

Contents

	Preface	XIII
0	Introduction	1
0.1	Subject of the book	1
0.2	Building Physics and Applied Building Physics	1
0.3	Units and symbols	2
0.4	References	5
1	Outdoor and indoor conditions	7
1.1	Overview	7
1.2	Outdoor conditions	7
1.2.1	Dry bulb (or air) temperature	8
1.2.2	Solar radiation	12
1.2.2.1	Beam insolation	14
1.2.2.2	Diffuse insolation	16
1.2.2.3	Reflected insolation	17
1.2.2.4	Total insolation	18
1.2.3	Long wave radiation	19
1.2.4	Relative humidity and (partial water) vapour pressure	22
1.2.5	Wind	24
1.2.5.1	Wind speed	24
1.2.5.2	Wind pressure	26
1.2.6	Precipitation and wind-driven rain	27
1.2.6.1	Precipitation	27
1.2.6.2	Wind driven rain	30
1.2.7	Standardized outside climate values	32
1.2.7.1	Design temperature	32
1.2.7.2	Thermal reference year	32
1.2.7.3	Moisture reference year	34
1.2.7.4	Equivalent outside temperature for condensation and drying	36
1.2.7.5	Very hot summer day, very cold winter day	39
1.3	Indoor conditions	39
1.3.1	Dry bulb (or air) temperature	39
1.3.1.1	In general	39
1.3.1.2	Measured data	40
1.3.2	Relative humidity and (partial water) vapour pressure	42
1.3.2.1	In general	42
1.3.2.2	Measured data	42
1.3.3	Water vapour release indoors	46
1.3.4	Indoor climate classes	47
1.3.5	Inside/outside air pressure differentials	49

1.4	References.	49
2	Performance metrics and arrays.	51
2.1	Definitions	51
2.2	Functional demands	51
2.3	Performance requirements	51
2.4	Some history.	52
2.5	Performance arrays.	53
2.5.1	Overview.	53
2.5.2	In detail.	55
2.5.2.1	Functionality.	55
2.5.2.2	Structural adequacy	55
2.5.2.3	Building physics related quality	55
2.5.2.4	Fire safety	55
2.5.2.5	Durability	57
2.5.2.6	Maintenance	57
2.5.2.7	Costs	57
2.6	References.	57
3	Functional requirements and performances at the building level.	59
3.1	Thermal comfort.	59
3.1.1	In general	59
3.1.2	Physiological basis	59
3.1.3	Global steady state thermal comfort.	62
3.1.3.1	Clothing	62
3.1.3.2	Heat flow between the body and the environment	63
3.1.3.3	Comfort equations	64
3.1.3.4	Comfort parameters	65
3.1.3.5	Equivalent environments and comfort temperatures	65
3.1.3.6	Comfort appreciation	67
3.1.4	Local discomfort.	71
3.1.4.1	Draft	71
3.1.4.2	Vertical air temperature difference.	71
3.1.4.3	Radiant temperature asymmetry.	72
3.1.4.4	Floor temperature	73
3.1.5	Transient conditions	75
3.1.6	Comfort-related enclosure performance.	75
3.2	Health and indoor environmental quality.	76
3.2.1	In general	76
3.2.2	Health	77
3.2.3	Definitions	77
3.2.4	Relation between pollution outdoors and indoors	78
3.2.5	Physical, chemical and biological contaminants	79
3.2.5.1	Process related	79
3.2.5.2	Material related.	80

3.2.5.3	Ground related	82
3.2.5.4	Combustion related	83
3.2.6	Bio-germs	84
3.2.6.1	Bacteria	84
3.2.6.2	Mould	84
3.2.6.3	Dust mites	86
3.2.6.4	Insects	87
3.2.6.5	Rodents	88
3.2.6.6	Pets	88
3.2.7	Human related contaminants	88
3.2.7.1	Carbon dioxide (CO ₂)	88
3.2.7.2	Water vapour	89
3.2.7.3	Bio-odours	89
3.2.7.4	Environmental tobacco smoke	89
3.2.8	Perceived indoor air quality	91
3.2.8.1	Odour	91
3.2.8.2	Inside air enthalpy	92
3.2.9	Sick building syndrome	93
3.2.10	Contaminant control by ventilation	94
3.2.10.1	Ventilation effectiveness	94
3.2.10.2	Ventilation needs	94
3.2.11	Ventilation requirements	99
3.3	Energy efficiency	100
3.3.1	In general	100
3.3.2	Some statistics	101
3.3.3	End energy use in buildings	102
3.3.3.1	Lighting and appliances (function)	103
3.3.3.2	Domestic hot water	104
3.3.3.3	Space heating, space cooling and air conditioning	105
3.3.4	Space heating	105
3.3.4.1	Terminology	105
3.3.4.2	Steady state energy balance for heating at zone level	106
3.3.4.3	Steady state energy balance for heating at building level	112
3.3.5	Parameters defining the net energy demand for heating in residential buildings	113
3.3.5.1	Overview	113
3.3.5.2	In detail	114
3.3.6	Parameters defining the net energy demand for cooling in residential buildings	129
3.3.7	Gross energy demand, end energy use	131
3.3.8	Residential buildings ranked in terms of energy efficiency	131
3.3.8.1	Insulated buildings	131
3.3.8.2	Energy efficient buildings	132
3.3.8.3	Low energy buildings	132
3.3.8.4	Passive buildings	132
3.3.8.5	Zero energy buildings	133
3.3.8.6	Energy plus buildings	133
3.3.8.7	Energy autarkic buildings	133
3.4	Durability	133
3.4.1	In general	133

3.4.2	Loads	134
3.4.3	Damage patterns	135
3.4.3.1	Decrease in thermal quality	135
3.4.3.2	Decrease in strength and stiffness.	136
3.4.3.3	Stress, strain, deformation and cracking.	137
3.4.3.4	Biological degradation	139
3.4.3.5	Frost damage.	142
3.4.3.6	Salt attack	145
3.4.3.7	Chemical attack	149
3.4.3.8	Corrosion	151
3.5	Life cycle costs	152
3.5.1	In general	152
3.5.2	Total and net life cycle cost	152
3.5.3	Examples.	153
3.5.3.1	Optimal insulation thickness.	153
3.5.3.2	Whole building optimum from an energy perspective	155
3.6	Sustainability	161
3.6.1	In general	161
3.6.2	Life cycle analysis	162
3.6.2.1	Definition	162
3.6.2.2	Impacts	163
3.6.2.3	Total energy use	163
3.6.2.4	Total environmental load	164
3.6.2.5	Recycling	164
3.6.3	High performance buildings	165
3.7	References.	168
4	Heat-air-moisture performances at the envelope level	175
4.1	Introduction.	175
4.2	Air-tightness	175
4.2.1	Flow patterns	175
4.2.2	Performance requirements	177
4.2.2.1	Air in and outflow.	177
4.2.2.2	Inside air washing, wind washing and air looping	177
4.3	Thermal transmittance (U)	179
4.3.1	Definitions	179
4.3.1.1	Envelope parts	179
4.3.1.2	Envelope	179
4.3.2	Basis for performance requirements.	180
4.3.2.1	Envelope parts	180
4.3.2.2	Envelope	180
4.3.3	Examples of performance requirements	180
4.3.3.1	Envelope parts	180
4.3.3.2	Envelope	180
4.4	Transient thermal response.	184

4.4.1	Properties of importance	184
4.4.1.1	Opaque envelope parts	184
4.4.1.2	Transparent envelope parts	185
4.4.2	Performance requirements	185
4.4.2.1	Opaque envelope parts	185
4.4.2.2	Transparent envelope parts	185
4.4.3	Consequences for the building fabric	186
4.4.3.1	Opaque envelope parts	186
4.4.3.2	Transparent envelope parts	187
4.5	Moisture tolerance	188
4.5.1	In general	188
4.5.2	Built-in moisture	188
4.5.2.1	Definition	188
4.5.2.2	Requirements	188
4.5.2.3	Consequences for the building fabric	189
4.5.3	Rain and rain penetration	191
4.5.3.1	Definition	191
4.5.3.2	Requirements	192
4.5.3.3	Modelling	192
4.5.3.4	Consequences for the envelope	194
4.5.4	Rising damp	197
4.5.4.1	Definition	197
4.5.4.2	Requirements	197
4.5.4.3	Modelling	197
4.5.4.4	Consequences for the building fabric	200
4.5.5	Water heads	201
4.5.5.1	Definition	201
4.5.5.2	Requirements	202
4.5.5.3	Modelling	202
4.5.5.4	Consequences for the building fabric	202
4.5.6	Hygroscopic moisture	203
4.5.6.1	Definition	203
4.5.6.2	Requirements	204
4.5.6.3	Modelling	204
4.5.6.4	Consequences for the building fabric	204
4.5.7	Surface condensation	204
4.5.7.1	Definition	204
4.5.7.2	Requirements	204
4.5.7.3	Modelling	205
4.5.7.4	Consequences for the building fabric	206
4.5.8	Interstitial condensation	206
4.5.8.1	Definition	206
4.5.8.2	Modelling	207
4.5.8.3	Requirements	211
4.5.8.4	Consequences for the building fabric	211
4.5.8.5	Remark	212
4.5.9	All sources combined	212
4.5.9.1	Modelling	212

4.5.9.2	Requirements	213
4.5.9.3	Where actual models fail	215
4.6	Thermal bridges	220
4.6.1	Definition	220
4.6.2	Requirement	220
4.6.3	Consequences for the envelope	220
4.7	Contact coefficients	221
4.8	Hygrothermal stress and strain	221
4.9	Example of performance control: timber-framed walls	222
4.9.1	Assembly (from inside to outside)	222
4.9.2	Air-tightness	222
4.9.3	Thermal transmittance	223
4.9.4	Transient response	225
4.9.5	Moisture tolerance	226
4.9.5.1	Built-in moisture	226
4.9.5.2	Rain	226
4.9.5.3	Rising damp	226
4.9.5.4	Hygroscopic moisture and surface condensation	226
4.9.5.5	Interstitial condensation	226
4.10	References	233
5	Heat-air-moisture material properties	237
5.1	Introduction	237
5.2	Dry air and water	238
5.3	Building and isolating materials	239
5.3.1	Thermal properties	239
5.3.1.1	Definitions	239
5.3.1.2	List of design values, non-certified materials (ISO 10456)	239
5.3.1.3	Design values according to the standard NBN B 62-002 (edition 2001)	244
5.3.1.4	Measured data	253
5.3.2	Air properties	261
5.3.2.1	Design values	261
5.3.2.2	Measured data	261
5.3.3	Moisture properties	271
5.3.3.1	Design values (ISO 10456)	271
5.3.3.2	Measured data	276
5.3.4	Radiant properties	295
5.4	References	296
	Appendix	297