

Table of Contents

Chapter/section Contents

About the author	iii
Preface	v
Table of Contents	vii
Chapter 1 Introduction	1
1.1 Air-conditioning	1
1.2 Benefits of air-conditioning	2
1.3 Common air-conditioning systems in buildings	5
1.4 Energy consumption and environmental burdens and mitigation measures	7
1.4.1 Energy end-use statistics of Hong Kong	7
1.4.2 The world energy scene	10
1.4.3 Climate change and mitigation measures.....	12
1.4.4 Steps being taken in Hong Kong.....	15
1.5 Concluding remarks	15
References.....	16
Chapter 2 Psychrometry	17
2.1 Basic concepts.....	17
2.1.1 Dry air, water vapour and moist air	17
2.1.2 Properties and states of a substance	18
2.1.3 Intensive, extensive and specific properties	18
2.2 Psychrometric properties.....	19
2.2.1 Dalton's laws and perfect gas law	19
2.2.2 Moisture content	22
2.2.3 State of saturation	22
2.2.4 Degree of saturation.....	25
2.2.5 Dew point.....	26
2.2.6 Relative humidity	27
2.2.7 Specific volume.....	28
2.2.8 Specific enthalpy.....	28
2.2.9 Sensible, latent and total heat	31
2.2.10 Adiabatic saturation and thermodynamic wet-bulb temperature	33
2.3 Humidity measurement	37
2.3.1 Wet-bulb temperature	37
2.3.2 Other types of instruments for humidity measurement	40
2.4 Psychrometric chart.....	41

2.4.1	Psychrometric property evaluation using tabulated data	41
2.4.2	Key features of a psychrometric chart.....	44
2.4.3	Reading moist air properties from a psychrometric chart	46
2.5	Psychrometric processes	47
2.5.1	The general process	47
2.5.2	Sensible heating or cooling process.....	48
2.5.3	Cooling and dehumidification process	49
2.5.4	Room air diffusion process	52
2.5.5	Adiabatic mixing process	54
2.5.6	Adiabatic saturation process	58
2.6	The conventional all air cycle	60
2.6.1	Processes in an air-conditioning cycle.....	60
2.6.2	Construction of the conventional all air cycle	62
2.7	Thermal comfort.....	65
2.7.1	Heat exchanges between the human body and the environment	65
2.7.2	Factors affecting thermal comfort sensation	66
2.7.3	ASHRAE comfort envelopes.....	68
	References.....	70
Chapter 3	Building Heat Transfer and Cooling Load Calculation	71
3.1	Heat transfer fundamentals.....	71
3.1.1	Cooling load and heat transfers in buildings.....	71
3.1.2	Dynamic conduction heat transfer in a wall or slab	72
3.1.3	Steady state conduction and convection	76
3.1.4	Radiant heat transfer	79
3.1.5	Short wave and long wave radiation	84
3.2	Heat transfers into and out of an air-conditioned space.....	84
3.2.1	Opaque wall or slab.....	85
3.2.2	Fenestration.....	90
3.3	Outdoor and indoor design conditions.....	94
3.3.1	Intensity of solar radiation	94
3.3.2	Outdoor air temperature and humidity.....	106
3.3.3	Indoor design conditions	108
3.4	Design cooling load calculation	112
3.4.1	Heat gain, cooling load and heat extraction rate.....	112
3.4.2	The radiant time series method	113
3.4.3	Internal and other heat gains and cooling load.....	128
3.4.4	Remarks	130
	References.....	131

Chapter 4	Air Side Air-conditioning Systems	132
4.1	Introduction.....	132
4.1.1	Characteristics of space cooling load	133
4.1.2	Air-side system equipment and components.....	135
4.1.3	Basic automatic control for HVAC systems	137
4.2	Operating and control principles of CAV and VAV systems.....	138
4.2.1	Room air temperature control for an air-conditioned space.....	138
4.2.2	Constant air volume (CAV) system	139
4.2.3	Variable air volume (VAV) system.....	145
4.2.4	Variants of VAV system.....	149
4.3	Economizer cycle.....	154
4.4	Central fresh air/primary air system.....	158
4.4.1	Local and centralized supply	158
4.4.2	Choices of FA supply state	159
4.4.3	Air-to-air heat recovery wheel	160
4.5	Primary air fan coil system.....	165
4.5.1	Individual zone temperature control.....	165
4.5.2	Fan coil units and selection	165
4.5.3	Variable speed fan coil units.....	168
4.6	Chilled ceiling and beam system	168
4.6.1	Construction and characteristics of chilled ceiling and chilled beam	169
4.6.2	Configuration and characteristics of chilled ceiling / beam systems.....	171
4.6.3	Design of chilled ceiling / beam system in conjunction with the PA system.....	173
4.6.4	Control of chilled ceiling / beam system	177
Annex 4A	Essence of automatic control for air-conditioning systems	179
4A.1	Automatic control system and components.....	179
4A.2	Control actions.....	180
	References.....	188
Chapter 5	Space Air Diffusion, Fan Duct System, and Mechanical Ventilation	189
5.1	Introduction.....	189
5.2	Space air diffusion design	189
5.2.1	Effective draft temperature	190
5.2.2	Diffuser selection.....	191
5.2.3	Return grilles	195
5.3	Air duct system design	195
5.3.1	Energy and pressure lost due to air flow through a duct.....	195
5.3.2	The Darcy-Weisbach equation and friction factor	197
5.3.3	Equivalent duct diameter	199

5.3.4	Data and tool for duct sizing.....	201
5.3.5	Local loss coefficients and equivalent length for duct fittings.....	203
5.3.6	Duct size calculation methods	205
5.4	Operating characteristics of a fan-duct system.....	207
5.4.1	Fan duty.....	207
5.4.2	System component characteristics and operating point.....	210
5.4.3	Fans in series and parallel	213
5.4.4	Fan surge.....	215
5.4.5	Fan selection	216
5.5	Mechanical ventilation for temperature and contaminant control.....	217
5.5.1	Functions of mechanical ventilation systems	217
5.5.2	Applications that require a constant rate of ventilation	217
5.5.3	Dynamic analysis.....	218
5.5.4	Ventilation rate measurement	222
5.6	Duct leakage test.....	227
Annex 5A	Basic fluid mechanics	230
5A.1	Displacement, velocity, and acceleration	230
5A.2	Gravitational force, potential energy, and kinetic energy	230
5A.3	Potential and kinetic energy of fluid.....	231
5A.4	Pressure and energy of fluid.....	232
5A.5	Pressure drop and energy loss due to fluid flow	236
5A.6	The steady flow energy equation	238
	References.....	240
Chapter 6	Water-side Systems and Equipment.....	241
6.1	Introduction.....	241
6.2	Water chillers.....	242
6.2.1	The medium of heat transport	242
6.2.2	Refrigeration processes and cycle	243
6.2.3	Components of a vapour compression chiller.....	245
6.3	Chiller heat rejection method.....	250
6.3.1	Heat rejection system configurations	250
6.3.2	Impact on energy performance and equipment	253
6.4	Water pumps	255
6.4.1	Key features of pumps in air-conditioning systems	255
6.4.2	Pump performance.....	256
6.4.3	Materials of key components.....	257
6.5	Cooling towers.....	257
6.5.1	Heat and moisture transfer in a cooling tower	259

6.5.2	Water losses in cooling tower	265
6.5.3	Levelling and flow balancing of cooling towers	268
6.5.4	Cooling tower plume abatement.....	269
6.6	Heat exchangers	276
6.6.1	Heat exchangers in central air-conditioning systems	276
6.6.2	Heat exchanger performance analysis.....	278
	References.....	284
Chapter 7	Water-side Systems and Control.....	285
7.1	Single-loop pumping system with differential pressure bypass control	286
7.2	Single-loop pumping system with three-way control valves.....	290
7.3	Two-loop pumping system	291
7.4	Variable primary flow (VPF) systems	300
7.5	Water pressure and pressure test.....	303
7.6	System balancing.....	305
7.6.1	Basic system configuration and the need for balancing.....	305
7.6.2	Basic principles behind proportional balancing.....	307
7.6.3	Procedures of proportional balancing.....	310
Annex 7A	Chilled water circuit designs for in-situ chiller performance measurement ...	311
7A.1	Introduction.....	311
7A.2	Alternative chilled water circuit designs.....	312
7A.3	Water flow pattern and chiller load distribution.....	314
7A.4	Modifications to the alternative water circuit designs.....	315
7A.5	Condenser air or water entering temperature control	318
	References.....	320
Chapter 8	Water-side System Pipe Sizing and Control Valve Selection	322
8.1	Design process for the water-side system.....	322
8.2	Pressure loss estimation and pipe sizing	323
8.3	Control valves	326
8.3.1	Control valve characteristics	327
8.3.2	Control valve selection.....	334
8.3.3	Control valve and system balancing	338
8.3.4	Pressure independent control valves	342
Annex 8A	Case study on control valve selection.....	344
8A.1	Introduction.....	344
8A.2	Simulation results.....	345
8A.3	Conclusion.....	346
	References.....	347
Chapter 9	System Performance and Control Optimization	348

9.1	Introduction.....	348
9.2	Sequencing control of chiller plant equipment.....	349
9.2.1	Primitive chiller plant sequencing control methods	350
9.2.2	A simple approach for optimizing chiller plant sequencing control	352
9.3	Equipment performance prediction	357
9.3.1	Chiller model.....	357
9.3.2	Cooling tower model	359
9.3.3	Variable speed pump or fan model and power input prediction	361
9.4	Control optimization for a chiller plant.....	365
9.4.1	Required system and equipment models	366
9.4.2	Evaluation of the plant total power demand for one set of defined conditions ...	369
9.4.3	Optimization search	370
9.5	Control optimization for air-side systems and whole system optimization.....	373
9.5.1	Air-side system control optimization	373
9.5.2	VAV system control optimization.....	374
9.5.3	Air-side and water-side system control optimization.....	377
Annex 9A	Gordon-Ng Chiller Model	379
9A.1	Derivation of the model	379
9A.2	Observations and avoidance of co-linearity.....	383
	References.....	385
Chapter 10	Heating Systems, Heat Recovery Chillers, Heat Pumps and Absorption Chillers	386
10.1	Heating load calculation.....	386
10.2	Heating systems and equipment.....	387
10.2.1	Boilers	388
10.2.2	Radiators.....	389
10.2.3	Embedded floor heating panels.....	393
10.2.4	Hot water piping system.....	396
10.3	Heat recovery chillers and heat pumps.....	400
10.4	Absorption refrigeration.....	404
10.4.1	System configuration and processes	404
10.4.2	Evaporation and condensation characteristics of a homogeneous binary mixture	406
10.4.3	Theoretical coefficient of performance of an absorption refrigeration cycle.....	407
10.4.4	Choice of refrigerant and absorbent combination.....	410
10.4.5	Analysis of thermodynamic processes in absorption refrigeration systems	411
10.5	Applications of absorption refrigeration.....	415
10.6	Adsorption chiller.....	415
	References.....	417

Appendix A	Developing an Electronic Psychrometric Chart and Property Calculator	418
A.1	Introduction	418
A.2	Constructing a psychrometric chart	419
A.2.1	Axes and scales for the chart	419
A.2.2	Constant property lines on a psychrometric chart	421
A.2.3	Example chart	425
A.3	Psychrometric property calculations	427
A.3.1	Known properties for calculation of other properties	427
A.3.2	Psychrometric calculation methods	429
A.4	Evaluation of the supply air state in the space air-conditioning processes	433
Annex A.I	A method for solving saturation temperature from a known value of moisture content	436
Annex A.II	A method for solving w from known values of h & ϕ	438
Annex A.III	A method for solving h & w from known values of t_{wb} & ϕ	440
Annex A.IV	A method for solving h & w from known values of t_{wb} & μ	442
Annex A.V	A method for solving t_{wb} from known values of h & w	443
Appendix B	Data for Building Cooling Load Calculation	444
B.1	Summary Weather Data of Hong Kong from ASHRAE	445
B.2	Clear Sky Total Solar Irradiance Upon Vertical and Horizontal Surfaces (W/m^2)	448
B.3	Incident Angles (Degree) of Direct Solar Radiation upon Surfaces Facing Principle Directions	455
B.4.1	Solar Heat Gain Factors for Transmitted Solar Heat Gain	462
B.4.2	Solar Heat Gain Factors for Absorbed Solar Heat Gain	469