Modern Industrial Assessments
A Training Manual
Version 2.0

Sponsored by:

Produced by:
Dr. Michael R. Muller – Director
Michael Simek
Jennifer Mak
Bojan Mitrovic

The Office of Industrial Productivity and Energy Assessment
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.

*Modern 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.

*Modern 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.

*Modern 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. *Modern Industrial Assessments: A Training Manual* will be published for public consumption on World Wide Web at the address [http://oipea-www.rutgers.edu](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 *Modern 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 *Modern 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 the 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 modern 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

The content of this manual is offered as guidance. Rutgers University and all technical sources referred to in this publication do not
(a) make any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this publication, or that the use of any information, apparatus, method, or process disclosed in this publication may not infringe on privately owned rights;
(b) assume any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this publication.
The information presented does not reflect official views or policy of the above-mentioned institutions. Mention of trade names or commercial products does not constitute endorsement or recommendation of use.
# Table of Contents

1  INTRODUCTION .................................................................................................................................1

1.1. ENERGY .............................................................................................................................................2
   1.1.1. Building Energy Summary........................................................................................................10

2  ENERGY AND WASTE ASSESSMENT ...............................................................................................19

2.1. ASSESSMENT METHODOLOGY .................................................................................................19
   2.1.1. Client Selection Based on Industry Type..................................................................................19
   2.1.2. Techniques for Use of Information Obtained from Plant Survey...........................................21
   2.1.3. Types of Assessments................................................................................................................21
   2.1.4. Benefits of Industrial Assessments..........................................................................................22
   2.1.5. Assessment Structure.................................................................................................................25
   2.1.6. Techniques and Tools................................................................................................................27
   2.1.7. Identification, Selection, Analysis and Write-up of ARs.............................................................30
   2.1.8. Tasks and Data for Energy and Waste Assessments.................................................................35
   2.1.9. Load Calculations and Energy Analysis......................................................................................41

2.2. ENERGY AND WASTE INSTRUMENTATION FOR ASSESSMENTS ........................................44
   2.2.1. Equipment List...........................................................................................................................45
   2.2.2. Product and Supplier List...........................................................................................................46

3  EVALUATION OF ENERGY AND WASTE COSTS ........................................................................53

3.1. FINANCIAL ANALYSIS .....................................................................................................................53
   3.1.1. Definitions..................................................................................................................................53
   3.1.2. Sample Calculation of Savings..................................................................................................55
   3.1.3. Electric Bills and Rates..............................................................................................................59
   3.1.4. Examples of Gas Bills and Gas Rates..........................................................................................64
   3.1.5. Fuel Oil Rates..............................................................................................................................66

3.2. METHODS FOR ENERGY AND WASTE .....................................................................................67
   3.2.1. Estimates of Project Costs..........................................................................................................67
   3.2.2. Payback Periods.........................................................................................................................68
   3.2.3. Methods for Financing Conservation Projects..........................................................................69
   3.2.4. Comprehensive Simulated Assessment......................................................................................70

4  ELECTRICITY ........................................................................................................................................79
# Table of Contents

## 7.2. ABSORPTION REFRIGERATION ................................................................. 222
  7.2.1. Operation ............................................................................................... 222

## 7.3. MECHANICAL REFRIGERATION .......................................................... 226
  7.3.1. Mechanical Compression ........................................................................ 226
  7.3.2. Methods to Reduce Costs ........................................................................ 227

## 7.4. INSULATION .......................................................................................... 234
  7.4.1. Introduction ............................................................................................. 234
  7.4.2. Typical Performance Improvements ......................................................... 234
  7.4.3. Insulation of Tanks .................................................................................. 237
  7.4.4. Building Insulation .................................................................................. 238
  7.4.5. Recommended Insulation Standards ......................................................... 239
  7.4.6. Process Equipment ................................................................................... 241

## 8. HVAC .......................................................................................................... 243
  8.1. AIR CONDITIONING ................................................................................ 243
  8.1.1. Equipment ............................................................................................... 243
  8.1.2. Psychrometry .......................................................................................... 247
  8.1.3. Computation ............................................................................................ 248
  8.1.4. Energy Conservation .............................................................................. 249
  8.1.5. Terminology ............................................................................................. 262
  8.2. HVAC SYSTEMS ..................................................................................... 264
  8.2.1. Equipment Sizing Practices ..................................................................... 264
  8.2.2. Design for Human Comfort .................................................................... 266
  8.2.3. General Types of Building Heating and Cooling ...................................... 274
  8.3. VENTILATION ......................................................................................... 279
  8.3.1. Introduction ............................................................................................. 279
  8.3.2. Losses ...................................................................................................... 280
  8.3.3. Balance Air Flows ................................................................................... 282
  8.3.4. Types of Heat Exchangers ...................................................................... 285

## 9. WASTE ........................................................................................................ 289
  9.1. WASTE GENERATION ............................................................................ 289
  9.1.1. Sources of Manufacturing Wastes ............................................................ 289
  9.1.2. Compendium of Processes Producing Waste .......................................... 290
  9.2. HAZARDOUS WASTES .......................................................................... 298
  9.2.1. Types of Waste Generated ...................................................................... 298
  9.2.2. Typical Operations Using Materials Which Generate Hazardous Wastes ... 299
9.2.3. Hazardous Waste Generator's Responsibilities .......................................................... 300

9.3. WASTE GENERATION AND MANAGEMENT ......................................................... 301
9.3.1. Waste Reduction .................................................................................................. 301
9.3.2. Record Keeping .................................................................................................. 301

9.4. MAIN WASTE STREAMS ......................................................................................... 303
9.4.1. Solvent Wastes .................................................................................................. 303
9.4.2. Water-Based (Aqueous) Wastes ......................................................................... 304
9.4.3. Paint Wastes ..................................................................................................... 305
9.4.4. Used Oils .......................................................................................................... 306

9.5. SOURCE REDUCTION AND RECYCLING ........................................................... 307
9.5.1. Strategies in Waste Reduction ............................................................................ 308

10 INDUSTRIAL WASTE ............................................................................................... 313

10.1. PAINTING AND PRINTING ................................................................................. 313
10.1.1. Paint Wastes in Metalworking Industries ......................................................... 313
10.1.2. Reduction in Paint Waste .................................................................................. 314
10.1.3. Minimization of Waste in Printing Operations .................................................. 317

10.2. METALWORKING ............................................................................................... 322
10.2.1. Sources and Nature of Coolant Waste .............................................................. 322
10.2.2. Measures for Reducing Metalworking Coolant Waste ....................................... 323

10.3. CLEANING AND DEGREASING ...................................................................... 326
10.3.1. Solvents .......................................................................................................... 326
10.3.2. Other Cleaning Methods .................................................................................. 333

10.4. EXAMPLES OF WASTE REDUCTION ................................................................. 335
10.4.1. Opportunity Example in Transmission Repair Plant .......................................... 335
10.4.2. Waste Minimization for Electroplates ............................................................... 337
10.4.3. Waste Minimization for Paint Finishers ............................................................ 340

APPENDIX A .................................................................................................................. 343

Waste Reduction Sources of Information ........................................................................ 343

Sources of AR Ideas ....................................................................................................... 370

Pollution Prevention Publications ................................................................................... 370
Pollution and Waste ........................................................................................................ 371
Environmental Research Briefs .................................................................................... 374
List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>Building Energy Use</td>
<td>2</td>
</tr>
<tr>
<td>1.3</td>
<td>Industrial Energy Use</td>
<td>3</td>
</tr>
<tr>
<td>1.4</td>
<td>Load Shape Changes</td>
<td>4</td>
</tr>
<tr>
<td>1.5</td>
<td>Average Cost Savings for IAC Recommendations – 1</td>
<td>9</td>
</tr>
<tr>
<td>1.6</td>
<td>Average Cost Savings for IAC Recommendations – 2</td>
<td>10</td>
</tr>
<tr>
<td>1.7</td>
<td>Average Cost Savings for IAC Recommendations – 3</td>
<td>10</td>
</tr>
<tr>
<td>1.8</td>
<td>Energy Usage</td>
<td>15</td>
</tr>
<tr>
<td>1.9</td>
<td>Energy Costs</td>
<td>15</td>
</tr>
<tr>
<td>1.10</td>
<td>Electrical Costs</td>
<td>15</td>
</tr>
<tr>
<td>1.11</td>
<td>Energy Usage</td>
<td>16</td>
</tr>
<tr>
<td>1.12</td>
<td>Energy Costs</td>
<td>16</td>
</tr>
<tr>
<td>3.1</td>
<td>Relation of Demand (kW) to Energy (kWh)</td>
<td>61</td>
</tr>
<tr>
<td>3.2</td>
<td>Load Factor</td>
<td>62</td>
</tr>
<tr>
<td>3.3</td>
<td>Power Transmission</td>
<td>63</td>
</tr>
<tr>
<td>4.1</td>
<td>Components of Electrical Power</td>
<td>82</td>
</tr>
<tr>
<td>4.2</td>
<td>Motor Efficiency</td>
<td>96</td>
</tr>
<tr>
<td>4.3</td>
<td>Fan Drive: Variable Speed vs. Valve Control</td>
<td>101</td>
</tr>
<tr>
<td>5.1</td>
<td>Effect of Scale Thickness in Boilers on Heat Transfer</td>
<td>125</td>
</tr>
<tr>
<td>5.2</td>
<td>Effects of Feedwater Preheat on Boiler System Efficiency</td>
<td>126</td>
</tr>
<tr>
<td>5.3</td>
<td>Efficiency Loss Due to Blowdown</td>
<td>127</td>
</tr>
<tr>
<td>5.4</td>
<td>Acid Dew Point</td>
<td>128</td>
</tr>
<tr>
<td>5.5</td>
<td>Natural Gas Fuel Savings</td>
<td>134</td>
</tr>
<tr>
<td>5.6</td>
<td>Liquid Petroleum Fuel Savings</td>
<td>137</td>
</tr>
<tr>
<td>5.7</td>
<td>Stratification and Destratification of Air</td>
<td>148</td>
</tr>
<tr>
<td>5.8</td>
<td>Infrared Radiant Heater</td>
<td>150</td>
</tr>
<tr>
<td>5.9</td>
<td>Percent Excess Air From CO2 Reading</td>
<td>156</td>
</tr>
<tr>
<td>5.10</td>
<td>Cogeneration Cycles</td>
<td>162</td>
</tr>
<tr>
<td>5.11</td>
<td>Gas-Turbine Cycle</td>
<td>163</td>
</tr>
<tr>
<td>5.12</td>
<td>Steam-Turbine Cycle</td>
<td>164</td>
</tr>
<tr>
<td>6.1</td>
<td>Typical Centrifugal Pump Characteristics</td>
<td>175</td>
</tr>
<tr>
<td>6.2</td>
<td>Centrifugal Pump Curve</td>
<td>177</td>
</tr>
<tr>
<td>6.3</td>
<td>Typical Pump and System Curves, Driven by Adjustable Speed Drive</td>
<td>178</td>
</tr>
<tr>
<td>6.4</td>
<td>Typical Pump and System Curves for Pump with Throttling Valve</td>
<td>178</td>
</tr>
<tr>
<td>6.5</td>
<td>Pump Power Requirements for Throttling and Adjustable Speed Motors</td>
<td>179</td>
</tr>
<tr>
<td>6.6</td>
<td>Effect of Volume Control on Fan Horsepower</td>
<td>182</td>
</tr>
<tr>
<td>7.2</td>
<td>Mechanical Forced-Draft Cooling Tower</td>
<td>214</td>
</tr>
<tr>
<td>7.3</td>
<td>Free Cooling/Air Preheat</td>
<td>215</td>
</tr>
<tr>
<td>7.4</td>
<td>Indirect Free Cooling Loop</td>
<td>216</td>
</tr>
<tr>
<td>7.5</td>
<td>Two-Stage Absorption Chiller</td>
<td>223</td>
</tr>
<tr>
<td>7.6</td>
<td>Capacity as Function of Temperature of Heat Source and Cooling Water</td>
<td>224</td>
</tr>
</tbody>
</table>
Figure 7.7: Mechanical Compression Refrigeration System .......................................................... 227
Figure 7.8: Pressure-Enthalpy Diagram .................................................................................... 229
Figure 7.9: Partial Load Requirement for Centrifugal Refrigeration Compressors ................. 230
Figure 8.2: Modified Air Conditioning System Controls............................................................ 253
Figure 8.3: Economizer Cycle (Outdoor Temp. Switchover, Mixing Temp. Control) ............ 255
Figure 8.4: Economizer Cycle (Outdoor Temp. Switchover, Chilled H2O Control) ............... 255
Figure 8.5: Economizer Cycle (Enthalpy Switchover, Chilled H2O Control) ....................... 256
Figure 8.6: Effect of Volume Control on Fan Horsepower ...................................................... 261
Figure 8.7: Load vs. Efficiency .................................................................................................. 266
Figure 8.8: Control Valve Characteristics .................................................................................. 266
Figure 8.9: Comfort Zone Detail .............................................................................................. 267
Figure 8.10: Sprayed Coil Dehumidifier .................................................................................... 274
Figure 8.11: Evaporative Cooling & Air Washer ......................................................................... 275
Figure 8.12: Humidity Control Through Cooling Override ...................................................... 276
Figure 8.13: Single Zone - All Direct Control from Space Thermostat ........................................ 276
Figure 8.14: Dual Duct Air Handling System .......................................................................... 277
Figure 8.15: Multizone Air Handling Unit ............................................................................... 278
Figure 8.16: Hybrid VAV Control System ............................................................................... 279
Figure 9.1: Hierarchy of Waste Minimization ........................................................................... 307
Figure 9.2: Barriers ................................................................................................................... 308
Figure 9.3: Waste Reduction - Operation Phase ......................................................................... 309
Figure 9.4: Waste Reduction - Equipment Phase ....................................................................... 310
Figure 9.5: Waste Reduction - Process Phase .......................................................................... 311
Figure 10.1: Process Flow Diagram for Metalworking Industries ............................................. 324
Figure 10.2: Metalworking Coolant Material Flows .................................................................. 325
## List of Tables

**Table 3.1:** Energy Assessment Recommendations ................................................................. 56  
**Table 3.2:** Waste Assessment Recommendation ................................................................. 56  
**Table 3.3:** Total Cost Associated with Waste Streams ............................................................ 58  
**Table 3.4:** Handling Labor and Record Keeping Costs Breakdown ......................................... 59  
**Table 4.1:** Power Factor Correction ....................................................................................... 85  
**Table 4.2:** Highest Demands for Hypothetical Billing Period of May ..................................... 88  
**Table 4.3:** Typical Efficiency Comparison for 1800 rpm Motors: General Electric ............... 99  
**Table 4.4:** Typical Efficiency Comparison for 1800 rpm Motors: Westinghouse ................. 99  
**Table 4.5:** DuPont Recommended Illumination Levels .......................................................... 110  
**Table 4.6:** Alternative Lighting Systems ................................................................................ 117  
**Table 5.1:** Optimal Flue Gas Composition .............................................................................. 122  
**Table 5.2:** Boiler Efficiency (Natural Gas) .............................................................................. 124  
**Table 5.3:** Ultimate CO2 Values ............................................................................................. 129  
**Table 5.4:** Boiler Combustion Mixtures .................................................................................. 129  
**Table 5.5:** Combustion Efficiencies ....................................................................................... 131  
**Table 5.6:** Fuel Savings Realized by Preheating Combustion Air ........................................ 142  
**Table 5.7:** Thermal Storage High Spot Evaluation ................................................................. 168  
**Table 6.1:** Comparative Energy Usage with Various Methods of Control ......................... 180  
**Table 6.2:** Nominal Efficiency of Fans at Normal Operating Conditions .............................. 181  
**Table 6.3:** Fuel and Air Losses Due to Compressed Air Leaks ............................................... 189  
**Table 7.1:** Cost Comparison of Mechanical and Absorption Refrigeration ......................... 225  
**Table 7.2:** Recommended Thickness for Pipe and Equipment Insulation ............................ 235  
**Table 8.2:** Clothing Resistance ............................................................................................ 271  
**Table 8.3:** Garment Insulation Values .................................................................................... 272  
**Table 8.4:** Equations for Convection Heat Transfer Coefficients ........................................ 273  
**Table 9.1:** Waste Generated by Different Processes ............................................................. 290  
**Table 9.2:** Pollution Prevention Regulations ........................................................................ 300  
**Table 9.3:** Inventory of Waste Streams ................................................................................ 302  
**Table 9.4:** Parallel Paradigms .............................................................................................. 310  
**Table 10.1:** Transfer Efficiency in Painting ........................................................................... 315  
**Table 10.2:** Boiling Points and Relative Evaporation Rates for Solvents ............................. 332  
**Table 10.3:** Threshold Value Limits for Selected Halogenated Solvents ............................. 333  
**Table 12.1:** Dry Air Composition .......................................................................................... 396