FOREWORD ..... **iii**

ENERGY MANAGEMENT-PERFORMANCE CONTRACTING TASK FORCE ..... **iv**

NOTICE TO USERS OF THIS PUBLICATION ..... **v**

TABLE OF CONTENTS ..... **vii**

CHAPTER 1 ENERGY CONSERVATION MANAGEMENT **1.1**

1.1 ENERGY USE INFLUENCE FACTORS 1.1

1.2 HUMAN COMFORT NEEDS 1.1

1.3 ENERGY MANAGEMENT (OPERATION) 1.3

1.4 INITIAL COST VERSUS OPERATING COSTS 1.4

1.5 SOLAR ENERGY UTILIZATION 1.4

1.6 EVALUATION 1.4

1.7 ENERGY CONSERVATION CHECKLIST 1.6

1.8 SYSTEM MODIFICATIONS 1.7

1.9 STRUCTURE MODIFICATIONS 1.7

1.10 THE DESIGN PROCESS 1.8

1.11 ENERGY EFFICIENT DESIGN 1.8

1.12 HVAC SYSTEM EVALUATION 1.9

CHAPTER 2 AIR SYSTEMS **2.1**

2.1 AIR SYSTEM CLASSIFICATIONS 2.1

2.2 AIR SYSTEM BENEFITS 2.1

2.3 AIR SYSTEM DESIGN BASICS 2.1

2.4 DUCT SYSTEM AIRFLOW 2.2

2.5 TYPES OF AIR SYSTEMS 2.3

CHAPTER 3 HVAC SYSTEM FIELD CHECKS **3.1**

3.1 INTRODUCTION 3.1

3.2 FAN SYSTEMS 3.1

CHAPTER 4 HYDRONIC SYSTEMS **4.1**

4.1 GENERAL 4.1

4.2 TEMPERATURE CLASSIFICATION 4.1

4.3 HYDRONIC PIPING SYSTEMS 4.2

4.4 HYDRONIC TERMINAL UNITS 4.4

4.5 HYDRONIC SYSTEM ENERGY SAVINGS 4.6

4.6 HEAT PUMP SYSTEMS 4.7

CHAPTER 5 CONTROL SYSTEMS 5.1
5.1 BASIC CONTROL FUNCTIONS 5.1
5.2 LOCAL CONTROLS 5.1
5.3 CENTRAL CONTROLS 5.3
5.4 CONTROL SYSTEM TYPES 5.4
5.5 CONTROL DEVICES 5.5
5.6 EXISTING SYSTEM RETROFIT 5.6
5.7 COMPUTER SYSTEMS 5.11
CHAPTER 6 NEW AUTOMATION SYSTEM OPEN PROTOCOLS 6.1
6.1 BACNET PROTOCOL 6.1
6.2 OBJECT PROGRAMMING 6.2
6.3 SERVICES PROGRAMMING 6.3
6.4 IS BACNET BACKWARD COMPATIBLE? 6.3
6.5 POTENTIAL SYSTEM MAINTENANCE PROBLEMS 6.3
CHAPTER 7 DOMESTIC WATER SYSTEMS 7.1
7.1 ENERGY ANALYSIS 7.1
7.2 REDUCED WATER TEMPERATURES 7.2
7.3 HOT WATER USAGE 7.2
7.4 SYSTEM THERMAL LOSSES 7.3
CHAPTER 8 ELECTRICAL SYSTEMS 8.1
8.1 LIGHTING 8.1
8.2 POWER 8.7
8.3 ELECTRICAL EQUIPMENT 8.9
CHAPTER 9 INDOOR AIR QUALITY VS. ENERGY USAGE 9.1
9.1 GENERAL 9.1
9.2 CARBON DIOXIDE CONTROL 9.2
CHAPTER 10 THE ENERGY AUDIT 10.1
10.1 OBTAINING INITIAL COOPERATION 10.1
10.2 ESTABLISHING AN ENERGY CONSERVATION GOAL 10.1
10.3 THE BUILDING SURVEY 10.2
10.4 THE DATA BASE 10.5
10.5 USING THE AUDIT DATA 10.7

CHAPTER 11 ENERGY MANAGEMENT MAINTENANCE AND MONITORING 11.1

11.1 SCHEDULED MAINTENANCE 11.1

11.2 ENERGY CONSERVATION MONITORING 11.2

11.3 VERIFICATION PROCEDURES 11.2

CHAPTER 12 PERFORMANCE CONTRACTING 12.1

12.1 PLANNING FOR A FINANCED ENERGY PROGRAM 12.2

CHAPTER 13 ENERGY ESTIMATING PROCEDURES 13.1

13.1 DEGREE-DAY METHOD 13.1

13.2 ANALYSIS OF EXAMPLE FOR ENERGY CONSERVATION 13.6

CHAPTER 14 ECONOMICS OF ENERGY REDUCTION PROJECTS 14.1

14.1 GENERAL 14.1

14.2 COMPUTING FUEL SAVINGS 14.3

14.3 MAKING A SIMPLE CAPITAL INVESTMENT ANALYSIS 14.7

14.4 LIFE-CYCLE COSTING 14.9

CHAPTER 15 CFC REFRIGERANT REGULATION 15.1

15.1 WHERE ARE WE NOW? 15.1

15.2 CONCLUSIONS 15.3

CHAPTER 16 FUNDAMENTALS OF ENERGY TRANSFER 16.1

16.1 HEAT FLOW 16.1

16.2 PSYCHROMETRIC CHARTS 16.6

16.3 USE OF THE PSYCHROMETRIC CHART 16.8

16.4 AIR MIXTURE CONDITION CHANGES 16.14

16.5 OTHER CHARTS 16.22

CHAPTER 17 ENERGY RECOVERY SYSTEMS 17.1

17.1 COMFORT-TO-COMFORT 17.1

17.2 PROCESS-TO-COMFORT 17.2

17.3 PROCESS-TO-PROCESS 17.2

17.4 ENERGY RECOVERY EQUIPMENT IN GENERAL 17.3

17.5 EXCHANGER CONFIGURATIONS AND DESIGN 17.4

17.6 TYPES OF EXCHANGERS 17.5

17.7 EXCHANGER CHARACTERISTICS 17.6

17.8 EXCHANGER RATINGS AND STANDARDS 17.7

17.9 MECHANICS OF HEAT FLOW 17.7
17.10 EFFECTIVENESS 17.9
17.11 EXCHANGER CAPACITY REDUCTION 17.10
17.12 THERMAL TRANSFER FLUIDS 17.11
17.13 HEAT TRANSFER MEDIA EVALUATION 17.12
17.14 EQUIPMENT DESIGN 17.12
CHAPTER 18 AIR SIDE HEAT EXCHANGERS 18.1
18.1 FIXED PLATE EXCHANGERS 18.1
18.2 ROTARY WHEEL EXCHANGERS 18.4
18.3 HEAT PIPE EXCHANGERS 18.10
18.4 RUN-AROUND COIL EXCHANGERS 18.14
CHAPTER 19 MULTIPLE TOWER EXCHANGERS 19.1
19.1 DESCRIPTION 19.1
19.2 PRINCIPLES OF OPERATION 19.1
19.3 PERFORMANCE 19.2
19.4 APPLICATION 19.2
19.5 CAPACITY CONTROLS 19.3
19.6 MAINTENANCE 19.4
19.7 THERMAL TRANSFER FLUID 19.4
CHAPTER 20 DRY AIR COOLER EXCHANGERS 20.1
20.1 DESCRIPTIONS 20.1
20.2 THE TRANSFER PROCESS 20.2
20.3 CROSS CONTAMINATION 20.2
20.4 INDIRECT/DIRECT EVAPORATIVE COOLING SYSTEMS 20.4
CHAPTER 21 OTHER ENERGY SYSTEMS 21.1
21.1 SOLAR SYSTEMS 21.1
21.2 THERMAL STORAGE SYSTEMS 21.3
CHAPTER 22 HYDRONIC RECOVERY SYSTEMS 22.1
22.1 TWO-PIPE ENERGY RECOVERY SYSTEMS 22.1
22.2 THREE-PIPE ENERGY RECOVERY SYSTEMS 22.2
22.3 FOUR-PIPE ENERGY RECOVERY SYSTEMS 22.3
22.4 HOT GAS HEAT RECOVERY 22.4

22.5 CONDENSATE HEAT RECOVERY 22.4

22.6 WASTE WATER HEAT RECOVERY 22.5

22.7 TOTAL ENERGY SYSTEMS 22.5

CHAPTER 23 ENERGY RECOVERY SYSTEM INVESTMENT ANALYSIS 23.1

23.1 PARTIAL METHODS OF EVALUATION ENERGY RECOVERY SYSTEM INVESTMENT ANALYSIS 23.1

23.2 COMPREHENSIVE METHODS FOR EVALUATING INVESTMENT ALTERNATIVES 23.4

23.3 SPECIAL FACTORS TO CONSIDER IN INVESTMENT ANALYSIS 23.10

23.4 APPLICATION OF EVALUATION METHODS TO DIFFERENT KINDS OF DECISIONS 23.14

23.5 SUMMARY 23.16

GLOSSARY G.1

INDEX I.1

TABLES

Table 1–1	Factors Influencing Mechanical/Electrical System Load/Energy	1.2
Table 1–2	Monthly Building or Plant Utility Usage	1.5
Table 4–1	Heat Pump Coefficient of Performance (COP)	4.8
Table 7–1	Domestic Hot Water Usage	7.1
Table 7–2	Tank Loss	7.2
Table 8–1	Suggested Lighting Levels	8.3
Table 8–2	Relative Efficiency of Bulb Types	8.4
Table 8–3	Capacitor Correction for Power Factor	8.10
Table 10–1	Detailed Energy Audit Report Outline	10.4
Table 10–2	Audit Equipment Available for the Retrofit Team	10.5
Table 10–3	Equipment Available to the Retrofit Team	10.6
Table 12–1	Campus Facilities Energy Operating Costs	12.3
Table 12–2	Performance Contract Outline	12.4
Table 13–1	Average Monthly and Yearly Degree Days for Cities in the United States and Canada (Base 65°F) (Sample Table)	13.1
Table 13–2	Correction Factors for Outdoor Design Temperatures	13.2
Table 13–3	Unit Fuel Consumption Constants (Based on 0°F Outdoor Temperature, 70°F Indoor Temperature)	13.3
Table 14–1	Efficiency of Fuel Utilization	14.1
Table 14–2	Heating Values of Fuel Gases	14.4
Table 14–3	Heating Values of Fuel Oils	14.5
Table 14–4	Capital Recovery Factors	14.11
Table 15–1	Common Refrigerants Used Today	15.3
Table 16–1	Thermodynamic Properties of Moist Air Standard Atmospheric Pressure (14.696 psi)	16.10
Table 16–2	Thermodynamic Properties of Moist Air (Metric) Standard Atmospheric Pressure (101.325 kPa)	16.11
Table 17–1	Comparison of Air-to-Air Energy Recovery Systems	17.8
Table 17–2	Characteristics of Energy Recovery Devices	17.9
Table 18–1	Frost Threshold Temperature, T1, for Various Exhaust Air Conditions	18.4
Table 20–1	Core Heat Recovery Capacities	20.3
Table 21–1	Solar Air Systems	21.2
Table 21–2	Solar Liquid Systems	21.2

Table 23–1	Potential Costs to Consider in Investing in Energy Recovery Systems	23.1
Table 23–2	An Illustration That Payback Analysis Does Not Take Into Account Cash Flows Beyond the Payback Period	23.3
Table 23–3	An Illustration That the Undiscounted Payback Method Can Result in Inaccurate Methods	23.3
Table 23–4	Discounting Equations	23.5
Table 23–5	Illustrative Discounting of Representative Costs and Benefits	23.6
Table 23–6	Illustration of Net Present Value Method	23.7
Table 23–7	Kinds of Investment Decision Problems	23.14
Table 23–8	Net Benefits and Benefit/Cost Ration Rankings for a Set of Independence Projects	23.15
Table 23–9	6% Compound Interest Factors	23.17
Table 23–10	8% Compound Interest Factors	23.18
Table 23–11	10% Compound Interest Factors	23.19
Table 23–12	12% Compound Interest Factors	23.20
Table 23–13	15% Compound Interest Factors	23.21

FIGURES

Figure 2–1 Single Duct System 2.4
Figure 2–2 Volume System 2.5
Figure 2–3 Power Consumption for Fan Volume Control 2.6
Figure 2–4 Terminal Reheat System 2.6
Figure 2–5 Dual Duct Low Velocity System 2.7
Figure 2–6 Dual Duct High Velocity System 2.8
Figure 2–7 Multi-Zone System 2.9
Figure 4–1 A Series Loop System 4.2
Figure 4–2 A One-Pipe System 4.3
Figure 4–3 Direct-Return Two-Pipe System 4.3
Figure 4–4 Reverse Return Two-Pipe System 4.3
Figure 4–5 Three-Pipe System, Room Unit Control 4.4
Figure 5–1 Building Automation System 5.4
Figure 5–2 Typical Multiblade Dampers 5.5
Figure 5–3 Dead Band Control System 5.9
Figure 5–4 Background — EMCS Evolution 5.11
Figure 5–5 Functional Block Diagram of a Centralized Computer-Based System 5.12
Figure 5–6 Hierarchy Configuration of the Centralized Control Systems 5.12
Figure 5–7 Chiller Efficiency 5.16
Figure 5–8 Chiller Performance 5.16
Figure 5–9 Monitoring and Control Points for an Air Handling Unit 5.17
Figure 8–1 Building Energy Usage Reduction Due to 30% Lighting Wattage Reduction 8.1
Figure 8–2 Power Factor Relationships 8.9
Figure 8–3 Totally Enclosed, Fan-Cooled Motor Replacement 8.11
Figure 9–1 Cooling Tower 9.2
Figure 9–2 Cooling Tower Intake Louvers 9.2
Figure 9–3 Unit Ventilator 9.2
Figure 9–4 HVAC System 9.2
Figure 9–5 Cooling Coil/Fan Section 9.3
Figure 11–1 Control Station 11.1
Figure 11–2 Electric Power Consumption 11.3

Figure 16–1 Conductivity Defined for a Homogeneous Material 16.2
Figure 16–2 Conductance Defined for a Nonhomogeneous Material 16.2
Figure 16–3 Heat Flow/Thermal Resistance 16.3
Figure 16–4 Heat Transfer Flow Patterns 16.4
Figure 16–5 Heat Transfer Curves 16.4
Figure 16–6 Heat Transfer Relationship 16.5
Figure 16–7 Sample Psychrometric Chart (U.S. Units) 16.9
Figure 16–8 Psychrometric Chart — Typical Condition Points (U.S. Units) 16.12
Figure 16–9 Psychrometric Chart — Typical Condition Points (U.S. Units) 16.13
Figure 16–10 Psychrometric Chart — Typical Condition Points (Metric Units) 16.15
Figure 16–11 Enthalpy Change 16.16
Figure 16–12 Sensible Heating and Cooling 16.16
Figure 16–13 Humidification and Dehumidification 16.17
Figure 16–14 Psychrometric Chart/Processes 16.18
Figure 16–15 Cooling and Dehumidifying 16.18
Figure 16–16 Heating and Humidification 16.19
Figure 16–17 Total Heat Content Change 16.19
Figure 16–18 Mixing Airstream on the Psychrometric Chart 16.22
Figure 16–19 High Temperature Range Chart (60°F to 250°F D.B.) 16.23
Figure 16–20 Low Temperature Range Chart (–40°F to 50°F D.B.) 16.24
Figure 16–21 High Altitude Chart for Normal Temperature Range (5000 ft.) 16.24
Figure 16–22 High Altitude Chart for Normal Temperature Range (7500 ft.) 16.25
Figure 17–1 Comfort-to-Comfort Sensible 17.1
Figure 17–2 Comfort-to-Comfort Total Heat (Enthalpy) Transfer 17.1
Figure 17–3 Process-to-Comfort Energy Recovery System 17.3
Figure 17–4 Process-to-Process Energy Recovery System 17.3
Figure 17–5 Counterflow Airstreams 17.4
Figure 17–6 Parallel-Flow Airstreams 17.4
Figure 17–7 Cross-Flow Airstreams 17.4
Figure 17–8 Run-Around Coil Exchangers (Closed Heat Recovery Loop) 17.5
Figure 17–9 Rotary Wheel Exchanger 17.6
Figure 18–1 Plate Type Heat Exchanger 18.1

Figure 18–2 Pressure Drop vs. Flow (Fixed Plate Recovery Unit) 18.2

Figure 18–3 Plate Exchanger with Bypass Damper 18.3

Figure 18–4 Rotary Wheel Purge Section (Directionally Oriented Media) 18.6

Figure 18–5 Representative Pressure Drops for Rotary Wheel Exchangers 18.7

Figure 18–6 Typical Rotary Wheel 18.7

Figure 18–7 Effectiveness of Unequal 18.7

Figure 18–8 By-Pass Dampers 18.8

Figure 18–9 Condensation and Frosting 18.8

Figure 18–10 Face-and-Bypass Dampers 18.9

Figure 18–11 Variable Speed Drive 18.9

Figure 18–12 Heat Pipe Exchanger 18.10

Figure 18–13 Heat Pipe Operation 18.10

Figure 18–14 Heat Pipe Exchanger Effectiveness 18.12

Figure 18–15 Design for In-Duct Manual Spray Cleaning 18.12

Figure 18–16 Heat Pipe Exchangers in Series 18.13

Figure 18–17 Elevation New of Coil Loop Thermosiphons 18.13

Figure 18–18 Automatic In-Duct Spray 18.14

Figure 18–19 Run-Around Coil System 18.16

Figure 19–1 Twin-Tower Enthalpy Recovery Loop 19.1

Figure 19–2 Multiple Tower Exchange Process 19.1

Figure 19–3 Multiple Tower Operation and Control 19.3

Figure 19–4 Performance Characteristics of Liquid Sorbant Enthalpy Systems 19.3

Figure 20–1 Dry Air Evaporative Cooler Exchanger 20.1

Figure 20–2 Dry Air Cooler Exchanger 20.2

Figure 20–3 Schematic of Equipment 20.5

Figure 21–1 Roof Monitor as a Solar Collector. (Duct and Fan Circulates Trapped Hot Air Back to Floor Level.) 21.1

Figure 21–2 Solar Heating and Cooling System Schematic 21.1

Figure 21–3 Flat Plate Solar Collector (Air) 21.2

Figure 21–4 Air Solar Heating System 21.2

Figure 21–5 Solar Assisted Heat Pump Schematic 21.3

Figure 21–6 Integrated Storage System Schematic 21.4

Figure 22–1 Two-Pipe Energy Recovery System 22.1
Figure 22–2 Three-Pipe Energy Recovery System 22.2
Figure 22–3 Four-Pipe Energy Recovery System 22.3
Figure 22–4 Compressor Heat Recovery 22.5
Figure 22–5 Condensate Heat Recovery 22.5
Figure 22–6 Schematic of Laundry and Kitchen Hot Water Heat Recovery System 22.5
Figure 22–7 Typical Total Energy System 22.6