

Another approach which provides an instantaneous reading is to measure the actual speed and compare it with the nameplate speed. The fractional load, as a percent of full nameplate load, can be determined by dividing the operating slip by the full-load slip. The relationship between load and slip is nearly linear Other motors at the plant can often be used as replacements, reducing or eliminating the investment required for new motors. Adapter plates and couplings to accommodate the smaller motors are the major expense. Scheduling the changes to coincide with maintenance of the motors minimizes the installation costs.

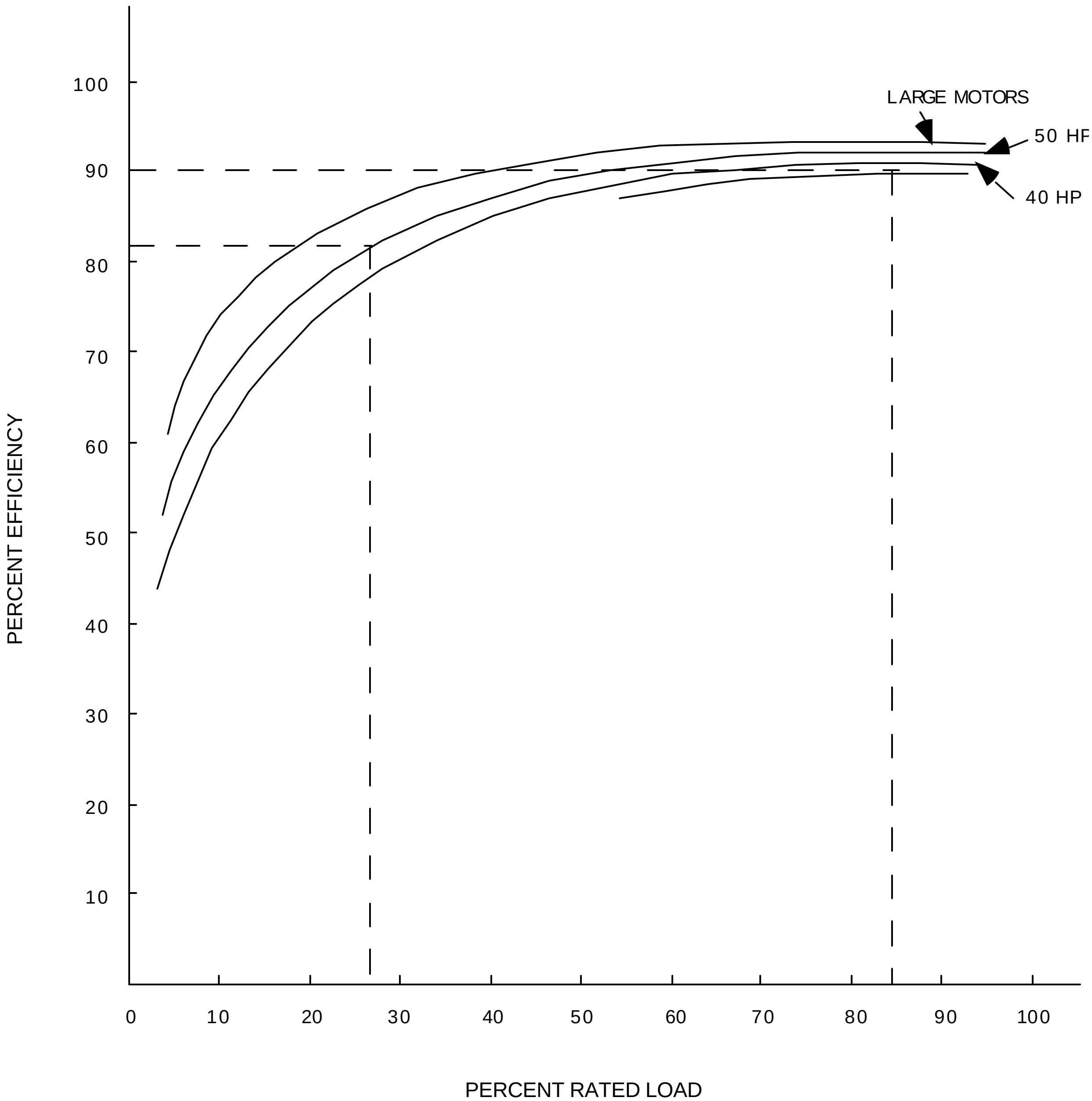


Figure 4.2: Motor Efficiency

(Typical T-Frame, NEMA Design B Squirrel Cage Induction Motor-1,800 rpm)

For example, the annual savings for replacing a 50-horsepower motor operating at 25 percent of rated load with a 15-horsepower motor which will operate near full load is:

$$L_{FL} = 0.746(hp)\left(\frac{1}{Eff_{FL} - 1}\right)$$

$$L_{PL} = 0.746(hp)(PL)\left(\frac{1}{Eff_{PL} - 1}\right)$$

where

L = losses - kW

Eff = motor efficiency

subscripts

FL = at full load

PL = at partial load

$$L_{FL} = 0.746(15)\left(\frac{1}{0.9 - 1}\right) = 1.24kW$$

$$L_{PL} = 0.746(50)(0.25)\left(\frac{1}{0.837 - 1}\right) = 1.82kW$$

Reduction in Losses = 0.58 kW

Annual Savings = 0.58 kW x 6,000 hrs/yr x $0.05/kWh = $174

4.2.3. High-Efficiency Motors

Purchase of high-efficiency motors should be standard practice with any new purchases. Payback of the premium paid for high-efficiency motors is usually less than two years for motors operated for at least 4,000 hours and 75 percent load. An exception may exist when the motor is only lightly loaded or operating hours are low, as with intermittent loads. The greatest potential occurs in the 1 to 20 horsepower range. Above 20 horsepower efficiency gains become smaller, and existing motors over 200 hp are already relatively efficient.

When motors are supplied by an equipment manufacturer, high-efficiency motors should be specified at the time of purchase. Otherwise, manufacturers normally supply motors of standard design because of their lower cost. Because of competitive pressure, these types of motors are likely to be less efficient. They have a lower power factor, not possible to spare, and they are more difficult to rewind.

The higher efficiency of high-efficiency motors is obtained by the use of thinner steel laminations in the stator and rotor; use of steel with better electromagnetic properties; addition of more steel; increase of the wire volume in the stator; improved rotor slot design; and the use of smaller more efficient fans. Each of these approaches involves more material, increased material costs, or higher manufacturing costs, which accounts for the higher first cost. However, the 25 to 30 percent higher initial cost is offset by lower operating costs. Other benefits of high-efficiency motors include less effect on performance from variations in voltage phase imbalance, and partial loading.

The calculation of simple payback for energy-efficient motors can be complex because of the variables involved. Determination of the operating cost of the motor requires multiplying the amount of electricity the motor uses by the number of hours the motor is operated and by the user's electrical cost. Each of these factors has its own variables, including changes in production schedules, variations in motor load, and demand charges. Some of these figures may be difficult to pinpoint.

Even when savings calculations are attempted, they can be subject to error because the actual efficiency of the particular motor is generally not known. All manufacturers do not use the same test technique to measure efficiency; as a result, ratings stamped on nameplates may not be comparable. Most manufacturers in the United States use a "nominal" efficiency that refers to a range of efficiencies into which a particular motor's efficiency must fall. Statistical techniques are used to determine the "minimum" efficiency of a motor with any given nominal efficiency. For example, a nominal efficiency of 90.2 percent has a minimum efficiency of 88.5 percent.

Many users report adopting high-efficiency motors as standard practice without attempting to justify the premium except in the case of larger-sized motors. In general, paybacks of approximately one year have been experienced.

Specific motors vary from published ratings. For instance, a 100-hp, 1,800-rpm, totally enclosed, fan-cooled motor from one manufacturer has a guaranteed minimum efficiency of 90.2 percent at full load in the standard line and 94.3 percent in the high-efficiency line. The equivalent size motor of another manufacturer has the same 90.2 efficiency rating for the standard model, but the high-efficiency model has a guaranteed minimum efficiency of 91.0 percent. Verification of actual efficiency of a particular motor requires the use of sophisticated testing equipment.

Because of this variation, the use of the guaranteed minimum efficiency is more conservative in evaluating savings because all motors should be equal to or higher than the value specified. Table 4.3 & Table 4.4 compare standard T-frame TEFC motors with high-efficiency motors.

	Standard T-Frame TEFC				**High Efficiency TEFC**			
	Nominal Average Expected Efficiecy			Guaranteed Minimum	Nominal Average Expected Efficiency			Guaranteed Minimum
Horse power	Full Load	75% Load	50% Load	Full-Load Eff	Full Load	75% Load	50% Load	Full-Load Eff
10	83.0	82.0	81.0	Not Available	90.2	91.0	91.0	88.9
15	84.0	84.0	83.0		91.7	92.4	92.4	90.6

20	86.0	87.0	87.0		93.0	93.6	93.6	92.0
25	86.0	87.0	87.0		93.0	93.6	93.0	92.0
30	88.0	88.0	88.0		93.0	93.6	93.6	92.0
40	88.0	88.0	87.0		93.6	94.1	93.6	92.7
50	89.0	89.0	89.0		94.1	94.1	94.1	93.3
75	91.5	91.5	91.0		95.0	95.0	94.5	94.3
100	92.0	92.0	91.0		95.0	95.0	95.0	94.3
125	91.5	91.5	90.0		95.0	95.0	94.1	94.3
150	93.0	93.0	91.5		95.8	95.8	95.4	95.2
200	93.0	93.5	93.0		95.8	95.8	95.8	95.2

Table 4.3: Typical Efficiency Comparison for 1 800 rpm Motors : General Electric

	Standard T-Frame TEFC				**High Efficiency TEFC**			
	Nominal Average Expected Efficiency			Guaranteed Minimum	Nominal Average Expected Efficiency			Guaranteed Minimum
Horse power	Full Load	75% Load	50% Load	Full-Load Eff	Full Load	75% Load	50% Load	Full-Load Eff
10	88.5	87.8	85.2	86.5	90.2	90.4	89.3	88.5
15	88.5	88.2	86.1	86.5	91.7	91.9	91.0	90.2
20	88.5	88.6	87.2	88.5	91.7	91.9	90.9	90.2
25	90.2	89.2	86.7	88.5	93.0	93.3	92.8	91.7
30	90.2	89.9	88.0	88.5	93.0	93.3	92.8	91.7
40	90.2	89.7	87.9	88.5	93.0	92.6	91.0	91.7
50	91.7	91.2	89.5	90.2	94.1	93.7	92.4	93.0
75	91.7	90.8	88.4	90.2	94.1	93.8	92.6	93.0
100	93.0	92.6	91.0	90.7	95.0	94.8	93.8	94.1
125	93.0	92.5	91.0	90.7	95.0	94.6	93.5	94.1
	Nominal Average Expected Efficiency			Guaranteed Minimum	Nominal Average Expected Efficiency			Guaranteed Minimum
Horse power	Full Load	75% Load	50% Load	Full-Load Eff	Full Load	75% Load	50% Load	Full-Load Eff
150	93.0	92.5	91.5	90.7	95.0	94.7	93.7	94.1
200	94.1	93.6	92.3	93.0	95.0	94.9	94.2	94.5

Table 4.4: Typical Efficiency Comparison for 1 800 rpm Motors : Westinghouse

4.2.4. Reduce Speed/Variable Drives

When equipment can be operated at reduced speeds, a number of options are available. Following examples are representative for the all industries.

Variable Frequency AC Motors

When centrifugal pumps, compressors, fans, and blowers are operated at constant speed and output is controlled with throttled valves or dampers, the motor operates at close to full load all the time--regardless of the delivered output. Substantial energy is dissipated by these closed dampers and valves. Significant energy savings can be realized if the driven unit is operated at only the speed necessary to satisfy the demand. Variable speed drives permit optimum operation of equipment by closely matching the desired system requirements.

Variable-frequency AC controllers are complex devices, and until recently have been expensive. However, they work with standard AC induction motors which allows them to be easily added to an existing drive. With lower equipment cost and increased electric costs, they become cost effective in many applications. Many types of pumps (centrifugal, positive displacement, screw, etc.) and fans (air cooler, cooling-tower, heating and ventilating, etc.), as well as mixers, conveyors, dryers, colanders, crushers, grinders, certain types of compressors and blowers, agitators, and extruders, are driven at varying speeds by adjustable-speed drives.

The following example illustrates the energy savings for an adjustable-speed drive on a fan. Figure 4.3 shows a fan curve for pressure versus flow characteristics. The intersection of the fan and system curve at point A shows the natural operating point for the system without flow control.

If a damper is used to control the flow, the new operating point becomes point B. However, if flow control is done by fan speed, the new operating point at reduced speed becomes point C.
The respective horsepowers are shown on the horsepower curves as points B' and C'.

Determination of the energy savings requires calculating the horsepower based on the fan curve and the duty cycle at which the fan is operating. The results for a fan controlled by damper are assumed to be as follows:

CFM %	Fan hp	Duty Cycle	Weighted hp
100	35	10	3.5
80	35	40	14.0
60	31	40	12.4
40	27	10	2.7
		Total	32.6

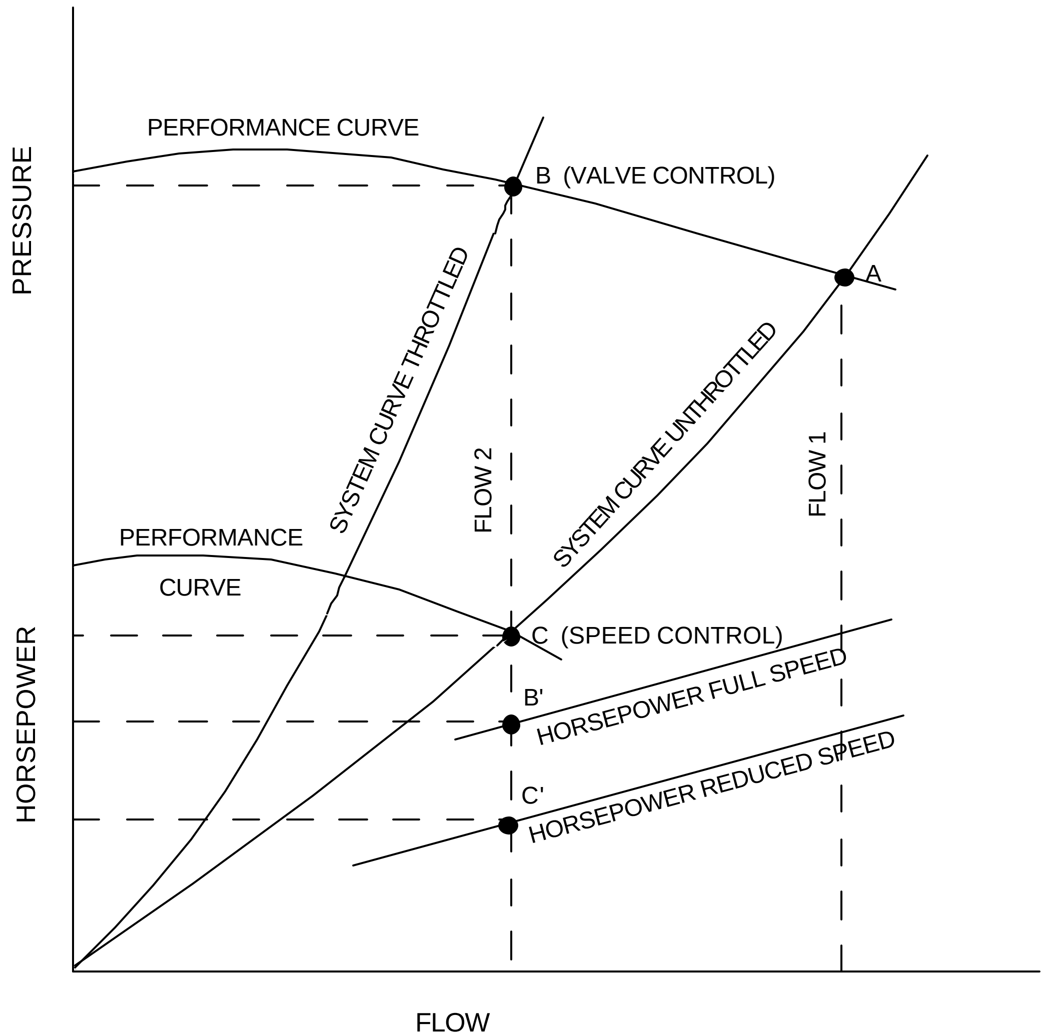


Figure 4.3: Fan Drive: Variable Speed vs. Valve Control

For machines that have a free discharge, the fan affinity formula below is used to calculate the reduced horsepower for a variable speed drive.

$$\frac{hp_1}{hp_2} = \left(\frac{N_2}{N_1}\right)^3$$

For example, the horsepower for a fan operated at one half speed is:

$$\frac{hp_1}{hp_2} = \left(\frac{0.5}{1}\right)^3 = 12.5\% \text{ of full load}$$

Consequently, significant savings are possible when speeds can be reduced.

The new fan horsepower with variable speed is:

CFM %	Fan hp	Duty Cycle	Weighted hp
100	35	10	3.5
80	18	40	7.2
60	7.56	40	3.024
40	2.24	10	0.224
		Total	13.948

The variable speed drive requires less than half the energy of the outlet damper for this particular duty cycle.
The annual savings (AS) is:

AS = (32.6 hp - 13.948 hp) x 6,000 hrs x $0.041/hp-hr = $4,590/yr

The installed cost of variable drive for a 35-hp motor is approximately $10,000. Equipment costs per hp decrease significantly with size, starting at about $250/hp for a 75-hp motor.

In actual practice, the efficiency of the motor should be factored in for a more accurate savings calculation based on kW input. The efficiency of the motor begins to drop significantly below 50 percent of rated capacity.

The above calculations assume a free discharge. If a static head is present, as in the case of a pump, the static head changes the system curve so that the affinity laws cannot be used directly to calculate the horsepower at reduced speed. In this case, precise knowledge of the pump and the system curves is required. Then detailed analysis with the aid of a computer is advisable.

Solid State DC Drives

Similar energy savings can be realized by varying speed with a DC drive. First cost is greater than for a variable frequency AC motor drive, particularly in a retrofit situation where the existing AC motor can be used directly with the electric controller. Brush and commutator maintenance is also a major cost with DC drives. DC systems are also more sensitive to corrosive and particle-laden atmospheres which are common in an industrial environment.

Accordingly, AC drives are preferred unless process conditions requires some of the special characteristics of a DC system such as very accurate speed control, rapid reversal of direction, or constant torque over rated speed range. Applications include driving of extruders, drawing machines, coaters, laminators, winders, and other equipment.

Other established techniques for varying the speed of a motor are electromechanical slip devices, fluid drives, and the wound-rotor motor. These devices control speed by varying the degree of slip between the drive and the driven element. Because the portion of mechanical energy that does not drive the load is converted to heat, these devices are less efficient and are used primarily because of special characteristics in a given application. For example, fluid drives might be used for a crusher because they are characterized by generally high power capacities, smooth torque transmission, tolerance for shock loads, ability to withstand periods of stall conditions, inherent safety (totally enclosed with no moving contact), and a tolerance of abrasive atmospheres.

Because AC and DC drives alter the operating speed of the prime mover, they are preferred for energy conservation reasons.

Mechanical Drives

Mechanical variable-speed drives are the simplest and least expensive means of varying speed. This type of adjustable sheaves that can be opened or closed axially, thus changing the effective pitch at which the belt contacts the sheaves.

The chief advantages of mechanical drives are simplicity, ease of maintenance, and low cost. Their chief advantage is a moderate degree of maintenance and less accurate speed control (normally 5 percent).

Belt drives are available for low to moderate torque applications over a power range to 100 hp. Efficiencies of belt drives are 95 percent, and reduction ratio can be as much as 10:1.

Metal chain drives for high torque are also available. These are similar in principle to belt drives, but use metal belts instead of rubber-fabric belts.

Single-Speed Reduction

When a single speed will satisfy the need for speed reduction, less expensive options are available. Although variable speed offers the advantage of using optimum speed in all situations, if the speed range is narrow and the portion of time operated at the lower speeds is small, a slower single speed is probably the most cost-effective approach.

Belt drives: With a belt drive, a speed reduction can be accomplished at minimum expense by simply changing belt sheaves. Since the change can be conveniently reversed by reinstalling the old sheaves, this method has application when a reduced output is needed only for an extended period, such as seasonally. Another opportunity may exist when production levels are reduced for an indefinite time, but the original capacity may be required again in the future.

Gear reducers: A similar approach may be taken with a gear change where gear reducers are used.

Motor change: A slower-speed motor can also be substituted when a one-time speed reduction is needed.

Two-Speed Motors

A two-speed motor is an economical compromise between a fixed single-speed and a variable drive. As illustrated in the previous example, energy savings are significant because the power required is proportional to the cube of the speed (rpm). In practice, a slight increase may result from friction losses. This approach can be used in combination with some throttling to control output within a narrower range.

Two speeds can be obtained with a single winding, but the slower speed must be one-half of the higher. For example, motor speeds might be 1,800/900, 1,200/600, or 3,600/1,800. When a motor at other ratios is required, two sets of stator windings are necessary. Multispeed squirrel-cage motors can also be obtained which have three or four synchronous speeds.

The cost of two-speed motors is approximately twice the cost of a single-speed motor. If a motor can be operated at the slower speed for any appreciable time, the savings will easily justify the added investment. Multispeed motors also need more expensive starters because the overload protectors must be sized differently at each speed.

4.2.5. Load Reduction

A reduction in motor load is, of course, one of the best means of reducing electric costs. Proper maintenance of equipment will also reduce motor load by eliminating friction losses from such sources as the misalignment of equipment, frozen bearings, and belt drag. Proper lubrication of all moving parts such as bearings and chain drives will minimize friction losses. The substitution of ball or roller bearings for plain bearings, particularly on line shafts, is another good power saver.

4.2.6. High-Starting Torque

Loads requiring “normal” starting torque can be satisfied by a National Electrical Manufacturers Association (NEMA) B motor (the general-purpose motor most commonly used in industrial plants) or a NEMA A motor. Where high-inertia loads are involved, selection of a motor specifically designed for high-torque capability can permit use of a smaller motor. A NEMA B motor sized to handle high-starting loads will operate at less-than-rated capacity once the load has been accelerated to full speed. On the other hand, selection of a smaller motor of NEMA C or D design can provide the same starting torque as a NEMA B motor but will operate closer to the full-rated load under normal running conditions.

4.2.7. Rewound Motors

Rewinding can reduce motor efficiency, depending on the capability of the rewinding shop. Shops do not necessarily use the best rewind procedure to maintain initial performance. In some cases the loss inefficiency, particularly with smaller-sized motors, may not justify rewinding.

Ideally, a comparison should be made of the efficiency before and after a rewinding. A relatively simple procedure for evaluating rewind quality is to keep a log of no-load input current for each motor in the population. This figure increases with poor quality rewinds. A review of the rewind shop's procedure should also provide some indication of the quality of work. Some of the precautions that must be taken are as follows:

- When stripping to rewind a motor, unless the insulation burnout is performed in temperature-controlled ovens an inorganic lamination insulation had been used, the insulation between laminations may break down and increase the eddy current losses
- Roasting the old winding at uncontrolled temperature, or using a hand-held torch to soften varnish for easier coil removal, should signal the need to go elsewhere.
- If the core loss is increased as a result of improper burnout, the motor will operate at a higher temperature and possible fail prematurely.
- If the stator turns are reduced, the stator core loss will increase. These losses are a result of leakage (harmonic) flux induced by load current and vary as the square of the load current.
- When rewinding a motor, if smaller diameter wire is used, the resistance and the I2R losses will increase.

Rewinding techniques vary among repair shops and should be investigated before deciding where to have motors rewound.

A rewinding method developed by Wanlass Motor Corporation claims to increase efficiencies as much as 10 percent. The firm's technique involves replacing the winding in the core with two windings designed to vary motor speed according to load. Claims of improved efficiency have been disputed and trade-offs have been determined to exist in other features of motor design (cost, starting torque, service life, etc.) While the Wanlass motor has been in existence for over a decade, potential users should recognize that the design remains controversial and has been generally regarded in the motor industry as offering no improvement over that which can be achieved through conventional winding and motor design techniques.

4.2.8. Motor Generator Sets

Solid-state rectifiers are a preferred source of direct current (DC) for DC motors or other DC uses. Motor-generator sets, which have been commonly used for direct current, are decidedly less efficient than solid-state rectifiers. Motor-generator sets have efficiencies of about 70 percent at full load, as opposed to around 96 percent for a solid-state rectifier at full load. When the sets are underloaded, the efficiency is considerably lower because efficiency is the product of the generator and motor efficiencies.

4.2.9. Belts

Closely associated with motor efficiency is the energy efficiency of V-belt drives. Several factors affecting V-belt efficiency are

1. Overbelting: A drive designed years ago with ratings in existence then should be reexamined. Higher-rated belts, with resulting increase in efficiency.
2. Tension: Improper tension can cause efficiency losses of up to 10 percent. The best tension for a V-belt is the lowest tension at which the belt will not slip under a full load.
3. Friction: Unnecessary frictional losses will result from misalignment, worn sheaves, poor ventilation, or rubbing of belts against the guard.
4. Sheave diameter: While a sheave change may not be possible, in general, the larger the sheave, the greater the drive efficiency.

Substitution of the notched V-belt (cog belt) for the conventional V-belt offers attractive energy savings. The V-belt is subjected to large compression stresses when conforming to the sheave diameter. The notched V-belt has less material in the compression section of the belt, thereby minimizing rubber deformation and compression stresses. The result is higher operating efficiency for the notched V-belt.

Given a 60-hp motor, annual operating cost (6,000 hrs) is $18,000. A conservative 1 percent improvement in efficiency results in annual savings of $180. The premium cost for six, size 128 belts is $78.

4.3. *LIGHTING*

Many lighting systems that represented good practice several years ago are inefficient in view of today's higher electrical costs. A lighting conservation program not only saves energy but is also a highly visible indication of management's interest in conserving energy in general. The importance of lighting conservation, therefore, should be considered not only for its dollar savings but also for its psychological effect on the plant's entire conservation program.

Table 4.5 shows the minimum average in service footcandles for lighting the interior of service buildings and areas. The illumination level specified is to be provided on the work surface, whether this be horizontal, vertical, or oblique. When there is no definite work area, it is assumed that the illumination is measured on a horizontal plane, 30 inches above the floor.

4.3.1. Lighting Standards

The first step in any lighting conservation program is to adopt a lighting standard. A new standard issued by the Illuminating Engineering Society provides for a range of illuminance instead of a single value. Within the recommended range, the level of illuminance can vary depending on the age of the workers, the importance of speed and accuracy, and the reflectance of the task background.

DuPont's recommended illumination levels for various working conditions are shown in Table 4.5. Management should adopt these or similar lighting standards to ensure uniform application of lighting levels. Without a standard, reductions in lighting are often nonuniform or inconsistent and may result in insufficient illumination in some areas.

LIGHTING SERVICE BUILDING INTERIORS

Area	Footcandles* in Service	Area	Footcandles* in Service
Offices		Machine and millwright shops	
Private	70	Rough bench and machine work	50
Small	70	Medium bench and machine	
General	70	work and tool maker's shop	100
Stenographic	100	Fine bench and machine work	200**
Drafting rooms	125	Extra fine bench and machine work	500**
Files		Paint shops	
Active	30	Ordinary hand painting,	
Inactive	10	rubbing, and finishing	30
Mail room		Fine finishing	70
Sorting	50	Spray painting booth	30
General	30	Sheet metal shops	
Conference rooms	70	Ordinary bench work	30
Corridors and stairways	20	Layout bench	70
Toilets and washrooms	20	Machines--presses, shears,	
Rest rooms	10	stamping, etc.	50
Janitor's closets	10	Welding shops	
Lunch areas	30	General illumination	50

Main entrances	
Patios	5
Doorways and foyers	20
Lobbies	30
Interview rooms	50
Exits, at floor	5
Medical and first aid	
Reception	50
First aid rooms	125
Doctor’s offices	70
Nurse’s offices	70
Dressing rooms	20
Cot rooms	20
Telephone equipment	
Switchboards	50
Terminal and rack equipment	50
Reproduction area	
Blue print room	50
Locker and shower and wash rooms	20
Mechanical equipment operating areas (fan rooms, etc.)	20
Electrical equipment operating areas (motors, etc.)	20
Inactive storage	5
Loading docks and ramps	10
Store and stock rooms	
General--live storage	20
Rough bulky material	10
Bin area used for dispensing	
Small stock items	50
Tool cribs	30
Gate houses	
Pedestrian entrance	20
Car entrance	5
Solvent storage and dispensing	
Storage in drums	5
Dispensing	10
Cylinder sheds	10
Pump houses	20
Warehouses--general traffic area	5
Warehouses (in storage aisle at floor level)	15
Precision manual arc welding	1,000**
Carpenter and woodworking	
Rough sawing and bench work	30
Medium machine and bench work	50
Fine bench and machine work	100
Electrical shops (maintenance)	
General	30
Bench work--general	70
Insulating coil winding	100
Testing	70
Instrument shops (maintenance)	
General	50
Bench work	100
Pipe shops	
General (bending, etc.)	20
Cutting and threading	30
Laboratories--hoods, benches, and desks	
Research	70
Control	50
Power and steam plants	
General	50
Front of panels (vertical at 66 inches above floor)	
Centralized control room	40
Ordinary and boiler control boards	30
Bench boards (horizontal)	50
Boiler room--main floor and basement	20
Boiler room--galleries and stairs	10
Gauge boards--front of panel (vertical)	30
Crusher house	10
Coal conveyors and ash handling equipment	5
Condensers, deaerators, and evaporators	10
Auxiliaries, boiler feed pumps, tanks, compressors, power switchgear, battery rooms, screen house, intake well, transformer rooms, etc.	20
Catwalks	3
Water-treating area	20
Refrigeration compressors, air compressors, etc.	20

* The illumination level in any area should be increased so that it is not less than 1/5 the level in any adjacent area.
** Obtained with a combination of general lighting and specialized supplementary lighting.

MANUFACTURING GENERAL ˜

Area	Footcandles in Service	Area	Footcandles in Service
Hand furnaces, boiling tanks, stationary dryers, stationary and gravity crystallizers, etc.	20	Electrical operating equipment (motors, general controls, etc.)	20
Mechanical furnaces, generators and stills, mechanical dryers, evaporators, filtration mechanical crystallizers	30	Electrical control rooms where equipment requires frequent checking, adjustment, etc.	30
Tanks for extractors, cooking nitrators, percolators, electrolytic cells	30	Weigh scales, gauges, thermometers, rotameters, etc.	
		Vertical on face of dials, scales, etc.	30
Tank and vat porthole lights, etc.		Control laboratories	50
Light interiors	20	Outdoor platform and tank farms	
Dark interiors	70	Active areas	5
Beaters, ball mills, grinders	30	Inactive areas	0.5
Mechanical operating equipment (compressors, fans, pumps, etc.)	20	Stairs, ladders, and steps	3

˜ Operating personnel do not perform exacting visual tasks except at process control panels, scales, gauges, thermometers, etc. Necessary lighting generally is obtained with combination of general lighting plus specialized supplementary lighting

LIGHTING OUTDOOR AREAS y

Area	Footcandles in Service	Area	Footcandles in Service
Bulletin and poster boards	10-V	Railroad yards	0.2
Flood lighting--building exteriors	15-V (max)	Roadways	
Entrances		Curves and intersections	0.5
Active (pedestrian or conveyance, or both)	5	Platforms, catwalks, stairs, ladders, etc.	
Inactive (normally locked, infrequently used)	0.5	Platform operating decks	5
		Catwalks, stairs, and ladders	3
Loading and unloading platforms	3	Storage yards	0.5
Freight car and truck interiors	3	Plant parking lots	
Outdoor work areas	3	General parking areas	0.3
Protective lighting		Entrances, exits, and walkways	2
Boundaries and fence	0.2	Gasoline dispensing pumps	3
Vital locations or structures	5		
Building surroundings	1		
General inactive area	0.1		

ψ As a matter of reference in comparing outdoor lighting values, the intensity of full moonlight at the earth's surface is approximately 0.025 footcandles.

Table 4.5: DuPont Recommended Illumination Levels

4.3.2. Light Meter Audit

After standards have been adopted, a light meter audit to determine the existing lighting levels should be conducted for the entire plant. The condition of the lamps and fixtures should be taken into account when the audit is made. The cleanliness of the fixtures has an important effect on the light output. Also, some depreciation of light intensity occurs over the life of most lamps. If group relamping has been used, the lighting level will depend on the age of the lamps. Light loss of 10 to 15 percent is normal for standard 40 W fluorescent lamps that are approaching end of life.

4.3.3. Methods to Reduce Costs

A couple of examples how to save electric energy are given in the sections below. Some of them are rather simple and the implementation requires only the will to overcome some old entrenched habits of the people at the work place.

Turn off Lights

The most obvious and beneficial step to conserve energy is to turn off lights when they are not needed. This approach often requires an extensive publicity program to enlist the support of all employees. First-line supervisors must understand that conserving light is as much a part of their job responsibility as improving productivity. An effective way for members of management to show support for energy conservation is to turn off lights in their own offices when unoccupied.

Frequently, lights can be turned off in storage or operating areas that are not in use or are seldom occupied during periods of reduced production on the evening or the midnight shift. For example, it is common practice to leave office light on until the cleaning crew has completed its work instead of turning them off as soon as the offices are vacated.

The lighting circuitry may not provide the flexibility needed for a partial curtailment. In this case, the cost to modify the wiring must be compared with the potential energy savings to determine whether rewiring is justified.

Fluorescent lamps are commonly left on over noon hours or other short periods because of the belief that frequent starts will shorten tube life. This problem is substantially reduced now with tubes that are more tolerant of starts and the increased cost of energy compared with the tube cost. The break-even point for fluorescent lighting is usually 5 to 15 minutes, depending on the electric rate, lamp cost, and lamp replacement labor rate. With incandescent lights, however, energy will be saved each time they are turned off. For high-intensity discharge (HID) lamps, it is usually not practical to turn lights off for brief periods (less than 30 minutes) because of the long lamp restart time.

Automatic Controllers

A technique for ensuring that lights are turned off when the room is unoccupied is to use presence detectors (infrared, capacitance, or ultrasonic) that detect when the room is unoccupied and will automatically turn off the lights. One lighting control product, for example, uses an ultrasonic sensor which can handle up to four 20 amp circuits. This allows control of electrical devices as well as lights. The unit costs about $150 uninstalled. The presence of people in a room is determined by a sensor that detects interruptions in the ultrasonic sound waves transmitted by the unit. The sensor then sends a signal to a controller to turn lights on or off. The sensor has a time-delay knob that can be manually set anywhere from 1 to 12 minutes to ensure that equipment stays on for a certain period of time after a room is occupied.

As an example, annual savings for a unit controlling 5,000 watts of lighting that reduces lighting by two hours per day, five days per week at $0.05/kWh would be $125.

Another device that is used to avoid leaving lights on needlessly is a microprocessor-based automatic lighting control. These relatively inexpensive devices can be programmed to turn off lights when not needed. For example, one programmable controller being offered for about $500 can control up to 50 switches. The user can override the off function by turning on lights at his particular area. This is done with individual wall switches that cost about $30 per unit installed. When a lighting circuit turns off according to schedule, the toggle switches are moved to the off position. Switches can also be used alone with an existing energy management system. The traditional approach has been to install lighting control systems separately, but firms are attempting to incorporate lighting systems with an energy management system because it is more cost effective.

A plant which has the opportunity to turn off significant unneeded lights at various times should consider one of the many automatic lighting controls available.

Remove Lamps

Another direct method to reduce lighting is simply to remove lamps from service where less light is needed. This approach frequently applies to offices or areas in which uniform lighting has been provided. For example, if the fixture is located over an office doorway, lamps can often be removed without reducing the illumination level at the desktop. Office lighting loads can frequently be reduced 25 percent by this arrangement.

In four-lamp fixtures, two of the four lamps can be removed if only a partial reduction in illumination is possible.

Excess lighting is also frequently provided in aisles, particularly when natural daylight may be sufficient. Lighting levels in storage areas are often higher than needed. This situation can develop when former operating areas are utilized for storage. Removal of lamps from these less-critical areas does not affect production.

Ballasts in fluorescent fixtures continue to consume current (approximately 10 percent of total load) after the lamps have been removed. The entire fixture should, therefore, be disconnected if lamps are removed (except for some lamp systems that have circuit interrupting lamp holders).

Maintain Lamps

Dirt and dust accumulations on the fixtures greatly affect lamp efficiencies. Light intensity can depreciate up to 30 percent by the time lamps are replaced; in extremely dirty conditions, depreciation can be higher. A minimal cleaning schedule for an average industrial environment is to clean fixtures when the lamps are replaced. The number of lamps required to provide the desired illumination level will depend on the plant's maintenance program. Initially, additional lighting to offset the gradual depreciation of light caused by dirt must be provided. If clean luminaires will improve lighting levels enough to permit the removal of some lamps, more frequent lamp maintenance may be justified. Cleaning costs must be balanced with energy costs to determine the optimum cleaning schedule.

Dirty or discolored luminaire diffusers can also reduce light output considerably. Replacement or complete removal may allow the lighting requirements to be satisfied with fewer lamps.

Lower-Wattage Fluorescent Lamps and Ballasts

A reduction in fluorescent light level by removing lamps from service can result in a spotty effect that is unattractive or provides an unacceptably low or nonuniform level of illumination. An alternate approach to energy saving is substitution of lower-wattage fluorescent lamps and ballasts. The substitution may or may not reduce the lighting level, depending on the type of lamp used. Because the variety of fluorescent lamps is so extensive, the following discussion refers to the general purpose 4-foot rapid start lamp, but reduced-wattage lamps are also available in other sizes and types.

a) Standard Lamp: The standard lamp for many years has been the 40-watt cool white, CW (or warm white, WW) lamp. This is the least expensive lamp, but also the least energy efficient. Several more cost-effective fluorescent lamp systems are available which use less wattage.

b) Energy Saver (ES) Lamp: A first-generation reduced wattage or energy-saving lamp was introduced in 1974 in 35-watt ratings (now typically rated at 34 watts). These lamps can be used as direct replacements for 40-watt lamps in existing luminaires. They emit the same color white light as the lamps they replace. Energy consumption is reduced by 13 to 15 percent with a comparable reduction in light output. The conversion to the lower illumination level need not cause personnel problems because the level of illumination will temporarily increase if the existing system is relamped as a group and the luminaires are cleaned. The ES lamps cost approximately 40 percent more than the standard lamps. If the lower lumen output is acceptable, the energy savings results in an attractive payback.

c) Lite White Lamps: A second generation of reduced-wattage lamps, generically designated as “lite white”, is available when more lumen output is needed than the ES lamp provides. The lite white lamps consume about the same energy as the ES lamps (34 watts) but with only about 6 percent reduction in light output. The color of light, however, has a somewhat lower color-rendering index than that of the cool white lamps. Although lite white color differs from cool white, the lamps are considered compatible in the same system. These lamps cost about 50 percent more than the standard lamps.

d) Lite White Deluxe: If color rendition is important, a third generation of ES lamp, designated as “lite white deluxe”, can be used. This lamp combines the high efficiency of the lite white lamp with even better color discrimination than the standard lamp. The lite white deluxe costs approximately three times as much as the standard lamp, but it can still be justified on the basis of energy saving. For example, a lite white deluxe costs $2.30 more than the standard lamp. Annual energy savings would be $1.80 (6,000 hrs. @ $0.05/kWh) for a payback of 1.3 years. If conditions permit use of the lower cost ED or lite white lamp, payback is about four months.

e) Sylvania has a lamp that operates at only 32 watts in the ES and lite white deluxe type. The premium is about 10 percent more and provides a similar payback of about four or five months on the premium.

f) Ballasts: Several options are available in the ballasts that can be used with any of the lamps described above. The standard electromagnetic ballast is the least efficient but also least expensive type ballast. It is normally provided by the luminaire manufacturer unless another type is specified. The standard electromagnetic ballast is not economical in sizes of 34 watts and above.

g) ES Ballasts: A more efficient low-loss or energy-saving electromagnetic ballast is also available. In evaluating the ballasts, the savings must be considered as a unit with the lamps since the more efficient ballasts permit the lamps to operate at lower wattage as well. A two 34-watt lamp system with an ES ballast saves 8 to 10 watts over the same system with a standard ballast. The premium for the high-efficiency ballast is approximately $6. Annual savings would be about $2.70 (6,000 hrs. @ $0.05/kWh).

h) Electronic Ballasts: More energy-saving electronic ballasts can also be used. Electronic ballasts operate at a frequency of 25 kilohertz (25,000 Hz) compared to the 60 hertz for standard ballasts. The higher frequency allows the lamps to operate at lower wattage. ES lamps must be used with rapid start ballasts. Good quality fluorescent luminaires manufactured in recent years are normally equipped with such ballasts.

Initial problems of reliability with the electronic ballasts appear to have been overcome. Electronic ballasts, however, have many small components and a relatively short product history compared with the simple construction and long-established high reliability of the magnetic ballasts.

With electronic ballasts, approximately 10 less watts per two 34-watt lamp system are saved over the same system with an energy efficient ballast. The premium for the electronic ballast over an ES ballast is about $13. Annual savings would be $3.00 (6,000 hrs @ $0.05/kWh). The payback for the electronic ballast is about twice as long as that of the energy-saving ballast. Comparative prices for standard ballast, energy-saving magnetic ballast, and electronic ballast are approximately $16, $22, and $35, respectively.

i) Performance-Matched Systems: For minimum wattage systems it is necessary to use performance-matched fluorescent systems in which the lamp and ballast are specifically tailored to each other for optimum efficiency. Such systems might not operate satisfactorily if other than their designated companion ballasts and lamps are used. However, performance-matched systems use considerably less energy (28 watts per lamp) than the conventional 40-watt systems.

The premium necessary for the electronic ballasts with these systems may reduce the payback to unacceptable levels. However, when four lamps can be operated off of one ballast, the economics are more attractive. Plants should evaluate the high-performance systems based on their electrical rates, conditions, and payback standards.

Energy-saving lamps are designed to operate closer to the optimum operating temperatures than conventional lamps and are not suitable for use in ambient temperatures below 60°F. At the lower temperatures ES lamps may be difficult to start or show sign of instability in operation by flickering. Accordingly, some low-temperature applications, such as warehouses, may not be suitable for ES lamps.

Below 60°F, standard fluorescent lamps will have a lower light output depending on the draft and lamp enclosure. Plastic sleeves or other jacketing that can retain heat can improve output when the light output has been noticeably reduced. However, light output will also start to decrease if above-bulb-wall temperatures exceed 100°F.

Some problems with ballast failure have been reported by users of ES lamps. ES lamps cause a slight increase in voltage across the capacitor, which in turn can cause premature failure in older ballasts. The problem, therefore, should be considered temporary until overage ballasts have been replaced.

A general problem to provide a more energy-efficient lighting system in a retrofit situation would be to replace any 40-watt lamps with one of the 34-watt lamps most suitable to the plant's conditions. This substitution can be done as individual lamps burn out, or they can be replaced on a group basis. The rapid payback usually justifies group replacement. More energy-efficient ballasts should also be substituted, but only as replacements are needed.

When a lower illumination level is acceptable but removal of a lamp would cause a problem of uneven illumination, a more uniform reduction in light level can be achieved by substituting special lamps.

Sylvania markets two versions of an ES lamp called Thrift/Mate. These lamps are intended to replace only one of a pair of lamps on the same ballast. When so installed, both the Thrift/Mate and the conventional lamp operate at reduced wattage. The two versions, designated TM33 and TM50, reduce energy consumption by 33 and 50 percent, respectively. The reduction in light output of the luminaire is equivalent to the reduction in power consumption.

Another method is to replace one of the two fluorescent lamps in a two-lamp fixture with a phantom tube. The phantom tube produces no light itself and the remaining real lamp in the fixture produces only about 70 percent of its normal illumination. The net result is a saving of two-thirds in the power used, with an illumination level of about one-third of that normally derived from a two-lamp fixture.

Fluorescent Retrofit Reflectors

Specular retrofit reflectors for fluorescent fixtures are available in two basic types: semirigid reflectors, which are secured in the fixtures by mechanical means, and adhesive films, which are applied directly to the interior surfaces of the fixture. Either silver or aluminum may be used as the reflecting media. On the average, silver film reflectors have a reflective film index between 94 and 96 percent; the index for aluminum is 85 to 86 percent. (Film applied directly to the existing fixtures is generally less efficient than the semirigid reflectors since it conforms to the fixture contours and cannot be formed to direct light in any specific manner.)

In regard to the energy aspects of the reflectors, manufacturers claim the reflectors permit the removal of two lamps from a four-lamp dirty fixture, the illumination directly underneath the fixture is essentially the same. But at angles to either side of the fixture, the decrease is much more significant. The fixture has been changed from a diffuse fixture to a sharp cut-off fixture. The additional illumination level with the reflectors is due in part from enabling the remaining two lamps to operate at a lower temperature, which increases their light output 6 to 12 percent.

While removal of two lamps reduces energy 50 percent, the comparison is not on an equal basis and several trade-offs should be recognized.

- As mentioned, the light pattern is more limited in area. The result can be nonuniform lighting on the work plane, dark spots between the fixtures, and darkened walls.
- The above claim of equivalent illumination is based on a comparison with a dirty fixture. The footcandles with two lamps and reflector is only 65 percent as much as four lamps with a clean conventional fixture.

- Lamp failure in a delamped fixture will not have the partial illumination provided by the second pair of lamps. Consequently, prompt replacement of burned-out lamps becomes more critical.
- The efficiency of any reflector depends on how well it is maintained. Even in a clean office environment the loss of light output due to dirt buildup in an unmaintained fixture can be as much as 35 percent. The reflectors may be more difficult to clean than normal fixture surfaces.
- Silver films are relatively new and their durability is somewhat unknown.
- The cost of a reflector often approaches the price paid for a new fixture. Approximate installation costs for the reflectors range from $35 to $65.

If the above trade-offs are acceptable, then the energy savings would justify their use. However, if a one-third reduction in light output is acceptable, a more cost-effective option would be to use the Thrift/Mate lamps and possibly upgrade the cleaning schedule. The illumination from a clean two-lamp fixture will be equivalent to the illumination from a dirty two-lamp fixture with the retrofit reflector. Also, if unequal lighting is acceptable, possibly one-third of the existing fixtures could be removed instead.

Lamp Relocation

Poorly arranged light wastes energy. Traditionally, light systems have been designed to provide a uniform level of light through out on entire area. However, with the increased cost of electric energy, the emphasis today is on designing illumination for the type of task and the location where it will be performed.

Nonuniform light is actually more visually pleasing as well as less energy-consuming. When the actual work area is properly lighted, the remaining area requires only a moderate level of general lighting to provide reasonable visibility and to prevent an excessive brightness imbalance, which can cause visual discomfort.

Task lighting has a number of advantages:

- High light levels are concentrated only where needed and are matched specifically to the seeing task. Overall lighting energy usage is thereby reduced.
- Less heat is liberated by the lighting system.
- Lighting is usually more easily relocated as operations change.
- Luminaire maintenance and lamp replacement expenses are usually less because they are more readily accessible.
- Units are individually controlled, permitting them to be shut off when not needed.
- Lighting effectiveness is improved by permitting the most advantageous positioning. Reflection and shadows can be avoided.

Lighting System Replacement

Existing incandescent or mercury lighting systems are usually candidates for replacement. Incandescent lighting is suitable for certain applications, but its low efficiency makes it uneconomical for general illumination. A rapid payback can almost always be shown for replacing mercury with more efficient light sources, and especially with high-pressure sodium.

If a lighting system must be designed to fit a new or modified installation, the alternative systems, listed with their relative output in Table 4.6, should be considered.

High-pressure sodium (HPS) lamps provide the most light per energy input and are the most economical when their color characteristics are suitable (The decided yellow color of low-pressure sodium lamps is usually unsatisfactory for most industrial areas). This lamp is offered in a wide choice of wattages, ranging from a nominal 70 watts to 1,000 watts. Luminaire manufacturers also offer a broad variety of luminaires suitable for various applications in outdoor lighting, manufacturing, and office lighting.

Approximate Initial Lumens per Watt Including Ballast

	Smaller Sizes	**Middle Sizes**	**Larger Sizes**
Low Pressure Sodium	90	120	150
High Pressure Sodium	84	105	126
Metal Halide	67	75	93
Fluorescent	66	74	70
Mercury	44	51	57
Incandescent	17	22	24

Table 4.6: Alternative Lighting Systems

HPS lighting has found wide acceptance as warehouse lighting, where color rendition is usually not critical. The high ceiling height common in warehouses is well-suited to HPS lighting. To meet the challenge of illuminating warehouse aisles, asymmetrical luminaires specifically designed for aisle lighting are available. Overlap of light between fixtures will be adequate even if the luminaires are as much as three times as far apart as their mounting height from the floor. HPS luminaires are also available for low mounting heights. The flexibility of HPS lighting has permitted significant inroads into areas that were formerly reserved for fluorescent lighting.

For comparable wattage, HPS lamps deliver about 50 percent more lumens than mercury lamps, and 500 percent more than incandescent light sources. Efficacy of most sources increases at higher wattages, so for maximum economy, the HPS lighting system should be designed to use the largest sized lamps that are consistent with good lighting practice and controlled brightness.

4.3.4. Summary of Different Lighting Technologies

The potential for energy savings in lighting is twofold, the industry has produced some money (but not many) energy saving products primarily because design engineers have specified excessive lighting levels over the years, and secondly some technological advances have occurred.

Incandescent

Incandescent lighting can be described by the following features:

- Light produced by heating an element until it glows.
- Main reason for use is color rendition and dimming, although recently dimming has been made available for other types of light.
- Reduced wattage/reduced output replacements are now available although no more efficient.
- One type of PAR lamp is now being offered which has a infrared reflective film which makes the filament hotter and brighter.

Fluorescent

Fluorescent lighting can be summed as follows:

- Light is produced by emitting an electronic field which causes the phosphorous to glow (fluoresce).
- More efficient.
- Varying levels of color rendering are available depending on the quality of the rare earth phosphors, and the cost. Color rendering is arbitrary way to compare the color of the light using sunlight as 100 percent.
- New T8 (one inch diameter) lamps produce light more efficiently than previous lamps, but must be used with electronic ballasts.
- Compact fluorescent - twin tube, exit signs. (mention temperature, ref.)

High Energy Discharge

The following types of lamps fall under the high energy discharge category.

- Mercury Vapor
- Metal Halide
- High Pressure Sodium
- Low Pressure Sodium

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5 HEAT

5.1. BOILERS

A boiler is a device that extracts energy in the form of heat from some type of fuel through a combustion process that can then be distributed to necessary areas to do useful work. In the process, the carrying media (water or steam) transfers the energy as heat and is cyclically reheated again and again. There are examples that exist where the media (steam) is not returned, such as locomotives, but in the industrial processes covered in this manual it would constitute an exception for the norm. For the most part, boilers are part of systems that take advantage of the phase changes that occur in substances (for example water to steam). The phase changes are associated with large amount of energy storage which can be later harnessed to perform work.

5.1.1. Introduction

There are three principal boiler categories: (1) natural draft vs. forced draft, (2) hot water vs. steam, and (3) fire in tube vs. water in tube. In a natural draft boiler, the combustion air is drawn in by natural convection and therefor there is little control over the air/fuel ratio. For forced draft boilers, the quantities of combustion air and air/fuel mixture are controlled by a blower. Some boilers produce hot water, typically in the 160^0 to 190^0F range, while others produce steam. Steam boilers may be low pressure (approximately 15 psi), medium pressure (15 to 150 psi), or high pressure (150 to 500 psi). Finally, boilers may be fire in tube or water in tube boilers. In a fire in tube boiler, the hot gases flow through tubes that are immersed in water, where as in a water tube boiler, the water flows through tubes heated by the hot combustion gases. There are also some very high temperature and superheated boilers but these are seldom encountered in typical manufacturing operations. 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. The following measures are also applicable to utility boilers. Other than the major differences of not being natural draft boilers and producing steam at greater than 150 psi, utility boilers are similar to boilers commonly used by industry.

This section includes demand-side management strategies for boiler systems. Combustion air blower variable frequency drives, air/fuel ratio reset, turbulators, high-pressure condensate return systems, steam trap repair, and steam leak repair are discussed in this section.

5.1.2. Boiler Operation and Efficiency

The ideal model of a boiler operation is based on the Carnot cycle. The Carnot cycle is defined as two reversible isothermal and two reversible adiabatic processes. Heat is added to the cycle during isothermal process at high temperature T_H, then follows a adiabatic process producing work as the working fluid is expanded to a lower pressure, during the next isothermal stage, heat is rejected to the low temperature reservoir at T_L. During the last stage the working fluid is adiabatically compressed to finish the cycle. Carnot cycle is the most efficient cycle for given set of low and high temperatures and its efficiency is given by:

$$\eta = 1-(\Delta T_L/T_H)$$

The efficiency of a real boiler will always be lower then the ideal cycle. If the Carnot cycle is to work using a phase changing medium, a model can be represented in a four-stage system. The first stage would be a boiler that operates at constant temperature while adding heat to the working medium. The second stage would be an expansion device (turbine) that operates adiabatically. The third stage would be a condenser that operates at constant temperature while rejecting heat from the medium and the final stage would be a compressor or a pump that adiabatically brings the medium to the starting point. Most boilers are designed to operate at near constant pressure. If the devices are operated near the saturation region, they will operate at constant temperature as well as constant pressure. The quality of medium is quite low at the end of expansion and the fluid before compression will be a mixture of liquid and vapor.

Boiler Efficiency Tips

1. Conduct flue gases analysis on the boiler every two months. Optimal percentages of O_2, CO_2, and excess air in the exhaust gases are given by:

Fuel	**O2 (%)**	**CO2 (%)**	**Excess Air (%)**
Natural Gas	2.2	10.5	10
Liquid Petroleum Fuel	4.0	12.5	20
Coal	4.5	14.5	25
Wood	5.0	15.5	30

Table 5.1: Optimal Flue Gas Composition

The air fuel ratio should be adjusted to the recommended optimum values if possible; however, a boiler with a wide operating range may require a control system to constantly adjust the air-fuel ratio.

2. A high flue gas temperature often reflects the existence of deposits and fouling on the fire and/or water side(s) of the boiler. The resulting loss in boiler efficiency can be closely estimated on the basis that a 1-% efficiency loss occurs with every 40^0F increase in stack temperature.

   It is suggested that the stack gas temperature be recorded immediately after boiler servicing (including tube cleaning) and that this value be used as the optimum reading. Stack gas temperature readings should be taken on a regular basis and compared with the established optimum reading at the same firing rate. A major variation in the stack gas temperature indicates a drop in efficiency and the need for either air-fuel ratio adjustment or boiler tube cleaning. In the absence of any reference temperature, it is normally expected that the stack temperature be less than 100^0F above the saturated steam temperature at a high firing rate in a saturated steam boiler (this doesn't apply to boilers with economizers and air preheaters).

3. After an overhaul of the boiler, run the boiler and re-examine the tubes for cleanliness after thirty days of operation. The accumulated amount of soot will establish the criterion as to the necessary frequency of boiler tube cleaning.

4. Check the burner head and orifice once a week and clean if necessary.

5. Check all controls frequently and keep them clean and dry.

6. For water in tube boilers that burn coal or oil, the soot should be blown out as much as once a day. The National Bureau of Standards indicates that 8 days of operation can result in an efficiency reduction of as much as 8%, caused solely by sooting of the boiler tubes.

7. The frequency and amount of blowdown depends upon the amount and condition of the feedwater. Check the operation of the blowdown system and make sure that excessive blowdown does not occur. Normally, blowdown should be no more than 1% to 3% of steam output.

Purity of water used for steam generation is extremely important. It is not usually possible to use waters found in nature as boiler feedwater. Most of them can be used if properly treated, though. What is necessary is the removal of impurities or their conversion into some sort of harmless form. Among other means is a systematic removal by blowdown. This way an excessive accumulation of solids is prevented. Water treatment prevents the formation of scale and sludge deposits on the internal surfaces of boilers. Scale formations severely retard the heat flow and cause overheating of metal parts. The scale build-up and heat transfer relationship is demonstrated in Figure 5.1.

Excess Air	O2 %	CO2 %	Net Stack Temperature						
			220	230	240	246	250	260	270
0.0	0.0	11.8	85.3	85.1	84.9	84.8	84.7	84.5	84.2
2.2	0.5	11.5	85.2	85.0	84.8	84.7	84.6	84.4	84.1
4.5	1.0	11.2	85.1	84.9	84.7	84.6	84.5	84.2	84.0
6.9	1.5	11.0	85.0	84.8	84.6	84.5	84.4	84.1	83.9
9.5	2.0	10.7	84.9	84.7	84.5	84.3	84.2	84.0	83.8
12.1	2.5	10.4	84.8	84.6	84.4	84.2	84.1	83.9	83.7
15.0	3.0	10.1	84.7	84.5	84.2	84.1	84.0	83.8	83.5
18.0	3.5	9.8	84.6	84.4	84.1	84.0	83.9	83.6	83.4
21.1	4.0	9.6	84.5	84.2	84.0	83.8	83.7	83.5	83.2
24.5	4.5	9.3	84.3	84.1	83.8	83.7	83.6	83.3	83.1
28.1	5.0	9.0	84.2	83.9	83.7	83.5	83.4	83.2	82.9
31.9	5.5	8.7	84.1	83.8	83.5	83.4	83.3	83.0	82.7
35.9	6.0	8.4	83.9	83.6	83.3	83.2	83.1	82.8	82.5
40.3	6.5	8.2	83.7	83.4	83.2	83.0	82.9	82.6	82.3
44.9	7.0	7.9	83.5	83.3	83.0	82.8	82.7	82.4	82.1
49.9	7.5	7.6	83.4	83.1	82.8	82.6	82.5	82.2	81.9
55.3	8.0	7.3	83.1	82.8	82.5	82.3	82.2	81.9	81.6
61.1	8.5	7.0	82.9	82.6	82.3	82.1	82.0	81.6	81.3
67.3	9.0	6.7	82.7	82.3	82.0	81.8	81.7	81.4	81.0
74.2	9.5	6.5	82.4	82.1	81.7	81.5	81.4	81.0	80.7
81.6	10.0	6.2	82.1	81.8	81.4	81.2	81.1	80.7	80.3
89.8	10.5	5.9	81.8	81.4	81.1	80.9	80.7	80.3	79.9
98.7	11.0	5.6	81.5	81.1	80.7	80.5	80.3	79.9	79.5
108.7	11.5	5.3	81.1	80.7	80.3	80.1	79.7	79.4	79.0
119.7	12.0	5.1	80.6	80.2	79.8	79.4	79.4	78.9	78.5

Table 5.2: Boiler Efficiency (Natural Gas)

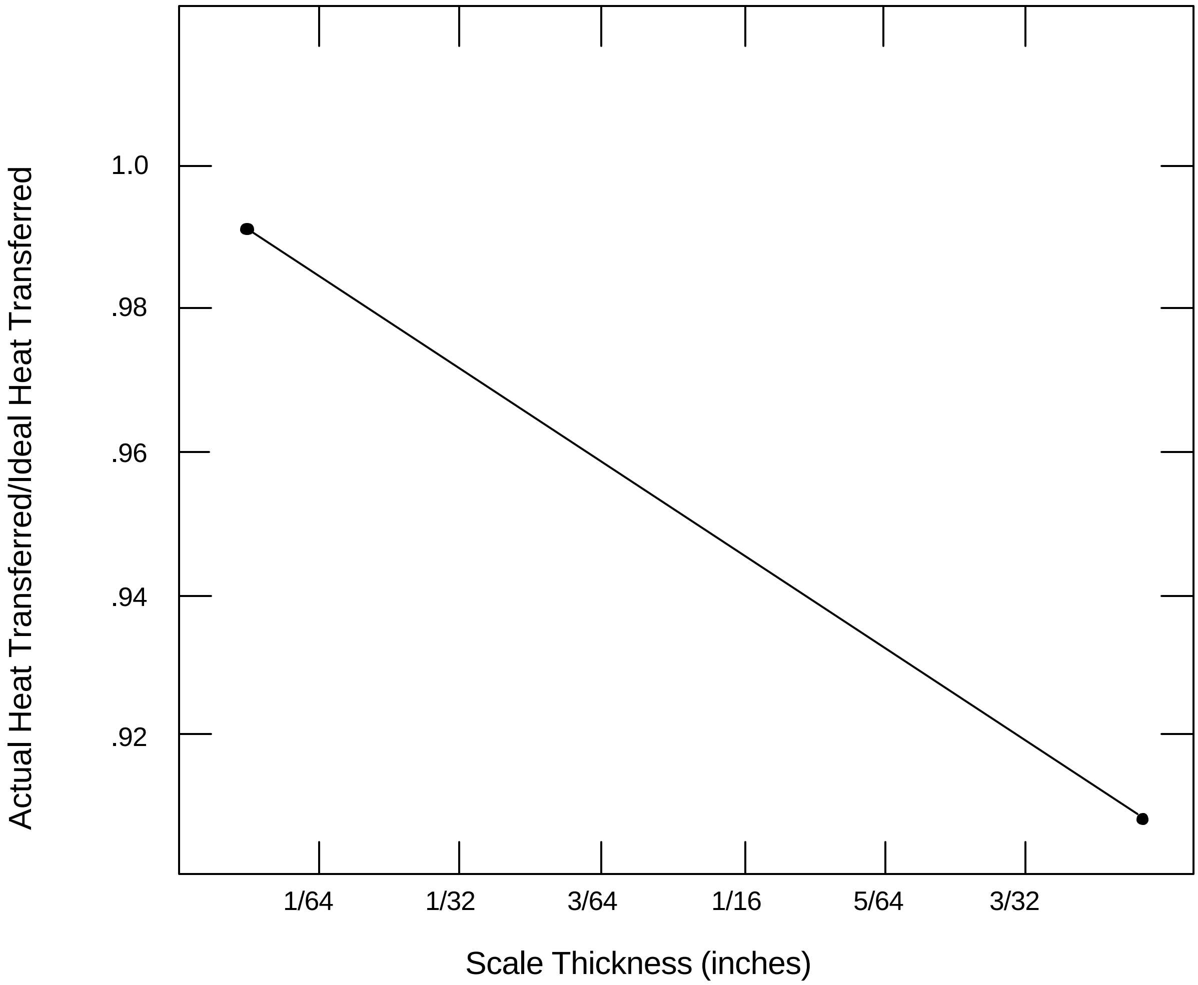


Figure 5.1: Effect of Scale Thickness in Boilers on Heat Transfer

Economizers use heat from moderately low temperature combustion gases after the gases leave the steam generating section (or in many cases also after going through a superheating segment). Economizers are heating the feedwater after it is received from the water feed pumps, so the water arrives at a higher temperature into a steam generating area. Economizers are once through forced flow convection heat transfer devices. A typical design uses steel tubes where the water is fed at pressures higher than the pressure in the steam generation part. The feed rate has to correspond to the steam output of the boiler. The following picture shows the effect of preheating of the feed water on the efficiency of a boiler unit.

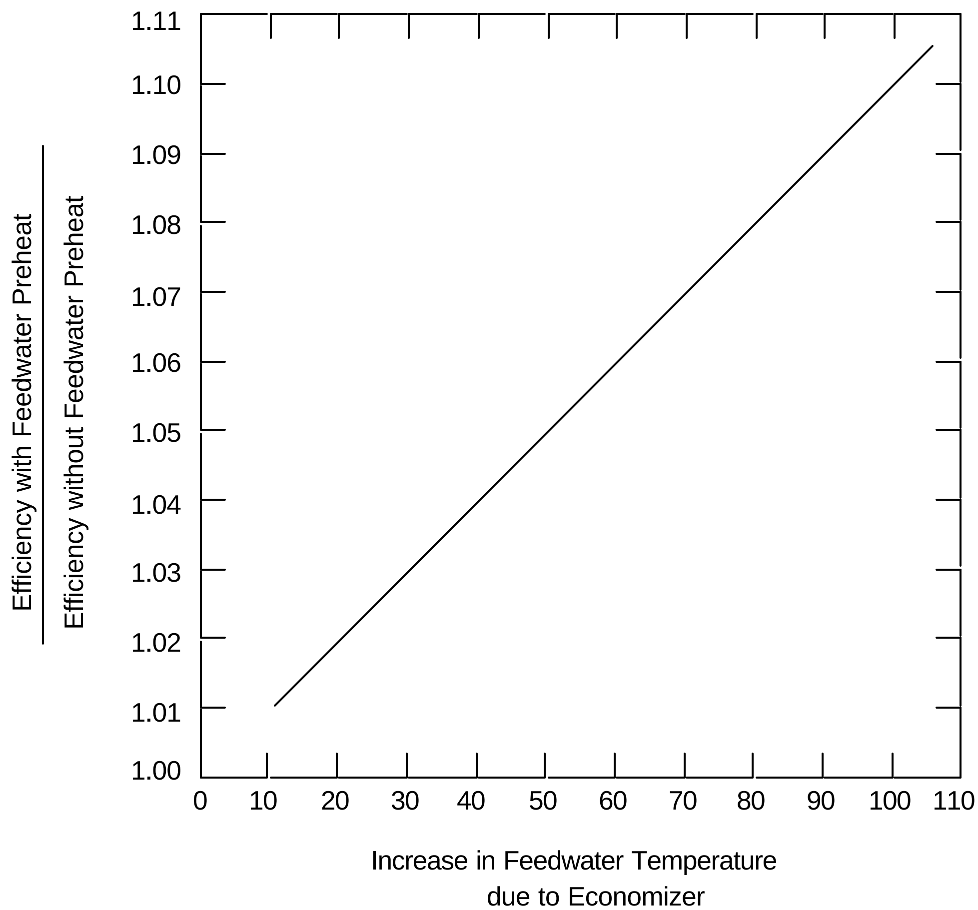
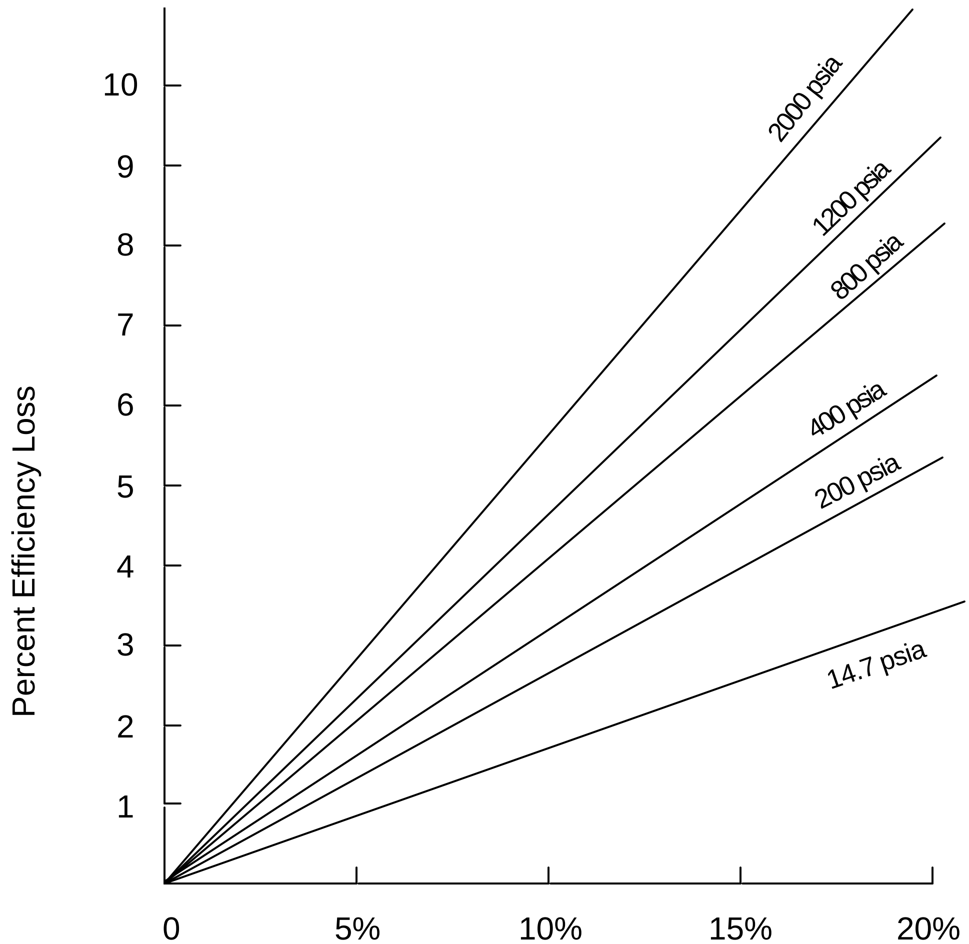


Figure 5.2: Effects of Feedwater Preheat on Boiler System Efficiency

Although blowdowns are an absolute necessity for the operation of a boiler, it is important that one realizes that, depending on the pressure, each blowdown decreases the efficiency of the boiler. The following picture illustrates this. Note how sharply the efficiency loss increases with higher pressures.



Percent Blowdown,

$$\frac{\dot{M}_{Blowdown}}{\dot{M}_{Steam\ Produced}} \times 100$$

Figure 5.3: Efficiency Loss Due to Blowdown

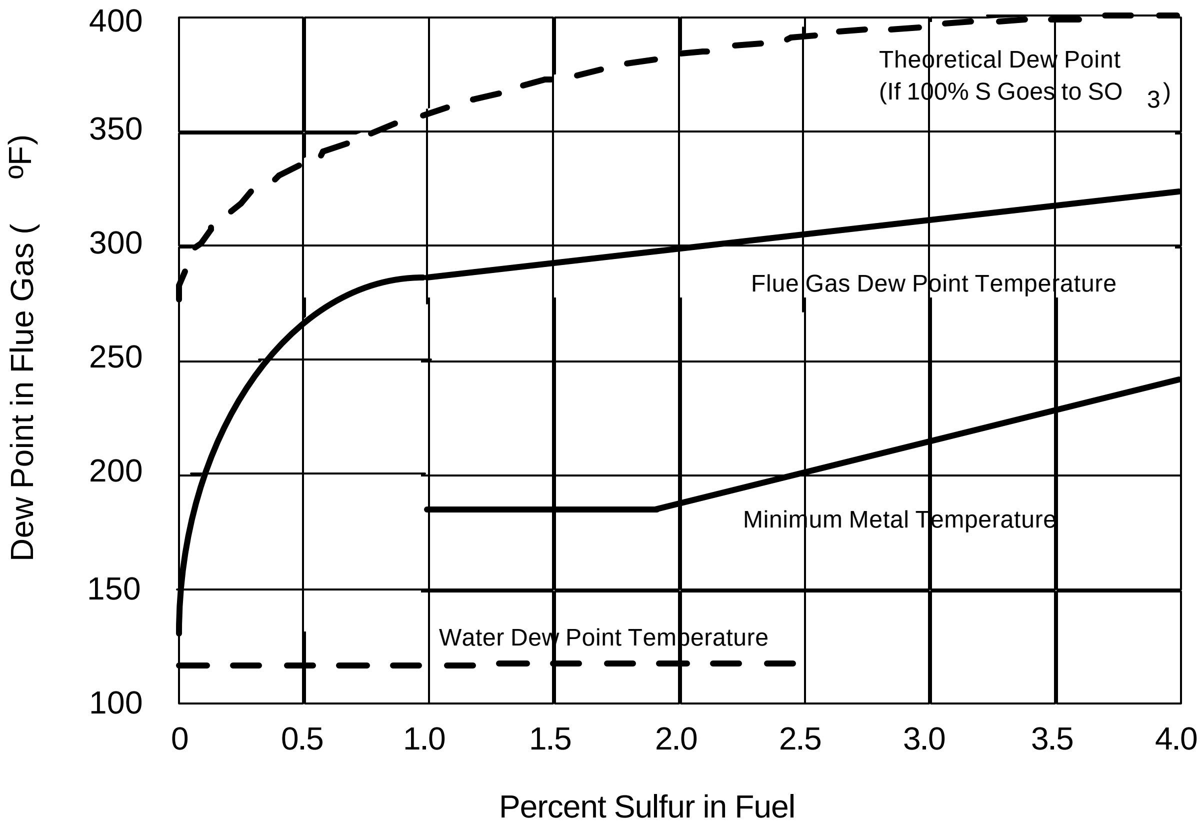


Figure 5.4: Acid Dew Point

Combustion in Boilers

Heat is released through a process called “combustion” burning. Combustion is the release of energy in the form of heat through the process of oxidation. The energy is stored in the bonds of carbon based fuels that are broken down during combustion.

To make the combustion happen a mixture of fuel, oxygen and heat is necessary. During the process of combustion, elements of fuel mix with oxygen and reconfigure to form new combinations of the same elements. The result is heat, light and new element combinations. The goal is to maximize heat and that can happen when the combustion process is tightly controlled.

<u>Complete Combustion</u>:

CARBON
HYDROGEN + OXYGEN
NITROGEN = WATER
CO_2
NITROGEN

Incomplete Combustion:

CARBON HYDROGEN	+	OXYGEN NITROGEN	=	SOOT + ALDEHYDES WATER CO_2 CO NITROGEN

Perfect combustion (stoichiometric combustion) is the process of burning the fuel without an excess of combustion air. This process should develop the "ULTIMATE CO2" amounts in the combustion products.

Natural Gas (can vary)	11.7 - 12.1%
Propane	13.7%
No. 2 Oil	15.2%
No. 4 Oil	16.0%

Table 5.3: Ultimate CO2 Values

While these values can be sometimes achieved, Table 5.4: "Boiler Combustion Mixtures" shows realistic values.

Fuel	CO2	O2	Excess Air
Natural Gas	10.5%	3.5 - 4.0%	20%
Propane	11.0 - 11.5%	3.5 - 4.0%	20%
No. 2 Oil	11.5 - 12.0%	3.5 - 4.0%	20%
No. 4 Oil	12.5 - 13.0%	3.5 - 4.0%	20%

Table 5.4: Boiler Combustion Mixtures

Carbon in burning to carbon monoxide, gives off only about one third of the available heat. A 1/8 in. of soot on the heat exchanger increases fuel consumption by over 8% as a rule of thumb. Incomplete combustion, which results in the formation of CO, is dangerous because it is odorless, colorless, tasteless, and contrary to popular belief, it is non-irritating. The gas is also lighter than air and consequently, if it is escaping from a plugged or leaking boiler fireside, can rise to occupied areas. CO can only be detected with special test or monitoring equipment.

Causes of Incomplete Combustion

1. Insufficient or Too Much Oxygen
   - Air problems (rule of thumb - 1 cubic foot of air for every 100 Btu's of gross heating value).
   - Minimum air intake openings for a given input.

     Oil - unconfined = 28 square inches per gallon
     confined = 140 square inches per gallon
     Gas - draft hood = 1 square inch per 5,000 Btu
     barometric = 1 square inch per 14,000 Btu
     direct = 1 square inch per 17,500 Btu

2. Insufficient or too much fuel
   - Fuel is not vaporized - possible reasons
     - ◊ Worn nozzle
     - ◊ Clogged nozzle
     - ◊ Pump pressure is incorrect
     - ◊ Pump, lines, filter or tank lines are clogged
     - ◊ Cold fuel
   - Water in fuel - possible causes
     - ◊ Supplier doesn't supply quality fuel
     - ◊ Tank outside
     - ◊ Cover of the fill and vent not protected from elements

3. Insufficient or inconsistent heat
   - The ignition system is used to provide the proper temperature (called kindling point) for the light off of the vaporized fuel under design conditions. When design conditions are not met, light off will not occur.
   - An established flame is usually sufficient to maintain the kindling point. However, any time the combustion temperature falls below the kindling point, the combustion triangle is broken and combustion stops.
   - Safety device will shut the fuel off within 3 seconds of flame failure.

Calculating Combustion Efficiency

The calculation of combustion efficiency is based upon three factors.

1. Chemistry of fuel
2. Net temperature of the stack gases
3. The percentage of oxygen or carbon dioxide by volume in the stack gases

Eyeballing the flame for color, shape and stability is not enough for maximizing efficiency. Commercial analyzers are available to accurately gauge combustion efficiency. The simplest units measure only O_2 or CO_2.

Process Type	Efficiency [%]
Fireplace	10-30
Space Heater	50-82
Commercial Atmospheric Gas Boiler	70-82
Oil Power Burner	73-85
Gas Power Burner	75-83
Condensing Furnace (Gas or Oil)	85-93

Table 5.5: Combustion Efficiencies

There are no standard performance efficiency levels that commercial boiler manufacturers must adhere to. The efficiency is reported in different terms:

Thermal Efficiency - A measure of effectiveness of the heat exchanger. It does not account for radiation and convection losses.
Fuel to Steam Efficiency - This term is a measure of the overall efficiency of the boiler. It accounts for radiation and convection losses.
Boiler Efficiency - Used both ways.

The cost savings in boiler operation can be achieved by employing system controls. Temperature setback devices can result in savings up to 18% of annual heating costs. The controllers can sense the temperature inside or outside, possibly both. They control the boiler cycling and/or control valves based upon the ratio of the two inputs and the rate of change of each. Burner controls maximize the burner's efficiency. This can be done by using two-stage (high-low) burners. Another possibility is utilization of higher voltage electronic ignition, which improves light off and consequently reduces associated soot accumulation. Employment of interrupted ignition reduces the run time of ignition components by approximately 98% during heating season. This in turn increases ignition life.

5.1.3. Typical Performance Improvements

Some performance improvements are easily achieved and most of them are really just proper maintenance or operation procedures. This section covers a few of the more common ones.

Adjustment of Fuel and Air Ratio

Description

For each fuel type, there is an optimum value for the air/fuel ratio. For natural gas boilers, this is 10% excess air, which corresponds to 2.2% oxygen in the flue gas. For coal-fired boilers, the values are 20% excess air and 4% oxygen. Because it is difficult to reach and maintain these values in most boilers, it is recommended that the boiler air/fuel ratio be adjusted to give a reading of 3% oxygen in the flue gas (about 15% excess air) for gas-fired boilers and 4.5% (25% excess air) for coal-fired boilers. Combustion analyzers are available that give readings are available for less than $1,000, and it is often recommended that these be purchased. For natural gas boilers, the efficiency is a function of excess/deficient air and stack temperature. The curves for oil- and coal-fired boilers are similar. Because the efficiency decreases rapidly with deficient air, it is better to have a slight amount of excess air. Also, the efficiency decreases as the stack gas temperature increases. As a rule of thumb, the stack temperature should be 50^0 to 100^0F above the temperature of the heated fluid for maximum boiler efficiency and to prevent condensation from occurring in the stack gases. It is not uncommon that as loads on the boiler change and as the boiler ages, the air/fuel ratio will need readjusting. It is recommended that the air/fuel ratio be checked as often as monthly.

Definitions

Stack Gases - The combustion gases that heat the water and are then exhausted out the stack (chimney).

Air/Fuel Ratio - The ratio of combustion air to fuel supplied to the burner.

Applicability

Facility Type - Any facility that has a forced draft boiler.

Climate - All climates.

Demand-Side Management Strategy - Strategic conservation.

For More Information:

Dyer, D.P., G. Maples, etc., Boiler Efficiency Improvement, Boiler Efficiency Institute, Auburn, AL, 1981, pp. 4-31.

Air/Fuel Ratio Reset: Costs and Benefits1

Options	Installed Costs ($)2	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)3	Simple Payback (yr)
Air/Fuel Ratio Reset	1,673	2,339	5,691	0.3

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database. All values are averages based on the data base data. The implementation rate for this measure was 70%.
2. One example from the IAC data base to further clarify the costs is as follows: Adjusting the air/fuel ratio on a 6.3 MMBtu/h boiler at a concrete plant resulted in energy and cost savings of 1,814 MMBtu/yr and $4,760/yr. The implementation cost was $1,500, which was the cost for flue gas analysis equipment and labor.

3. The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

§ *Case Study #1: Adjust Boiler Air-Fuel Ratio*

IMPLEMENT PERIODIC INSPECTION AND ADJUSTMENT
OF COMBUSTION IN A NATURAL GAS FIRED BOILER

Current Practice and Observations

During the audit, the exhaust from the boilers was analyzed. This analysis revealed excess oxygen levels that result in unnecessary energy consumption.

Recommended Action

Many factors including environmental considerations, cleanliness, quality of fuel, etc. contribute to the efficient combustion of fuels in boilers. It is therefore necessary to carefully monitor the performance of boilers and tune the air/fuel ratio quite often. Best performance is obtained by the installation of an automatic oxygen trim system, which will automatically adjust the combustion to changing conditions. With the relatively modest amounts spent last year on fuel for these boilers, the expense of a trim system on each boiler could not be justified. However, it is recommended that the portable flue gas analyzer be used in a rigorous program of weekly boiler inspection and adjustment for the two boilers used in this plant.

Anticipated Savings

The optimum amount of O2 in the flue gas of a gas fired boiler is 2.0%, which corresponds to 10% excess air. Measurements taken from the stack on the 300 HP boiler gave a temperature of 400^0F and a percentage of oxygen at 6.2%. By controlling combustion the lean mixture could be brought to 10% excess air or an excess O2 level of 2%. This could provide a possible fuel savings of 3%.

The 300 HP natural gas boiler is used both for production and heating. It is estimated that 100% of the natural gas is consumed in the boiler.

Therefore the total savings would be:

Savings in Fuel (thermos/yr): = (% burned in boilers) x (annual thermos per year) x (percent possible fuel savings)

= (1.0 x (56,787 thermos/yr) x (0.02)

= 1,136 thermos/yr

Savings in Dollars ($/yr): = (thermos Saved/yr) x (cost/therm)
= 1,136 thermos/yr x $0.644/therm
= $732/yr

Implementation

It is recommended that you purchase a portable flue gas analyzer and institute a program of monthly boiler inspection and adjustment of the boilers used in the plant. The cost of such an analyzer is about $500 and the inspection and burner adjustment could be done by the current maintenance personnel. The simple payback is:

$500 cost / $732 = 8.2 months

Simple Payback = 8.2 months

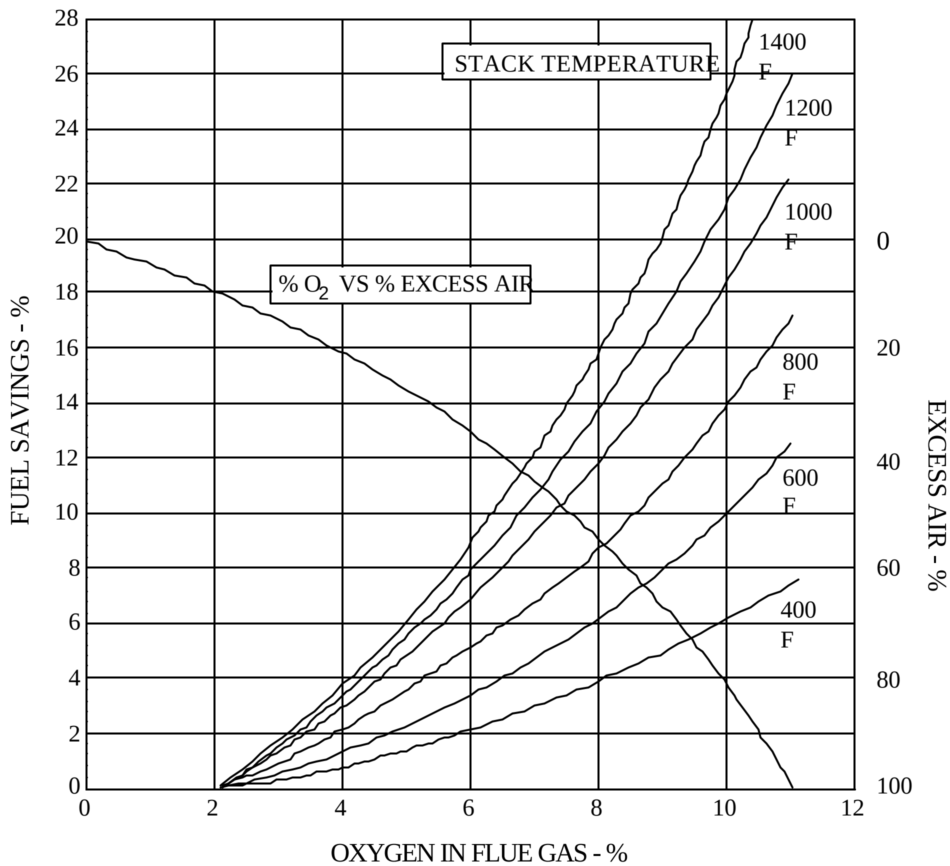


Figure 5.5: Natural Gas Fuel Savings[1]

[1]. ***Energy Conservation Program Guide for Industry and Commerce***, National Bureau of Standards Handbook 114, September 1974, p.3-48.

Note: Fuel savings determined by these curves reflect the following approximation: The improvement in efficiency of radiant and combination radiant and convective heaters or boilers without air pre-heaters that can be realized by reducing excess air is 1.5 times the apparent efficiency improvement from air reduction alone due to the accompanying decrease in flue gas temperature.

As an example, for a stack temperature of 600^0FF and O2 in flue gas of 6%, the fuel savings would be 3%. If desired, excess air may be determined as being 36%.

§ *Case Study #2: Adjust Boiler Air-Fuel Ratio*

IMPLEMENT PERIODIC INSPECTION AND ADJUSTMENT
OF COMBUSTION IN AN OIL FIRED BOILER

Current Practice and Observations

During the audit, flue gas samples were taken from the boiler. The boiler was operating with too much excess air resulting in unnecessary fuel consumption.

Recommended Action

Many factors including environmental considerations, cleanliness, quality of fuel, etc. contribute to the efficient combustion of fuels in boilers. It is therefore necessary to carefully monitor the performance of boilers and tune the air/fuel ratio quite often. Best performance is obtained by the installation of an automatic oxygen trim system that will automatically adjust the combustion to changing conditions. With the relatively modest amounts spent last year on fuel for these boilers, the expense of a trim system on each boiler could not be justified. However, it is recommended that the portable flue gas analyzer be used in a rigorous program of weekly boiler inspection and adjustment for the two boilers used in this plant.

Anticipated Savings

The optimum amount of O2 in the flue gas of an oil fired boiler is 3.7%, which corresponds to 20% excess air. The boiler measured had an O2 level of 8.5 % and a stack temperature of 400^0F. From the Figure 5.6, using the measured stack temperature and excess oxygen for the boiler indicates a possible fuel saving of nearly 4.0% for the oil fired boiler.

It is assumed that the boiler consumes all of the fuel oil consumed during the year. The possible savings is then the sum of the products of amount used and percent saved.

ES = (10,339 gallons/yr) x (0.04 savings.) = 414 gallons/yr

Therefore the total cost savings would be:

Cost Savings = (414 gallons/yr) x ($1.03/gallon) = $426/yr

<u>*Total Annual Savings = $426*</u>

<u>Implementation</u>

It is recommended that you purchase a portable flue gas analyzer and institute a program of monthly boiler inspection and adjustment of the boilers used in the plant. The cost of such an analyzer is about $500 and the inspection and burner adjustment could be done by the current maintenance personnel. The simple payback period will then be:

$500 implementation cost / $426 savings = 1.2 years

<u>***Simple Payback = 1.2 years***</u>

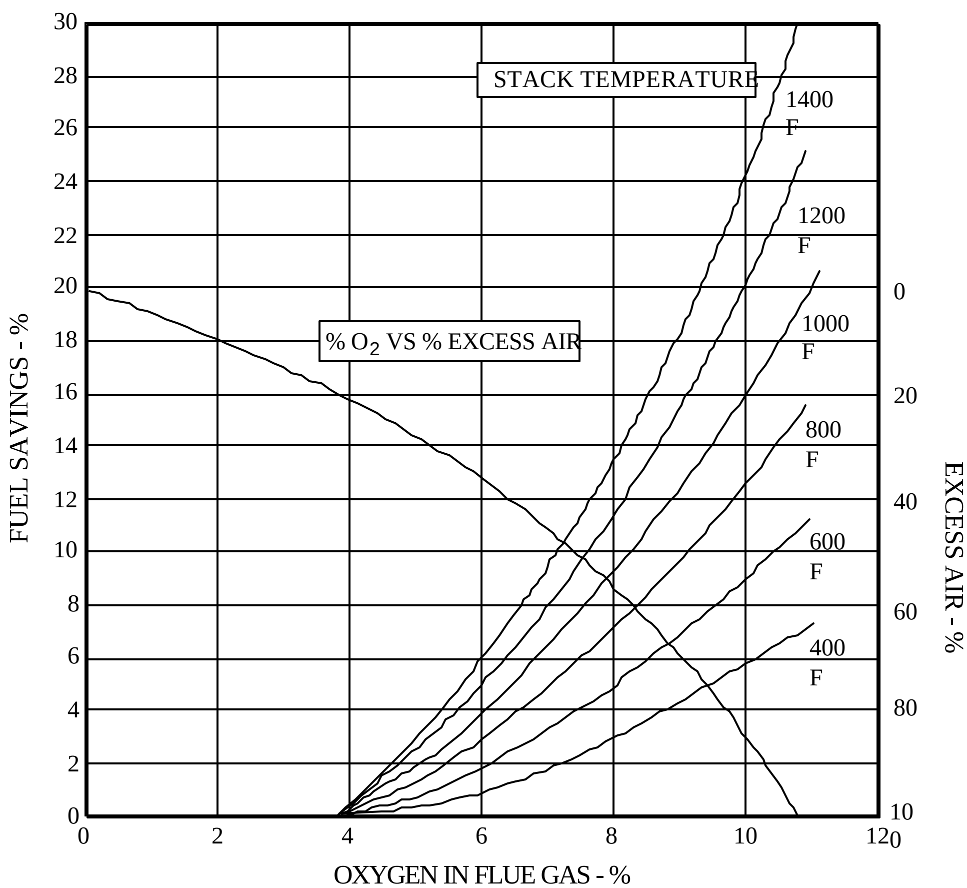


Figure 5.6: Liquid Petroleum Fuel Savings[2]

Note: Fuel savings determined by these curves reflect the following approximation: The improvement in efficiency of radiant and combination radiant and convective heaters or boilers without air pre-heaters that can be realized by reducing excess air is 1.5 times the apparent efficiency improvement from air reduction. This is due to the decrease in flue gas temperature which must follow increased air input.

As an example, for a stack temperature of 800^0F and O2 in flue gas of 6%, the fuel savings would be 3%. If desired, excess air may be determined as being 36%.

For further recommendations, see the “Boiler Efficiency Tips” in Section 5.1.2.1.

Elimination of Steam Leaks

Description

Significant savings can be realized by locating and repairing leaks in live steam lines and in condensate return lines. Leaks in the steam lines allow steam to be wasted, resulting in higher steam production requirements from the boiler to meet the system needs. Condensate return lines that are leaky return less condensate to the boiler, increasing the quantity of required make-up water. Because make-up water is cooler than condensate return water, more energy would be required to heat the boiler feedwater. Water treatment would also increase as the make-up water quantity increased. Leaks most often occur at the fittings in the steam and condensate pipe systems. Savings for this measure depend on the boiler efficiency, the annual hours during which the leaks occur, the boiler operating pressure, and the enthalpies of the steam and boiler feedwater.

Definitions

Enthalpy - A measure of the energy content of a substance.

Applicability

Facility Type - Any facility having a steam boiler.
Climate - All climates.
Demand-Side Management Strategy - Strategic conservation.

Steam Leak Repair: Costs and Benefits1

Options	Installed Costs ($)2	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)3	Simple Payback (yr)

2. *Energy Conservation Program Guide For Industry and Commerce,* National Bureau of Standards Handbook 115, September 1974, p.3-48.

Steam Leak Repair	873	1,628	5,548	0.2

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database. All values are averages based on the data base data. The implementation rate for this measure was 81%.
2. One example from the IAC data base to further clarify the costs is as follows: Repairing steam leaks on a 600 hp boiler system at a rendering plant resulted in energy and cost savings of 986 MMBtu/yr and $4,535/yr. The implementation cost was $350.
3. The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

Maintenance of Steam Traps

Description

A steam trap holds steam in the steam coil until the steam gives up its latent heat and condenses. In a flash tank system without a steam trap (or a malfunctioning trap), the steam in the process heating coil would have a shorter residence time and not completely condense. The uncondensed high-quality steam would be then lost out of the steam discharge pipe on the flash tank. Comparing the temperature on each side of the trap can easily check steam trap operation. If the trap is working properly, there will be a large temperature difference between the two sides of the trap. A clear sign that a trap is not working is the presence of steam downstream of the trap. Nonworking steam traps allow steam to be wasted, resulting in higher steam production requirement from the boiler to meet the system needs. It is not uncommon that, over time, steam traps wear and no longer function properly.

Definitions

Condensate - The hot water that is created from the steam that has condensed.

Applicability

Facility Type - Any facility having a steam boiler.
Climate - All climates.
Demand-Side Management Strategy - Strategic conservation.

For More Information

Kennedy, W.J., W.C. Turner, Energy Management, Prentice-Hall, Englewood Cliffs, NJ, 1984.

Steam Trap Repair: Costs and Benefits**1**

Options	Installed Costs ($)2	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)3	Simple Payback (yr)
Steam Trap Repair	2,560	5,431	14,885	0.17

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database. All values are averages based on the data base data. The implementation rate for this measure was 79%.

2. One example from the IAC data base to further clarify the costs is as follows: Repairing one steam trap resulted in energy and cost savings of 105 MMBtu/yr and $483/yr on a 600 hp boiler at a rendering plant. The implementation cost was $220.
3. The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

High Pressure Condensate Return Systems

Description

If pressurized condensate return is exposed to atmospheric pressure, flashing will occur. Flash tanks are often designed into a pressurized return system to allow flashing and to remove noncondensable gases from the steam. The resulting low-pressure steam in the flash tank can often be used as a heat source. A more efficient alternative is to return the pressurized condensate directly to the boiler through a high-pressure condensate return system. Heat losses due to flashing are significant, especially for high-pressure steam systems. Steam lost due to flashing must be replaced by water from the city mains (at approximately 55^0F). This causes the feedwater mixture to the boiler to be significantly below its boiling point, resulting in higher fuel consumption required by the boiler to increase the temperature of the feedwater to the boiling point. The water treatment costs are also greater with increased amounts of flash losses.

In a retrofit application, a closed, high-pressure condensate return system would prevent the flashing that occurs in the existing system by returning the condensate to the boiler at a higher pressure and temperature, thereby reducing boiler energy requirements and water treatment costs. Noncondensable gases (such as air and those formed from the decomposition of carbonates in the boiler feedwater treatment chemicals) can be removed from a closed condensate return system through the use of variable orifice discharge modules (VODMS). VODMS are similar to steam traps in that they return condensate but also can remove noncondensable gases. In a system that does not contain VODMS, these gases can remain in the steam coil of the equipment being heated and can form pockets of gas that have the effect of insulating the heat transfer surfaces, thus reducing heat transfer and decreasing boiler efficiency.

Definitions
Flashing - Pressurized condensate changes phase into steam if the pressure is suddenly reduced.

Applicability
Facility Type - All facilities that have a steam system with a high-pressure condensate return system.
Climate - All climates.
Demand-Side Management Strategy - Strategic conservation.

For More Information
Industrial Assessment Center (IAC). Contact the IAC nearest to your area.

High Pressure Condensate Return Systems: Costs and Benefits1

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
High Pressure Condensate Return	31,341	2,850	12,791	2.4

1. Tabulated data were taken from the Industrial Assessment Center (IAC) data base. All values are averages based on the data base data. The implementation rate for this measure was 59%.
2. One example from the IAC data base to further clarify the costs is as follows: Installing of high-pressure condensate return system equipment at food processing plant resulted in energy and cost savings of 4,727 MMBtu/yr and $14,100/yr. The implementation cost was $37,000.
3. The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

Variable Frequency Drives for Combustion Air Blowers

Description

The load on a boiler typically varies with time, and, consequently, the boiler varies between low and high fire. The amount of combustion air required changes accordingly. Common practice has been to control a damper or vary the positions of the inlet vanes in order to control the air flow; that is, when inlet air is required the damper is essentially closed and is opened, as more air is required. This is an inefficient method of air flow control because air is drawn against a partially closed damper whenever the maximum amount of combustion air is not required. It is much more efficient to vary the speed of the blower by installing a variable-frequency drive on a blower motor (Note that it is sometimes expensive to install a variable-frequency drive if inlet vanes exist). Because the power required to move the air is approximately proportional to the cube of the air flow rate, decreasing the flow rate by a factor of two will result in a reduction of power by a factor of eight. This measure is particularly significant on boilers of 3.3 MMBtu/h or greater.

Combustion air blower variable-frequency drives are available from boiler manufacturers for new boiler installation. They also may be retrofitted to an existing boiler with few changes to the boiler.

Definitions

Firing Rate - As the load on a boiler varies, the amount of fuel supplied to the boiler varies in order to match the load.

Applicability

Facility Type - Applicable to any facility that has a large, forced draft boiler

Climate - All climates.

Demand-Side Management Strategy - Strategic conservation.

For More Information

Industrial Assessment Center (IAC). Contact the IAC nearest to your area.

Witte, L.C., P. S. Schmidt, D.R. Brown, Industrial Energy Management and Utilization, Hemisphere Publishing Corp., Washington, DC, 1988, pp. 530-532.

(ASD) - Variable-Frequency Drives: Costs and Benefits1

Options	Installed Costs ($)2	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)3	Simple Payback (yr)
Combustion Air Blower Variable-Frequency Drives	23,967	1,115	13,789	1.7

1. Tabulated data were taken from the Industrial Assessment Center (IAC) data base. All values are averages based on the data base data. The implementation rate for this measure was 33%.
2. One example from the IAC data base to further clarify the costs is as follows: Installing variable speed drives and corresponding controls on two 250 hp combustion air fans at a food processing plant resulted in energy and cost savings of 488,445 kWh/yr and $28,000/yr. The implementation cost was $80,000.
3. The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

5.2. HEAT RECOVERY SYSTEMS

Heat recovery systems are installed to make use of some of the energy which otherwise would be lost into the surroundings. Usually, the systems use a hot media leaving the process to preheat other, or sometimes the same, media entering the process. Thus energy otherwise lost, does useful work.

5.2.1. General Considerations

The first step in heat recovery analysis is to survey the plant and take readings of all recoverable energy that is being discharged into the atmosphere. The survey should include analysis of the following conditions:

- Exhaust stack temperatures
- Flow rates through equipment
- Particulates, corrosives of condensable vapors in the air stream

Ventilation, process exhaust and combustion equipment exhaust are the major sources of recoverable energy. Table 5.6 illustrates typical energy savings achieved by preheating combustion air with hot exhaust gases from process or furnaces.

Furnace outlet	**Combustion air preheat temperature, ^{0}F**

Temp. ^{0}F	400	500	600	700	800	900	1000	1100	1200	1300
2600	22	26	30	34	37	40	43	46	48	50
2500	20	24	28	32	35	38	41	43	45	48
2400	18	22	26	30	33	36	38	41	43	45
2300	17	21	24	28	31	34	36	39	41	43
2200	16	20	23	26	29	32	34	37	39	41
2100	15	18	22	25	28	30	33	35	37	39
2000	14	17	20	23	26	29	31	33	36	38
1900	13	16	19	22	25	27	30	32	34	36
1800	13	16	19	21	24	26	29	31	33	35
1700	12	15	18	20	23	25	27	30	32	33
1600	11	14	17	19	22	24	26	28	30	32
1500	11	14	16	19	21	23	25	27	29	31
1400	10	13	16	18	20	22	25	27	28	30

Note: 1. Numbers represent fuel savings, in percent.
2. Natural gas with 10% excess air. Other charts are available for different fuels and various amount of excess air.

Table 5.6: Fuel Savings Realized by Preheating Combustion Air

Regardless of the amount or temperature of the energy discharged, recovery is impractical unless the heat can be effectively used somewhere else. Also, the recovered heat must be available when it is needed.

Waste and heat recovery systems can be adapted to several applications:

- ♦ Space heating
- ♦ Make-up air heating
- ♦ Water heating
- ♦ Process heating
- ♦ Combustion air preheating
- ♦ Boiler feed water preheating
- ♦ Process cooling or absorption air conditioning

5.2.2. Types of Heat Recovery Equipment

Choosing the type of heat recovery device for a particular application depends on a number of factors. For example air-to-air equipment is the most practical choice if the point of recovery and use are closely coupled. Air-to-liquid equipment is the logical choice if longer distances are involved. Included in this section are five types of heat recovery systems.

⇒ Economizers
⇒ Heat pipes
⇒ Shell and tube heat exchangers

⇒ Regenerative units
⇒ Recuperators

Economizers

Economizers are air-to-liquid heat exchangers. Their primary application is to preheat boiler feed water. They may also be used to heat process or domestic water, or to provide hot liquids for space heating or make-up air heating equipment.

The basic operation is as follows: Sensible heat is transferred from the flue gases to the deaerated feed water, as the liquid flows through a series of tubes in the economizer, which is located in the exhaust stack.

Most economizers have finned tube heat exchangers constructed of stainless steel while the inlet and outlet ducts are carbon steel lined with suitable insulation. Maximum recommended waste gas temperatures for standard units are around 1,800^{0}F. According to economizer manufacturers, fuel consumption is reduced approximately 1% for each 40^{0}F reduction in flue gas temperature. The higher the flue gas temperature the greater potential for energy savings.

Heat Pipes

The heat pipe thermal recovery unit is a counter flow air-to-air heat exchanger. Hot air is passed through one side of the heat exchanger and cold air is passed through the other side in the opposite direction. Heat pipes are usually applied to process equipment in which discharge temperatures are between 150 and 850 ^{0}F. There are three general classes of application for heat pipes:

1. Recycling heat from a process back into a process (process-to-process)
2. Recycling heat from a process for comfort and make-up air heating (process-to-comfort)
3. Conditioning make-up air to a building (comfort-to-comfort)

Heat pipes recover between 60 to 80% of the sensible heat between the two air streams. A wide range of sizes is available, capable of handling 500 to 20,000 cubic feet of air per minute. The main advantages of the heat pipe are:

No cross contamination
Operates without external power
Operates without moving parts
Occupies a minimum of space

Shell and Tube Heat Exchangers

Shell and tube heat exchangers are liquid-to-liquid heat transfer devices. Their primary application is to preheat domestic water for toilets and showers or to provide heated water for space heating or process purposes.

The shell and tube heat exchanger is usually applied to a furnace process cooling water system, and is capable of producing hot water approaching 5 to 10^0F of the water temperature off the furnace. To determine the heat transfer capacity of the heat exchanger the following conditions of the operation must be known:

1. The amount of water to be heated in gallons per hour
2. The amount of hot process water available in gallons per hour
3. Inlet water temperature and final water temperature desired
4. Inlet process water temperature

Regenerative Unit (Heat Wheel)

The heat wheel is a rotary air-to-air energy exchanger which is installed between the exhaust and supply air duct work in a make-up or air heating system. It recovers 70 to 90% of the total heat from the exhaust air stream. Glass fiber ceramic heat recovery wheels can be utilized for preheating combustion air with exhaust flue gas as high as $2{,}000^0$F. Heat wheels consist of rotating wheel, drive mechanism, partitions, frames, air seals and purge section. Regeneration is continuous as energy is picked up by the wheel in the hot section, stored and transferred to the cooler air in the supply section as the wheel rotates through it.

Recuperators

Recuperators are air-to-air heat exchangers built to provide efficient transfer of heat from hot exhaust gases to cooler air stream. Recuperators are generally used in the following processes:

- Preheating combustion air
- Preheating material that has to be heated in the process
- Recovery heat from hot gas to supplement or replace the primary heat source in process or comfort heating applications

There are many different types of recuperator designs available today. The recuperator described below is primarily used for combustion air preheating.

It consists of three basic cylinders, the hot gases flow up through the inner cylinder, cold combustion air enters at the bottom of the outer cylinder, flows upward and down through the middle cylinder, exiting from the bottom of the middle cylinder. Heat energy from exhaust gases is transferred through the inner cylinder wall to the combustion air by a combination of conduction and radiation heat transfer. The net effect is preheated air temperature as high as $1{,}000^0$F with inlet exhaust gases entering at $2{,}000^0$F and exiting at $1{,}300^0$F.

5.3. HEATING SYSTEMS

Heating systems are an integral part of industry today. They are used for process heating, drying, and comfort/space heating. The main purpose of industrial space heating is to provide comfortable conditions for the people working in these areas but also for purposes such as storage of goods or providing a precise environment for sensitive equipment.

5.3.1. Overview

The objective of heating is to produce a steady, balanced environment regardless of the outside conditions. The type of clothing worn and the additional heat sources such as process waste heat must also be considered when implementing a system. Conservation of energy in heating means getting the most efficient use out of energy while consuming as little as possible. Energy can be conserved by reducing building heat loss by filling gaps and properly insulating. Avoiding overheating practices such as heating a building when it is unoccupied can also save in energy costs.

The existing industrial heating systems are for the most part inefficient, dated and are often the principal consumers of energy. The most widely used system is the conventional convection heater which is highly inefficient and consumes large amounts of energy. Convection heaters use the circulation of steam or high-pressure hot water in order to generate space heat. Inefficiencies can be attributed to the fact that much energy is lost in heating the space, or the medium, surrounding the object. It then relies on convection between the medium and the surface of the object to increase its temperature, or create warmth.

Another dilemma associated with space heating involves the loss of heat due to stratification. Most systems are designed to heat an area in order to maintain a desired temperature. Energy is wasted because a majority of the heat is either lost to infiltration and ventilation or eventually rises to the ceiling level requiring more energy to keep the working level heated. There are several energy conservation opportunities that can be applied to these operations to reduce the use of energy. This section describes these measures, namely destratification fans and radiant heating systems, and how they can be applied in industry.

5.3.2. Destratification Fans

Destratification fans are used to destratify air in buildings. In this section the theory of operation and some design considerations will be covered.

Introduction

Stratification is a result of an increasing air temperature gradient between the floor and the ceiling in an enclosed area, usually due to stagnant air. When there is insufficient air movement, the hot air will rise to the ceiling, resulting in warmer temperatures in the upper portion of the area and cooler air temperatures at the working level near the floor. An example of stratification is shown in Figure 5.7(a). If stratification is present, the heating requirements of the facility are increased because the heating system is continually working to maintain the thermostat setpoint temperature. The thermostat setpoint operates according to the temperature at the working level. Much effort is required to make up for the heat the working level loses due to this physical occurrence. The destratification process initiates the movement of the air, creating a more uniform temperature distribution within the enclosed space. The air temperature at the floor level becomes nearly equal to the air temperature at the ceiling thus reducing the amount of energy needed to heat the facility. The amount of heat lost to ventilation and infiltration is also reduced due to the overall reduction in heat being generated.

Ceiling Fans

The basic function in destratification is to pull the air from the ceiling level down to the floor level and allow it to mix with the cooler air and increase the temperature at the working level. This benefits the comfort of the workers and also reduces the energy use of the facility. This process can be accomplished by two different means. The first and most common device used is the ceiling fan. The fan draws the air from above the fan and forces it downward by the power of the specific motor and blade combination. The resulting motion is an air plume, with the warm air moving downward and outward and essentially creating an mixture like the one shown in Figure 5.7(b). The total air volume and coverage is dependent on the motor size, height of the fan and the specifications of the fan blade (design, size, rpm). Ceiling fans are also applicable in cooling conditions. It creates motion in the air and this can assist with evaporative cooling of the skin surface. The total number of fans needed for a facility can be determined by the following equation.

$$\frac{\text{Total Plant Area}}{\text{Fan Area Coverage}} = \text{Number of Fans Needed}$$

The Fan area coverage depends on the type and size of fan used and this information can usually be obtained from the fan manufacturer. Placement of the fans is also important. The simplest method of determining placement is to calculate distance between each fan. This can be accomplished by using

$$\text{Distance} = \sqrt{(\text{Fan Area Coverage})}$$

Corner fans should be placed half this distance from each wall and consecutive fans should be placed this distance apart to obtain maximum coverage. Obstacles such as stacked merchandise or office partitions should be taken into consideration when choosing and placing fans.

§ *Case Study*

In calculating the energy and cost savings of this implementation it is first necessary to calculate the Energy Savings of the fans ($E_{S,F}$).

$$E_{S,F} = \{[(U \text{ x } A)_W + (U \text{ x } A)_I \text{ x } DH_{AT} + (U \text{ x } A)_C \text{ x } DH_{CT} - [(U \text{ x } A)_W + (U \text{ x } A)_I + (U \text{ x } A)_C] \text{ x } DH_{PT}\} / EFF$$

where

U = heat transfer coefficient
A = area
DH_{AT} = annual heating degree hours at current average temperature
DH_{CT} = annual heating degree hours at ceiling temperature
DH_{PT} = annual heating degree hours at proposed mixed temperature
EFF = efficiency of the heating system

subscripts

W = of the walls, windows, and doors
I = of the infiltration
C = of ceiling/roof

The amount of additional energy consumed by the destratification fans is given by

$$E_{DF} = \text{Number of Fans} \times W \times OH$$

where

W = wattage of each fan
OH = operating hours during the heating season

The total annual energy savings (ES) can now be found by

$$ES = E_{S,F} - E_{DF}$$

Using this information, it is simple to calculate the annual cost savings (CS) of this implementation.

$$CS = (E_{S,F} \times \text{Fuel Cost}) - (E_{DF} \times \text{Fuel Demand Cost})$$

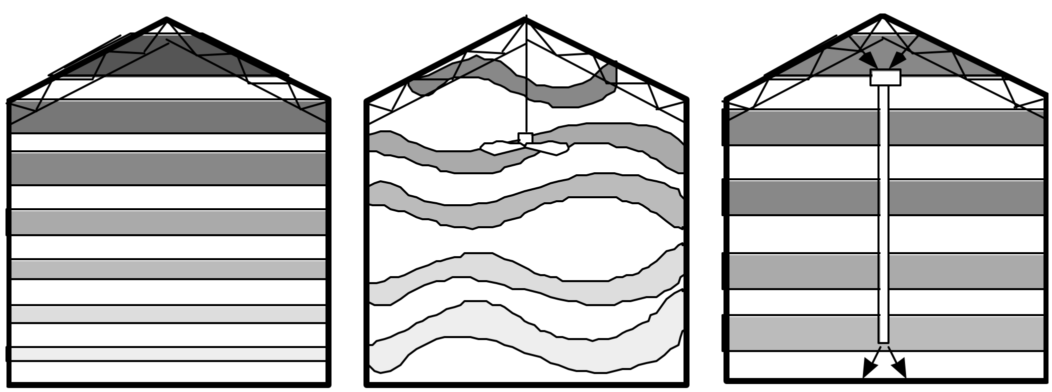
Finally a simple payback can be found using

$$\text{Payback} = (\text{Number of Fans} \times (\text{Cost per Fan} + \text{Installation Cost})) / CS$$

A case study for one plant yielded a potential energy savings of 305.59 MMBtu/yr with cost savings of $1,643.20. This measure, which involved 19 fans, had an implementation cost of $3,420. The suggested fan type was the 60" model, estimated to cover about 2,150 ft2, with a price of approximately $90 per unit and an installation cost of $90, resulting in a total of $180 per fan. The simple payback period was 2.08 years. The typical payback period for the installation of destratification fans is approximately 2 years.

Ducting

Another option for destratifying the air is to install a hanging device that uses a fan to pull the warm air from the ceiling, sends it downward through a duct/tube and redistributes the air at the floor level as shown in Figure 5.7(c). This device has its advantages and disadvantages. It aids in the destratification process and creates a more uniform temperature distribution without creating disturbing drafts. It is also simple to install and can easily be relocated throughout the building. On the other hand, these devices may be a bit cumbersome and unsightly. They would extend from the ceiling down to the floor and create additional obstacles for the workers or just may not be appropriate for some areas of the plant. These devices also do not possess the cooling applications of the ceiling fans and are only useful for the heating season.



(a) (b) (c)

Figure 5.7: Stratification and Destratification of Air

a) Stratification air pattern, (b) Destratification air pattern using a ceiling fan,

(c) Destratification air pattern using ducting

5.3.3. Electric Heating

Electrical resistance heating is often inexpensive and convenient to install. However, electric energy costs at least twice as much as other sources of heat, such as steam or natural gas, although greater efficiency in use may partially offset this difference. Before a decision is made to heat with electricity, the savings these alternative sources can produce should be evaluated in relation to the cost to install them. For example, consider the replacement of a 500,000-Btu-per hour electric heater with a 500,00-Btu-per-hour natural gas dryer.

Annual Cost of ELECTRIC HEATER
$= 500{,}000 \text{ Btu/hr} \times \$14.65/10^6 \text{ Btu} \times 80\% \text{ Eff.} \times 6{,}000 \text{ hrs/yr} = \$35{,}200$

Annual Cost of Natural Gas Dryer
$= 500{,}000 \text{ Btu/hr} \times \$3.00/10^6 \text{ Btu} \times 50\% \text{ Eff.} \times 6{,}000 \text{ hrs/yr} = \$4{,}500$

The energy cost saving is = \$35,200 - \$4,500 = \$30,700/yr

5.3.4. Radiant Heaters

Radiant heaters are used for heating spaces by converting electric or gas energy. It is important to think thoroughly about the whole picture before recommending radiant heaters because if considered in isolation they probably would not make an economic sense.

Introduction

When dealing with the use of energy for the purpose of heating sometimes it is better to deal directly with the source of the problem. Convection heaters are inefficient heating devices in themselves. A lot of energy is wasted in heating the space and using that heated air to convectively warm the people and/or objects within that space. Radiant heaters take a different approach. Radiant heaters operate similar to the sun. Radiant energy is transferred at the speed of light as electromagnetic waves. The heaters emit infrared radiation which is absorbed by the people/objects that it strikes, which elevates the temperature of the body, but does not heat the air through which it travels.

Types of Radiant Systems

Radiant heating systems can be gas-fired or electric. The type of radiant heating system used is determined by the sources available from the building in which the system is installed. For example, electric radiant heating systems may be installed in an area of the building where gas is unavailable. Natural gas is more cost effective than electricity and produces lower operating costs. The efficiencies for both electric and gas systems are approximately the same but natural gas infrared systems have a longer lifetime. A radiant heating system is often a relatively easy retrofit measure but may also be integrated into new construction. Radiant heaters come in different sizes, styles and shapes according to their application. Figure 5.8 shows a typical example of a radiant heater. In relation to equipment performance, radiant sources can be categorized into four groups. A low temperature system has source temperatures up to 300^0F and would typically be used as a floor or ceiling heater. A low-intensity system has sources up to 1200^0F. A medium-intensity system has temperatures up to 1800^0F and would typically include a porous matrix unit. High-intensity systems have source temperatures up to 5000^0F and usually consist of an electrical reflector lamp and high temperature resistors. Low-temperature heating systems are usually use in residential and perimeter heating applications such as schools, offices, and airports. These systems are often incorporated directly into the building structure. Low-, medium-, and high-intensity systems have more industrial and commercial uses and are usually assembled units that are installed into existing structures.

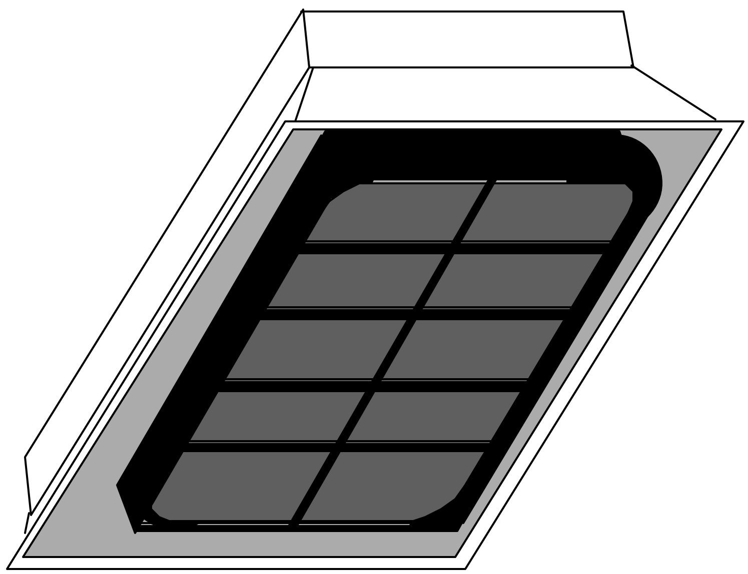


Figure 5.8: Infrared Radiant Heater

Applications

Use of radiant systems is ideal for comfort heating. Since the infrared radiation elevates body temperature without heating the air through which it travels, the same degree of comfort provided by the convection heaters can be maintained at lower indoor air temperatures with radiant heaters. This measure also eliminates the problem of stratification. It is beneficial to use these heaters in spaces where the ceilings are high and stratification is prominent. It is also very practical for areas that are frequently exposed to the outside air such as loading docks. Radiant spot heating helps workers to maintain a comfortable working temperature even though the space air may be cold. Radiant heat, unlike convection, does not require a medium to travel through and thus has a much higher heat transfer rate.

An advantage of this is its short response time. The person/object will feel the effects of the system shortly after it is engaged. The rate of energy transfer is dependent upon many different factors including temperature, emissivity, reflectivity, absorptivity, and transmissivity. Emissivity is a radiative property that indicates how efficiently the surface emits compared to an ideal radiator and its value ranges between 0 and 1. Reflectivity, absorptivity, and transmissivity are the fractions of incident radiation reflected, absorbed, and transmitted, respectively.

For use in process heating, the conventional heating methods can also be replaced with radiant systems. Since radiation does not need to travel through a medium, more heating work can be accomplished in less space. The response time when compared with convection heaters can prove to be an advantage in these industrial applications. The shut down time for an infrared burner varies from one to 30 seconds. Gas or electric radiant heaters may be used for different heating applications. Applications include cooking, broiling, melting and curing metals, curing and drying rubber and plastics, and preshrinking and finishing of textiles.

§ *Case Studies*

In calculating the energy and cost savings for using infrared radiant heaters the method differs according to the application of the system.

Comfort heating

For the radiant comfort heating system, the method is quite simple. First calculate the amount of energy (E_{RH}) consumed by the infrared units.

$$E_{RH} = HL \times \text{Number of Units} \times PR \times OH$$

where

HL = average heating load
PR = total power rating of each unit
OH = operating hours per year

Next, an estimate of the current energy usage for the convective heaters (E_{CH}) must be made. Then taking the difference in these two values,

$$ES = E_{CH} - E_{RH}$$

the total annual energy savings can be determined. Multiplying this number by the cost of fuel yields the total cost savings for the year.

$$CS = ES \times \text{Fuel Cost}$$

Or an alternate method for computing these savings is simply

$$ES = \text{Current Usage x } \{1\text{- } (EFF_c / EFF_R)\}$$

and

$$CS = ES \times \text{Fuel Cost}$$

where

EFF_C = efficiency of the convective system
EFF_R = efficiency of the radiant system

Note that although this evaluation is generally valid, these savings are based on the efficiency of the systems, where in most cases the savings are determined by the cost of the fuel. This is especially true in the case where different energy sources are being considered, i.e. natural gas or electricity.

One study estimated a current energy use of 5,000 x 106 Btu/yr. Installation of 18 radiant heaters yielded energy savings of 2,786 x 106 Btu/yr and cost savings of $10,406/yr. The implementation cost including piping and labor came to a total of $28,960 resulting in a payback period of 2.8 years.

Process heating

To find the savings for replacing a process unit with an infrared system, many more factors must be taken into account. For example, one case study involved replacing process ovens with infrared burners. The ovens were used to heat molds which in turn, baked cones. The first step in this savings estimation was to calculate the efficiency of the current ovens. This was accomplished by estimating the amount of energy (E_C) used to heat the product per year.

$$E_C = BS \times B \times OH \times [H_V + CP \times (Tf - Ti)]$$

where

BS = average batch size
B = # of batches per hour
OH = operating hours per year
Hv = heat of vaporization of water (assuming batch is 100% water)
CP = specific heat of water
Tf = final temperature of cone
Ti = initial temperature of batter

Once the total amount of energy consumed by the ovens (E_O) is obtained, the overall oven efficiency can be determined by

$$EFF_C = E_C / E_O$$

The heat transfer rates for the new and the old system were then found and compared. The convective heat transfer rate in the blue flame mode was approximated to be around 1.0 Btu/hr-ft2-deg. F based on the characteristics of the current ovens. The radiant heat transfer rate (U_R) was found by using the following equation.

$$U_R = F \times a \times \sigma \times (T_1^4 - T_2^4)/(T_g - T_m) = 1.3 \text{ Btu/ hr ft}^2 \text{ F}^\circ$$

where

F = radiation shape factor
a = absorptivity of the mold
σ = Boltzmann's constant
T_1 = radiant heater surface temperature
T_2 = mold surface temperature
T_g = gas temperature in the oven
T_m = mold temperature

Comparing these rates, U_R was found to be 30% larger than U_C, the convective coefficient. If there were 30% savings, the energy savings would be

ES = Total Gas used by Ovens x Percent Savings

And the cost savings

CS = ES x Cost of Natural Gas

Calculating the payback is simply

Payback = Implementation Costs / CS

where the implementation costs include equipment and installation.

The results of this study showed that there was a total energy savings of 5,440 MMBtu/yr and a total cost savings of $31,280/yr. For estimation purposes, it was assumed that 65% of the total gas use was consumed in order to obtain these approximations. The cost of implementation for each oven was $10,500. For all nine ovens the total implementation cost was $94,500. This data yields a payback period of 3.0 years.

5.4. FURNACES AND BURNERS

Furnaces and burners are devices designed to release energy from one form (hydrocarbon bonds) and convert it into another form (heat). The energy is typically released from gas or oil fuels through a combustion process. What type of burner or furnace to use and what is the most efficient way of operation highly depends on the process where it is used? There is always more than one way of solving an engineering problem, however, in some industries years of research and study of the processes involved might indicate to one recognized approach and therefore define quite narrowly the equipment best suited. It is obvious that one has to be careful not to recommend a change of a furnace without knowing the reason why the old seemingly inefficient one is used. On the other hand, with the sufficient knowledge supporting the change, the most desirable thing to do is to implement such a proposal.

5.4.1. Burner Combustion Efficiency

Conserving fuel in heating operations such as melting or heat treating is a complex operation. It requires careful attention to the following:

- Refractories and insulation
- Scheduling and operating procedures
- Preventative maintenance
- Burners
- Temperature controls
- Combustion controls

Providing the correct combustion controls will increase combustion efficiency measurably. Complete combustion of Natural Gas yields:

a) Carbon dioxide
b) Water vapor

If gas is burned with the chemically correct amount of air, an analysis of the products of combustion will show it contains about 11-12% CO_2 at 20-22% water vapor. The remainder is nitrogen, which was present in the air and passed through the combustion reaction essentially unchanged.

If the same sample of natural gas is burned with less than the correct amount of air ("rich" or "reducing fire"), flue gas analysis will show the presence of hydrogen and carbon monoxide, products of incomplete combustion. Both of these gases have fuel value, so exhausting them from furnaces is a waste of fuel (see Figure 5.9).

If more than the required amount of air is used (lean or oxidizing flame), all the gas will be burnt but the products of combustion will contain excess oxygen. This excess oxygen is an added burden on the combustion system - it is heated and then thrown away thereby wasting fuel.

The following steps should be taken to upgrade burner and combustion controls:

1. Use sealed-in burners. Make all combustion air go through the burner - open cage type burners are very inefficient.
2. Use power burners. Inspirator or atmosphere burners have very poor mixing efficiency at low inputs, especially if gas pressure is low.
3. Install a fuel/air ratio control system.

5.4.2. Premix Burner Systems

Premix burner systems commonly use a venturi mixer known as an aspirator or proportional mixer. Air from the blower passes through the venturi, creating suction on the gas line, and the amount of gas drawn into the mixer drops in proportion to air flow. Aspirator systems are fairly simple to adjust and maintain accurate air/fuel ratios over wide turndown ranges, but their use is limited to premix burners.

5.4.3. Nozzle Mix Burners

Nozzle mix burners used with a Ratio Regular System is widely used for industrial furnace applications. Orifices are installed in the gas and air lines to a burner and then adjusted so that air and gas are in correct burning proportions when pressure drops across the orifices are equal. Once the orifices are set, they will hold the correct air/gas ratio as long as the pressure drop remains the same, no matter what firing rate. Ratio Regular systems have good accuracy and are fairly easy to adjust.

On large furnaces where fuel consumption is extremely high, or on furnaces where very close control of the atmosphere is required, extremely accurate air/fuel ratio control is vital, both for fuel economy and product quality. On these installations hydraulic or electronic flow controls are often used.

These systems feature fixed orifices in both gas and air streams, and these orifices are sized to pass proportional amounts of gas and air at equal pressure drops, pressure drop signals are fed to a ratio controller which compares them. One of the outstanding features of this system is that the air/fuel ratio can be adjusted by turning a dial. Since a burner can be thrown off correct gas ratios by changes in ambient air temperature and humidity, this ratio adjustment feature permits the operator to set the burner back to peak operating efficiency with very little effort.

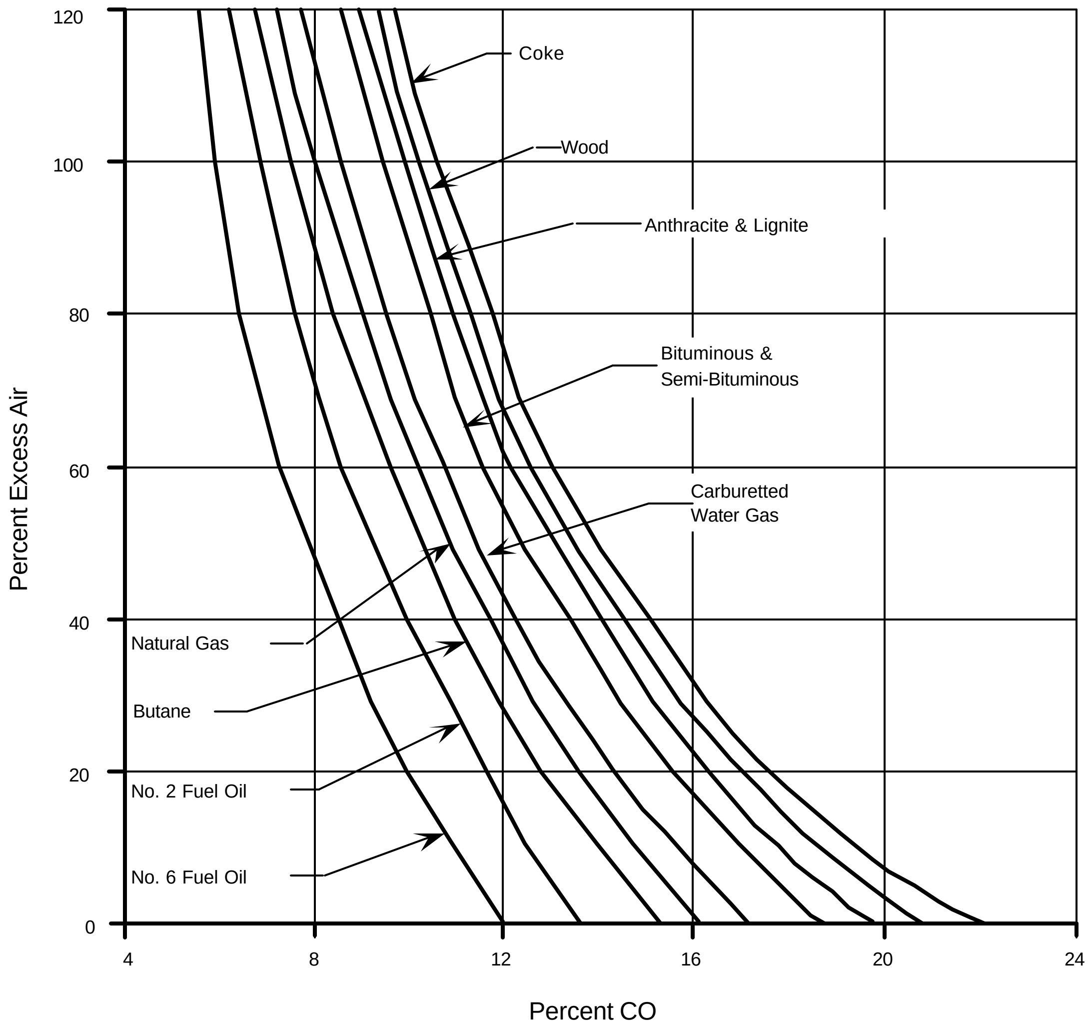


Figure 5.9: Percent Excess Air From CO2 Reading

On multiple burner furnaces, the combustion products of all burners mix together before they reach the flue gas sampling point (Furnaces should have manifold flue gas outlets in order to obtain common sampling point for flue gas analysis.) If, for example, some of the burners are unintentionally set lean, and others rich, the excess air from the lean burners could consume the excess fuel from the rich burners, producing flue gas with ultimate CO2 and practically no free oxygen or combustibles. Samples of these gases could be misleading and show correct air/gas ratio, when in fact they are not. Also, if a burner is set rich and the excess combustibles in the flue gases find air in the stack and burn there, flue gas analysis will again suggest that the burner be properly adjusted.

To overcome the problem of misleading flue gas analysis in multi-burner furnaces, metering orifices should be installed on the gas lines to each burner. If pressure drops across all orifices are identical, gas flow to each burner will be the same.

5.4.4. Furnace Pressure Controls

Furnace Pressure Controls will afford additional energy savings, particularly on top-flued furnaces. If a furnace operates under negative pressure, cold air is drawn into it through badly fitted doors and cracks. This cold air has to be heated, adding to the burden on the combustion system and wasting fuel. If the furnace operates at high positive pressure, flames will sting out through doors, site ports and other openings, damaging refractories and buckling shells. Ideally a neutral furnace pressure overcomes both these problems.

Automatic furnace pressure controls maintain a predetermined pressure at hearth level by opening or closing dampers in response to furnace pressure fluctuations.

In summation, good air/fuel ratio control equipment and automatic furnace pressure controls are two useful weapons for combating gas energy wastage in heating operations.

Properly applied, they also offer the side benefits of improved product quality and shortest possible heating cycles.

5.4.5. Furnace Efficiency

Conventional refractory linings in heating furnaces can have poor insulating abilities and high heat storage characteristics. Basic methods available for reducing heat storage effect and radiation losses in melt and heat treat furnaces are:

1. Replace standard refractory linings with vacuum-formed refractory fiber insulation material.
2. Install fiber liner between standard refractory lining and shell wall.
3. Install ceramic fiber linings over present refractory liner.

The advantages?

- Refractory fiber materials offer exceptional low thermal conductivity and heat storage. These two factors combine to offer very substantial energy savings in crucible, reverberatory and heat treat furnaces.
- With bulk densities of 12-22 lbs/cu ft, refractory fiber linings weigh 8% as much as equivalent volumes of conventional brick or castables.
- Refractory fibers are resistive to damage from drastic and rapid changes in temperature.
- Fiber materials are simple and fast to install.
- The density of fiber refractory is low, so there is very little mass in the lining, therefore much less heat is supplied to the lining to bring it to operating temperature. This results in rapid heating on the start-up. Conversely, cooling is also rapid, since there is less heat stored in the lining.
- More comfortable working environment is attainable due to lower shell surface temperatures.

The basic design criteria for fiber lined crucible furnaces are the same as used for furnaces lined with dense refractories. Two rules should be followed.

1. The midpoint of the burner should be at the same level as the bottom of the crucible, and the burner should fire tangentially into the space between the crucible and lining.
2. The space between the outside of the crucible, and the furnace lining near the top should be about 10% of the crucible diameter.

Crucible furnaces can be constructed using a combination of fiber with dense refractory or almost entirely out of fiber. Increasing the proportion of fiber will increase the energy savings and maximize the other benefits previously listed.

Fiber materials are available in varying thickness, suitable for a complete monolithic installation, and composition to handle 2,400^{0}F, 2,600^{0}F, and 2,800^{0}F.

The higher temperature compositions contain high aluminum fiber, which lowers the amount of shrinkage at elevated operating temperatures.

5.4.6. Furnace Covers

If preheating of combustion air utilizing furnace flue gas temperatures is contemplated, installation of furnace covers is mandatory. The difficulty in the past, in the fabrication and use of furnace covers, has been the problems of thermal shock and spalling, materials available today, such as refractory fiber, have eliminated these problems.

In addition to technological advantages of fiber insulation, industry has also developed the capability of vacuum forming these materials over a variety of metallic support structures. Fiber insulation can be formed over either expanded metal or angle iron frames, or both, with V-type anchors attached. The anchors are made from high temperature alloys, holding the fiber to the metallic support structures to provide an integral, fully secured assembly. No part of the anchor system is exposed to excessive temperatures, this eliminates attachment problems for ladle preheaters, crucible furnace covers, and induction furnace covers. Installation of furnace covers improves the thermal efficiency of the process by approximately 50%.

5.5. *COGENERATION*

Cogeneration is the simultaneous production of electric power and use of thermal energy from a common fuel source. Interest in cogeneration stems from its inherent thermodynamic efficiency. Fossil fuel-fired central stations convert only about one-third of their energy input to electricity and reject two-thirds in the form of thermal discharges to the atmosphere. Industrial plants with cogeneration facilities can use the rejected heat in their plant process and thereby achieve a thermal efficiency as high as 80 percent.

5.5.1. The Economics of Cogeneration

In-plant generation of electricity alone is not usually economical; a variable use must be made of the by-product waste heat. For this reason the demand for both types of energy must then be in balance, typically 100 kW versus 600,000 Btuh, for a gas turbine installation.

In most potential applications of industrial cogeneration, more electric power would be produced in meeting the plant's thermal requirement than could be used internally. However, the enactment of PURPA (Public Utility Regulatory and Policies Act " of 1978) greatly expanded the application for cogeneration by granting qualified cogenerators the right to:

- Interconnect with a utility's grid.
- Contract for backup power with the utility at nondiscriminatory rates.
- Sell the power to the utility at the utility's avoided cost.

There are several reasons for considering cogeneration besides energy savings.

- Energy independence
- Replacement of aging equipment
- Expansion of facilities
- Environmental considerations
- PURPA franchise to sell electricity
- Power factor improvement

However, plant conditions must fit certain requirements for a successful cogeneration application. Some factors are:

- The nature of the process must be suitable for cogeneration. Certain processes lend themselves more readily to cogeneration, such as refining, petrochemical, and pulp and paper industries, which have accounted for many of the larger cogeneration installations to date.

- The rate differential between electricity and fossil fuels should be relatively high on an equivalent Btu basis.

- Plant operation of 6,000 hours per year is usually the minimum needed to justify an installation and continuous operation improve reliability by minimizing dependence on the starting system.

- A source of waste fuel in suitable quantity provides an attractive incentive for cogeneration.

Although plant conditions may appear favorable for cogeneration, the long-term situation should also be considered before proceeding with a project.

1. The long-range cost of fuel for gas- and oil-fired units must be considered. Fuel prices have varied widely so that current prices may not be a reliable benchmark on which to base project returns. Inevitably the price of gas and oil can be expected to increase as worldwide reserves continue to diminish.

   Gas-fired cogeneration accounts for the major portion of present generating capacity because of the advantages of gas as a fuel. However, the recent glut of natural gas should not be taken as an assured long term supply at current prices.

   High-sulfur-bearing and solid-waste fuels with fluidized bed combustion are alternate fuels involving less price risk but greater investment.

2. Excess coal-fired generating facilities and abundant coal supplies can result in increased competition from utilities and lower avoided costs.

3. Utilities may press for repeal of PURPA or at least the ability to discount the avoided cost purchase rate. Accordingly, the future is uncertain for cogeneration projects based on avoided cost revenues.

   Utilities' cogeneration contracts may also impose certain restrictions or penalties for plant maintenance, outages, hours of operations, backup power charges, etc. based on the utilities' needs for additional cogeneration capacity.

4. The economic viability of the plant that would use the steam or electricity from a cogeneration facility should be assured. Foreign competition and corporate mergers are causing many revisions in manufacturing facilities. Because significant investment is involved in cogeneration facilities, long-term continuity of operations is important.

5. Reliability requirements of the cogeneration facility will be important. If third-party financing or operation is being considered, the plant loses some control over an important part of its operation. With in-plant generation, providing a reliable electric supply places additional responsibility and demands on plant operating and maintenance personnel. Because cogeneration systems generally involve a complex system of engines, generators, heat recovery equipment, controls, and accessories, the nature of the installation increases the possibility of problems. The cost of penalty for additional utility charges for any outage can be significant where demand charges are high.

Aside from long-term effects, other alternatives to cogeneration may negate some of its benefits.

1. Renegotiating rates may enable an industrial plant to duplicate the potential economic benefits of cogeneration without the risk of building and operating a power plant.

2. Load management techniques may be able to modify peak demands.

3. Major technological improvements or process changes can occur and significantly alter the present energy requirements.

4. Where available capital is limited, energy conservation may be able to reduce electrical consumption significantly by using projects with more attractive returns.

5.5.2. Cogeneration Cycles

There are many possible types of cogeneration cycles but most can be considered variations of the two basic cycles shown in Figure 5.10.

In the case of the cogeneration cycle with a gas turbine topping cycle, air is compressed and injected into the combustor along with the fuel, generally natural gas. The combustion gases at high temperature and pressure expand rapidly in the turbine, doing work in the process. The turbine drives an electrical generator and air compressor. The exhaust gas from the turbine, which is still at a high temperature, is then used to generate steam in a waste heat boiler.

The cost of a gas turbine with heat recovery equipment ranges between $600 to $1,000/kW, depending on the specific design conditions. Gas turbine systems costs are reduced by over 50 percent with larger units.

There are several advantages of the gas turbine system in comparison with the steam/turbine system.

- Lower capital cost (normally 50 to 70 percent of steam/turbine cost)
- Lower operating and maintenance cost.
- Higher power-to-heat ratio which is generally more desirable in industrial applications.

A reciprocating engine, generally a diesel, can be used in lieu of the turbine to supply the motive power. Since the exhaust from the engine is at a much lower temperature, only low pressure steam (maximum of 50 psig) or hot water can be generated without supplemental heating.

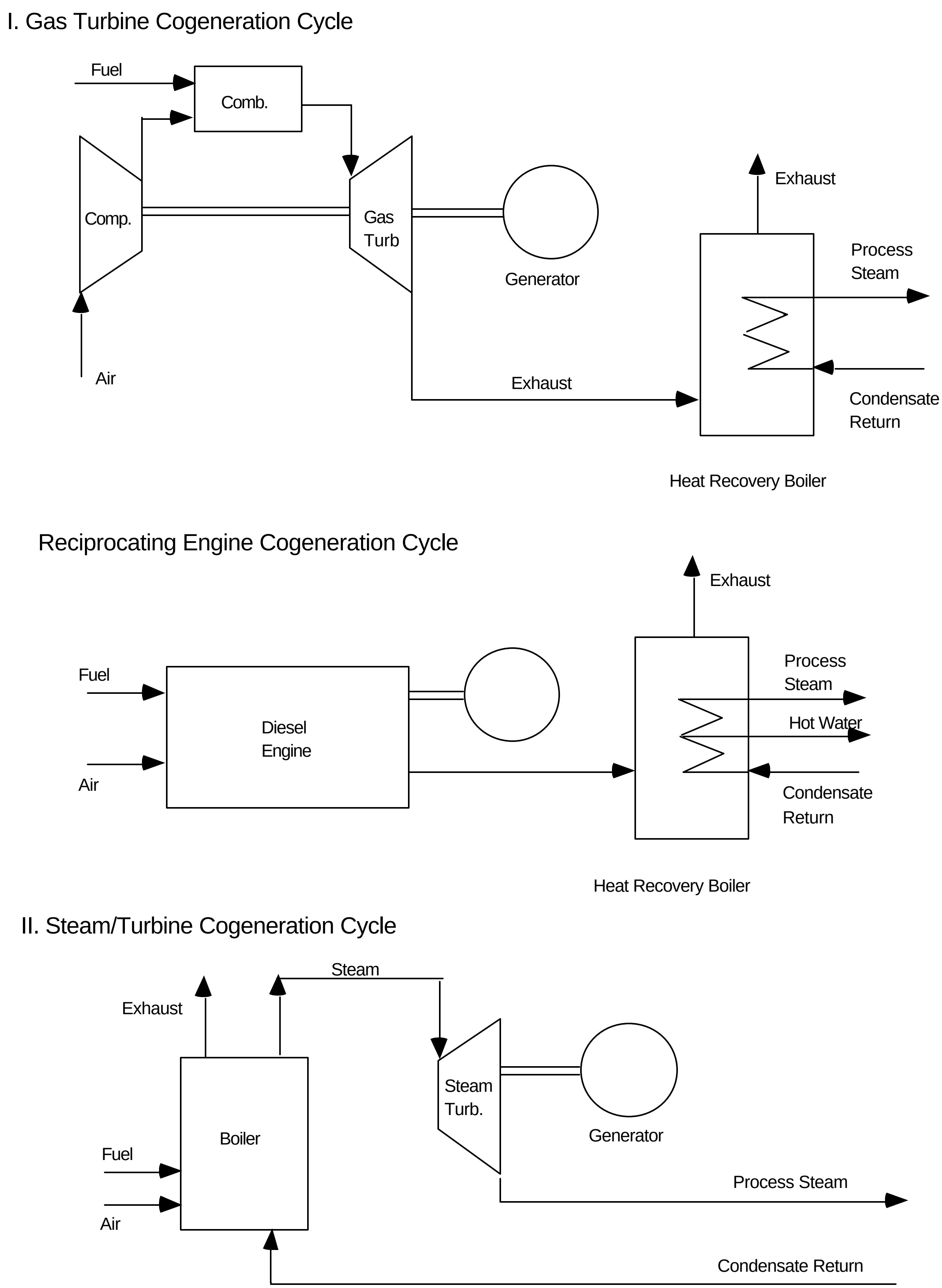


Figure 5.10: Cogeneration Cycles

5.5.3. Cogeneration High-Spot Evaluation

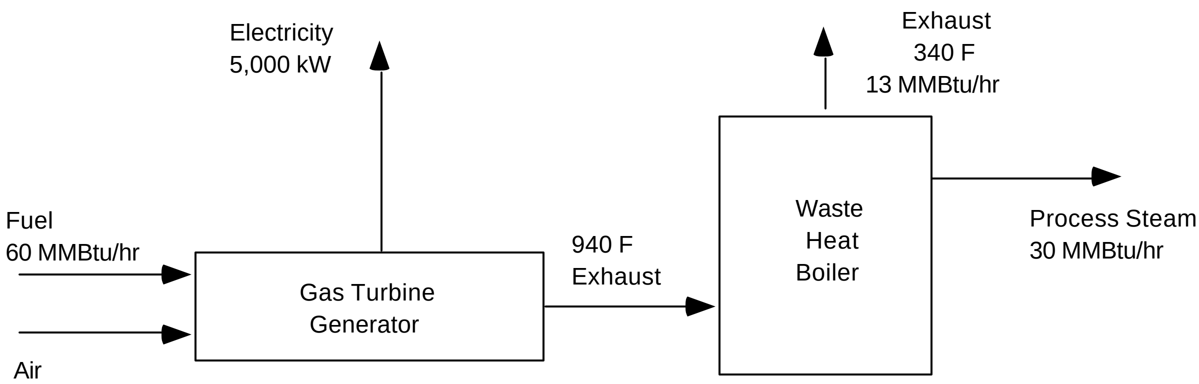


Figure 5.11: Gas-Turbine Cycle

Given process steam demand = 30,000 lbs/hr equivalent to 30 MMBtu/hr

Heat Input to Boiler = (30 MMBtu/hr) / (70% Waste heat eff.) = 43 MMBtu/hr

Exhaust = 43-30 = 13 MMBtu/hr
Electrical output (based on typical 100 kW/600,000 Btu):

$$= \{(30 \text{ MMBtu/hr}) / (0.6 \text{ MMBtu/hr})\} \text{ x } 100 \text{ kW} = 5{,}000 \text{ kW}$$

Equivalent Btu's = 5,000 kW × 3413 Btu/kW = 17 MMBtu/hr
Total Energy Input = 17 + 30 + 13 = 60 MMBtu/hr
Annual cost of operation:

$$= 60 \text{ MMBtu/hr} \times 8{,}000 \text{ hrs} \times \$3.00/\text{MMBtu/hr} = \$1{,}440{,}000/\text{yr}$$

Avoided cost of purchased electricity:

$$= 5{,}000 \text{ kW} \times 8{,}000 \text{ hr} \times \$0.05/\text{kWh} = \$2{,}000{,}000/\text{yr}$$

Avoided cost of steam:

= {[(30 MMBtu/hr) x (80,000 hr)] / [80% Steam boiler eff.]} x $3.00 / MMBtu = $900,000 per year

Annual Saving = $2,000,000 + $900,000 - $140,000 = $1,460,000/yr
Investment = $1,000/kW × 5,000 kW = $5,000,000/yr

Payback = $5,000,000 / 1,460,000 = 3.4 years

Given - process steam demand = 30,000 lbs/hr, equiv. to 30 MMBtu/hr

- boiler steam = 600 psig, 750 F
- turbine steam rate = 12.2 lbs/kWh @ 70% eff. = 17.4 act. lbs/kWh
  (Refer to Turbine Steam Tables for other conditions)

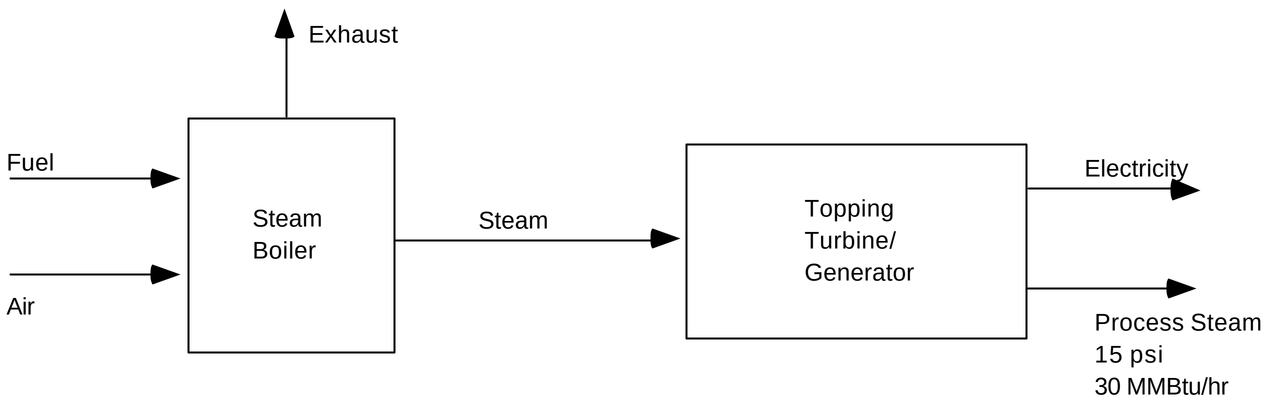


Figure 5.12: Steam-Turbine Cycle

KWh = (30,000 lbs/hr) / (17.4 lbs/kWh) = 1720 kW

Equivalent Btu/hr = 1720 × 3413 × 10-6 = 5.4 MMBtu/hr

Total energy input = (5.4 + 30) / (80% boiler eff.) = 44 MMBtu/hr

Annual cost of operation:
= 44 MMBtu/hr × 8,000 hrs × $3.00/MMBtu = $1,056,000/yr
Avoided cost of electricity:
= 1720 kW × 8,000 hrs × $0.05/kWh = $688,000/yr
Avoided cost of process steam:

= [(30 MMBtu/hr) / (80% boiler eff.)] x (80,000 hrs) x ($3,00/MMBtu/hr) = $900,000/yr

Annual Saving = $688,000 + $900,000 - $1,056,000 = $532,000/yr
Investment = $1,500/kW × $1,720 kW = $2,580,000/yr

Payback = ($2580,000) / ($532,000) = 4.8 years

Oil- and gas-fired engine cogeneration systems are most suitable for smaller installations (under 1 MW). Packaged units are available from a few kilowatts to over a megawatt. The systems include a prime mover, generator switchgear, heat recovery, and controls. Equipment costs range from $500 to $1,000/kW. Installation costs for plumbing, electrical, and other facilities typically add 50 to 150 percent to the equipment cost. Total turnkey costs range from $700 to $2,000/kW.

Experience with the smaller size units (under 100 kW) has been relatively short. In the steam/turbine system, fuel is burned in a boiler to generate steam. The steam is passed through a topping turbine, which drives the electric generator. The exhaust steam is then used for process heating.

The greatest advantage of these systems is their ability to use practically any kind of fuel including lower-cost solid or waste fuels, either alone or in combination.

Capital cost of steam turbine systems is higher, typically 50 to 100 percent greater than a gas turbine system using natural gas or oil.

5.5.4. Estimate of Savings

A high-spot of savings should be made as early in the investigation as possible to confirm that cogeneration is merited, a detailed energy-load analysis should be made. This involves preparing a profile on the plant's steam and electric usage, taking into account daily, weekly, monthly, and seasonal variations. Using actual loads instead of average loads is important to determine whether periods of low-load factor are a problem. System performance will be best where output is steady instead of fluctuating with load.

With this data, plant personnel can select the most advantageous cogeneration cycle, taking into account various possible operating conditions and equipment options. A computer model analysis is very useful for this purpose. Equipment vendors can be utilized if outside assistance is needed to make the computer analysis.

The options which can be considered are as follows:

- Combined cycle - permits the use of a flexible instead of fixed ratio of electrical to thermal energy to adjust for variations in the steam demand.
- Steam pressure - the higher the pressure the more efficient the turbine steam rate.
- Steam injection - adds to turbine efficiency.
- Extraction turbine - provides process steam for use at different pressures.
- Water treatment method - high-pressure steam turbines require more sophisticated boiler feedwater treatment.
- Dual burners - burners capable of burning more than one fuel add flexibility to use lowest cost fuel.
- Degree of automation - fully automatic systems increase price significantly.
- Duct burner in exhaust stream - increases output and permits generation of higher pressure steam.
- Steam condenser - permits additional electrical generation from steam turbine at some loss in efficiency.
- Generator type - power factor is improved with higher cost synchronous generator.
- Parallel or independent operation will affect switchgear selection.

After the operating conditions and cogeneration facilities have been fully defined, the savings and investment estimates should be revised to complete the initial evaluation of the cogeneration facility.

When high-pressure steam or gas must be reduced in pressure through a pressure-reducing valve, a simpler system known as "induction generation" can be used to generate electricity.

Summary

If circumstances indicate there may be an application for cogeneration, certain precautions should be taken before proceeding with an evaluation. Assurance should be obtained that a change in conditions that would significantly affect the project economics is not likely to occur.

Also, the possibility of alternate approaches should be investigated. Similar benefits of cogeneration may be realized through other means which would require less capital and provide better return.

Where cogeneration is determined to be a viable option, a high-spot estimate of savings will confirm the need for further study. For a more detailed evaluation, an energy load analysis is required. Based on this information, the most appropriate cogeneration cycle and various equipment options can be selected. A full evaluation can then be made based on the projected production of electric power and thermal energy and required investment in facilities.

5.6. THERMOENERGY STORAGE SYSTEMS

The application of thermal storage is based on savings from using lower cost electrical rates with nighttime operation to provide daytime thermal needs.

5.6.1. General

Basically, two conditions must be present to make thermal storage attractive. First, there must be a significant difference between night and daytime electrical costs. The difference can be increased by higher summertime rates and inclusion of a ratchet provision for the next 11 months. Utilities generally encourage thermal storage because it permits them to transfer a portion of their daytime load from expensive peaking facilities to nighttime base-loaded, higher efficiency coal and nuclear plants.

Accordingly, the electric rate structure will encourage customers to shift their electrical load from daytime peak hours to nights and weekends by any or all of the following provisions in the rate structure.

- Time-of-day energy charge.
- Demand charges (per kW peak power consumed during peak hours each month).
- Winter/summer rates for energy and/or demand charges.
- A ratchet clause (monthly demand is the same or same percentage of the highest demand in previous 11 months).

Second, the daytime refrigeration load must result in high daytime cost, generally from peak demands, which have the potential to be reduced with thermal storage. Plants with one-shift operation or high solar load can be good candidates. Thermal storage has found application, for example, in office air conditioning. On the other hand, industrial plants with three-shift operation are normally not good candidates because of their more constant load.

Before considering thermal storage as a means of reducing electrical cost, alternate methods should be evaluated, as in most energy conservation approaches. Some possible alternate methods are absorption refrigeration, demand control, load scheduling, and using an emergency generator for peak shaving.

5.6.2. High Spot Evaluation

Where thermal storage appears to be a viable option, a high spot evaluation should be made to determine if further investigation is justified (see Table 5.7). The incremental electrical cost must be detailed into its separate components for this evaluation. In this example, it is assumed there is no off-peak demand charge and the off-peak electrical energy rate is less than the on-peak rate. For simplicity it is also assumed that the daytime refrigeration load increases the peak demand directly by 1 kW for each kW of load. In practice, the peak demand may be caused in part by other operations, so therefore, the actual potential reduction in peak demand from thermal storage would depend on its interrelationship with other loads.

5.6.3. Electric Load Analysis

Because of this interrelationship with other loads, a detailed electrical load analysis is necessary to determine the impact thermal storage will have on the existing peak demand. Use of average loads will not be satisfactory for this purpose.

The operating cost per ton for a thermal storage system is also higher than for a conventional system. The refrigeration machine must operate at a lower temperature, which requires more energy per ton. There is also some inherent loss in storage. One system reported that power consumption increased by 17 percent when the system was producing ice.

Table 5.7 shows that incremental investment for thermal storage results in an attractive payback. However, it should be emphasized that the example attributes maximum demand saving over the full year of operation and for the full capacity of the unit. A well-documented analysis of all energy flows and costs is needed for a more in-depth evaluation. A number of questions will also have to be answered as part of the evaluation, such as:

- should the thermal storage be for heating storage, cooling storage, or both?
- should the system handle 100 percent of the cooling load or only the portion needed for load leveling?
- should the storage system be water or ice?
- should the storage system be for a daily or weekly cycle?

Generally, systems have been for daily cycles and load levelers only.

Electrical Rate:	On-Peak	Off-Peak
Demand kW	$9.40	NC
Energy kWh	$0.03	$0.025
Conventional Refrigeration System		
Demand Cost/ton-yr = $/kW × 12 months		
	= $9.40 × 12 =	$113/yr
Energy Cost/ton-yr = 1 kWh/ton × $/kWh × hrs/yr		
	= $0.03 × 8,000 =	$240
Total Cost/ton-yr	= $113 + $240 =	$353
Thermal Storage System		
Cost/ton-yr = 1 kWh/ton × % increase × $/kWh × hrs/yr		
	= 1 × 1.20 × $0.025 × 8,000 =	$240
Savings = $353 - $240 =		$113
Investment		
Investment/ton - Conventional Refrigeration System		$400
Investment/ton - Thermal Storage System		$550
Additional Investment/ton ($550 - $400)		$150

Table 5.7: Thermal Storage High Spot Evaluation

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6 PRIME MOVERS OF ENERGY

6.1. PUMPS

Pumps are widely used for transfer of liquids from one place to another. Pumps are usually driven by electric motors, thus some of the considerations about pumps and electric motors might overlap. For some specific applications, pumps can be driven by compressed air or hydraulically.

There are a lot of different types of pumps used in the industry. Pump selection depends upon the application. For example, centrifugal pumps are used predominantly for transfer of large volumes, metering pumps are used for precise delivery of liquids, ensuring constant discharge regardless of back pressure in the lines, and progressive cavity pumps or peristaltic pumps are used for delivery of very viscous materials.

It is a norm that a pump manufacturer also provides pump curves at the time of the sale. They are essential for establishing the operation range and if any changes for pumping systems are considered the curves have to be looked at.

6.1.1. Operation

Opportunities for savings in pump operation are often overlooked because pump inefficiency is not readily apparent.

The following measures can improve pump efficiency:

1. Shut down unnecessary pumps.
2. Restore internal clearances if performance has changed significantly.
3. Trim or change impellers if head is larger than necessary.
4. Control by throttle instead of running wide open or bypassing the flow.
5. Replace oversized pumps.
6. Use multiple pumps instead of one large pump.
7. Use a small booster pump.
8. Change the speed of the pump for the most efficient match of horsepower requirements with output.

Pumps can run inefficiently because:

1. Present operating conditions differ from the design conditions. This change often occurs after a plant has undertaken a water conservation program.
2. Oversized pumps were specified and installed to allow for future increases in capacity.
3. Conservative design factors were used to ensure the pump would meet the required conditions.
4. Other design factors were chosen at the expense of pump efficiency when energy costs were lower.

Pump Survey

A survey of pumps should concentrate on the following conditions associated with inefficient pump operation. These are discussed in order of decreasing potential for energy savings in existing installations. For the survey to produce worthwhile savings, only pumps above a certain size, such as 25 horsepower, need be checked.

1. Excessive pump maintenance. This problem is often associated with:
a) Oversized pumps that are heavily throttled.
b) Pumps in cavitation.
c) Badly worn pumps.
d) Pumps that are misapplied for the present operation.
2. Any pump system with large flow or pressure variations. When normal flows or pressures are less than 75 percent of their maximum, energy is probably being wasted from excessive throttling, large bypassed flows, or operation of unneeded pumps.
3. Bypassed flow. Bypassed flow, either from a control system or deadhead protection orifices, is wasted energy.
4. Throttled control valves. The pressure drop across a control valve represents waster energy, which is proportional to the pressure drop and flow.
5. Fixed throttle operation. Pumps throttle at a constant head and flow indicate excess capacity.
6. Noisy pumps or valves. A noisy pump generally indicates cavitation from heavy throttling or excess flow. Noisy control valves or bypass valves usually mean a high pressure drop with a corresponding high energy loss.
7. A multiple pump system. Energy is commonly lost from bypassing excess capacity, running unneeded pumps, maintaining excess pressure, or having a large flow increment between pumps.
8. Changes from design conditions. Changes in plant operating conditions (expansions, shutdowns, etc.) can cause pumps that were previously well applied to operate at reduced efficiency.
9. A low-flow, high-pressure user. Such users may require operation of the entire system at higher pressure.
10. Pumps with known overcapacity. Overcapacity wastes energy because more flow is pumped at a higher pressure than required.

Once the inefficient pumps have been identified, the potential savings and the cost of implementing the changes should be analyzed. Comparison of the actual operating point with the pump performance curve will facilitate the analysis. Actual performance may differ from the original design because of process changes, faulty basic data, conservative safety margins, or planned expansions never realized.

Energy Conservation Measures

Energy may be saved in pump operation in a number of ways, including the following techniques arranged in approximate increasing order of investment cost.

1. Shut Down Unnecessary Pumps

This obvious but frequently overlooked energy-saving measure can often be carried out after a significant reduction in the plant's water usage. If excess capacity is used because flow requirements vary, the number of pumps in service can be automatically controlled by installing pressure switches on one or more pumps.

2. Restore Internal Clearances

This measure should be taken if performance changes significantly. Pump capacity and efficiency are reduced as internal leakage increases from excessive backplate and impeller clearances and worn throat bushings, impeller wear rings, sleeve bearings, and impellers.

3. Trim or Change Impellers

If head is excessive, this approach can be used when throttling is not sufficient to permit the complete shutdown of a pump. Trimming centrifugal pump impellers is the lowest cost method to correct oversized pumps. Head can be reduced 10 to 50 percent by trimming or changing the pump impeller diameter within the vendor's recommended size limits for the pump casing.

4. Control by Throttling

Controlling a centrifugal pump by throttling the pump discharge wastes energy. Throttle control is, however, generally less energy wasteful than two other widely used alternatives: no control and bypass control. Throttles can, therefore, represent a means to save pump energy.

5. Replace Oversized Pumps

Oversized pumps represent the largest single source of wasted pump energy. Their replacement must be evaluated in relation to other possible methods to reduce capacity, such as trimming or changing impellers and using variable speed control.

6. Use Multiple Pumps

Multiple pumps offer an alternative to variable speed, bypass, or throttle control. The savings result because one or more pumps can be shut down at low system flow while the other pumps operate at high efficiency. Multiple small pumps should be considered when the pumping load is less than half the maximum single capacity.

7. Use a Small Booster Pump

The energy requirements of the overall system can be reduced by the use of a booster pump to provide the high-pressure flow to a selected user and allow the remainder of the system to operate at a lower pressure and reduced power.

8. Change Pump Speed

Variable-speed drives yield the maximum savings in matching pump output to varying system requirements. However, variable speed drives generally have a higher investment cost than other methods of capacity control. Several types of variable-speed drives can be considered:

- Variable-speed motors, either variable frequency or DC.
- Variable-speed drives such as traction drives, for constant-speed motors.
- Two-speed motors when low speed can satisfy the requirements for significant portion of the time.

As an example of the savings from the use of a smaller pump, assume 300 tons of refrigeration is required during the summer months but only 75 tons for the remaining nine months. One of two 700-gpm chilled-water pumps, equipped with 40-horsepower motors, is operated during the winter, with two thirds of the flow bypassed. A new 250-gpm pump designed for the same discharge head as the original two units consumes only 10 horsepower. The electric savings from operating the small pump during the winter is:

Annual Savings = (40 hp - 10 hp) x 6,000 hrs/yr x 9 mos/12 x \$0.041/hp-hr
= \$5,540

The installation cost of a new pump is about \$5,000.

The following example illustrates the possible savings from trimming an impeller. A double suction centrifugal pump with a 13.75-inch diameter impeller pumps process water. The demand is constant, 2,750 gpm, and the pump is controlled by a manual throttle valve. The pump operates at 164-feet head, 2,750 gpm and 135.6-brake horsepower (point A in **Figure 6.1**). A 16-psig (37-foot) pressure drop occurs across the partially closed throttle valve, with only a 6-foot drop across the completely open valve.

If the pump were exactly matched to the system requirements, only 127 feet of head would be required without the valve. Because even the fully open valve has a 6-foot pressure drop, the minimum head required becomes 133 feet. To this, a 5 percent allowance should be added as a tolerance for the accuracy of the field measurements and impeller trimming. The minimum total head required, therefore, is 140 feet. Based on the pump affinity laws, the trimmed impeller diameter should be 13 inches, as shown in step 1 below.

With a trimmed 13-inch impeller, the pump will operate slightly throttled at 140-feet head, 2,750 gpm and 115.7-brake horsepower, as shown by point B in **Figure 6.1**. The trimmed impeller reduces power consumption by 19.9-brake horsepower and saves \$5,440 per year (see steps 2-4).

Trimming and balancing an impeller usually cost less than $1,000, and payback, therefore, is less than three months.

1. Determine the impeller diameter to reduce head from 164 feet to 140 feet while maintaining 2,750-gpm flow. Apply the affinity laws and note that both the head and flow are reduced as the impeller is trimmed.

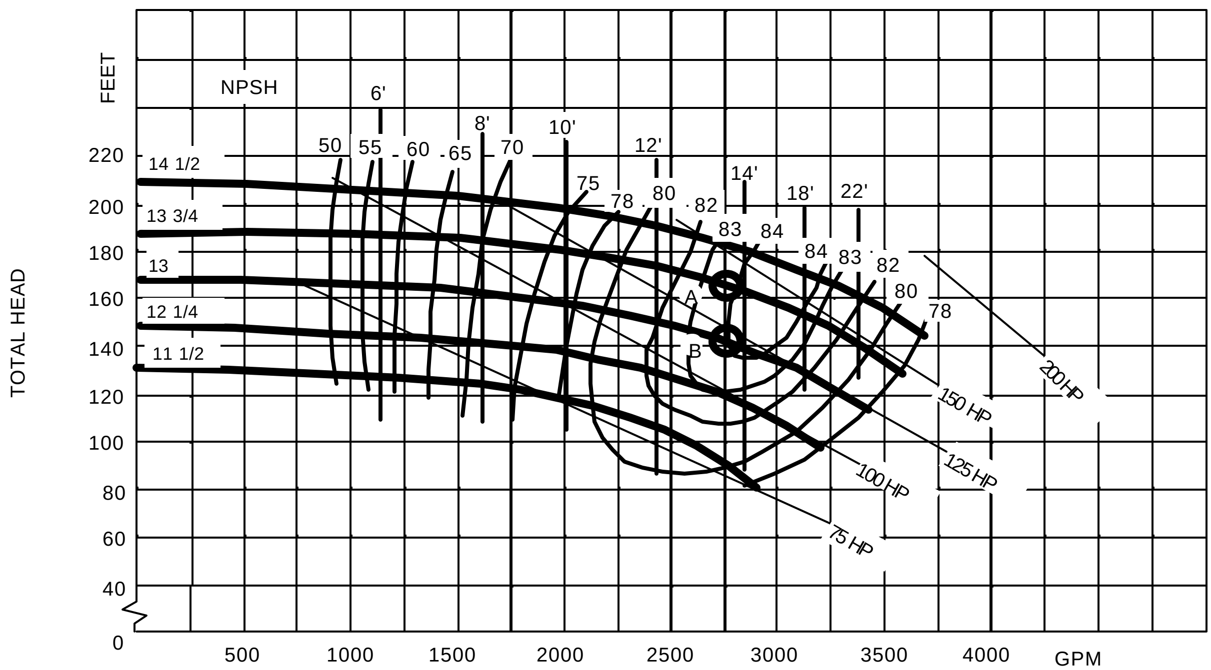

Figure 6.1: Typical Centrifugal Pump Characteristics

a) $H_1 / H_2 = D_1^2 / D_2^2$ and $Q_1 / Q_1 = D_1 / D_1$ $\quad H_1Q_1 / H_1Q_1 = D_1^3 / D_1^3$

b) Holding Q constant $= D_1 / D_2 = (H_1 / H_2)^{1/3} = (164 / 140)^{1/3} = 1.054$

c) $D_1 = (D_2 / 1.054) = 13.0$ inches

H = head in feet; H_1, before the reduction, and H_2, after the reduction
D = diameter of the impeller in inches
Q = flow in gpm
E = pump efficiency

2. Point A: Oversized pump (13.75-inch impeller) throttle back to 2,750 gpm.
bhp = (H x Q x (SG)) / (3,960 x E) = (164 x 2,750) / (3,960 x 0.84) = 135.6

3. Point B: Trimmed impeller (13 inches) throttled back to 2,750 gpm.
   bhp = (140 x 2,750) / (3,960 x 0.84) = 115.7

4. Annual Savings = 135.6 - 115.7 = 19.9 bhp
   \$/yr = 19.9 x (1/0.90) motor eff. x 6,000 hrs/yr x \$0.041/hp-hr
   = \$5,440

As with other equipment, energy conservation for pumps should begin when the pump is designed. Nevertheless, the savings from modification of an existing system often justify the cost.

The following example illustrates the application of affinity laws for variable frequency drive pump savings. With fans the affinity laws can be applied directly because the system resistance is purely flow-related. With pumps or fans having a static head offset, the system resistance curve also changes with pump speed.

A typical centrifugal pump curve in **Figure 6.2** shows that by throttling the 1,750 rpm motor the pump delivers 2,500 gpm at 236 ft. head. Given a system analysis showing that 150 ft. of head is required to deliver 2,500 gpm with no throttling, the savings for operating the pump at reduced speed without throttling can be determined by the following trial-and-error method.

The affinity laws are: $S_1 / S_2 = Q_1 / Q_2 = (H_1 / H_2)^{1/2} = (BHP_1 / BHP_2)^{1/3}$
where

S_1 = original pump speed, rpm
S_2 = new pump speed, rpm
Q_1 = flow on original pump curve, gpm
Q_2 = system flow required, gpm
H_1 = head on original pump curve, ft.
H_2 = head required by system for Q_2, ft.
BHP_1 = pump horsepower at Q_1 and H_1
BHP_2 = pump horsepower required for operation at Q_2, H_2

1. Assume a new pump speed, try 1,500 rpm.
2. Calculate the speed ratio, S_1 / S_2 = 1,500/1,700 = 0.8571
3. Calculate Q_1 from the affinity laws.
   $Q_1 = Q_2 / (S_1 / S_2)$ = 2,500/0.8571= 2,917 gpm
4. Determine H_1 from the original curve at Q_1 = 233 ft.
5. Calculate H_2 from the affinity laws:
   $H_2 = (S_1 / S_2)^3 \times H_1$ = 0.8571 x 233 = 199.7 ft.
6. Compare H_2 from step 5 with the desired H_2. Since H_2 at 199.7 ft. is greater than the desired H_1 at 150 ft., the calculation must be repeated using a lower rpm. Several iterations of this procedure give:
   S_1 = 1,405 rpm, Q_1 = 3,114 gpm, and H_1 = 232.5 ft.

From Q_1 and H_1 above a new operating point 1 is determined. The important concept here is that point 1 is not the original system operating point (2,500 gpm, 236 ft.). Rather it is the one and only point on the original pump curve that satisfies the affinity law equations at the new operating point 2 (2,500 gpm, 150 ft.). It must be determined before BHP_2 can be calculated from the affinity laws.

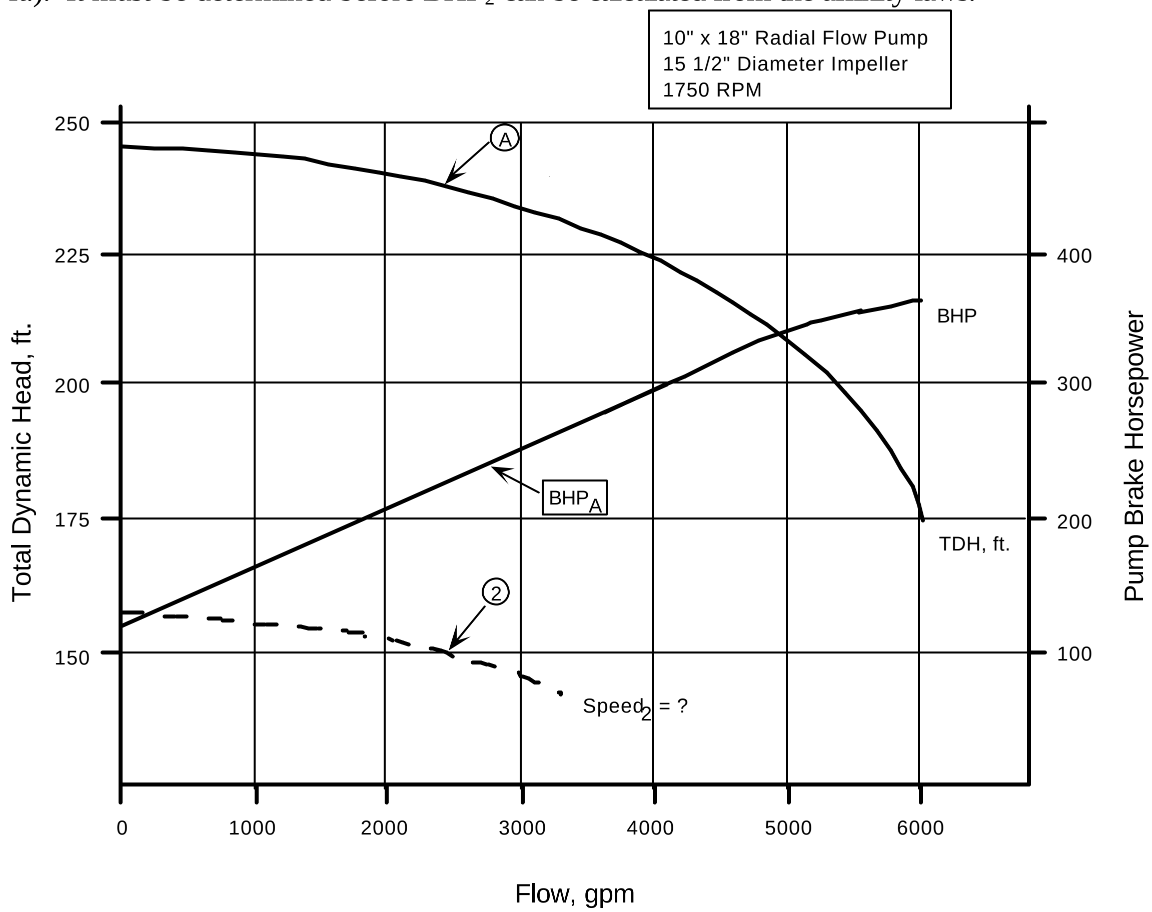

Figure 6.2: Centrifugal Pump Curve

7. From the pump curve determine BHP_1 for Q_1 at 3,114 gpm.
   $BHP_1 = 258$
8. Calculate BHP_2 using affinity law
   $BHP_2 = BHP_1 \text{ x } (S_2 / S_1)^3$
   $= 258 \text{ x } (1{,}405/1{,}750)^3 = 258 \text{ x } 0.5175$
   $= 133.5$ BHP
9. From the pump curve determine the actual BHP (BHP_A) for the original operating point at 2,500 gpm. $BHP_A = 230$ BHP
10. Determine reduction in horsepower: BHP savings = 230 - 133.5 = 96.5 BHP
    Note the savings are not found from $BHP_1 - BHP_2$, but $BHP_A - BHP_2$

Manual calculation of savings for variable speed drives will be tedious if they must be determined for a number of conditions. Computer programs can simplify the task.

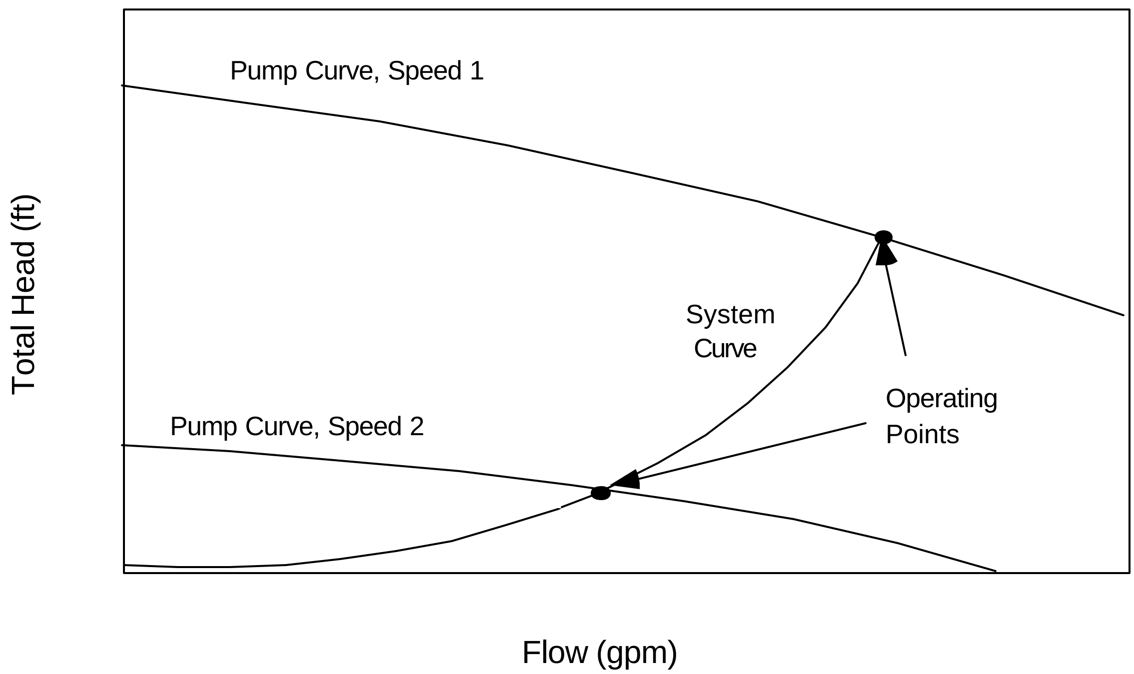

Figure 6.3: Typical Pump and System Curves, Driven by Adjustable Speed Drive

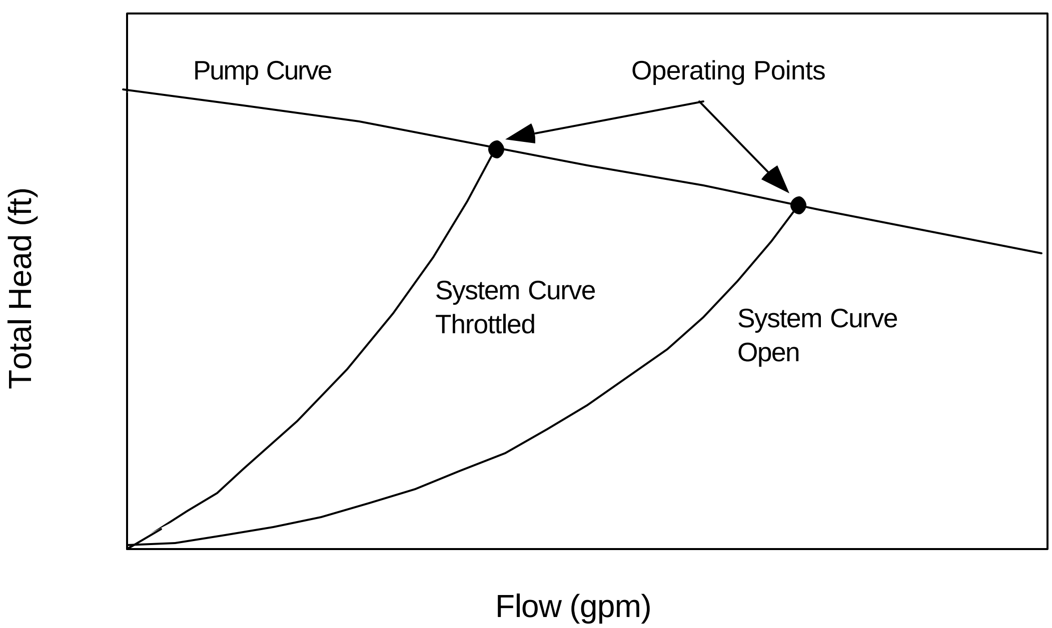

Figure 6.4: Typical Pump and System Curves for Pump with Throttling Valve

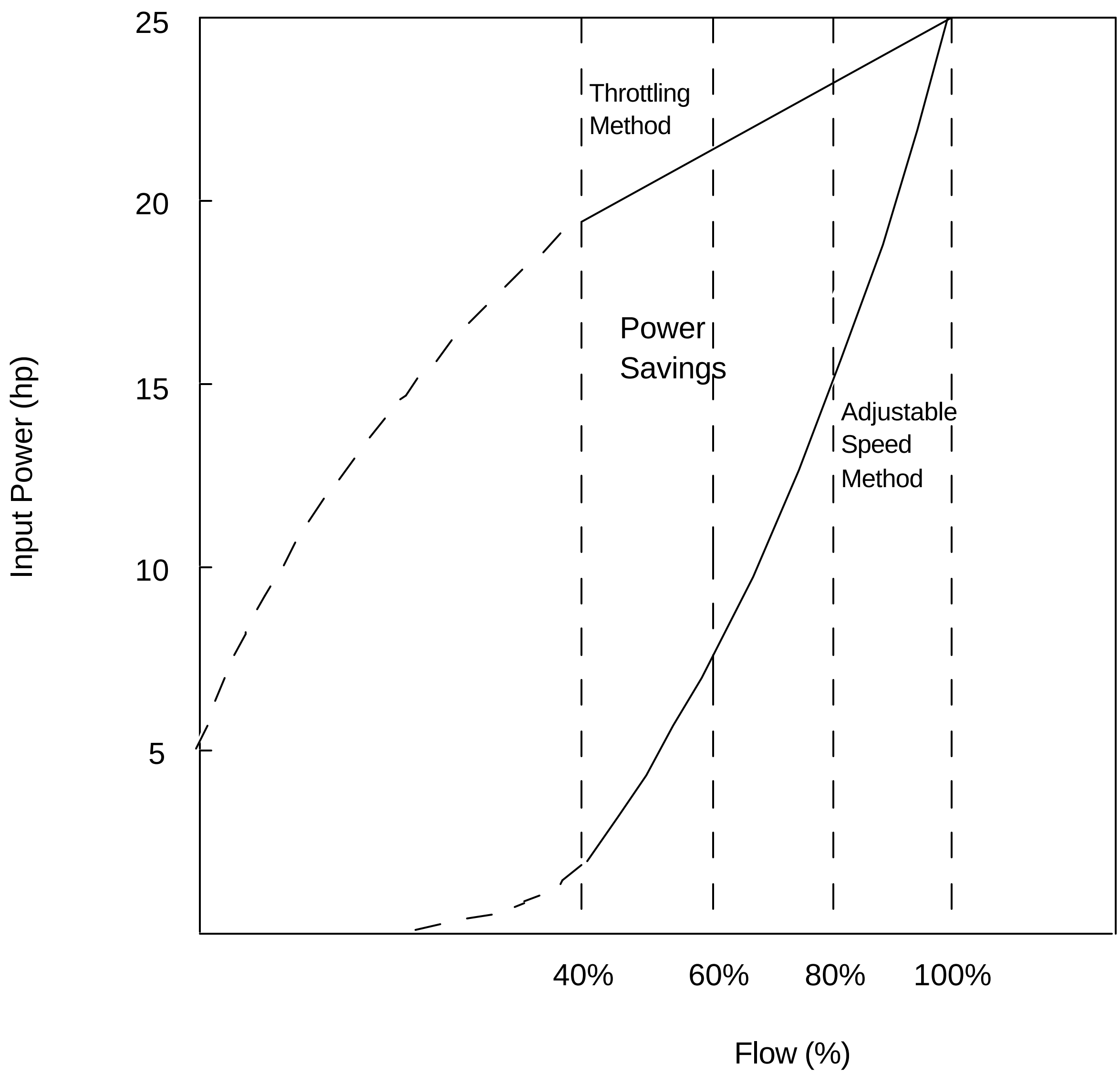

Figure 6.5: Pump Power Requirements for Throttling and Adjustable Speed Motors

6.1.2. Considerations for Installation Design

The position of the pump with respect to the reservoir from which the liquid is to be taken is of utmost importance. If the pump is higher than the tank from which the fluid is being pumped the boiling of the fluid at local temperature can occur. The formation of the bubbles is called cavitation. The bubble collapse can happen at the higher pressure region (tips of the impeller), thus causing “cavitation erosion”. The efficiency of the pump is very low and the damage of the impeller will follow soon. The fatigue failure is the problem. In order to avoid cavitation in the pump, the installation has to satisfy a condition of net positive suction head (NPSH). The manufacturer of the pump supplies the net positive suction head required and that is the minimum pressure head at the inlet for the type and model of the pump which has to be maintained in order to avoid cavitation inside the pump. The net positive suction head required accounts for pressure drop inside the pump. The pressure head at the inlet has to be calculated for each installation. The conventional tools for pressure losses in pipes are commonly used and adequate. Since the occurrence of bubble forming inside the housing of the pump is absolutely forbidden the backpressure of the system is of the same importance as NPSH. The adequate backpressure will prevent the formation and can be achieved, if not available by the nature of the system, by installation of backpressure valve.

OPERATING SITUATION	HOURS OF OPERATION	AVERAGE kW USAGE	PROPELLER FAN ENERGY [kWh]	BLOWER FAN ENERGY [kWh]
Constant Operation at Full Capacity	1202.2	P = 16.2 B = 32.4	19475.6	38951.2
Single Speed Fan Cycling	P = 765.3 (*) B = 852.7	P = 16.2 B = 32.4	12397.9	27627.5
Two Speed Fan Cycling	P = 1132 (*) B = 1146	P = 4.3 B = 8.55	4867.6	9798.3
Variable Control at Constant Speed	1202.2	P = 2.72 B = 5.44	3270	6540
Variable Speed Control	1202.2	P = 1.99 B = 3.98	2392.4	4704.8

(*) The propeller fan will operate slightly fewer hours in these modes because of the cross tower's cooling effect with the fan off.

Table 6.1. Comparative Energy Usage with Various Methods of Control

6.2. FANS

Fans provide the necessary energy input to pump air from one location to another while they overcome the various resistances created by the equipment and the duct distribution system. Fans have been classified in a general way as either centrifugal fans or axial-flow fans, according to the direction of airflow through the impeller. There are a number of subdivisions of each general type. Generally, the subdivisions consist of different styles of impellers and the strength and arrangement of construction. Because of the type of impeller dictates fan characteristics, it influences the amount of energy (horsepower) the fan needs to transport the required volume of air. The centrifugal fan has four basic types of impellers--airfoil, backward curved, radial, and forward-curved. Table 6.2 gives the nominal efficiency of the various types of fans at normal operating conditions.

Type of Fan	Efficiency %
Axial Fan	85-90
Centrifugal Fans	
Airfoil Impeller	75-80
Backward-Curved Impeller	70-75
Radial Impeller	60-65
Forward-Curved Impeller	55-60

Table 6.2: Nominal Efficiency of Fans at Normal Operating Conditions

Reductions in exhaust airflows are usually obtained by adjustment of dampers in the duct. Damper control is a simple and low-cost means of controlling airflow, but it adds resistance, which causes an increase in fan horsepower. Accordingly, if fan output is heavily throttled or dampered, the savings opportunity of alternate methods of volume control should be investigated.

More efficient methods of volume control are to:

1. Install inlet vane control.
2. Reduce the speed of the fan.
3. Provide variable-speed control.

Figure 6.6 shows the reduction in horsepower realized by reducing fan speed.

Before alternate methods of volume control are considered, the condition of the existing fan and duct system should be checked. Some factors that can reduce fan efficiency are:

1. Excessive static-pressure losses through poor duct configuration or plugging.
2. Duct leakage from poor joints or flange connections, access doors left open, damage or corrosion, etc.
3. An improperly installed inlet cone, which inadequately seals the fan inlet area and allows excessive air recirculation.
4. Excessive fan horsepower caused by poor fan maintenance, such as bad bearings, shaft misalignment, worn impeller blades, or corroded fan housing.
5. Dirt and dust accumulations on fan blades or housing.
6. Buildup of negative pressure.

Once the existing system operates as efficiently as possible, alternate methods to control flow can be evaluated.

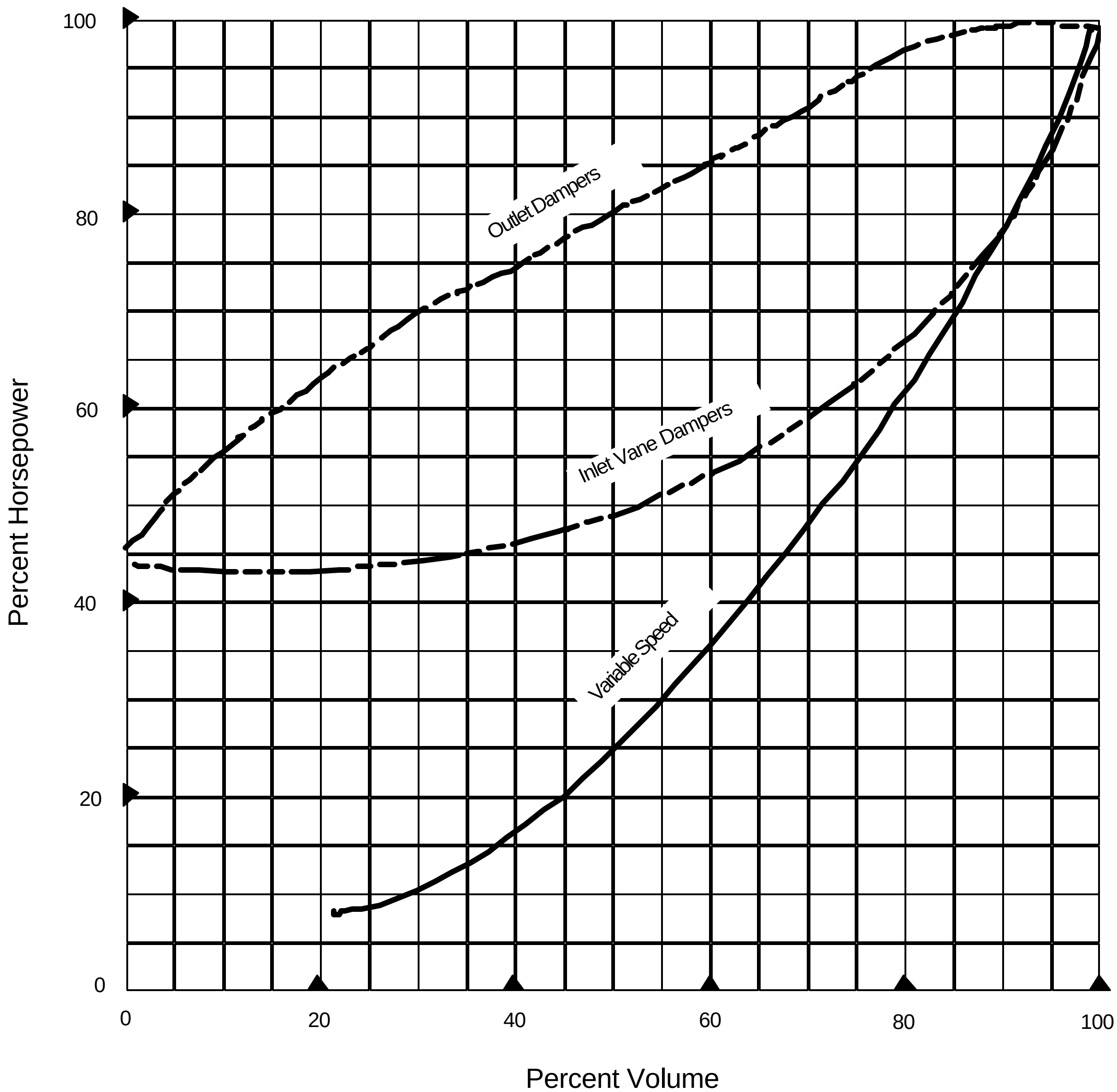

Figure 6.6: Effect of Volume Control on Fan Horsepower

6.2.1. Inlet Vane Control

Inlet vane control is the most commonly used device for automatic control of centrifugal or in-line fan output after damper control. Pre-spinning as well as throttling the air prior to its entry into the wheel reduces output and save power. Fans must be of sufficient size to permit retrofitting; the wheel diameter should be larger than 20 inches.

6.2.2. Reduced Speed

When fan output can be reduced permanently, an economical method is to change belt sheaves. A slower-speed motor can also be used if the first approach is not suitable. A two-speed motor is another alternative if the fan operates at low volume for a significant portion of the time but full capacity is still required part-time.

As an example of the savings to be realized from a reduction in fan speed, assume the exhaust airflow requirements have been reduced 50 percent on a 20-horsepower centrifugal fan. Reducing fan rpm 50 percent by changing belt sheaves will halve fan output. **Figure 6.6** shows a horsepower comparison of various methods of centrifugal fan control for typical fans. A 50 percent reduction with an outlet damper requires 80 percent of rated power; with a slower-speed motor, only 25 percent of rated power is required. (Refer to the variable speed control curve on the figure.) Therefore:

Annual Savings = (20 hp x 80% - 20 hp x 25%) x 6,000 hrs/yr x $0.041/hp-hr
= $2,700

The reduction in fan output will result in operation of the electric motor at less than rated capacity. If the horsepower required at the reduced flow is less than about one third of rated horsepower, the potential savings for substitution of a smaller motor should also be investigated.

6.2.3. Variable Speed

If fan output must be varied but operates at reduced capacity much of the time, a variable drive should be evaluated. (See separate discussion on variable-speed drives.) Automatic variation of fan speed through fluid or magnetic couplings or variable-speed motors has limited application because of the high initial cost.

6.3. AIR COMPRESSORS

Air compressors in manufacturing facilities are often large consumers of electricity. There are two types of air compressors: reciprocating and screw compressors. Reciprocating compressors operate in manner similar to that of an automobile engine. That is, a piston moves back and forth in a cylinder to compress the air. Screw compressors work by entraining the air between two rotating augers. The space between the augers becomes smaller as the air moves toward the outlet, thereby compressing the air.

6.3.1. General

Screw compressors have fewer moving parts than reciprocating compressors have and are less prone to maintenance problems. However, especially for older types of screw compressors, screw compressors tend to use more energy than reciprocating compressors do, particularly if they are oversized for the load. This is because many screw compressors continue to rotate, whereas reciprocating compressors require no power during unloaded state.

This section includes demand-side management measures for increasing outside air usage, reducing air leakage around valves and fittings in compressor air lines, recovering air compressor cooling water, recovering air compressor waste heat, pressure reduction, adding screw compressor, controls, compressor replacement, and adding low-pressure blowers.

6.3.2. Typical Performance Improvements

1. Use Outside Air For Compressor Intakes

If compressor power is measured:

$$ES = \sqrt{3} \times V \times LFA \times H \times WR$$

$$LFA = LA \times LPF \times LFT + UA \times UPF \times UFT$$

If compressor power is not measured:

$$ES = \frac{HP \times FR \times LF \times C_2 \times H \times WR}{EFF}$$

$$FR = \frac{\left(\frac{P_{do}}{P_i}\right)^{\frac{k-1}{kN}} - 1}{\left(\frac{P_{dm}}{P_i}\right)^{\frac{k-1}{kN}} - 1}$$

$$LF = FL \times FTL + FU \times FTU$$

$$WR = \frac{WI - WO}{WI}$$

OR

$$WR = \frac{TI - TO}{TI + 460}$$

2. Compressor Controls

$$ES = \frac{HP \times C \times H \times FR \times (LFC - LFP)}{EFF}$$

3. Install Small Compressor

$$ES = \left[\frac{P \times (FU_L \times TU_L + FL_L \times TL_L)}{Eff_L} - \frac{P \times (FU_S \times TU_S + FL_S \times TL_S)}{Eff_S} \right] \times H \times C \times FR$$

HPS is based on cfm loading during off peak periods

4. Reduce Compressor Air Pressure

$$ES = \frac{(1 - FR) \times HP \times LF \times UF \times C \times H}{EFF}$$

5. Reduce Compressed Air Leaks

Leak diameter estimated on site

$$ES = L \times H \times C_5$$

$$L = \frac{P_i \times C_2 \times V_f \times \frac{k}{k-1} \times N \times C_4 \times \left[\left(\frac{P_0}{P_i} \right)^{\frac{k-1}{k \times N}} - 1 \right]}{E_a \times E_m}$$

$$V = \frac{NL \times (T_i + 460) \times \frac{P_l}{P_i} \times C_1 \times C_2 \times C_d \times \frac{pD^2}{4}}{C_3 \sqrt{T + 460}}$$

6. Install a Lower Pressure Blower

For replacing plant compressed air used in plating tanks for agitation

$$ES = (PC - PB) \times H \times C_1$$

$$PC = \frac{P_i \times C_2 \times V_f \times \frac{k}{k-1} \times N \times C_3 \times \left[\left(\frac{P_0}{P_i} \right)^{\frac{k-1}{k \times N}} - 1 \right]}{E_{ac} \times E_{mc}}$$

$$PB = \frac{P_i \times C_2 \times Q \times \frac{k}{k-1} \times N \times C_3 \times \left[\left(\frac{P_0}{P_i} \right)^{\frac{k-1}{k \times N}} - 1 \right]}{E_{ab} \times E_{mb}}$$

7. Recover Compressor Waste Heat

Flow and temperature of compressor exhaust air measured on site

$$ES = \frac{r \times Q \times C_p \times C_1 \times (T_e - T_r) \times HH}{EFF}$$

Waste Heat Recovery

<u>Description</u>

For both screw and reciprocating compressors, approximately 60% to 90% of the energy of compression is available as heat, and only the remaining 10% to 40% is contained in the compressed air. This waste heat may be used to offset space heating requirements in the facility or to supply heat to a process. The heat energy recovered from the compressor can be used for space heating during the heating season. The amount of heat energy that can be recovered is dependent on the size of the compressor and the use factor. For this measure to be economically viable, the warm air should not have to be sent very far; that is the compressor should be located near the heat that is to be used.

Definitions

Use Factor - The fraction of the yearly hours that the compressor is used.

Applicability

Facility Type - Any facility that uses an air compressor and has a use for the waste heat.
Climate - Wherever space heating is required for a significant portion of the year.
Demand-Side Management Strategy - Strategic conservation.

For More Information

Varigas Research, Inc., Compressed Air Systems, A Guidebook on Energy and Cost Savings, Timonium, MD, 1984.

Compressor Waste Heat Recovery: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Waste Heat Recovery	2,098	676	2,786	0.8

1. Tabulated data were taken from the Industrial Assessment Center (IAC) data base. All values are averages based on the database data. The implementation rate for this measure was 34%.
2. One example from the IAC data base to further clarify the costs is as follows: The waste heat from a 75 hp screw compressor was used to heat the plant. The energy savings were 417 MMBtu/yr, the cost savings were $2,594/yr, and the implementation cost was $1,530 - giving a simple payback of seven months.

The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

Operating Pressure Reduction

Description

Demand and energy savings can be realized by reducing the air pressure control setting on an air compressor. In many cases, the air is compressed to a higher pressure than the air-driven process equipment actually requires. By determining the minimum required pressure, one may find that the pressure control setting on the compressor can be lowered. This is done by a simple adjustment of the pressure setting and applies to both screw and reciprocating compressors. The resulting demand and energy savings depend on the power rating of the compressor, the load factor, the use factor, the horsepower reduction factor, the current and proposed discharge pressures, the inlet pressure, and the type of compressor. This measure should only be considered when the operating pressure is greater than or equal to 10 psi higher than what is required for the equipment (with exception to situations with extremely long delivery lines or high pressure drops).

Definitions

Power Rating - The power indicated by the air compressor manufacturer-usually shown on the nameplate.
Power Reduction Factor - The ratio of the proposed power consumption to the current power consumption, based on operating pressure.

Inlet Pressure - The air pressure at the air intake to the compressor, usually local atmospheric pressure.

Applicability
Facility Type - Any facility that has an air compressor.
Climate - All.
Demand-Side Management Strategy - Strategic conservation.

For More Information
National Technical Information Service, Compressed Air Systems, A Guidebook on Energy and Cost Savings, #DOE/CS/40520-T2, March 1984.

Pressure Reduction: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost savings ($/yr)[3]	Simple Payback (yr)
Pressure Reductions	864	187	2,730	1.0

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database. All values are averages based on the data base data. The implementation rate for this measure was 48%.
2. One example from the IAC data base to further clarify the costs is as follows: Reducing the air pressure control setting on a 75 hp air compressor from 115 psig to 100 psig resulted in energy savings of 22,500 kWh and cost savings of $1,180/yr. The implementation cost was $270, resulting in a simple payback of three months.
The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

Elimination of Air Leaks

Description
Air leaks around valves and fittings in compressor air lines may represent a significant energy cost in manufacturing facilities. Sometimes up to 20% of the work done by the compressor is to make up for air leaks. The energy loss as a function of hole diameter at an operating pressure of 100 psi is shown in the following table:

Hole Diameter [in]	Free Air Wasted [ft^3/yr] by a Leak of Air at 100 psi	Energy Wasted Per Leak [kWh/h]
3/8	90 400 000	29.9
¼	40 300 000	14.2
1/8	10 020 000	3.4
1/16	2 580 000	0.9
1/32	625 000	0.2

Source: National Bureau of Standards
Rule of Thumb --=5%-10% of total energy consumption

Table 6.3: Fuel and Air Losses Due to Compressed Air Leaks

Definitions
Gage Pressure - The system pressure supplied by the compressor.
Absolute Pressure - The sum of the gage pressure and the atmospheric pressure. The gage and the absolute pressures are used in calculating the amount of air lost due to air leaks.

Applicability
Facility Type - Any facility that has an air compressor.
Climate - All.
Demand-Side Management Strategy - Strategic conservation and peak clipping.

For More Information
American Consulting Engineers' Council, Industrial Market and Energy Management Guide, SIC 32 Stone, Clay and Glass Products Industry, Washington, DC, 1987, P. III-30.

Turner, et. al., Energy Management Handbook, John Wiley and Sons, New York, NY, 1982, pp. 424-425.

Leakage Reduction: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Leakage Reduction	934	230	3,540	0.3

1. Tabulated data were taken from the Industrial Assessment Center (IAC) data base. All values are averages based on the data base data. The implementation rate for this measure was 79%.
2. One example from the IAC data base to further clarify the costs is as follows: Repairing air leaks in a compressed air system having air compressors of 150 hp, 60 hp and 25 hp-all operating at 110 psig-resulted in energy savings of 35,750kWh and cost savings of $2,760/yr. The implementation cost was $500.
3. The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

§ *Case Study*

Estimated Energy Savings = 408.0 MMBtu/yr
Estimated Cost Savings = $5,730/yr
Estimated Implementation Cost = $460
Simple Payback = 1 month

Recommended Action

Leaks in compressed air lines should be repaired on a regular basis.

Background

The cost of compressed air leaks is the energy cost to compress the volume of lost air from atmospheric pressure to the compressor operating pressure. The amount of lost air depends on the line pressure, the compressed air temperature at the point of the leak, the air temperature at the compressor inlet, and the estimated area of the leak. The leak area is based mainly upon sound and feeling the airflow from the leak. The detailed equations are included at the end of the AR. An alternative method to determine total losses due to air leaks is to measure the time between compressor cycles when all air operated equipment is shut off.

The plant utilizes one 75hp compressor that operates 8,520 hrs/yr. Measurements taken during the site visit showed the compressor to continuously draw 77.7 hp. Approximately 24% of this load is lost to air leaks in the plant. The majority of the air leaks are due to open, unused lines. There are several plant locations where pneumatic machinery could be connected to the primary air line, but at the time of the site visit, no machines were connected. These open lines were typically found on or near I-beams. The terms “I-beam #1, #2, and #3” are used in the tables of this AR to label the leaks. In order to allow for correct location of these open lines, a list of the terms and their approximate locations follow:

Terms	Description
I-Beam #1	Leak located on I-beam near rotary automatic #2.
I-Beam #2	Leak located on I-beam near catalogue machine.
I-Beam #3	Leak located on hose attached to I-beam near Machine 6700.

Anticipated Savings

Values for all factors affecting the cost of compressed air leaks were determined during the site visit, and are listed in the following tables. Because of long piping runs to the equipment, the compressed air temperature is estimated to be the same as room temperature.

Condition of Pneumatic System at Time of Site Visit

Variable	
Air temperature at compressor inlet, °F	92
Atmospheric pressure, psia	14.7
Compressor operating pressure, psig	115
Air temperature at the leak, °F	72
Line pressure at the leak, psig	115
Compressor motor size, hp	75
Compressor motor efficiency	91.5%
Compressor type	Screw
Number of stages	1
Compressor operating hours, per year	8,520
Electric cost, per MMBtu	$14.05

Using these values, the volumetric flow rate, power lost due to leaks, energy lost and cost for leaks of various sizes were calculated specifically for the conditions at this plant. The results are shown in the following table.

As the table shows, the cost of compressed air leaks increases exponentially as the size of the leak increases. As part of a continuing program to find and repair compressed air leaks, the table or graph can be referenced to estimate the cost of any leaks that might be found.

Cost of Compressed Air Leaks At This Plant

Hole Diameter	Flow Rate *Cfm*	Power Loss *hp*	Energy Lost *MMBtu/yr*	Energy Cost *per year*
1/64	0.5	0.1	0.2	$31
1/32	1.8	0.4	8.7	$122
1/16	7.2	1.7	36.9	$518
1/8	29.0	6.9	149.7	$2,103
3/16	65.2	15.4	334.1	$4,694
1/4	115.8	27.4	594.4	$8,351
3/8	260.6	61.7	1,334.8	$18,805

The estimated energy savings and corresponding cost savings for the air leaks found during the site visit are listed in the table below:

Summary of Savings

Machine	Leak Diameter *In*	Power Loss *hp*	Energy Savings *MMBtu/yr*	Cost Savings *per year*
Cardboard Boxes Area	1/16	1.7	36.9	$518
Cardboard Boxes Area	1/16	1.7	36.9	$518
Hand Dye	1/16	1.7	36.9	$518
Straight Knife	1/8	6.9	149.7	$2,103
Web	1/16	1.7	36.9	$518
I-beam #1	1/16	1.7	36.9	$518
I-beam #2	1/16	1.7	36.9	$518
I-beam #3	1/16	1.7	36.9	$518
TOTALS		18.8	408.0	$5,729

From the table above, the total estimated energy savings from repairing the air leaks are 408.0 MMBtu./yr and the total cost savings are $5,730/yr.

Implementation Costs

In general, implementation of this AR involves any or all of the following:

1) replacement of couplings and/or hoses;
2) replacement of seals around filters;
3) shutting off air flow during lunch or break periods; and
4) repairing breaks in lines, etc.

Specific repairs and implementation costs for the leaks found during the site visit are given in the table below.

Implementation Costs

Machine	Repair Needed	Parts	Labor	Total Cost
Cardboard Boxes Area	install shut-off valve	$50	$25	$75
Cardboard Boxes Area	install shut-off valve	$50	$25	$75
Hand Dye	install shut-off valve	$50	$25	$75
Straight Knife	replace coupling	$2	$25	$27
Web	change 0.5" tube	$9	$25	$34
I-beam #1	install shut-off valve	$50	$25	$75
I-beam #2	install shut-off valve	$50	$25	$75
I-beam #3	replace coupling	$2	$25	$27
TOTALS		$263	$200	$463

Assuming that this work can be done by facility maintenance personnel, these leaks can be eliminated for approximately $460. Thus, the cost savings of $5,730 would pay for the implementation cost of $460 in about 1 month.

Equations for Air Flow, Power Loss, and Energy Savings

The volumetric flow rate of free air exiting the hole is dependent upon whether the flow is choked. When the ratio of atmospheric pressure to line pressure is less than 0.5283, the flow is said to be choked (i.e., traveling at the speed of sound). The ratio of 14.7 psia atmospheric pressure to 129.7 psia line pressure is 0.11. Thus, the flow is choked. The volumetric flow rate of free air, V_f, exiting the leak under choked flow conditions is calculated as follows:

$$V_f = \frac{NL \times (T_i + 460) \times \frac{P_l}{P_i} \times C_4 \times C_5 \times C_d \times \frac{pD^2}{4}}{C_6 \sqrt{T_l + 460}}$$

where

V_f	= volumetric flow rate of free air, cubic feet per minute
NL	= number of air leaks, no units
T_i	= temperature of the air at the compressor inlet, °F
P_l	= line pressure at leak in question, psia
P_i	= inlet (atmospheric) pressure, 14.7 psia
C_4	= isentropic sonic volumetric flow constant, 28.37 ft/sec-°$R^{0.5}$
C_5	= conversion constant, 60 sec/min
C_d	= coefficient of discharge for square edged orifice[1], 0.8 (no units)
D	= leak diameter, inches (estimated from observations)
C_b	= conversion constant, 144 in^2/ft^2
T_l	= average line temperature, °F

The power loss from leaks is estimated as the power required to compress the volume of air lost from atmospheric pressure, Pi, to the compressor discharge pressure, P, as follows[2]:

$$L = \frac{P_i \times C_6 \times V_f \times \dfrac{k}{k-1} \times N \times C_7 \times \left[\left(\dfrac{P_0}{P_i} \right)^{\frac{k-1}{k \times N}} - 1 \right]}{E_a \times E_m}$$

Where

L	= power loss due to air leak, hp
k	= specific heat ratio of air, 1.4, no units
N	= number of stages, no units
C_7	= conversion constant, 3.03 x 10^{-5} hp-min/ft-lb
P_o	= compressor operating pressure, psia
E_a	= air compressor isentropic (adiabatic) efficiency, no units
E_a	= 0.88 for single stage reciprocating compressors
E_a	= 0.75 for multi-stage reciprocating compressors
E_a	= 0.82 for rotary screw compressors
E_a	= 0.72 for sliding vane compressors
E_a	= 0.80 for single stage centrifugal compressors
E_a	= 0.70 for multi-stage centrifugal compressors
E_a	= 0.70 for turbo blowers

1. A.H. Shapiro, The Dynamics and Thermodynamics of Compressible Fluid Flow, Vol 1, Ronald Press, NY, 1953, p. 100.
2. Compressed Air and Gas Institute, Compressed Air and Gas Handbook, Fifth Edition, New Jersey, 1989, Chapters 10 and 11.
3. Pneumatic Handbook, 7th ed., Anthony Barber, Trade and Technical Press, 1989, p. 49.

E_a = 0.62 for Roots blowers[3]
E_m = compressor motor efficiency, no units

The annual energy savings, *ES*, are estimated as follows:

$$ES = L \times H \times C_8$$

where

H = annual time during which leaks occurs, h/yr

C_8 = conservation factor, 0.002545 MMBtu/hp-h

The annual cost savings, *CS*, can be calculated as follows:

$$CS = ES \text{ x } unit\ cost\ of\ electricity$$

Quantifying air leaks is relatively simple if the system can be shut down for 10 to 15 minutes and if there is an operating pressure gage in the system.

It is a good idea to ask plant personnel to shut down their compressors briefly (and close a valve near the compressor if the compressor begins to relieve the system pressure through and automatic bleed). It is important to assure that there are no plant processes taking air from the system at the time of this test--the only thing relieving the pressure should be leaks. If there is not an operating plant pressure gage in the system, a cheap one and a collection of bayonet fittings should be at hand so the gage can be attached to the end of one of the plant's supply hoses.

One should monitor the pressure decay as a function of time for about a 10 psi drop and then measure the sizes of the major receivers/accumulators and major air headers. The pressure drop test never takes more than 15 minutes, and usually less. Measuring the size of major receivers and air lines is a short job for an experienced student. Small lines (1.5 inch or less) can be ignored and leaving them out makes the result conservative.

Application of the perfect gas law will yield the leak rate in scfm. Then one can turn to a reference like the DOE/C/40520-TZ by Varigas Research to get compressor hp required per scfm. It is possible to correct the 100 psig data there to other pressures.

This is a much better procedure than listening for leaks and 'quantifying' them by ear as to such things as 'roar', 'gush', 'whisper', etc. because the leak rate is reasonably quantified in a conservative way. It has the disadvantage of leaving the assessment team clueless about the cost of repair, which must then be estimated. It is a good practice to listen for the big leaks and to try to see what is causing them to aid in eliminating costs.

This procedure, along with a couple of other common projects is covered in two publications:

Darin W. Nutter, Angela J. Britton, and Warren M. Heffington, "Five Common Energy Conservation Projects in Small- and Medium-Sized Industrial Plants," 15th National Industrial Energy Technology Conference, Houston, TX, March 1993, pp. 112-120.

The same article was rewritten for Chemical Engineering. The reference is:
"Conserve Energy to Cut Operating Costs," Chemical Engineering, September 1993, pp. 126-137

Cooling Water Heat Recovery

Description

Air compressors, 100 hp and larger, are often cooled by water from a cooling tower. The temperature of the water after leaving the cooling coils of the compressor may be sufficiently high that heat can be extracted from the water and used in a process. For example, boiler feedwater could be preheated by the water used to cool the compressor. Preheating make-up water displaces boiler fuel that would ordinarily be used to heat the make-up water.

Definitions

Cooling Coil - Finned tubes on a water-cooled compressor through which water flows and across which air flows.

Applicability

Facility Type - Any manufacturing facility that has a large, water-cooled air compressor.
Climate - All.
Demand-Side Management Strategy - Strategic conservation.

Waste Water Heat Recovery: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Waste Water Heat Recovery	16,171	3,306	14,676	1.1

1. Tabulated data were taken from the Industrial Assessment Center (IAC) data base and represent HOT waste water IN GENERAL, not just cooling water. All values are averages based on the data base data. The implementation rate for this measure was 41%.
2. One example from the IAC data base to further clarify the costs is as follows: Installing a heat exchanger to recover heat from waste water to heat incoming city water resulted in energy savings of 145 MMBtu/yr, cost savings of $777/yr, and an implementation cost of $2,600, giving a simple payback of 3.4 years.
3. The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

Compressor Controls

Description

Screw compressors may consume up to 80% of their rated power output when they are running at less than full capacity. This is because many screw compressors are controlled by closing a valve; the inlet throttling valve on a typical throttled-inlet, screw-type compressor is partially closed in response to a reduced air system demand. The pressure rise across the compression portion of the unit does not decrease to zero, and thus power is still required by the unit. Accordingly, an older unit will continue to operate at 80% to 90% and a new unit at 40% to 60% of its full load capacity horsepower. When several screw-type air compressor are being used, it is more efficient to shut off the units based on decreasing load than to allow the units to idle, being careful not to exceed the maximum recommended starts/hour for the compressor. Modular systems that conserve energy by operating several small compressors that are brought on line as needed instead of operating one large compressor continuously are often found in retrofit and new installations.

Definitions

None.

Applicability

Facility Type - Any facility that has screw-type air compressors.
Climate - All.
Demand-Side Management Strategy - Strategic conservation.

Screw Compressor Controls: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Screw Compressor Controls	3,463	342	5,074	0.7

1. Tabulated data were taken from the Industrial Assessment Center (IAC) data base. All values are averages based on the data base data. The implementation rate for this measure was 48%.
2. One example from the IAC data base to further clarify the costs is as follows: Installing controls on a 100 hp compressor resulted in energy savings of 128,600 kWh and a cost savings of $6,750/yr, at an implementation cost of $1,500.
3. The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

Outside Air Usage

Description

The amount of work done by an air compressor is proportional to the temperature of the intake air. Less energy is needed to compress cool air than to compress warm air. On average, outside air is cooler than in inside a compressor room. This is often the case even on very hot days. Piping can often be installed so that cooler outside air can be supplied to the intake on the compressor. This is particularly simple and cost-effective if the compressor is located adjacent to an exterior wall.

The energy and cost savings are dependent on the size of the compressor, the load factor, and the number of hours during which the compressor is used. The payback period is nearly always less than two years. The load factor is fairly constant for compressors that operate only when they are actually compressing air. Most reciprocating compressors are operated in this manner. When that are on, they operate with fairly constant power consumption, usually nearly equal to their rated power consumption; when they are cycled off, the power consumption is zero. Screw compressors are often operated in a different manner. When loaded (i.e., actually compressing air), they operate near their rated power, but when compressed air requirements are met, they are not cycled off but continue to rotate and are "unloaded." Older screw compressors may consume as much as 85% of their rated power during this unloaded state. Therefore, if a screw compressor is to be operated continuously, it should be matched closely to the compressed air load that it supplies. Often, plant personnel purchase compressors having several times the required power rating. This may be done for a variety of reasons, but often in anticipation of expansion of the facility and a commensurate increase in the compressed air requirements.

Definitions

Rated Load - The power usage indicated by the air compressor manufacturer; usually shown on the nameplate.
Load Factor - The average fraction of the rated load at which the compressor operates.

Applicability

Facility Type - Any facility that uses compressed air in its operations. The savings increase as the size of the compressor and the hours of use increase for both types of compressors.
Climate - Any climate in which the average outdoor air temperature is less than the air temperature in the compressor room.
Demand-Side Management Strategy - Strategic conservation and peak clipping.

<u>For More Information</u>

Witte, L.C., P.S. Schmidt, D.R. Braun, Industrial Energy Management and Utilization, Hemisphere Publishing Corp., Washington, DC, 1988, pp.433, 437.

Baumeister, T., L.S. Marks, eds., Standard Handbook for Mechanical Engineers, 7th Edition, McGraw-Hill Book Co., New York, NY, 1967, pp. 14.42-14.61.

Outside Air Usage: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Outside Air Usage	593	82	1,246	0.5

1. Tabulated data were taken from the Industrial Assessment Center (IAC) data base. All values are averages based on the data base data. The implementation rate for this measure was 52%.
2. One example from the IAC data base to further clarify the costs is as follows: Supplying outside air to the intakes of three air compressors (100 hp, 75 hp, and 50 hp) resulted in energy and cost savings of 10,050 kWh and $490/yr. The implementation cost was $780.
3. The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

Compressor Replacement

<u>Description</u>

It is often advantageous to install a smaller compressor to more closely match the compressed air requirements normally met by oversized or large compressors, for processes that have periods of low compressed air usage. A smaller compressor will reduce energy usage and associated costs because the smaller compressor will operate at a better efficiency than the larger compressor when air requirements are low. Generally pre-1975 stationary screw-type compressors, if oversized for the load, will run unloaded much of the time when the load is low. They are unloaded by closing the inlet valve and hence are referred to as modulating inlet type compressors. Based on manufacturers' data, these compressors can consume as much as 85% of the full load horsepower when running unloaded. Some pre- and post-1975 compressor manufacturers have developed systems that close the inlet valve but also release the oil reservoir pressure and reduce oil flow to the compressor. Other strategies have also been developed but are not usually found on older (pre-1975) screw-type compressors. The unloaded horsepower for screw compressors operating with these types of systems typically ranges from 80% to 90% of the full load horsepower for older compressors and from 40% to 60% for newer compressors, depending on the particular design and conditions. In any event, if the compresses air requirements are reduced during particular periods (such as a third shift), but are not eliminated entirely, then installing a smaller compressor to provide the air requirements during these periods can be cost-effective.

Definitions
None.

Applicability
Facility Type - Any facility that has a screw compressors and in which there are time periods during which the compressed air requirements are low.
Climate - All.
Demand-Side Management Strategy - Strategic conservation.

Optimum Sized Equipment: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Compressor Replacement	11,826	975	9,828	1.2

1. Tabulated data were taken from the Industrial Assessment Center (IAC) data base. All values are averages based on the data base data. The implementation rate for this measure was 39%.
2. One example from the IAC data base to further clarify the costs is as follows: A manufacturer of computer peripheral equipment replaced a 200 hp air compressor with a 75 hp air compressor. The energy savings were $61,850 kWh and the cost savings were $2,725. The implementation costs were $4,000.
3. The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

Low-Pressure Blowers

Description

Compressed air is sometimes used to provide agitation of liquids, to control vibration units for material handling (as air lances), and for other low-pressure pneumatic mechanisms. For such purposes, it is more efficient to use a blower to provide the required low-pressure air stream. Use of low-pressure air from the blower would reduce energy consumption by eliminating the practice of compressing air and then expanding it back to low pressure for use.

Definitions
Plating Tanks - Tanks containing chemicals used in plating operations, such as chrome plating.

Applicability
Facility Type - Any facility having plating tanks.
Climate - All.

Demand-Side Management Strategy - Strategic conservation and peak clipping.

Reduce Compressed Air Usage: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Low-Pressure Blowers	3,023	404	5,677	0.5

1. Tabulated data were taken from the Industrial Assessment Center (IAC) data base. All values are averages based on the data base data. The implementation rate for this measure was 54%.
2. One example from the IAC data base to further clarify the costs is as follows: A plating facility added a low pressure blower. The energy savings were $41,000 kWh/yr and the cost savings were $3,200/yr. The implementation cost was $5,000.
3. The energy cost savings are based on proposed dollar savings as reported to IAC from the center, usually almost identical to actual savings reported from the facility.

§ Case Study

Estimated Energy Savings = 428.7 MMBtu/yr
Estimated Cost Savings = $5,720/yr
Estimated Implementation Cost = $8,500
Simple Payback = 18 months

Recommended Action

A low pressure blower should be installed to provide agitation air for 3 plating tanks. Use of low pressure air from a blower, as compared to use of compressed air, would reduce electrical consumption by eliminating the current practice of compressing air and the expanding it back to the lower pressure.

Background

A 100 hp compressor is currently in use at this facility, and a significant amount of the power consumed by the compressor (31%) is used to provide air to agitate 3 plating tanks. This compressor produces compressed air at 117 psig, but less pressure is actually needed to provide effective agitation. The pressure and flow rate requirements for effective agitation are calculated from the following equations:

$$Q = AF \times F$$

and

$$P_a = (0.43 \times SD \times SG) + 0.75$$

where

Q	= flow rate required for agitation, cfm
AF	= agitation factor
A	= surface area of agitation tanks, 63.5 sq. ft.
Pa	= pressure required for agitation, psig
SD	= depth of solution, 3 ft.
SG	= specific gravity of water, 1.0

For agitation tanks containing water, the agitation factor is 1.0 cfm/sq. ft.[1] The effective surface area of the tanks is 63.5 sq. ft. Thus, the flow rate required for agitation is calculated as follows:

$$Q = 1..0 \times 63.5 = 63.5 cfm$$

The pressure required for effective tank agitation is calculated as follows:

1. Serfilco '91-'92 Catalog "U" p. 118

$$P = 0.43 \times 3.0 \times 1.0 + 0.75 = 2\, psig$$

Because the difference between the pressure delivered by the compressor and the pressure required for effective tank agitation, the compressor is doing a large amount of unnecessary work. By implementing a blower that has a pressure output more closely matched to the agitation requirement, significant energy savings can be realized.

Anticipated Savings

Energy savings due to use of air at reduced pressure, *ES*, are estimated as follows[1]:

$$ES = (PC - PB) \times H \times C_1$$

where

PC	= power consumed by compressor to agitate tank, hp
PB	= power consumed by blower to agitate tank, hp
H	= operating hours, 5,746 h/yr
C_1	= conversion factor, 0.756 kW/hp

The volume of free air used for agitation V_f at this plant as obtained from the plant personnel is 130 cfm. The power PC that is required to compress the volume of free air V_f needed for agitation from atmospheric pressure Pi to the compressor discharge pressure P_o can be calculated as follows[2]:

$$PC = \frac{P_i \times C_2 \times V_f \times \dfrac{k}{k-1} \times N \times C_3 \times \left[\left(\dfrac{P_0}{P_i} \right)^{\frac{k-1}{k \times N}} - 1 \right]}{E_{ac} \times E_{mc}}$$

where

P	= inlet (atmospheric pressure), 14.7 psia
C_2	= conversion constant, 144 in^2/ft^2
V_f	= volumetric flow rate of free air, 130 cfm
k	= specific heat ration of air, 1.4 (no units)

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1. Compressed Air and Gas Handbook, 1961.

2. Compressed Air and Gas Handbook, Fifth Edition, Compressed Air and Gas Institute, New Jersey, 1989, Chapters 10 and 11.

N	= number of stages, 1 stage
C_3	= conversion constant, 3.03 x 10-5 hp-min/ft-lb
P_o	= pressure at the compressor outlet, 131.7 psia (117 psig)
E_{ac}	= air compressor isentropic (adiabatic) efficiency, 82%
E_{ac}	= 0.88 for single stage reciprocating compressors
E_{ac}	= 0.75 for multi-stage reciprocating compressors
E_{ac}	= 0.82 for rotary screw compressors
E_{ac}	= 0.72 for sliding vane compressors
E_{ac}	= 0.80 for single stage centrifugal compressors
E_{ac}	= 0.70 for multi-stage centrifugal compressors
E_{mc}	= compressor motor efficiency, 92% for a 100 hp motor

Thus, the power that is currently consumed by the compressor to provide air for tank agitation is calculated as follows:

$$PC = \frac{14.7 \times 144 \times 130 \times \dfrac{1.4}{0.4} \times 1 \times \left(3.03 \times 10^{-5}\right) \times \left[\left(\dfrac{131.7}{14.7} \right)^{\frac{0.4}{1.4 \times 1}} - 1 \right]}{0.82 \times 0.92}$$

Similarly the power required by the blower to provide the same amount of air for agitation, PB, can be calculated as follows:

$$PB = \frac{P_i \times C_2 \times Q \times \dfrac{k}{k-1} \times N \times C_3 \times \left[\left(\dfrac{P_b}{P_i} \right)^{\frac{k-1}{k}} - 1 \right]}{E_{ab} \times E_{mb}}$$

where

Pb = pressure at the blower outlet, 17.7 psia (3 psig). This value accounts for P_a plus losses in the air lines.
Eab = blower isentropic (adiabatic) efficiency, 60%
Eab = 0.70 for turbo blowers
Eab = 0.62 for Roots blowers[1]
Emb = compressor motor efficiency, 92% for a 100 hp motor

Thus, the power that would be consumed by the blower to provide air for tank agitation is estimated as follows:

1. Anthony Barber, Pneumatic Handbook, 7th ed., Trade and Technical Press, 1989, p.49

$$PB = \frac{14.7 \times 144 \times 63.5 \times \dfrac{1.4}{0.4} \times 1 \times \left(3.03 \times 10^{-5}\right) \times \left[\left(\dfrac{17.7}{14.7} \right)^{\frac{0.4}{1.4}} - 1 \right]}{0.60 \times 0.80}$$

For this facility, the energy savings, *ES*, that can be realized by installing a blower to provide agitation air for the three tanks are estimated as follows:

$$ES = (33.7 - 1.6) \times 5746 \times 0.746 = 137{,}597 \frac{kWh}{yr} = 469.7 \frac{MMBtu}{yr}$$

The annual cost savings, *CS*, can be estimated as follows:

CS = ES X unit cost of electricity

$$CS = \left(469.7 \frac{MMBtu}{yr} \right) \times \left(\frac{\$13.34}{MMBtu} \right) = \$6{,}265 / yr$$

Implementation Cost

Implementation of this AR involves purchase and installation of a low pressure blower and corresponding controls. The purchase price for a blower that will provide a 3 psig air at a flow of 63.5 cfm, including controls, is estimated as $7,500. The installation cost is estimated as $1,000, including modifications to tanks described below, giving a total implementation cost of $8,500. Thus, the cost savings of $5,720/yr would have a simple payback of about 18 months.

In order for a 3 psig blower to deliver 63.5 cfm of air, the size of the air outlets in the tanks may have to be modified. Assuming that there are 12 total outlets (4 outlets per tank), the required outlet diameter is calculated from the equation for unchoked flow (less than the speed of sound) as follows:

$$D = \sqrt{\frac{4 \times Q \times \sqrt{T_l + 460}}{NL \times C_5 \times C_6 \times C_7 \times C_{db} \times p \times (T_i + 460) \times \sqrt{\left(\frac{P_l}{P_i}\right)^{\frac{2\times(k-l)}{k}} - \left(\frac{P_l}{P_i}\right)^{\frac{(k-1)}{k}}}}}$$

where

T	= average line temperature, °F
NL	= number of outlets used for agitation, 12
C_5	= conversion constant, 60 sec/min
C_6	= conversion constant, 1/144 in^2/ft^2
C_7	= isentropic subsonic volumetric flow constant, 109.61 ft/sec-°R0.5
C_{bd}	= coefficient of discharge for subsonic flow through a square edged orifice, 0.6
T_i	= temperature of the air at the compressor inlet, 101°F
P_l	= line pressure at the agitation tanks, 17.7 psia

Thus, the required diameter of the air outlets is calculated as follows:

$$D = \sqrt{\frac{4 \times 63.5 \times \sqrt{75+460}}{12 \times 60 \times \frac{1}{144} \times 109.61 \times 0.6 \times p \times (101+460) \times \sqrt{\left(\frac{17.7}{14.7}\right)^{\frac{2\times 0.4}{1.4}} - \left(\frac{17.7}{14.7}\right)^{\frac{0.4}{1.4}}}}}$$

D = 0.20 inches

Therefore, if the current diameter of the air outlets is not equal to 0.20 inches, the outlets should be enlarged.

6.3.3. General Notes on Air Compressors

1. Screw units use 40-100% of rated power unloaded.

2. Reciprocating units are more efficient, more expensive.

3. About 90% of energy consumption becomes heat (10%).

4. RULE OF THUMB: Roughly 20 hp per 100 cfm @ 100 psi.

5. Synchronous belts generally are not appropriate (cooling fins, pulley size).

6. Use low pressure blowers vs. compressed air whenever possible (agitation, heat guns, pneumatic transfer, etc.).

7. Cost of sir leaks surprisingly high.

8. Second, third, weekend shifts may have low air needs that could be served by smaller compressor.
9. Outside air is cooler, denser, easier to compress than warm inside air.

10. Friction can be reduced by using synthetic lubricants.

11. Older compressors are driven by older, less efficient motors.

12. Compressors may be cooled with chilled water or have reduced condenser capacity.

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7 THERMAL APPLICATIONS

7.1. COOLING SYSTEMS

For process cooling it is always best from the standpoint of energy conservation to use the least expensive form of energy first. That is, for a piece of equipment or a process that is air cooled, first use outside air (an economizer) if the outside air temperature is low enough. The next step, in appropriate climates, would be to use direct evaporative cooling. This is a process in which air passing through water droplets (a swamp cooler) is cooled, as energy from the air is released through evaporation of the water. Evaporative cooling is somewhat more energy intensive than the economizer but still provides some relatively inexpensive cooling. The increase in energy use is due to the need to pump water.

Indirect evaporative cooling is the next step up in energy use. Air in a heat exchanger is cooled by a second stream of air or water that has been evaporatively cooled, such as by a cooling tower and coil. Indirect evaporative cooling may be effective if the wet-bulb temperature is fairly low. Indirect evaporative cooling involves both a cooling tower and swamp cooler, so more energy will be used than for the economizer and evaporative cooling systems because of the pumps and fans associated with the cooling tower. However, indirect cooling systems are still less energy intensive than systems that use a chiller. The final step would be to bring a chiller on line.

Many plants have chillers that provide cooling for various plant processes. Chillers consist of a compressor, an evaporator, an expansion valve, and a condenser and are classified as reciprocating chillers, screw chillers, or centrifugal chillers, depending on the type of compressor used. Reciprocating chillers are usually used in smaller systems (up to 25 tons [88 kW]) but can be used in systems as large as 800 tons (2800 kW). Screw chillers are available for the 80 tons to 800 tons range (280 kW to 2800 kW) but are normally used in the 200 tons to 800 tons range (700 kW to 2800 kW). Centrifugal chillers are available in the 200 tons to 800 tons range and are also used for very large systems (greater than 800 tons [2800 kW]). The evaporator is a tube-and-shell heat exchanger used to transfer heat to evaporate the refrigerant. The expansion valve is usually some form of regulating valve (such as a pressure, temperature, or liquid-level regulator), according to the type of control used. The condenser is most often a tube-and-shell heat exchanger that transfers heat from the system to the atmosphere or to cooling water.

7.1.1. Introduction

This section contains information pertaining to cooling systems, particularly chiller systems. Refer to Brief #4 "Outside Air Economizers," Brief #5, "Evaporative Cooling," Brief #6, "Cool Storage," and Brief #7, "Heat Recovery from Chillers" in DSM Pocket Guidebook, Volume 2: Commercial Technologies for information relating to cooling systems that may be found in industry. Topics discussed in this section include condenser water and chilled water temperature reset at the chiller, hot-gas defrost of chiller evaporator coils, and two-speed motors for cooling tower fans.

7.1.2. Cooling Towers

The most common types of cooling towers dissipate heat by evaporation of water which is trickling from different levels of the tower. Usually the water is sprayed into the air, so the evaporation is easier. Cooling towers conserve water, prevent discharge of heated water into natural streams and also avoid treating large amounts of make-up water. The wet-bulb temperature should not exceed the maximum expected temperature, which occurs in the summer.

In the past most cooling towers were atmospheric. They relied on natural air circulation, making them not very efficient in their cooling capacity. In addition, high pumping heads were required to force the water to a certain height and let it run down on the system of platforms after spraying. The spray losses were substantial and make-up water was required in significant amount.

Three types are widely used today. Mechanical forced-draft towers (see Figure 7.2), induced-draft towers (see Figure 7.1) and hyperbolic. Mechanical forced-draft is designed to provide an air supply at ground level and at amounts that are easily controlled by fans. Unfortunately, there are some problems with this design as well. Firstly, it is a non-uniform distribution of air over the area.

Comparison of F.D. Blower Tower vs. Propeller Tower for 400 Tons

Cooling Tower Type	Operating Fan Motor hp	Fan Motor kW[1]	Tower Pump Head ft[2]	Additional Pump Motor kW[3]	Total Operating kW
Counterflow with Blower	40	32.4	23	6.9	39.3
Crossflow w/Propeller	20	16.2	10	3.0	19.2

1. Fan and pump motor efficiencies assumed to be 92%.
2. That portion of total pump attributable to the cooling tower; sum of static lift plus losses in tower's internal water distribution system.
3. Pump efficiency assumed to be 82%.

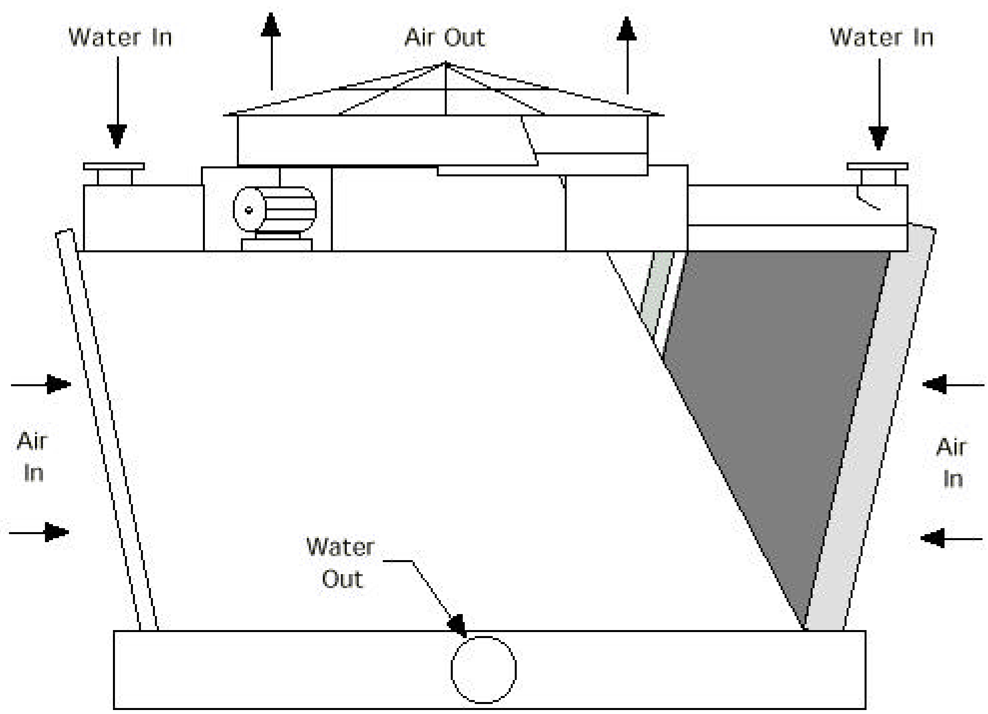


Figure 7.1: Induced Draft Cooling Tower

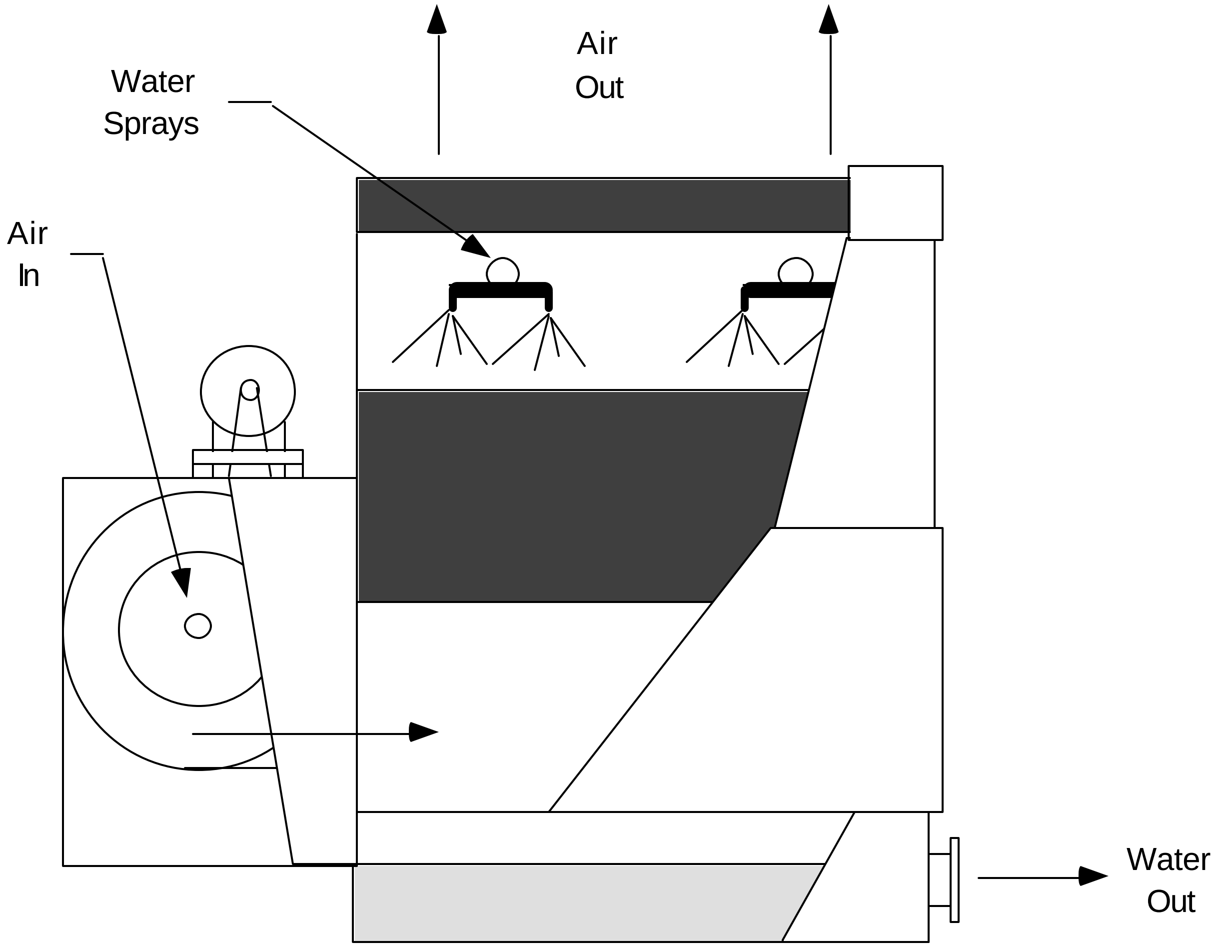


Figure 7.2: Mechanical Forced-Draft Cooling Tower

Secondly, the vapor is recirculated from the discharge into the inlet causing ice formation on the blades of draft fans (only when the temperatures drop low enough in the winter months). Thirdly, the physical limitations of the fan size might prove a problem.

In case of induced-draft towers, the fan is mounted on the top of the roof. This arrangement improves air distribution. The make-up of water is also less. Hyperbolic tower is based on the chimney effect. The effect of the chimney eliminates the need for fans which are necessary for both induced-draft and mechanical forced-draft cooling towers. If the tower is of a substantial height, above 250 feet, the tower orientation should be with its broad side to the prevailing winds in the region. Shorter towers should have long axis parallel to the prevailing winds.

Utilizing free cooling is one method of off-setting the load on a chilled water system. Free cooling uses evaporative cooling to provide chilled water needs when outside conditions are ideal. Figures 7.3 and 7.4 show two methods of free cooling.

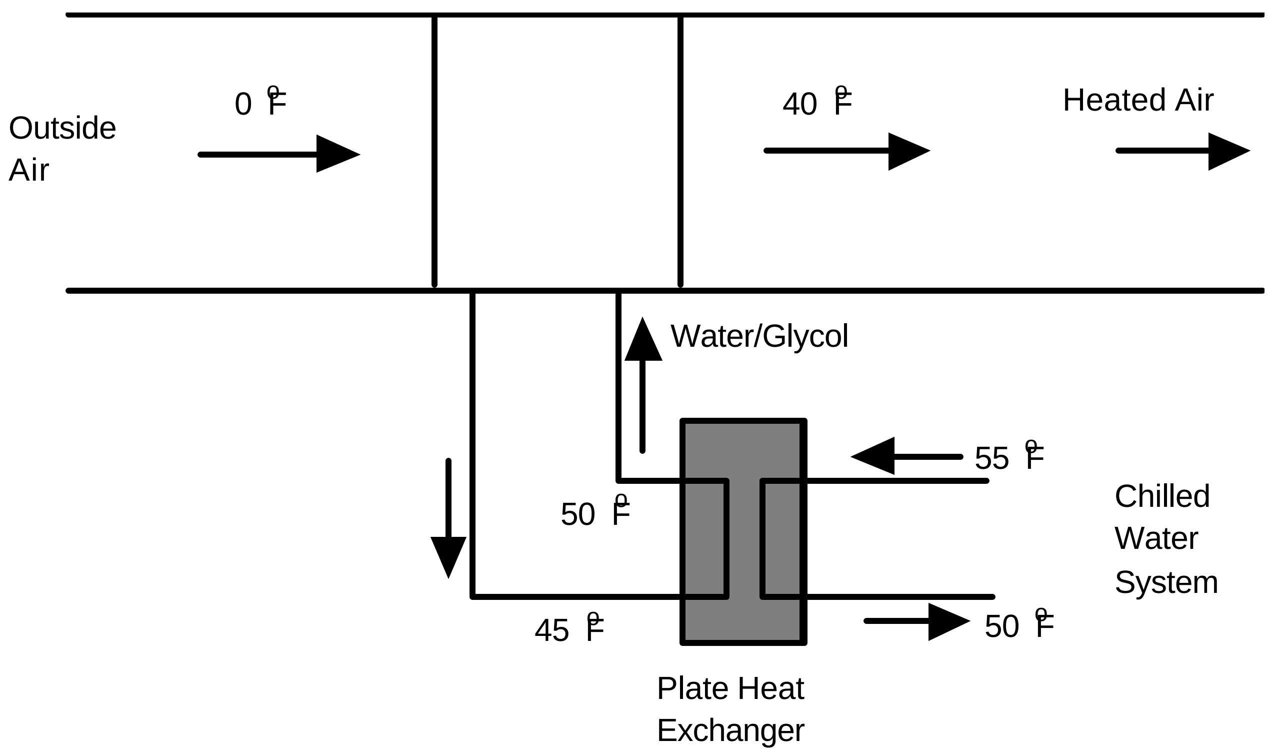


Figure 7.3: Free Cooling/Air Preheat

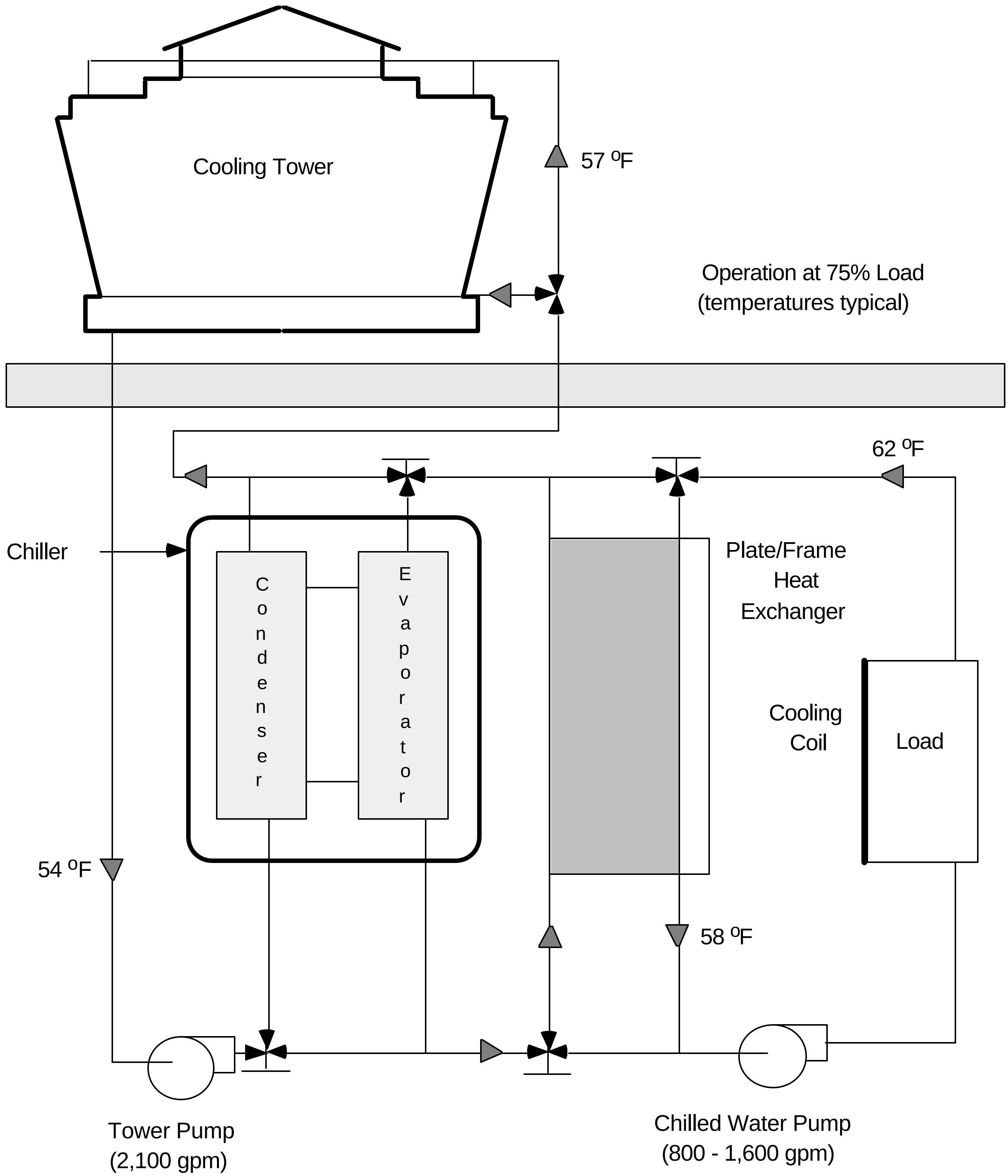


Figure 7.4: Indirect Free Cooling Loop

Free Cooling (Water Side Economizer) Define Operating Conditions

	Peak Load Design Conditions	Off Season Design Conditions	
Comfort Cooling Data Processing	700 Tons 300 Tons	200 Tons 300 Tons	
Total Load	1000 Tons	500 Tons	
		Alternate Number One	Alternate Number Two
Flow Rate	2400 GPM	1200 GPM	2400 GPM
Returning Temperature	55ºF	60ºF	60ºF
Leaving Temperature	45ºF	50ºF	55ºF

7.1.3. Typical Performance Improvements

Improvements in chilled water systems are described in the following sections. Thorough understanding of the operation and knowing all local conditions (temperatures, prevailing winds etc.) are keys to providing an accurate analysis of the problem.

Condenser Water Temperature Adjustment

Description

The power consumption of any chiller increases as the condensing water temperature rises. This is because, as the condenser temperature increases, the pressure rise across the compressor increases and, consequently, the work done by the compressor increases. Condensing water temperature setpoints are typically in the range between 65ºF and 85ºF, but can be as low as 60ºF. In many cases the setpoint temperature is in the middle of the range, at about 75ºF. A rule of thumb is that there is a 0.5% improvement in chiller efficiency for each degree Fahrenheit decrease in the setpoint temperature for the condenser water. The improvement tends to be higher near the upper range of setpoint temperatures and decreases as the setpoint temperature decreases. The amount of allowable decrease in the setpoint temperature must be determined by a detailed engineering analysis that includes the following: the system capacity, minimum requirements for the plant process served by the condenser water system, and number of hours per year that the wet bulb temperature is below a given value.

Definitions

Condenser - The unit on the chiller in which heat is transferred out of the refrigerant. Cooled condensing water flows over tubes containing a vaporized refrigerant in a tube-and-shell heat exchanger. As the refrigerant cools, it condenses into a liquid and releases heat to the condensing water.

Condensing Water - Water that has been cooled in a cooling tower that is used to condense vaporized refrigerant in the condenser.

Applicability

Facility Type - Any facility that has a chiller.

Climate - All climates. It is advantageous to reduce the condensing water temperature in both humid and dry climates.

Demand-Side Management Strategy - Strategic conservation.

For More Information

ASHRAE Handbook, 1996 Equipment, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, 1988, Ch. 17.

Industrial Assessment Center (IAC). Contact the IAC nearest to your area.

Condenser Water Supply Temperature Reset: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Condenser Water Supply Temp. Reset	2,678	498	6,217	0.4

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database. All values are averages based on the data base data. The implementation rate for this measure was 67%.
2. One example from the IAC data base to further clarify the costs is as follows: Resetting the condenser water temperature at an electronics plant resulted in energy and cost savings of 58,218 kWh/yr and $2,390/yr. The implementation cost was $200.
3. The energy cost savings are based on proposed dollar savings from the IAC report, usually almost identical to actual savings reported from the facility.

Chilled Water Supply Temperature Adjustment

Description

The efficiency of chillers increases as the chilled water temperature increases. This is because, in order to obtain lower temperature chilled water, the refrigerant must be compressed at a higher rate, which in turn increases the compressor power requirements and decreases the efficiency of the chiller. There is approximately a 1% increase in efficiency for each degree Fahrenheit increase in the chilled water setpoint temperature. The efficiency increase tends to be higher near the lower temperatures in the setpoint range and decreases as the setpoint temperature increases. The amount of allowable increase must be determined by a detailed engineering analysis that evaluates the load requirements from the chiller, the design chilled water temperature, and other aspects of the system. It is not uncommon to find chilled water setpoints that are lower than is required from industrial chillers.

Definitions

Evaporator - The unit on the chiller in which heat is transferred to the refrigerant. Warm water flows over tubes containing a liquid refrigerant in a tube-and-shell heat exchanger. Heat is extracted from the water as the refrigerant vaporizes and the temperature of the water is reduced to the desired chilled water temperature.

Chilled Water - Water in the evaporator that is cooled when heat is removed to vaporize the refrigerant.

Applicability

Facility Type - Any facility that has a chiller.
Climate - All climates.
Demand-Side Management Strategy - Strategic conservation.

For More Information

ASHRAE Handbook, 1996 Equipment, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, 1988, Ch. 17.

Industrial Assessment Center (IAC). Contact the IAC nearest to your area.

Chilled Water Supply Temperature Reset: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Chilled Water Supply Temp. Reset	766	384	4,449	0.2

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database. All values are averages based on the data base data. The implementation rate for this measure was 57%.
2. One example from the IAC data base to further clarify the costs is as follows: Resetting the chilled water temperature in a manufacturing plant resulted in energy savings of 39 MMBtu/yr, a cost savings of $537/yr, and no implementation cost, thus giving an immediate payback.
3. The energy cost savings are based on proposed dollar savings from the IAC report, usually almost identical to actual savings reported from the facility.

Variable Speed (or Two-Speed) Motors for Cooling Tower Fans

Description

Cooling tower performance is affected by the outdoor wet-bulb temperature. Higher wet-bulb temperatures correspond to higher air saturation temperatures. As air loses the ability to extract heat from water droplets flowing through a cooling tower (increasing wet-bulb temperature), a higher air flow rate is required to remove the desired amount and reduce the condenser water to the design temperature. The cooling water fan motor is often sized to perform under design conditions (i.e., full water flow rate at maximum air flow rate and design wet-bulb temperature). During periods of lower outdoor wet-bulb temperature, the design amount of cooling can be obtained with lower air flow rates. As the air flow rate decreases, the fan speed and the motor power requirements also decrease. It may then be beneficial to install a two-speed motor for the cooling tower fan to reduce the fan motor power consumption. Two-speed motors may be part of new or retrofit construction. Savings for the addition of a two-speed fan motor are estimated based on the number of hours per year that the wet-bulb temperature occurs at various ranges between design wet-bulb and minimum wet-bulb temperatures and the power requirements for various air flow rates. It should also be noted that variable speed drives for fan motors achieve cooling tower energy savings in the same manner as two-speed motors.

Definitions

Wet-Bulb Temperature - Thermodynamic wet bulb temperature is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature. High wet-bulb temperatures correspond to higher air saturation conditions. For example, dry air has the ability to absorb more moisture than humid air, resulting in a lower, wet-bulb temperature.

Applicability

Facility Type - Any facility that has a cooling tower.

Climate - All climates. It is advantageous to install two-speed motors on cooling towers in both humid and dry climates; however, the benefits are greater in climates that experience a low wet-bulb temperature.

Demand-Side Management Strategy - Strategic conservation.

For More Information

Industrial Assessment Center (IAC). Contact the IAC nearest to your area.

Motor Master, Washington State Energy Office, Olympia, WA, 1992.

Two-Speed Motors on Cooling Tower Fans: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Two-Speed Motors on Cooling Tower Fans	4,170	164	2,400	1.7

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database in 1994. The implementation rate for this measure was 20%.
2. One example from the IAC data base to further clarify the costs is as follows: Installing two-speed motors on the cooling towers at a plastic film extrusion plant resulted in energy and cost savings of 58,335 kWh/yr and $2,680/yr. The implementation cost was $8,900.

3. The energy cost savings are based on proposed dollar savings from the IAC report, usually almost identical to actual savings reported from the facility.

Hot Gas Defrost

Description

Frost builds up on air cooler unit (freezer) evaporator coils when the unit operates at less than 32ºF. Frost is the result of moisture in the air freezing to the coil as the air passes over the coil. The performance of the coil is adversely affected by frost. Frost acts as an insulator and reduces the heat transfer capability of the coil, and it restricts airflow through the coil. Frost buildup is unavoidable and must be removed periodically from the coil.

One method of frost removal is to use the hot refrigerant discharge gas leaving the compressor. During the defrost cycle, hot gas is circulated through the coil to melt the frost. Hot-gas defrost systems may be used for all cooling unit capacities and may be included in new or retrofit construction. For retrofit applications, hot-gas defrost systems most often replace electric resistance defrost systems. Using waste heat off the hot-gas side for defrost may result in savings on the order of 10% to 20% of the total system usage.

Definitions

Hot-Gas - The refrigerant vapor discharged by the compressor. This vapor is superheated; the temperature of the vapor has been raised above that which normally occurs at a particular pressure.

Climate - All climates.

Demand-Side Management Strategy - Strategic conservation.

For More Information

ASHRAE Handbook 1996 Equipment, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, 1988, p. 8.3.

Evaporator Coils Defrost: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Hot-Gas Defrost	9,750	489	6,656	1.4

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database. All values are averages based on the data base data.
2. One example from the IAC database to further clarify the costs is as follows: Installing a hot-gas defrost system in a dairy resulted in energy and cost savings of 20,500 kWh/yr and $1,070/yr. The implementation cost was $2,500.

4. The energy cost savings are based on proposed dollar savings from the IAC report, usually almost identical to actual savings reported from the facility.

7.2. ABSORPTION REFRIGERATION

Packaged absorption liquid chillers are used to produce chilled liquid for air-conditioning and industrial refrigeration processes. The chillers are usually powered by low-pressure steam or hot water, which can be supplied by the plant boiler or by waste heat from a process.

Where prime energy is needed, mechanical refrigeration is usually preferable. Conditions favorable to absorption refrigeration are where sources of waste heat are available.

7.2.1. Operation

In the absorption cycle, two distinct chemicals are used and the cycle is driven by heat. The most common absorption system fluids are water as the volatile fluid and lithium bromide brine as the absorber fluid.

Figure 7.5 illustrates the operation of a two-stage absorption chiller. Refrigerant enters the top of the lower shell from the condenser section and mixes with refrigerant being supplied from the refrigerant pump. Here the liquid sprays over the evaporator bundle. Due to the low vacuum (6 mm Hg) some of the refrigerant liquid vaporizes, cooling the refrigerant water to a temperature that corresponds closely to the shell pressure.

As the refrigerant vapor/liquid migrates to the bottom half of the shell, a concentrated solution of liquid bromide is sprayed into the flow of descending refrigerant. The hygroscopic action between lithium bromide (a salt with an especially strong attraction for water) and water--and the related changes in concentration and temperature--result in the extreme vacuum in the evaporator directly above.

Dissolving lithium bromide in water also gives off heat which is removed by the cooling water. The resultant dilute lithium bromide solution collects in the bottom of the absorber where it flows down to the solution pump.

The dilute mixture of lithium bromide and refrigerant vapor is pumped through the heat exchangers, where it is preheated by a hot, concentrated solution from the concentrators (generators). The solution then flows to the first-stage concentrator where it is heated by an external heat source of steam or hot water. The condenser water used in the absorber and the condenser is normally returned to a cooling tower.

The vapor is condensed in the second concentrator where the liquid refrigerant flows to the lower shell and is once again sprayed over the evaporator. The concentrated solution of lithium bromide from the concentrators is returned to the solution pump where it is recycled to the absorber.

The degree of affinity of the absorbent for refrigerant vapor is a function of the concentration and temperature of the absorbent solution. Accordingly, the capacity of the machine is a function of the temperature of the heat source and cooling water (see Figure 7.6).

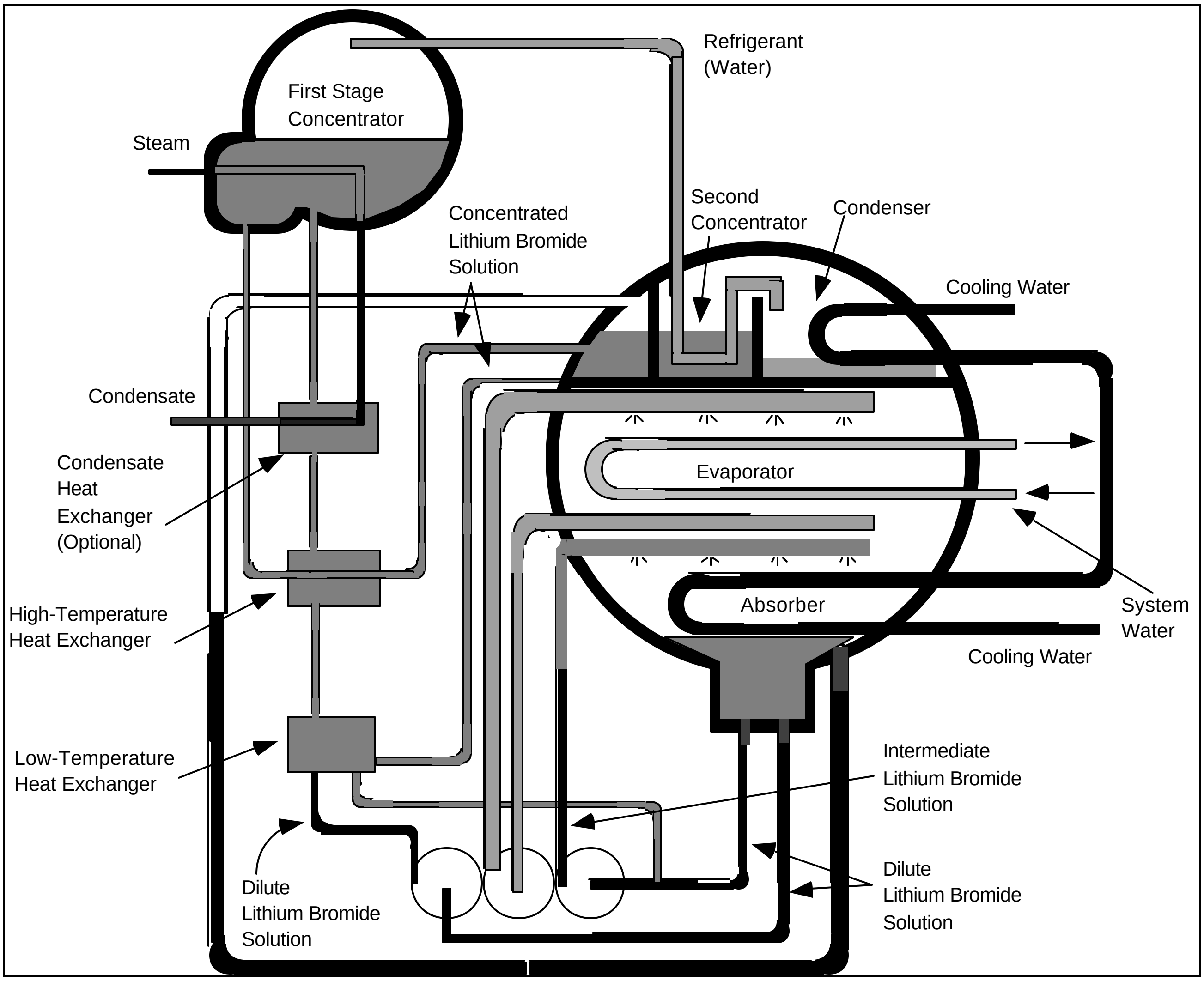


Figure 7.5: Two-Stage Absorption Chiller

Two-stage absorption requires higher water temperature or steam pressure, but because no additional heat is required in the second concentrator, two-stage absorption machines are 30 percent to 40 percent more efficient. However, two-stage absorption machines cost significantly more than single-stage absorption units on an equal tonnage basis.

Capacity

Modern absorption refrigeration units range in capacity from about 100 tons to 1,60 tons for chilled water service. Most ratings are based on a minimum chilled water outlet temperature of 40ºF, a minimum condenser water temperature of 70ºF at the absorber inlet, and a generator steam pressure of 12 psig. Hot water or hot process fluids can be used in lieu of steam for the generator; however, the fluid inlet temperature must be at least 240ºF for maximum capacity.

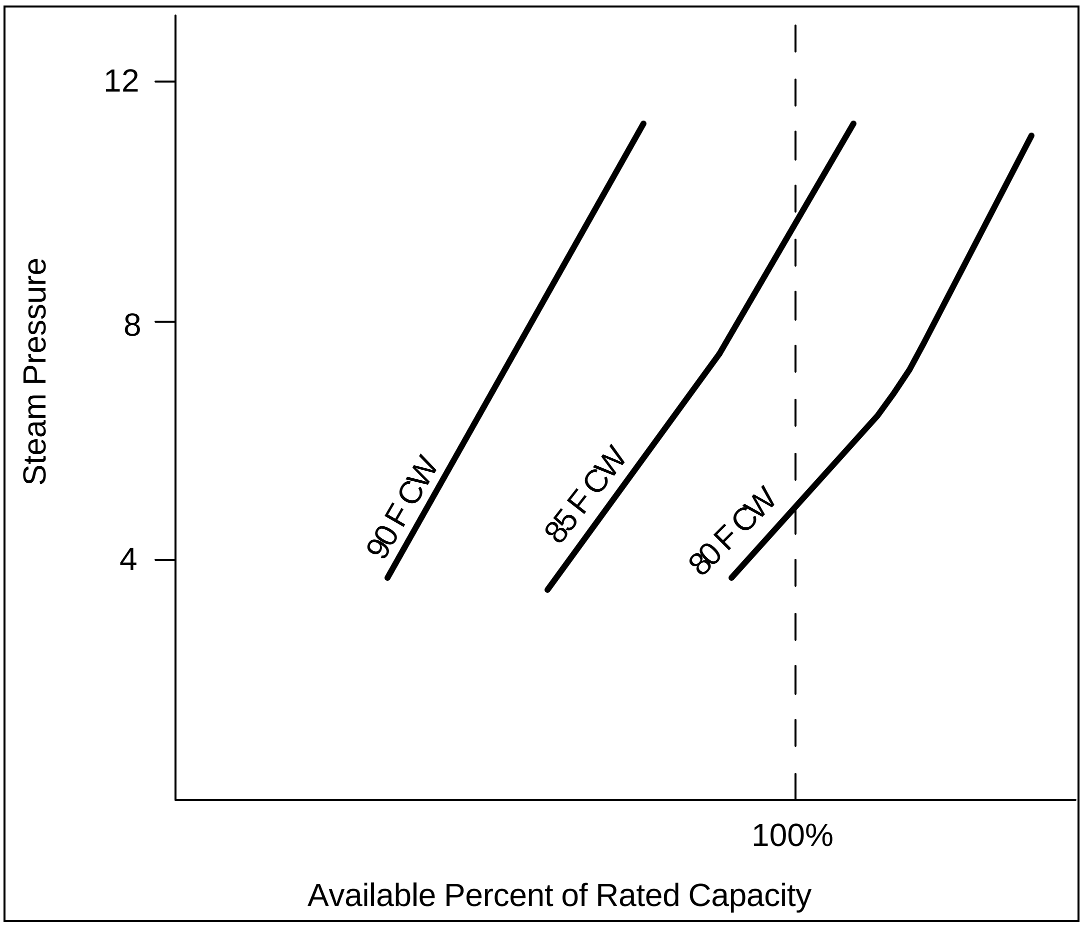


Figure 7.6: Capacity as Function of Temperature of Heat Source and Cooling Water

Operating Problems

Every effort must be made to keep the system air-tight, as even very small leaks can cause problems and are difficult to detect. Air entering the machine causes

- The lithium bromide solution to become highly corrosive to metals.

- The lithium bromide solution to crystallize.
- The chilled water temperature to increase.
- Refrigeration capacity to decrease.

Crystallization occurs when the lithium bromide solution does not go through the normal dilution cycle. When this happens, the solution becomes so concentrated that it crystallizes and plugs the solution lines. The unit must then be shut down and decrystallized. Crystallization can be caused by a power failure, controller malfunction, extreme variations in the condenser water temperature, or operator error in inadvertently allowing air to enter the machine. It is indicated by a rise in the outlet chilled-water temperature, a loss of solution pump (or a noisy solution pump), a loss of solution level in the absorber, and generator flooding.

Although absorption refrigeration machines are generally more difficult to operate and require more maintenance than reciprocating and centrifugal machines, they allow waste stream to be utilized more efficiently and in the proper application can result in substantial energy savings.

Mechanical Refrigeration	
Typical hp required Cost/ton-hr	= 1 hp/ton = $0.041
Absorption Refrigeration	
Typical steam required for single-stage Cost/ton-hr	= 18 lbs @ 14 psig/ton = 18 lbs/hr x $4.01/M lbs steam = $0.072
Typical steam required for two-stage Cost/ton-hr	= 12 lbs/hr @ 14 psig/ton = 12 lbs/hr x $4.01/M lbs. steam = $0.048
Typical gas required for direct-fired, two-stage Cost/ton-hr	= 13,000 Btu/ton = 13,000 Btu/hr x $3.00/MMBtu = $0.039

Table 7.1: Cost Comparison of Mechanical and Absorption Refrigeration

Direct-Fired Two-Stage Absorption Refrigeration

A recent development is the use of direct gas firing or waste heat as the energy source in lieu of steam. The gas stream must be 550ºF for use in this application. Possible sources are drying ovens, heat-treating facilities, paint-baking ovens, process ovens, or any process which gives off a clean, high-temperature exhaust gas. A special advantage of this unit is that it can be directly integrated into a packaged cogeneration system.

Table 7.1 shows a cost comparison of mechanical and absorption refrigeration. The attractiveness of absorption refrigeration depends on the relative cost of electricity and fuel if prime energy is used, or the availability of waste heat, which requires no prime energy.

With the unit costs selected for the manual, the two-stage absorption system is slightly more costly to operate than mechanical refrigeration. Where waste heat can be utilized, absorption refrigeration is, of course, the obvious choice.

In considering the use of waste heat for absorption refrigeration, it is worth a reminder that the first step should be to determine whether reducing or eliminating the waste heat is possible. A common application is the use of absorption refrigeration to utilize steam vented to atmosphere. However, in most cases a thorough study of the steam system will identify means of balancing the system to eliminate the loss of steam.

7.3. MECHANICAL REFRIGERATION

Refrigeration machines provide chilled water or other fluid for both process and air conditioning needs. Of the three basic types of refrigeration systems (mechanical compression, steam jet, and absorption), mechanical compression is the type generally used.

The energy requirements of the steam jet refrigeration unit are high when compared with those for mechanical compression; therefore, the use of steam jet refrigeration is limited to applications having very low cost steam at 125 psig, a low condenser water cost, and a high electrical cost. With today's energy costs, this type of system is rarely economical.

7.3.1. Mechanical Compression

The mechanical compression refrigeration system consists of four basic parts; compressor, condenser, expansion device, and evaporator. The basic system is shown in Figure 7.7. A refrigerant, with suitable characteristics, is circulated within the system. Low-pressure liquid refrigerant is evaporated in the evaporator (cooler), thereby removing heat from the warmer fluid being cooled. The low-pressure refrigerant vapor is compressed to a higher pressure and a correspondingly higher saturation temperature. This higher pressure and temperature vapor is condensed in the condenser by a cooler medium such as cooling tower water, river water, city water, or outdoor air. The higher pressure and temperature refrigerant liquid is then reduced in pressure by an expansion device for delivery to the evaporator.

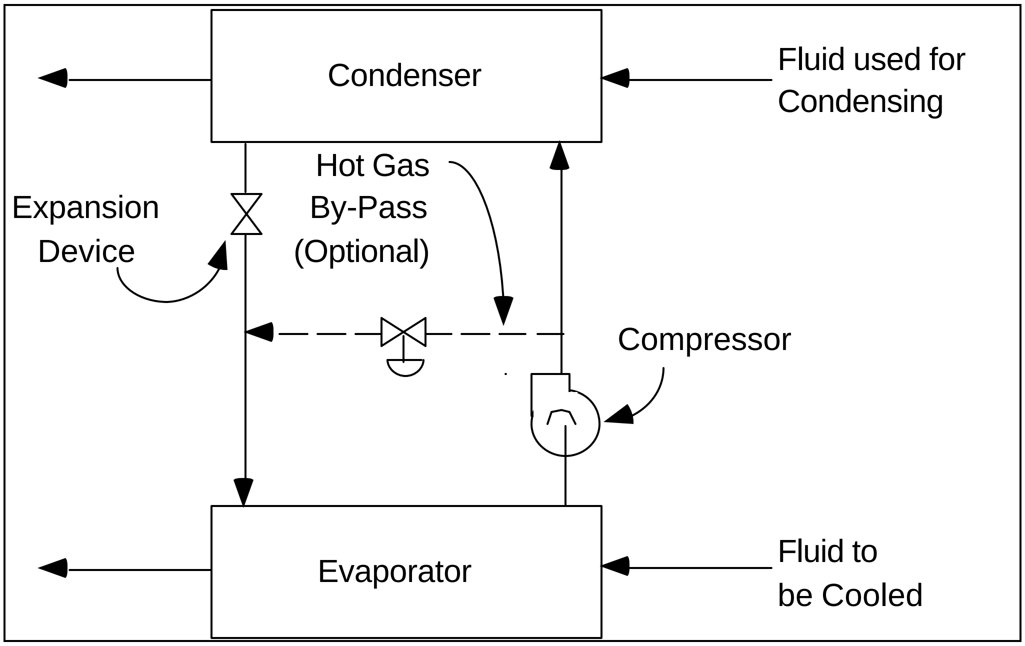


Figure 7.7: Mechanical Compression Refrigeration System

Reciprocating compressors offer the lowest power requirement per ton of refrigeration. For example, a 100 ton capacity machine would use 1 kW/ton with a centrifugal compressor whereas the same machine would use 0.8 kW/ton with a reciprocating compressor. Although the reciprocating unit is more energy efficient, the savings are not sufficient to justify replacement in a normal situation.

The characteristics of a centrifugal compressor make it ideal for air conditioning applications because it is suitable for variable loads, has few moving parts, and is economical to operate. The power requirement of the centrifugal compressor is about 0.75 kW/ton when 45ºF chilled water is produced, and it requires 3 gpm/ton of condenser water. Mechanical compressors are normally driven by an electric motor although many installations utilize a steam turbine drive.

7.3.2. Methods to Reduce Costs

The ultimate users of the cooling system and the distribution system, as well as the refrigeration machines, must be operated efficiently. The following steps will lead to the most energy-efficient operation of the refrigeration system.

1. Use refrigeration efficiently.
2. Operate at the lowest possible condenser temperature/pressure (lowest entering condenser water temperature).

3. Operate at the highest possible evaporator temperature/pressure (highest leaving chilled-water temperature); do not overcool.
4. Operate multiple compressors economically.
5. Recover heat rejected in the condenser.
6. Use a hot gas bypass only when necessary.

Use Refrigeration Efficiently

The most direct saving will obviously result from shutting down the equipment when refrigeration is not required. Short of shutting down equipment, the refrigeration load may be reduced by ensuring the cooling medium is utilized efficiently at the point of use. A typical problem is overcooling. Other unnecessary losses are inadequate insulation or poor operating practices such as simultaneous heating and cooling.

A reduction in refrigeration load will, of course, reduce the operation of the refrigeration machines, including the associated pumps and cooling towers. Economizer cycles on air conditioning units will also permit early shutdown of refrigeration machines. Refer to the HVAC section for details of economizer cycle operation.

Reduce the Condensing Temperature (Pressure)

The most significant method to reduce compressor horsepower (aside from load reduction) is to lower the condensing temperature (pressure). Typically, efficiency improves about 1.5 percent for each 1 degree decrease in refrigerant condensing temperature.

The pressure-enthalpy diagram Figure 7.8 illustrates how energy is conserved in the refrigerant cycle (Carnot cycle). At point 1 the refrigerant liquid starts evaporating and absorbs heat from the cooling load. At point 2 all of the liquid is evaporated and emerges as a vapor. Between point 2 and 3 mechanical work is performed to compress the working fluid in the compressor. Between points 3 and 4, the vapor passes to the condenser where heat is removed by the cooling water and the refrigerant returns to the liquid state. Between points 4 to 1 the refrigerant experiences a drop in pressure induced by the expansion valve. Lowering the condensing pressure lowers line 3-4 to 3'-4', thereby reducing the load on the compressor.

Opportunities to reduce condensing temperature will exist when the cooling tower or air-cooled condenser is operating at less than full capacity. Because the cooling tower or air-cooled condenser is designed for summer conditions, excess capacity should exist in the winter. Rather than controlling to a constant condensing temperature, the lowest possible temperature consistent with the capability of the refrigeration system should be used. Although additional costs are incurred for cooling, these are more than offset by the reduction in compressor horsepower. The condition of the cooling tower or air-cooled condenser is also important for obtaining minimum temperature.

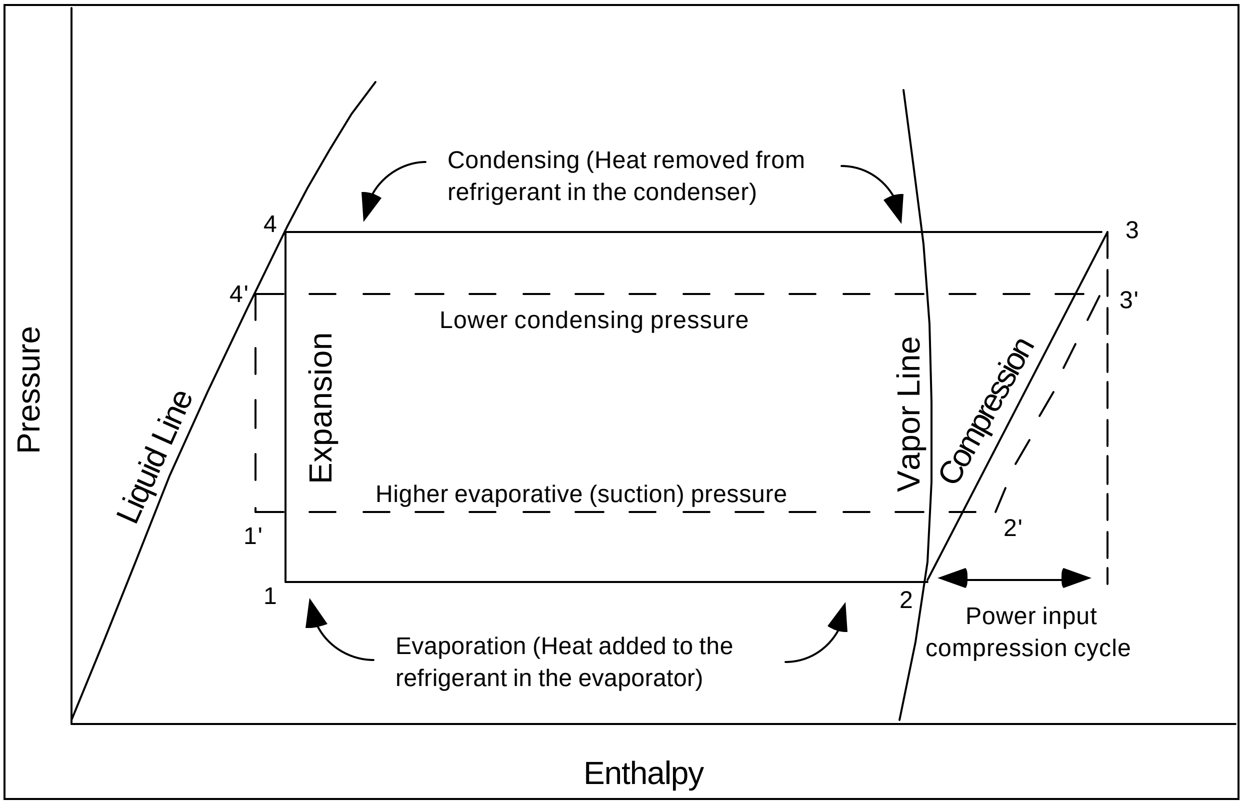


Figure 7.8: Pressure-Enthalpy Diagram

Although it is economical to operate at a lower condenser temperature than the design temperature, too low a condensing temperature reduces the pressure differential across the refrigerant control (condensing pressure to vaporizing temperature), which reduces the capacity of the control and results in starving the evaporator and unbalancing the system. As a rule of thumb, the condenser temperature (refrigerant side) should not be less than 35ºF above the refrigerant temperature in the evaporator.

The partial-load power requirements of a typical centrifugal refrigeration compressor at different entering condenser water temperatures are shown in Figure 7.9.

The following example calculates the annual savings from reducing the condenser water temperature. A 1,000-ton refrigeration compressor rated at 750 kilowatts at full load is operating at a 700-ton load. The condenser water temperature is reduced from 85ºF to 65ºF during the five winter months.

Percent design Load = (700 ton actual load) / (1,000 ton design load) x 100 = 70%

From Figure 7.9, the percent of full load power at 70 percent design load is:

At 85ºF condenser water, 65.5 percent	
At 65ºF condenser water, 60.0 percent	
Input kW at 85ºF condenser water	= 750 x 65.6%
	= 491
Input kW at 65ºF condenser water	= 750 x 60.0%
	= 450
Savings	= 41 kW
Annual Savings = 41 kW x 6,000 hrs/yr x 5 mos/12 x 0.05 $/kWh	
	= $5,130

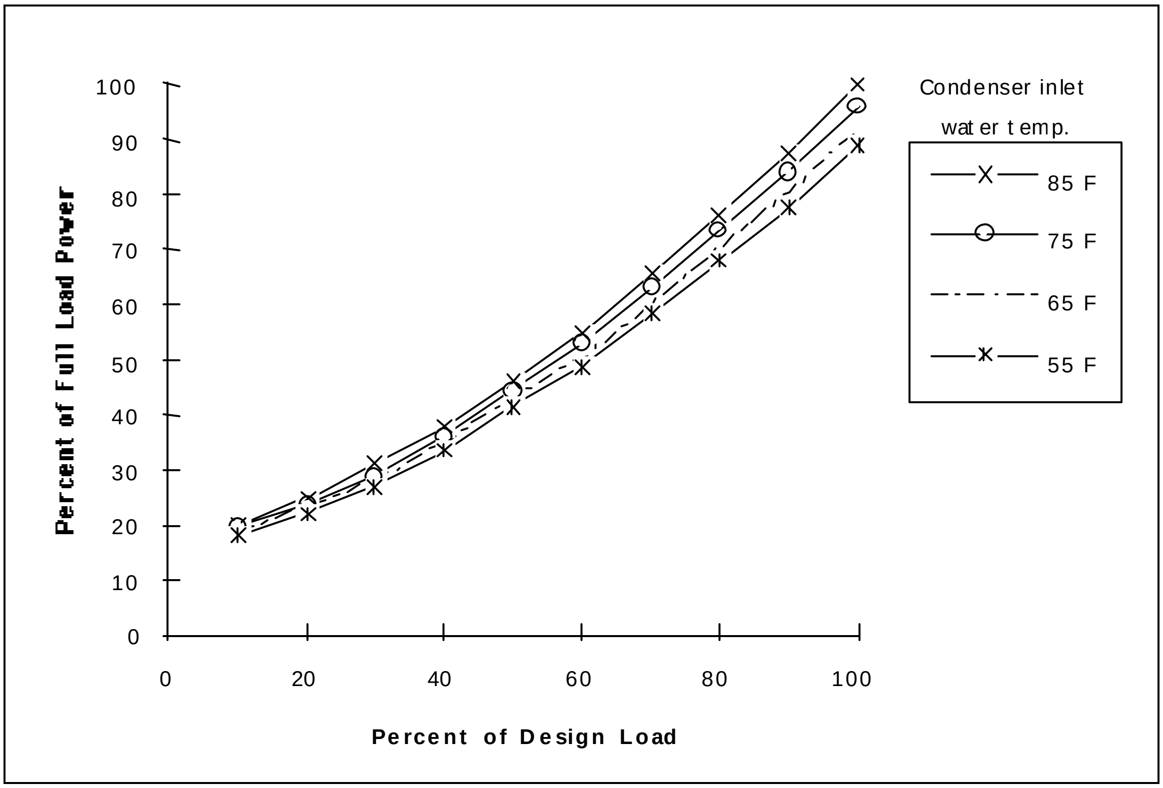


Figure 7.9: Partial Load Requirement for Centrifugal Refrigeration Compressors

Closely related to lower cooling water temperature is proper maintenance of the condensers. Inadequate water treatment can lead to scaling which can decrease heat transfer through the heat exchanger tubes. A gradual increase in refrigerant temperature at constant load conditions is an early signal of condenser tube fouling.

Raise the Evaporator Temperature (Pressure)

An increase in evaporator temperature reduces the energy required by the refrigeration machine because it must perform less work (reduced lift) per ton of refrigeration produced. The amount of energy reduction depends on the type of refrigeration machine. For a centrifugal machine, the reduction is approximately 1 to 1.5 percent for each degree the evaporator temperature increases.

As shown in Figure 7.8 increasing the evaporator temperature raises line 1-2 to 1'-2', thereby reducing the load on the compressor between points 2 and 3. The effect is the same as reducing the compressor load by a reduction in condensing pressure (temperature) described in the previous method.

Consult the actual performance curve for the individual machine for a more accurate estimate of horsepower reduction.

In some cases a higher evaporator temperature may not be possible if it is fixed by production requirements. An opportunity to increase the evaporator temperature (chilled water temperature) will exist when the flow of chilled water to the various areas is throttled. The throttle condition indicates that less than full design flow is required by the units to satisfy the load. The chilled-water temperature can be increased until it reaches the point at which any single user is requiring close to full flow. The system temperature will be controlled by the single user that first reaches full capacity.

While some reduction in compressor power is obtained by increasing the leaving chilled-water temperature, greater savings are possible with a centrifugal compressor by changing the compressor speed. The reason is that, at a constant speed, the chilled-water temperature is raised by closing the prerotation vanes on the compressor. This causes the reduction in power to be less than expected for the corresponding increase in evaporating temperature. The speed change could be accomplished by changing gears; or if a variable chilled-water temperature is appropriate, a variable-speed drive could be considered.

To find the savings from an increase in the chilled-water temperature from 45ºF to 50ºF, use the following example. The refrigeration machine is rated at 1,000 tons and operates at an average load of 600 tons for five months per year.

Conditions: input = 412 kW; 1,800 gpm condenser water
Annual Savings = 412 kW x (50ºF - 45ºF) x 1% x 6,000 hrs/yr x 5 mos/12 x $0.05/kWh
= $2,580

Note that the condenser water flow does not change.

Operate Multiple Compressors Economically

If an installation has multiple refrigeration units, economic operation of these units can reduce energy consumption. The operating characteristics of the types of compressors used will determine the economical mode of operation. The power requirements of reciprocating compressors make their operation more efficient if one compressor is unloaded or shut down before a second compressor is unloaded. On the other hand, the partial load requirements of a centrifugal compressor, as shown in Figure 7.9 make it more economical to operate two compressors at equal partial load than one compressor at full load and the second at low load. For example, it is more economical to operate two centrifugal compressors at 80 percent of capacity than one at 100 percent and the second at 60 percent.

The same approach can be used in the assignment of refrigeration machines to cooling equipment. It is important that the capacity of the refrigeration machine match the capacity of the cooling unit(s) it serves. Therefore, in a system of multiple refrigeration machines and cooling units, care must be taken to assign the refrigeration machines to the cooling units correctly.

Where two or more refrigeration machines supply separate chilled water systems and are located in close proximity to each other, interconnection of the chilled water systems can be considered. With this modification, during periods of light loads one machine may be able to carry the load for more than one system.

The following example illustrates the savings from operating two compressors equally loaded, based on five months per year operation. One centrifugal compressor rated at 1,000 tons, 750 kilowatts, and 85ºF entering condenser water temperature is operating at a 900-ton load and 75ºF entering condenser water. A second 1,000-ton compressor is not running.

From Figure 7.9 you can see the percent of full-load power at 75ºF entering condenser water is:

At 90 percent design load, 84.0 percent
At 45 percent design load, 40.5 percent
Input kW at 900 tons = 750 kW x 84%
= 630
Input kW (two units at 450 tons each)
= 750 kW x 40.5% x 2 compressors
= 608
Savings = 22 kW
Annual Savings = 22 kW x 6,000 hrs/yr x 5 mos/12 x $0.05/kWh
= $2,750

Recover Heat

A majority of the time, heat rejected from a condenser can be recovered. The amount of heat rejected in the condenser is 12,000 Btu per hour plus the heat of compression (about 2,500 Btu/hr per ton), giving a total heat rejection of 14,500 Btu/hr per ton produced.

The use of a split condenser permits partial recovery of rejected heat. A split condenser uses two cooling water streams: a process stream that is preheated in the first condenser and cooling tower water for the second condenser. The preheating of a process stream reduces the heating load on the cooling tower.

This heat recovery scheme is applicable only if the plant can use a low temperature heat source.

In the following example, a mechanical compressor rated at 1,000 tons is operating five months a year at an average 600-ton load. The savings from recovering 50 percent of the rejected heat to preheat water now heated by a steam hot water heater are:

Heat Rejected = 600 tons x 14,500 Btu/ton-hr
= 8,700,000 Btu/hr
Annual Savings = 8,700,000 Btu/hr x 50% x 6,000 hrs/yr x 5 mos/12 x $4.24 / 106 Btu
= $46,100

Reduce Operation of Hot-Gas Bypass

On mechanical refrigeration machines, the primary elements for load controls are the suction damper, or vanes, and the hot-gas bypass which prevents compressor surge at low loads. The suction vanes are used to throttle refrigerant gas flow to the compressor within the area of stable compressor operation. As load or flow drops, where it approaches the compressor surge point, the hot-gas bypass is opened to maintain constant gas flow through the compressor. Below this load point for the hot-gas bypass, compressor flow, suction, and discharge conditions remain fairly constant, so that power consumption is nearly constant. Obviously, opening the hot-gas bypass too soon, or having a leaking hot-gas bypass valve, will increase operating cost (kilowatts per ton).

It is not uncommon to find the bypass controls taken out of service, with the bypass set to maintain a fixed opening and constantly recycle high-pressure refrigerant vapors to the suction side of the compressor. A second frequent deficiency occurs when the hot-gas bypass is faulty or grossly oversized and is leaking through. A third source of energy loss is faulty load control, which can cause improper operation of the hot-gas bypass valve.

Considerable energy can be saved and capacity recouped if the defective hot-gas bypass valves and their controls are corrected.

Optimize Refrigeration Performance

The most basic approach to reducing refrigeration costs is to ensure that the units are operating at maximum efficiency. To monitor performance, each refrigeration machine must have proper instrumentation. This instrumentation includes flowmeters for both the chilled water and the condenser water, pressure gauges at the inlet and outlet of both the condenser and evaporator, and temperature wells in both the inlet and outlet of the condenser and the evaporator. These temperature wells should be located in such a manner that a liquid can be placed in the well. The temperature measuring device used to test the equipment should read accurately to one-tenth of a degree.

7.4. INSULATION

Although generally not viewed as a part of the mechanical design system, insulation is an important part of every plant or building where any transfer of fluids or gases takes place and the their temperature is required to be different then that of ambient air. Properly insulated pipes, tanks and other equipment can save thousands of dollars.

7.4.1. Introduction

There are several opportunities in the industrial sector to realize energy savings by installing insulation in manufacturing facilities. Good insulation design and installation are very important in terms of performance and energy efficiency. It is essential to determine the most appropriate type and thickness of insulation for specific applications. The most cost-effective approaches involve insulating pipes and tanks. These opportunities are described in this section.

7.4.2. Typical Performance Improvements

Process Temperature (ºF)

Nominal Size (in)	Pipe	150	250	350	450	550	650	750	850	950	1050
1	Thickness	1	1.5	2	2.5	3.5	4	4	4.5	5	5.5
	Heat loss	11	21	30	41	49	61	79	96	114	135
	Surface Temp.	73	76	78	80	79	81	84	86	88	89
1.5	Thickness	1	2	2.5	3	4	4	4	5.5	5.5	6
	Heat loss	14	22	33	45	54	73	94	103	128	152
	Surface Temp.	73	74	77	79	79	82	86	84	88	90
2	Thickness	1.5	2	3	3.5	4	4	4	5.5	6	6
	Heat loss	13	25	24	47	61	81	105	114	137	168
	Surface Temp.	71	75	75	77	79	83	87	85	87	91
3	Thickness	1.5	2.5	3.5	5	4	4.5	4.5	6	6.5	7
	Heat loss	16	28	39	54	75	94	122	133	154	184
	Surface Temp.	72	74	75	77	81	83	87	86	87	90
4	Thickness	1.5	3	4	4	4	5	5.5	6	7	7.5
	Heat loss	19	29	42	63	88	102	126	152	174	206
	Surface Temp.	72	73	74	78	82	86	85	87	88	90

Nominal Size (in)	Pipe	150	250	350	450	550	650	750	850	950	1050
6	Thickness	2	3	4	4	4.5	5	5.5	6.5	7.5	8
	Heat loss	21	38	54	81	104	130	159	181	208	246
	Surface Temp.	71	74	75	79	82	84	87	88	89	91
8	Thickness	2	3.5	4	4	5	5	5.5	7	8	8.5
	Heat loss	26	42	65	97	116	155	189	204	234	277
	Surface Temp.	71	73	76	80	81	86	89	88	89	92

Table 7.2: Recommended Thickness for Pipe and Equipment Insulation

Steam and Hot Water

Description

Steam lines and hot water pipes should be insulated to prevent heat loss from the hot fluids. Recommended thickness for pipe insulation may be determined from the reference given below. The energy and cost savings depend on a number of things, such as the size of the pipe, the temperature of the fluid and the ambient, the efficiency of the heat supply, and the heat transfer coefficient.

Definitions

Heat Transfer Coefficient - A parameter used in determining heat loss.

Applicability

Facility Type - All facilities with uninsulated steam and hot water systems.
Climate - All.
Demand-Side Management Strategy - Strategic conservation.

For More Information

Kennedy, W. Jr., W.C. Turner, Energy Management, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1984, pp. 204-221.

1997 ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, 1997.

Steam Lines and Hot Water Pipes: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Steam Lines and Hot	2,087	948	3,201	0.7

Water Pipes				

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database. All values are averages based on the data base data. The implementation rate for this measure was 68%.
2. One example from the IAC data base to further clarify the costs is as follows: Insulating 500 ft of condensate return pipes located throughout a plant having a 300 MMBtu/hr steam boiler resulted in energy savings of 370 MMBtu/yr and a cost savings of $960/yr. The implementation cost was $1,920.
3. The energy cost savings are based on proposed dollar savings from the IAC report, usually almost identical to actual savings reported from the facility.

Cold Water

Description

Lines containing chilled water should be insulated to prevent condensation and frost buildup on the lines and to prevent heat gain. Condensation will occur whenever moist air comes into contact with a surface that is at a temperature lower than the dew point of the vapor. In addition, heat gained by uninsulated chilled water lines can adversely affect the efficiency of a cooling system.

Definitions

Chilled Water - Water that is cooled by a chiller. It is usually used for process cooling in industrial applications.

Applicability

Facility Type - All facilities having uninsulated chilled water lines.
Climate - All.
Demand-Side Management Strategy - Strategic conservation.

For More Information

Industrial Assessment Center (IAC). Contact the IAC nearest to your area.

Chilled Water Pipes: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Chilled Water Pipes	970	56	850	1.1

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database in 1994. Today the database does not have a separate category for Chilled Water Pipes. The implementation rate for this measure was 52%.
2. One example from the IAC database to further clarify the costs is as follows: Insulating 250 ft of cold pipe in a brewery resulted in energy savings of 3,500 kWh/yr and a cost savings of $234/yr. The implementation cost was $1,200.

3. The energy cost savings are based on actual dollar savings as reported to IAC from the facility.

7.4.3. Insulation of Tanks

Tanks, similar to pipes, should be properly insulated if their purpose is to hold media at certain temperatures, especially for prolonged periods of time.

Hot Media

Description

Often, tanks containing hot fluids in manufacturing operations lack adequate insulation. The tanks may be insulated with blanket type flexible insulation (1 in. thick, 1.5 lb density) or rigid insulation, depending on the type of tank. The savings would increase as the boiler efficiency decreases. The savings would also increase as the temperature in the tank increases.

Definitions

Condensate - The hot water that is the steam after it has cooled and consequently condensed.

Applicability

Facility Type - All facilities.

Climate - All.

Demand-Side Management Strategy - Strategic conservation.

Hot Tanks: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Hot Tanks	1,700	1,183	5,198	0.4

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database. All values are averages based on the data base data. The imp lementation rate for this measure was 44%.
2. The cost of insulation is typically around $\$0.50/ft^2$. One example from the IAC database to further clarify the costs is as follows: Insulating the manufacturing tanks in a food plant resulted in energy savings of 135 MMBtu/yr and cost savings of $470/yr. The implementation cost was $1,090. The tanks had a top area of 50 ft^2 and side areas of 175 ft^2 and contained fluids at temperatures between 150°F and 230°F. The tanks were located in a room at 70°F.
3. The energy cost savings are based on proposed dollar savings from the IAC report, usually almost identical to actual savings reported from the facility.

Cold Media

Description

Uninsulated tanks containing cold fluids are occasionally found in applications, such as chilled water tanks that are located in areas where there can be considerable heat gain through the tank surfaces. If the air surrounding the tank is at a higher temperature than that of the tank, heat will be transferred to the contents of the tank. By insulating these tanks, the heat transfer and load on the system will be reduced, resulting in significant energy savings.

Definitions

Coefficient of Performance (COP) - The ratio between thermal energy out of and electrical energy into the system.

Applicability

Facility Type - Any facility having uninsulated cold tanks and significant operating hours.
Climate - All.
Demand-Side Management Strategy - Strategic conservation.

For More Information

1989 ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA, 1989, Ch. 22.

Cold Tanks: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Cold Tanks	460	36	520	0.7

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database in 1994. Today the database does not have a separate category for Cold Tanks. All values are averages based on the data base data. The implementation rate for this measure was 54%.
2. One example from the IAC database to further clarify the costs is as follows: The energy savings on a refrigeration system having a COP of 2.0 and an uninsulated chilled water tank of 47 ft^2 at a temperature of 52°F in a room at 85°F would be over 2636 kWh/yr if the tank were insulated with 1 in. fiberglass.
3. The energy cost savings are based on actual dollar savings as reported to IAC from the facility.

7.4.4. Building Insulation

Any uninsulated surface (doors, walls, roofs) is a potential heat sink in buildings. The example in the following section can be extrapolated for basically any surface, R-values being the key in evaluating different types of insulation.

Dock Doors

Description

Uninsulated dock doors can be a source of significant heat loss in manufacturing facilities. The doors can often be insulated by installing styrofoam or fiberglass in the door panels. The savings depend on the size of the doors, the efficiency of the heating system, the R-values of the insulated and uninsulated doors, and the number of degree heating hours per year.

Definitions

Degree Heating Hours - A measure relating ambient temperature to heating energy required. If the outside temperature is 1 degree below the base temperature in the plant for 1 hour then that represents 1 degree heating hour.

R-Value - Measure of resistance to heat transfer in Btu/hr-ft2-°F.

Applicability

Facility Type - All facilities with overhead doors.

Climate - Any climate in which heating is required.

Demand-Side Management Strategy - Strategic conservation.

For More Information

1997 ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., Atlanta, GA.

Dock Doors: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Dock Doors	2,882	540	2,590	1.1

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database. All values are averages based on the data base data. The implementation rate for this measure was 52%.
2. One example from the IAC database to further clarify the costs is as follows: Installing insulation on an uninsulated dock door resulted in an energy savings of 459 MMBtu/yr, a cost savings of $2,157/yr, and an implementation cost of $3,700, giving a simple payback of 1.7 years.
3. The energy cost savings are based on proposed dollar savings from the IAC report, usually almost identical to actual savings reported from the facility.

7.4.5. Recommended Insulation Standards

Many insulating materials are not suitable for use in direct contact with austenitic stainless steel at or above 140ºF or with aluminum. If installed wicking type insulation materials become wet, the soluble ingredients leach out and deposit on the surface of the metal substrate. The deposited ingredients usually consist of sodium silicate (if insulation has been inhibited) and chlorides and alkalites.

The chlorides in these deposits can cause stress corrosion cracking of austenitic stainless steel at temperatures above 140ºF if there is not enough sodium silicate inhibitor to neutralize them.

Alkaline ingredients in insulation, when wet, can cause corrosion of unprotected aluminum substrate. Where aluminum substrate protection is required, fibrated asphalt cutback should be included in the installation cost.

Excess wetting with water or especially with acid solution can substantially reduce the service life of the inhibitor.

Wet insulation can corrode unprotected carbon steel pipe and equipment, especially during storage or shutdown periods.

Lowest Cost System

The lowest cost system recommended is based on both installed and continuing cost, consistent with reasonable safety and return on investment. In other words, the lowest cost thermal insulation system is one that will remain in place for the design life of the system and one that will provide the desired function. Most often, the options available might not be as trivial as one might suspect. Interruption of production must also be accounted for.

Economic Factors to be Considered in Basic Insulation Selection

<u>Glass Fiber</u>

Glass fiber insulation has the disadvantage of moisture absorption and low resistance to abuse. The continuing maintenance can offset any advantage of the initial cost.

<u>Calcium Silicate</u>

Calcium silicate and inhibited calcium silicate provide the lowest cost system in the temperature range between 300ºF and 1200ºF. They are also satisfactory down to 140ºF if polyisocyanurate foam is not suitable.

<u>Polyisocyanurate</u>

Polyisocyanurate foam is preferred to both glass fiber and calcium silicate for low temperature applications (140ºF to 300ºF). When compared with calcium silicate, polyisocyanurate has better moisture resistance which is particularly important for outdoor application. Material and installation costs are comparable with those for calcium silicate. Polyisocyanurate insulation is suitable over a temperature range of -100ºF to 300ºF and, therefore, is excellent for dual temperature applications.

<u>Mineral Wool</u>

Mineral wool provides the lowest cost system in the temperature range of 1200ºF to 1800ºF. This is true only if the metal surfaces to be insulated are not austenitic stainless steel and/or abuse resistance is not a factor.

Finish Factors Influencing Insulation Selection

Where allowed, the lowest initial-cost finish for pipe is kraft aluminum laminate. The finish is limited to dry, indoor, low-traffic areas, and may discolor with age. The lowest cost finish on a continuing basis for pipe and cylindrical sections of indoor or outdoor equipment, if chemical resistance is not an issue, is a smooth aluminum jacket fastened with stainless steel bands.

Reinforced mastic finishes should be used only over irregular shapes and where absolutely necessary.

Stainless steel pipe covering is recommended only in special situations where other finishes do not provide adequate protection.

7.4.6. Process Equipment

Insulating process equipment does not differ in principle from insulating tanks or pipes. The purpose is to maintain certain temperatures where required and minimize heat input to make up for heat transfer losses.

Injection Mold Barrels

Description

The barrels on injection molding machines are heated to a very high temperature so that the plastic will flow into the mold. The heat loss from the barrels contributes to the air conditioning load in the plant as well as increasing the energy required to keep the barrels hot. Rock wool blanket insulation is made specifically for this purpose and is easily removed if maintenance on the barrels is required. This measure is not recommended when ABS or PVC plastics are being molded because the shear forces generate so much heat that cooling is required.

Definitions

Barrels - The portion of an injection molding machine through which the molten plastic is forced by the piston.

Applicability

Facility Type - Any injection molding facility.

Climate - All.

Demand-Side Management Strategy - Strategic conservation.

Insulate Equipment: Costs and Benefits[1]

Options	Installed Costs ($)[2]	Energy Savings (MMBtu/yr)	Cost Savings ($/yr)[3]	Simple Payback (yr)
Injection Mold	2,435	695	3,621	0.7

Barrels

1. Tabulated data were taken from the Industrial Assessment Center (IAC) database. All values are averages based on the data base data. The implementation rate for this measure was 46%.
2. One example from the IAC database to further clarify the costs is as follows: Insulating injection mold barrels resulted in an energy savings of 375 MMBtu/yr, a cost savings of $2,589, and an implementation cost of $2,028, giving a simple payback of ten months.
3. The energy cost savings are based on proposed dollar savings from the IAC report, usually almost identical to actual savings reported from the facility.

REFERENCES

1. Handisyde, C.C., and Melluish, D.J., *Thermal Insulation of Buildings*, HMSO, 1971
2. Malloy, J.F., *Thermal Insulation*, Van Nostrand Reinhold, 1969
3. The Association of Energy Engineers, *Corporate Energy Management Manual*, The Fairmont Press, 1979
4. Thumann A., and Mehta D.P., *Handbook of Energy Engineering*, The Fairmont Press, 1992

8 HVAC

8.1. AIR CONDITIONING

Air conditioning controls the working environment in order to maintain temperature and humidity levels within limits defined by the activity carried out at the location. The environment can be maintained for people, process or storage of goods (food is just one example). An air conditioning system has to handle a large variety of energy inputs and outputs in and out of the building where it is used. The efficiency of the system is essential to maintain proper energy balance. If that is not the case, the cost of operating an air conditioning system will escalate. The system will operate properly if well maintained and operated (assumption was that it was properly designed in the first place, however, should sizing be a problem, even a relatively costly redesign might prove financially beneficial in a long run).

Air conditioning is the process of treating air to control its temperature, humidity, cleanliness, and distribution to meet the requirements of the conditioned space. If the primary function of the system is to satisfy the comfort requirements of the occupants of the conditioned space, the process is referred to as comfort air conditioning. If the primary function is other than comfort, it is identified as process air conditioning. The term ventilation is applied to processes that supply air to or remove air from a space by natural or mechanical means. Such air may or may not be conditioned.

8.1.1. Equipment

Air conditioning systems utilize various types of equipment, arranged in a specific order, so that space conditions can be maintained. Basic components consist of:

- A fan to move air.
- Coils to heat and/or cool the air.
- Filters to clean the air.
- Humidifiers to add moisture to the air.
- Controls to maintain space conditions automatically.
- A distribution system to channel the air to desired locations, including dampers to control the volume of air circulated, as shown in Figure 8.1.

Within each basic component there are different types and styles, each with their own operating characteristics and efficiency, method and materials of construction, and cost, all of which greatly affect the initial design and resulting operating economics of the system. While this manual is directed principally to conservation with existing installations, ideally energy conservation should start during the initial design and equipment-selection stages of the system.

Fans

The centrifugal fan with a backward-curved impeller is the predominant fan used in “built-up” type air conditioning units, while the forward-curved impeller centrifugal fan is used in “package” type air handling units.

Coils

Coils are used in air conditioning systems either to heat or cool the air. The typical coil consists of various rows of deep finned tubing. The number of fins per inch varies from 3 to 14. The greater the number of fins per inch and depth of the row, the greater its heat transfer rate will be. An increase in heat transfer surface results in an increase in heat transfer efficiency and also an increase in airflow resistance all of which will increase fan horsepower.

Heating coils " will use either steam or hot water as a heating medium. The primary purpose of the coil depends upon its location in the air handling system. A preheater is the name given to a coil located in the makeup outdoor air duct. The preheater’s purpose is to raise the temperature of makeup air to above freezing. The heating coil doing the final heating of the air before it enters the conditioned space is referred to as a reheater. Its purpose is to maintain satisfactory space temperature by adding heat to the supply air when it is required.

The general purpose of cooling coils " is to cool the air. The cooling medium used is typically chilled water, brine, or refrigerant in a direct expansion-type coil. Direct expansion-type coils are used on small systems when a chilled-water system is not economical. Chilled water is used on all other systems when the air temperature required is above 50ºF. When the air temperature required is less than 50ºF, a brine solution is used as the cooling medium because of its exposure to subfreezing temperatures in the refrigeration machine.

Air Washers

A spray-type air washer consists of a chamber or casing containing a spray nozzle system, a tank for collecting the spray water, and an eliminator section at the discharge end for removal of entrained drops of water from the air. An air washer can be used either to humidify or dehumidify the treated air depending upon the temperature of the spray water. Air washers will also do some cleaning of the air. The efficiency of an air washer can be increased by increasing the volume of circulated spray water. When spray water is used for humidification purposes, it is recirculated with only sufficient makeup to satisfy evaporative losses. When spray water is used for cooling, it is most often mixed with chilled water. The amount of chilled water is controlled to provide desired results.

The use of air washers in the comfort air conditioning field has been gradually replaced by the use of cooling coils. Some industrial air conditioning systems, particularly in the textile industry, still use air washers.

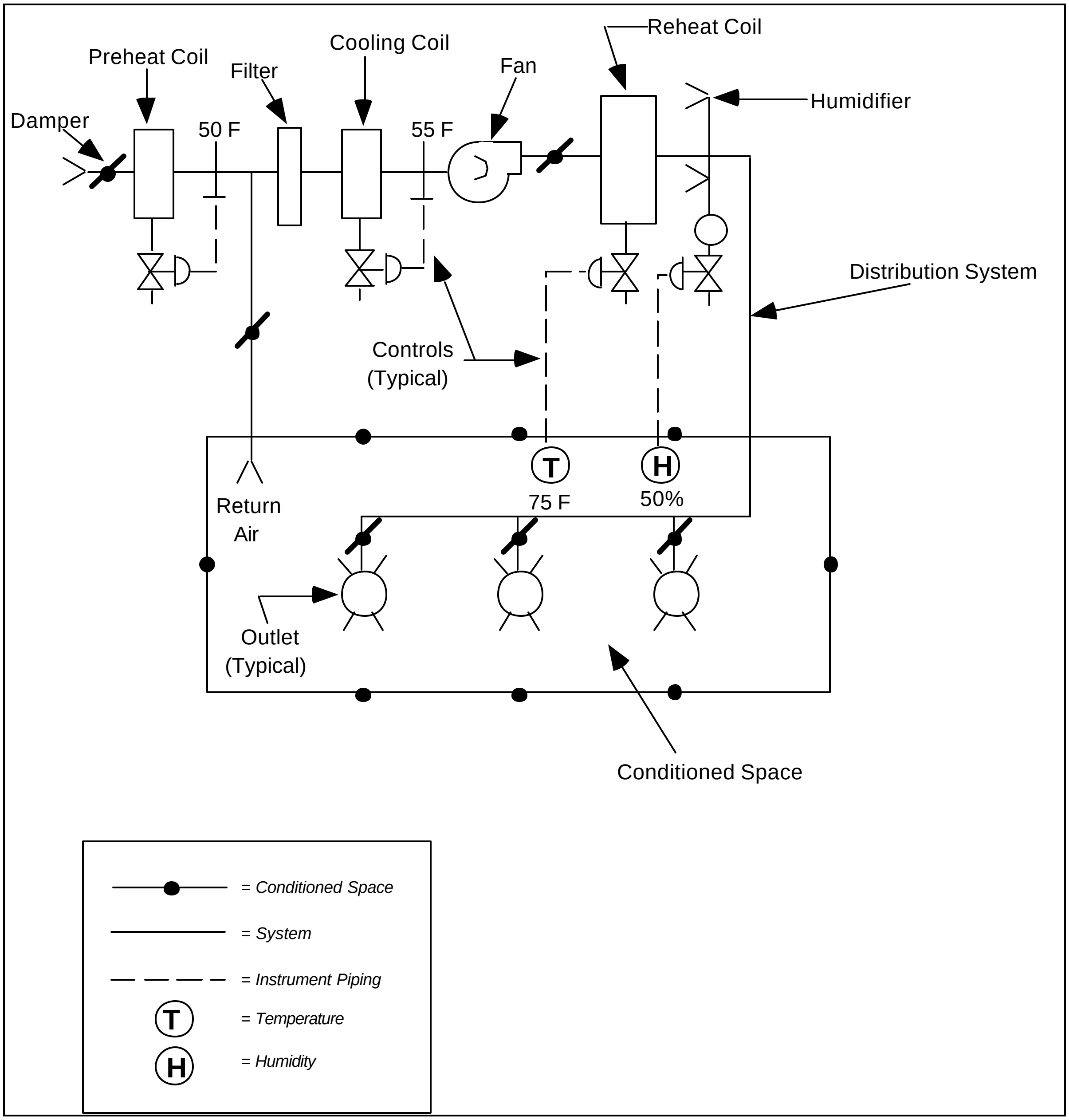


Figure 8.1: Air Conditioning Equipment

Air Cleaners

Air cleaners (filters) are used to reduce the dirt content of the air supplied to the conditioned space and to keep equipment clean. The type of air cleaning equipment required depends upon the requirements of the conditioned space, the amount of dirt to be removed from the airstream, and the size of the dirt particles to be removed. The smaller the particle size, the harder and more expensive the air cleaning job.

The three operating characteristics that distinguish the various types of air cleaners are efficiency, airflow resistance, and life or dust-holding capacity. Efficiency measures the ability of the air cleaner to remove particulate matter from an airstream. The interpolation of air cleaner ratings for efficiency and holding capacity is complicated by the fact that there are three types of tests, along with certain variations, employed for testing filters. The operating conditions that exist are so varied that there is no individual test that will adequately describe all filters.

Air cleaners used in the comfort air conditioning field fall into three broad categories: fibrous media, renewable media, and electronic. Various combinations of these types can be used. Air cleaners for industrial applications fall into five basic types: gravity and momentum collectors, centrifugal collectors, fabric collectors, electrostatic precipitators, and wet collectors.

The installation cost and the operating cost of an air cleaning system vary over a wide range. Therefore, an economical installation is one in which the air cleaning unit(s) provides only the degree of cleaning required to satisfy the conditioned space.

The pressure drop associated with the air cleaning devices varies from a low of 0.1 inch of water gage (inches W.G.) to 10.0 inches W.G. In comfort air conditioning, generally, the higher the air cleaner efficiency, the higher its pressure drop will be. Fan horsepower is required to overcome pressure drop.

Humidifiers

Humidifiers are devices that add moisture to the airstream, thereby raising the relative humidity of the conditioned space. In most comfort air conditioning systems and in many industrial air conditioning systems, humidifying devices are commonly sparging steam or atomizing water directly into the airstream.

Since the advent of energy conservation, the standards for comfort air conditioning systems have been reviewed and revised. One of the revisions eliminates the humidity control as a comfort air conditioning system standard, since controlling humidity requires additional energy year-round. In industrial air conditioning systems where humidity control is a factor, it is recommended that this need be reviewed and be reduced to the lowest degree the process will permit.

Controls

The control system of an air conditioning system contains various loops which automatically control select functions of the air conditioning system operation. The control system can be very simple or very complex depending upon the size and complexity of the air conditioning system, the extent of operation, and the degree of sophistication desired.

Control systems can control temperature, humidity, duct pressure, airflow, sound alarms, and provide data to remote locations. These systems are operated either pneumatically or electronically, or a combination of both. For the most economical operation of the air conditioning system, controls must be maintained. Their calibrations should be routinely checked along with the proper operation of valves and dampers.

Distribution System

A duct network comprises the distribution system, transporting the air between the conditioning equipment and the conditioned space(s). The system consists of outlet and inlet terminals (diffusers, registers, grilles) for distribution of air within the conditioned space, and dampers (automatic and manual) for control of air volume. The design of the distribution system greatly affects the amount of pressure drop (resistance) it adds to the total system. Low-pressure (low-velocity) systems are designed with duct velocities of 1,300 fpm or less for comfort air conditioning systems and up to 2,000 fpm for industrial air conditioning systems. High-pressure (high-velocity) systems employ duct velocities from 2,500 fpm on small systems (1,000 to 3,000 cfm) up to 6,000 fpm on large systems (40,000 to 60,000 cfm). Higher duct velocities result in higher duct system resistance (pressure drop) which results in increased fan horsepower.

8.1.2. Psychrometry

Psychrometry deals with the determination of the thermodynamic properties of moist air and the utilization of these properties in the analysis of conditions and processes involving moist air. Air conditioning deals with changing the properties of air to provide desired results in the conditioned space. The psychrometric chart, a graphical representation of the thermodynamic properties of moist air, is an invaluable aid in illustrating and solving air conditioning problems.

Since the properties of moist air are affected by barometric pressure, corrections must be made when installation is done at other than sea level (29.92 inches Hg). Psychrometric charts are available for elevations at sea level, 2,500 feet, 5,000 feet, 7,500 feet, and 10,000 feet. Also, charts are available for different temperature ranges. The properties of moist air shown on a psychrometric chart are:

- Dry bulb (DB) temperature
- Wet bulb (WB) temperature

- Dew point temperature (DP)
- Relative humidity (RH) in percent
- Specific humidity (W) in grains per pound
- Specific enthalpy (h) in Btu per pound
- Specific volume (V) in cubic feet per pound.

A description of these terms is listed under the Terminology section.

8.1.3. Computation

The following formulae and factors are used in the air conditioning field:

$$\text{Btu} = (\text{lbs})\ (\text{sp. heat})\ (\Delta t)$$

$$\text{Btu/hr} = (\text{lbs/hr})\ (\text{sp. heat})\ (\Delta t)$$

$$\text{Btu/hr} = (\text{lbs/hr})\ (h_g - h_f)^*$$

$$\text{Lbs/hr}_{\text{std. air}} = (\text{cfm})\ (\text{lbs/cf})\ (60\ \text{min/hr})$$
$$= (\text{cfm})\ (0.075)\ (60)$$
$$= (\text{cfm})\ (4.5)$$

$$\text{SH, Btu/hr}_{\text{std. air}} = (\text{lbs/hr})\ (\text{sp. heat})\ (\Delta t)$$
$$= (\text{cfm})\ (4.5)\ (0.24)\ (\Delta t)$$
$$= (\text{cfm})\ (1.08)\ (\Delta t)$$

$$\text{cfm} = \text{SH} / [(1.08)(\text{room temperature} - \text{supplied air temperature})]$$

$$\text{LH, Btu/hr}_{\text{std. air}} = (\text{lbs/hr})\ (h_g - h_f)\ (\text{grains of moisture diff./7,000 grains/lb})$$
$$= (\text{cfm})\ (4.5)\ (1{,}054)\ (\text{grains diff./7,000})$$
$$= (\text{cfm})\ (0.68)\ (\text{grains diff.})$$

$$\text{Lbs/hr}_{\text{water}} = (\text{gpm})\ (\text{lbs/gal})\ (\text{min/hr})$$
$$= (\text{gpm})\ (8.33)\ (60)$$
$$= (\text{gpm})\ (500)$$

$$\text{hp}_{\text{air}} = [(\text{cfm})(\Delta P)] / [(6{,}350)(\text{fan efficiency})]$$

$$\text{hp}_{\text{water}} = [(\text{gpm})(\Delta P)] / [(3{,}960)(\text{pump efficiency})]$$

where

Δt = temperature difference

ΔP = pressure difference

* $(h_g - h_f)$ = 1,054 Btu/lb represents the heat of vaporization at 70°F. Variation in value for different conditions will be small.

8.1.4. Energy Conservation

The potential for energy conservation in the air conditioning field can vary greatly depending upon the following:

1. Design of systems
2. Method of operation
3. Operating standards
4. Maintenance of control systems
5. Monitoring of system
6. Competence of operators

The techniques to optimize the energy requirements of air conditioning systems are discussed under the following headings:

1. Operate systems only when needed.
2. Eliminate overcooling and overheating.
3. Eliminate reheat.
4. Minimize mechanical cooling and heating.
5. Minimize amounts of makeup and exhaust air.
6. Minimize the amount of air delivered to a conditioned space.
7. Recover energy.
8. Maintain equipment.

Examples of various energy-saving methods used in the following discussion are based on a facility having the following characteristics:

1. Supply fan capacity : 10,000 cfm @ 3,0 in S.P., 6.8 bhp
2. Outdoor air : 30% = 3,000 cfm
3. Return air : 70% = 7,000 cfm
4. Room temperature : 75ºF DB, 62.5ºF WB, 55.0ºF DP, 50% RH
5. Room loads : summer = 108,000 Btu/hr/(sensible heat)
   : winter = 216,000 Btu/hr/(sensible heat)
6. Space, volume : 55,000 cu. ft.
7. Space, area : 5,500 sq. ft.
8. Space, cfm/sq. ft. : 1.8
9. Space, supply air temp. : summer design = 65ºF,
   : winter design = 95ºF
10. Design preheater load : 162,000 Btu/hr = 169 lbs/hr (based on 50ºF disc. temp.)
11. Design on cooling coil load : 364,500 Btu/hr = 30 tons
12. Design outdoor temp. : summer = 95ºF DB, 78ºF WB; winter 0ºF
13. Design outdoor

degree days : 5,220 (65ºF), 3,100 (55ºF), 2,100 (50ºF)

14. Design outdoor avg. winter temp. : 41.4ºF (Oct. to Apr. inclusive)
    < 67.0ºF, 3,052 hrs/yr
    38.0ºF = Avg. < 50ºF, 3,543 hrs/yr
    33.0ºF = Avg. < 40ºF, 2,162 hrs/yr
15. Equiv. hrs/season refrig. at full load : 750 hrs

Operate Systems Only When Needed

Air conditioning systems, including refrigeration machines, pumps, and cooling tower systems, should be operated only when areas are occupied (for comfort air conditioning systems) and when processes are operating (for noncomfort air conditioning system). It is not uncommon for systems to operate continuously. Reducing operating hours will reduce electrical, cooling, and heating requirements. Continuous operation during normal working hours of 8 a.m. to 5 p.m., five day per week, such as that for an office building is a good example of excessive operation of equipment.

§ *Example One*

Find the savings by reducing operating hours from 168 hours per week to 50 hours per week

Savings from Reduced Fan Operation

= (Supply fan bhp) (Cost, $/hp-yr) [(hrs/wk shut off) / (hrs/wk current operation)]
= (6.8) ($360) [(168 - 50) / (168)] = $1,720/yr

Savings from Reduced Space Heating Operating

= {[(24)(deg day)(design htg. load, Btu/hr)] / [room T - outside T]}(stm. cost, $/MM-Btu)
x{(hrs/week off) / (hrs/week current on)}(allowance for heat up)
= {[(24)(5,220)(216,000)] / [(75 - 0)]}{$4.24 / 106}{(168 - 50) / 168}(0.5) = $537/yr

Savings from Reduced Preheater Operation of Outdoor Air

= (cfm) (1.08)* (design disc. temp. - avg. temp. < disc. temp.)
x (hrs/yr temp. < disc. temp.) x (stm. cost, $/MM-Btu)
x {(hrs/week off) / (hrs/week current operation)}
= (3,000) (1.08) (50 - 38) (3,543) {$4.24 / 106}{(168 - 50) / 168} = $410/yr

* Factor of 1.08 = 0.075 lbs/cu. ft. x 0.24 sp. heat x 60 min/hr

Savings from Reduced Cooling Operation

= (design cooling oil load, tons) (equiv. hrs/season @ full load)
x (refrig. sys. load, hp/ton) {(hrs/week off) / (hrs/week current operation)}
x (cost, \$/hp-hr) (allowance for cool down)
= (30) (750) (1.25){(168 - 50) / 168}(\$0.041) (0.75) = \$607/yr

Summary of Total Annual Savings

Fans	=	\$1,720
Space heating	=	537
Preheater	=	410
Space cooling	=	607
Total	=	\$3,274

Eliminate Overcooling and Overheating

Eliminating overcooling and overheating normally requires revising operating standards and modifying air conditioning system controls. Instead of maintaining a constant temperature, the more energy efficient method is to allow the temperature to fluctuate within a dead-band range. Heating should be used only to keep the temperature of the conditioned space from going typically below 68ºF to 70ºF and cooling should be used only to keep the temperature from exceeding 78ºF to 80ºF. These conditions apply only during normal hours of occupancy. During unoccupied periods, the standard should specify minimum conditions necessary to protect the building's contents. Process requirements may, of course, dictate maintaining special conditions. Figure 8.1 shows a single zone system with a simple control system which results in overcooling and overheating. Figure 8.2 shows this system with a modified control system which would eliminate simultaneous cooling and heating.

§ *Example Two*

The cooling coil and reheat coil are controlled as shown in Figure 8.1. Find the savings during the heating season if the coils were controlled in sequence as shown in Figure 8.2. Assume that the mixed air temperature entering the cooling coil is 68ºF, and the heating season is seven months long.
Savings from Eliminating Excessive Cooling

= {[(cfm)(1.08)(temp. diff.)] / [Btu/hr-ton]}(hp/ton) (\$/hp-yr) (htg. season, mos./12)
= {[(10,000)(1.08)(68 - 50)] / [12,000]}(1.25) (\$360)(7/12) = \$2,835/yr

Total Annual Savings

Cooling	=	$3070
Reheating	=	2,835
Total	=	$5,905

§ *Example Three*

Find the savings resulting from changing the room thermostat setting from 75ºF to 68ºF during the heating season--only if it saves energy. Given:

1. Room heating load at 75ºF = 216,000 Btu/hr
2. Room heating load at 68ºF = (216,000)(68/75) = 195,800 Btu/hr

Annual Cost
= {[(24)(deg day)(design htg. load, Btu/hr)] / [room T - outside T]}(stm. cost, $/MM-Btu)
Annual Cost75ºF
= {[(24)(5,220)(216,000)] / [(75 - 0)]}{$4.24 / 106} = $1,530
Annual Cost68ºF
= (annual cost at 75ºF) [(68ºF - winter average temp.) / (75ºF - summer average temp.)]
= ($1,530)[(68 - 41.4) / (75 - 41.4)] = $1,210

Note: Difference in cost is proportional to temperature difference maintained with ambient temperature

Total Annual Savings = $1,530 - $1,210 = $320

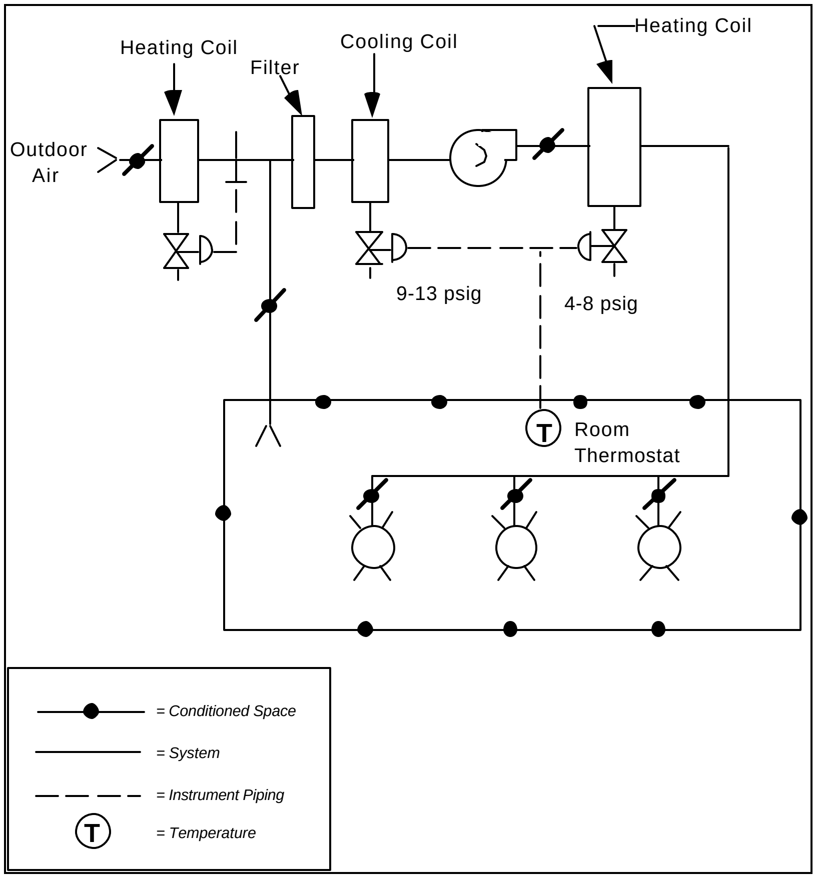


Figure 8.2: Modified Air Conditioning System Controls

Eliminate Reheat

When humidity control is required, the conventional method is to cool the air to the required dew point temperature to remove the excess moisture and then reheat the air to deliver it at the desired humidity and temperature (see Figure 8.2). The cost of reheat for humidity control is not considered justified in today's energy situation for comfort air conditioning systems.

Setting standards for humidity levels is not recommended for normal air conditioning comfort and should be discontinued. Likewise, no system should operate in a manner that requires it to heat and cool at the same time. At any given instant the system should be either heating or cooling--never both.

The process of cooling and then reheating is inefficient, whether for humidity control or because of system design.

Economizer Cycle

Many air conditioning systems operate with a fixed minimum amount of outdoor air. The mechanical refrigeration load on these systems can be reduced by modifying the system to utilize outdoor air--up to 100 percent of its supply airflow--when outdoor air is cooler than return air. This is referred to as an economizer cycle. Many systems do not have an economizer cycle and fail to take advantage of its potential savings.

An economizer cycle will eliminate or reduce mechanical cooling when the outdoor air is cooler than return air. When outdoor air is warmer than return air conditions, only the minimum amount of outdoor air is used.

The switchover point of an economizer cycle is usually done by one of two methods--sense outdoor dry bulb (DB) temperature or sense outdoor and return air enthalpy (heat content). Figure 8.3, Figure 8.4 (dry bulb method), and Figure 8.5 illustrate the two methods of economizer control.

In the outdoor DB temperature switchover method, when the outdoor DB temperature is above the set point temperature, the dampers are in their normal position--the outdoor damper is closed and the return air damper is fully open. When the outdoor DB temperature is less than the set point temperature, the dampers are modulated by the temperature controller.

In the enthalpy switchover method, the enthalpy controller senses the dry bulb temperature and relative humidity in both the outdoor air and return airstreams. It then feeds these values into an enthalpy logic center. The logic center compares the enthalpy (heat content) of each airstream and allows outdoor air to be used whenever its enthalpy is less than that of the return air.

When the outdoor enthalpy is greater than the enthalpy of the return air, the dampers are maintained in their normal position--the same manner as the outdoor temperature switchover method. When the outdoor enthalpy is less than the enthalpy of the return air, the dampers are also modulated by the temperature controller.

The enthalpy switchover method is more efficient because it is based on the true heat content of the air. The enthalpy of air is a function of both the DB temperature and its relative humidity (or wet bulb temperature). Therefore, DB temperature alone is not a true measure of the air's heat content. Under certain conditions, air with a higher DB temperature can have a lower enthalpy than air with a lower DB temperature because of differences in humidity. The outdoor DB temperature switchover method utilizes a single conservative DB temperature between 55ºF to 60ºF, which ensures the enthalpy of the outdoor air is always less than the enthalpy of the return air. On the other hand, since the enthalpy switchover method determines the use of outdoor air on its enthalpy, the switchover point will vary and normally occur at a higher outdoor DB temperature than the DB temperature typically selected for the outdoor DB switchover method. Consequently, less mechanical cooling is required than with the outdoor DB temperature switchover method.

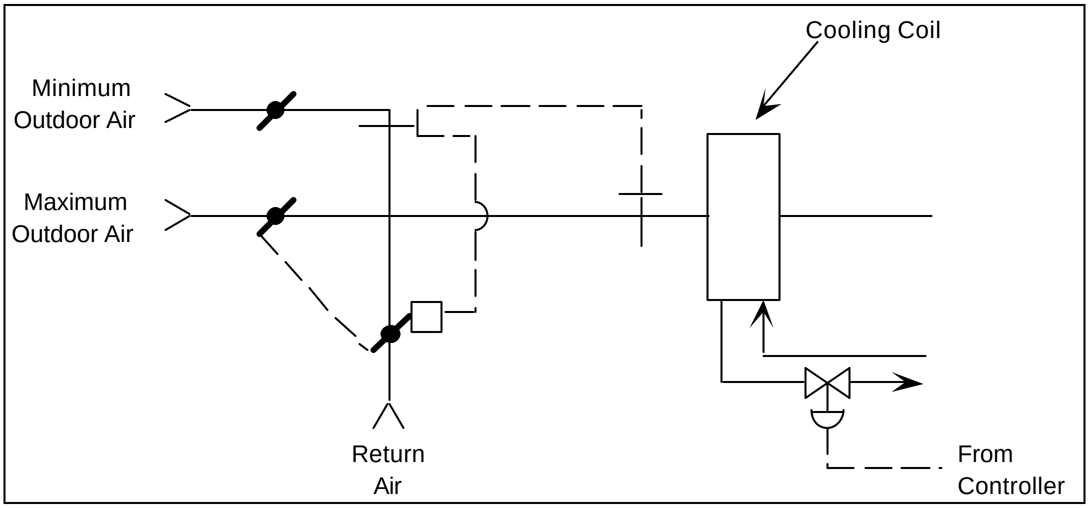


Figure 8.3: Economizer Cycle (Outdoor Temp. Switchover, Mixing Temp. Control)

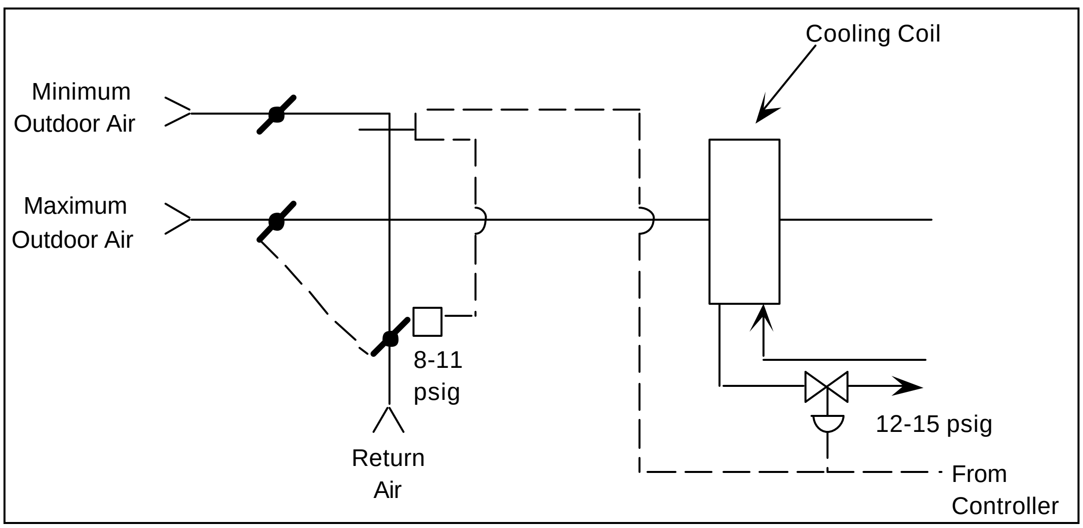


Figure 8.4: Economizer Cycle (Outdoor Temp. Switchover, Chilled H_2O Control)

In the method shown in Figure 8.3, which is found in many installations, the makeup air and return air dampers are controlled to maintain a fixed mixed air temperature. In Figure 8.4 the control system that operates the chilled-water valve also operates the makeup air and return air dampers in sequence with the chilled-water valve. The method illustrated in Figure 8.4 is better because it results in a lower load on the cooling coil.

The preferred method, however, is shown in Figure 8.5, which utilizes enthalpy control for switchover.

The savings resulting from an economizer cycle vary with the type of economizer cycle control and the type of air conditioning system control. Savings for different conditions are given in the examples shown below.

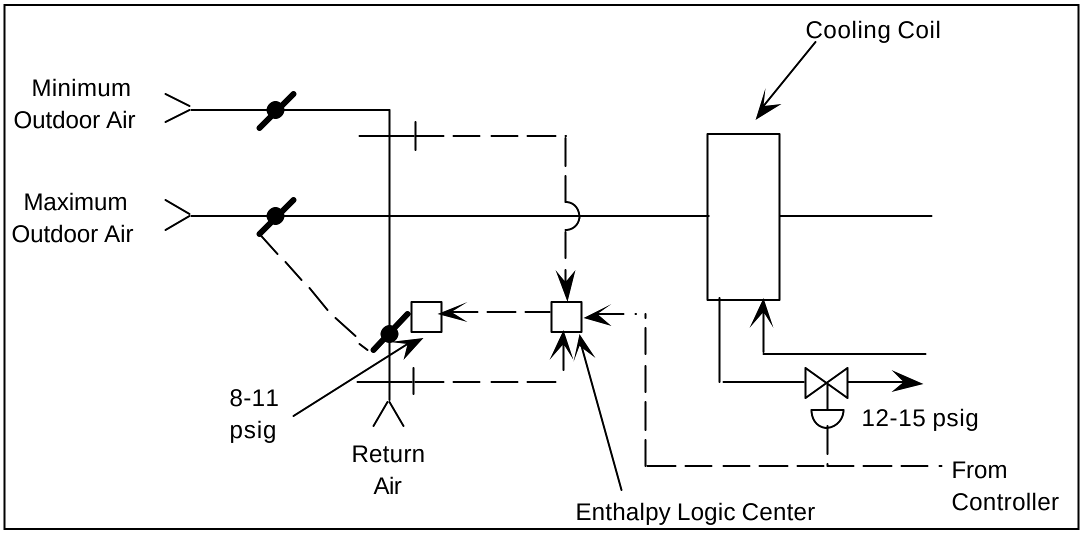


Figure 8.5: Economizer Cycle (Enthalpy Switchover, Chilled H2O Control)

§ *Example Four*

Condition A--Outdoor Temperature Method

Find the savings resulting from an economizer cycle with outdoor temperature switchover at 56.5ºF on a year-round air conditioning system (continuously operating). The preheater discharge temperature is controlled at 40ºF. Savings are determined in two steps.

1. Economizer savings when the outdoor temperature is < 40ºF. The temperature of the air entering the cooling coil when the outdoor air is less than 40ºF is 64.5ºF*.

   = {[(cfm)(1.08)(temp. diff.)] / [Btu/ton]}(hp/ton) cost, $/hp-yr)
   x {(hrs temp < 40ºF) / (8,760)}
   = {[(10,000)(1.08)(64.5 - 56.5)] / [12,000]}(1.25) ($360)(2,162/8,760) = $800/yr
2. Economizer savings when the outdoor temperature is between 40ºF and 56.5ºF. (Above 56.5ºF only minimum 30% outdoor air is used.) The average temperature of air entering the cooling coil is approximately 67ºF*, which represents the midpoint between the maximum and the minimum temperature that would occur.

   = {[(10,000)(1.08)(67* - 56.5)] / [12,000]}{(1.25) ($360)[(3,052)/(8,760) = $1,400/yr

		Max	Min
Outdoor temp.	=	56.5ºF	40.0ºF
30% outdoor air	=	17.0	12.0

70% return air @ 75ºF	=	52.5	52.5
Avg. temp.	=	69.5	64.5

Average = (69.5ºF + 64.5ºF) / 2 = 67ºF

Annual Savings for Condition A

Outdoor temp. < 40ºF	= $ 800
Outdoor temp. between 40ºF and 56.6ºF	= 1,400
Total	$2,280

*Temperature of air entering coil.

Condition B-- Enthalpy switchover Method

Given the same conditions as the previous example, Condition A, find the savings from an economizer cycle using the enthalpy method. To determine either the enthalpy, the wet bulb (WB) temperature or dry bulb temperature (DB) and relative humidity are needed. The enthalpy value for the particular condition can be read from a psychrometric chart.

For this example, an average outdoor relative humidity of 50 percent at 56.5ºF is assumed, which corresponds to 47.5ºF WB temperature. The actual additional reduction in cooling load over the outdoor temperature method will depend on the outdoor air conditions at the time. The reduction can vary over the range from no reduction when conditions approach 62.5ºF WB to a maximum reduction when approaching 47.5ºF WB. For practical purposes it can assumed an average reduction of approximately one half of the maximum.

The cooling load when all return air is used is:

Btu/hr = (ret. air cfm) (4.5) ($h_{ret.\ air}$ - $h_{cooling\ air\ disc.}$)

= (7,000) (4.5) (28.2 - 19.0)

= 289,000 or 24.15 tons

The cooling load when all outdoor air is used is zero.

Therefore, the average reduction in cooling load using outdoor air with the enthalpy switchover method is:

Reduction cooling load = 289,800 / 2 = 144,900 Btu/hr

Enthalpy remains constant for any given WB temperature irrespective of DB temperatures. Accordingly, the number of hours for which a given enthalpy existed can be obtained from local weather records of WB temperatures. For this example, the outdoor WB temperature was between 47.5ºF WB and 62.5ºF WB for approximately 2,000 hours per year.

Additional annual savings using enthalpy control:

= [(Btu/hr saved) / (Btu/ton)](refrig., hp/ton)(cost, \$/hp-yr)[(hrs. applicable) / (8,760) = [(144,900) / (12,000)](1.25)(\$360)[(2,000) / (8,760)] = \$1,240/yr

Total annual savings for the enthalpy switchover method over no economizer cycle include the above savings plus the savings for the DB switchover outdoor temperature method in the previous example.

Outdoor temperature method	=	\$2,280
Additional savings with enthalpy method	=	1,240
Total	=	\$3,520

Minimize Amounts of Makeup and Exhaust Air

The amount of makeup air a system must have depends upon the largest demand caused by the following:

1. Ventilation for people
2. Satisfaction of exhaust air
3. Overcoming infiltration

In many systems, the sum of items No. 2 and 3 dictates the amount of makeup air required. When this is the case, the amount of air being exhausted should be reviewed to determine if it is excessive. Minimizing infiltration requires that all openings between conditioned and nonconditioned spaces be closed and that doors and windows fit tightly. The ventilation rate for people can vary between 5 to 20 cfm and sometimes higher depending on the use of the room.

Also, excessive damper leakage can result in an excessive amount of makeup air.

§ *Example Five*

Excess makeup air in the winter will result in additional heating load. Find the cost to preheat 1,000 cfm of outdoor air to 50ºF.

Cost = (cfm) (1.08) (50ºF - avg. temp. < 50) (hrs./yr. temp < 50ºF)
x (stm. cost, \$/MM-Btu)
= (1, 000) (1.08) (50 - 38) (3,543) (\$4.26 x 10^{-6}) = \$194/yr.

Excess make-up air in the summer will result in additional cooling load. The cost of cooling is estimated to be $410/yr.
Total annual savings = $194 + $410 = $604

Minimize the Amount of Air Delivered to a Conditioned Space

The amount of air delivered to a conditioned space is governed by one or more of the following:

1. Heating and/or cooling load
2. Delivery temperature
3. Ventilation requirements (exhaust, people, infiltration)
4. Air circulation (air changes)

The design of both comfort and many industrial air condition systems requires that, for good air circulation, the amount of supply air should provide an air change every 5 to 10 minutes. Many systems are designed for a 6- to 7-minute change. Reducing airflow will reduce fan horsepower. The model that has been used requires heat, and the air change is 5.6 minutes (1.8 cfm per square foot, 10-foot high ceiling).

The method used in reducing the system's airflow has a great influence on the amount of horsepower saved. Three methods normally used are:

1. Fan discharge damper
2. Fan vortex damper (fan inlet)
3. Fan speed change

§ *Example Six*

Find the savings resulting from reduced reheat and fan horsepower on a year-round air conditioning system when the airflow is reduced from 1.8 cfm per square foot (5.6 minute air change) to 1.1 cfm per square foot (9.1 minute air change).

1. Find the new airflow
   cfm_2 = (cfm)[(air $change_2$) / (air $change_1$)] = 10,000 (1.1/1.8) = 6,110
2. Find the new supply temperature:
   Supplied air inlet temp. = room temp. - [(given room sensible load, Btu/hr]) / [(1.08)(cfm)]
   = 75 - [(108,000) / (1.08 x 6,110)] = 58.6ºF
3. Find the savings from reheat reduction:
   $Cost_{(1.8)}$ = (cfm) (1.08) (T_2 - T_1) (cost, $/MM-Btu/hr-yr)

= (10,000) (1.08) (65 - 56.5) [($37,100) x 10-6] = $3,410/yr

$Cost_{(1.1)}$ = (6,110) (1.08) (58.6 - 56.5) [($37,100) x 10-6] = $514/yr

Annual Savings (Reheat Reduction) = $3,410 - $514 = $2,900

4. Find the cfm reduction (in percent):

cfm reduction = [(cfm_2) / (cfm_1)] (100) = [(6,110) / (10,000)] (100) = 61%

5. Find the savings from fan horsepower reduction:

Method of Reduction	hp Red.* %	Initial hp	Saved hp	Cost $/hp-yr	Savings** $/yr
Outlet Damper	14.2	6.8	0.97	360	349
Inlet Vane Damper	45.0	6.8	3.06	360	1,100
Fan Speed	63.8	6.8	4.34	360	1,560

*From Figure 8.6

**Based on continuous operation

6. Find the total savings:

Method	$ Savings Fan hp	Reheat		Total
Outlet Damper	$349/yr	$2,900/yr	=	$3,249/yr
Inlet Vane Damper	$1,100/yr	$2,900/yr	=	$4,000/yr
Fan Speed	$1,560/yr	$2,900/yr	=	$4,460/yr

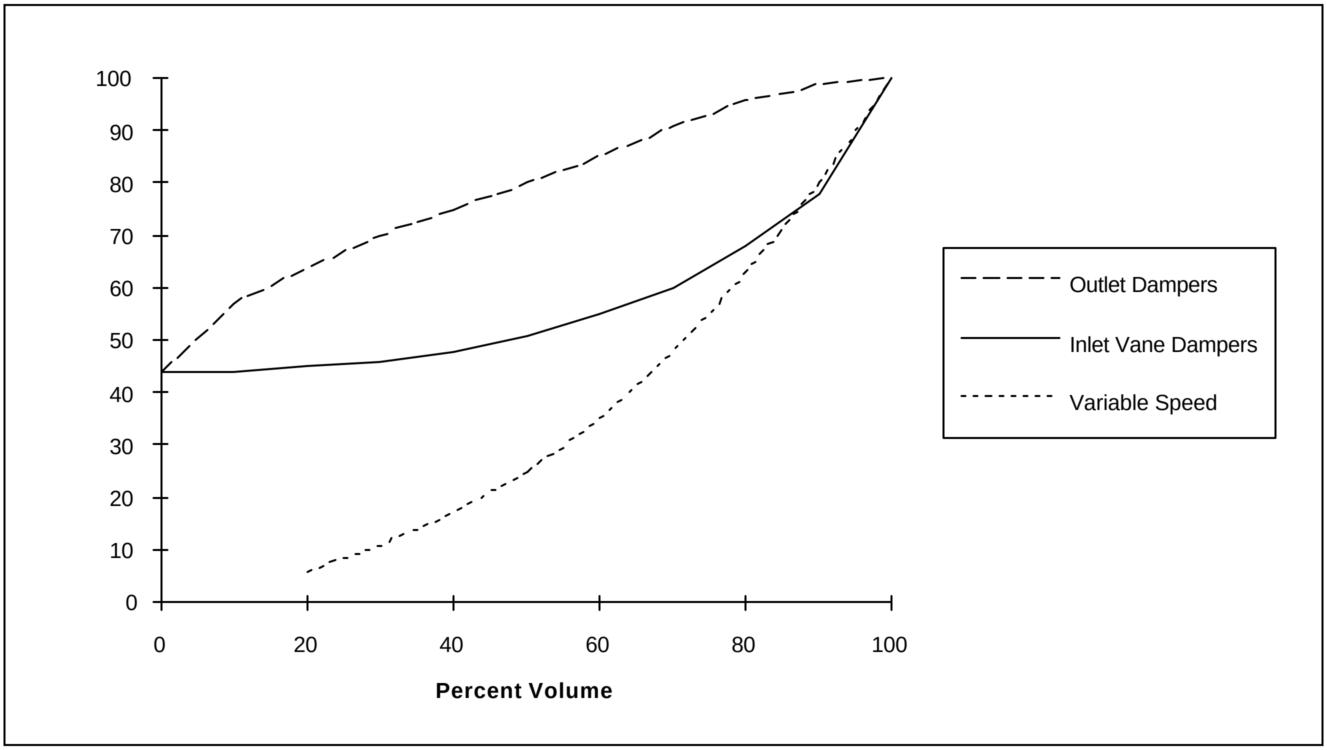


Figure 8.6: Effect of Volume Control on Fan Horsepower

Recover Energy

The use of air-to-air heat exchangers permits the exchange of energy between an exhaust airstream(s) and makeup airstream(s). Many of the exchangers will permit the exchange of only sensible heat while a few will permit the exchange of enthalpy (total heat). The transfer recovery efficiency of air-to-air heat exchangers varies from 55 percent to 90 percent, depending upon the type of heat exchanger and the face velocity.

Maintain Equipment

The physical condition of the air handling unit is important to its efficient operation.

Filters should be cleaned or replaced as soon as the maximum allowable pressure drop across the filter is attained. If dirt builds up to a point where the pressure drop exceeds the maximum allowable, the resulting system pressure increase will reduce the fan's pressure and subsequently reduce the air handler's efficiency.

As mentioned in an earlier section, dampers should seal tightly. Air leakage due to poor damper operation or condition will result in added loading of the air handling unit.

The fans should be checked for lint, dirt, or other causes for reduced flow.

The terminology commonly used in air conditioning is given in the following section.

8.1.5. Terminology

Adiabatic process:	A thermodynamic process during which no heat is added to, or taken from, a substance or system.
Air cleaner:	A device used to remove airborne impurities.
Air conditioning:	The process of treating air so as to control simultaneously its temperature, humidity, cleanliness, and distribution to meet the requirements of the conditioned space.
Air conditioning, comfort:	The process of treating air so as to control simultaneously its temperature, humidity (optional), cleanliness, and distribution to meet the comfort requirements of the occupants of the conditioned space.
Air conditioning, industrial:	Air conditioning for uses other than comfort.
Air washer:	A water spray system or device for cleaning, humidifying, or dehumidifying the air.
British Thermal Unit (Btu):	The Btu is defined as 778.177 foot-pounds if it is related to the IT (international table) calorie in such a way that 1 IT calorie per (kg)(ºC) = 1 Btu per (lb)(ºF), with 1 lb = 453.5924 g. Approximately, it is the heat required to raise the temperature of a pound of water from 59ºF to 60ºF.
Calorie:	Heat required to raise the temperature of 1 gram of water 1ºC, actually, from 4ºC to 5ºC. Mean calorie = 1/100 part of the heat required to raise 1 gram of water from 0ºC to 100ºC
Dehumidification:	The condensation of water vapor from air by cooling below the dew point or removal of water vapor from air by chemical or physical

methods.

Enthalpy:	Thermodynamic property of a substance defined as the sum of its internal energy plus the quantity PV/j, where P = pressure of the substance, V = its volume, and j = the mechanical equivalent of heat. Formally called by the obsolete names total heat and heat content.
Enthalpy, specific:	A term sometimes applied to enthalpy per unit weight.
Evaporative cooling:	The adiabatic exchange of heat between air and a water spray or wetted surface. The water approaches the wet bulb temperature of the air, which remains constant during its traverse of the exchanger.
Heat, latent:	Change of enthalpy during a change of state, usually expressed in Btu/lb. With pure substances, latent heat is absorbed or rejected at constant pressure.
Heat, sensible:	Heat which is associated with a change in temperature; specific heat exchange of temperature; in contrast to a heat interchange in which a change of state (latent heat) occurs.
Humidifier:	A device to add moisture to the air.
Humidstat:	A regulatory device, actuated by changes in humidity, used for the automatic control of relative humidity.
Humidity, relative:	The ratio of the mole fraction of water vapor present in the air, to the mole fraction of water vapor present in saturated air at the same temperature and barometric pressure. It equals the ratio of the partial pressure or density of the water vapor in the air, to the saturation pressure or density of water vapor at the same temperature.
Humidity, specific:	Weight of water vapor (steam) associated with one lb. weight of dry air, also called humidity ratio.
Preheating:	In air conditioning, to heat the air in advance of other processes.
Psychrometric chart:	A graphical representation of the thermodynamic properties of moist air.
Temperature, dew point:	The temperature at which the condensation of water vapor in a space begins for a given state of humidity and pressure as the temperature of the vapor is reduced. The temperature corresponding to saturation

	(100 percent relative humidity) for a given absolute humidity at constant pressure.
Temperature, dry bulb:	The temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.
Temperature, wet bulb:	Thermodynamic wet bulb temperature is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature. Wet bulb temperature (without qualification) is the temperature indicated by a wet bulb psychrometer constructed and used according to specifications.
Thermostat:	An instrument which responds to changes in temperature and which directly or indirectly controls temperature.
Ventilation:	The process of supplying or removing air, by natural or mechanical means, to or from any space. Such air may or may not have been conditioned.
Volume, specific:	The volume of a substance per unit mass; the reciprocal of density.

8.2. HVAC SYSTEMS

In this chapter, HVAC will be treated like a system of different functions put together. However, in some cases it is important to analyze the individual components as well.

8.2.1. Equipment Sizing Practices

Usually all existing energy consuming systems are oversized.

Reasons:

1. All HVAC design procedures are conservative.

2. A "Safety Factor" is then applied.

3. Design is for a near-extreme weather condition which is very seldom obtained (2-3% of annual hours).

4. Standard equipment size increments usually result in further oversizing.

Any attempt to conserve energy amplifies the effect of statements above.

Operating efficiencies of equipment decrease with decreasing load - usually exponentially (see Figure 8.7).

Reducing Capacity by Fan/Pump Slowdown

$$\frac{HP_1}{HP_2} = \left(\frac{CFM_1}{CFM_2}\right)^3$$

or

$$\frac{HP_1}{HP_2} = \left(\frac{GPM_1}{GPM_2}\right)^3$$

Thus: If CFM/GPM is reduced by 10%, the new hp will be 73% of original
For CFM/GPM reduction of 40%, new hp will be 22% of original.

But: Reducing hp output of the motor also reduces its efficiency.

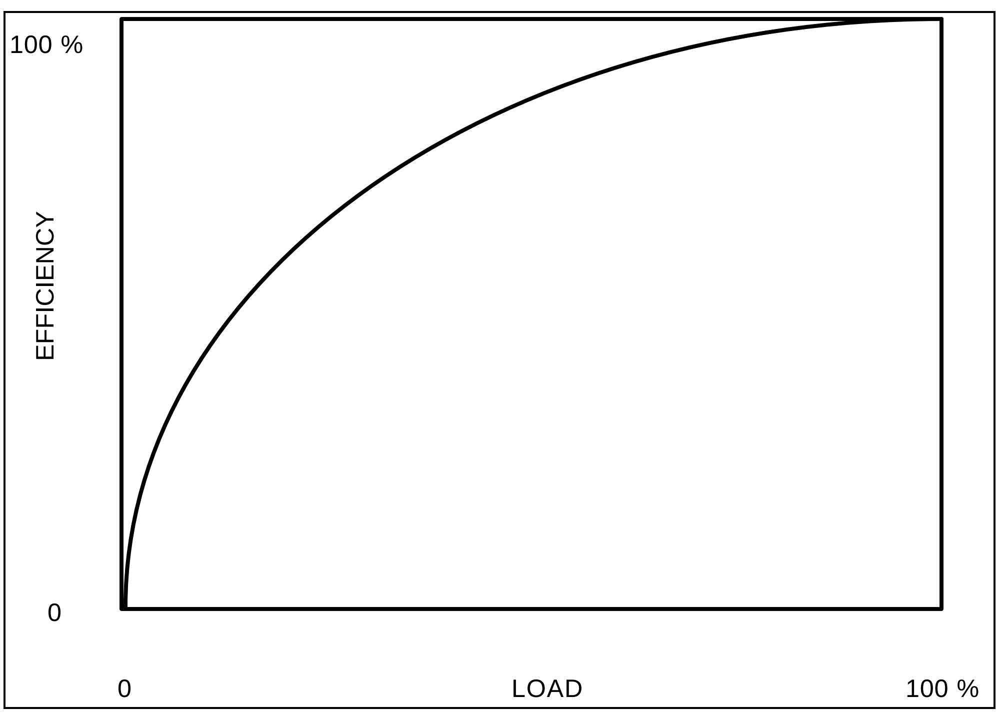


Figure 8.7: Load vs. Efficiency

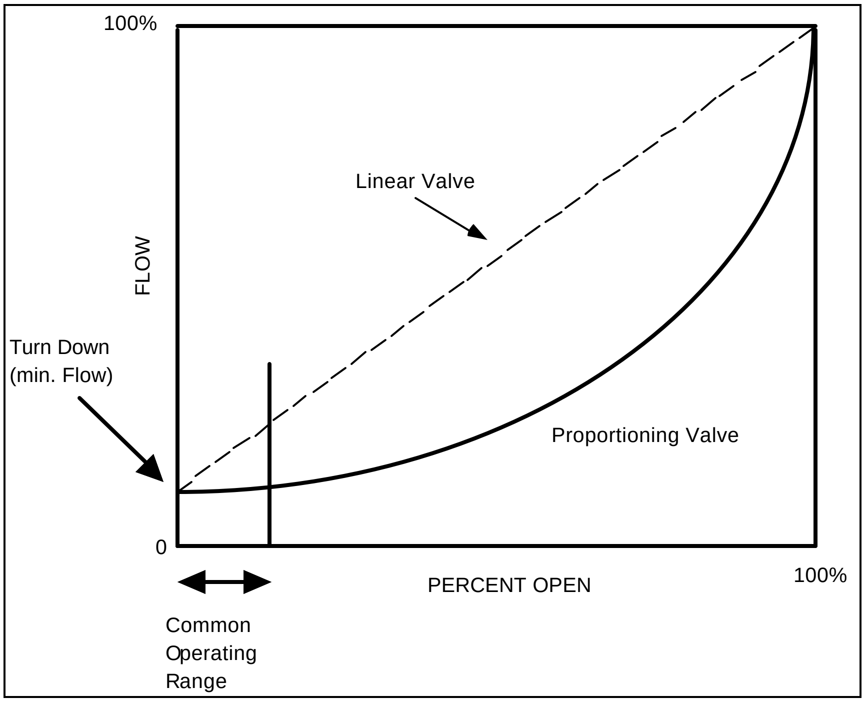


Figure 8.8: Control Valve Characteristics

Maximize HVAC Savings

1. Reduce fan & pump horsepower - replace motors if necessary.

2. Reduce operating time - turn it off when not needed.

3. Retrofit existing HVAC systems to some form of VAV (Variable Air Volume) systems.

4. Eliminate or minimize reheat.

5. Maintain, calibrate & upgrade control systems.

8.2.2. Design for Human Comfort

Providing comfortable conditions for people engaged in the working process is not a superfluous luxury, as might be viewed by some. Good working conditions definitely increase productivity, besides the indirect benefit of employees' satisfaction in the workplace. However, all the comfort should be provided at the minimum expense, whether a company or a private residence.

Outline

- Determination of indoor conditions and how they affect energy use.
- Impact upon equipment selection, ducting, and register design.
- How to determine if certain conditions will meet acceptable comfort criteria.
- Prevalent thoughts on comfort, including
    - Factors of influence
    - Calculation procedures
- Indoor design conditions
- Ventilation
    - ≥15 cfm fresh air per person
    - ASHRAE Standard 62-1989, "Ventilation for Acceptable Indoor Air Quality."

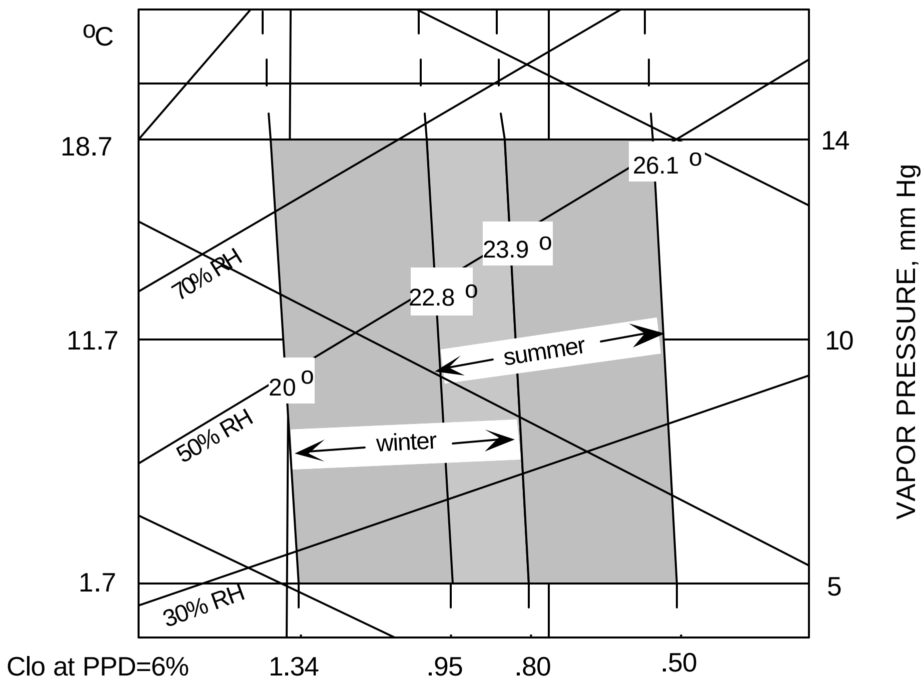


Figure 8.9: Comfort Zone Detail

1. Summer
    - Take hot, moist air and <u>cool</u> it and <u>dehumidify</u> it
2. Winter
    - Take dry, cold air and <u>warm</u> it and <u>humidify</u> it
3. Questions
    - To what temperature?
    - To what humidity?

- What is the impact upon energy cost?

ASHRAE STANDARD 90-1980

"Energy Conservation in New Building Design"

1. Summer
   - $T_{room} \geq 78^{o}F$
   - ϕ_{room}: Min HVAC energy use
   - ≥ 0.3 ACH (residential)

where ϕ denotes humidity

2. Winter
   - $T_{room}\ \psi\ 72^{o}F$
   - $\phi_{room}\ \psi\ 30\%$
   - ≥ 0.3 ACH (residential)

From the Comfort Chart

1. SUMMER
   - $73^{o}F\ \psi\ T_{db}\ \psi\ 81^{o}F$
   - $20\%\ \psi\ \phi\ \psi\ 60\%$

2. Winter
   - $68^{o}F\ \psi\ T_{db}\ \psi\ 75^{o}F$
   - $30\%\ \psi\ \phi\ \psi\ 70\%$

Since 1970, most of the work on comfort has been to re-define the x-axis on the comfort chart (see Figure 8.9) to be more general (i.e., include effects of heat radiation, clothing, metabolism, air motion, etc.).

The EUROPEAN approach is to minutely quantify comfort (reason: they don't heat their buildings as much). The UNITED STATES approach is to simply adjust the thermostat (becoming less acceptable to do so).

Comments and Observations

1. ASHRAE is slow and conservative. Not aggressive in implementing energy policy (reacts, does not act).

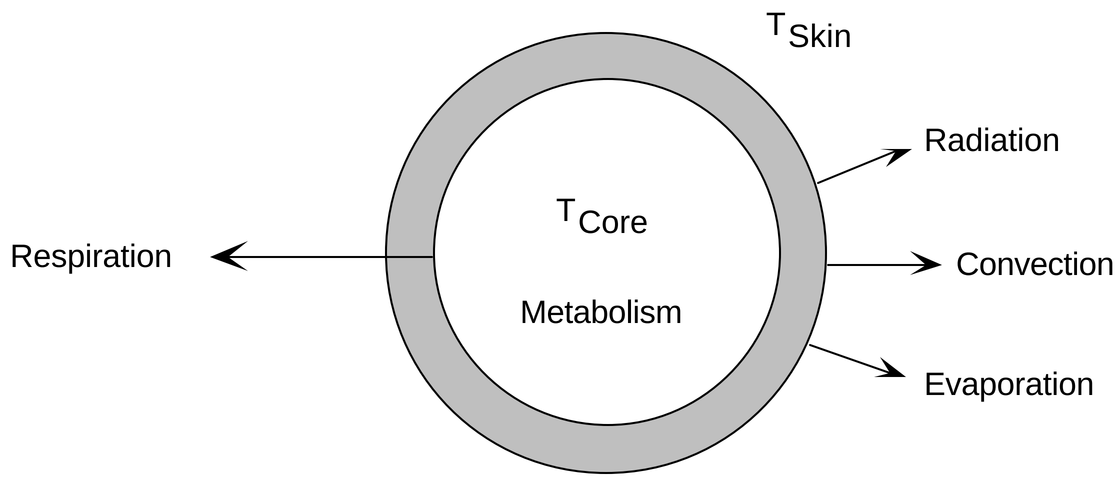
2. Productivity is a key element. Change in Standards will be difficult unless accompanied by a change in people's attitudes (psychology).

3. If you know you are uncomfortable, it does little good to know why.

4. ASHRAE has done little in the area of transferring knowledge of comfort to design practice.

Factors Affecting Comfort

1. Biological



T_{CORE} ≈ 37ºC $\underline{+}$ 1ºC (98.6ºF)
T_{SKIN} ≈ 92.7ºF (buffer; adjusts to ambient)

Metabolic Heat Generation in an adult male:

- ~ 100 W; seated at rest
- ~ 850 W; heavy exercise
- ~ 1,500 W; Olympic athlete

Various Activities[a]	**Btu/h-ft²**	**met**[b]
Resting		
Sleeping	13	0.7
Reclining	15	0.8
Seated, quiet	18	1.0
Standing, relaxed	22	1.2

Various Activities[a]	Btu/h-ft^2	met[b]
Walking (on the level)		
0.89 m/s	37	2.0
1.34 m/s	48	2.6
1.79 m/s	70	3.8
Office Activities		
Reading, seated	18	1.0
Writing	18	1.0
Typing	20	1.1
Filing, seated	22	1.2
Filing, standing	26	1.4
Walking about	31	1.7
Lifting/packing	39	2.1
Driving/Flying		
Car	18-37	1.0-2.0
Aircraft, routine	22	1.2
Aircraft, instrument landing	33	1.8
Aircraft, combat	44	2.4
Heavy vehicle	59	3.2
Miscellaneous Occupational Activities		
Cooking	29-37	1.6-2.0
House cleaning	37-63	2.0-3.4
Seated, heavy limb movement	41	2.2
Machine work		
sawing (table saw)	33	1.8
light (electrical industry)	37-44	2.0-2.4
heavy	74	4.0
Handling 50-kg bags	74	4.0
Pick and shovel work	74-88	4.0-4.8
Miscellaneous Leisure Activities		
Dancing, social	44-81	2.4-4.4
Calisthenics/exercise	55-74	3.0-4.0
Tennis, singles	66-74	3.6-4.0
Basketball	90-140	5.0-7.6
Wrestling, competitive	130-160	7.0-8.7

a Compiled from various sources. For additional information see Buskirk (1960), Passmore and Durnin (1967), and Webb (1964).

b 1 met = 18.43 Btu/h-ft^2

Table 8.1: Heat Flux Generated by Various Activities

2. Clothing

- Clothing resistance (clo); 1 *clo* = 0.155 $m^2\cdot{}^oC/W$ = 0.88 $h\text{-}ft^2\text{-}{}^oF/Btu$
- 1 *clo* ≈ R-1

clo	ATTIRE
1/2	Slacks, short sleeve shirt
1	Three-piece suit
4	Fur Coat

Table 8.2: Clothing Resistance

Garment description[a]	I/clo	Garment description[a]	I/clo
Underwear		*Dresses and Skirts*	
Man's briefs	0.04	Skirt (thin)	0.14
Panties	0.03	Skirt (thick)	0.23
Bra	0.01	Long-sleeve shirt dress (thin)	0.33
T-shirt	0.08	Long-sleeve shirt dress (thick)	0.47
Full slip	0.16	Short-sleeve shirt dress (thin)	0.29
Half slip	0.14	Sleeveless, scoop neck (thin)	0.23
Long underwear top	0.20	Sleeveless, scoop neck (thick)	0.27
Long underwear bottom	0.15	*Sweaters*	
Footwear		Sleeveless vest (thin)	0.13
Ankle-length athletic socks	0.02	Sleeveless vest (thick)	0.22
Calf-length socks	0.03	Long-sleeve (thin)	0.25
Knee socks (thick)	0.06	Long-sleeve (thick)	0.36
Panty hose stockings	0.02	*Suit Jackets and Vests (lined)*	
Sandals/thongs	0.02	Single-breasted (thin)	0.36
Slippers (quilted, pile-lined)	0.03	Single-breasted (thick)	0.44
Boots	0.10	Double-breasted (thin)	0.42
Shirts and Blouses		Double-breasted (thick)	0.48
Sleeveless, scoop-neck blouse	0.12	Sleeveless vest (thin)	0.10
Short-sleeve, dress shirt	0.19	Sleeveless vest (thick)	0.17
Long-sleeve, dress shirt.	0.25	*Sleepwear and Robes*	
Long-sleeve, flannel shirt	0.34	Sleeveless, short gown (thin)	0.18
Short-sleeve, knit sport shirt	0.17	Sleeveless, long gown (thin)	0.20
Long-sleeve, sweat shirt	0.34	Short-sleeve hospital gown	0.31
Trousers and Coveralls		Long-sleeve, long gown (thick)	0.46
Short shorts	0.06	Long-sleeve pajamas (thick)	0.57
Walking shorts	0.08	Short-sleeve pajamas (thin)	0.42
Straight trousers (thin)	0.15	Long-sleeve, long wrap robe)	0.69
Straight trousers (thick)	0.24	(thick)	

Sweat pants	0.28	Long-sleeve, short wrap robe	0.48
Overalls	0.30	(thick)	
Coveralls	0.49	Short sleeve, short robe (thin)	0.34

a “Thin” garments are made of lightweight, thin fabrics worn in the summer; “thick” garments are heavyweight, thick fabrics worn in the winter.

Table 8.3: Garment Insulation Values

3. Environmental indices
    - Operating temperature

$$T_o = \frac{h_r T_r + h_c T_a}{h_r + h_c}$$

$$T_o = a T_r + (1 - a) T_a$$

where T_r = mean radiant temperature
and T_a = dry bulb temperature

$$\frac{1}{3} \le a \le \frac{2}{3}$$

$$T_r = \frac{1}{N} \sum_{i=1}^{N} T_i$$

- Convection

Equation	Limits	Condition	Remarks/ Sources
$h_c = 0.061\ V^{0.6}$	40 < V < 800	Seated w/moving air	Mitchell (1974)
$h_c = 0.55$	0 < V < 40		
$h_c = 0.475 + 0.044V^{0.67}$	30 < V < 300	Reclining w/moving air	Colin & Houdas (1967)
$h_c = 0.90$	0 < V < 30		
$h_c = 0.92V^{0.53}$	100 < V < 400	Walking in still air	V is walking speed Nishi & Gagge (1970)
$h_c = (M - 0.85)^{0.39}$	1.1 < M < 3.0	Active in still air	Gagge (1976)
$h_c = 0.146V^{0.39}$	100 < V < 400	Walking on treadmill in still air	V is treadmill speed. Nishi & Gagge (1970)
$h_c = 0.068V^{0.69}$	30 < V < 300	Standing in moving air	Seppeman (1972)
$h_c = 0.70$	0 < V < 30		

Table 8.4: Equations for Convection Heat Transfer Coefficients

where h_c is in Btu/h ft^2
V is in fpm
M in met units; 1 met = 18.43 Btu/h ft^2

Standard Conditions for Comfort

- Icl = 0.60 *clo*
- m = 1 *met*
- V ψ 20 *fpm*
- Tr = Ta
- im = 0.4 (Moisture permeability index) - (85% are comfortable)

8.2.3. General Types of Building Heating and Cooling

The following pages show schematics (Figures 8.10-8.16) of many types of heating and cooling systems. Both equipment and controls are shown in the pictures to give an idea of how typical HVAC systems are designed.

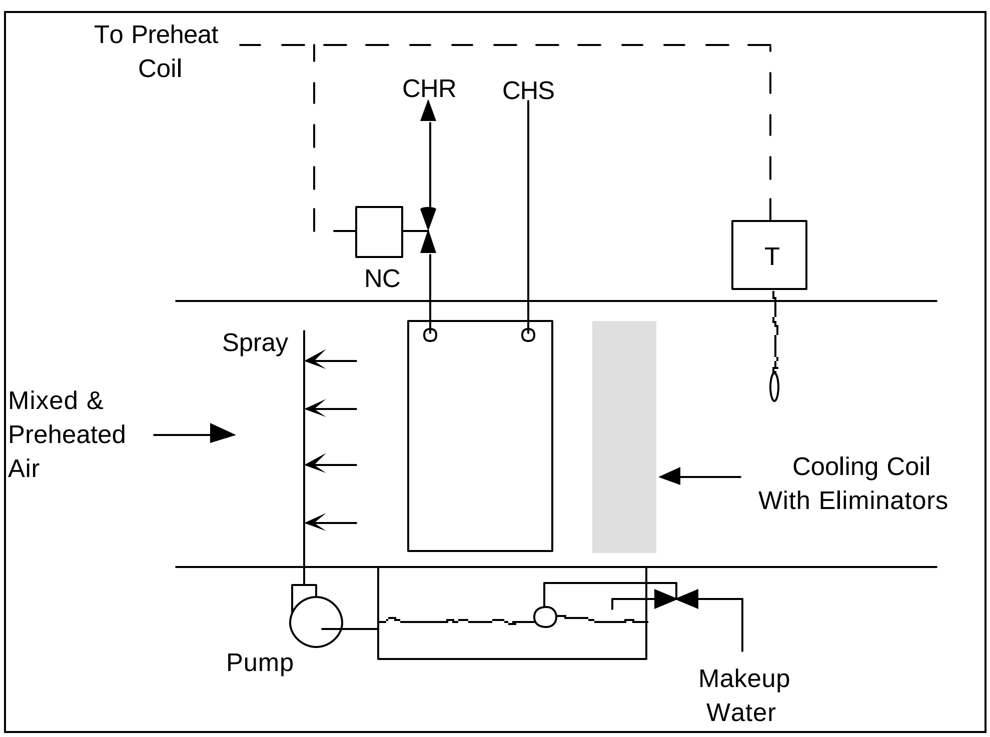


Figure 8.10: Sprayed Coil Dehumidifier

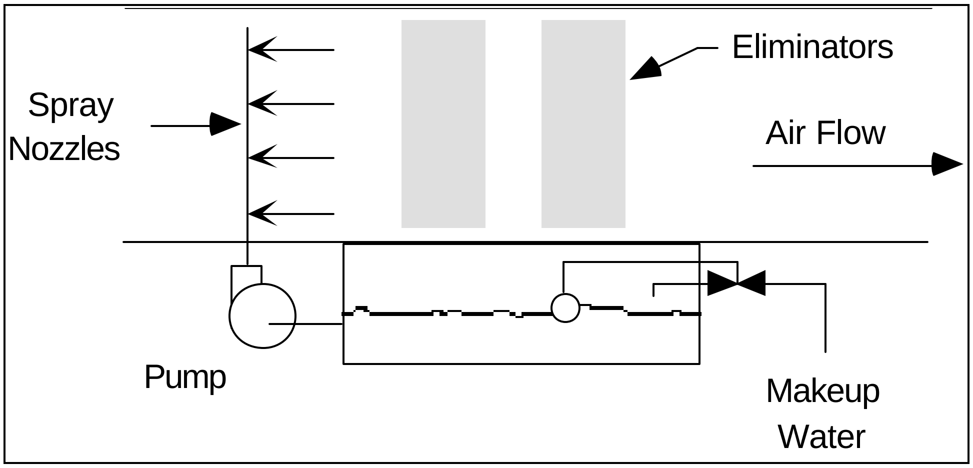


Figure 8.11: Evaporative Cooling & Air Washer

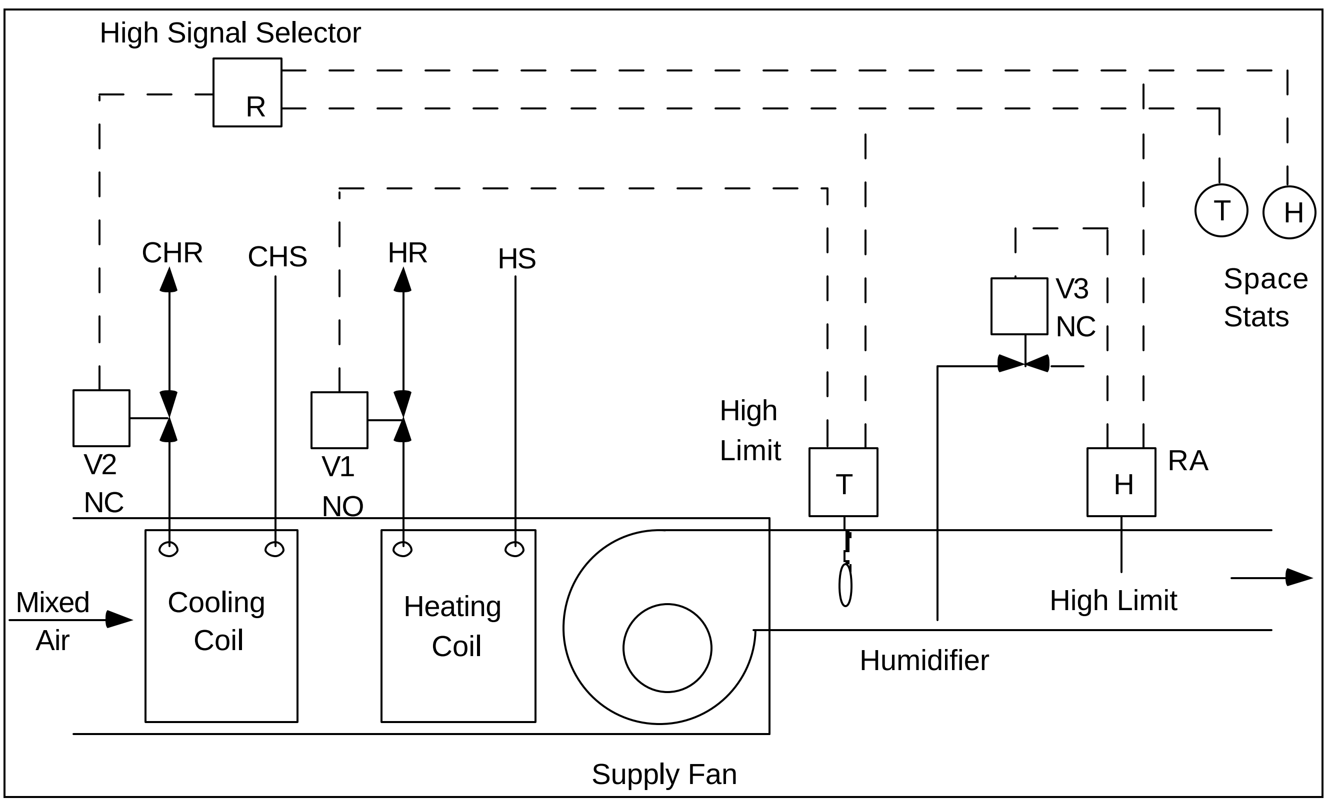


Figure 8.12: Humidity Control Through Cooling Override

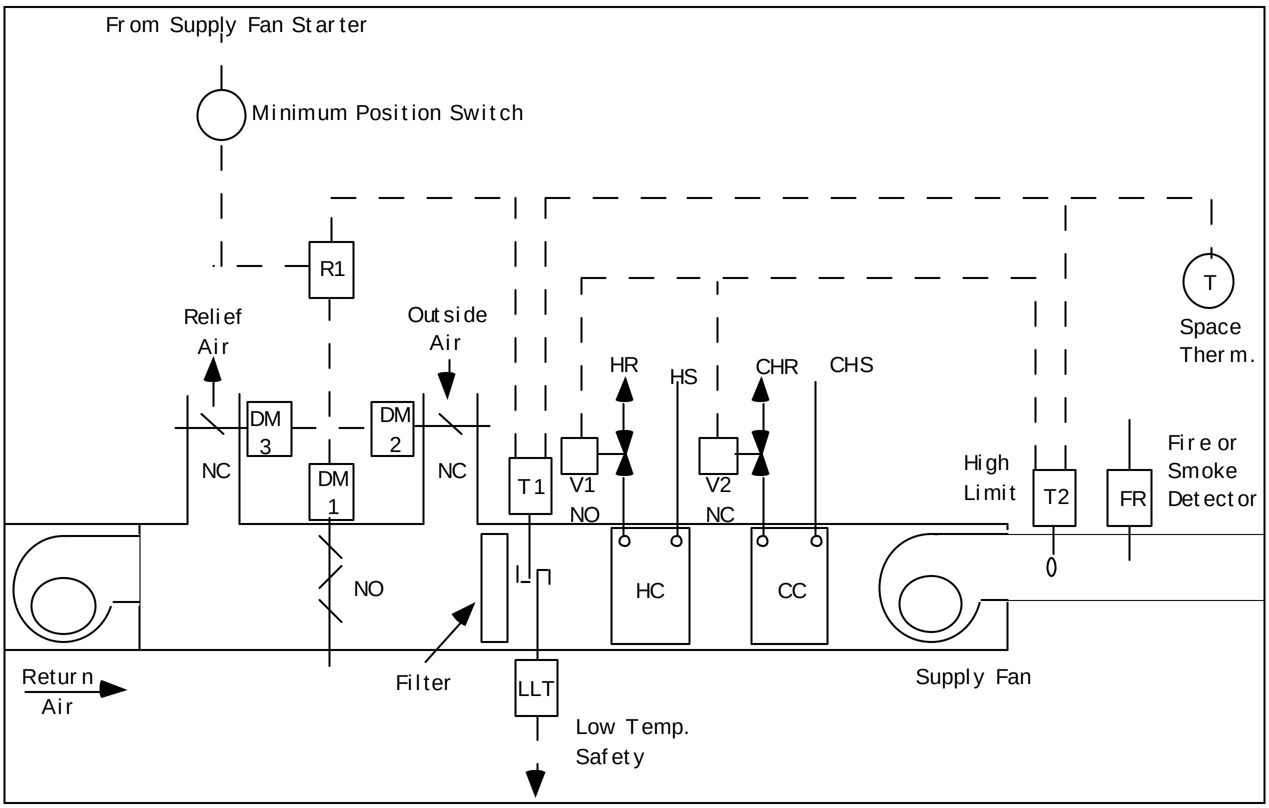


Figure 8.13: Single Zone - All Direct Control from Space Thermostat

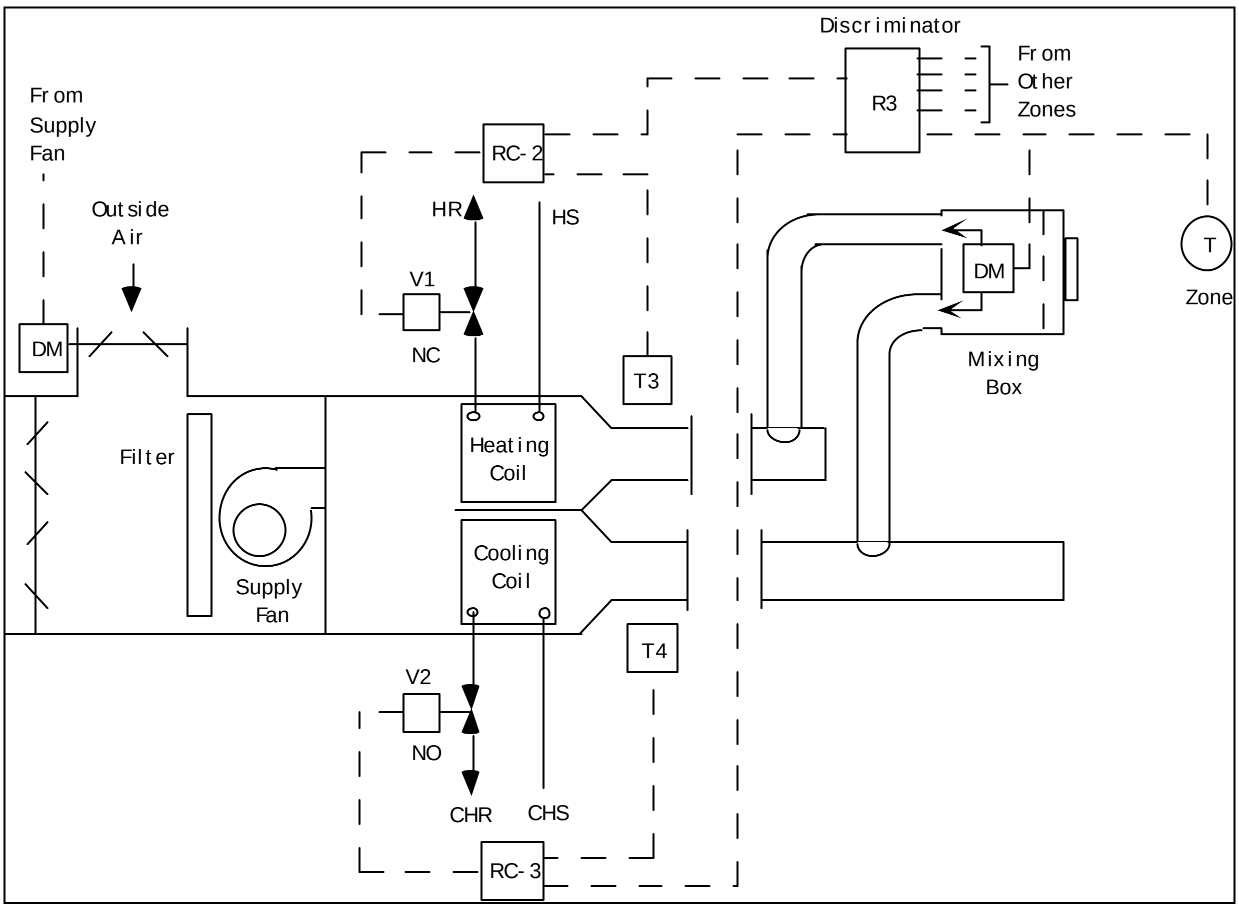


Figure 8.14: Dual Duct Air Handling System

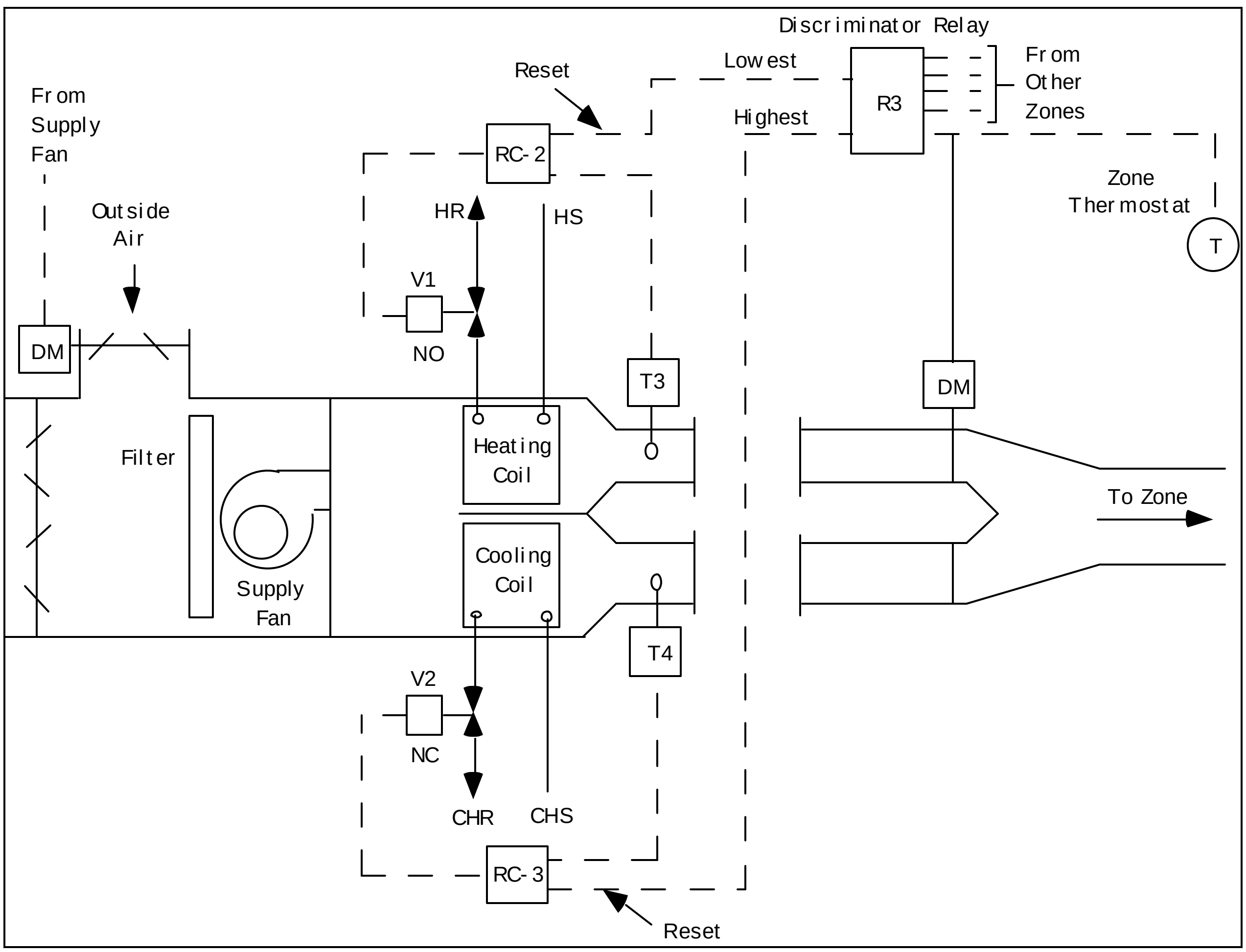


Figure 8.15: Multizone Air Handling Unit

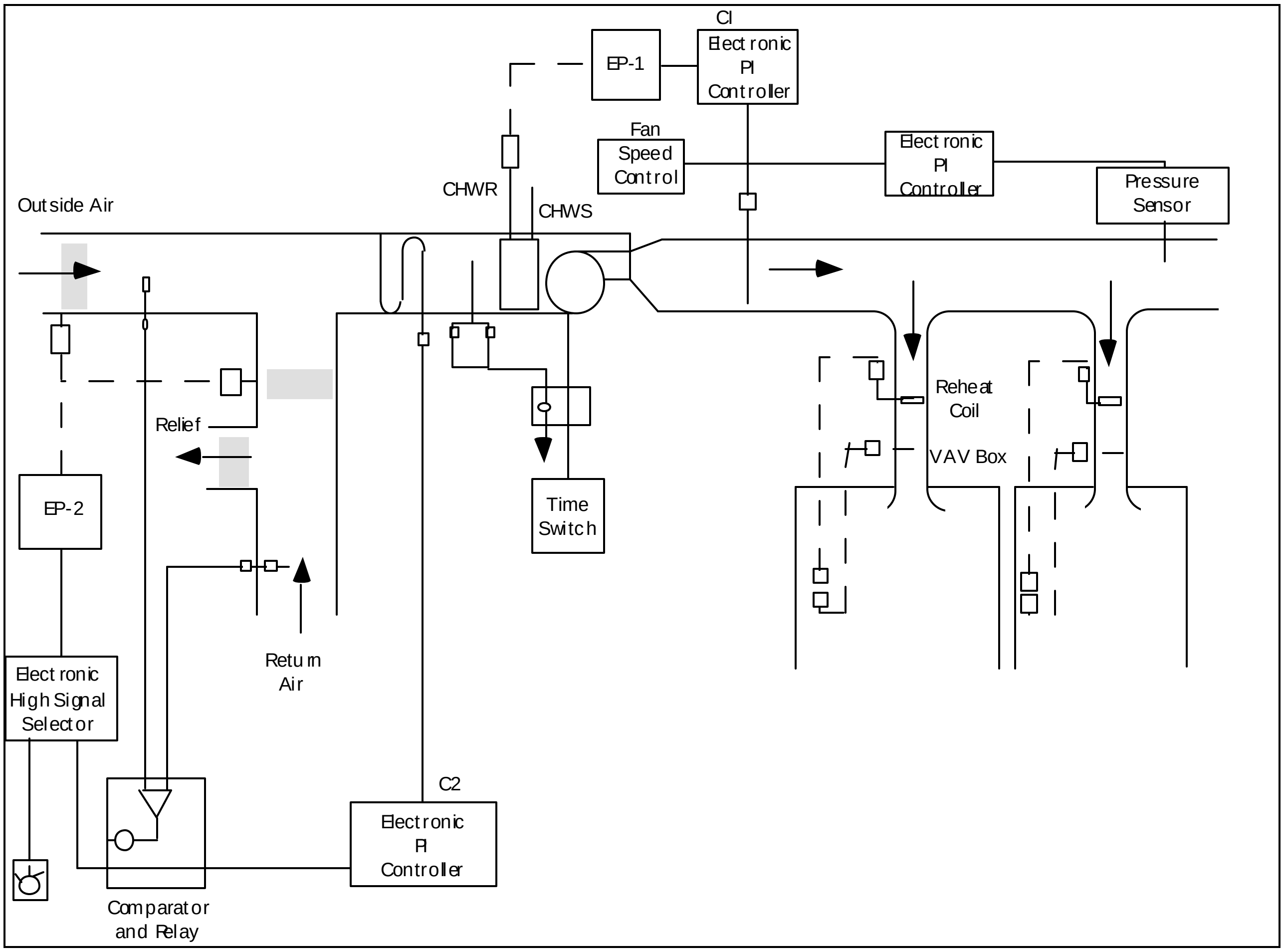


Figure 8.16: Hybrid VAV Control System

8.3. VENTILATION

Many operations require ventilation to control the level of dust, gases, fumes, or vapors. Excess ventilation for this purpose can add significantly to the heating load. All air that is exhausted from the building must be replaced by outside air.

8.3.1. Introduction

During the heating season the air must be heated to room temperature by makeup air units or by infiltration and mixing with room air. When process heating is also involved, excess ventilation results in a loss of energy at all times.

A common problem during the winter heating season is negative building pressure resulting from attempting to exhaust more air than can be supplied. The most obvious problem encountered with air starvation is difficulty in opening doors. Negative pressure will lead to a number of other problems.

1. Heaters, ovens, and other plant equipment that depend on natural draft cannot operate properly under negative pressure and their combustion efficiency drops.
2. Downdrafts can cause condensation and corrosion. Fumes can also be drawn into the plant, affecting employee health and effectiveness.
3. Without proper exhaust, air stagnation creates concentrations of fumes or odors. Warm, moist air may even condense on manufactured products or mechanical and electrical equipment.
4. Workers near the building's perimeters may be subjected to drafts as the pressure differential between inside and outside draws cold air through doors and windows. Downdrafts can also occur around ventilation hoods which are temporarily inoperative. Turning up the thermostat causes employees in the middle of the building to become uncomfortable and offers little help to those near the walls.
5. Exhaust fans cannot work at rated capacity under negative pressure, and dust, dirt, and contaminants in the plant increase. Maintenance, housekeeping, and operating costs rise, and equipment wears out much faster. If new exhaust fans are added without equivalent makeup air capacity, equipment efficiency suffers.

Exhaust air flows are usually established for the more demanding winter conditions when negative pressures may exist. Consequently, with no adjustment to the exhaust system during the non-heating season when the building pressure is at equilibrium with the outside air, the exhaust rate will be greater. Where no process heating is involved, the resulting higher summer exhaust rate is not a problem. However, when process heating is involved, such as with ovens, the higher exhaust rate will increase the heat loss.

8.3.2. Losses

Losses of air from buildings are inevitable. The air which was heated will slowly seep through gaps around windows, doors and ducts. It is a situation that has to be dealt with. On the other hand, not only would the total elimination of air leaks be prohibitively expensive, but also could also cause condensation and/or pressure inequality in the building with respect to the outside.

Room Air

The following two equations may be used to estimate makeup air heating costs on an hourly and yearly basis.

Hourly Cost = 1.08 x cfm x Δt x (C/eff.)

Yearly Cost = (0.154 x cfm x D x dg x C) / eff.

where

cfm = air volume, cfm
Δt = outside temperature - inside temperature, ºF
C = cost of fuel, \$/Btu
eff = heater efficiency; if unknown, use 0.80 for indirect-fired heater
D = operating time, hours/week
dg = annual degree days: 4,848 for New York City, New York or 5,930 for Pittsburgh, Pennsylvania

For example, assume 10,000 cfm with 40ºF outside temperature, operating 15 shifts per week.

Cost/hr = 1.08 x 10,000 x (70 - 40) x (\$3.00/10^6Btu) x (1/80%) = \$1.215

Annual Cost = 0.154 x 10,000 x 120 x 4,848 x (\$3.00/10^6Btu) x (1/80%) = \$3,360

High-Temperature Exhaust

In the case of a high-temperature exhaust, as from an oven, the loss is magnified because the air contains useful energy. During the heating season, cool makeup air needs to be warmed to room temperature first before being heated to the necessary temperatures in the ovens. This extra energy input is unnecessary unless the amount of makeup air could be minimized.

An example of the potential saving for a reduction in exhaust for 1,000 cfm at 250ºF is as follows:

1. Saving for heating outside air to 65ºF, given:
   cfm = 1,000
   D = 120 operating hours per week
   dg = 2,500 degree days
   C = \$4.24/MMBtu heat in steam

Using the above formula:

Annual savings = 0.154 x 1,000 x 120 x 2,500 x (\$4.24/106) = \$196/yr

2. Saving for reduction in process heat load (250ºF - 65ºF)

Annual Saving = 1,000 cfm x 1.08* x (250ºF - 65ºF) x 6,000 hrs/yr x \$4.24/MMBh heat in steam**
= \$5,080/yr

Total Saving = \$196 + \$5,080 = \$5,276/yr

Additional saving in fan horsepower is possible if fan speed is reduced.

* 1.08 = 60 min/hr x 0.075 lbs/cu ft x 0.24 specific heat of air

** If a direct-fired gas makeup unit is used, the air is heated at nearly 100 percent efficiency. For an indirect unit an efficiency of 80 percent or $3.75/MMBtu can be used.

Air -Water Mixture

The air loss is considerably greater when water vapor is included with the exhaust, as occurs with washing or drying.

As an example of the heat loss from an exhaust including water vapor, the enthalpy of dry air at 110ºF is 26.5 Btu per pound; the enthalpy of a saturated mixture of air and water vapor is 87.5 Btu per pound of dry air.

The extent of this loss emphasizes the importance of using minimum exhaust where heated baths are involved. A high temperature psychrometric chart can be used to determine enthalpies at other conditions.

8.3.3. Balance Air Flows

Too often no provision is made to supply sufficient makeup air. Consequently, it must leak through doors, windows, and stray openings, producing undesirable drafts in the vicinity of the leakage.

Barring the ability to make sufficient reduction in exhaust to balance the air supply and demand, the best practice is to add more makeup air units to supply heated air in amounts equal to that exhausted and distribute it in the region of the exhaust system. While this will contribute little to energy conservation, it will eliminate the problems associated with negative pressure.

Plant personnel should check all exhausts to determine if losses can be reduced or eliminated. Measures than can be taken to reduce exhaust losses are:

1. Shut off fans when equipment is down.
2. Reduce volume to a minimum but adequate amount to satisfy ventilation needs.
3. Reduce temperature.
4. Recover exhaust.

Shut off Fans

The most obvious improvement is to shut off any exhaust fans that are not needed. Exhaust fans are often left running even if the equipment they are ventilating is down. Some typical examples are spray booths and ovens or dryers. Fans are typically left on during periods of no production, such as evenings or weekends.

Reduce Volume

The next best improvement is to reduce exhaust rates to the minimum, but adequate, amount. Some reduction in existing rates may be possible because:

1. Exhaust rates may have been established with a large margin of safety when energy costs were not a significant factor.
2. The exhaust rate may have been increased at one time to resolve a temporary problem which no longer exists.
3. Rates may be set to satisfy the most extreme need, which may be far in excess of normal operation.

In the first case, a simple adjustment of the damper setting to reduce flow may be sufficient. Where production loads fluctuate, the damper setting can be varied with the load when practical.

§ *Improve Hood Design*

Often, one of the most direct and easiest means to reduce the volume of exhaust air is by proper hood design. In many instances, equally effective ventilation can be provided with less exhaust by improving the design of the exhaust hoods. The result is lower fan power consumption and reduced heat loss. In general, the most effective hood designs are those which completely surround the emission source with minimum openings to the surrounding area. Following are some guidelines for optimum hood design.

<u>Enclosure</u>

The more complete the enclosure, the less exhaust air is required. Exhaust hoods are commonly located at a considerable distance from the surface of a tank. As a consequence, room air is exhausted along with the fumes. Rates are also increased if control is upset by cross drafts in the area. The following steps can provide a more complete enclosure.

1. Extend the hood vertically on one or more sides. This approach can be taken where access is not necessary on all sides.
2. Provide a hanging drop cloth or plastic strips that will allow for access when necessary without undue interference with operation.

<u>Distance from Source</u>

If enclosing the source with side panels is not practical, the hood should be as close as possible to the source and shaped to control the area of contamination. The required volume varies as the square of the distance from the source.

Flanging

The addition of flanges will eliminate air flow from ineffective zones where no contaminant exists. Air requirements can be reduced as much as 25 percent by incorporating flanges in the hood design.

Capture Velocity

The air flow past the source must be sufficient to capture the contaminant. However, if no standards are used, proper capture velocity or volume should be determined to avoid unnecessary exhaust.

Large Openings

Where exhaust openings are large in size, the hood can be made more effective by incorporating multiple take-offs, slotted openings, baffles, etc. Hoods with this feature will provide more uniform flow over the area to be ventilated and reduce total air requirements.

Outside Air

The introduction of outside air, where possible, at the point of ventilation will reduce the amount of room air exhausted. Heating requirements will, therefore, be reduced.

Reduce Temperature

Process requirements usually dictate the temperature at which the process must be maintained. However, a review of conditions may indicate opportunities to reduce temperature in the following areas:

- Current practice maintains temperature above standard to provide a wide margin of safety.
- The standard was established arbitrarily or without adequate testing.

- The standard was established to handle a worse-case scenario which no longer exists or occurs rarely (at which time exhaust rate could be increased).

Recover Heat

Heat recovery from the exhaust air should be considered after first completing the steps to reduce exhaust loss by any of the above methods.

Precautions

Several precautions should be considered in the evaluation of a heat recovery system.

1. Because air is less dense than water, large volumes of air are required to approach the equivalent Btu content of waste water. Where heat recovery from both systems cannot be beneficially utilized, a heat recovery system for water is generally preferable to air because of the formers better payback and lower maintenance. The plantwide potential for waste recovery should, therefore, be studied first to ensure the design of any installation will be coordinated with an overall plan.
2. Any evaluation of savings must reflect the actual hours of use. For example, if air-to-air heat recovery from an oven is planned for heating the building, the recovery system will be in use only during the heating season. Furthermore, if the oven is not operating continuously, the heat recovery system will be available for this purpose for an even shorter period.
3. Although considerable heat may be lost in exhaust gases, especially when a number of sources are involved, the potential for heat recovery is dependent on the temperature of the gases. When the temperature range is low (200ºF to 400ºF), the potential for economical recovery is minimized.
4. The exhaust gases may contain some contaminants that will foul heat exchanger surfaces. In this situation, the ease of cleaning the exchanger is of prime importance.

8.3.4. Types of Heat Exchangers

A couple of different design approaches are introduced. As the name indicates, the heat exchanger is a device where heat from one medium is transferred into another. This way, some of the energy otherwise lost is used to help achieve desired conditions.

Rotary Heat Exchanger

Because the matrix in this type of exchanger has fine air passages, the rotor may soon become blocked if it is installed in an airstream containing contaminants. This heat exchanger has the highest efficiency, recovering 70 to 85 percent of the exhaust energy, including both latent and sensible heat. It is best suited to a clean airstream since some short circuitries of the exhaust air to the supply side can occur.

Sealed Heat Pipe Heat Exchanger

The heat pipe operates on the principle that when heat is applied to one end of a sealed tube, evaporation of a fluid in the pipe occurs. The vapor flows to the cold end where it is condensed. The condensed working fluid is then transported by capillary action to the warm end where the cycle is repeated. In this exchanger, the fins mounted on the outside of the tube to aid heat transfer may also become blocked with contaminants. Heat exchanger efficiency decreases when deposits build up on the surface, so keeping the surfaces clean is important. The unit recovers 60 to 80 percent of the sensible heat.

The use of a filtering system and/or periodic cleaning is often necessary to ensure clean surfaces. The advantages of the heat pipe are: minimal maintenance (it contains no moving parts) and no cross-contamination (the exit and incoming gas streams are completely sealed off from each other).

Plate Heat Exchanger

Heat transfer is accomplished by the counterflow of the two streams between the plates. This type of exchanger is less likely to become blocked with contaminants and is more easily cleaned. Maintenance is also minimized because there are no moving parts. This type is suitable for either air-to-air or air-to-water heat recovery. About 70 percent of the sensible heat is recovered by these units.

The equipment cost for an air-to-air heat exchanger from one manufacturer ranges from $0.60 to $1.60 per cfm depending on the size, usage, efficiency, airflow, pattern, etc. An air-to-water heat exchanger costs from $1.30 to $3.10 per cfm, again depending on efficiency, size, usage, etc. Installation costs range from 1 to 2.5 times the cost of the equipment.

If the exhaust gases contain oil mists and other contaminants, some form of filter unit may be necessary ahead of the heat exchanger. Either a conventional filter or electrostatic precipitator can be considered.

Coil-Run-Around System

The above three types of heat exchangers require the supply and exhaust stream to be brought together. A coil-run-around unit permits the two streams to be physically separated by using an intermediary fluid, usually ethylene glycol, to transfer energy between the two streams. The ethylene glycol is circulated in a closed loop through heat exchangers in the "hot" and "cold" stream. Coil-run-around systems recover 60 to 65 percent of the sensible heat between the two streams.

Hot Oil Recovery System

This system has the advantages of eliminating heat exchanger fouling and reducing pollution abatement problems. In this system, exhausts are passed through cool, cascading oil, which absorbs most of the heat as well as the high boiling chemicals. The hot oil passes over exchange coils containing incoming process water and is then recycled.

Where flammable solvents are used, lower flammable limit (LFL) monitoring equipment is necessary. Improved LFL systems include self-checking equipment and completed control loops that allow the use of modulated dampers to provide for minimal safe ventilation requirements. The self-checking system eliminates much of the periodic need to calibrate and check the function of safety circuits. Accordingly, exhaust reduction can be considered for drying ovens containing solvent vapors. The capital expenditure for an LFL monitor is about $15,000.

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9 WASTE

9.1. WASTE GENERATION

Almost any operation will generate some sort of waste. Even non-industrial type of a business will have a waste in terms of paper, cardboard, etc.. If the waste is landfilled, it is rather obvious that the space available is limited. If the waste is incinerated, a secondary waste and heat are created. Waste generators need to concentrate on the waste reduction at the source. If that is not possible, recycling is the second choice, and as the last resort, treatment of wastes that will give relatively harmless products.

9.1.1. Sources of Manufacturing Wastes

In order to be able to deal successfully with any waste issues, an auditor has to know what usually constitutes waste and where and how it is generated. Nothing can be as valuable as personal experience but even an inexperienced person doing the assessment can get a good idea from the following lists.

- Raw Materials
  - Containers, packing
  - Off-spec and expired lots
  - Spoiled batches

- Processes

Cleaning	Coating/Painting
Reactions	Plating/Anodizing/Chromating
Machining	Casting/Molding
Testing	Extracting/Refining
Printing	Packaging

Process Wastes

- Cleaning

Alkaline baths	Acidic baths
Solvents	Rags
Sludges	Oil and Grease
Grit	Rinse water

- Painting

Thinner	Paint sludge
Overspray	Filters
Containers	Unused paint
Paint stripper	Masking

- Machining

Metal chips	Trimming waste
Cutting coolants	Tapping oil
Hydraulic oil	Tramp oil
Filters	Rags

- Printing

Lithographic plates	Plate process solutions
Silver	Photo process solutions
Press washes	Rags
Paper	Inks

9.1.2. Compendium of Processes Producing Waste

Table 9.1: Waste Generated by Different Processes

General industrial category	Unit operation	Common waste streams	Pollution prevention and recycle/reuse measures
Chemical processing (SIC: 28,29)	•Blending/mixing •Reaction to form product •Vessel cleaning	• Tank cleanout solutions • Tank cleanout solids • Reagent (liquid and powder) spills to floor • Reaction byproducts • Air emissions • Dust from powdered raw material	• Use Teflon lined tanks • Clean lines with "Pigs" instead of solvents or aqueous solutions • Use squeegees to recover clinging product prior to rinsing • Use Clean In Place (CIP) systems • Clean equipment immediately after use • Treat and reuse equipment cleaning solutions • Use cylindrical tanks with height to diameter ratios close to one to reduce wetted surface • Use tanks with a conical bottom outlet section to reduce waste associated with the interface of two liquids • Increase use of automation • Convert from batch operation to continuous processing • Use dry cleaning methods whenever possible • Use squeegees, mops and vacuums for floor cleaning • Use pumps and piping to decrease the frequency of spillage during material transfer • Install dedicated mixing equipment to optimize

General industrial category	Unit operation	Common waste streams	Pollution prevention and recycle/reuse measures
			reuse of used rinse and to preclude the need for inter-run cleaning • Use in process recycling whenever possible • Install floating covers on tanks of volatile materials to reduce evaporation • Order paint pigments in paste form instead of dry powder to eliminate hazardous dust waste
Food processing (SIC: 20)	•Mixing/blending • Cooking/baking	• Equipment cleaning waste waters • Floor washing waste waters • Solid materials from mixer cleaning (e.g. dough) • Spent cooking oils	• Use dry cleaning methods whenever possible • Use high pressure washing equipment • Use squeegees and mops and for floor cleaning • Use continuous processing to eliminate the need for inter-run cleaning
Metal working (SIC: 33-39)	• Melting	• Air emissions • Hazardous slags • Non-hazardous slags • Metal dust • Scrubber sludge	• Recycle non ferrous dust • Alter raw materials to reduce air emissions • Use induction furnaces instead of electric arc or cupola furnaces to reduce dust and fumes • Reuse high ferrous metal dust as raw material • Use high quality scrap (low sulfur) to reduce hazardous sludge generation • Use an alternative desulfurizing agent to eliminate hazardous slag formation • Alter Product Requirements to eliminate unnecessary use of desulfurizing agent (calcium carbide) • Separate iron from slag and remelt • Treat disulfurization slag in a deep quench tank instead of spraying water onto an open pile to reduce air emissions
	• Casting	• Spent sand • Flashing • Reject castings	• Recycle casting sand • Use sand for other purposes (e.g. construction fill, cover for municipal landfills) • Avoid contamination of flashing and reject castings and reuse as feed stock • Recover metals from casting sand
	• Extrusion	• Scrap end pieces	• Avoid contamination of end pieces and reuse as feed stock
	• Coldworking (bending, pulling)	• Scrap metal	• Recycle scrap metal to foundry

General industrial category	Unit operation	Common waste streams	Pollution prevention and recycle/reuse measures
	• Machining (cutting, lathing, drilling, tapping)	• Metal scrap • Spent hydraulic oils • Spent lubricating oils • Leaked oils • Dirty rags or towels	• Segregate metals for sale to a recycler • Reprocess spent oils on site for reuse • Install shrouding on machines to prevent splashing of metal working fluids • Utilize a central coolant system for cleaning and reuse of metal working fluid • Maintain machines with a regular maintenance program to prevent oil leaks • Implement a machine and coolant sump cleaning program to minimize coolant contamination
	• Grinding	• Metal and abrasive dust	• Separate (flotation, magnetic) and recycle scrap to foundry
	• Heat treatment	• Air emissions	• Improve furnace control
Printing (lithography, gravure, flexography, letterpress, screen) (SIC: 27)	• Image production	• Scrap film • Spent film processing solutions	• Use glass marbles to raise fluid levels of chemicals to the brim to reduce contact with atmospheric oxygen • Recycle film for silver recovery • Use electronic imaging and laser plate making • Use water-based image processing chemicals • Closely monitor chemical additions to increase bath life • Use squeegees to prevent chemical carry-over in manual processing operations • Use counter current washing in photo processors • Recycle processing baths for nickel recovery • Use silver free films • Use "washless" processing equipment
	• Plate, cylinder and screen making	• Spent plate processing solutions	• Use water-based developers and finishers • Use an automatic plate processor • Use counter-current rinsing to reduce rinse water volume (gravure) • Use drag-out reduction methods (gravure)-*see surface coating* Sell used plates to an aluminum recycler
	• Make-ready	• Scrap paper • VOC emissions	• Automate ink key setting system • Reuse scrap printed paper for make-ready • Use ink water ratio sensor • Computerized registration • Use automated plate benders

General industrial category	Unit operation	Common waste streams	Pollution prevention and recycle/reuse measures
	• Printing	• Scrap paper • VOC emissions • Damaged rubber blankets • Waste ink • Waste printing press oils	• Install web break detectors to prevent excessive waste paper • Eliminate chemical etching and plating by using alternative printing technologies (Presensitized lithographic, plastic or photopolymer, hot metal, or flexographic) • Use a waterless plating system • Use automatic ink levelers • Schedule jobs to minimize the need for cleanup (light colors before dark) • Use dedicated presses for each color • Use less toxic solvents • Use soy or water-based inks • Automate ink mixing • Cover ink containers when not in use
	• Clean-up	• VOC emissions • Left over ink from fountains • Waste roller cleaning solution • Dirty rags • Paint skin from open ink containers • Used plates	• Use press cleanup rags as long as possible before disregarding • Recycle waste ink and cleanup solvent • Use automatic cleaning equipment • Remove rollers from the machines and clean in a closed solvent cleaner • Prevent excessive solvent usage during cleaning (operator training) • Segregate spent solvents (by color) and reuse in subsequent washings • Improve cleaning efficiency by maintaining cleaning system (rollers, cleanup blade)
Surface coating (SIC: 24, 25, 34-39)	• Painting	• Off-specification or outdated paint • Empty paint and solvent containers • Paint sludge • Spent paint filters • Booth cleanout waste (overspray) • Spent cleaning solvent • VOC emissions	• Use tight fitting lids on material containers to reduce VOC emission • Convert to higher efficiency technologies • Convert to electrostatic powder coating • Convert from water curtain spray booths to a dry system • Convert to robotic painting • Use low VOC or water based paint • Purchase high volume materials in returnable bulk containers • Train operators for maximum operating efficiency • Automate paint mixing
			• Use compressed air blowout for line cleaning prior to solvent cleaning • Shorten paint lines as much as possible to reduce line cleaning waste • Schedule production runs to minimize color changes • Recycle cleaning solvent and reuse • Use paint without metal pigments

General industrial category	Unit operation	Common waste streams	Pollution prevention and recycle/reuse measures
	• Plating (electro, electroless) • Anodizing	• Spent alkaline cleaning solutions • Spent acid baths • Spent cyanide cleaning solutions • Spent plating solutions • Filter sludge • Waste rinse water • Waste water treatment sludge • Vent scrubber waste	• Use high purity anodes to increase solution life • Lower the concentration of plating baths • Reduce drag-in with better rinsing to increase solution life • Use deionized water for make-up and rinse water to increased solution life • Extend solution life with filtering or carbonate freezing • Use cyanide free solutions whenever possible • Replace cadmium-based solutions with zinc solutions • Replace hexavalent chromium solutions with trivalent solutions • Return spent solutions to the manufacturer • Use lower concentration plating baths • Reduce drag-out by racking parts for maximum drainage • Reduce drag-out by slowing withdrawal speed and increasing drain time • Rack parts for maximum drainage • Use drain boards between tanks for solution recovery • Reduce water use with counter current rinsing • Use fog nozzles over plating tanks and spray rinsing instead of immersion rinsing • Use reactive rinsing • Mechanically and air agitate rinse tanks for complete mixing • Use a still rise as the initial rinsing stage • Use automatic flow control • Recovery metals from rinse water (Evap., Ion exchange, R.O., Electrolysis, Electrodialysis) and reuse rinse water • Use precipitating agents in waste water treatment that produce the least quantity of waste • Use separate treatments for each type of solution and sell sludge to a recycler
	• Stripping of paint, varnish, lacquer	• Spent solvents • VOC emissions • Spent caustic solutions • Spent sand and other blasting media • Paint dust	• Use mechanical stripping methods • Use cryogenic stripping • Use non-phenolic strippers to reduce toxicity associated with phenol and acid additives • Maintain clean conditions before painting to avoid surface contamination resulting in paint defects
	• Metal plating removal	• Spent acid solution • Tank sludge	• Recover metals from spent solutions and recycle
Surface preparation/	• Chemical etching	• Spent acidic solution	• Reduce solution drag-out from process tanks • Prevent solution drag-out from upstream tanks

General industrial category	Unit operation	Common waste streams	Pollution prevention and recycle/reuse measures
cleaning (SIC: 24, 25, 34-39)	• Solvent cleaning (vapor degreasing, solvent dip)	• Tank sludge • Waste rinse water • Spent solvents • Solvent recycle still bottoms • VOC emission • Solvent tank sludge	• Use deionized water in upstream rinse tanks • Treat and reuse rinse waters • Recover and reuse spent acid baths • Use tight-fitting lids on material containers and solvent cleaning tanks to reduce VOC emissions • Convert to aqueous cleaning system • Convert to less toxic hydrocarbon cleaners • Use peel coatings on raw materials to eliminate need for cleaning • Use water-based cutting fluids during machining to eliminate need for solvent cleaning Increase freeboard space and install chillers on vapor degreasers • Distill contaminated solvents for reuse • Remove sludge from tanks on a regular basis • Slow insertion and withdrawal of parts from vapor degreasing tank to prevent vapor drag-out • Maintain water separator and completely dry parts to avoid water contamination of solvent • Convert to aqueous cleaning • Use silhouette entry covers to reduce evaporation area • Avoid inserting oversized object to reduce piston effect • Allow drainage before withdrawing object • Eliminate the need for cleaning with improved handling practices
	• Aqueous cleaning	• Spent cleaning solutions • Waste rinse waters • Oil sludge • Tank sludge	• Remove sludge from tanks on a regular basis • Minimize part contamination before washing • Eliminate the need for cleaning with improved handling practices • Extend solution life by minimizing drag-in • Use alternatives for acid and alkaline (e.g. water, steam, abrasive) • Preinspect parts to prevent drag-in of solvents and other cleaners • Install mixers on each cleaning tanks • Closely monitor solutions and make small additions to maintains solution strength instead of lathe infrequent additions • Implement a regular maintenance program to keep racks and tanks free of rust, cracks, or corrosion • Apply a protective coating to racks and tanks • Reduce solution drag-out to prevent solution loss • Use counter current rinsing to reduce waste water • Use reactive rinsing to extend bath life
	• Abrasive cleaning	• Used buffing wheels • Spent compound	• Use water based or greaseless binders to increase wheel life • Use liquid spray (water based) adhesive instead of

General industrial category	Unit operation	Common waste streams	Pollution prevention and recycle/reuse measures
			bar abrasives to prevent over use of material and easier part cleaning • Carefully control water level in Mass Finishing Equipment
	• Dry and wet rag cleaning	• Spent solvent wetted rugs • Oil soaked rags	• Wash and reuse rags on-site • Use an off-site rag recycling service • Minimize use of rags through worker training
Paper and pulp manufacturing (SIC: 26)	• Wood Preparation • Pulping • Screening • Washing • Thickening • Bleaching • Stock preparation • Paper machine • Finishing and Converting	• Wood waste (saw dust, bark) • Acid and Alkaline waste waters • Toxic waste waters and sludges • Wood fiber waste • Non-hazardous waste water treatment sludge	• Use diffusion pulp wash systems to maximize efficiency • Maintain spray water temperature of 60°– 70° F to maximize rinse efficiency • Employ a closed cycle mill process to minimize waste water production • Reuse rich white water in other applications • Use felt showers to minimize the amount of fresh water use • Recycle white water • Develop segregated sewer systems for low suspended solids, high suspended solids, strong wastes, and sanitary sewer • Improve process control to prevent spills of material • Minimize overflows or spills by installing level controls in process tanks and storage tanks • Install redundant key pumps and other equipment to avoid losses caused by equipment failure and routine maintenance • Provide a storage lagoon before the biological treatment system to accept long-term shock loads • Replace the chlorination stage with an oxygen or ozone stage • Recycle chlorination stage process water • Use water from the counter current washing system in the chlorination stage • Perform high consistency gas phase chlorination
Textile processing (SIC: 22)	• Fabric weaving • Milling • Sewing • Pressing • Dying	• Waste thread, yarn and material • Dye contaminated waste water	• Market waste material as clean-up rags • Recover dye from waste waters
Waste water treatment (SIC: 20, 22, 26, 28, 29, 31, 33-39)	• pH adjustment • Filtration • Mixing • Flocculating • Clarification • Polishing	• Treated effluent • Hazardous treatment sludge • Non-hazardous treatment sludge	• Use alternative flocculants to minimize sludge volume. • Use filter a filter press and drying oven to reduce sludge volume • Automatically meter treatment chemicals • Minimize contamination of water before treatment
Plastic formation (SIC: 30)	• Injection Molding	• Machine clean-out waste (pancakes) • Scrap plastic parts	• Maintain machines with a regular maintenance program to prevent oil leaks • Regrind and reuse scrap plastic parts

General industrial category	Unit operation	Common waste streams	Pollution prevention and recycle/reuse measures
		• Plastic pellet spill to floor • Spent hydraulic oil • Oil-soaked absorbent	• Filter and reuse hydraulic oil • Use and industrial vacuum for spill cleanup instead of absorbent
	• Extrusion	• Scrap end pieces	• Avoid contamination of end pieces and reuse as feed stock
	• Foaming	• Fugitive air emissions • Stack releases • Scrap foam	• Improved material handling (mixing and transfer) to avoid spills • Implement a regular maintenance program to reduce fugitive emissions from leaky valves and pipe fittings
	• Composite materials	• Empty resin and solvent containers • Spent cleaning solvents • Waste washdown water • Cleanup rags • Waste fabric • Gelcoat and resin overspray • VOC emissions • Waste resins • Resin and solvent contaminated floor sweeping	• Maximize production runs to reduce cleanings • Regenerate cleaning solvent on-site and reuse • Use less toxic and volatile solvent substitutes • Reduce transfer pipe size • Use more efficient spray method for gelcoat application • Modify material application methods to prevent material spillage • Cover solvent and resin container to minimize evaporative losses
Glass processing (SIC: 32)	• Melting • Blowing • Molding	• Scrap glass • Contaminated granular raw materials	• Avoid contamination of scrap glass and reuse as feed stock
Leather processing (SIC: 31)	• Tanning • Finishing	• Scrap leather material • Waste processing solution	• Recycle spent tanning solution
Fastening/ joining/ assembly (SIC: 24, 25, 27, 34-39)	• Gluing (adhesive) • Mechanical fastening • Welding • Part testing • Fluid filing	• Used adhesive container • Adhesive solvent air emissions • Dried adhesive • Shielding gas emissions • Metal slag • Gasoline (motor test) • Oil and grease spilled to floor • Spent clean-up rags or towels	• Purchase adhesive in bulk containers • Use water-based adhesives • Use more efficient adhesive applicators • Use a rag recycle service • Reuse rags until completely soiled • Use rags sized for each job

9.2. HAZARDOUS WASTES

It is a useful practice to divide waste into two categories, non-hazardous and hazardous. Each category groups waste according to one very important common denominator that determines to a large degree the way the waste is treated. Depending which category the waste belongs to, the proper method of disposal must be selected (sometimes the method is mandated by the law) and adequate funds made available. In most cases treatment of hazardous waste will be much more expensive than non-hazardous one. However, in many instances the process can be adapted to avoid hazardous waste generation, thus solving the problem at the source. For that reason, it is necessary that an auditor be familiar with different alternatives to common practices.

1. Non hazardous wastes
   Examples: cardboard, pallets, cooling water
   Disposal: landfill solids, sewer waste water

2. Hazardous wastes

Categories	**Examples**	
Corrosive	H_2SO_4	D002
Reactive	$NaClO_4$	D003
Ignitable	C_6H_6	F005
Toxic	Cr	D007

9.2.1. Types of Waste Generated

Everyday industry uses products containing hazardous materials:

- Rust removers, which contain concentrated acid or alkaline solutions
- Equipment cleaners, which contain flammable or combustible liquids
- Waste oil, lubricants, and fluids
- Spent solvents
- Spent caustic parts washing detergent solution
- Parts cleaning tank sludge
- Oily waste sump sludge
- Spent antifreeze
- Used rags, containing combustible or flammable solvents

- Paints with flammable or combustible thinners or reducers

9.2.2. Typical Operations Using Materials Which Generate Hazardous Wastes

Typical processes or operations that generate hazardous wastes are listed below with the type of waste produced.

1. Oil and grease removal generates:
    - ignitable waste,
    - spent solvents,
    - combustible solids, and
    - waste acid/alkaline solutions.
2. Parts and equipment cleaning generates:
    - ignitable waste,
    - spent solvents,
    - combustible solids, and
    - waste acid/alkaline solutions.
3. Rust removal generates:
    - waste acids, and
    - waste alkaline.
4. Paint preparation generates:
    - spent solvents,
    - ignitable wastes,
    - ignitable paint waste, and
    - paint wastes with heavy metals.
5. Painting generates:
    - ignitable paint wastes,
    - spent solvents,
    - paint wastes with heavy metals, and
    - ignitable wastes.
6. Spray booth, spray guns, and brush cleaning generates:
    - ignitable paint wastes,
    - heavy metal paint wastes, and
    - spent solvents.
7. Paint removal generates:
    - ignitable paint wastes,
    - heavy metal paint wastes, and
    - spent solvents

Remember, if a nonhazardous waste or material is mixed with a hazardous waste, the mixture becomes hazardous. For example, when a sawdust absorbent is used to clean up hazardous spills in a shop, the sawdust then becomes a hazardous waste. In addition, unused hazardous materials that become too old to be used also become hazardous wastes. Good management supervision and employee training will help reduce waste in these areas.

9.2.3. Hazardous Waste Generator's Responsibilities

- Identify and quantify hazardous wastes
- Determine Status: CESQG (conditionally exempt SQG), SQG (small quantity generator), LQG (large quantity generator)
- Comply with regulations
  On-site storage
  On-site treatment
  On-site disposal
  Transport
  Offsite disposal at approved TSDF
  Plan for accidents, emergencies
  Pollution prevention plan (CA)

Table 9.2: Pollution Prevention Regulations

STATUTE	Implications	Waste Streams Affected
Clean Air Act (1970, amended 1977,1990)	Permits	VOC emissions (Solvent evaporative losses)
Resource Conservation and Recovery Act (1976, amended 1984)	Shipping and disposal records	Waste ink Spent solvents Soiled rags and paper towels
Clean Water Act (1972, amended 1977, 1987)	Publicly Owned Treatment Works (POTW) compliance	Wastewater from image production, screen making and screen reclamation
Emergency Planning and Community Right-to-Know Act (1986)	Form R reporting	Waste streams containing chemicals listed in Toxic Release Inventory (TRI) document

9.3. WASTE GENERATION AND MANAGEMENT

Management of waste related activities, like any other activities, must be conceptualized before any action is taken. All the variables have to be known, including projected amount of waste in the future. The technologies available have to be evaluated. This represents landfills, pulverization, incineration, magnetic separation, paper and plastics recovery, composting, gasification, anaerobic digestion and so on. After evaluating all options, the overall strategy in waste management has to be formulated and should be based on the most beneficial technology available. It is advisable, since the economic and political climate might change, to review the chosen strategy periodically and with respect to all existing laws (especially new which could have been enacted after a strategy was selected).

9.3.1. Waste Reduction

To be successful, waste reduction programs must be organized. It is not hard to organize waste reduction, but owners and managers will need to spend a little bit of time at first to get started. Keep in mind the following seven principles of waste reduction.

1. Management must be committed to waste reduction for it to work.
2. Businesses should know the types of hazardous waste they generate, how it is produced, and how much is produced.
3. Businesses should know how the hazardous wastes are managed and how much present waste management costs.
4. “Good housekeeping” reduces spills and other waste.
5. Store different waste types in different containers.
6. Train all employees in hazardous waste handling and waste reduction methods.
7. Be aware of the hazardous materials regulations that apply to the business. Someone should be assigned to keep track of environmental regulations.

9.3.2. Record Keeping

As specified above, a waste generator has to keep a record. That will allow everybody to track individual substances according to the needs, should they arise. The record of movement of all hazardous substances through the plant, from one manufacturing cell to another, or simply as a material flow, is a very useful tool. The example given in Table 9.3 is a hypothetical printing operation with many steps that are typical for such an operation. In the reference section at the end of the chapter there is a lot of material about hazardous waste. It is always in the company’s interest to deal with the issue of hazardous waste according to all the regulations. The penalties for noncompliance are high, and in serious cases could even cause shutdown of the operation. In the beginning of this manual it is emphasized that the industrial assessments are not compliance assessments. However, it is to the benefit of the company to be informed of the consequences of noncompliance and the auditor’s job to help in solving problems related to waste and hazardous waste in particular.

Table 9.3: Inventory of Waste Streams

Stream Number	Plant/Process Source	Waste Stream Components	Approximate Annual Production
1	Raw materials receiving	Waste paper and cardboard	
2		Damaged pallets	
3		Scrap plastic protective wrapping	
4	Inventory control	Expired ink	
5		Expired photo-processing reagents	
6	Image production	Exposed film	
7		Silver recovered from wastewater before release	
8		Wastewater containing spent reagents	
9	Screen making	Scrap nylon mesh	
10		Waste emulsion	
11		Wastewater from emulsion rinse off	
12	Ink handling	Evaporated ink thinner	
13		Excess ink from special color mixing	
14		Empty ink containers	
15	Printing	Contaminated or dried ink	
16		Scrap paper	
17		Solvent-wetted and soiled paper towels	
18		Scrap vinyl	
19		Scrap PVC	
20		Scrap Polycarbonate	
21		Contaminated solvent cleaner	
22		Evaporative loss of solvent cleaner	
23		Contaminated alcohol cleaner	

24		Evaporative loss of alcohol cleaner	
25	Special coating process	Scrap urethane film	
26		Empty urethane containers	
27	Plant and equipment cleanup	Solvent-wetted and soiled paper towels	
28		Waste mop water from floor cleaning	
29	Product shipping	Waste cardboard	
30	Screen cleaning	Ink remover	
31		Emulsion remover	
32		"Haze" remover	
33		Rinse water	
34		Solvent-wetted and soiled paper towels	
35		Damaged screens	
36	On- and Off-site materials recycling	Scrap PVC (ground onsite)	
37		Reclaimed polycarbonate sheets	
38	Office functions	Waste paper and cardboard	

9.4. MAIN WASTE STREAMS

The five main waste streams generated by industry include:

- Solvent wastes
- Water-based (aqueous) wastes
- Paint wastes
- Used oils
- Miscellaneous wastes

9.4.1. Solvent Wastes

Parts cleaning operations usually generate spent solvent waste in the form of solvent sink mineral spirits and immersion cleaner solvent. Other solvents may include other types of degreasers and paint thinners. If generators spill these materials or use them for purposes other than parts cleaning, degreasing or removing paints, they may generate additional unnecessary waste. Solvents also evaporate easily. The use of solvent sinks for parts washing either on an owned or leased basis is being accepted as general good practice. Solvent reuse and waste containment are ideal features in this practice. The economics of the contracted service are also favorable, considering the current on-site labor costs for equipment maintenance and off-site disposal. The addition of drip trays to both solvent sinks and hot tanks would be beneficial to capture any losses. These are due to spillage as well as unauthorized uses (i.e. floor cleaning) for the solvent where the solvent is not recovered.

9.4.2. Water-Based (Aqueous) Wastes

Aqueous hazardous wastes refer to water-based detergent wastes and waste sump solids that are hazardous because they contain caustics, high levels of metals, and/or oily dirt. These wastes are typically generated by parts washing equipment.

If a business uses a jet spray washer, hot tank, or spray cleaner, it probably generates an aqueous detergent waste, aqueous caustic detergent waste, and/or waste sump solids. The majority of the heavy metal residue, oil and grease removed from hot tank operations occurs after the actual hot tank use. The heavier concentrations of waste residues are found in the waste sump. Standard practice currently is to use a high-velocity spray wand to dislodge these wastes as necessary. This can be done by use of a solids collection tray with overflow to the sump or periodic cleanout of the sump by a waste hauler for disposal at a permitted TSD facility. The bulk of the oil, grease, and heavy metal residues that are removed in jet spray parts cleaning operations. This occurs with the initial exposure to the wash solutions. In certain repair operations where there are a substantial quantity of parts to be processed, a two stage cleaning operation would provide clean parts in shorter times by using two washing devices in series. The first device would remove the heaviest residue, and the second device would provide the finish cleaning. The following are reduction practices concerning these types of wastes.

- Use a jet spray with a detergent only solution instead of a caustic-based solution. This trend is continuing with the change-over to aluminum parts in place of ferrous metals which require caustic solutions. The waste solution from the washer is hazardous if it contains metals or oily dirt. Consider pre-washing parts to reduce contamination of the washing solution. Or, try using two hot tanks, one with detergent solution only for aluminum parts, and one containing caustic detergent solution for all other types of parts.

- Place an inexpensive steel tray or pan next to the tank and drain the parts in the tray for a few minutes after cleaning them. Carefully empty any detergent remaining in the tray back into the tank.

- Designate a set of bays as primarily intended for service requiring hot tank or jet spray parts cleaning and locate the equipment near these bays. This will help reduce spills and drips within the shop, reducing floor cleaning waste.

- To extend the life of the cleaning solution and clean parts faster, consider an extra tank which would contain partially spent solution for rinsing most of the dirt and grime off the parts. Or, use a non-heated tank with partially spent solution for pre-rinsing.

- If a hot tank does not have heating elements on the bottom of the tank, the solids can easily be removed from the solution to extend the life of the cleaning solution. If the cleaning solution has become weak, the solution can be tested and more detergent or caustic material added as needed. Some equipment leasing services will provide this maintenance service for the tanks the business owns.

- Screening the solids before they reach the sump will reduce future sump cleaning costs.

- A leased system can be easier to use since new detergent compounds, tank maintenance, and waste management are included in the price of the service. A disadvantage to leasing is that it can be costly.

- Purchasing equipment is another option for parts cleaning. However, a business must make certain that its waste storage, transportation, and disposal techniques are safe and legal. Some equipment leasing services will provide raw material supply and waste removal services for tanks that the business owns.

- If a business owns parts cleaning equipment and transports the waste off-site for recycling, treatment, or disposal, the generator must have a registered hazardous waste hauler remove the aqueous caustic detergent waste.

- If the plant is large and owns a hot tank or jet spray washer equipment, an on-site aqueous waste treatment system may be cheaper than off-site disposal.

9.4.3. Paint Wastes

One of the most direct means of reducing paint waste is to use low-toxicity paints, i.e. water-based or non-metal products. Using water based paints helps to reduce the use of organic solvents, which become hazardous wastes and also a source of air pollution. Another approach the waste reduction is to use mechanical paint stripping. Substituting with bead blasting or cryogenic coating processes can help avoid caustics and solvents.

Various approaches to improve paint application:

- Segregating paint and solvent waste from other trash
- Purchasing paints only in quantities needed (to avoid discard)
- Reducing overspray

- Controlling paint quality to avoid defective batches requiring stripping and repainting
- Scheduling and sequencing paint operation more efficiently to reduce clean-up frequency

9.4.4. Used Oils

There are several oil loss reduction practices and used oil recycling technologies that may be useful for minimizing the disposal of waste oil. Oil wastes are generated primarily by the following industrial applications.

- Oil and grease removal in vehicle maintenance
- Waste oil from plant equipment maintenance
- Cleanup operations in industries

The amount of oil generated in a particular process can be decreased or sometimes eliminated by modifying or completely changing a given process. Water-based coolants and fluids often perform equally or better than similar oil-based fluids. Waste oil concentrated at the source of generation helps to segregate types of oils and oily water and reduces the risk of contamination with other hazardous materials.

Simple treatment, such as gravity settling, promotes the separation of oil/water wastes to substantially reduce the volume of waste oil. Avoid using more of the oil product than is necessary and adopt practices for using and re-using materials as much as possible.

As in many cases, adopting better housekeeping practices, which require very little cost, can have a large effect on the amount of waste oil produced. Some of these practices include:

- Avoiding contamination of used oils with other liquids, both hazardous and nonhazardous. A cleaner waste oil has more value in the marketplace.

- Preventing spills - Using properly designed storage tanks and documenting the dollar value of any spillage which does occur can lessen the probability of a spill.

- Look for creative uses; a waste oil generated in one process can sometimes be used in another.

- Installing collection/drip pans - Placing pans under machinery and lubrication operation will allow for the recovery of oils instead of their disposal with absorbents or rags.

- Examine types of oil wastes periodically; new products enter the market constantly which can offer savings as well as performance.

- Laundering oil-soaked rags - During laundering, oil can become biodegradable.

- Using rags and adsorbents to their limit - Adsorbent and rags are often thrown out before their useful life is over. Using them to capacity reduces the volume of contaminated adsorbents.

9.5. SOURCE REDUCTION AND RECYCLING

The following picture shows graphically the hierarchy of waste minimization. The way the problem is attacked is in a sequence from left to right as seen in the picture.

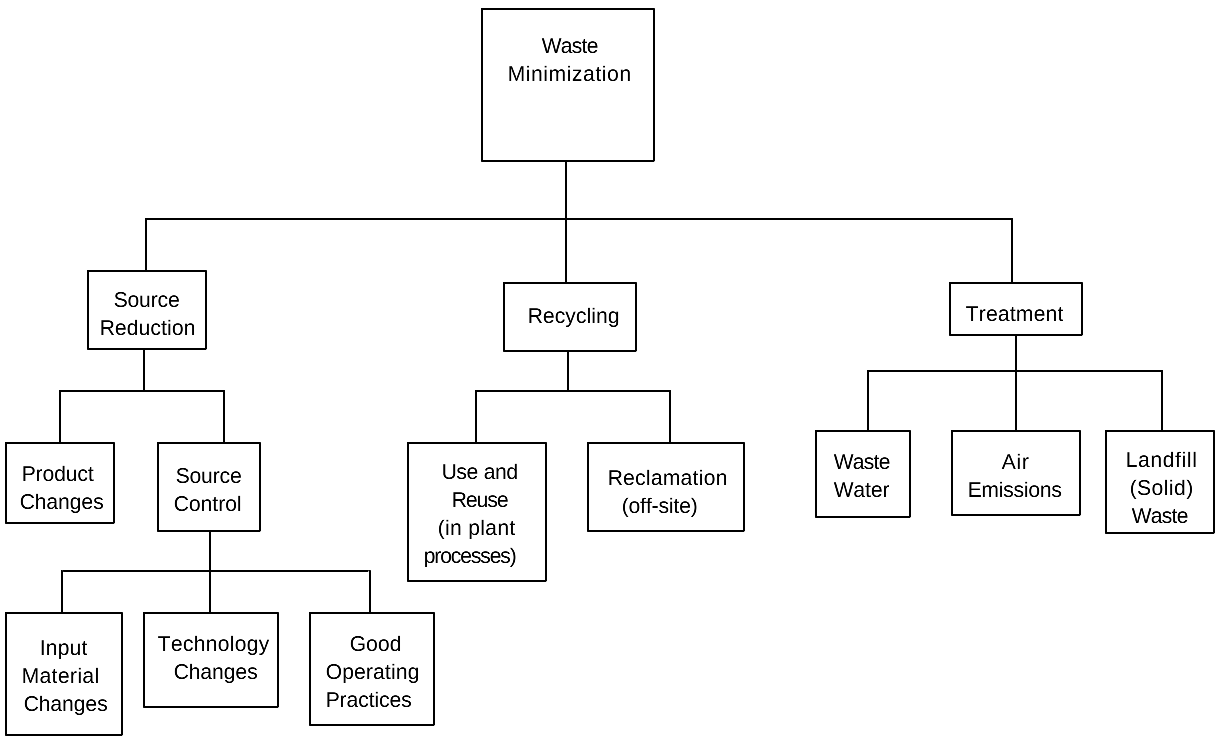

Figure 9.1: Hierarchy of Waste Minimization

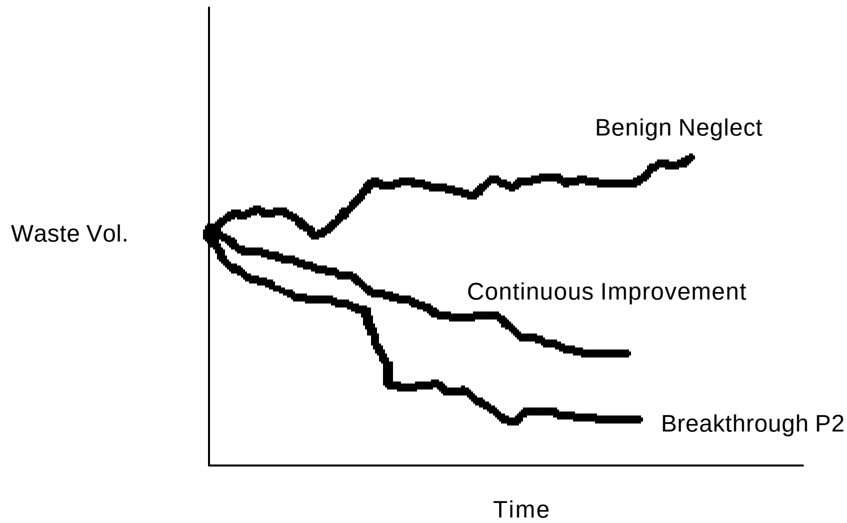

Figure 9.2: Barriers

Figure 9.2 shows how pollution prevention efforts relate to the actual volume of waste. It is much more difficult to handle the situation when the waste accumulates or nobody pays attention to the problem for a long time. Timely active response is essential.

9.5.1. Strategies in Waste Reduction

Different strategies bring different results. The following diagrams emphasize the sequence which is the easiest to take in the waste minimization efforts. The simplest step is also the cheapest to implement and gives the fastest return on investment.

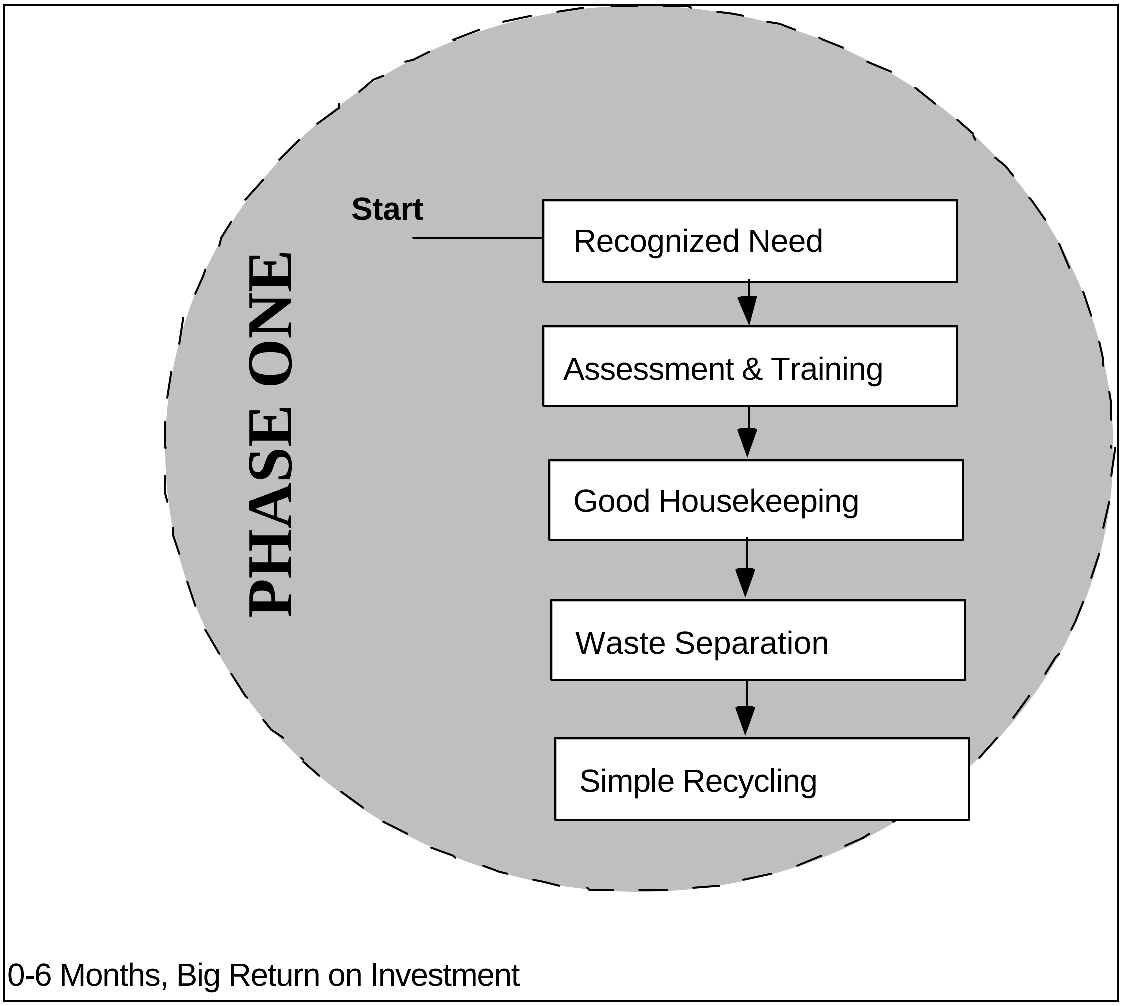

Figure 9.3: Waste Reduction - Operation Phase

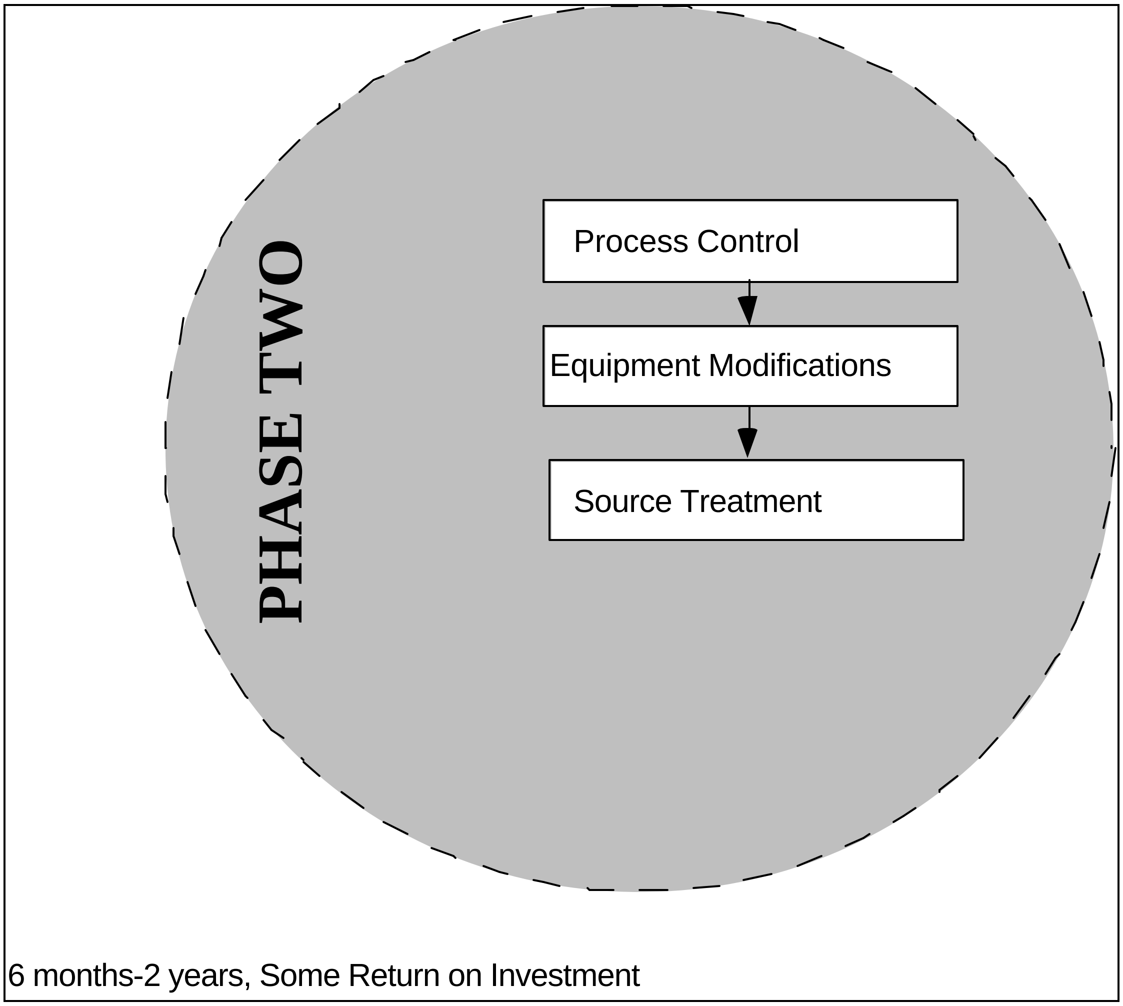

Figure 9.4: Waste Reduction - Equipment Phase

There is a parallel between Total Quality Management and Pollution Prevention. Most of the time, companies conscientious about quality are also taking care of their waste and it can be expressed even in a similar philosophy of both programs.

TQM	P2
Customer Satisfaction	Stakeholder Satisfaction
Continuous Improvement	Continuous Reduction
Management by Measurement	Monitor Waste
Maximize Productivity	Minimize Waste
Zero Defects	Zero Emissions

Table 9.4: Parallel Paradigms

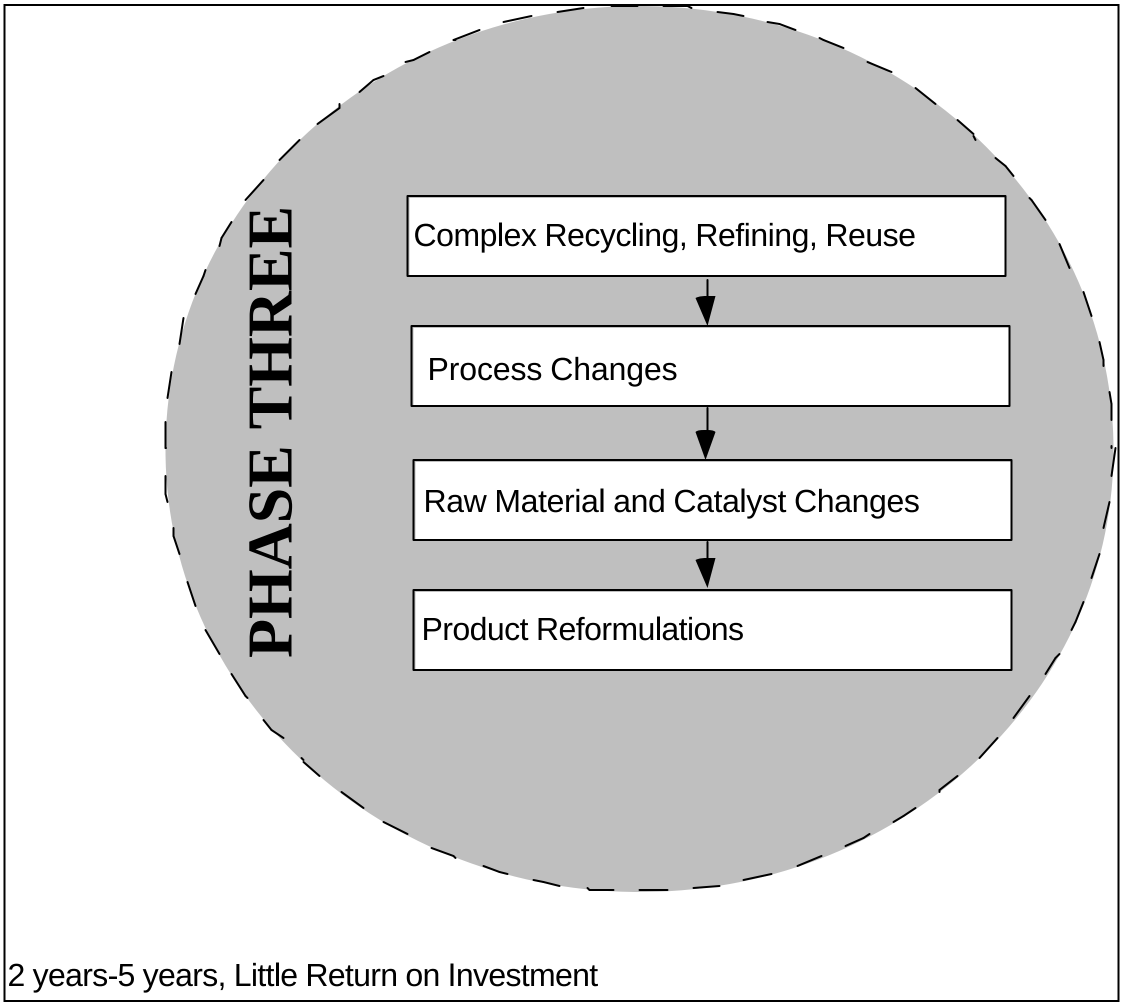

Figure 9.5: Waste Reduction - Process Phase

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10INDUSTRIAL WASTE

10.1. PAINTING AND PRINTING

Parts have to be painted for reasons of corrosion protection, differentiation and aesthetics, to name just a few. Most paints today are solvent based and are applied by liquid spray method. The paint is mixed with carrier and then sprayed onto a surface with an air pressurized spray gun. Most carriers are organic solvent based. During this process two waste components are generated: waste solvents and paint sludges. The paint sludge is normally the larger one of these two. It is generated when overspray happens and solvent dries. The recovery of this component typically happens in the scrubber sump. The second waste is generated during the cleaning process.

Printing industry faces a similar problem. Unused inks or paper with ink residues and then solvents used to clean the presses and other equipment. In both cases VOC is also present. Alternatives discussed in the following chapters can be of significant help in reducing all hazardous pollutants.

10.1.1. Paint Wastes in Metalworking Industries

1. Some practical considerations

   Painting is a necessary operation for corrosion protection. It is usually the largest source of waste in the plant. Most of the plant managers were sold on at least one of these "sacred cows":

   -Do not try to change the way painters do things.
   -Paint waste is an inevitable part of the product cost.
   -If it ain't broke, why try to fix it?

   What must be done before you can successfully reduce painting wastes?

   -Focus management's attention onto the <u>true</u> <u>costs</u> of paint wastes.

2. Common problems to get management's attention:

- VOC emissions:
  - purchase price of solvent;
  - close to permit limits?
  - could the limits be increased?
  - how much additional production could be taken on before exceeding limits?
- Special wastes:

- paint booth strapping
- booth filters and lining material
- water-curtain skimming

- Wastewater:
  - If operating a treatment plant, is "goop" from booth curtain causing problems?
  - If discharging to a publicly owned treatment works (POTW), are you paying surcharges for bod, cod, or metals?

- Cost accounting:
  - Few companies have ever really put together the full story on paint waste costs

3. What happens when management reconsiders painting?

Company A:
- figured true cost of "low-cost" product line

Company B:
- collect powder-paint from cleanouts for use on items needing protection, but not appearance-sensitive

Company C:
- collect paint leftovers and use it on hidden structural parts

Company D:
- works with paint supplier to recycle paint
- actively markets using recycled paint

Company E:
- rebuilt paint room to handle color changes
- replaced solvent pre-cleaning with aqueous
- revised spray system for low-voc paints
- installed thinner recovery system
- found a way to re-use solvent still bottoms

10.1.2. Reduction in Paint Waste

Over the past decade people have learned that either burying or burning hazardous waste is a problem. In recent years, Congress and the EPA have emphasized effective treatment of hazardous waste prior to its land disposal. Treatment alone, however, will not remedy all hazardous waste problems. The reduction of waste generation, recovery and reuse is essential. As a result, the need for treatment, storage and disposal of waste will be reduced as well.

Virtually every painting process involves hazardous materials or produces hazardous waste. Waste reduction, though not inexpensive, will conserve our nation's resources and protect public health and the environment. At the same time it will probably save business's money in a long run.

Over the past two decades, an increased awareness has developed of harmful effects to human health and the environment from uncontrolled releases of hazardous substances and wastes as pollutants. Everybody has to pay attention to preventing hazardous wastes problems by cutting down on generating the waste at its source. Preventing the generation of hazardous waste is inherently preferable to controlling it after it is generated. The following quotation reflects the national policy formulated by the US Congress:

> "The Congress hereby declares it to be the national policy of the United States that, wherever feasible, the generation of hazardous waste is to be reduced or eliminated as expeditiously as possible. Waste nevertheless generated should be treated, stored, or disposed of so as to minimize the present and future threat to human health and the environment."

Paint Application

Most paint application wastes are caused by either paint overspray, or the paint not reaching the target. The amount of overspray results from the design and operation of the system used. The efficiency of some of the systems used is listed in Table 10.1.

PAINTING METHOD	TRANSFER EFFICIENCY [%]
Conventional air atomized spray	30-60
Conventional pressure atomized spray	65-70
Electrostatic air atomized spray	65-85
Electrostatic centrifugal atomized spray	85-95
Powder coating	90-99
Roller/Flow coating	90-98

Table 10.1: Transfer Efficiency in Painting

Some general recommendations follow:

- Use equipment with low overspray. Implementation of better employee operating practices are essential in cases when the spray systems are operated manually. Proper training of operators and all personnel who work with the painting machinery promotes waste reduction. The good condition of an application equipment reduces waste and produces better finish as well.

Therefore, preventive maintenance is extremely important. All parts should be periodically, or as necessary, cleaned. Also lubricate in places recommended by the equipment manufacturer.
- To avoid overspray keep air pressure as low as possible and position the spray gun perpendicular to the surface.

Paint Stripping

Paint stripping comes into a picture when a bad finish has been produced, the coating has to be removed and the process of painting repeated. Many paint stripping wastes are generated because of a failure of the system. Some waste reduction methods are listed bellow:
- Inspect parts. The surfaces must be clean and dry with no rust.
- Avoid overspray by using proper painting technique.
- The maintenance of the equipment is essential.
- Use non-phenolic strippers to reduce toxicity associated with phenol and acid additives.
- Locate solvent soak tanks away from paint curing ovens to reduce the adverse effect of solvent on a painted surface.
- Use mechanical (cryogenic) paint stripping with plastic bead blasting to handle parts made of soft metal. Such items are inappropriate for sand blasting or glass bead blasting.

Solvents and Thinners

It is very desirable to reduce solvent emissions produced by evaporation from process equipment and coated parts. At the same time the subject of solvent recovery is of utmost importance. The following measures can reduce either:

- Keep solvent tanks from heat sources.
- Use high solids content formulations.
- Use powder coating techniques.
- Use water based paints.
- Reuse cleaning solutions and solvents.
- Try to minimize variety of solvents in use.
- Sequence batches from light to dark.

Waste Reduction Technologies In Painting

- High Transfer Efficiency Paint Application

Problem:	overspray
Solution:	HVLP paint guns
Benefit:	reduced paint consumption (CA. 25%)

Disadvantages: cost, applicability, operator, training

- Gun Cleaning

  Problem: solvent air emission from gun cleaning
  Solution: enclosed paint gun cleaners
  Benefit: reduced solvent consumption
  Disadvantage: start-up cost

- VOC Emissions

  Problem: VOC emissions from high-solvent paints
  Solution: water-borne and high-solids paints
  Benefits: reduced emissions, solvent wastes
  Disadvantages: availability, corrosion, drying

- Spent Clean-Up Solvents

  Problem: management of hazardous waste
  Solution: recycle with solvent recovery unit
  Benefits: reduced expenditure
  Disadvantages: waste segregation, energy, labor, nitrocellulose explosion hazard

10.1.3. Minimization of Waste in Printing Operations

Image Processing

The primary waste streams are wastewater containing photoprocessing chemicals and silver dissolved from film development. Most chemicals are biodegradable and discharged into the sewer lines. Permits are required and biochemical oxygen demand (BOD) is monitored. Silver should be recovered and mercury specially handled if present.

Plate or Cylinder Processing

Photographic processes are used in all of the major printing operations for image conversion and plate making. Photographic wastes therefore comprise a large portion of the hazardous waste generated in these industries. Photographic processing solutions, developers, hardeners, plating chemicals, fountain solutions, or fixing baths that are sent to publicly owned treatment works ("POTW) for disposal, however, are exempt from new RCRA requirements. Silver containing solutions that pass through electrolytic chemical replacement, or ion exchange silver recovery units located on the premises are exempt in a similar fashion. However, if the wastes are sent off site for recycling, they must be accompanied by the Manifest.

Printing Process

In the printing operations the waste is mostly the printing ink. The solid wastes include waste paper from printing imperfections, web breaks and tears, paper at the end of the web, overruns, paper wrappers, cardboard cores and miscellaneous solid wastes. In addition there are used ink containers, used plates, damaged or worn rubber blankets, waste press oils used for lubrication, cleanup solvents and rags.

Material Handling and Storage Options

Good practices can reduce or even eliminate waste resulting from obsolescence and improper storage.

- The proper storage conditions will guarantee stated shelf life of many chemicals.
- Reusing rinsewater as long as possible.
- Use marbles in small scale photo developers to bring up the liquid level.
- Keep the storage area clean to prevent contamination.
- “First-in-first-out” prevents missing expiration dates.
- Raw material should be ordered in just-in-time fashion as much as possible.

Solid Waste

A portion of the solid waste generated by the printing industry is non-hazardous. These wastes should be managed using reduction techniques and source reduction.

- Used lithographic plates should be sold for aluminum recycling.
- Recycle empty containers.
- Recycle spoiled photographic film and paper.
- Install web break detectors.
- Monitor press performance.

Wastewater Options

The toxicity of wastewater from plating operations can be reduced by dragout reduction. Examples of different options follow.

- Position the part on the rack to drain more easily.
- Use drain boards to collect dragout and return it to the plating tank.
- Raise temperature to reduce surface tension of the solution.

Other waste reduction options include:

- Material substitution where possible.

- Wastewater reduction by counter-current washing, using squeegees to wipe off excess liquid and extending the bath life.
- Silver recovery and spent chemicals reuse.
- Removal of heavy metals.

Cleanup Solvents and Waste Inks

Ink recovery machines are currently on the market and come in variety of sizes. Another possibility might be to send the waste ink back to the manufacturer for black ink production. Solvents can be recovered by simple batch distillation if quantities justify the purchase of the equipment, otherwise could be recycled with professional recyclers.

- Segregate spent solvent and inks according to the color.
- Use as little solvent as possible.
- Schedule jobs using light colors first, possibly reducing the necessity for cleaning.
- Save unused ink for the future
- Try to prolong life press wipes by using the dirty ones for the first passes.

§ *Case Study of Screen Printing Plant*

<u>Process Description</u>

This plant uses screen printing to produce, in several varieties and color schemes, fleet (transportation truck) decals, beverage dispensing machine colored panels and toothbrush backings. Raw materials include plastic sheets, rolls and spools of plastic stock, inks, adhesives, urethane and various other chemicals and solvents related to image production and printing operations.

The printing process begins with the plant receiving a mylar sheet with a positive image, paper copy, or a computer file from clients. Some artwork is done in-house. Images received on a computer disk, and other images developed on-site, are processed in a computerized system to yield a mylar positive. The image sheets are then transported to the screen-making department.

Printing screens range from 2 inches by 4 inches to 4 feet by 10 feet in overall dimension. To produce a new screen, mesh material is unrolled, cut to size then stretched and mounted on rectangular aluminum frames.

Screen images are produced in several steps. First, large screens are coated with a photo-sensitive emulsion in an automated system. Emulsion is applied to smaller screens manually. Coated screens are then covered with mylar sheets containing positive images and are placed on a "burn table" which exposes screens to ultraviolet light for a specified period of time. That hardens the emulsion through transparent areas exposed to light. After exposure, screens are removed from the "burn table" and the uncured emulsion is washed away with a warm water high-pressure spray.

A prepared screen is mounted horizontally on a press, and ink is troweled into an above-screen reservoir. Ink used in printing is received in 3 to 5 gallon containers from which it is used directly or is blended to customer specified colors in an ink-mixing area. During printing, a mechanical "wipe" moves across the screen and forces ink through porous areas onto substrate sheets. Subsequent use of other screen images in a set produces a multi-colored image on the sheets. After printing, the substrate is placed on a conveyor for transport through an ink-curing oven. After curing, some of the printed substrates are coated with an adhesive or a thin urethane film followed by heat-curing. Finished materials are inspected, packaged and shipped to customers.

At the end of a printing run, screens are cleaned for reuse. Initially, excess ink is removed from screens with a putty knife. Next, they are hand-wiped with solvent-wetted paper towels while still positioned on the press. After surface ink removal, screens are removed from presses and are transported to a screen washing room. In this room, screens are positioned upright over a trough and ink-remover, and occasionally a "ghost" image remover is brushed into screen material, followed by a high pressure heated water rinse. In cases where it is not required to save a screen image, an emulsion remover is used to remove hardened emulsion. Clean screens are allowed to air dry and are returned to storage for future use.

<u>Inventory of Waste Producing Operations:</u>

1. Raw material receiving
2. Inventory control (expired raw materials)
3. Image production
4. Screen making
5. Ink handling
6. Printing
7. Special coating processes
8. Plant and equipment cleanup
9. Product shipping
10. Screen cleaning
11. On and Off-site materials recycling
12. Office functions

<u>AR Example</u>

1. Products produced in plant:

   Screen printed plastics sheets and film

2. Selected waste producing process:

   Ink cleanup utilizing liquid solvents that are currently removed from paper towels with use of a wringer, collected in 55 gallon drums, and shipped off-site as a hazardous waste.

3. Waste streams generated:
   - Contaminated liquid solvents (alcohol and solvent cleaners)
   - Solvent evaporation during handling
   - Soiled paper towels

4. Waste stream(s) selected for reduction:
   - Waste liquid solvents (alcohol and solvent cleaners).

5. AR identification, evaluation, and selection:
   - Extend printing runs to minimize clean-up operations (insufficient information).
   - Eliminate use of solvents by using a water-based ink (technical feasibility questions).
   - Install a distillation unit for recovery and reuse of solvent and alcohol (selected for recommendation).

6. Outline of AR analysis:
   Reduction in Waste Amounts:
   - (Amount of solvent shipped off-site/yr)(% of solvent recoverable through distillation) = Solvent waste reduction/yr.
   - (Amount of alcohol shipped off-site/yr)(% of alcohol recoverable through distillation) = Alcohol waste reduction/yr.

   <u>Cost savings associated with waste reduction:</u>
   - (Solvent waste reduction/yr)(Purchase cost/lb for solvent) = Solvent raw material cost savings/yr
   - (Alcohol waste reduction/yr) (Purchase cost/lb for alcohol) = Alcohol raw material cost savings/yr
   - (% of total hazardous waste (HW) adm. time spent on solvent and alcohol)(Cost of HW adm. time/yr)(% of solvent and alcohol recoverable through distillation) = Administrative cost savings associated with solvent and alcohol/yr
   - (% of total HW labor costs associated with solvent and alcohol)(Total HW labor costs/yr)(% of solvent and alcohol recoverable through distillation) = Labor cost savings associated with solvent and alcohol/yr.
   - (% of solvent recoverable through distillation)(Amount of solvent shipped off-site/yr)(Cost of solvent HW shipment) = Off site removal cost savings for solvent/yr.
   - (% of alcohol recoverable through distillation)(Amount of alcohol shipped off-site/yr)(Cost of alcohol HW shipment) = Off-site removal cost savings for alcohol/yr.

7. Sources of needed data:
   - Amount of solvent shipped off-site/yr (from purchasing records)
   - % of solvent recoverable through distillation (estimated by assessment team).
   - Amount of alcohol shipped off-site/yr (from purchasing records)
   - % of alcohol recoverable through distillation (estimated by assessment team).

- Purchase cost/lb for solvent (from purchasing records)
- Purchase cost/lb for alcohol (from purchasing records)
- % of total HW administration time spent on solvent and alcohol (estimated by plant manager)
- Cost of HW administration time/yr (estimated by plant manager)
- % of total HW labor costs associated with solvent and alcohol (estimated by plant manager)
- Total HW labor costs/yr (estimated by plant manager
- Amount of solvent shipped off-site/yr (from shipping manifests)
- Cost of solvent HW shipments (from shipping manifests)
- Amount of alcohol shipped off-site/yr (from shipping manifests)
- Cost of alcohol HW shipments (from shipping manifests)

8. Calculations:

Reduction in waste amounts:

- (78,936 lbs/yr)(90%) = 71,042 lbs/yr reduction
- (42,504 lbs/yr)(90%) = 38,253 lbs/yr reduction

Cost savings associated with waste reduction:

- (71,042 lbs/yr)($0.55/lb) = $39,073/yr savings
- (38,253 lbs/yr) ($0.35/lb) = $13,388/yr savings

10.2. *METALWORKING*

In order to provide friction reduction and cooling of the machined part as well as the tool bid, coolant fluids are introduced into a point of application. The fluid also helps to remove metal particles (chips). The fluids can be categorized into: straight oil based, synthetic or semisynthetic and soluble oil. Today the most common are soluble oil coolants. Water is the major ingredient of these oils. The attempt should be made to reduce the volume of metalworking fluids. The way to do that is to introduce reconditioning and recycling of the fluids.

10.2.1. Sources and Nature of Coolant Waste

1. Outdated or contaminated raw materials (coolant concentrate, additives)

   - Rare occurrences

2. Spills and "splatter loss"

- Use of paper towels or rags to wipe-down machine surfaces; may be disposable with landfill waste.
- Use of absorbents on floor to collect liquid coolant; may be disposable with landfill waste.
- Mop water from floor cleanup; may be added to liquid coolant waste shipped off site or discharged into a sewer (if allowable).

3. Dragout on workpieces and metal shavings

4. Evaporation of volatile substances (e.g., water) at all air interfaces

   - Periodic need to add make-up reagents (e.g., water).

5. Degradation of use characteristics

   - Physical contamination with tramp oil, dust and debris.
   - Bacterial contamination: offensive odor (rancidity) discourages continued use.
   - Incorrect off-specification formulation.

10.2.2. Measures for Reducing Metalworking Coolant Waste

1. All waste streams
   - Redesign products to eliminate some or all machining steps
   - Utilize "dry" metalworking (e.g. grinding) where feasible

2. Outdated raw materials
   - Improve inventory control

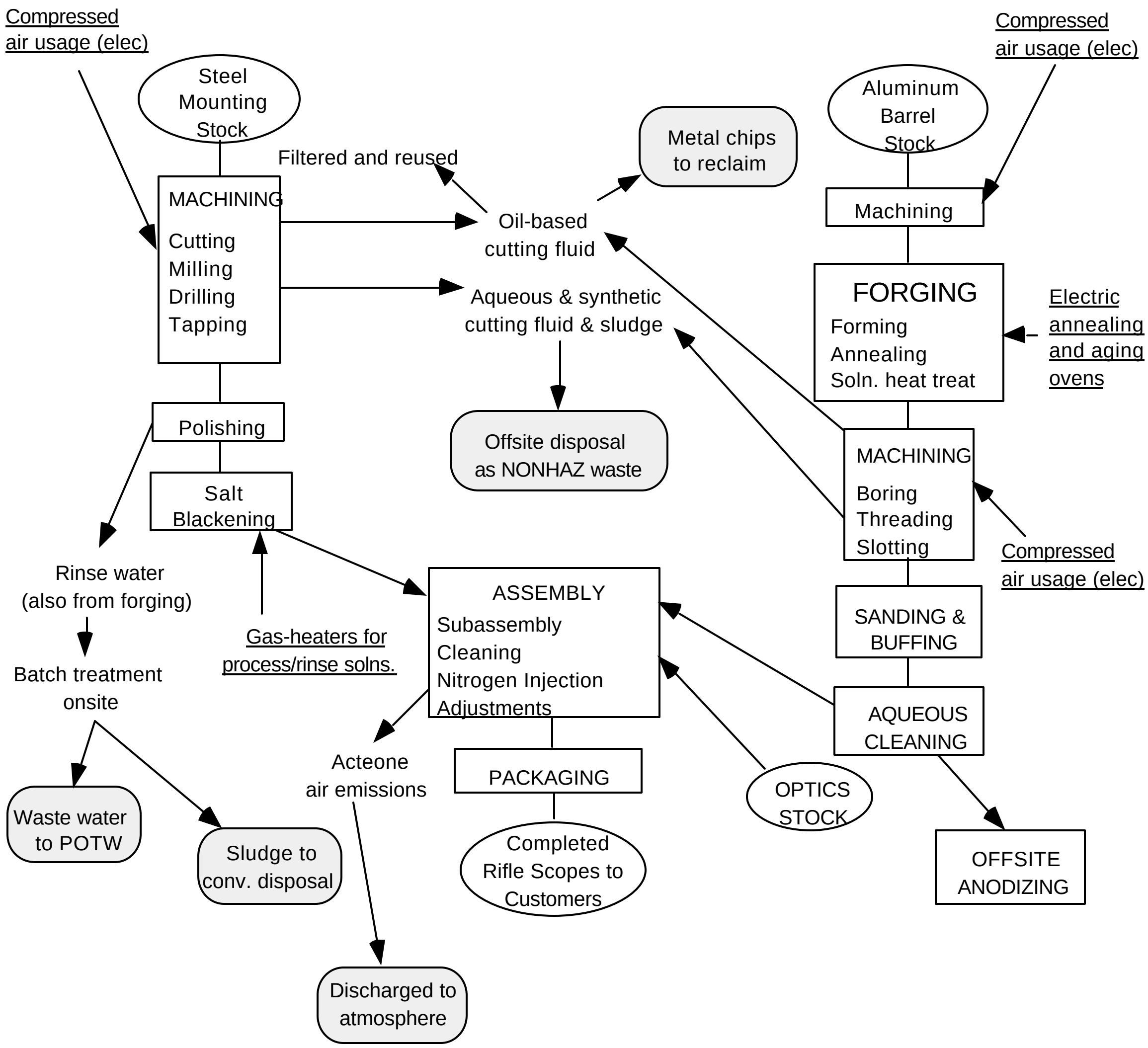

Figure 10.1: Process Flow Diagram for Metalworking Industries

3. Spills and "splatter loss"

Spills

- Improve materials handling methods

Splatter loss

- Install splash-guards on equipment
- Reposition coolant nozzles to minimize splatter loss
- Reduce coolant flow rate onto workpiece

4. Dragout on workpieces and on metal shavings
- Drain and recycle coolant collected in shaving containers
- Centrifuge shavings and recover coolant for reuse

- Use lower viscosity coolant

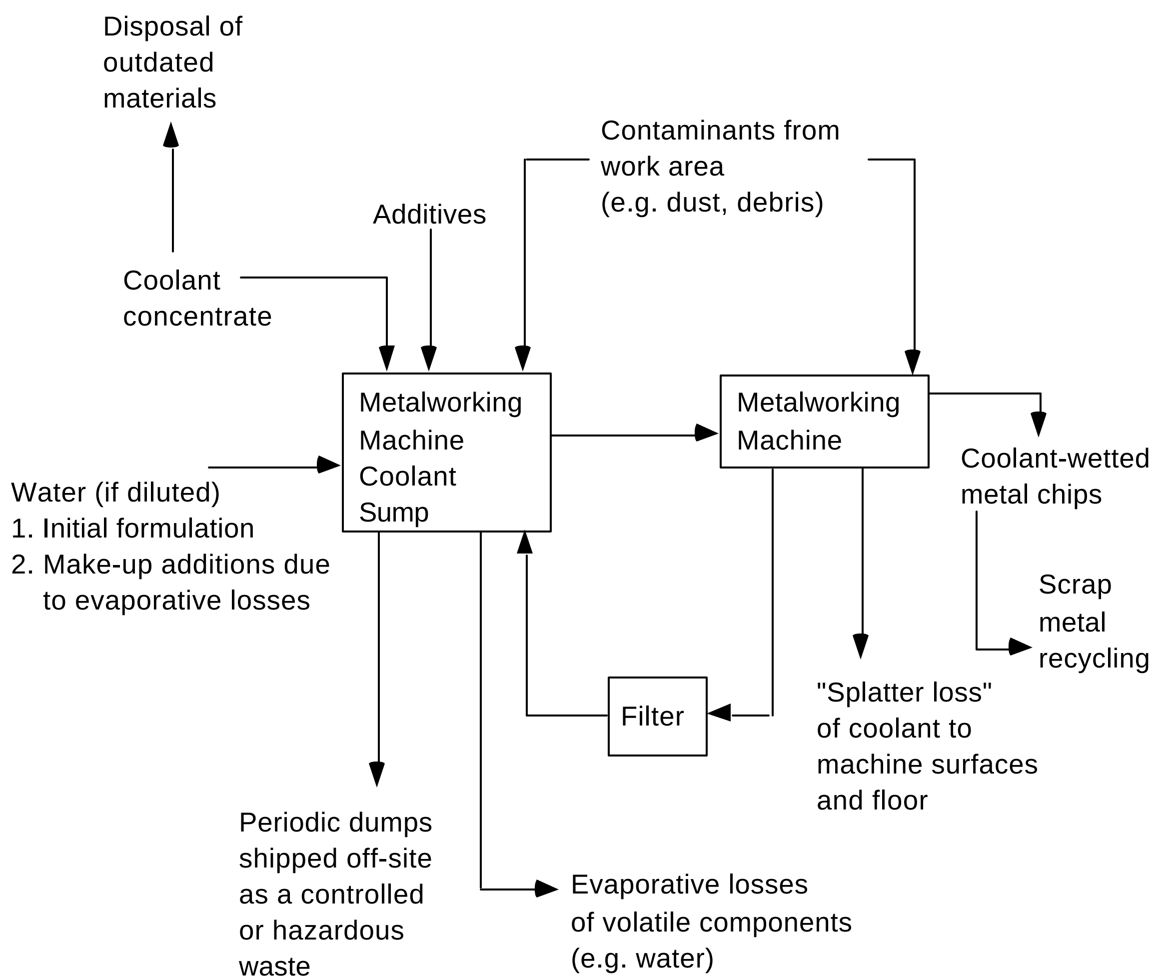

Figure 10.2: Metalworking Coolant Material Flows

5. Evaporative losses

   - Cover coolant sump tanks
   - Minimize coolant heating (Add insulation, actively cool)

6. Degradation of coolant characteristics

   Extend coolant life by:
   a) Optional formulation and reformulation
      - Maintain water quality: testing and treatment
      - Maintain proper concentrations of active ingredients: periodic testing

b) Prevent contamination
   - Cover coolant sump tanks
   - Degrease metals before machining (may generate new waste streams)

c) Remove contaminants (Self-contained systems available)
   - Oil: absorbents, skimmers, coalescers, aeration, porous media separators, centrifugation
   - Participants and metal fines: filtration, settling, coalesces, cyclones, centrifugation, magnetic separators
   - Bacteria: pasteurization, add bactericides, timely removal of metal chips and fines, agitate coolant in sumps

7. Disposal of waste coolant

   Reduce volume of waste water-based coolant shipped off site

   a) Treat chemically to allow discharge into a sewer
   b) Physical pretreatment to allow water discharge into a sewer: ultrafiltration
   c) Use evaporator to reduce waste stream volume

10.3. CLEANING AND DEGREASING

The way to clean surfaces of grease, oils, and other organic substances is to employ an organic solvent. During the process of cleaning substantial volume of pollutants is generated. The pollutants can be classified into two categories. The liquid waste solvent and degreasing agents which serve as carriers for unwanted organic matter, and emissions to the air containing volatile cleaners. The industry uses cold cleaning, vapor degreasing, and precision cleaning. Cold cleaning means simple dipping of a part into a solution of a solvent or applying it onto a part with a brush or cloth. Vapor degreasing uses dedicated equipment where the solvent is heated to a point of boiling, producing solvent saturated vapor. The part is being inserted into the area, vapor condensates on the surfaces of the part, and drips down back into the liquid bath taking the grease with it. Precision cleaning is used for instruments or electronics. The solvents have to be pure and evaporate very rapidly.

10.3.1. Solvents

A main focus of this chapter is on solvent wastes primarily because solvents are widely used in industry and because of their effect on human health and the environment. Solvents used in industry are essentially organic compounds such as aliphatic or aromatic hydrocarbons, esters, ethers, ketones, alcohol, amines, halogenated hydrocarbons. Not only are many of these solvents toxic to living organisms, but the very same properties that make them useful are responsible for their potential threat to the environment and human health. In particular, their high volatility results in air emissions which can cause air pollution and flammability problems at disposal sites. The hazardous constituents of solvents persist in the environment. Finally, land disposal of solvent wastes is a problem because of the solvents' ability to dissolve or penetrate polymeric liners and to dewater clay liners.

A hierarchy for solvent waste reduction would include:

1. Source Reduction - focuses on in-plant changes that can be made to either reduce or eliminate the generation of the solvent waste. This alternative is the most preferable water management option, and should be explored first.
2. Recycling - refer to the reuse of a wastestream substance as an ingredient or feedstock in a production process, or reclamation of a waste material, involving recovery of reusable constituent fractions. Recycling is less preferable than source reduction, and should be explored second
3. Treatment - refer to destruction of wastes through the use of technologies such as biodegradation, fixation, and incineration. Treatment is the least preferable option of the three components of waste reduction, and should be explored after source reduction and recycling alternatives are addressed.

Source reduction, recycling, and treatment practices all serve to either reduce the volume or the toxicity of wastes that are generated and ultimately lad disposed. Technically and economically feasible source reduction, recycling, and treatment methods for solvent wastes exist.

For solvent waste reduction there are three basic source reduction objectives.

1. Eliminate solvent use.
2. Reduce solvent use or loss.
3. Increase solvent recyclability.

Regulatory Trends in Solvent Waste Management

The 1984 amendments to RCRA impose a national ban on the land disposal of halogenated and non-halogenated solvent waste (RCRA waste nos. F001-F005). The land-ban restrictions were effective in November, 1986 (RCRA Sec. 3004(e)). A nation-wide variance for SQGs ended on November 8, 1988, and these new land-ban restrictions impacted solvent waste management practices. In the opening clauses of RCRA, Congress declared that "certain classes of land disposal facilities are not capable of assuring long-term containment of certain hazardous wastes ... and land disposal, particularly landfill and surface impoundment, should be the least favored methods for managing hazardous wastes" (RCRA Sec. 1002(a)(7)). Congress further stated that "alternatives to existing methods of land disposal must be developed ..." (RCRA Sec. 1002(a)(8)).

Intensive Solvent Use Industries

Solvents are commonly used in dry cleaning, cold cleaning, solvent extraction, and vapor degreasing. They are also essential to the production of coatings, stains, wood-treatment chemicals, printing inks, pesticides, and agricultural chemicals. Solvents are used as inert reaction media in chemical and pharmaceutical formulation.

Solvents are incorporated into a manufactured product for several applications, such as printing ink. The volatility of solvents imparts fast-drying properties in the ink. In other applications, such as vapor degreasing of metal parts, the use of solvent is confined to the cleaning process. Then, the solvent becomes "spent" as it picks up oil and grease from the metal parts.

Most applications result in generation of a solvent waste and, therefore, most user industries are also generators of solvent waste. Solvent wastes include off-specification batches of products containing solvents and contaminated or spent solvents from process applications. One method assessors may use to identify solvent-user industries is to identify solvent waste generators and assume that high-volume solvent waste generators are high-volume users. Assessors should examine a business's waste manifests to determine if the business is a solvent waste generator. Some industries that employ solvent-use intensive operations include:

- Solvent Reclamation - SIC 7399
- Coatings Manufacturer - SIC 2851
- Cyclic Compounds and Intermediates - SIC 2865
- Industrial Organic Chemicals Manufacturing - SIC 2869
- Pesticides and Agricultural Chemicals Formulation - SIC 2879
- Inks Manufacturing - SIC 2893
- Chemical Preparations - SIC 2899
- Petroleum Refining - SIC 2910
- Semiconductors Manufacturing - SIC 3674
- Electronic components Manufacturing - SIC 3679
- Motor Vehicles Manufacturing - SIC 3711
- Aircraft Manufacturing - SIC 3721
- National Security - SIC 9711
- Dry Cleaning - SIC 7215, 7216, 3582
- Vehicle Maintenance - SIC 5511, 7538
- Pharmaceuticals Manufacturing - SIC 2834
- Metal Furniture Manufacturing -SIC 2514, 2522
- Photographic Processing - SIC 7395, 7333, 7819

Intensive Solvent Use Operations

Compared to the number of industries that use solvents and generate solvent waste, the number of specific types of operations in which solvents are used is relatively small. For example, one intensive solvent use operation, parts cleaning, is performed in electronic components manufacturing, vehicle manufacturing, aircraft manufacturing, metal finishing industries, and in equipment maintenance shops of almost any industrial facility. Similarly, equipment cleaning is performed in paint manufacturing, pesticide formulation, semiconductors manufacturing, and other manufacturing processes. The following is a list of these common solvent-use operations.

- Parts Cleaning
- Equipment Cleaning
- Surface Coating Application
- Reaction Medium
- Entrainer Azeotropic Distillation
- Extraction Medium

Solvent Wastes

Solvent wastes are generated primarily by the following industrial applications.

- Paint and coating plants that use solvents to clean equipment
- Metal working and machine plating shops that use solvents during degreasing
- Cleaning of surfaces in the electrical, electronics, and printing industries

Solvent Recycling Technologies

The main solvent and reduction techniques include:

1. Distillation - separation techniques which rely on the boiling point differences of the components of a liquid waste.
2. Solids Removal - elimination of suspended particles to reduce fouling.
3. Emulsion or Dispersion Breaking - the separation of solvent or oil droplets in water, or of water droplets in oil.
4. Dissolved and Emulsified Organics Recovery - organics separation techniques which concentrate the organics so they can be recovered.

Each of these operations may be performed on their own or in sequence. The recyclable product may be the solvent or the isolated contaminants, or both.

On-Site Recycling Equipment

Due to recent developments, small solvent recycling units are now commercially available for businesses generating low volumes of waste solvents. The simple heating and condensing systems remove impurities from the solving waste stream, returning the solvent or the solvent blend to the process that generated it.

§ *Example 1*

> B/R Instrument Corporation's solvent recovery system was used by a laboratory at Toronto General Hospital. The distillation unit cleaned xylene and chloroform to 100% purity and isopropyl alcohol to 99.7%. The lab recovered $180 per week of solvents which could otherwise have required costly off-site disposal.

Some companies have been able to scale down their equipment considerably since the equipment was first marketed.

§ *Example 2*

> The Brighton Corporation introduced its first solvent recovery system over 20 years ago. They now manufacture units with capacities as small as 7-1/2 gallons of solvent treated per hour.

§ *Example 3*

> The Finish Engineering Company manufactures solvent recovery equipment in a variety of sizes. The smallest of these units reclaims solvents having a boiling point of 160 degrees C or less. The waste solvent is reclaimed in 15 gallon batches, although clean solvent can be drawn off during operation. Recovery levels range from 80 to 95%, depending on the amount and type of contamination.

Solvent Loss Reduction Options

Solvents are most frequently used in:

1. The soak tank
2. The vapor degreaser

The vapor degreaser, because it produces a lot of air pollutants, has been studied in much greater detail with respect to pollution control. However, the main methods for reducing waste are the same for both the degreaser and the soak tank. The two most important goals are to reduce solvent vapor loss and to maintain solvent quality. The following methods were considered the most successful in achieving these objectives.

Implement better operating practices to reduce wastes. Good housekeeping procedures can significantly affect the amount of solvent waste produced. These include:

1. Separators should be cleaned and checked frequently to avoid cross-contamination of solvents or water which can lead to acid formation. Also, parts should not be allowed to enter the degreaser while wet.

2. Promptly removing sludge collected at the bottom of the tank increases cleaning efficiency by not allowing contaminants to adsorb solvent and dissolve into the solution. As solvents are used, their ability to neutralize acids lessens. While the common practice is to add new solvent to the aged solvent, a more efficient method is to analyze the solvent and add specific components. The expense of analysis will be offset by the savings in solvent for tanks of approximately 500 gallons or more.

Based on better operation practices, other waste reduction techniques include:

- Standardizing the solvent used to allow for recycling.
- Consolidating cold cleaning operations into a centralized vapor degreasing operation.
- Locating cold cleaning tanks away from heat sources.
- Controlling the amount of heat supplied to vapor degreasers.
- Avoiding spraying parts above the vapor zone or cooling jackets.
- Avoiding solvent vapor drag-out.

3. Install lids/silhouettes on tanks - all tanks should be covered when not in use. Covers that can be used even during the cleaning process (known as “silhouette entries”) are available for an even greater reduction in vapor loss. All covers should be designed to slide horizontally over the top of the tank, since this disturbs the vapor zone less than hinged covers.
4. Increase the freeboard space on tanks - an increased freeboard has been proven to decrease emission. Early degreasers had a freeboard equal to one-half the tank width. When the US EPA in the mid-1970s recommended a 75% free board, emissions were decreased up to 46%. Increasing the freeboard to 100% can provide an additional 39% reduction where air turbulence is present.
5. Install freeboard chillers in addition to cooling jackets - a second set of refrigerated coils is installed above the condenser coils. These coils chill the air above the vapor zone and create a second barrier to vapor loss. Reductions in solvent use of up to 60% have been realized. However, water contamination of the solvent can occur due to frost buildup on the coils, so special water collection equipment is also necessary.

Reduction of solvent wastes can be accomplished through a wide variety of existing techniques and practices in applications involving parts cleaning, process equipment cleaning, coating applications, air emission control, and other operations. Source reduction measures should be addressed before recycling options are considered. Treatment of residuals, although ultimately necessary, should be addressed last, after source reduction and recycling options are fully explored. Source reduction techniques are extremely processor application-specific. While very effective, some source reduction techniques should be applied with caution because of cost implications. Good operational control of human factors in production is of paramount importance to discrete or batch operations. Improvement of operating practices is such areas as employee training, closer supervision, and employee motivation can accomplish a lot with a minimum cost.

Solvent and waste recycling options include on-site or off-site reclamation, primarily through distillation and burning with energy recovery. Recycling technologies mostly rely on conventional proven techniques. Treatment alternatives rely mainly on thermal, chemical, or biological oxidation of solvent wastes. Techniques are available to deal with a wide range of waste types and concentrations. The current regulatory climate provides incentives for reducing solvent wastes.

Halogenated Solvents

PROS:

- Stability
- Ease of Drying
- Effectiveness in removing oils

CONS:

- Restrictions on use/current phase-out
- Stratospheric ozone depletion
- Global warming potential
- Ground smog formation
- Hazardous solvent wastes
- Worker safety & health:
  - Chronic and acute effects
  - Carcinogenic
  - Teratogenic

Chlorinated Vapor Degreasing Solvent	**Boiling Points**		**Evaporation**
	°F	°C	Rate @ 25 °C
1,1,1 Trichloroethane	166-169	74-76	6.00
Trichloroethylene	189	87	6.39
Perchloroethylene	250	121	2.59
Methylene Chloride	104	40	14.5
Freon (CFC-113)	117-118	47-48	21.00

* Relative to n-butyl acetate, which has been assigned a value of 1

Table 10.2: Boiling Points and Relative Evaporation Rates for Solvents

	OSHA Limits*		**ACGIH****
Solvent	**Time Weighted Average**	**Short-Time Exposure Limit**	**Threshold Limit Value**
1,1,1 Trichloroethane	350 ppm	450 ppm	350 ppm
Trichloroethylene	50 ppm	200 ppm	50 ppm

Perchloroethylene	25 ppm	170 ppm	50 ppm

* ppm = parts per million

** ACGIH is American Conference of Governmental Industrial Hygienists

Table 10.3: Threshold Value Limits for Selected Halogenated Solvents

10.3.2. Other Cleaning Methods

Replacement Solutions and Substitutes

Cleaner Substitution Considerations

- Establish Cleaning Standard
  - Minimize testing
  - Selection viz. cleaning efficacy tests
- Health
- Waste Treatment
- Corrosion
- Economy
- Water Quality
  - Good quality and low hardness means longer service life for cleaner
  - Rinse water-deionized water or softened water can be considered

Cleaning Method Evaluation

When choosing a cleaning method, the following has to be considered:

- Process to be performed
- Presence of metals
- Soils to be removed
- Process time cycle
- Work load
- Frequency of equipment use
- Available equipment, space capital
- Drains and waste disposal method

Cleaning Methods:

- Immersion
- Spray
- Electrolytic
- Ultrasonic

Mechanical Action:

- Turbulence/agitation
- Abrasives
- Deformation
- Ultrasonic Cleaning
- Heat
- Electrocleaning (direct current hydrogen scrubbing at the cathode)

Steps In Equipment Selection Process

1. Cleaning Process Objective
2. Part Analysis
3. Soil Analysis
4. Part Orientation/Material Handling
5. Production Volume Requirements
6. Plant Layout / Floor Space Requirements
7. Wastewater Management
8. Equipment Selection

Aqueous Cleaning

Advantages

- Provides water break-free surface free of smut or particulate soils
- Operating costs are often lower
- Worker exposure to toxic vapors is eliminated / reduced
- Worker and community RTK reporting is eliminated
- Spent cleaners do not present long-term liability

Your Decision to Switch to Aqueous Cleaning Will Mean:

- Cleaner parts
- Less expensive cleaning
- Environmentally safer cleaners

Benefits Resulting from New Aqueous Cleaning System

- Annual chemical purchases are reduced
- Aqueous system is utilized by fewer operators.
- Due to extensive filtration and oil removal, waste disposal cost dropped since aqueous chemistry is easily handled in waste treatment system.
- System is personnel and environmentally friendly.
- Cost savings
- High emission levels of chlorinated solvents are no longer a concern.
- Better cleaning results due to the new system's ability to remove all of the different processing fluids found on the part.
- Reduction in waste disposal
- Elimination of some wash procedures.

10.4. EXAMPLES OF WASTE REDUCTION

The following section gives several examples of waste elimination and reduction in a few different manufacturing plants.

10.4.1. Opportunity Example in Transmission Repair Plant

1. Products produced in plant:
   Heavy vehicle rebuilt transmissions and assorted replacement parts

2. Selected waste producing process:
   Metalworking and machining of component parts

3. Waste streams:

   - Metal scrap
   - Contaminated or off spec-coolant
   - Waste oil skimmed from coolant and stored in oil collection tank until off-site shipment
   - Evaporative losses of water

4. Waste stream (s) selected for reduction:
   Contaminated or off-spec coolant

5. Waste AR identification, evaluation and selection:

   - Replace metal working equipment with units that do not utilize a liquid coolant (special applications only, lengthy payback).
   - Add chemicals to coolant to extend life (limited effectiveness as a sole measure).

- Purchase and utilize a recycling system to extend the life of coolant and reuse the coolant on-site (selected for recommendation).

6. Outline of AR analysis:

   Reduction in waste amounts:
   - (% reduction on amount of coolant concentrate needed/yr)(Amount of coolant concentrate purchased/yr) = Raw material reduction/yr

   Cost savings associated with waste reduction:
   - (Raw material reduction/yr)(Unit cost of coolant concentrate) = Raw material cost savings/yr
   - Plant waste administration cost reduction: negligible

   Additional considerations:
   - (Extra hours/week labor)(Labor costs) = Additional labor costs
   - Additional costs for needed chemical additives

7. Sources of needed data:

   - % reduction in amount of coolant needed/yr (estimated by assessment team)
   - Amount of coolant purchased/yr (from purchasing records)
   - Unit cost of coolant (from purchasing records)
   - Extra hours/week labor (estimated by assessment team)
   - Labor costs (estimated by plant manager)
   - Additional costs for needed chemical additives (estimated by assessment team)

8. Calculations:

   Reduction in waste amounts:
   - (75%)(2,200 gal/yr) = 1,650 gal/yr or 18,480 lbs/yr

   Cost savings associated with waste reduction:
   - (1,650 gal/yr)($7.10/gal for coolant concentrate) = $11,715/yr cost savings

   Additional costs associated with implementation:
   - (5 hrs/wk)(52 wks/yr)($15/hr) = $3,900/yr additional labor costs
   - $2000/yr chemical additive cost

9. Implementation consideration:

   - Net cost savings for this measure is:
     ($11,715 - $3,900 - $2,000)/yr = $5,815/yr

- Implementation requires purchase of a metal working coolant recycling system (estimated cost: $20,000)
- It is suggested that a hand-held refractometer be purchased to monitor proper coolant concentrate and water ratio to increase coolant life (estimated cost: $200)
- Plant advised to contact coolant supplier for vendor recommendations

10.4.2. Waste Minimization for Electroplates

All electroplating facilities have one thing in common: the generation of hazardous waste. However, the most important wastestream is wastewater. The source of this wastestream is carry-over of plating chemicals by the workpiece, from plating bath to rinse. The basic way to reduce this wastestream is to reduce it at the source:

- Minimize the amount of carry-over, often called dragout;
- Reduce the amount of rinsewater used.

Suggestions for the reduction of dragout and rinsewater are summarized here. Implementation of these suggestions will:

- Help meet requirements for discharge of treated wastewater to the local POTW;
- Save money;
- Not compromise product quality.

<u>Dragout Reduction</u>

Reducing dragout will keep expensive plating chemicals in the tanks where they belong. Every percentage reduction of dragout will result in a corresponding reduction in water treatment costs. Minimizing drag-out produces savings both in raw materials and in disposal costs. In addition, less rinsewater is needed.

The following techniques significantly reduce drag-out:

1) Withdraw workpieces at slower rates; the faster an item is removed from the process bath, the thicker the film on the workpiece and the greater the drag-out volume will be. Slower withdrawal is the most important way to minimize drag-out. When workpieces are removed manually, try to incorporate slow withdrawal into process operation instructions. If your plant operates automated lines, adjust the hoist to remove workpiece racks at the slowest possible rate.

2) Improve drainage:

- Increase drainage time: 10 seconds drain will allow 90% of the drag-out to drain back into the tank. Install drip-bars or rails above the process tanks to ensure adequate drainage time is provided;
- Use drainage boards between process and rinse tanks to route drippage back to process tanks;
- Position workpieces so that dripping is maximized:
- Objects should be tilted;
- Position parts so that they extend more in area than in-depth, to reduce film thickness;
- Turn or twist the parts so that fluid flows off the part by the quickest route.

3) Lower the bath concentration; for example an acid copper plating bath can be operated in the range of 27 to 32 oz/gal of copper sulfate. By using 28 instead of 32 oz/gal, a 12.5% reduction of drag-out can be achieved.

§ *Example 1*

Consider a small job-shop, which plates a variety of parts manually (315 racks per 8 hour day). Nickel is the major metal plated. The amount of drag-out was 4 gallons of plating solution per day. By implementing above mentioned drag-out reduction techniques, they managed to reduce the drag-out with 50%, to 2 gallons a day.

Savings Evaluation:

- Cost of installation of drip — - $1,000
- Savings in raw material (plating solution) — 500 gal.
  (2 gal/day x 250 working days)
- Pay-back period: 5 weeks
- Annual savings in raw material costs: — + $8,750
  ($17.5 gallon x 500 gal)

NOTE: Additional savings in water treatment costs can be added to this amount.

<u>Rinsing Efficiency</u>

Efficient rinsing uses the least water possible to produce the desired level of cleanliness. Reducing the volume of rinsewater will lower the costs of water, energy, treatment and disposal. Several efficient methods exist which adequately rinse the workpiece.

1) Counter-current rinsing; for example, in a three tank system, the workpiece enters the first rinse tank which has the most contaminated rinsewater. It is then moved to the second tank, and then to the last where it contacts fresh rinsewater. So the rinse water flow moves in an opposite direction to the workpiece flow.

§ *Example 2*

If the dragout is 1 gallon/hour, concentration of chrome 16 oz/gal; dilution to 0.002 oz/gal would require a dilution ratio of 8000:1.

One rinse needs	8000 gallon/hour
Two rinses need	90 gallon/hour (90 x 90 = 8100)
Three rinses need	20 gallon/hour (20 x 20 x 20 =8000).

What would the savings of the installation of a third tank be in the case of this example? Rinse water savings are 70 gallons per hour, 1.17 gallon per minute. Water and sewer charges are $18/1000 gallon. Assume the plater has a precipitation system, which costs annually about $2,000 per gallon of flow per minute (Pollution Prevention Tips North Carolina, 1989).

Savings Evaluation:

- Costs installing third tank - $2,500
- Savings sewer charges:
  70 gallon x 8 hour x 250 days x $18/1000 gallon/ hour: + $2,520
- Saving wastewater treatment:
  $1.17 x $2,000 = + $2,340
- Pay-back period: 6 months
- Annual savings: $4,860

2) Reuse rinsewater within your plating facility. Take advantage of the nature of the contaminated rinse water to reduce water usage and increase rinsing efficiency.

§ *Example 3*

Reuse the rinsewater of an acid dip rinse tank to neutralize the rinsewater in an alkaline clean rinse tank. Rinsing efficiency is enhanced because of better removal of the soapy film on part surfaces. This will reduce water consumption for this basic cleaning process by one-half.

Savings Evaluation:

If water consumption is reduced from 90 gallon per hour to 45 gallon per hour by reusing rinsewater, the savings will be:

- Rinsewater savings:
  45 gallon / hr x 8 hr x 250 days x $18/1000 gallon $1,620
- Wastewater treatment savings:
  45/60 gallon per minute x $2,000 $1,500
- Annual savings: $3,120

Further Information

Reduction of drag-out and rinsewater are important first steps to minimize waste production and save money at the same time. There are many possibilities to reduce the production of waste in an economically feasible manner.

10.4.3. Waste Minimization for Paint Finishers

Paint finishers generate a variety of hazardous wastes in their operations. The most important wastestreams are:

- Paint sludge (filters, booths)
- VOC's from paints and degreasers

This example focuses on paint sludge.

The source of paint sludge is the failure of all of the paint to deposit on the object, either by spraying above or around the object or by bouncing off, usually called overspray. Overspray can be significantly reduced at the source by

- Operator training
- Equipment selection

Suggestions for reduction of the amount of overspray are summarized here. Implementation of these suggestions will save you money, in

- Disposal costs
- Raw material costs
- Costs of future liabilities.

<u>Operator Training</u>

Since many spray systems are manually operated, the equipment operator has a major impact on the amount of waste produced. Proper spraying has also advantages for the operators in that it requires less work and produces a higher quality finish.

§ *Example 4*

A company that manufactures TV cabinets started an operator training program. Before the training, it required 55 strokes to spray each cabinet. After the training program, the number of strokes was reduced to 32. With spraying of 400 cabinets a day, this resulted in savings of 8,800 strokes per operator.

The following aspects of proper spray technique are important for high quality and low waste:

- Gun Speed: must be constant and not too high, generally 20 feet per minute is adequate.
- 50% Overlap: More than 50% will result in wasted strokes, less than 50% will result in streaks. Aiming the gun at the bottom of the previous pattern will give 50% overlap.
- Gun Distance: constant and in a range of 6 to 8 inches, depending on operator.

- Arcing: perpendicular to the surface at all times.
- Triggering: difficult, but important to get high quality and to prevent paint waste.

§ *Example 5*

When a two feet by three feet surface is not triggered, it is conceivable that the operator might carry over as much as six inches beyond the edges. He will spray an area three feet by four feet, which results in a waste of 6 square feet paint.

Equipment Selection

The transfer efficiency, the amount of coating which is applied to the object divided by the amount of coating sprayed from the gun, varies between different guns. Calculated data show that the High Volume Low Pressure (HVLP) spray is most efficient. The higher the efficiency, the lower the amount of waste produced.

§ *Example 6*

A paint finisher changes from air assisted airless to HVLP sprays and increases transfer efficiency from 45% to 75%. To maintain the same quality, the same amount of coating solids is applied, suppose 1,280 gallons a year. Assume a percentage solids of 32%, the finisher applies 1,280/0.32 = 4,000 gallons a year. As the transfer efficiency is not 100%, the painter needs more than 4,000 gallons: 4,000/(transfer efficiency) gallons of coating a year. So by increasing the transfer efficiency to 75%, he saves 3,556 gallons of coating a year. This results, assuming costs of coating $25 a gallon, in annual savings of $88,900.

Calculations of savings in raw material costs:

• Transfer efficiency	45%	75%
• Coating solids applied (gal/yr)	1,280	1,280
• Coating applied (gal/yr) (32% solids)	4,000	4,000
• Coating usage (gal/yr) 4,000/(transfer efficiency)	8,889	5,333
• Costs coating ($) ($25/gallon)	$222,225	$133,325
• Savings in raw material costs:	$88,900	

Also, higher transfer efficiency results in savings in disposal costs. By using the HVLP spray, the amount of coating solids oversprayed decreases from 1,565 to 427 gallons a year.

As the solid waste not only consists of coating solids, but also of filters, booths or water (in case of a water curtain-booth), the oversprayed solids is multiplied by five (5) to get a more realistic figure of the total amount of solid waste generated. It follows from the calculations, that disposal costs can be decreased by $14,420.

Calculations of savings in disposal costs:

• Transfer efficiency	45%	75%
• Coating solids applied (gal/yr)	1,280	1,280
• Coating solids used (gal/yr) (0.32 x coating used)	2,845	1,707
• Coating solids oversprayed (gal/yr)	1,565	427
• Solid waste generated (gal/yr) (5 x solids oversprayed)	7,825	2,135
• Costs disposal ($) ($140/55-gallon drum)	$19,880	$5,640
Savings in disposal costs	$14,420	

Increase of transfer efficiency from 45% to 75% results in TOTAL SAVINGS of $103,320.

Further Information

Operator training and transfer efficiency improvement are important ways to minimize paint waste and save money at the same time. There are many possibilities to reduce waste in an economically feasible manner. Think about, for instance, the use of less hazardous paints

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3. Wilson, D.C., *Waste Management Planning, Evaluation, Technologies*, Claredon Press Oxford, 1981
4. Overcash, M.R., *Techniques for Industrial Pollution Prevention*, Lewis Publishers, 1986
5. U.S. EPA, Waste Minimization Opportunity Assessment Manual, EPA/625/7-88/003, 1988

APPENDIX A

Waste Reduction Sources of Information

U. S. EPA offices that can provide pollution prevention information include:

U.S. EPA Solid Waste Office
Waste Management Division
401 M Street SW
Washington, D.C. 20460
(703) 308-8402

U.S. EPA Office of Pollution Prevention and Toxics
401 M Street SW
Washington, D.C. 20460
(202) 260-3810

U.S. EPA Office of Air and Radiation
Mail Drop 6101
401 M Street SW
Washington, D.C. 20460
Phone:(202) 260-7400
Fax:(202) 260-5155

U.S. EPA Office of Water
401 M Street SW
Washington, D.C. 20460
(202) 260-5700

U.S. EPA Office of Research & Development
Center for Environmental Research Information
26 Martin Luther King Drive
Cincinnati, OH 45268
(513) 569-7562

U.S. EPA Risk Reduction Engineering Laboratory
26 Martin Luther King Drive
Cincinnati, OH 45268
(513) 569-7931

U.S. EPA Office of Solid Waste and Emergency Response
[For questions regarding RCRA and Superfund (CERCLA), call (800) 424-9346 or

(703) 920-9810. To reach the Analytical Hotline, call (703) 821-4789.]

U.S. EPA Regional Offices:

Region 1 (VT,NH,ME,MA,CT,RI)
One Congress Street
John F. Kennedy Building
Boston, MA 02203-0001
Phone:(617) 565-3420
Fax:(617) 565-3660
Toll Free (800) 372-7341

Region 2 (NY, NJ, PR, VI)
290 Broadway - 26th Floor
New York, NY 10007-1866
Phone:(212) 637-5000
Fax:(212) 637-3526

Region 3 (PA,DE,MD,WV,VA,DC)
1650 Arch Street (3PM52)
Philadelphia, PA 19103
Phone:(215) 814-5254
Fax:(215) 814-5253

Region 4 (KY, TN, NC, SC, GA, FL, AL, MS)
100 Alabama Street, SW
Atlanta, GA 30303
Phone:(404) 562-9900
Fax:(404) 562-8174
Toll Free:(800) 421-1754

Region 5 (WI, MN, MI, IL, IN, OH)
77 West Jackson Blvd.
Chicago, IL 60604-3507
Phone:(312) 353-2000
Fax:(312) 353-4135
Toll Free:(800) 621-8431

Region 6 (NM, OK, AR, LA, TX)

1445 Ross Avenue Suite 1200
Fountain Place 12th Floor
Dallas, TX 75202-2733
Phone:(214) 655-6444
Fax:(214) 665-7113
Toll Free:(800) 887-6063

Region 7 (NE, KS, MO, IA)
726 Minnesota Ave.
Kansas City, KS 66101
Phone:(913) 551-7003
Toll Free:(800) 223-0425

Region 8 (MT, ND, SD, WY, UT, CO)
999 18th Street, Suite 500
Denver, CO 80202-2466
Phone:(303) 312-6312
Toll Free:(800) 227-8917

Montana Operations Office
U.S. EPA Federal Building
301 South Park Drawer 10096
Helena, MT 59626-0096
U.S.A.
Phone:(406) 441-1123

Region 9 (CA, NV, AZ, HI, GU)
75 Hawthorne Street
San Francisco, CA 94105
Phone:(415) 744-1305
Toll Free:(800) 231-3075

Region 10 (AK, WA, OR, ID)
1200 6th Avenue
Seattle, WA 98101
Phone:(206) 553-1200
Toll Free:(800) 424-4372

State Level:

The following lists agencies at the state or territory level as well as universities and other organizations that can provide assistance in the areas of pollution prevention and treatment:

Alabama

Department of Environmental Management
1751 Congressman W.L. Dickenson Drive
Montgomery, AL 36109-2608
Information:(334) 271-7700
Mailing Address: P.O. Box 301463
Montgomery, AL 36130-1463

Additional Department of Environmental Management Field Offices in Alabama

110 Vulcan Road
Birmingham, AL 35209-4702
Phone:(205) 942-6168
Fax:(205) 941-1603

2204 Perimeter Road
Mobile, AL 36615-1131
Phone:(334) 450-3400
Fax:(334) 479-2593

2708 6th Avenue, SE
Suite B
Decatur, AL 35603
Phone:(205) 353-1713
Fax:(205) 340-9359

Environmental Institute for Waste Management Studies
University of Alabama
College of Engineering
203 Bevill Building
Tuscaloosa, AL 35487-0207
Phone:(205) 348-8401
FAX:(205) 348-9659
Email: senigec@coe.eng.ua.edu

Hazardous Material Management and Resource Recovery Program (HAMMAR)
University of Alabama
Tuscaloosa, AL 35487-0203

(205) 348-8401
FAX 348-9659

Retired Engineers Waste Reduction Program
P.O. Box 1010
Muscle Shoals, AL 35660
(205) 386-2807

Alaska

Alaska Health Project
Waste Reduction Assistance Program
1818 West Northern Lights, Suite 103
Anchorage, AK 99517
(907) 276-2864

Alaska Department of Environmental Conservation
Pollution Prevention Program
P.O. Box O
Juneau, AK 9981-1800
(907) 465-2671

Alaska Department of Environmental Conservation
410 Willoughby Avenue
Suite 105
Juneau, AK 99801-1795
Phone:(907) 465-5260
FAX:(907) 465-5274

Arizona

Arizona Department of Economic Planning and Development
1645 West Jefferson St.
Phoenix, AZ 85007
(602) 255-5705

Arizona Department of Environmental Quality
Office of Waste and Water Quality Management
2005 N. Central Ave., Room 304
Phoenix, AZ 85004
(602) 257-2380

Arkansas

Arkansas Industrial Development Commission
One State Capitol Mall
Little Rock, AR 72201
(501) 682-1121
Arkansas Department of Pollution Control and Ecology
Hazardous Waste Division - P.O. Box 8913
Little Rock, AR 72219-8913
(501) 570-2861

California

California Environmental Protection Agency
400 P Street
Room 4310
Sacramento, CA 95814
Phone:(916) 324-9924
FAX:(916) 324-1788

Bay Area Hazardous Waste Reduction Committee (BAHWRC)
City of Berkeley Environmental Health
2180 Milvia, Room 309
Berkeley, CA 94708
(415) 644-6510

State of California-EPA
Department of Toxic Substances Control (DTSC)
400 P Street
P.O. Box 806
Sacramento, CA 95812-0806
Phone:(916) 322-0504

California Conference of Directors of Environmental Health
Ventura County Environmental Health
800 S. Victoria
Ventura, CA 93009
(805) 654-5039

California Environmental Business Resources Assistance Center
100 South Anaheim Boulevard
Suite 125

Anaheim, CA 92805
(714) 563-0135
(800) 352-5225

Central Valley Hazardous Waste Management Committee
Environmental Management Division
8475 Jackson Road, Suite 230
Sacramento, CA 95826
(916) 386-6160

Local Government Commission
909 12th Street
#205
Sacramento, CA 95814
(916) 448-1198

Pollution Prevention Program
San Diego County Department of Health Services
P.O. Box 85261
San Diego, CA 92186-5261
(619) 338-2205, -2215

Colorado

Colorado Office of Environment
Colorado Department of Public Health and Environment
4300 Cherry Creek Drive South
Denver, CO 80220-3716
Phone:(303) 692-3004
FAX:(303)782-4969

Pollution Prevention Waste Reduction Program
Colorado Department of Health
4210 E. 11th Ave.
Denver, CO 80220

Connecticut

Connecticut Department of Environmental Protection
Bureau of Environmental Services
79 Elm Street
Hartford, CT 06106
Phone:(203) 424-3579

FAX:(203) 566-7232

Bureau of Waste Management
Connecticut Department of Environmental Protection
18-20 Trinity Street
Hartford, CT 06101
(203) 566-8476

Connecticut Technical Assistance Program
900 Asylum Avenue, Suite 360
Hartford, CT 06105
(203) 241-077

Delaware

Delaware Department of Natural Resources and Environmental Control
89 Kings Highway
Dover, DE 19901
Phone:(302) 323-4542
FAX:(302) 739 6242

Pollution Prevention Program in Dept. of Natural Resources & Environmental Control
89 Kings Highway
P.O. Box 1401
Dover, DE 19903
(302) 739-3822

District of Columbia

Office of Recycling
D.C. Department of Public Works
2000 14th Street, NW, 8th Floor
Washington, D.C. 20009
(202) 939-7166

U.S. Department of Energy
Conservation and Renewable Energy
Office of Industrial Technologies
Office of Waste Reduction
Waster Material Management Division
Bruce Cranford CE-222
Washington, D.C. 20585

(2020) 586-9496

Florida

Florida Department of Environmental Protection
Douglas Building
3900 Commonwealth Blvd.
Tallahassee, FL 32399-3000
Phone:(904) 488-7454
FAX:(904) 488-7093

Hazardous Waste Reduction Management
Waste Reduction Assistance Program
Florida Dept. of Environmental Regulation
2600 Blair Stone Road
Tallahassee, FL 32399-2400
(904) 488-0300

Environmental Quality Corporation
259 Timberlane Road
Tallahassee, FL 32312-1542
(904) 386-7740

Waste Reduction Assistance Program
Florida Dept. of Environmental Regulation
2600 Blair Stone Road
Tallahassee, FL 32399-2400
(904) 488-0300

Georgia

Hazardous Waste Technical Assistance Program
Georgia Institute of Technology
GTRI/ESTL
151 6th Street
O'Keefe Building, Room 143
Atlanta, GA 30332
(404) 894-3806

Environmental Protection Division
Georgia Department of Natural Resources
205 Butler Street S.E.Suite 1152

Atlanta, GA 30334
Phone:(404) 656-4713
FAX:(404)651-5778

Guam

Solid and Hazardous Waste Management Program
Guam EPA
IT&E Harmon Plaza Complex, Unit D-107
130 Rojas Street
Harmon, GU 96911
(671) 646-8863-5

Hawaii

Department of Planning and Economic Development
Financial Management and Assistance Branch
P.O. Box 2359
Honolulu, HI 96813
(808) 548-4617

Hawaii Department of Health
Solid and Hazardous Waste Branch
Waste Minimization
5 Waterfront Plaza, Suite 250
500 Ala Moana Blvd.
Honolulu, HI 96813
(808) 586-4226

Idaho

Division of Environmental Quality
Department of Health and Welfare
1410 North Hilton St.
Statehouse Mail
Boise, ID 83720-9000
Phone:(208) 373-5879
FAX:(208) 373-0576

Illinois

Illinois Department of Natural Resources

325 West Adams, Room 300
Springfield, IL 62704-1894
Phone:(217) 785-0138
FAX:(217) 785-8575

Hazardous Waste Research and Information Center
Illinois Department of Energy & Natural Resources
One E. Hazelwood Drive
Champaign, IL 61820
(217) 333-8940

Industrial Waste Elimination Research Center
Pritzker Department of Environmental Engineering
Illinois Institute of Technology
3201 South Dearborn
Room 103 Alumni Memorial Hall
Chicago, IL 60616
(312) 567-3535

Illinois Environmental Protection Agency
Office of Pollution Prevention
2200 Churchill Road
P.O. Box 19276
Springfield, IL 62794-9276
Phone:(217) 785-5735
FAX:(217) 782-9039

Indiana

Environmental Management & Education Program
School Civil Engineering
Purdue University
2129 Civil Engineering Building
West Lafayette, IN 47907-1284
(317)-494-5036

Indiana Department of Environmental management
100 North Senate, IGNC 1303
Indianapolis, IN 46206
Phone:(317) 233-3043
FAX:(317) 232-8564

Indiana Department of Environmental Management
Office of Technical Assistance
P.O. Box 6015105
South Meridian Street
Indianapolis, IN 46206-6015
(317) 232-8172

Iowa

Iowa Department of Natural Resources
Wallace State Office Building
900 East Grand Avenue
Des Moines, IA 50319-0034
Phone:(515) 281-6284
Fax:(515) 281-8895

Iowa Department of Natural Resources
Energy Division
Wallace State Office Bldg.
900 East Grand Avenue
Des Moines, IA 50319
Phone:(515) 281-8518
FAX:(515) 281-6794

Iowa Waste Reduction Center
75 BRC
University of Northern Iowa
Cedar Falls, IA 50614
(800) 422-3109
(319) 273-2079

Iowa Waste Reduction Center
University of Northern Iowa
75 Biology Research Complex
Cedar Falls, IA 50614
(319) 273-2079

Kansas

Division on Environment
Department of Health and Environment
Forbes Field, Building 740
Topeka, KS 66620

Phone:(913) 296-1535
FAX:(913) 296-8464

Engineering Extension Program
Ward Hall 133
Kansas State University
Manhattan, KS 66506
(913) 532-6026

Kentucky

Kentucky Natural Resources and Environmental Protection Cabinet
Capital Plaza Tower, 5th Floor
500 Mero Street
Frankfort, KY 40601
Phone:(502) 564-3350
FAX:(502) 564-3354

Waste Minimization Assessment Center
Department of Chemical Engineering
University of Louisville
Louisville, KY 40292
(502) 588-6357

Kentucky Partners
Room 312
Ernst Hall
University of Louisville
Louisville, KY 40292
(502) 588 7260

Louisiana

Louisiana Department of Environmental Quality
PO Box 82263
Baton Rouge, LA 70884-2263
Phone:(504) 765-0741
FAX:(504) 765-0746

Department of Environmental Quality
Office of Solid and Hazardous Waste
P.O. Box 82178
Baton Rouge, LA 70884-2178

(504) 765-0355

Alternate Technologies Research and Development
Office of the Secretary
Louisiana Department of Environmental Quality
P.O. Box 44066
Baton Rouge, LA 70804
(504) 342-1254

Maine

Office of Pollution Prevention
Department of Environmental Protection
State House Station 17
Augusta, ME 04333
Phone:(207) 289-2811

Office of Waste Reduction and Recycling
Maine Waste Management Agency
State House Station 154
Augusta, ME 04333
(207) 289-5300

Maryland

Hazardous and Solid Waste Management Administration
Maryland Department of the Environment
2500 Broening Highway - Bldg. 40
Baltimore, MD 21224
(301) 631-3315

Maryland Environment Service
2020 Industrial Drive
Annapolis, MD 21401
(301) 454-1941

Technical Extension Service
Engineering Research Center
University of Maryland
College Park, MD 20742
(301) 454 1941

Massachusetts

Executive Office of Environmental Affairs/Office of Technical Assistance
100 Cambridge Street, Room 1904
Boston, MA 02202
(617) 727-3260

Source Reduction Program
Massachusetts Department of Environmental Protection
1 Winter Street, 7th Floor
Boston, MA 02108
(617) 292-5870

Massachusetts Department of Environmental Protection
75 Grove Street
Worcester, MA 01606
(508) 792-7650

Michigan

Resource Recovery Section
Department of Natural Resources
P.O. Box 30241
Lansing, MI 48909
(517) 373-0540

Office of Waste Reduction Services
Michigan Departments of Commerce and Natural Resources
P.O. Box 30004
Lansing, MI 48909
(517) 335-1178

Minnesota

Minnesota Pollution Control Agency
Solid and Hazardous Waste Division
520 Lafayette Road
St. Paul, MN 55155-4194
Phone:(612) 296-6300
Toll Free:(800) 657-3864

Additional Offices for Minnesota Pollution Control Agency

Brainerd Regional Office
MPCA North Central Regional Office
1601 Minnesota Drive
Brainerd, MN 56401 (218) 828-2492

Detroit Lakes Regional Office
MPCA Northwest Regional Office
714 Lake Avenue
Lake Avenue Plaza, Suite 220
Detroit Lakes, MN 56501
Phone:(218)847-1519

Duluth Regional Office
MPCA Northeast Regional Office
Duluth Government Service Center
Room 704, 320 W. Second Street
Duluth, MN 55802
Phone:(218) 723-4660

Marshall Regional Office
MPCA Southwest Regional Office
700 North Seventh Street
Marshall, MN 56258
Phone:(507) 537-7146
Fax:(507) 537-6001

Rochester Regional Office
MPCA Southeast Regional Office
18 Wood Lake Drive SE
Rochester, MN 55904
Phone:(507) 285-7343
Fax:(507) 280-5513

Minnesota Technical Assistance Program
1313 5th Street S.E., Suite 207
Minneapolis, MN 55414
(612) 627-4646
(800) 247-0015 (in Minnesota)

Minnesota Office of Waste Management
1350 Energy Lane
St. Paul, MN 55108

(612) 649-5741

Waste Reduction Institute for Training Application
Research, Inc. (WRITAR)
1313 5th Street, S.E.
Minneapolis, MN 55414
(612) 379-5995

Mississippi

Waste Reduction & Minimization Program
Bureau of Pollution Control
Department of Environmental Quality
P.O. Box 20305
Jackson, MS 39289-1305
Phone:(601) 961-5545
FAX:(601) 354-6612
Mississippi Technical Assistance Program (MISSTAP) and Mississippi Solid Waste Reduction Assistance Program (MSWRAP)
P.O. Drawer CN
Mississippi State, MS 39762
(601) 325-8454

Missouri

Missouri Environmental Improvement and Energy Resource Authority
P.O. Box 744
325 Jefferson St.
Jefferson City, MO 65102
(314) 751-4919

Missouri Department of Natural Resources
Hazardous Waste Program
P.O. Box 176
Jefferson City, MO 65102 - 0176
Phone:(314) 751-3176
FAX:(314) 751-7869

Missouri Department of Natural Resources
Division of Energy
P.O. Box 176
Jefferson City, MO 65102 - 0176
Phone:(314) 751-4000

Montana

Montana Environmental Quality Council
Room 106
State Capitol
Helena, MT 59620
Phone:(406) 444-3742
FAX:(406) 444-3036

Department of Health and Environmental Sciences
Room A-206
Cogswell Building
Helena, MT 59620
(406) 444-3454

Solid and Hazardous Waste Bureau
Department of Health and Environmental Sciences
Cogswell Building
Room B-201
Helena, MT 59620
(406) 444-2821

Nebraska

Groundwater Section
Nebraska Department of Environmental Quality
P.O. Box 98922
Statehouse Station
Lincoln, NE 68509-8922
Phone:(402) 471-0096
FAX:(402) 471-2909

Nevada

Nevada Small Business Development Center - Technical Assistance Program
Business Environmental Program
College of Business Administration, MS032
University of Nevada - Reno
Reno, NV 89557-0100
(702) 784-1717
(800) 882-3233

Division of Conservation and Natural Resources
333 West Nye Lane, Room 128
Capitol Complex
Carson City, NV 89710
Phone:(702) 687-4670
FAX:(702) 687-5856

State Energy Conservation Program
Office of Community Services
Nevada Energy Program
Capital Complex
44 W. King
Carson City, NV 89710
(702) 687-4990

New Hampshire

New Hampshire Department of Environmental Services
PO Box 95
6 Hazen Drive
Concord, NH 03302-0095
Phone:(603) 271-3503
FAX:(603) 271-2867

New Jersey

New Jersey Hazardous Waste Facilities Siting Commission
Room 614
28 West State Street
Trenton, NJ 08608
(609) 292-1459
(609) 292-1026

Hazardous Waste Advisement Program
New Jersey Department of Environmental Protection & Energy
401 East State Street
Trenton, NJ 08625
(609) 777-0518

New Jersey Institute of Technology
Hazardous Substance Management Research Center
Advanced Technology Center Building

323 Martin Luther King Jr. Blvd.
University Heights
Newark, NJ 07102
(201) 596-5864

Environmental Research and Health Assessment
Division of Science and Research
New Jersey Department of Environmental Protection
CN 409
401 East State Street, Floor 7
Trenton, NJ 08625-0409
Phone:(609) 633-3834

New Mexico

Economic Development Department
Bataan Memorial Building
State Capitol Complex
Santa Fe, NM 87503
(505) 827-0380

Hazardous and Radiation Waste Bureau
Environmental Improvement Division
1190 St. Francis Drive
Santa Fe, NM 87503
(505) 827-2926

State of New Mexico Environment Department
Groundwater Remediation Section
1190 Saint Frnacis Drive
O.O. Box 26110
Sana Fe, New Mexico 87502
Phone:(505) 827-2831
FAX:(505) 827-2965

New York

New York Environmental Facilities Corporation
50 Wolf Road
Albany, NY 12205
(518) 457-4222

Environmental Compliance Services
Erie County Office Building
95 Franklin Street
Buffalo, NY 14202
(716) 846-6716

North Carolina

Department of Environmental, Health, and Natural Resources
Pollution Prevention Pays Program
Office of Waste Reduction
3825 Barrett Drive, 3rd Floor
Raleigh, NC 27609-7221
(919) 733-7015 or (919) 571-4100
Waste Reduction Resource Center
3825 Barrett Drive, Suite 300
P.O. Box 27687
Raleigh, NC 27611-7687
(919) 571-4100
(800) 476-8686

North Dakota

Environmental Health Section
State Department of Health
1200 Missouri Ave.
Bismarck, ND 58502
(701) 258-2070

Division of Waste Management
Department of Health
1200 Missouri Ave., Room 302
Bismarck, ND 58502-5520
(701) 224-2366

Ohio

Division of Solid and Infectious Waste
Attn.: Pollution Prevention Section
Ohio Environmental Protection Agency
P.O. Box 1049

1800 Watermark Dr.
Columbus, OH 43266-0149
(614) 644-2917

Ohio Technology Transfer Organization (OTTO)
Ohio Department of Development
77 South High Street, 26th Floor
Columbus, OH 43225-0330
(614) 644-4286

Ohio Department of Natural Resources
Fountain Square
Columbus, OH 43224-1387
(614) 265-6333

Ohio Environmental Protection Agency
Division of Solid and Hazardous Waste Management
Pollution Prevention Section
P.O. Box 1049
Columbus, OH 43216-1049
Phone:(614) 644-2917
Fax:(614) 728-1245

Oklahoma

Oklahoma State Department of Health
Hazardous Waste Management Service
1000 N.E. 10th St.
Oklahoma City, OK 73117
(405) 271-5338

Hazardous Waste Management Service
Oklahoma State Department of Health
1000 Northeast 10th Street
(405) 271-7047

Oregon

Oregon Hazardous Waste Reduction Assistance Program
Department of Environmental Quality
811 Southwest Sixth Avenue

Portland, OR 97204-1390
(503) 229-5913 (6570)
(800) 452-4011 (in Oregon)

Pennsylvania

Pennsylvania Technical Assistance Program
248 Calder Way, Suite 306
University Park, PA 16801
(814) 865-0427

Center of Hazardous Material Research
Subsidiary of the University of Pittsburgh Trust
320 William Pitt Way
Pittsburgh, PA 15238
(412) 826-5320
(800) 334-2467

Division of Waste Minimization and Planning
Department of Environmental Resources
P.O. Box 2064
Harrisburg, PA 17120
(717) 787-7382

Technical Specialist
PENNTAP
112 S. Burrowes Street
University Park, PA 16801
(814) 865-1914

NETAC
University of Pittsburgh Applied Research Center
615 William Pitt Way
Pittsburgh, PA 15238
(412) 826-5511

Puerto Rico

Government of Puerto Rico
Economic Development Administration

Box 362350
San Juan, PR 00936
(809) 758-4747

Rhode Island

Office of Environmental Coordination
Rhode Island Department of Environmental Management
83 Park Street
Providence, RI 02903
(401) 277-3434
(800) 253-2674 (in Rhode Island)

South Carolina

Center for Waste Minimization/ Hazardous Waste
Department of Health and Environmental Control
2600 Bull Street
Columbia, SC 29201
(803) 734-5200

Hazardous Waste Management Research Fund
Institute for Public Affairs
4th Floor, Ganbrell Hall
University of South Carolina
Columbia, SC 29208
(803) 777-8157

Clemson University
Continuing Engineering Education Program
P.O. Drawer 1607
Clemson, SC 29633
(803) 656-4450

Sumter Technical College
South Carolina Environmental Training Center
506 N. Guignard Dr.
Sumter, SC 29150

South Dakota

Dept. of Environmental and Natural Resources
523 East Capitol
Pierre, SD 57501-3181
(605) 773-3151

Division of Environmental Regulations
Department of Water and Natural Resources
Joe Foss Building, Room 416
523 E. Capital Ave.
Pierre, SD 57501
(605) 773-3153

Tennessee

Tennessee Valley Authority
Mail Code Old City Hall Building 2f71b
Knoxville, TN 37901
(615) 632-3160

Tennessee Valley Authority
Mail Code HV2S27OC
Chattanooga, TN 37402
(615) 751-3731

Tennessee Valley Authority
1195 Antioch Pike
Nashville, TN 37219
(615) 360-1680

Waste Reduction Assistance Program
Center for Industrial Services
University of Tennessee
226 Capitol Blvd. Building
Suite 401
Nashville, TN 37219
(615) 242-2456

Texas

RENEW
Texas Water Commission
P.O. Box 13087 Capitol Station
Austin, TX 78711-7761
(512) 463-7761

Texas Technical University
P.O. Box 4679
Lubbock, TX 79409-3121
(806) 742-1413

Utah

Department of Chemical Engineering
3290 MEB
University of Utah
Salt Lake City, UT 84112
(801) 581-5763

Department of Environmental Quality
288 North 1460 West
Salt Lake City, UT 84114-4810
(801) 538-6121

Utah State University
UMC 14
Logan, UT 84322
(801) 750-3227

Planning and Program Development
Bureau of Solid and Hazardous Waste Management
Utah Department of Health
P.O. Box 16690
288 North 1460 West Street
Salt Lake City, UT 84116-0690
(801) 538-6170

Vermont

APPENDIX B

THERMODYNAMIC ANALYSIS

Topics covered are selected materials from thermodynamics. Included are areas which are the most likely to be less familiar to a general auditor.

Psychrometrics

Psychrometrics is the study of moist air equilibrium thermodynamic processes. Why is it important? People need to maintain an internal environment that is comfortable (temperature, humidity, fresh air). Therefore, the HVAC system must regulate all three variables.

VARIABLE	SUMMER	WINTER
Temperature	High	Low
Humidity	High	Low
Air Flow	Low	Low

The brief summary covers:

1. Properties of real air
2. Limitations due to saturation (Boiling Curve)
3. Definitions of state variable

- Humidity Ratio (lb of moisture/lb of dry air)
- Enthalpy (Btu/lb of dry air)
- Specific Volume = 1/Density

The molecular weight of air is given as:

$$m = 28.9645 \frac{lb_m}{lb \times mol}$$

Thus, the gas constant can be found for air, R_a, by dividing the universal gas constant by the molecular weight.

$$R_a = \frac{1545.32}{28.9645} = 53.352 \frac{ft \times lb}{lb_m \times R}$$

Properties of Air

COMPONENT	% BY VOLUME
N_2	78.08
O_2	20.95
Ar	0.93
CO_2	0.03
Ne	0.0018
He	0.0005
CH_4	0.00015
H_2	0.00005
SO_2	Small
Kr	Small
Xe	Small
O_3	Small

Table 12.1: Dry Air Composition

Water Vapor

By manipulating the ideal gas equation, a relationship between the ideal gas law and the density for air can be developed.

$$PV = mRT \text{ or } \rho = m/V = P/RT$$

Looking at the new equation one can see that the density is inversely proportional to the to the gas constant R. So using the information obtained for air in the previous section the density of air to the density of water vapor based on proportionality can be compared. From this, it can be concluded that water vapor is much less dense than dry air.

$$r_a \propto \frac{1}{53.352} >> r_w \propto \frac{1}{85.778}$$

Real Air (Moist Air)

Realistically, air is not completely dry; it contains some moisture.

- x% Water Vapor
- (1-x)% Dry Air

In order to determine the density of real air, one must consider the densities of both dry air and water vapor.

$$\rho = \rho_a + \rho_w$$

Then substitute the densities with the ideal gas relation found in the previous section.

$$\begin{aligned} r &= \frac{P_a}{R_a T} + \frac{P_w}{R_w T} \\ &= \frac{P - P_w}{R_a T} + \frac{P_w}{R_w T} \\ &= \frac{P}{R_a T} - \frac{P_w}{R_a T}\left(1 - \frac{R_a}{R_w}\right) \\ &= \frac{P}{R_a T} - 0.378\frac{P_w}{R_a T} \end{aligned}$$

Amount of Water Vapor in a Moist Air Mixture

The amount of moisture in an air mixture is described by the humidity ratio, W. The humidity ratio can be defined by:

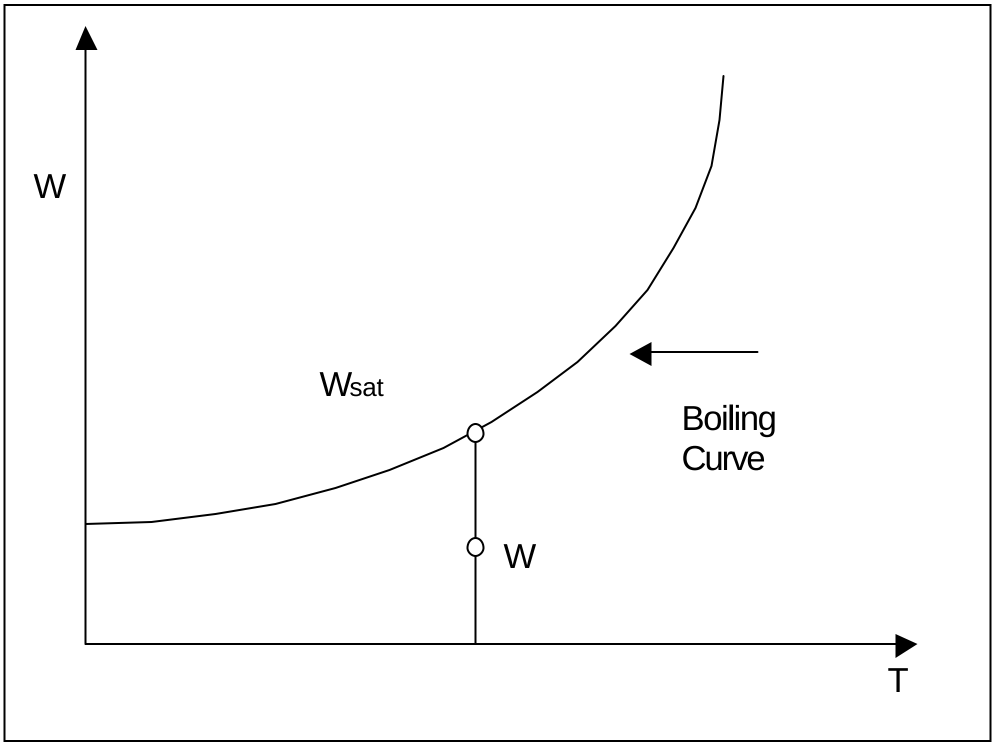
$$W = (\text{lb}_m \text{ of moisture }/V)/(\text{lb}_m \text{ of dry air }/V)$$

Some manipulation and substitution yields an expression for the humidity ratio.

$$W = \frac{x_w m_w}{x_a m_a} = \frac{\frac{m_w}{m_a} x_w}{x_a} = \frac{\frac{18.015}{28.9645} x_w}{1 - x_w}$$

$$W = \frac{0.622\frac{P_w}{P}}{1 - \frac{P_w}{P}} = 0.622\frac{P_w}{P - P_w} = 0.622\frac{P_w}{P_a}$$

This expression shows that the humidity ratio is proportional to the ratio of water pressure to the air pressure. The figure below shows how the humidity ratio varies with respect to temperature. As one can see, the humidity ratio increases significantly as temperature increases.



Energy Content

Enthalpy, h, is a measure of the energy content in the air. The enthalpy of an air/moisture mixture can be expressed as:

$h = h_a + Wh_w$

using

$h_a = 0.24T$

$h_w = h_{fg}$ (at 32°F) $+ C_{p,s} (T - 32)$

where

h_{fg} = latent heat of vaporization, Btu/lb

$C_{p,s}$ = specific heat of water vapor = 0.444 Btu/lb-°F

Substituting these in for the first equation results in:

h = 1075.15 + 0.444(T - 32)

= 1061 + 0.444

$\therefore$ h = 0.24T + W(1061 + 0.444T)

where

T is in °F

W is in lb $_{m,w}$ /lb $_{m,a}$

Relative Humidity

$$f = \frac{x_w}{x_{w,s}} = \frac{f\left(T, \frac{P_w}{P}\right)}{f(T)}$$

$$f = \frac{\frac{P_w}{P}}{\frac{P_{w,s}}{P}} = \frac{P_w}{P_{w,s}}$$

where $P_{w,s}$ is found from the Boiling Curve

$$0 \le \phi \le 1$$

Given ϕ and T, to get W:

1. T $\rightarrow$ $P_{w,s}$ (from Boiling Curve)
2. $P_w = \phi P_{w,s}$
3. W = 0.622 (P_w /(P-P_w))

Specific Volume

Specific volume is defined as the volume per unit mass.

$$v_a = \frac{v}{m_a}$$

Once again using the ideal gas law

$$PV = RT$$

$$v_a = \frac{R_a T}{P_a} = \frac{R_a T}{P - P_w} = \frac{R_a T}{P\left(1 - \frac{P_w}{P}\right)}$$

$$\frac{R_a T}{P} = 1 + 1.608W$$

Since specific volume is volume divided by mass, it can also be defined as the inverse of density (mass divided by volume).

$$r = \frac{1}{v_a}$$

§ *Psychrometric Example*

Given: $T_1 = 90°$ F, $\phi = 0.90$
Calculate the energy per pound of dry air to cool to 57°F, $\phi = 1$.

Method 1 (Analytical)
- At State 1:

$x_{w,1} = 0.90 = P_{w,1} / P_{ws,1}$
(From Table 2 in Chapter 6 of ASHRAE Fundamentals)
$P_{ws,1} = 0.6489$ psi

P = (0.90)(0.6489) = 0.629 psi
$W_1 = 0.622 \text{ x } 0.629(14.7 - 0.629) = 0.02780$ [lb_m / lb_a]
$h_1 = (0.24)(90) + (0.02780)[1061 + (0.444)(90)] = 52.2$

- State 3:

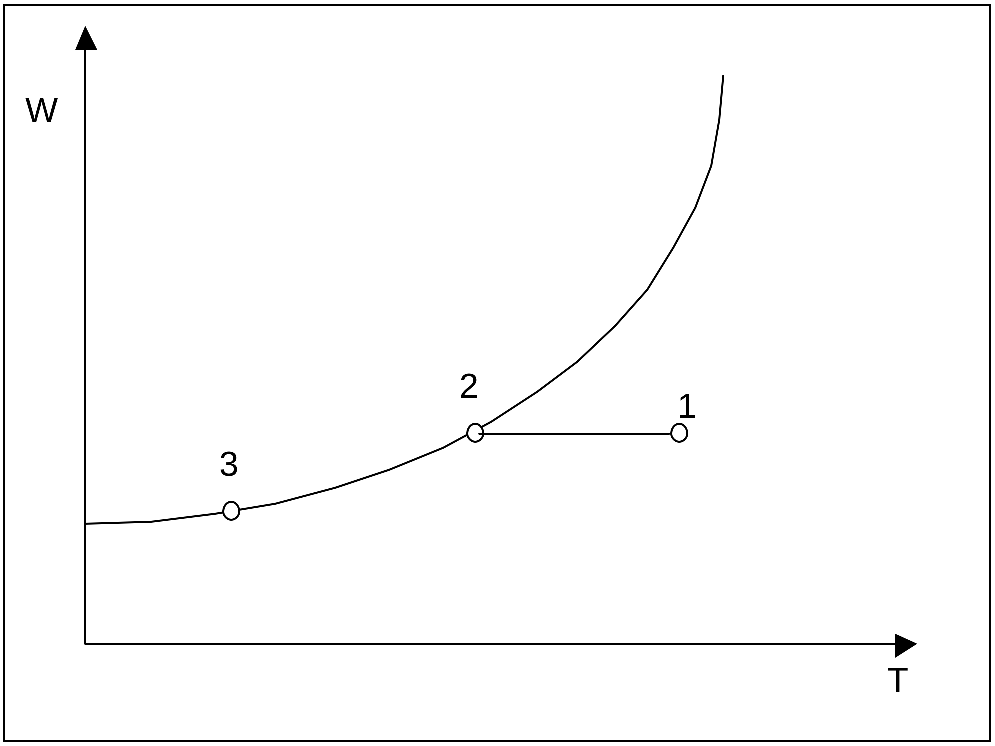
$P_{was,3} = P_{ws,57 \text{ deg F}} = 0.2302$ psi
h = (0.24)(57) + (0.009895)[1061 + (0.444)(57)] = 24.4 [Btu/lb]

$\therefore$ $\Delta h = 24.4 - 52.2 = -27.8$ [Btu/lb of dry air]

Method 2 (Graphical)
1. Locate point 1 at $T_1 = 90°$F, $\phi = 0.90$;
Read $h_1 \approx 52.5$ Btu/lb

2. Locate point 3 at T_3 = 57°F, ϕ = 1;
Read $h_3 \approx$ 24 [Btu/lb]

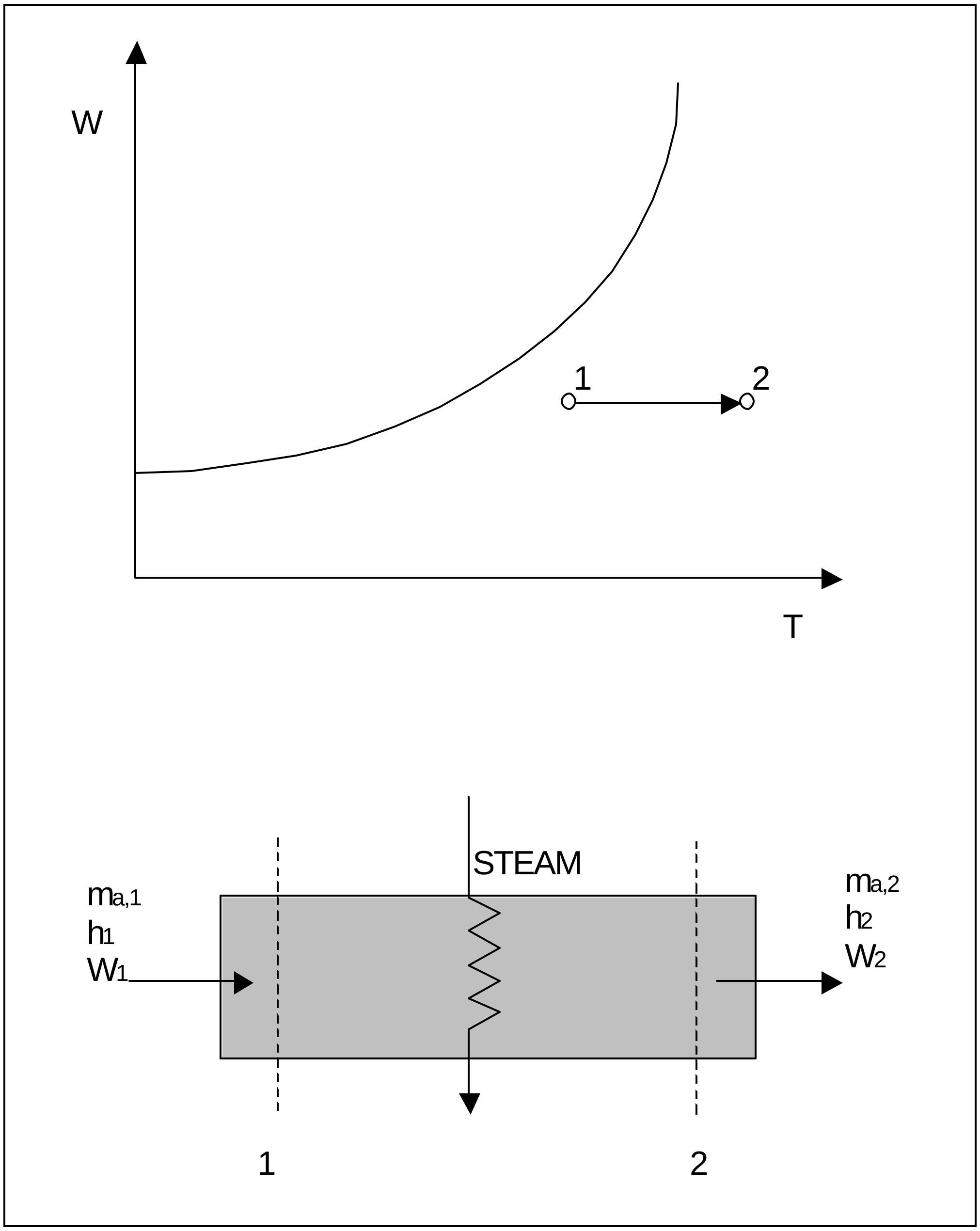
3. Calculate Δh
Δh = 24 - 52.5 = -28.5



Air Conditioning Processes

Air conditioning of air is done to ensure either proper conditions for a specific process or make more pleasant working environment for the people.

Heat Addition to Moist Air



Conservation of mass

$$\dot{m}_{a,1} = \dot{m}_{a,2}$$
$$\dot{m}_{a,1}W_1 = \dot{m}_{a,2}W_2 \rightarrow W_2 = W_1$$

Conservation of energy

$$q_{1\rightarrow 2} = \dot{m}_{a,1}\left(h_2 - h_1\right)$$

§ *Example*

Given: T_1 = 35°F, ϕ_1 = 100%, 20,000 cfm_1
Air to be heated to 100°F
Find: The heater size required.

- State 1

Specific volume = 1/Density

$$v = \frac{1}{r} = \frac{RT}{P}\left[1 + 1.608W\right]$$

$$r = \frac{P_{a,1}}{R_a T\left(1 + 608W_1\right)}$$
$$= \frac{(14.7)(144)}{(53.35)(460 + 35)(1 + 1.608W_1)}$$

$P_{ws,1}$ = 0.09998 → from tables or charts at 35°F

∴ P = (0.09998)(1) = 0.09998

W_1 = 0.622 x 0.09998 / (14.7 - 0.09998) = 0.004259

∴ h 1 = (0.24)(35) + (0.004259)[1061 + (0.444)(35)]

h_1 = 12.985 Btu/lb

- State 2

$W_2 = W_1 = 0.4259$
$h_2 = (0.24)(100) + (0.004259)[1061 + (0.444)(100)]$
$h_2 = 28.708$ Btu/lb

Calculate the mass flow rate of air:

$$\dot{m}_a = \left(20{,}000\,\tfrac{ft^3}{\min}\right)\left(60\,\tfrac{\min}{hr}\right) r_{a,1}$$

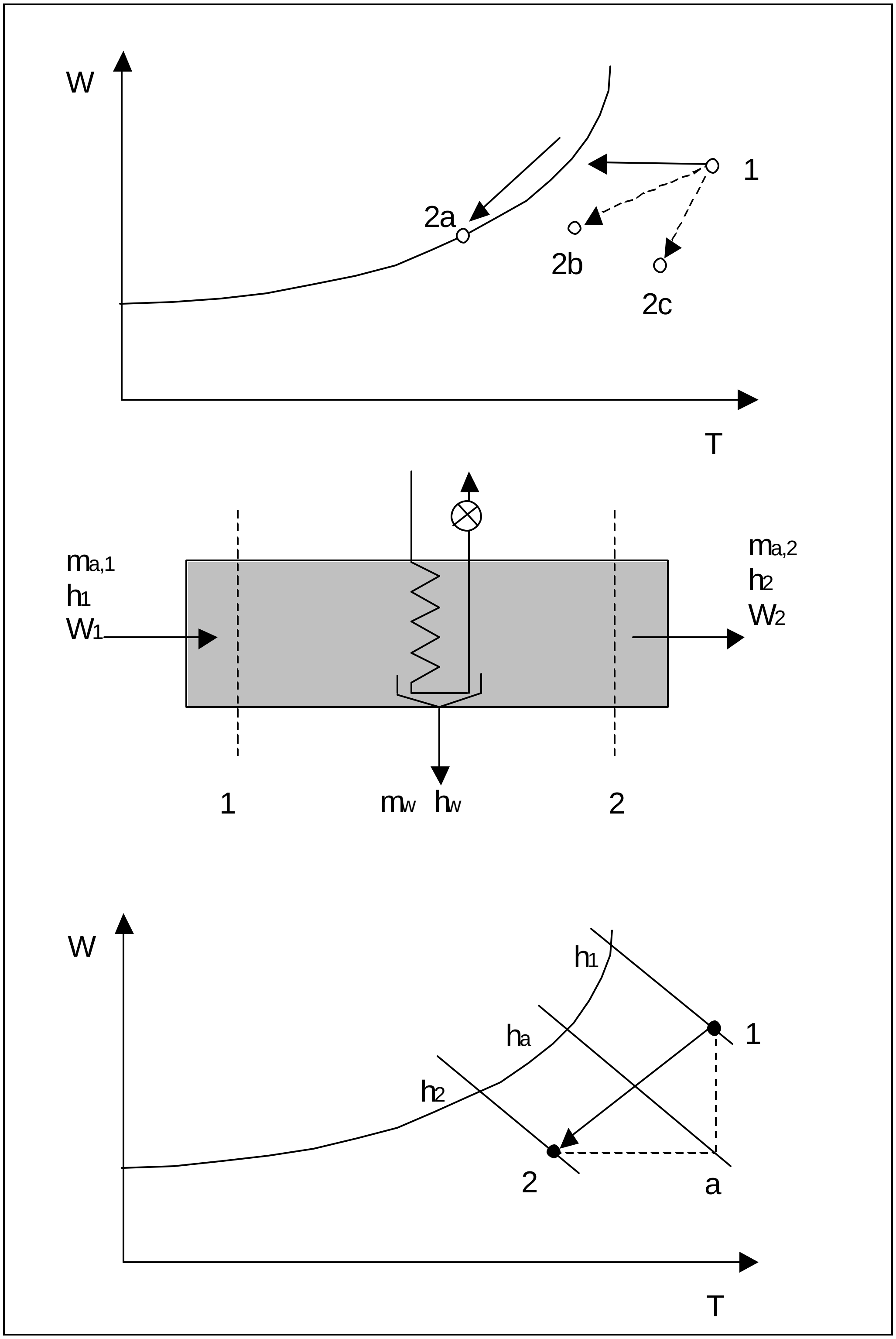
$$r_{a,1} = \frac{(14.7)(144)}{(53.35)(495)[1+(1.608)(0.004259)]} = 0.07961\frac{lb}{ft^3}$$

$$\dot{m}_a = \left(20{,}000\,\tfrac{ft^3}{\min}\right)\left(60\,\tfrac{\min}{hr}\right)\left(0.07961\,\tfrac{lb}{ft^3}\right) = 95{,}534\,\tfrac{lb}{hr}$$

$$q_{1\rightarrow 2} = \left(95{,}534\frac{lb}{hr}\right)\left(28.708 - 12.985\frac{Btu}{lb}\right) = 1.502\frac{MMBtu}{hr}$$

$$q_{boiler} = \frac{1.502\times 10^6}{h_{boiler}} = \frac{11.502\times 10^6}{0.8} = 1.878\times 10^6\,\frac{Btu}{hr}$$

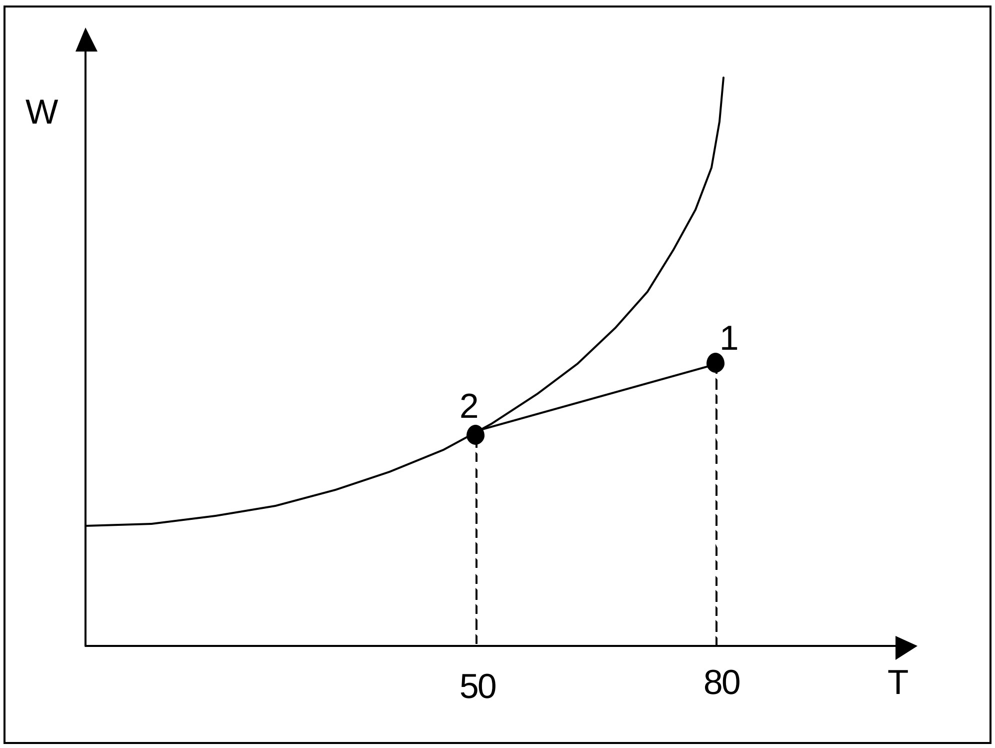
Cooling of Moist Air



h_1 - h_a is all latent heat removal
h_a - h_2 is all sensible heat removal
h_1 - h_2 is total heat removal

§ *Example*

Determine the tons of refrigeration required to cool 10,000 cfm of air at 85°F dry bulb temperature, ϕ = 0.50, to 50°F, ϕ = 1



From the chart

$h_1 \approx 34.5$ $\quad v_1 \approx 14.01$
$h_2 \approx 20.2$ $\quad W_1 \approx 0.013$
$W_2 \approx 0.0076$

From tables, $h_{w,2}$ = 18.11 Btu/lb_a
or
$h_{w,2} = C_p$ (T - 32) = 1 {Btu/[lb deg F(50 - 32 deg F)]} = 18 Btu/lb_a

$\dot{m}_a$ = (10,000 ft^3 /min) / (14.01 ft^3 /min) = 713.8 lb dry air per minute

$q_{1?\ 2} = m_a [(h_2 - h_1) + (W_1 - W_2) h_w]$
= [713.8 (lb/min)] {[20.2 - 34.5 (Btu/lb)] + (0.013 - 0.0076)(18)(Btu/lb)}

= -10.138 Btu/min

That is, the heat removal rate is 10,138 Btu/min or 608,278 Btu/h.

1 ton of A/C = (1 ton of ice/day) x (day/24hr) x (144Btu/lb) x (2,000 lb/ton)

where the latent heat of fusion for ice is 144 Btu/lb.

1 ton of A/C = 12,000 Btu/h

$$q = \frac{608{,}278 Btu/hr}{12{,}000 Btu/hrton} = 50.7 tons$$

Heat Loss Calculations

$$Q = Q_{TRANS} + Q_{INFIL}$$

where
- Q = total heat loss
- Q_{TRANS} = transmission heat loss
- Q_{INFIL} = infiltration heat loss

$$Q_{TRANS} = UA(T_i - T_o)$$

where
- UA = heat loss coefficient
- T_i = inside air temperature
- T_o = outside air temperature

$$Q_{INFIL} = Q_{SENS} + Q_{LATENT}$$

where
- Q_{SENS} = sensible heat loss
- Q_{LATENT} = latent heat loss

$$Q_{SENS} = V\rho C_p(T_i - T_o)$$

where
- V = volume of air entering building
- ρ = air density
- C_p = specific heat of air

$$Q_{LATENT} = V\rho\,(W_i - W_o)\,h_{fg}$$

where

W_i = inside air humidity ratio
W_o = outside air humidity ratio
h_{fg} = latent heat of vapor at T_i

Simple Equations for Standard Air

$$Q_{SENS} = 0.018 \times V\,(T_i - T_o)$$

$$Q_{LATENT} = 79.5 \times V\,(W_i - W_o)$$

Heat Gain Calculations

$$Q = Q_{TRANS} + Q_{FEN} + Q_{INT}$$

where
Q_{FEN} = fenestration heat gain
Q_{INT} = internal heat gain

$$(Q_{TRANS} / A) = \alpha I_t + h(T_o - T_s) - \varepsilon \delta R$$

where
α = absorptance of surface for solar radiation, no units
I_t = solar radiation incident on surface, Btu/hr ft^2
h_o = heat transfer coefficient, Btu/hr ft^2 °F
T_o = outdoor air temperature, °F
T_s = surface air temperature, °F
ε = emittance of surface, no units
δR = difference between radiation incident on the surface and black body radiation at T_o, Btu/hr ft^2

$$(Q_{TRANS} / A) = h_o(T_{SOL\text{-}AIR} - T_S)$$
$$T_{SOL\text{-}AIR} = T_o + \alpha I_t / h_o - \varepsilon \delta R / h_o$$

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