

Table of Contents

Preface	XIII
Acknowledgements	XV
0 Introduction	1
0.1 Subject of the book.....	1
0.2 Building physics.....	1
0.2.1 Definition.....	1
0.2.2 Constraints.....	2
0.2.2.1 Comfort.....	2
0.2.2.2 Health and wellbeing.....	2
0.2.2.3 Architecture and materials.....	3
0.2.2.4 Economy.....	3
0.2.2.5 Sustainability.....	3
0.3 Importance.....	3
0.4 History.....	5
0.4.1 Applied physics.....	5
0.4.1.1 Heat, air and moisture.....	5
0.4.1.2 Acoustics.....	5
0.4.1.3 Lighting.....	6
0.4.2 Thermal comfort and indoor air quality.....	6
0.4.3 Building services.....	7
0.4.4 Building design and construction.....	8
0.4.5 The situation at the University of Leuven (KULeuven) and elsewhere.....	8
0.5 Units.....	9
0.6 Symbols.....	10
Further reading.....	12
1 Heat transfer	15
1.1 Overview.....	15
1.1.1 Heat.....	15
1.1.2 Temperature.....	15
1.1.3 Sensible and latent heat.....	15
1.1.4 Why are heat and temperature so compelling?.....	16
1.1.5 Some definitions.....	17
1.2 Conduction.....	17
1.2.1 Conservation of energy.....	17
1.2.2 The conduction laws.....	18
1.2.2.1 First law.....	18
1.2.2.2 Second law.....	20
1.2.3 Steady state.....	20
1.2.3.1 One-dimensional flat assemblies.....	20
1.2.3.2 Two dimensions, cylinder symmetric.....	28
1.2.3.3 Two and three dimensions: thermal bridges.....	29

1.2.4	Transient.....	33
1.2.4.1	Periodic boundary conditions: flat assemblies.....	34
1.2.4.2	Any boundary conditions: flat assemblies.....	44
1.2.4.3	Two and three dimensions: thermal bridges.....	47
1.3	Heat exchange at surfaces.....	48
1.4	Convection.....	49
1.4.1	In general.....	49
1.4.2	Typology.....	51
1.4.2.1	Driving forces.....	51
1.4.2.2	Flow types.....	51
1.4.3	Quantifying the convective surface film coefficient.....	52
1.4.3.1	Analytically.....	52
1.4.3.2	Numerically.....	52
1.4.3.3	Dimensionally.....	53
1.4.4	Values for the convective surface film coefficient.....	55
1.4.4.1	Flat surfaces.....	55
1.4.4.2	Cavities.....	58
1.4.4.3	Pipes.....	59
1.5	Radiation.....	60
1.5.1	In general.....	60
1.5.2	Definitions.....	61
1.5.3	Reflection, absorption and transmission.....	61
1.5.4	Radiant bodies.....	64
1.5.4.1	Black.....	64
1.5.4.2	Grey.....	71
1.5.4.3	Coloured.....	73
1.5.5	Simple formulae.....	74
1.6	Building-related applications.....	75
1.6.1	Surface film coefficients and reference temperatures.....	75
1.6.1.1	Indoors.....	76
1.6.1.2	Outdoors.....	78
1.6.2	Steady state: flat assemblies.....	80
1.6.2.1	Thermal transmittance of envelope parts and partitions.....	80
1.6.2.2	Average thermal transmittance of parts in parallel.....	82
1.6.2.3	Electrical analogy.....	84
1.6.2.4	Thermal resistance of an unvented cavity.....	84
1.6.2.5	Interface temperatures.....	86
1.6.2.6	Solar transmittance.....	87
1.6.3	Local inside surface film coefficients.....	90
1.6.4	Steady state: two and three dimensions.....	92
1.6.4.1	Pipes.....	92
1.6.4.2	Floors on grade.....	93
1.6.4.3	Thermal bridges.....	94
1.6.4.4	Windows.....	98
1.6.4.5	Building envelopes.....	99
1.6.5	Heat balances.....	101

1.6.6	Transient.....	101
1.6.6.1	Periodic: flat assemblies.....	101
1.6.6.2	Periodic: spaces.....	102
1.6.6.3	Thermal bridges.....	106
1.7	Problems and solutions.....	106
	Further reading.....	121
2	Mass transfer.....	125
2.1	Generalities.....	125
2.1.1	Quantities and definitions.....	125
2.1.2	Saturation degrees.....	127
2.1.3	Air and moisture transfer.....	127
2.1.4	Moisture sources.....	129
2.1.5	Air and moisture in relation to durability.....	130
2.1.6	Links to energy transfer.....	132
2.1.7	Conservation of mass.....	132
2.2	Air.....	133
2.2.1	Overview.....	133
2.2.2	Air pressure differentials.....	134
2.2.2.1	Wind.....	134
2.2.2.2	Stack.....	135
2.2.2.3	Fans.....	136
2.2.3	Air permeances.....	136
2.2.4	Airflow in open-porous materials.....	140
2.2.4.1	The conservation law adapted.....	140
2.2.4.2	One dimension: flat assemblies.....	141
2.2.4.3	Two and three dimensions.....	143
2.2.5	Airflow across assemblies with air-open layers, leaky joints, leaks and cavities.....	144
2.2.6	Air transfer at the building level.....	145
2.2.6.1	Definitions.....	145
2.2.6.2	Thermal stack.....	145
2.2.6.3	Large openings.....	146
2.2.6.4	The conservation law applied.....	147
2.2.6.5	Applications.....	149
2.2.7	Combined heat and air flow in open-porous materials.....	151
2.2.7.1	Heat balance equation.....	151
2.2.7.2	Steady state: flat assemblies.....	152
2.2.7.3	Steady state: two and three dimensions.....	156
2.2.7.4	Transient: flat assemblies.....	156
2.2.7.5	Transient: two and three dimensions.....	157
2.2.7.6	Air permeable layers, joints, leaks and cavities.....	157
2.2.7.7	Vented cavity.....	157
2.3	Water vapour.....	160
2.3.1	Water vapour in the air.....	160
2.3.1.1	Overview.....	160

2.3.1.2	Quantities	161
2.3.1.3	Vapour saturation pressure	161
2.3.1.4	Relative humidity	166
2.3.1.5	Changes of state in humid air	167
2.3.1.6	Enthalpy of humid air	167
2.3.1.7	Measuring air humidity	168
2.3.1.8	Vapour balance indoors	168
2.3.1.9	Relative humidity at a surface	171
2.3.2	Vapour in open-porous materials	172
2.3.2.1	Different compared with air?	172
2.3.2.2	Sorption/desorption isotherm and specific moisture ratio	173
2.3.3	Vapour transfer in the air	177
2.3.4	Vapour flow by diffusion in open-porous materials and assemblies ...	179
2.3.4.1	Flow equation	179
2.3.4.2	Mass conservation	181
2.3.4.3	Applicability of the <equivalent> diffusion concept	182
2.3.4.4	Steady state: flat assemblies	182
2.3.4.5	Steady state: two and three dimensions	192
2.3.4.6	Transient regime	193
2.3.5	Vapour flow by diffusion and convection in open-porous materials and assemblies	195
2.3.6	Surface film coefficients for diffusion	201
2.3.7	The surface film coefficient for diffusion applied	204
2.3.7.1	Diffusion resistance of an unvented cavity	204
2.3.7.2	Do vented cavities enhance drying?	204
2.3.7.3	Surface condensation and the vapour balance indoors	206
2.4	Moisture	207
2.4.1	Overview	207
2.4.2	Water flow in a pore	208
2.4.2.1	Capillarity	208
2.4.2.2	Poiseuille's law	210
2.4.2.3	Isothermal water flow in a pore contacting water	212
2.4.2.4	Isothermal water flow in a pore after water contact	218
2.4.2.5	Non-isothermal water flow in a pore after water contact	219
2.4.2.6	Remark	219
2.4.3	Vapour flow in a pore that contains water isles	219
2.4.3.1	Isothermal	220
2.4.3.2	Non-isothermal	220
2.4.4	Moisture flow in a pore that contains water isles	221
2.4.5	Moisture flow in materials and assemblies	221
2.4.5.1	Transport equations	221
2.4.5.2	Moisture permeability	223
2.4.5.3	Mass conservation	224
2.4.5.4	Starting, boundary and contact conditions	224
2.4.5.5	Remarks	225
2.4.6	Simplified moisture flow model	225

2.4.6.1	How it looks.....	225
2.4.6.2	Applying the simplified model.....	227
2.5	Problems and solutions.....	240
	Further reading.....	263
3	Combined heat, air and moisture flow	267
3.1	Introduction.....	267
3.2	Material and assembly level	267
3.2.1	Assumptions.....	267
3.2.2	Solution	267
3.2.3	Conservation of mass	268
3.2.4	Conservation of energy.....	269
3.2.5	Flux equations.....	272
3.2.5.1	Heat.....	272
3.2.5.2	Mass, air	272
3.2.5.3	Mass, moisture.....	273
3.2.6	Equations of state.....	273
3.2.6.1	Enthalpy and vapour saturation pressure versus temperature.....	273
3.2.6.2	Relative humidity versus moisture content	273
3.2.6.3	Suction versus moisture content.....	274
3.2.7	Starting, boundary and contact conditions.....	274
3.2.8	Two examples of simplified models	274
3.2.8.1	Non-hygroscopic, non-capillary materials	274
3.2.8.2	Hygroscopic materials at low moisture content	276
3.3	Whole building level.....	277
3.3.1	Balance equations	277
3.3.1.1	Vapour.....	277
3.3.1.2	Air	279
3.3.1.3	Heat	279
3.3.1.4	Closing the loop.....	281
3.3.2	Sorption-active surfaces and hygric inertia.....	282
3.3.2.1	Generalities	282
3.3.2.2	Sorption-active thickness.....	283
3.3.2.3	Zone with one sorption-active surface.....	285
3.3.2.4	Zone with several sorption-active surfaces.....	287
3.3.2.5	Harmonic analysis	287
3.3.3	Consequences.....	288
3.4	Problems and solutions.....	291
	Further reading.....	305
	Postscript.....	309