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