HANDBOOK OF AIR CONDITIONING AND REFRIGERATION

Shan K. Wang

Second Edition



McGraw-Hill

New York San Francisco Washington, D.C. Auckland Bogotá
Caracas Lisbon London Madrid Mexico City Milan
Montreal New Delhi San Juan Singapore
Sydney Tokyo Toronto

CONTENTS

Preface to Second Edition xi Preface to First Edition xiii

Chapter 1. Introduction	1.1
Chapter 2. Psychrometrics	2.1
Chapter 3. Heat and Moisture Transfer through Building Envelope	3.1
Chapter 4. Indoor and Outdoor Design Conditions	4.1
Chapter 5. Energy Management and Control Systems	5.1
Chapter 6. Load Calculations	6.1
Chapter 7. Water Systems	7.1
Chapter 8. Heating Systems, Furnaces, and Boilers	8.1
onaptor of fronting dystems, i amades, and boners	
Chapter 9. Refrigerants, Refrigeration Cycles, and Refrigeration	
Systems	9.1
Chapter 10. Refrigeration Systems: Components	10.1
Chapter 11. Refrigeration Systems: Reciprocating, Rotary, Scroll, and Screw	v 11.1

Systems	Heat Pumps, Heat Recovery, Gas Cooling, and Cogeneration	12.1
Chapter 13.	Refrigeration Systems: Centrifugal	13.1
Chapter 14.	Refrigeration Systems: Absorption	14.1
Chapter 15.	Air Systems: Components—Fans, Coils, Filters, and Humidifiers	15.1
Chapter 16. Units	Air Systems: Equipment—Air-Handling Units and Packaged	16.1
Chapter 17.	Air Systems: Air Duct Design	17.1
Chapter 18.	Air Systems: Space Air Diffusion	18.1
Chapter 19.	Sound Control	19.1
Chapter 20.	Air Systems: Basics and Constant-Volume Systems	20.1
Chapter 21.	Air Systems: Variable-Air-Volume Systems	21.1
Chapter 22. and Smoke	Air Systems: VAV Systems—Fan Combination, System Pressure, Control	22.1
Chapter 23.	Air Systems: Minimum Ventilation and VAV System Controls	23.1
Chapter 24.	Improving Indoor Air Quality	24.1
Chapter 25.	Energy Management and Global Warming	25.1
	Air Conditioning Systems: System Classification, Selection, ual Systems	26.1

Chapter 27. Air Conditioning Systems: Evaporative Cooling Systems and Evaporative Coolers	27.1
Chapter 28. Air Conditioning Systems: Space Conditioning Systems	28.1
Chapter 29. Air Conditioning Systems: Packaged Systems and Desiccant-Based Systems	29.1
Chapter 30. Air Conditioning Systems: Central Systems and Clean-Room Systems	30.1
Chapter 31. Air Conditioning Systems: Thermal Storage Systems	31.1
Chapter 32. Commissioning and Maintenance	32.1
Appendix A. Nomenclature and Abbreviations	A.1
Appendix B. Psychrometric Chart, Tables of Properties, and I-P Units to SI Units Conversion	B.1

Index follows Appendix B

INDEX

Abbreviations, A.9–A.10	Absorption heat pumps, 14.22–14.24
Absolute zero, 2.5	case study: series connected,
Absorption chiller-heaters, 14.20–14.22	14.22-14.24
actual performance, 14.22	functions of, 14.22
heating cycle, 14. 20– 14. 22	Absorption heat transformer, 14.24–14.26
Absorption chillers, double-effect, direct-fired,	coefficient of performance, 14.26
14.6–14. 18	operating characteristics, 14.24–14.25
absorber and solution pumps, 14.6–14.7	system description, 14.24–14.25
air purge unit, 14. 8– 14. 9	Accuracy, 2.6
capacity control and part-load operation,	Adiabatic process, 2.11
14. 16 –14. 17	Adiabatic saturation process, ideal, 2.11
coefficient of performance, 14.14	Air:
condenser, 14. 7– 14. 8	atmospheric, 2.1
condensing temperature, 14.19-14.20	dry air, 2.1–2. 2
controls, 14. 16– 14. 18	mass, 3.25
cooling water entering temperature, 14.19	moist air, 2.1
cooling water temperature control,	primary, 20.4
14. 17- 14. 18	process, 1. 4- 1. 5
corrosion control, 14.20	recirculating, 20.4
crystallization and controls, 14.17	regenerative, 1.4-1.5
difference between absorption and centrifugal	secondary, 20.4
chillers, 14. 18- 14. 19	transfer, 20.4
evaporating temperature, 14.19	ventilation, 4.29
evaporator and refrigerant pump, 14.6	Air cleaner, electronic, 15.69-15.70
flow of solution and refrigerant, 14.9-14.11	Air conditioning, 1.1–1.2,
generators, 14. 7– 14. 8	industry, 1.15
heat exchangers, 14.6-14.7	project development, 1.16-1.17
heat removed from absorber and condenser,	Air conditioning processes, 20.41–20.53
14. 19	adiabatic mixing, 20.50-20.52
mass flow rate of refrigerant and solution,	air washer, 20.46
14. 11 – 14. 12	bypass mixing, 20.52-20.53
monitoring and diagnostics, 14.18	cooling and dehumidifying, 20.47-20.50
operating characteristics and design consider-	heating element humidifier, 20.46
ations, 4.18-4.20	humidifying, 20. 45- 20. 47
performance of, 14. 11- 14. 16	oversaturation, 20.46-20.47
rated conditions, 14.20	reheating, recooling and mixing,
safety and interlocking controls, 14.18	20. 74 –20. 75
series flow, parallel flow, and reverse parallel	relative humidity of air leaving coil,
flow, 14.8-14.9	20. 49- 20. 50
Standard 90.1-1999 minimum efficiency re-	sensible heat ratio, 20.41-20.43
quirements, 14.20	sensible heating and cooling,
system description, 14.6-14.8	20. 44- 20. 45
thermal analysis, 14. 12- 14. 14	space conditioning, 20.43-20.44
throttling devices, 14.8	steam injection humidifier, 20.45-20.46
~	· · · · · · · · · · · · · · · · · · ·

Air conditioning systems, 1.2	Air conditioning systems, space conditioning,
air, cooling and heating systems designation,	28. 1- 28. 3
26. 2 -26. 3	advantages and disadvantages, 28.2-28.3
central, 1.6	applications, $28.1-28.2$
central hydronic, 1.6	induction systems, 28.3
classification, basic approach, 26.1-26.2	Air contaminants, indoor, 4.27-4.28, 15.61
classification of, 1.3-1.10, 26.2-26.3	Air duct design, principles and considerations,
clean room, 1.5	17. 43 – 17. 51
comfort, $1.2-1.3$	air leakage, 17. 48 – 17. 50
desiccant-based, 1.4	critical path, 17.48
evaporative-cooling, 1.4	design procedure, 17.5 1 – 17.5 2
individual room, 1.4	design velocity, 17.45-17.46
packaged, 1.6	duct layout, 17.52-17.53
space, 1. 5	duct system characteristics, 17.52
space conditioning, 1.5	ductwork installation, 17.50
thermal storage, 1.5	fire protection, 17.50–17.51
unitary packaged, 1.6	optimal air duct design, 17.43-17.45
Air conditioning systems, individual,	sealing requirements of ASHRAE Standard
26. 8- 26. 9	90.1–1999, 17. 49– 17. 50
advantages and disadvantages, 26.9	shapes and material of air ducts, 17.50
basics, 26. 8- 26. 9	system balancing, 17. 46– 17. 47
Air conditioning systems, packaged terminal,	Air expansion refrigeration cycle, 9.45-9.49
26. 13 –26. 15	flow processes, $9.47-9.48$
equipment used, 26. 13– 26. 14	thermodynamic principle, 9.45-9.47
heating and cooling mode operation,	Air filters, 15.64–15.68
26. 13 –26. 14	classification of, 15.65
minimum efficiency requirements,	coarse, 15. 65
ASHRAE/IESNA Standard 90.1–1999,	filter installation, 24.7-24.8
26.14-26.15	filtration mechanism, 15.64–15.65
system characteristics, 26.13, 26.15	high-efficiency, 15. 66– 15. 67
Air conditioning systems, room,	low-efficiency, 15.65-15.66
26.9–26. 13	medium-efficiency, 15.66–15.67
configuration, 26. 10– 26. 11	service life, 24.7
controls, 26. 12	ultrahigh-efficiency, HEPA and ULPA filters,
cooling mode operation, 26.11	15.68
energy performance and energy use intensi-	Air filters, rating and assessments, 15.61-15.62
ties, 26. 11– 26. 12	dust-holding capacity, 15.62
equipment used in, 26.9–26.10	efficiency, 15.61
features, 26.12	pressure drop, 15.6 1- 15.6 2
system characteristics, 26.12-26.13	service life, 15.62
Air conditioning systems, selection:	Air filters, test methods, 15.62–15.64
applications and building occupancies,	composite efficiency curves, 15.63–15.64
26.4–26.5	di-octylphthalate (DOP), 15. 62– 15. 63
energy efficiency, 26.7	dust spot, 15.62
fire safety and smoke control, 26.7–26.8	minimum efficiency reporting values
indoor air quality, 26.5–26.6	(MERVs), 15. 64– 15. 65
initial cost, 26.8	penetration, 15.63
maintenance, 26.8	removal efficiency by particle size, 15.63
requirements fulfilled, 26.4	selection, 15.71–15.72
selection levels, 26.3–26.4	test unit, 15.64
sound problems, 26.6–26.7	weight arrestance, 15.62
space limitations, 26.8	Air filters to remove contaminants, 24.6–24.8
system capacity, 26.5	filter selection for IAQ, 24.6–24.7
zone thermal control, 26.6	remove indoor air contaminants, 24.6

Air filtration and industrial air cleaning,	Air jets (Cont.)
15. 60 – 15. 61	throw, 18. 7
Air flow, basics, 17.2-17.8	transition zone, 18.6,
Bernoulli equation, 17.2	velocity profile, 18.6
equation of continuity, 17.7-17.8	Air movements, 4. 20– 4. 23
laminar flow and turbulent flow, 17.6-17.7	Air systems, 1.6-1.8, 20.2-20.4
pressure, 17.3	air conditioning rules, 20.63
stack effect, 17.5-17.6	air distribution system, 20.3
static pressure, 17.3-17.4	air economizer mode, 22.5
steady flow energy equation, 17.2-17.3	air-handling system, 20.2
total pressure, 17.5	classification, 20.39
velocity distribution, 17.3	constant volume systems, 20.40-20.41
velocity pressure, 17.4–17.5	cooling and heating mode, 22.4
Air flow, characteristics, 17.8–17.10	mechanical ventilation system, 20.3
air duct, types, 17.8	minimum outdoor air recirculating mode,
pressure characteristics, 17.8–17.10	22.5
static regain, 17.9	mixing-exhaust section, 22.8
system pressure loss, 17.10	occupied and unoccupied mode, 22.5
Air-handling units, 1.8 , 16.1–16. 12	operating modes, 22.4-22.5
casing, 16.4	part-load operation, 22.4-22.5
classification of, 16. 2– 16. 4	purge-mode, 22.5
coil face velocity, 16.8–16.9	regenerative systems, 20.3–20.4
coils, 16. 5	reheating, recooling, and mixing,
component layout, 16.6–16.8	20.74–20.75
controls, 16.6	smoke control systems, 20.4
draw-through or blow-through unit, 16. 2	terminals, 20.4
exhaust section, 16.6	ventilation systems, 20.3
factory fabricated or field-built AHU, 16.3	warmup, colddown, and nighttime setback
fans, 16.4–16. 5	mode, 22.5
filters, 16. 5	Air temperature:
functions of, 16. 1– 16. 2	comfort air conditioning systems,
horizontal or vertical unit, 16.2	4.20-4.21
humidifiers, 16. 5– 16. 6	indoor, 4.20-4.23
mixing, 16.6–16. 7	processing air conditioning systems, 4.23
outdoor air intake, 16.6	Air washer, 1.11
outdoor air (makeup air) or mixing AHU,	Amplifiers, 2.7
16.2	Annual energy use, HVAC&R systems,
selection, 16.9–16. 12	1.14
single zone or multizone, 16.2–16.3	Artificial intelligence, 5.45 – 5.5 3
rooftop or indoor AHU, 16. 4	Artificial neural networks (ANN), 5.50-5.53
Air jets, 18.5–18. 11	learning method, 5.52-5.53
Archimedes number, 18.11	neuron, 5. 51
centerline velocities, 18.8–18.9	neuron activation transfer 5.51–5.52
characteristic length, 18.8	net topology, 5.51
confined, 18.8–18. 10	ASHRAE/IESNA Standard 90.1–1999,
confined, airflow pattern, 18.9–18.10	building envelope trade-off option, 3.50
core zone, 18.5	compliance for building envelope,
entrainment ratio, 18.7	3.48-3.50
envelope, 18.5	controls, 5.66–5.67
free isothermal, 18.5–18.7	off-hour controls, 5.66–5.67
free nonisothermal, 18.10–18.11	Atmospheric dust, 15.6 1
main zone, 18.6	Atmospheric extinction coefficient, 3.26
surface effect, 18.8	Automated computer-aided drafting (Auto-
terminal zone. 18.6	CAD). 1.26

Bernoulli equation, 17.2	Campus-type water systems, 7.53-7.58
Boilers, hot water, 8.9-8.15	building entrance, 7.56
cast-iron sectional, 8.12	control of variable-speed distribution pump,
chimney or stack, 8.14	7. 56
combustion efficiency, 8.13	distribution pipes, 7.58
condensing and noncondensing, 8.13	multiple-source distributed building loop,
electric, 8.17	7.57–7.58
fire-tube, 8.10	plant-distributed building loop, 7.56-7.57
flow processes, 8. 10– 8. 12	plant-distribution building loop, 7.54-7.56
forced-draft arrangements, 8.12	pressure gradient of distribution loop, 7.54
gas and oil burners, 8. 13	Carbon adsorbers, activated, 15.70–15.71
heating capacity control, 8.14	reactivation, 15. 71
minimum efficiency requirements,	Cascade systems, 9.40–9.43
8.13 – 8.14	advantages and disadvantages, 9.40-9.41
safety control, 8.14–8.15	performance, 9.42–9.43
Scotch Marine packaged boiler,	Central plant, 1.8–1.9
8.10-8.12	
	Central systems, 30.2
selection of fuel, 8.9–8.10	air and water temperature differentials,
types of, 8.10	30.5–30.6
Boiling point, 2.4–2.5	control at part load, 30.4
Building:	controls in water, heating, and refrigerating
energy star, 25.10	systems, 30.4
green, 25.8–25. 10	floor-by-floor systems vs. air systems serving
shell building, 3.48	many floors, 30.2–30.3
speculative building, 3.48	influence of inlet vanes on small centrifugal
Building automation and control network (BAC-	fans, 30.5-30.7
net), 5.4 1	separate air system, 30.2-30.3
Building automation systems, 5.2	size of air system, 30.2
Building envelope, 3.2	types of VAV central systems, 30.7
ceiling, 3.2	Central systems, clean-room, 30.14-30.24
energy-efficient and cost-effective measures,	airflow, 30. 14- 30. 16
3. 50 –3. 51	case-study: integrated-circuit fabrication,
exterior floor, 3.2	30. 16– 30. 24
exterior wall, 3.2	design considerations, 30.24
fenestration, 3.2	effect of filter pressure drop difference on
partition wall, 3.2	system performance, 30.22-30.24
roof, 3. 2	energy use of components, 30.17
skylight, 3. 2	indoor requirements, 30.16-30.17
slab on grade, 3.2	operating characteristics, 30.18-30.19
Standard 90.1-1999, 3.48-3.50	part-load operation and controls,
wall below grade, 3.2	30. 19 –30. 20
window, 3.2	pressurization, 30.16
Building material:	summer mode operation, 30.19
closed-cell, 3.16	system characteristics, 30.13
open-cell, 3.13	system description, 30.14-30.15,
Building tightness, or building air leakage,	30. 17- 30. 18
20.5–20.6	system pressure, 30.21
air change per hour at 50 Pa (ACH50), 20.6	temperature and relative humidities, 30.16
effective leakage area, 20.5	winter mode operation and controls,
exfiltration, 20.14	30.20-30.21
flow coefficient C _{flow} , in cfm/ft ² , 20. 6	Central systems, dual-duct VAV, 30.10-30.11
infiltration, 20.14	system characteristics, 30.8
volume flow rate of infiltration, 20.14	system characteristics, 50.0 system description, 30.10–30.11
volume now rate of minimation, 20-14	system description, 50.10-50.11

Central systems, fan-powered VAV,	Centrifugal chiller (Cont.)
30. 11 – 30. 13	system balance at full load, 13.25
case-study: Taipei World Trade Center,	system characteristics, 13.12-13.13
30. 12- 30. 13	system description, 13.9
supply volume flow rate and coil load, 30.11	temperature lift at part-load, 13.29-13.31
system characteristics, 30.13	water-cooled, 13.7-13.9
system description, 30.11	Centrifugal chiller, multiple-chiller plant,
Central systems, single zone VAV, 30.7–30.9	13. 33 –13. 36
supply volume flow rate and coil load,	chiller staging, 13.34
30. 7 –30. 8	design considerations, 13.35-13.36
system characteristics, 30.8	parallel and series piping, 13.33-13.34
system description, 30.7	Standard 90.1-1999 minimum efficiency re-
zone temperature control, 30.8	quirements, 13.35
Central systems, VAV cooling, VAV reheat, and	Centrifugal compressor:
perimeter-heating VAV, 30.9-30.10	performance map, 13. 15 – 13. 18
supply volume flow rate and coil load, 30.9	surge of, 13. 15– 13. 16
system characteristics, 30.8	Centrifugal compressor map:
system description, 30.9	at constant speed, 13.16-13.18
zone temperature control, 30.10	at variable speed, 13.17-13.18
Centrifugal chiller, 1.12	Centrifugal pumps, 7.30-7.34
air purge, 13. 24	cavitation, 7.33
auxiliary condenser, 13.9-13.11	net positive suction head (NPSH), 7.33
capacity control, 13. 19- 13. 21	net static head, 7.32
capacity control by variable speed, 13.20	performance curves, 7.32-7.33
capacity control using inlet vanes, 13.20	pump efficiency, 7.32
chilled water leaving temperature control,	pump power, 7.32
13. 22	selection, 7.33-7.34
comparison between inlet vanes and variable	total head, 7.30-7.32
speed, 13. 21	volume flow, 7.30
condenser water temperature control, 13.23	Centrifugal refrigeration systems, 13.1–13.7
controls, 13. 22 –13. 24	compressor, 13. 3– 13. 4
difference between centrifugal compressors	free refrigeration, 13.31–13.33
and fans, 13. 19	free refrigeration, principle of operation,
double-bundle condenser, 13.9–13.10	13. 31 –13. 32
evaporating and condensing temperatures at	free refrigeration capacity, 13.32-13.33
part-load, 13. 26- 13. 27	purge unit, 13. 5- 13. 7
faults detection and diagnostics, 13.24	refrigerants, 13.2-13.3
functional controls and optimizing controls,	system components, 13.4–13.5
13.22	Chilled-water storage systems, stratified,
incorporating heat recovery, 13.9-13.13	31. 18– 31. 23
operating characteristics, 13.24–13.35	basics, 31.18-31.19
operating modes, 13.9-13.11	case-study, 31. 23–28
part-load operation, 13.25-13.27	charging and discharging, 31.18,
part-load operation characteristics,	31. 26– 31. 27
13.25-13.26	charging and discharging temperature,
performance rating conditions, 13.8–13.9	31.22-31.23
refrigerant flow, 13.7-13.8	chilled water storage system, 31.23-31.25
required system head at part-load operation,	concentric double-octagon diffusers,
13.19–13.20	31.24-31.26
safety controls, 13.23-13.24	diffusers, 31.20–31.22
sequence of operations, 13.24–13.25	figure of merit, 31.19
short-cycling protection, 13.23	inlet Reynolds number, 31.21–31.22
surge protection, 13.24	part-load operation, 31.27-31.28

Chilled-water storage systems, stratified (Cont.)	Coils, sensible cooling and heating (dry coils)
self-balancing, 31.22	(Cont.)
storage tanks, 31.19	effectiveness ε , 15.42
stratified tanks, 31.19-31.20	fin efficiency η_f , 15.41–15.42
system characteristics, 31.10	fin surface efficiency η_s , 15.41
system description, 31.18	fluid velocity and pressure drop, 15.44
system performance, 31.28	heat transfer in sensible cooling process,
thermocline and temperature gradient,	15. 39 –15. 41
31. 20– 31. 21	heating coils, 15.44
Chlorofluorocarbons (CFCs), 1.12	JP parameter, 15.41
Clean room, 4.31	number of transfer units (NTU), 15.43
Clean space, 4.31	part-load operation, 15.44
Clearness number of sky, 3.26	surface heat transfer coefficients,
Clothing:	15. 41 –15. 42
efficiency, 4. 6	Coils, water cooling (dry-wet coils),
insulation, 4.7	15.48–15.5 2
CLTD/SCL/CLF method of cooling load calcu-	dry-part, 15. 50
lation, 6. 26- 6. 32	dry-wet boundary, 15. 48– 15. 49
exterior walls and roofs, 6. 26- 6. 28	part-load operation, 15.50–15.51
fenestration, 6. 28	selection, 15. 51 – 15. 52
infiltration, 6. 31	wet-part, 15. 50
internal loads, 6. 29– 6. 31	Cold air distribution, 18. 28– 18. 30
night shutdown mode, 6. 32	
	case-study, Florida Elementary School, 18.29
wall exposed to unconditioned space,	
6.28-6.29	characteristics, 18.29
Codes and standards, 1.23–1.25	vs. conventional air distribution, 18. 28
Cogeneration, 12.25–12.26	with fan-powered VAV boxes, 18.30
using a gas turbine, 12.28–12.29	high induction nozzle diffusers,
Coil accessories, 15.56–15.57	18.28–18.29
air stratification, 15.58 – 15.59	performance of ceiling and slot diffusers,
air vents, 15. 56	18. 29 –18. 30
coil cleanliness, 15.57	surface condensation, 18.30
coil freeze protection, 15.58-15.60	Commissioning, 32.1
condensate collection and drain system,	cost of HVAC&R commissioning, 32.5
15. 57 –15. 58	necessity of HVAC&R commissioning,
condensate drain line, 15.58	32. 1 –32. 2
condensate trap, 15.58	scope of, 32. 2– 32. 3
drain pan, 15. 58	team of HVAC&R commissioning, 32.4
Coil characteristics, 15.32–15.39	when to perform, 32.4–32.5
coil construction parameters, 10.3-10.4	Compound systems with flash cooler:
contact conductance, 15.37-15.39	coefficient of performance, 9.33, 9.38
direct-expansion (DX), 15.33	coil core surface area F_s , 15.40
fins, 15. 33– 15. 37	enthalpy of vapor mixture, 9.32-9.33
interference, 15.38	flow processes, 9.31
steam heating, 15.33	fraction of evaporated refrigerant in flash
types of, 15. 33– 15. 34	cooler, 9. 31- 9. 32, 9. 35- 9. 37
water circuits, 15.38-15.39	three-stage, 9.35-9.38
water cooling, 15.33	two-stage, 9.31-9.33
water heating, 15.33	Compound system with vertical intercooler,
Coils, DX (wet coils), 10.2–10. 10	two-stage, 9. 38- 9. 40
(See also DX coils)	comparison between flash coolers and inter-
Coils, sensible cooling and heating (dry coils),	coolers, 9.40
15.39–15.48	Compressibility factor, 2.2–2.3
Chilton-Colburn j-factor, 15. 41	Compressors, reciprocating, 11.5

Computational fluid dynamics (CFD),	Condensers, air-cooled (Cont.)
18. 51 – 18. 54	oil effect, 10.29
conducting CFD experiments, 18.54	selections, 10.30
numerical methods, 18.52-18.53	subcooling, 10.29
Reynolds-averaged Navier-Stokes equations,	volume flow, 10.28
18. 52	warm air circulation, 10.29
velocity vectors of the airflow in a duct sec-	Condensers, evaporative, 10.30-10.33
tion, 18. 53	condensation process, 10.30
Computer-aided design, 1.25-1.26	cooling air, 10.32
Computer-aided design and drafting (CADD),	heat transfer, 10.30–10.32
1.25–1.26	low ambient air control, 10.33
Computer-aided design and interface, 17.73	selection and installations, 10.33
Computer-aided drafting, 1.26	site location, 10.32–10.33
Computer-aided duct design and drafting,	water spraying, 10.32
17.72–17.73	Condensers, water-cooled, 10. 22– 10. 26
Computer-aided duct drafting, 17.72	capacity, 10.26
Computer-aided running processes of duct sys-	double-tube condenser, 10.22–10.23
tem, 19.73	effect of oil, 10. 25
Computer-aided schedules and layering,	·
17.72–17.73	heat transfer, 10.24–10.25
	part-load operation, 10.26
Computer-aided piping design and drafting,	performance, 10.25 – 10.26
7.58–7.60	shell-and-tube condensers, 10.22–10.25
computer-aided design capabilities,	subcooling, 10.25
7.59 – 7.60	types of, 10.22
computer-aided drafting capabilities,	Conduit induction system, 1.11
7.58–7.59	Constant-volume multizone system with reheat,
input data and reports, 7.60	20.74-20.78
pressure losses and network technique,	control systems, 20. 75– 20. 76
7.59	operating parameters and calculation,
pump and system operations, 7.59	20. 76 –20. 78
system and pipe size, 7.59	reheating, recooling and mixing,
Condensation:	20.74-20.75
in buildings, 3. 17 –3. 18	system characteristics, 20.78
concealed condensation in building en-	Constant-volume single-zone systems, cooling
velopes, 3.18	mode operation, 20. 53- 20. 59
visible surface, 3.17–3.18	air conditioning cycle, cooling mode opera-
Condensation process, 10.20–10.21	tion, 20. 53– 20. 54
heat rejection factor, 10.21-10.22	cooling mode operation in summer,
total heat rejection, 10.21-10.22	20. 53- 20. 56
Condensers, 10. 20– 10. 36	cooling mode operation in winter with space
automatic brush cleaning for, 13.13-13.15	humidity control, 20.55–57
effect of brush cleaning system, 13.14-13.15	cooling mode operation in winter without
principle and operation, 13.13-13.14	space humidity control, 20.55-57
type of, 10. 22	outdoor ventilation air and exhaust fans,
Condensers, air-cooled, 10.26-10.30	20. 58- 20. 59
clearance, 10.29	part-load operation and controls, 20.58
condenser temperature difference,	two-position or cycling control, 20.58
10. 28 -10. 29	water flow rate modulation, 20.58
condensing temperature, 10.29,	Constant-volume single-zone systems, heating
construction, 10. 26- 10. 28	mode operation, $20.69-20.74$
cooling air temperature rise, 10.28	dual-thermostat, year-round zone temperature
dirt clogging, 10.29	control, 20. 73- 20. 74
heat transfer process, 10.26-10.28	heating mode with space humidity control,
low ambient control 10 20 10 30	20.71_20.73

Constant-volume single-zone systems, heating	Controllers (Cont.)
mode operation (Cont.)	flash erasable programmable read-only mem-
heating mode without space humidity control,	ory (flash EPROM), 5.25
20. 69- 20. 70	normally closed or normally open, 5.22
part-load operation, 20.73	pneumatic, 5.22–5.23
Constant-volume systems, 20.40–20.41	random-access memory (RAM), 5.24
energy per unit volume flow, 20.41	read-only memory (ROM), 5.23
system characteristics, 20.40-20.41	system, 5.23-5.26, 5.38-5.39
Control loop, 5.5	unit, 5. 23 – 5. 26, 5. 39
closed, 5. 5	Controls:
open, 5. 5	alarming, 5.60
Control medium, 5.11	discriminator, 5.60
Control methods, 5.7–5.9	functional, 5.58–5.61
comparison of, 5.8-5.9	generic, 5. 59- 5. 60
direct-digital-control (DDC), 5.7	graphical displays, 5. 59
electric or electronic control, 5.7-5.8	scheduling, 5. 59- 5. 60
pneumatic control, 5.7	specific, 5.6 0- 5.6 1
Control modes, 5.9-5.16	trending, 5. 59
compensation control or reset, 5.15	Cooling coil load, 6.32-6.34
differential, 5.9	duct heat gain, 6.33
floating control, 5.11	fan power, 6.33
modulation control, 5.10	temperature of plenum air, 6. 34
offset or deviation, 5.13	ventilation load, 6.34
proportional band, 5.12	Cooling coil load, components, 6.7-6.8
proportional control, 5.11–5.13	Cooling load:
proportional-integral-derivative (PID) control,	components, 6.6-6.7
5.14-5.15	external, 6.7
proportional plus integral (PI) control,	internal, 6.7
5.13-5.14	Cooling load calculations:
step-control, 5. 10- 5. 11	historical development, 6.11–6.12
throttling range, 5.12	heat balance, 6.12–6.14
two-position, 5.9–5.10	transfer function, 6.14-6.16
Control systems, 5. 2	Cooling media, 9.3
direct digital control (DDC), 1.9	Cooling towers, 10. 34 –10. 36
dual-thermostat year-round zone temperature	approach, 10.36, 10.41
control, 20. 73– 20. 74	blowdown, 10.36
Control valves, 5.26–5.31 ,	construction materials, 10.43
actuators, 5. 26– 5. 27	counterflow forced draft, 10.35-10.36
equal-percentage, 5.28	counterflow induced draft, 10.34-10.35
flow coefficient, 5. 31	crossflow induced draft, 10.34-10.35
linear, 5. 28	factors affecting performance, 10.40
quick-opening, 5. 29	fill configuration, 10. 42– 10. 43
rangeability, 5. 29	heat and mass transfer process, 10.37-10.39
three-way, 5.27	makeup, 10. 36
two-way, 5.27	optimum control, 10.43-10.44
Controlled device, 5.5	outdoor wet-bulb temperature, 10.41
Controlled variable, 5.2	part-load operation, 10.43
Controllers, 5.21–5.26	performance, 10.40 — 10.43
direct-acting and reverse-acting, 5.21–5.22	range, 10.36, 10.40
direct digital, 5.23-5.26	thermal analysis, 10.36–10.39
electric and electronic, 5.23	tower capacity, size, 10. 37 – 10. 39
electric erasable programmable read-only	tower coefficient (NTU), 10.36–10.39, 10.41
memory (EEPROM), 5.24	water-air ratio, 10. 41
111011011 (220 100111), 0027	

Cooling towers (Cont.)	Demand-controlled ventilation (DC V), CO ₂ -
water circulating rate, 10.40	based (Cont.)
water distribution, 10.43	purge mode, 23. 10
Cooling towers, operating considerations,	substantial lag time in space CO2 concentra-
10. 46 -10. 48	tion dilution process, 23.8-23.8
blowdown, 10.47	vs. time-based constant-volume control,
fogging, 10. 46– 10. 47	23. 5 – 23. 6
freeze protection, 10.46	Depletion of the ozone layer, 1.15
interference, 10.46	Desiccant-based air conditioning systems,
Legionnaires' disease, 10.47	29. 22- 29. 27
maintenance, 10.47-10.48	applications, 29. 34- 29. 35
recirculation, 10.46	conditions to apply, 29. 34– 29. 35
Coordination, 1.19	desiccant dehumidification and sensible cool-
Copenhagen Amendments and Vienna Meeting,	ing, 29. 22– 29. 24
9.10-9.11	desiccants, 29.24-29.26
Corrosion, 7.25	lithium chloride, 29.26
	molecular sieves, 29.26-29.27
	rotary desiccant dehumidifiers, 29.27
Daily range, mean, 4.39	silica gel, 29. 26
Dalton's law, 2.3–2.4	system characteristics, 29.21
Dampers, 5.32–5.38	Desiccant-based air conditioning systems, for
actuators, 5.33	operating rooms, 29.32–29.34
butterfly, 5. 32	indoor environment, 29.32–29.33
characteristic ratio, 5.35–5.37	system description, 29.33 – 29.34
gate, 5. 32	Desiccant-based air conditioning systems, for
opposed-blade, 5.33 , 5.35 – 5.37	retail store, 29. 31–32
parallel-blade, 5.33, 5.35–5.37	operating characteristics, 29.31–29.32
- 1	performance, 29.32
sizing, 5. 37 – 5. 38 split, 5. 32 – 33	
• •	system description, 29.31–29.32
DDC programming, 5.53 – 5.55	Desiccant-based air conditioning systems, for
evolution, 5. 53	supermarket, 29.27–29.31
graphical, 5.53–5.54	air conditioning cycle, 29. 30– 29. 31
for mechanical cooling control, 5. 55	gas heater, 29. 30
templates, 5.54	heat-pipe heat exchanger, 29. 29- 29. 30
DDC tuning controllers, 5.55–5.56	indirect evaporative cooler, 29.30
adaptive control, 5.56	loads in supermarkets, 29. 27
PI controllers, 5.55	operating parameters in rotary desiccant de-
self-tuning, 5.55	humidifier, 29. 29
Degree days:	part-load operation and controls, 29.31
cooling with a base temperature of 50 °F, 4.39	refrigeration, 29.30,
heating with a base temperature of 65 °F, 4.39	space conditioning line, 29. 28 – 29. 29
number of, 4. 39	system description, 29.25, 29.28
Degree of saturation, 2.8	of the control systems, 1.20–1.21
Demand-controlled ventilation (DCV), CO ₂ -	Design
based, 23.5-23.12	documents, 1.21–1.22
application of, 23. 11– 23. 12	Design-bid, 1.17
ASHRAE Standard 62–1999, 23. 7	Design-build, 1.17
base ventilation, 23.9–23.10	Design intent, 32.1
CO ₂ -based DCV system, 23.10-23.11	Desorption isotherm, 3.11
CO ₂ sensor or mixed-gases sensor, 23.7	Diagram:
location of CO ₂ sensor, 23.7–23.8	pressure-enthalpy, 9.17-9.18
minimum outdoor air recirculation mode,	temperature-entropy, 9.18-9.19
23.6	Direct expansion (DX) coil, 1.4

Discharge all temperature controls,	Duct sizing methods (Cont.)
23. 18 -23. 23	static regain method, 17.54-17.55
basics, 23.18	T-method, 17.55-17.56
discharge air temperature reset, 23.22-23.23	Duct static pressure and fan controls, 23.23-23.26
operation of air economizer, 23.21-23.22	comparison between adjustable-frequency
outdoor air intake, 23. 21 – 23. 22	drives and inlet vanes, 23.24-23.26
system description, 23.19-23.21	duct static pressure control, 23.23-23.24
Distribution of systems usage, 1.10	sensor's location, 23.24
Diversity factor, 1.20	set point, 23. 24
Drawings, 1.22	Duct systems with certain pressure losses in
air duct diagram, 1.22	branch takeoffs, 17.56–17.66
control diagrams, 1.22	condensing two duct sections, 17.59-17.60
detail, 1. 22	cost optimization, 17.56–17.59
equipment schedule, 1.22	design characteristics, 17.56
floor plans, 1. 22	local loss coefficients for diverging tees and
legends, 1.22	wyes, 17.60–17.62
piping diagram, 1. 22	return or exhaust duct systems, 17.63
sections and elevations, 1.22	Duct systems with negligible pressure loss at
Duct cleaning, 17. 74– 17. 75	branch ducts, 17.66–17.72
Duct construction, 17.12–17.18	local loss coefficients, 17.68–17.69
duct hanger spacing, 17.17	pressure characteristics of airflow in supply
fiberglass ducts, 17.18	ducts, 17.66–17.68
flame speed and smoke developed, 17.13	rectangular supply duct with transversal slots
flat oval ducts, 17. 17 – 17. 18	17. 67
flexible ducts, 17.18	return or exhaust duct systems, 17.71-17.72
material, 17. 12– 17. 13	supply duct systems, 17.66
maximum pressure difference, 17.12	DX coils, wet coils, 10.2–10. 10
rectangular ducts, 17.13	air-side pressure drop, 10.8
rectangular metal duct construction, 17.15	construction and installation, 10.3–10.4
round ducts, 17. 17	DX coil effectiveness, 10.6–10.7
thickness of galvanized sheets, 17.14, 17.17	face velocity, 10.7-10.8
transverse joint reinforcement, 17.16	part-load operation, 10.8-10.10
Duct friction losses, 17.22–17.31	selection of DX coils, 10.10
absolute and relative roughness, 17.22–17.24	simultaneous heat and mass transfer,
circular equivalents, 17.27 – 17.31	10.5–10.6
Colebrook formula, 17.24	superheated region, 10.5
Darcey-Weisbach equation, 17.22	two-phase region, 10.4-10.5
duct friction chart, 17.24–17.26 17.25–17.26	two-region model, 10.4–10.5
duct roughness, 17.25	Dynamic losses, 17.31–17.38
friction factor, 17.22–17.24	converging and diverging tees and wyes,
Moody diagram, 17.22–17.23	17.34–17.37
roughness and temperature corrections, 17.25	elbows, 17. 31– 17. 34
Rouse limit, 17.24	entrances, exits, enlargements, and contrac-
Swamee and Jain formula, 17.24	tions, 17.38
Duct insulation, 17.1 9– 17. 22	uons, 17.50
duct insulation by ASHRAE Standard	
90.1–1999, 17. 19– 17. 21	Earth-sun distance, 3.25
temperature rise and drop, 17.19	Economizer cycle, economizers, and econo-
temperature rise curves, 17.21–17.22	mizer control, 21.8–21.16
Duct liner, 17. 74	air economizers, 21.8
Duct sizing methods, 17.5 3 – 17.5 6	ANSI/ASHRAE Standard 90.1 – 1999 econo-
constant velocity method, 19.53–19.54	mizer control specifications,
equal friction method, 17.53	21.14–21.16
-1 110mon monton, 11.00	MART I MARTO

Economizer cycle, economizers, and econo-Energy use (energy consumption) (Cont.) mizer control (Cont.) heating-cooling equipment, 25.13 comparison of air and water economizers, Energy use, index, 9.55-9.55 21.14 energy efficiency ratio (EER), 9.55 comparison of enthalpy-based and temperaenergy use intensities, 25.5-25.6 ture-based, 21.10-21.12 heating season performance factor (HSPF), 9.55 differential enthalpy, electronic enthalpy, and fixed enthalpy, 21.8-21.9 integrated part-load value (IPLV), 9.56 enthalpy (-based) economizer control, kW/ton, 9.55-9.56 **21.**8-**21.**9 seasonal energy efficiency ratio (SEER), fixed dry-bulb and differential dry bulb, 9.56 21.9-21.10 Engineering responsibilities, 1.18-1.19 sequence of operations of a differential dry-Engineer's quality control, 1.20 bulb, 21.10 Environment: sequence of operations of a differential encleanest, 1.13 thalpy, 21.9 most precise, 1.13 water economizer, 21.8, quietest, 1.13 water economizer control, 21.12-21.14 Environmental problems, 1.15 Effective temperature, 4.14 Equation of state: Electric heating fundamentals, 8.15-8.16 of an ideal gas, 2.2 electric duct heaters, 8.17 of a real gas, 2.2 electric furnaces and electric heaters. Evaporative coolers, add-on, 27.18-27.24 8.16 - 8.17indirect-direct cooler to a DX packaged sys-Electricity deregulation, 25.14-25.15 tem, 27.18-27.20 California approach, 25.15 tower and coil combination, 27.22-27.23 case-study: automatic control of RTP, tower coil and rotary wheel combination, 25.16-25.17 **27.**20-**27.**22 prior to deregulation, 25.14 Evaporative cooling, 27.1 real-time pricing (RTP), 25.15-25.16 air washers, 27.4 Energy conservation measures, 25.10-25.11 direct, 27.2 case-study-for an office, 25.12 direct evaporative coolers, 27.3-27.4 Energy cost budget method, ASHRAE/IESNA evaporative pads, 27.4 Standard 90.1-1999, 25.28 operating characteristics, 27.6 Energy efficiency, 1.13-1.15, 25.1-25.2, 25.5 rigid media, 27.4 25.10 rotary wheel, 27.4-27.6 during design, construction, commissioning, saturation efficiency, 27.2-27.4 and operation, 25.2 Evaporative cooling, indirect, 27.6-27.13 energy audits, 25.6 effectiveness, 27.10-27.11 energy retrofits, 25.6-25.7 heat transfer process, 27.7-27.10 energy service companies (ESCOs), 25.7 operating characteristics, 27.11-27.12 federal mandates, 25.5 part-load operation and control, 27.12-27.13 performance contracting, 25.7-25.8 process, 27.6 reduction of unit energy rate, 25.2-25.3 Evaporative cooling, indirect-direct two-stage Energy management and control systems systems, 27.13-27.18 (EMCS), 5.3 case study: Nevada's College, 27.16-27.18 Energy management systems, 5.3 energy efficiency ratio and energy use intensi-Energy use (energy consumption), 1.13-1.15, ties, 27.16 25.1 - 25.2indirect-direct two-stage evaporative cooler, between HVAC&R system characteristics, **27.**13 – **27.**15 25.12-25.13 system characteristics, 27.17-27.18 building energy consumption and thermal using outdoor air as cooled and wet air, storage systems, 31.2 **27.**15 fan, motor, and drive combined efficiency, using return air as wet air and outdoor-return **25.**13 – **25.**14 air mixture as cooled air, 27.15-27.16

Evaporative cooling systems, 27.1 – 27.2	Fan coil systems, 28. 3 – 28. 5
beware of dampness, sump maintenance, and water leakage, 27.24	operating characteristics, 28.3–28.5 system description, 28.3
design considerations, 27.24–27.26	Fan coil systems, four-pipe, 28.9 – 28.15
scope of applications, 27.24	chilled water supplied to coils, 28.11 – 28.12
selection of summer outdoor design condi-	dedicated ventilation system, 28.10–28.11
tions, 27. 24– 27. 26	exhaust air to balance outdoor ventilation air,
Evaporative heat loss, 4.7–4.9	- 28. 12
diffusion, 4.8–4.9	general description, 28.9–28.10
maximum, 4. 7– 4. 8	operating parameters, 28.14–28.19
due to regulatory sweating, 4.7–4.8	part-load operation, 28.13
respiration losses, 4.7	space recirculation systems, 28.11
from skin surface, 4.7	system characteristics, 28.14–28.15
Evaporators, 10.2–10. 20	zone temperature control and sequence of op-
air-cooler, 10. 2	erations, 28.13–28.14
circulating rate, 10. 20	Fan coil systems, two-pipe, 28. 20– 28. 24
counterflow or parallel flow, 10. 20	applications, 28.24
direct-expansion liquid cooler, 10.18	changeover two-pipe systems, 28. 23 – 28. 24
down-feed or up-feed, 10. 20	nonchangeover two-pipe systems, 20:23 – 20:24
DX coil (wet coils) 10.2–10. 10	28.20-28.23
flooded liquid cooler, 10.12–1020	system characteristics, 28.15
liquid cooler, 10.2	Fan coil units, 28. 5– 28. 9
liquid overfeed cooler, 10.18–10.20	coils, 28.7
mechanical pump or gas pump, 10.20	cooling and dehumidifying, 28. 8– 28. 9
Energy, 9.19	fan, 28.6–28.7
Expansion tank:	filters, 28. 7
closed, 7.21	sound power level, 28.9
diaphragm, 7.21–23	volume flow rate, 28. 7 – 28. 8
fill pressure, 7.21	Fan combinations, 22.4
open, 7.20–7.21	operating modes, 22.4–22.5
water logging, 7.24–7.2 5	Fan combinations, supply and exhaust fans,
	22.8–22.14
	air-economizer mode, 22.13
Factors affecting control processes, 5.56-5.58	operating characteristics, 22.9-22.10
climate change, 5.56-5.57	pressure variation at the mixing box,
disturbance, 5.57	22. 13 –22. 14
intermittent operation, 5.57	recirculating mode and design volume flow
load, 5. 56	rate, 22. 9- 22. 12
performance of control processes, 5.57-5.58	recirculating mode, 50% design flow rate,
system capacity, 5.57	22. 12 -22. 13
thermal capacitance, 5.58	system characteristics, 22.8-22.9
turndown ratio, 5.57	warmup and colddown mode, 22.13
Fan capacity modulation, 15.20-15.24	Fan combinations, supply and relief fans,
ac inverter, 15.20–15.2 1	22. 14– 22. 18
adjustable pitch, 15.24	air economizer mode and design volume flow
blade pitch, 15.24	rate, 22.14-22.16
controllable pitch, 15.24	air economizer mode, 50% design flow, 22.17
fan speed with adjustable frequency drives,	design considerations and controls,
15. 20– 15. 21	22. 17- 22. 18
inlet cone, 15. 23– 15. 24	recirculating mode, 22.14-22.15
inlet-vanes, 15.21–15.23	warmup and cool-down mode, 22.17
pulse-width-modulated inverter, 15.21	Fan combinations, supply and return fans,
variable-speed drives (VSDs), 15.20-15.21	22. 18- 22. 21
Fan coil, 1.5	air economizer mode, 22.20-22.21

Fan combinations, supply and return fans	Fan selection (Cont.)
(Cont.)	comparison between various type of fans,
comparison of three fan combination systems,	15. 31 – 15. 32
22. 21 –22. 22	estimated fan sound power level,
controls, 22.21	15. 30- 15. 31
recirculating mode, 22.18-22.20	Fans, fundamentals, 15.2-15.7
Fan construction and arrangements,	air temperature increase through fan, 15.5
15. 25 –15. 29	blower, 15. 2
drive arrangements and direction of dis-	compression ratio, 15.2
charge, 15.26-15.28	functions, 15.2
high-temperature fans, 15.27	influence of elevation and temperature,
safety devices, 15. 28- 15. 29	15. 6– 15. 7
sizes and class standards, 15.25-15.26	performance curves, 15.5-15.6
spark-resistant construction, 15.28	power and efficiency, 15.4-15.5
width and inlets, 15. 26- 15. 27	pressure, 15.4
Fan-duct systems, 20.14 – 20.17	types of, 15.2–15.3
fan laws, Buckingham π method,	volume flow rate or capacity, 15.4
20. 15 – 20. 17	Fan stall, 15.24–15.2 5
inlet system effect, 20. 18- 20. 19	Fan surge, 15.24
inlet system effect loss, 20.19	Fans, axial, 15.14–15.20
inlet system effect loss coefficient,	hub ratio, 15. 14— 15. 15
20. 19 –20. 20	number of blades, 15.20
outlet system effect, 20. 20 –20. 22	performance curves, 15.17–15.19
outlet system effect loss coefficient,	power-volume flow curves, 15.17–15.19
20.22-20.23	pressure-volume curves, 15.17
	propeller, 15.15
selecting fans considering system effect losses, 20.23-20.24	2 -
	reverse operation, 15. 20
system effect, mechanism, 20.17,	static pressure developed, 15. 17
system operating point, 20.15	tip clearance, 15.20
Fan-duct systems, combination, 20.24–20.31	total efficiency-volume flow curves,
connected in series, 20.25–20.26	15. 18- 15. 19
fan combined in parallel and connected in se-	tube-axial, 15. 15– 15. 16
ries with a duct system, 20.26–20.27	typical vane-axial fan, 15. 19 – 15. 20
two parallel fan-duct systems with another	types of, 15.14–15.16
duct system, 20.28–20.30	vane-axial, 15.15-15.16
Fan-duct systems, modulation, 20.31–20.38	velocity triangles, 15.16–15.17
blade pitch variation of axial fan, 20.35-20.36	Fans, centrifugal, 15.7-15.4
modulation curve, 20. 31 –20. 32	backward-curved, 15.8–15. 10
using dampers, 20.33	blades, 15.7
using inlet cone, 20.34–20.35	blast area, 15.8
using inlet vanes, 20.34	energy losses, 15.9
varying fan speed, 20.35-20.36	forward-curved, 15. 11 – 15. 12
Fan energy use, criteria of Standard 90.1–1999,	impeller (fan wheel), 15.7–15.8
17.10-17.12	power-volume flow curves, 15.10-15.11
for constant volume systems, 17.10–17.11	pressure-volume curves, 15.9
for VAV systems, 17. 11 – 17. 12	radial-bladed, 15. 10- 15. 12
Fan-powered VAV box, 1.8	roof ventilators, 15.14
Fan room, 16.24–16.28	total efficiency-volume flow curves, 15.10
isolated, 16. 24- 16. 25	total pressure increase at fan impeller,
layout considerations, 16.25-16.28	15.7–15. 8
open, 16. 24	tubular or in-line, 15. 12– 15. 13
types of, 16. 24– 16. 25	unhoused plug/plenum,15.12-15.14
Fan selection, 15. 29- 15. 32	velocity triangles, 15.8
case-study, 15.32	Fans, crossflow, 15. 3– 15. 4

ANN models, 3.64	Gaseous contaminants adsorbers and chemisorbers (Cont.)
ARX models, 5. 63- 5. 64	granular activated carbon (GAC) applications
comparison of ARX and ANN models, 5.65	24.10-24.11
expert systems rule-based, 5.62–5.63	granular activated carbon (GAC) perfor-
system and component models, 5.64	mance, 24.9-24.10
Fenestration, 3.29–3.31	indoor gaseous contaminants, 24.8-24.9
Fiberglass in HVAC&R systems, 19.17–19.18	Gibbs-Dalton law, 2.4
problems, 19. 17– 19. 18	Global radiation, 3.27–3.28
recommendations, 19.18	Global warming, 1.15, 25.3–25.5
Field experience, 1.21	CO_2 release, 25.4
Finite difference method, 6. 34– 6. 39	effect, 1. 15
cooling loads, 6.3 9	Kyoto Protocol, 25.3
interior nodes, 6.36–6.37	mitigating measures, 25.4-25.5
simplify assumptions, 6. 36	refrigerant emissions, 25.4–25.5
space air temperature, 6.38–6.39	total equivalent warming impact, 25.3–25.4
surface nodes, 6. 37- 6. 38	Goal to provide an HVAC&R system, 1.17
Flooded liquid cooler, 10.12–10.20	Green buildings, 25.8–25.10
construction, 10. 12– 10. 14	basics, 25.8–25.9
cooling capacity, 10. 17	case-studies, 25. 9– 25. 10
evaporating temperature, 10.16	green building assessment (GBA), 25.9
fouling factor, 10.14–10.15	Greenhouse effect, 1.15
heat transfer, 10. 14	Orcemouse enect, 1.13
oil effect, 10.17	
part-load operation, 10. 17– 10. 18	Heat:
performance, 10. 16– 10. 17	convective, 6. 2
pool boiling and force convection model,	latent, 2.10
10. 15 – 10. 16	
	radiative, 6. 2 sensible, 2. 10
temperature difference $T_{\sf ee}$ - $T_{\sf el}$, ${f 10.16}-{f 10.17}$	
	stored, 6.2
Flow resistance, 17.38–17.43	Heat capacity, 3.8
connected in parallel, 17.41–17.42 connected in series, 17.40–17.41	Heat of sorption, 3.12
of duct system, 17.42–17.44	Heat pipe heat exchangers, 12. 23 – 12. 24 Heat pump, 12. 1 – 12. 3
of Y-connection, 17.42–17.43	classification of, 12.3
Flow sensors, 5.19–5.20	cycle, 12.2–12. 3
Fouling factor, 10.14–10.15	Heat pump systems, air-source, 12.5–12. 13
Fuzzy logic, 5.45 – 5.47	capacity and selection, 12.13
fuzzy logic controller, 5. 47	compressor, 12.6–12.7
fuzzy sets, 5.45	controls, 12. 13
membership function, 5.45	cooling mode, 12.9
production rules, 5.45-5.47	cycling loss and degradation factor, 12. 11 defrosting, 12. 12– 12. 13
	heating mode, 12. 19
Geografing 12.25 12.20	
Gas cooling, 12. 25 – 12. 29 engine jacket heat recovery, 12. 28	indoor coil, 12. 7– 12. 8 outdoor coil, 12. 8
exhaust gas heat recovery, 12.27—12.28	reversing valve, 12. 7– 12. 8
•	Standard 90.1–1999 minimum efficiency re-
gas-engine chiller, 12.25–12.27	
gas engines, 12.27	quirements, 12.12
Gaseous contaminants adsorbers and chemisor-	suction line accumulator, 12.8 – 12.9
bers, 24.8–24.12	system performance, 12.9–12.11
activated carbon adsorbers, 24.9	Heat pump systems, ground-coupled and surface
chemisorption, 24.11	water, 12.17–12.19
chemisorption performance, 24.11	Heat pump systems, groundwater, 12.13-12.17

meat pump systems, groundwater (Com.)	Hemy's equation, 7.25
groundwater systems, 12.14	Hot water heating systems:
for hospital, 12. 14– 12. 15	design considerations, 8.25-8.26
for residences, 12.15-12.16	finned-tube heaters, 8.24-8.25
Standard 90.1-1999 minimum efficiency re-	part-load operation and control, 8.26
quirements, 12.17	two-pipe individual loop, 8.23-8.24
Heat recovery, air-to-air, 12.19-12.24	types of, 8. 23
comparison between various heat exchangers, 12.24	using finned-tube heaters, 8. 23 – 8. 26 Humidifiers, 15. 72 – 15. 85
effectiveness, 12. 19- 12. 20	humidifying load, 15.72–15.73
fixed-plate heat exchangers, 12.20-12.21	selection and design, 15.83-15.84
heat pipe heat exchangers, 12.23-12.24	space relative humidity, 15.72
rotary heat exchangers, 12.12. 21 – 12. 23	types of, 15. 73
runaround coil loops, 12.21	Humidifiers, atomizing and wetted element,
types of, 12. 19	15. 76– 15. 78
Heat recovery systems, 12.3-12.5	air washers, 15.79-15.82
heat balance and building load analysis,	bypass control, 15.81
12.4-12.5	characteristics, 15.82-15.83
Heat rejecting systems, 10.48-10.51	construction of air washer, 15.79-15.80
comparison between various systems,	case study: White Plains ultrasonic project,
10. 48- 10. 50	15.77
Standard 90.1-1999, 10.5 0- 10. 51	centrifugal atomizing, 15.77-15.78
types of, 10. 48	functions of air washer, 15.80
Heat transfer:	humidification process, 15.76
conductive, 3.3-3.4	oversaturation, 15.81
convective, 3.4-3.5	performance of air washer, 15.80-15.81
fundamentals, 3.2	pneumatic atomizing, 15.78
overall, $3.6-3.7$	single-stage or multistage, 15.81-15.82
radiant, 3.5–3. 6	ultrasonic, 15.77
Heat transfer coefficients, 3.8-3.11	wetted element, 15.78
forced convection, 3.9	Humidifiers, steam and heating element,
natural convection, 3.10	15. 73 – 15. 76
radiant, 3. 8- 3. 9	characteristics and requirements, 15.76
surface, 3.10-3.11, 4.5	heating element, 15.75
Heating load, 6. 39– 6. 42	steam grid, 15. 73 – 15. 74
basic principles, 6. 39	steam humidifiers with separators,
heat loss from products, 6.41	15. 74 –15. 75
infiltration, 6.4 1	Humidity:
latent heat loss, 6.41	comfort air conditioning systems, 4.23-4.24
night shutdown operation, 6.4 1 – 6.4 2	process air conditioning systems, 4.24
pickup load and oversizing factor, 6.42	Humidity ratio, 2.7
setback, night, 6.4 1 – 6.4 2	Humidity sensors, 5.18–5.19
transmission loss, 6. 38– 6. 40	HVAC&R industry, 1.15
unheated spaces, 6.40-6.41	h- w chart, 2.19
Heating systems, 8. 1– 8. 2	Hygrometers:
control and operations of multizones, 8.30-8.31	capacitance, 2.17–2.18
design considerations, 8.30	Dunmore resistance, 2.16–2.17
design nomograph, 8.30	electronic, 2.16–2.17
low-pressure ducted warm air, 8.17-8.22	ion-exchange resistance, 2.16-2.17
radiant floor panel, 8.27-8.31	mechanical, 2.16
selection of, 8.2	Hysteresis, 3. 11– 3. 12
system characteristics, 8.31	
thermal characteristics of floor panel,	
8 28 8 20	Ice point 24 .25

Ice storage systems:	Infrared heating, 8.31 – 8.35
comparison of various systems, 31.17-31.1	basics, 8. 31- 8. 32
types of, 31. 5	beam radiant heaters, 8.32
Ice storage systems, encapsulated, 31.13-31.	15 design and layout, 8. 33 – 8. 35
charging and discharging, 31.15	Insufficient communication, 1.17
chiller priority and storage priority, 31.15	Insulation material, 3.19
controls, 31. 14– 31. 15	moisture content, 3.19-3.21
encapsulated ice containers, 31.13	Interoperability, 5.41
location of chiller and storage tank, 31.14	system integration, 5.41
system characteristics, 31.10	, , ,
Ice storage systems, ice-harvesting,	
31. 15 –31. 17	Knowledge-based systems (KBS), 5.47-5.51
chiller operation, 31.17	development of KBS, 5.49
ice making or charging, 31.16-31.17	expert-systems, 5.47 – 5. 51
system characteristics, 31.10	knowledge acquisition, 5.49
system description, 31.15–31.16	knowledge-base, 5.48
Ice storage systems, ice-on-coil, external melt	
31.10–31.13	testing, verification, and validation, 5.49
case-study, 31.13	user interface, 5.48–5.49
ice builders, 31.11	user micriace, 5.40—5.47
ice-charging control, 31.11	
refrigeration feed, 31.1	Larel responsibility for IAO cases
_	Legal responsibility for IAQ cases, 24.13–24.15
system characteristics, 31.10, 31.11-31.13	
system description, 31.10–31.11	HVAC&R engineer, 24.14–24.15
Ice storage systems, ice-on-coil, internal melt	
31.6-31.10	who is legally responsible, 24.13–24.14
brine and glycol solution, 31.6–31.7	Legionnaires' disease, 10.47
case-study: operation modes, 31.7-31.8	Liquid absorbents, 9.3
direct cooling, 31.9	Lithium-bromide solution, properties of,
ice-burning or ice melting, 31.9	14.3–14.6
ice-charging or ice making, 31.8	enthalpy-concentration diagram, 14.5-14.6
ice storage tank, 31.7-31.8	equilibrium chart, 14.4
on-peak, 31.9	mass balance in solution, 14.3
system characteristics, 31.9-31.10	vapor pressure, 14.3–14.4
system description, 31.6	Load:
Indicator, 2.6	block, 6.9–6. 10
Indoor air contaminants, 4.27–4.28	coil, 6.3
bioaerosols, 4.28	DX coil, 6.3
combustion products, 4.28	heating coil, 6.3
nicotine, 4.28	peak load, 6. 9- 6. 10
occupant-generated contaminants, 4.28	profile, 6.9
radon, 4. 28	refrigeration, 6. 3
total particulates concentration, 4.28	space cooling, 6.3
volatile organic compounds, 4.28	Load calculation method:
Indoor air quality (IAQ), 4.27	CLTD/SCL/CLF method, 6. 15, 6. 26– 6. 31
acceptable, 4.29	finite difference, 6. 34- 6. 39
basic strategies to improve, 4.29	TETD/TA method, 6. 15- 6. 16
IAQ problems, 24. 1– 24. 2	transfer function (TFM), 6.14-6.26
IAQ procedure, 4.29	Load ratio, 5.13
ventilation rate procedure, 4.29-4.31	
Indoor design conditions, 4.1–4.2	
Infrared heaters:	Machinery room, refrigerating, 9.58-9.59
electric, 8. 32- 8. 33	Maintenance, HVAC&R, 32.5-32.6
gas, 8. 32	contractors and personnel, 32.5-32.6

Maintenance, HVAC&R (Cont.)	Night shutdown operating mode (Cont.)
fault detection and diagnostics assisting pre-	night shutdown period, 6.3-6.4
dictive maintenance, 32.6	warm-up period, 6.4–6. 6
Maintenance to guarantee IAQ, 24.12-24.13	Noise, 4. 32
coils and ductwork, 24. 12– 24. 13	airflow, 19.5–19.6
inspection, service, and access, 24.12	from chiller and pumps, 19.4-19.5
monitoring of operation conditions, 24.12	diffusers and grilles, 19.6
Mass-transfer coefficients, convective, 3.15	maximum duct velocities, 19.5-19.6
Masterformat, 1.23	poor fan entry and discharge, 19.6
Measurements, pressure and airflow, 17.75–17.78	Noise control, recommended procedure, 19.3–19.4
equal-area method, 17.77-17.78	Noise control for typical air system,
log-linear rule for round duct, 17.77-17.78	19. 25 –19. 26
log Tchebycheff rule, 17.7717.78	combination of supply fan noise and terminal
manometer, 17.75-17.77	noise, 10.25
measurements in air ducts, 17.76-17.77	environment adjustment factor, 19.26
Pitot tube, 17. 75 – 17. 77	estimated sound pressure level for space
Mechanical work, 4.4	served by terminal units, 19.25-19.26
Metabolic rate, 4.4	plenum ceiling effect, 19.26
Microbial growth, eliminating, 24.4-24.6	Nomenclature, A.1-A.6
basics, 24. 4	Greek letter symbols, A.8-A.9
eliminate water leaks, 24.5	subscripts, A.6-A.8
microbial growth, 24.4-24.5	
pressurization control, 24.5	
prevent damped surface and material, 24.5	Open data communication protocol, 5.41
purge, 24. 5	application layer, 5.42-43
ultraviolet germicidal irradiation, 24.5-24.6	ARCNET, 5.44
Moist air, 2.1–2. 2	BACnet, 5.41-5.44
calculation of the properties of, 2.3	data link/physical layer, 5.43-5.44
density, 2.10	Ethernet, 5. 43 – 5. 44
enthalpy, 2.8–2.9	local area networks (LANs), 5.43
moist volume, 2.9–2.10	LonTalk, 5.44
sensible heat, 2.10–2.1 1	LonTalk LAN, 5.44
Moisture content, 3.11	master-slave/token passing (MS/TP), 5.44
Moisture migration in building materials,	network layer, 5.43
3. 13 -3. 14	network technology, 5.43-5.44
Moisture permeability index, 4.8	point-to-point, 5.44
Moisture-solid relationship, 3.12-3.13	proprietary network, 5.44
Moisture transfer, 3.11–3.17	Outdoor air requirements for occupants,
from the surface, 3.14–3.15	4. 30- 4. 31
in building envelopes, 3.16–3.17	Outdoor design conditions, 4.38–4.42
Montreal Protocol and Clean Air Act, 9.10-9.11	Outdoor design temperature, 4.38–4.42
Multistage vapor compression systems, 9.29-9.31	1.0% summer wet-bulb, 4.39 summer dry-bulb, 4.39
compound systems, 9.29-9.30	summer mean coincident wet-bulb, 4.39
interstage pressure, 9.30-9.31	winter dry-bulb, 4.39
flash cooler and intercooler, 9.31	Overlooked commissioning, 1.17
Nativials technology 5.42, 5.44	Destroyed existence 20.2, 20.4
Network technology, 5.43 – 5.44 Night shutdown operating mode, 6.3 – 6.6	Packaged systems, 29.2 -29.4

comparison between packaged and central

systems, **29.**2–**29.**3

types of, 29.4

conditioning period, 6.6

cool-down period, **6.4-6.6** influence of stored heat, **6.6**

Packaged syster	ns, fan-powered VAV,	Packaged units (Cont.)
29. 18- 29. 3	22	indoor air quality, 16.18
case-study: ro	ooftop packaged unit,	indoor environmental control, 16.17-16.18
29. 20-2		scroll compressors and evaporative con-
controls, 29.2	20,	densers, 16. 18
	e flow rate and coil load,	selection of, 16. 19– 16. 22
29. 19–2		Standard 90.1-1999 minimum efficiency re
	cteristics, 29.21	quirements, 16.19
•	ption, 29. 18- 29. 19	types of, 16. 12
	ns, perimeter-heating VAV,	Packaged units, indoor, 16.15-16.16
29.18	,	Packaged units, rooftop, 16.12-16.15
system charac	cteristics, 29.6	compressors, 16. 14- 16. 15
•	ns, single-zone constant-volume,	condensers, 16.15
29.4 -29.6	,	curb, 16. 13
controls, 29.5		DX-coils, 16. 13 – 16. 14
	tensities, 29.5	electric heating coil, 16.14
	e flow rate and coil loads,	gas-fired furnace, 16.14
29.4-29		heat pump, 16. 15
	cteristics, 29. 5– 29. 6	humidifiers, 16.14
system descri		supply, return, relief, and exhaust fans,
-	ns, single-zone VAV, 29. 7 – 29. 8	16. 14
controls, 29.7		Packaged units, rooftop, sound control,
system calcul		19. 29–19–32
•	cteristics, 29.6	basics, 19. 29
system descri		discharge side duct breakout, 19.31
•	ns, VAV cooling, 29. 9– 29. 12	sound source on return side, 19.31–19.32
	essure control, 29. 10– 29. 12	sound sources and paths, 19.30–19.31
	acteristics, 29. 10	structure-borne noise, 19.32
	ne flow rate and coil load, 29.10	Packaged units, split, 16. 16- 16. 17
	cteristics, 29.6	Panel heating and cooling, 28.33
-	iption, 29. 9– 29. 10	Personal computer workstation, 5.39–5.40
	ns, VAV reheat, 29. 12– 29. 18	Plant-building-loop, 7.43–7.51
	ater-cooled, and evaporative-	balance valves, 7.49-7.50
	ondensers, 29.17	building loop, 7.43
	omizer mode, 29.15	coil discharge air temperature control, 7.43
	r precision manufacturing,	common pipe thermal contamination, 7.51
29. 17 – 2	_	low ΔT , 7.49
	temperature control,	plant-loop, 7.43
29. 15 – 2		pressure differential control, 7.45
	outed airflow at DX coils,	sequence of operations, 7.46–7.49
29.14-2		staging control, 7.43-7.44
	on, 29. 16– 29. 17	system characteristics, 7.45–7.46
	cooling stages, 29.15-29.16	variable-speed pumps connected in parallel,
	and morning warm-up, 29.14	7.49
reset, 29. 16	and morning warm up, 2001	water leaving chiller temperature control,
sound control	1 29 17	7.43
	ne flow rate and coil load,	Plant-distributed pumping, 7.52–7.53
29. 12–2		Plant-through-building loop, 7.40–7.42
	cteristics, 29.6	bypass throttling flow, 7.40–7.41
-	iption, 29. 12– 29. 13	distributed pumping, 7.41
	nal air conditioner (PTAC), 1.4	variable flow, 7.41 – 7.42
	nal heat pump (PTHP), 1.4	Point or object, 5.25
Packaged units,		Poor indoor air quality, 1.17
controls, 16.1		Precision, 2.6
	· · · · · · · · · · · · · · · · · · ·	

Pressure flow characteristics, 22.22-22.24	Reciprocating refrigeration systems (Cont.)
fan characteristics, 22.7	balance of capacities of selected components,
mixing-exhaust section and conditioned	11. 35– 11. 36
space, 22.8	capacity control, 11.24-11.26
supply and relief fan combination, field sur-	compressor components, 11.5-11.8
vey system pressure characteristics,	crankcase heater, 11.7-11.8
22. 23 – 22. 24	cylinder block and piston, 11.7
supply and return fan combination system,	cylinder unloader, 11.24
22. 22 –22. 23	filter dryer and strainer, 11.10-11.11
system pressure diagram, 22.5-22.8	frost control, 11.27
VAV systems, fixed part, 22.5	hot-gas bypass control, 11.26
VAV systems, variable part, 22.5	liquid overfeed,11.3-11.4
variation of pressure in mixing box, 22.23	liquid receiver, 11.8
Pressure sensors, 5.19	liquid-suction heat exchanger, 11.8-11.10
reference pressure, 5.1 9	low-pressure and high-pressure controls,
Primary ambient-air quality standard, 4.29	11.26–11.27
Profile angle, 3.42	low-temperature control, 11.27
Properties of air, physical, A.15	minimum performance, ASHRAE/IESNA
Properties of moist air, thermodynamic,	Standard 90.1-1999, 11. 41- 11. 42
A.13-A.14	motor overload control, 11.29
Properties of water, physical, A.15	multistage, 11.4
Psychrometric chart, A.12	oil lubrication, 11.7
Pump-piping systems, 7.34–7.38	oil-pressure failure control, 11.27–11.29
connected in series, 7.35–7.36	on/off control, 11.24
modulation of, 7.36–7.37	pressure relief valves, 11. 11- 11. 12
operating point, 7.34–7.35	real cycle of a single-stage, 11.4–11.5
parallel-connected, 7.35–7.36	reciprocating compressors, 11.5
pump laws, 7.37	refrigerant charge valve, 11.12
system curve, 7.34	safety controls, 11.26–11.29
Psychrometer, 2. 12– 2. 13	service valves, 11 .11 – 11 .12
aspiration, 2.14–2.15	solenoid valves, 11.11
sling, 2. 14– 2. 15	speed modulation control, 11.24–11.26
Psychrometrics, 2.1	suction and discharge valves, 11.7
rsychiometrics, 2.1	system balance, 11.34–11.36
D volve 2.7	Reciprocating refrigeration systems, air-cooled
R-value, 3.7	direct-expansion, 11.36–11.42
overall, 3.7	compressor short cycling, 11.40
Radiant heat loss from building, 3.46–3.47	defrosting, 11.40–11.41
Radiated noise, 19.18–19.19	liquid slugging, 11.40
break-out and break-in, 19.18–19.19	main problems, 11.40–11.42
break-out and break-in sound power level,	oil returns, 11.40
19. 19 -19. 20	operating balance, 11. 36–11.37
duct rumble, 19.19	part-load operation using an unloader,
Radiation, atmospheric, 3.47	11.38–11.39
Reciprocating compression, performance,	pressure characteristics, 11.37–11.38
11.29-11.34	proper refrigerant charge, 11.41-11.42
condenser, 11.33–11.34	pump-down control, 11.39–11.40
evaporator, 11.32–11.33	Refrigerant flow control devices, 10.51–10.58
power input, 11.30–11.32	advantages of electric expansion valves, 10.56
refrigeration capacity, 11.30	analog valves, 10.55–10.56
Reciprocating refrigeration systems,	capacity superheat curve, 10.52
11.2–11.42	capillary tubes, 10.57–10.58
air-cooled reciprocating chiller, 11.2-11.3	cross charge, 10.53-10.54
air-cooled reciprocating DX cooler, 11.2	electric expansion valves, 10.55-10.56

Refrigerant flow control devices (Cont.)	Refrigerants (Cont.)
external equalizer, 10.52-10.53	recovery, recycle, and reclaiming, 9.11-9.13
float valves, high-side, 10.56	reducing leakage and preventing deliberate
float valves, low-side, 10.56-10.57	venting, 9. 11- 9. 13
hunting of thermostatic expansion valve,	restrict production of HCFCs, 9.10-9.11
10.10. 54 –10. 55	storage of, 9.59
limited liquid charge, 10.53-10.54	use of, 9. 7
liquid charge, 10.53-10.54	zeotropic, 9.3
operating characteristics, 10.51-10.52	Refrigerants, properties, 9.5-9.7
pulse-width-modulated valve, 10.55-10.56	effectiveness of refrigeration cycle, 9.5
step motor valve, 10.55	evaporating and condensing pressure, 9.6
straight charge, 10.53-10.54	inertness, 9.6
thermostatic expansion valves, 10.51-10.53	leakage detection, 9.6-9.7
Refrigerant piping for reciprocating refrigera-	oil miscibility, 9.6
tion system, 11.12-11.23	physical properties, 9.6
copper tubing, 11. 12- 11. 13	refrigeration capacity, 9.6
discharge line, 11.20-11.21	safety requirements, 9.5
discharge line sizing, 11.20-11.21	thermal conductivity, 9.6
double riser, 11. 16- 11. 17	Refrigerants safety, 9.56
liquid line, 11.21-11.23	Refrigerating machinery room, 9.58-59
liquid line sizing, 11.22–11.23	storage of refrigerants, 9.59
maximum pressure drop, 11.17	Refrigeration, 9.2
minimum refrigeration load for oil entrain-	unit of, 9. 17
ment up hot-gas riser, 11.20	Refrigeration compressors, 9.51-9.56
minimum refrigeration load for oil entrain-	direct-drive, belt drive, and gear drive, 9.53
ment up suction riser, 11.19	energy use index, 9.55–9.56
oil trap and piping pitch, 11.15-11.16	hermetic, semihermetic, and open, 9.53
parallel connections, 11.23	isentropic, and polytropic analysis, 9.54-9.55
piping design, 11.13	motor, mechanical, and compression effi-
pressure drop of valves, and fittings	ciency, 9. 54
11.15–11.16	performance, 9.53 – 9.56
size of copper tubing, 11.14	positive displacement and nonpositive dis-
sizing procedure, 11.14–11.15	placement, 9.51–9.53
suction line, 11. 15– 11. 20	volumetric efficiency, 9.53 – 9.54
suction line sizing, 11.18–11.19	Refrigeration cycles, 9.17
suction line sizing chart, 11.17-11.18	air expansion, 9. 45 – 9. 49
Refrigerants, 9.3	Carnot, 9. 19– 9. 21
azeotropic, 9.3	coefficient of performance, 9.21–9.22
blends, 9.3	cycle performance, 9.22-9.24
CFCs replacements, 9.13	determination of enthalpy by polynomials,
classification, 9.13–9.16	9.24-9.25
concentration shift, 11.46–11.47	ideal vapor compression, single stage,
conversions and replacements, 9.11	9.22-9.26
glide, 9.3–9.4, 11.46–11.47	performance, 9.19–9.21
global warming potentials, 9.7–9.10	Refrigeration effect, refrigerating load, refriger-
chlorofluorocarbons (CFCs) and halons, 9.16	ating capacity, 9.25–9.26
hydrochlorofluorocarbons (HCFCs),	Refrigeration processes, 9.16–9.17
9.15-9.16	Refrigeration systems, 9.2
hydrofluorocarbons (HFCs), 9.13-9.14	absorption, 9.2, 14.1–14.3
inorganic compounds, 9.16 near azeotropic, 9.3	air or gas expansion, 9.2 cascade, 9.40–9.43
numbering of, 9.4	
ozone depletion potentials, 9.7–9.10	centrifugal, 13.1–13.7 classifications, 9.49–9.51
phase-out of CFC's and halons, 9.10	compound, 9.31–9.3 1
Prince one of or or and minorio, 7:10	

Refrigeration systems (Cont.)	Return and exhaust inlets, 18.17–18.20
developments, recent ,9.51	exhaust inlets, 18.19
high-probability systems, application rules,	light troffer diffuser, 18.19-18.20
9. 56 -9. 57	return grilles, 18. 18- 18. 19
low-probability systems, application rules,	return slots, 18. 18- 18. 19
9. 57 -9. 58	troffer diffuser slot, 18.18-18.19
multistage vapor compression, 9.29-9.31	Return and exhaust systems, 22.2-22.3
reciprocating, 11.2-11.42	ANSI/ASHRAE Standard 90.1-1999
vapor compression, 9.2	dampers specifications, 22.3
Refrigeration systems, absorption, 14.1-14.3	enclosed parking garage ventilation, 22.3
applications, 14.3	exhaust hoods, 22.3
cost analysis, 14.2–14. 3	low-level return systems, 22.2-22.3
historical development, 14.2	return ceiling plenum, 22.2
types of, 14. 1- 14. 2	types of, 22. 2
Refrigeration systems, rotary, 11.42–11.43	Room, 6. 2
main components, 11.43	Room air conditioner, 1.4
rotary compressor, 11.42–11.43	Room heat pump, 1.4
system performance, 11.43	Room sound power level and room sound pres-
Refrigeration systems, screw, 11.55	sure level, relationship, 19.23–19.24
air-cooled screw chillers, 11.55	array of ceiling diffusers, 19.24
ASHRAE/IESNA Standard 90.1 – 1999 mini-	single or multiple sound sources,
mum performance, 11.54-11.55	19.23–19.24
capacity control, 11.53-11.52	27.20
controls, 11.53	Safety factor, 1.20
economizer, 11.54	Semiheated space, 3.49
electric expansion valves, 11.55	Sensible heat exchange, 4.5
location of installation, 11.55	Sensing element, 5.16
oil cooling, 11.51, 11.53	Sensitivity, 2.6
performance of twin-screw compressor,	Sensors, 2.6, 5.16–5.17
11.52–11.53	air, 5.16–5.18
screw compressors, 11.50–11.52	air quality (VOC), 5. 20
system performance, 11.55	CO ₂ , 5.20
types of, 11.50	drift, 5.16
variable volume ratio, 11.54	intelligent network, 5. 21
Refrigeration systems, scroll, 11. 43–1150	occupancy, 5.20–5.21
capacity control and part-load performance,	resistance temperature detectors (RTD), 5. 18
11.47 – 11.48	temperature sensors, 5.18
chillers, 11.48–11.49	wireless zone, 5.21
circulating concentration shift, 11. 46–	Sequence of operations, 5.5–5.6
11.47	Set point, 5.5
compressor performance, 11.46	Shading coefficients, 3.36
concentration shift, 11.46–11.47	Shading devices, 3.40–3.43
heat exchanger flow configuration, 11.47	draperies, 3.41
radial and axial compliance, 11.44–11.45	external, 3.42—3.43
scroll compressors, 11.44–11.45	indoor, 3.40–3.42
system characteristics, 11.48	overhang, 3.42
temperature glide, 11.46–11. 47	roller shades, 3.41 – 3.42
types of, 11.43–11.44 Polotive hymidity 2.7, 2.8	side fin, 3.42
Relative humidity, 2.7–2.8	venetian blinds, 3.40–3.41
Residuals, 5.61	Shading from adjacent buildings, 3.43–3.44
normalized, 5.62	Sick building, 4.27
Resistance temperature detectors (RTDs), 2.6,	Sick building syndrome, 1.17, 4.27
5.18 Patrofit remodeling and replacement 1.10	Silencers, 19. 12 – 19. 17
Retrofit, remodeling, and replacement, 1.19	characteristics, 19.14-19.15

Silencers (Cont.)	Software, load calculations and energy analysis,
dissipative, 19.14	6. 42 – 6. 49
free area ratio, 19.15	building load analysis and system thermody-
insertion loss, 19.15	namics (BLAST), 6.42
locations of, 19.15–19.16	TRACE-600, 6. 42- 6. 49
packless, 19.14	Sol-air temperature, 3.47
pressure drop of, 19.15	Solar angles, 3. 22– 3. 25
reflection-dissipative, 19.14	altitude angle, 3. 23 –3. 24
selection of, 19.17	angle of incidence, 3.23-3.25
self noise of, 19.15	hour angle, $3.22 - 3.24$
sound-attenuating plenum, 19.13–19.14	latitude angle, $3.22-3.24$
types of, 19. 13– 19. 14	relationships, 3.23-3.24
Silencers, active, 19.14	solar azimuth angle, 3.23-3.24
frequency limits, 19.16	solar declination angle, 3.22-3.24
operating characteristics, 19.16	surface-solar azimuth angle, 3.23-3.24
performance, 19.17	Solar constant, 3.25
system characteristics, 19.16–19.17	Solar heat gain coefficient (SHGC), 3.33
Simulation, energy software DOE-2.1E,	Solar heat gain factors, 3.37
25. 25 – 25. 28	Solar intensity, 3.24–3.25
energy efficiency measures, 25.27	direct normal radiation, 3.26
energy simulation software, 25.25-25.26	Solar radiation, 3.25–3.29
loads, 25. 25	apparent, 3.26
plant, 25. 27 –25. 28	diffuse radiation, 3.26
systems, 25. 26– 25. 27	direct radiation, 3.26
Simulation, system, 25. 17– 25. 19	extraterrestrial intensity of, 3.25
dynamic simulation, 25.18	for a clear sky, 3.26-3.283.28-3.29
energy simulation, 25.17	reflection of, 3.28
performance equations, 25.17-25.18	Sorption isotherm, 3.11–3.12
physical modeling, 25.18	Sound, 4. 32
sequential, 25.19	airborne, 4.32
simultaneous, 25.19	octave bands, 4.33
steady-state, 25.18–25.19	power, 4. 32
Simulation of a centrifugal chiller, 25.19–25.25	power level, 4.32–4.33
centrifugal compressor model, 25.23 – 25.25	pressure level, 4.32–4.33
condenser model, 25.22	Sound attenuation, along duct-borne path,
cooling tower model, 25.23	19.6–19.12
evaporator model, 25.20–25.21	duct-borne crosstalk,19.11
operating parameter, 25.20	in ducts, 19.6–19.9
simulation methodology, 25,20	at elbows and branch takeoffs, 19.9–19.10
system model, 25.19–25.20	end reflection loss, 19.10–19.11
Skin wetness, 4.9	inner-lined round ducts, 19.7
Smoke control and fire safety, 22.24–22.38	lined flexible ducts, 19.8–19.9
ANSI/NFPA 92A and 92B, 22,28	lined rectangular ducts, 19.8
automatic sprinkler on fire protection,	unlined rectangular sheet-metal ducts, 19.7
22.27 – 22.28	unlined round ducts, 19.7
effective area and flow rates, 22,27	Sound control, 19.1–19.2
fire safety in buildings 22.24–22.25	control at design stage, 19.3
smoke control in atria, 22.28	Sound control criteria, 4.34
smoke management in atria, malls, and large	A-weighted sound level, 4.34
areas, 22.28	noise criteria (NC), 4.34
smoke movement in buildings, 22.25–22.27	room criteria (RC), 4.34
zone smoke control, 22.31–22.32	Sound paths, 19.2–19.3
zone smoke control, design considerations,	airborne, 19.2
22. 32	duct-borne, 19.2

Smoke paths (Cont.)	Space airflow pattern, projecting flow,
radiated sound, 19.2	18. 44- 18. 48
structure-borne, 19.2-19.3	applications of desktop task conditioning sys
Space, 6. 2	tems, 18. 48
Space air diffusion, mixing flow, design proce-	benefits of, 18.44
dure, 18.31-18.34	desktop task conditioning systems,
choose an optimum throw/characteristic	18. 46 –18. 48
length ratio, 18.33	distance between target zone and supply out-
design characteristics of slot diffusers in	let, 18. 44
perimeter zone, 18. 33- 18. 34	horizontal vs. vertical jet, 18.44-18.46
drop of cold air jet, 18.34	industrial spot cooling systems, 18.44-18.46
final layout, 18.34	performance of desktop task conditioning
select the type of supply outlet, 18.31-18.32	systems, 18. 47 – 18. 48
sound level, 18.34	recommendations in spot cooling design,
total pressure loss of supply outlet, 18. 34	18. 46
volume flow rate per outlet or unit length,	target velocities, 18.46
18. 32 –18. 33	thermal sensation, 18.46
Space air diffusion, principles, 18.2–18.5	Space airflow pattern, stratified displacement
age of air, 18.4–18.5	flow, 18. 42– 18. 43
air change effectiveness, 18.4	comparison of stratified displacement flow
air diffusion performance index (ADPI),	and mixing flow, 18.43
18.3–18.4	operating characteristics, 18. 42– 18. 43
draft, 18. 2	· ·
•	two-zone stratified model, 18.42
draft temperature, effective, 18.2–18.3	Space airflow pattern, upward flow underfloor
nominal air change effectiveness, 18.5	air distribution, 18.48–51
nominal time constant, 18.5	applications, 18.51
space air velocity vs. space air temperature,	consistent access plenum temperature,
18.3	18.50
space diffusion effectiveness factor, 18.4	design considerations, 18.50–18.51
turbulence intensity, 18.2–18.3	floor plenum master zone air temperature
ventilation effectiveness, 18.4	control, 18. 50
Space airflow pattern, displacement flow,	heat unneutralized, 18.50
18. 38 – 18. 43	thermal storage of floor plenum, 18.49
ceiling plenum, 18.41	upward flow from floor plenum, 18.48–18.49
supply air velocity, 18.41	Space heat extraction rate, 6.3
unidirectional flow, 18.38-19.39	Space heat gain, 6.3
unidirectional flow for clean rooms,	Space pressurization and return/relief volume
18. 39 –18. 40	flow controls, 23.16-23.18
ventilating ceiling, 18.40-18.41	characteristics of space pressure control,
Space airflow pattern, mixing flow, 18.20-18.28	23. 16– 23. 17
airflow pattern, 18.20	VAV systems return/relief fan volume flow
principles and characteristics, 18.21	control, 23.17-23.18
reverse air streams in the occupied zone,	volume flow of air leakage and effective leak
18. 21	age area, 23.17
stratified mixing flow, 18.25-18.28	Space pressurization control, 24.13
stratified mixing flow using nozzles,	Space pressurization or building pressurization,
18. 27 – 18. 28	4. 37- 4. 38, 20. 7- 20. 14
types and locations of return and exhaust in-	airflow balance, 20.11-20.13
lets, 18. 21	air systems and mechanical ventilation sys-
types and locations of supply outlets, 18.21	tems, 20.11
using ceiling diffusers, 18.23–18.24	characteristics, 20.7
using high-side outlets, 18.21–18.23	by differential flow, 20. 11– 20. 13
using sill or floor outlets, 18.24–18.25	differentials, 4. 37 – 4. 38
using slot diffusers, 18.24	neutral pressure level, 20.7–20.9
aome of antiaocto, 10.27	modular prossure rever, 20.7 - 20.7

(Cont.)	
	fan characteristics, 22.7-22.8
stack effect, 20.7-20.8	
stack effect for high-rise buildings,	Temperature, 2.4
20.9–20. 10	dew point, 2.11
wind effect, 20. 10– 20. 11	globe, 4.9
•	mean radiant, 4.9–4.1 2
Specifications, 1.22–1.23	
Stairwell pressurization, 22.29–22.34	mean surface temperature of clothing, 4.5
bottom single injection or bottom and top in-	measurements, 2.6
jection, 22.34–22.35	operative, 4.5
characteristics, 22.29-22.30	Temperature scales, 2.4–2.5
overpressure relief and feedback control,	absolute scale, 2.5
22. 30 -22. 31	Celsius, 2.4–2. 5
pressure drop coefficient, 22.34	Fahrenheit, 2.4–2.5
stair and shaft vents, 22.31	Kelvin, 2. 4– 2. 5
system pressure loss, 22.33–22.35	Rankine, 2.4–2. 5
volume flow rate, 22. 32- 22. 33	thermodynamic, 2.5
Standard 90.1 – 1999 for building envelope,	Testing, adjusting, and balancing (TAB),
3. 48-50	32. 2- 32. 4
Standard 90.1-1999, simplified approach op-	Thermal comfort, 4.15-4.20
tion for small and medium HVAC&R sys-	ASHRAE comfort zones, 417-4.18
tems, 29.8-29.9	comfort-discomfort diagrams, 4.17-4.20
Steam point, 2.4-2.5	factors affecting, 4.14-4.15
Subcooling, 9.26	Fanger's comfort chart, 4.15-4.17
Superheating, 9. 26– 9. 27	Fanger's comfort equation, 4.15-4.17
Supply air condition, determination,	heart rate (HR), 4.19-4.20
20.62-20.66	predicted mean vote (PMV), 4.15-4.17
air conditioning rules, 20.63	thermal sensational scale, 4.16
graphical method, 20. 63 – 20. 64	Thermal insulation, 3.18-3.22
influence of sensible heat ratio, 20.64-20.66	economic thickness, 3.21
mindence of behavior mout rate, 2010.	Committee and
Supply outlets 18.11-18.17	Thermal interaction:
Supply outlets, 18.11 – 18.17	Thermal interaction:
ceiling diffusers, 18.12-18.14	between human body and indoor environ-
ceiling diffusers, 18. 12– 18. 14 gang-operated turning vanes, 18. 17	between human body and indoor environment, 4. 2
ceiling diffusers, 18. 12 –18. 14 gang-operated turning vanes, 18. 17 grilles, 18. 11 –18. 12	between human body and indoor environ- ment, 4. 2 steady-state thermal equilibrium, 4. 3
ceiling diffusers, 18. 12 –18. 14 gang-operated turning vanes, 18. 17 grilles, 18. 11 –18. 12 induction, 18. 14	between human body and indoor environ- ment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3
ceiling diffusers, 18. 12– 18. 14 gang-operated turning vanes, 18. 17 grilles, 18. 11– 18. 12 induction, 18. 14 nozzle diffusers, 18. 16– 18. 17	between human body and indoor environ- ment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17	between human body and indoor environ- ment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12 slot diffusers, 18.14–18.16	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21
ceiling diffusers, 18. 12– 18. 14 gang-operated turning vanes, 18. 17 grilles, 18. 11– 18. 12 induction, 18. 14 nozzle diffusers, 18. 16– 18. 17 nozzles, 18. 16– 18. 17 plenum box, 18. 14– 18. 15 registers, 18. 11– 18. 12 slot diffusers, 18. 14– 18. 16 split dampers, 18. 17	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5
ceiling diffusers, 18. 12– 18. 14 gang-operated turning vanes, 18. 17 grilles, 18. 11– 18. 12 induction, 18. 14 nozzle diffusers, 18. 16– 18. 17 nozzles, 18. 16– 18. 17 plenum box, 18. 14– 18. 15 registers, 18. 11– 18. 12 slot diffusers, 18. 14– 18. 16 split dampers, 18. 17 Supply volume flow rate, 20. 59– 20. 62	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5 benefits and drawbacks, 31.2-31.3
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12 slot diffusers, 18.14–18.16 split dampers, 18.17 Supply volume flow rate, 20.59–20.62 based on space cooling vs. heating load,	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5 benefits and drawbacks, 31.2-31.3 full storage or load shift, 31.3-31.5
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12 slot diffusers, 18.14–18.16 split dampers, 18.17 Supply volume flow rate, 20.59–20.62 based on space cooling vs. heating load, 20.59–60	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5 benefits and drawbacks, 31.2-31.3 full storage or load shift, 31.3-31.5 ice-storage and chilled water storage, 31.5
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12 slot diffusers, 18.14–18.16 split dampers, 18.17 Supply volume flow rate, 20.59–20.62 based on space cooling vs. heating load, 20.59–60 rated volume flow of supply and return fans,	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5 benefits and drawbacks, 31.2-31.3 full storage or load shift, 31.3-31.5 ice-storage and chilled water storage, 31.5 impact of electric deregulation, 31.2
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12 slot diffusers, 18.14–18.16 split dampers, 18.17 Supply volume flow rate, 20.59–20.62 based on space cooling vs. heating load, 20.59–60 rated volume flow of supply and return fans, 20.61–20.62	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5 benefits and drawbacks, 31.2-31.3 full storage or load shift, 31.3-31.5 ice-storage and chilled water storage, 31.5 impact of electric deregulation, 31.2 partial storage or load leveling, 31.3-31.5
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12 slot diffusers, 18.14–18.16 split dampers, 18.17 Supply volume flow rate, 20.59–20.62 based on space cooling vs. heating load, 20.59–60 rated volume flow of supply and return fans, 20.61–20.62 requirements other than cooling load,	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5 benefits and drawbacks, 31.2-31.3 full storage or load shift, 31.3-31.5 ice-storage and chilled water storage, 31.5 impact of electric deregulation, 31.2 partial storage or load leveling, 31.3-31.5 system description, 31.1-31.2
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12 slot diffusers, 18.14–18.16 split dampers, 18.17 Supply volume flow rate, 20.59–20.62 based on space cooling vs. heating load, 20.59–60 rated volume flow of supply and return fans, 20.61–20.62 requirements other than cooling load, 20.60–20.62	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5 benefits and drawbacks, 31.2-31.3 full storage or load shift, 31.3-31.5 ice-storage and chilled water storage, 31.5 impact of electric deregulation, 31.2 partial storage or load leveling, 31.3-31.5 system description, 31.1-31.2 Thermistors, 2.6
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12 slot diffusers, 18.14–18.16 split dampers, 18.17 Supply volume flow rate, 20.59–20.62 based on space cooling vs. heating load, 20.59–60 rated volume flow of supply and return fans, 20.61–20.62 requirements other than cooling load,	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5 benefits and drawbacks, 31.2-31.3 full storage or load shift, 31.3-31.5 ice-storage and chilled water storage, 31.5 impact of electric deregulation, 31.2 partial storage or load leveling, 31.3-31.5 system description, 31.1-31.2
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12 slot diffusers, 18.14–18.16 split dampers, 18.17 Supply volume flow rate, 20.59–20.62 based on space cooling vs. heating load, 20.59–60 rated volume flow of supply and return fans, 20.61–20.62 requirements other than cooling load, 20.60–20.62	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5 benefits and drawbacks, 31.2-31.3 full storage or load shift, 31.3-31.5 ice-storage and chilled water storage, 31.5 impact of electric deregulation, 31.2 partial storage or load leveling, 31.3-31.5 system description, 31.1-31.2 Thermistors, 2.6 Thermodynamic wet bulb temperature, 2.12 Thermometer, globe, 4.9
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12 slot diffusers, 18.14–18.16 split dampers, 18.17 Supply volume flow rate, 20.59–20.62 based on space cooling vs. heating load, 20.59–60 rated volume flow of supply and return fans, 20.61–20.62 requirements other than cooling load, 20.60–20.62 temperature difference vs. enthalpy differ-	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5 benefits and drawbacks, 31.2-31.3 full storage or load shift, 31.3-31.5 ice-storage and chilled water storage, 31.5 impact of electric deregulation, 31.2 partial storage or load leveling, 31.3-31.5 system description, 31.1-31.2 Thermistors, 2.6 Thermodynamic wet bulb temperature, 2.12 Thermometer, globe, 4.9 Total shortwave irradiance, 3.34, 3.37
ceiling diffusers, 18.12–18.14 gang-operated turning vanes, 18.17 grilles, 18.11–18.12 induction, 18.14 nozzle diffusers, 18.16–18.17 nozzles, 18.16–18.17 plenum box, 18.14–18.15 registers, 18.11–18.12 slot diffusers, 18.14–18.16 split dampers, 18.17 Supply volume flow rate, 20.59–20.62 based on space cooling vs. heating load, 20.59–60 rated volume flow of supply and return fans, 20.61–20.62 requirements other than cooling load, 20.60–20.62 temperature difference vs. enthalpy difference, 20.60	between human body and indoor environment, 4.2 steady-state thermal equilibrium, 4.3 transient energy balance, 4.3 two-node model, 4.2 Thermal resistance, 3.4 of airspaces, 3.21-3.22 convective, 3.5 Thermal resistance ratio, 3.19-3.21 Thermal storage systems, 31.1-31.5 benefits and drawbacks, 31.2-31.3 full storage or load shift, 31.3-31.5 ice-storage and chilled water storage, 31.5 impact of electric deregulation, 31.2 partial storage or load leveling, 31.3-31.5 system description, 31.1-31.2 Thermistors, 2.6 Thermodynamic wet bulb temperature, 2.12 Thermometer, globe, 4.9

TRACE 600 input (Cont.)	Variable-air-volume (VAV) systems (Cont.)
internal loads, 6. 46- 6. 47	dew point control, 23.27-23.28
job, 6. 44- 6. 45	diagnostics, 23.28
load methodology, 6.43-6.44	functional controls, 23.26-23.28
schedules, 6. 45 – 6. 46	interaction between controls, 23.29-23.30
structure and basics, 6.42-6.43	nighttime setback and warmup or cooldown
TRACE 600, minimum input, run, and outputs,	control, 23.26-23.27
6. 47	override, 23. 29- 23. 30
Transducers, 5. 21	recommendations for VAV controls,
Transfer function, method, 6.14-6.26	23. 28- 23. 29
ceiling, floors, and interior partition walls,	sequence control, 23.29
6. 16- 6. 17	specific controls, 23.2
conversion of heat gain to cooling load,	steam humidifier control, 23.27
6. 24 –6. 25	types of, 21. 2- 21. 3
electric motors, 6.21–6.23	VAV systems, dual duct, 21.33-21.44
equipment and appliances, 6.21-6.23	case-study, 21.42-21.44
exterior wall and roofs, 6.16	discharge air temperature control,
heat extraction rate, 6.25	21. 40- 21. 41
heat loss to surroundings, 6.25-6.26	mixing mode operation, 21.38
heat to space, 6.20	mixing VAV box, 21.36-21.38
infiltration, 6.24	number of supply fans, 21.36
lighting, 6. 18- 6. 21	part-load operation, 21.43-21.44
space air temperature, 6.2 5	system description, 21.33-36
window glass, 6.17	winter heating and winter cooling mode oper
Transmission losses, 19.19-19.23	ation, 21. 43
for selecting building structures, 19.23	zone control and sequence of operations,
TL _{in} for flat oval ducts, 19.22	21.38-21.40
TL _{in} for rectangular ducts, 19. 22	zone supply flow rate, 21.41-21.42
TL _{in} for round ducts, 19. 22	VAV systems, fan-powered, 21.44-21.56
TL _{out} for flat oval ducts, 19.21	design considerations, 21.55-21.56
TL _{out} for rectangular ducts, 19.21	fan energy use, 21.54-21.55
TL _{out} for round ducts, 19.20-19.21	fan-powered VAV box, 21.48-21.50
Transmitters, 5.21	parallel fan-powered VAV box, 21.48-21.50
Triple point, 2.4–2.5	parallel fan-powered VAV box, fan character-
T-w chart, 2.19	istics, 21. 50– 21. 51
·· · · · · · · · · · · · · · · · · ·	series fan-powered VAV box, 21.48-21.49
Unit conversion, Inch-Pound (I-P) units to SI	supply volume flow rate, 21.53 – 21.54
units, A.15-A.17	system description, 21.44-21.47
Updated technology, 1. 17	zone control and sequence of operations,
	21. 52- 21. 53
Valves, 7. 16- 7. 17	VAV systems, single-zone, 21.2-21.18
balancing, 7.17	air conditioning cycle and system calcula-
check, 7. 16- 7. 17	tions, 21.4, 21.16-21.17
connections and ratings, 7.17-7.18	system description, 21.3-21.5
gate, 7.16	year-round operation of, 21.5-21.8
globe, 7.16-7.17	zone temperature control - sequence of opera
materials, 7.18	tions, 21. 17– 21. 18
pressure relief, 7.17	VAV systems, VAV cooling, VAV reheat, and
Vapor retarders, 3.17, 3.18	perimeter heating VAV systems,
Variable-air-volume (VAV) systems, 1.11,	21. 18– 21. 33
21.2-21.56	air skin VAV system, 21.21
comparison between various VAV systems,	ANSI/ASHRAE Standard 90.1-1999 specifi
21. 56	cations, 21.20
	•

VAV systems, VAV cooling, VAV reheat, and	Ventilation control, minimum, mixed-plenum
perimeter heating VAV systems (Cont.)	pressure (Cont.)
minimum ventilation, discharge air tempera-	monitoring plenum pressure, 23.12-23.13
ture, and duct static pressure controls,	monitoring pressure drop of louver and
23. 30- 23. 34	damper, 23.13-23.14
perimeter heating VAV systems, 21.20-21.21	supply and return fans, 23.13
reheating VAV box, 21.23	Volume flow control, 5.33-5.35
sequence of operations, primary considera-	branch flow control, 5.33-5.34
tions, 23.30-23.35	bypass control, 5. 35- 5. 34
stability of zone control, 21.26-21.27	mixed-air control, 5.33-5.34
VAV box, 21. 21– 21. 23	
VAV box, pressure dependent and pressure in-	
dependent, 21.23	Warm air furnace, 8.3-8.9
VAV box, sound level, 21.23-21.25	annual fuel utilization efficiency (AFUE),
VAV cooling systems, 21.18-21.19	8. 7
VAV reheat system, case-study, 21.27-21.33	circulating fan, 8.3-8.4
VAV reheat system, cooling mode part-load	condensing or noncondensing, 8.7
operation, 21.29-21.30	control and operation, 8.8-8.9
VAV reheat system, dead-band mode,	gas burners, 8.3
21. 25- 21. 26	gas-fired, 8.3
VAV reheat system, winter cooling mode in	heat exchangers, 8.3
interior zone, 21. 32– 21. 33	ignition, 8.3
VAV reheat system, winter reheating in	minimum efficiency, 8.8
perimeter zone, 21. 30- 21. 32	power vent or natural vent, 8.7
VAV reheat system, volume flow rate and coil	steady state efficiency (SSE), 8.7
load, 21. 28- 21. 29	thermal efficiency, 8.6-8.7
VAV reheat systems, 21.19	types of, 8.3
VAV reheat zone temperature control se-	venting arrangements, 8.4
quence of operations, 21.25-21.26	Warm air heating system, low-pressure ducted,
Ventilation, 24.2	8. 17 -8. 23
air economizer, 24.2-24.3	duct efficiency, 8.20
minimum outdoor air damper and economizer	duct leakage, 8. 20- 8. 21
damper, 24. 3	location of furnace, 8.20
minimum ventilation control, 24.3	part-load operation and control, 8.21-8.22
outdoor air requirement, 24.2	supply and return duct, 8.18
purge operation, 24.2-24.3	supply duct and return plenum, 8.18
time of operation, 24.2	system efficiency, 8.20
Ventilation control, minimum, 23.2-23.5	thermal stratification, 8.21
ASHRAE Standard 62-1999, 23.3 -23.4	Water:
basic approach, 23.2	chilled, 1.8
conference rooms, 23.16	column (WC), 4. 38
direct measurement of minimum outdoor air	condenser, 1.8
intake, 23.15	valves, 5. 26
fan tracking systems, 23.15-23.16	vapor, 2. 1- 2. 2
high-occupancy areas, 23.5	Water heat gain factor, 10.21
indoor air quality procedure, 23.3-23.4	Water impurities, 7.25-7.26
outdoor air injection fan, 23.14-23.15	Water piping, 7. 7– 7. 16
recirculation of unused outdoor air,	dimensions, copper, 7.10-7.11
23. 4 –23. 5	dimensions, steel, 7.8-7.9
types of, 23. 2– 23. 3	expansion and contraction, 7.14-7.15
ventilation rate procedure, 23.3	fittings, 7. 18- 7. 19
Ventilation control, minimum, mixed-plenum	insulation, 7.7.15-7.16
pressure, 23.12-23.14	material, 7. 7
applications, 23.14	supports, 7.14-7.15

Water piping (Cont.) Water systems (Cont.) system accessories, 7.19 oxidation, 7.24-25 Water-source heat pumps, 1.5, 28.26-28.27 pressure drop, 7.5-7.7control, 28.30-28.3 pressurization control, 7.19-7.20 energy performance by ASHRAE Standard pump location, 7.23 90.1-1999, 28.27 temperature difference, 7.4-7.5 Water-source heat pump systems, 28.24-28.33 types of, 7.40 air system and maintenance, 28.29 variable flow, 7.40 case-study, 28.31-28.32 volume flow, 7.4-7.5close-circuit evaporative water cooler, volume flow, chilled water, 7.38-7.39 28.27-28.29 water velocity, 7.5 controls, 28.30-28.31 waterlogging, 7.24-25 design considerations, 28.32-28.33 wire-to-water efficiency, 7.37-7.38 loop temperatures, 28.25-28.26 Water treatments, 7.27-7.28 operating characteristics, 28.24-28.25 chemical feeding, 7.27 safety controls, 28.30 microbiological control, 7.26 storage tank, 28.29 scale and corrosion control, 7.26 system characteristics, 28.15 Wet bulb: system description, 28.24-28.35 constant, 2.13 water heater, 28.29 depression, 2.13 water-loop temperature control, 28.30 temperature, 2.12-2.14 Water systems, 1.8, 7.2 Window glass: accessories, 7.18-7.19 clear plate, 3.29 air in, 7.23-7.24 double-strength sheet glass, 3.36 campus type, 7.53-7.58 glass temperature, 3.35 chilled, 7.2 heat gain for double-glazing, 3.34-3.36 chiller plant, 7.39 heat gain for single-glazing, 3.32-3.34 closed, 7.2 insulating, 3.29 condenser or cooling, 7.2 low-emissivity (low-E), 3.29-3.30 dual-temperature, 7.2 optical properties, 3.30-3.31 evaporative-cooled, 7.2 reflective coated, 3.29 friction chart, copper pipes, 7.6 spectral transmittance, 3.31 tinted heat-absorbing, 3.29 friction chart, plastic pipes, 7.7 friction chart, steel pipes 7.6 type of, 3.29 - 3.30hot, 7.2 U-values, 3.33 maximum allowable pressures, 7.12-7.13 once through, 7.4 open, 7.2

Zone, 6.2