

TNI	Kozmická technika Príručka pre tepelnotechnický návrh Časť 7: Izolácie	TNI CEN/CLC/TR 17603-31-07 31 0540
------------	---------------------------------------------------------------------------------------------------	----------------------------------------------------------------------

Space Engineering - Thermal design handbook - Part 7: Insulations

Táto technická normalizačná informácia obsahuje anglickú verziu CEN/CLC/TR 17603-31-07:2021.
This Technical standard information includes the English version of CEN/CLC/TR 17603-31-07:2021.

Táto technická normalizačná informácia bola oznámená vo Vestníku ÚNMS SR č. 12/21

TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT

**CEN/CLC/TR 17603-31-
07**

August 2021

ICS 49.140

English version

**Space Engineering - Thermal design handbook - Part 7:
Insulations**

Ingénierie spatiale - Manuel de conception thermique -
Partie 7 : Isolations

Raumfahrttechnik - Handbuch für thermisches Design -
Teil 7: Isolationen

This Technical Report was approved by CEN on 21 June 2021. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

CEN and CENELEC members are the national standards bodies and national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



**CEN-CENELEC Management Centre:
Rue de la Science 23, B-1040 Brussels**

Table of contents

European Foreword.....	14
1 Scope.....	15
2 References	16
3 Terms, definitions and symbols	17
3.1 Terms and definitions	17
3.2 Abbreviated terms.....	17
3.3 Symbols.....	17
4 Foams	22
4.1 General.....	22
4.2 Inorganic foams	25
4.3 Organic foams	31
4.3.2 Thermal properties of organic foams	32
4.3.3 Mechanical properties of organic foams	35
4.3.4 Data on commercially available foams	53
5 Fibrous insulations	64
5.1 General.....	64
5.2 Bults.....	66
5.3 Blankets and felts	77
5.4 Papers	102
6 Multilayer insulations	108
6.1 General.....	108
6.1.1 Fundamental concepts concerning MLI performance	109
6.1.2 Failure modes	111
6.1.3 Heat transfer through an MLI	111
6.1.4 Cost	118
6.2 Radiation shields	118
6.2.1 Aluminium foils and aluminium coated plastic films	118
6.2.2 Gold foils and gold coated plastic films.....	119
6.2.3 Silver coated plastic films	119

CEN/CLC/TR 17603-31-07:2021 (E)

6.2.4	Operating temperature ranges	119
6.2.5	Normally used plastic films	120
6.3	Emittance of metallic foils	120
6.4	Emittance of metallized films	135
6.5	Absorptance of metallic foils	148
6.6	Radiation shields. miscellaneous properties	165
6.7	Radiation shields. measurement of the coating thickness	180
6.8	Spacers	183
6.8.1	Multiple-resistance spacers	184
6.8.2	Point-contact spacers	184
6.8.3	Superfloc	184
6.8.4	Single-component MLI	185
6.8.5	Composite spacers	185
6.8.6	One-dimensional heat flow through an mli with absorbing and scattering spacers	187
6.9	Spacers. miscellaneous properties	189
6.10	Complete systems	208
6.11	Normal heat transfer	209
6.12	Lateral heat transfer	251
6.13	Effect of singularities	257
6.13.1	Joints	257
6.13.2	Stitches and patches	269
6.14	Effect of evacuating holes	272
6.15	Effect of mechanical damage	276
6.16	Effect of inner gas pressure	277
6.17	Evacuation	285
6.17.1	Interstitial pressure during rapid evacuation	285
6.17.2	Interstitial pressure in outgas controlled situations	292
6.17.3	Self-pumping multilayer insulations	301
Bibliography		319
 Figures		
Figure 4-1: Resin thermal conductivity		23
Figure 4-2 : Gas thermal conductivity		23
Figure 4-3: Radiation thermal conductivity		24
Figure 4-4: Thermal conductivity, k , of several ceramic foams as a function of arithmetic mean temperature, T_m		26

CEN/CLC/TR 17603-31-07:2021 (E)

Figure 4-5: Linear thermal expansion, $\Delta L/L$, of several ceramic foams as a function of temperature, T	27
Figure 4-6: Temperature evolution of the hot and cold faces of several pieces of Zircon foam. Solid line: T_H , hot face. Dashed line: T_C , cold face.	28
Figure 4-7: Thermal conductivity k , of polyurethane foams vs. arithmetic mean temperature, T_m	32
Figure 4-8: Thermal conductivity, k , of cryopumped polystyrene foams.....	33
Figure 4-9: Thermal conductivity, k , vs. arithmetic mean temperature, T_m , of a polyurethane foam in the proximity of the condensation temperature of the filling gas.	34
Figure 4-10: Linear thermal expansion, $\Delta L/L$, of several organic foams as a function of temperature, T	35
Figure 4-11: Ultimate tensile strength, of several foams as a function of temperature, T	36
Figure 4-12: Ultimate shear strength, τ_{ult} , of several foams as a function of temperature, T	37
Figure 4-13: Tensile stress, σ , vs. strain, δ , for several polyurethane foams at 76, 195 and 300 K.....	46
Figure 4-14: Modulus of Elasticity-tensile- E , as a function of density, ρ , for several organic foams.....	46
Figure 4-15: Ultimate tensile strength, σ_{ult} , as a function of density, ρ , for several organic foams.....	47
Figure 4-16: Compressive stress, s , vs. strain, d , for several organic foams at 76, 195 and 300 K.....	47
Figure 4-17: Modulus of Elasticity-tensile- E , as a function of density, ρ , for several organic foams.....	48
Figure 4-18: Proportional limit-compressive- σ , as a function of density, ρ , for several organic foams.....	49
Figure 4-19: Ultimate tensile strength, σ_{ult} , and Modulus of Elasticity-tensile- E , as functions of temperature, T	50
Figure 4-20: Ultimate compressive strength, σ_{ult} , and Modulus of Elasticity-compressive- E , as functions of temperature, T	51
Figure 4-21: Ultimate compressive strength, σ_{ult} , as a function of temperature, T	52
Figure 4-22: Ultimate block shear strength, τ_{ult} , and Modulus of Elasticity-shear block- E , as functions of temperature, T	53
Figure 4-23: Strain, δ , vs. compressive stress, σ , of Fiberfill Structural Foams.	62
Figure 4-24: Dielectric constant, ϵ_r , and dissipation factor, D , vs. frequency, f . Stycast 1090.....	62
Figure 5-1: Thermal conductivity, k , vs. mean temperature, T_m , for several fibrous insulations. From Glasser et al. (1967) [23].	65
Figure 5-2: Thermal conductivity, k , of B & W Kaowool bulk vs. mean temperature, T_m	74
Figure 5-3: Thermal conductivity, k , of Carborundum Fiberfrax bulk and washed fibers vs. mean temperature, T_m	74
Figure 5-4: Temperature differential, $T_H - T_C$, vs. mean temperature of the hot face, T_H ,.....	75

CEN/CLC/TR 17603-31-07:2021 (E)

Figure 5-5: Temperature differential, $T_H - T_C$, vs. mean temperature of the hot face, T_H ,.....	75
Figure 5-6: Temperature differential, $T_H - T_C$, vs. mean temperature of the hot face, T_H ,.....	76
Figure 5-7: Temperature differential, $T_H - T_C$, vs. mean temperature of the hot face, T_H for different values of the insulation thickness, t . Fiberfrax washed fiber, $\rho =$ 96 kg.m^{-3}	76
Figure 5-8: Sound absorption coefficient, α , as a function of frequency, f , for B & W Kaowool blanket $2,54 \times 10^{-2} \text{ m}$ thick.....	86
Figure 5-9: Sound absorption coefficient, α , as a function of frequency, f , for the following Fiberfrax products:.....	86
Figure 5-10: Air permeability across B & W Kaowool blankets.....	87
Figure 5-11: Air permeability across Carborundum Fiberfrax blankets.....	88
Figure 5-12: Thermal conductivity, k , of B & Kaowool blankets vs. mean temperature, T_m	88
Figure 5-13: Thermal conductivity, k , of Fiberfrax blankets vs. mean temperature, T_m	89
Figure 5-14: Temperature differential, $T_H - T_C$, vs. temperature of the hot face T_H for different values of the blanket thickness, t . Fiberfrax Lo-Con Blanket & felt, $\rho = 64 \text{ kg.m}^{-3}$	89
Figure 5-15: Temperature differential, $T_H - T_C$, vs. temperature of the hot face, T_H ,	90
Figure 5-16: Sound absorption coefficient, α , as a function of frequency, f , for J-M Microlite Standard and Silicone Binder.	91
Figure 5-17: Calculated specific heat, c , as a function of temperature, T , for J.M Dyna- Quartz	91
Figure 5-18: Thermal conductivity, k , of J-M Micro-Quartz felt vs. mean temperature, T_m	93
Figure 5-19: Thermal conductivity, k , of J-M Dyna-Quartz vs. mean temperature, T_m	93
Figure 5-20: Thermal conductivity, k , of J-M Microlite "AA" and "B" vs. mean temperature, T_m	94
Figure 5-21: Compressive stress, σ , vs. compressive strain, δ , for J-M Dyna-Quartz.	94
Figure 5-22: Linear Shrinkage, LS , and Total Weight Loss, TWL , of J-M Micro-Quartz Felt as a function of temperature, T	95
Figure 5-23: Calculated specific heat, c , as a function of temperature, T , for several J-M insulations.	96
Figure 5-24: Thermal conductivity, k , of J-M Min-K 1301 vs. mean temperature, T_m . Numbers on curves indicate the density in kg.m^{-3}	97
Figure 5-25: Influence of ambient pressure on the variation of thermal conductivity, k , of J-M Min-K 1301 vs. mean temperature, T_m , for several filling gases.....	97
Figure 5-26: Thermal conductivity, k , of J-M Min-K 1301 vs. mean temperature, T_m , for different values of thickness, t	98
Figure 5-27: Thermal conductivity, k , of J-M Min-K 2000 vs. mean temperature, T_m	98
Figure 5-28: Influence of ambient pressure on the variation of thermal conductivity, k , of J-M Min-K 2000 vs. mean temperature, T_m , for several filling gases.....	99
Figure 5-29: Thermal conductivity, k , of J-M Min-K 2000 vs. mean temperature, T_m , for different values of thickness, t	99

CEN/CLC/TR 17603-31-07:2021 (E)

Figure 5-30: Thermal conductivity, k , of J-M unbounded B-Fiber batt vs. mean temperature, T_m	100
Figure 5-31: Thermal conductivity, k , of J-M Micro-Fibers felt Type "E" vs. mean temperature, T_m	100
Figure 5-32: Compressive stress, σ , vs. compressive strain, δ , for J-M Min-K 1301. Numbers on curves indicate the density in kg.m^{-3}	101
Figure 5-33: Compressive stress, σ , vs. compressive strain, δ , for J-M Min-K 2000.	101
Figure 5-34: Thermal conductivity, k , of B & W Kaowool, Carborundum Fiberfrax 970 paper, and Fiberfrax Hi-Fi 660 paper vs. mean temperature, T_m	106
Figure 5-35: Temperature differential, $T_H - T_C$, vs. temperature of the hot face, T_H , for different values of the paper thickness, t . Fiberfrax 970 paper, $\rho = 160 \text{ kg.m}^{-3}$	106
Figure 5-36: Temperature differential, $T_H - T_C$, vs. temperature of the hot face, T_H , for different values of the paper thickness, t . Fiberfrax Hi-Fi 660 paper.	107
Figure 5-37: Thermal reflectance, ρ , of Fiberfrax 970-J paper vs. mean temperature, T_m	107
Figure 6-1: Effective thermal conductivity, k_{eff} , of multilayer insulations as compared with other insulation materials. From Glaser et al. (1967) [23].	109
Figure 6-2: Effective thermal conductivity, k_{eff} , of several multilayer insulation systems as a function of the characteristic temperature, T . Calculated by the compiler.	116
Figure 6-3: Summary of data concerning hemispherical total emittance, ε , of Aluminium foils and thin sheets as a function of temperature, T	121
Figure 6-4: Summary of data concerning hemispherical total emittance, ε , of Copper as a function of temperature, T	122
Figure 6-5: Hemispherical total emittance, ε , of Copper as a function of temperature, T	123
Figure 6-6: Hemispherical total emittance, ε , of Copper as a function of temperature, T	124
Figure 6-7: Hemispherical total emittance, ε , of Gold vs. temperature, T	125
Figure 6-8: Hemispherical total emittance, ε , of Molybdenum vs. temperature, T	126
Figure 6-9: Hemispherical total emittance, ε , of Nickel vs. temperature, T	128
Figure 6-10: Hemispherical total emittance, ε , of oxidized Nickel as a function of temperature, T	129
Figure 6-11: Normal total emittance, ε' , of Nickel as a function of temperature, T	130
Figure 6-12: Normal total emittance, ε' , of Inconel as a function of temperature, T	131
Figure 6-13: Normal total emittance, ε' , of Inconel X as a function of temperature, T	132
Figure 6-14: Hemispherical total emittance, ε , of Platinum as a function of temperature, T	133
Figure 6-15: Hemispherical total emittance, ε , of Silver as a function of temperature, T	134
Figure 6-16: Hemispherical total emittance, ε , of Aluminized Mylar as a function of coating thickness, t_c	136
Figure 6-17: Hemispherical total emittance, ε , of Copper on Mylar as a function of coating thickness, t_c	137

CEN/CLC/TR 17603-31-07:2021 (E)

Figure 6-18: Hemispherical total emittance, ε , of Goldized Mylar as a function of coating thickness, t_c	138
Figure 6-19: Hemispherical total emittance, ε , of Gold on Double Aluminized Mylar as a function of Gold thickness, t_c	139
Figure 6-20: Hemispherical total emittance, ε , of Silvered Mylar as a function of coating thickness, t_c	140
Figure 6-21: Hemispherical total emittance, ε , of Silvered Mylar overcoated with Silicon Monoxide as a function of Silver thickness, t_c	141
Figure 6-22: Hemispherical total emittance, ε , of Aluminized Kapton as a function of temperature, T	143
Figure 6-23: Hemispherical total emittance, ε , of Aluminized Kapton as a function of coating thickness, t_c , for $T = 300$ K.	144
Figure 6-24: Hemispherical total emittance, ε , of Aluminized Kapton as a function of coating thickness, t_c , for $T = 400$ K.	145
Figure 6-25: Hemispherical total emittance, ε , of Single-Goldized Kapton as a function of temperature, T	146
Figure 6-26: Hemispherical total emittance, ε , of Single-Silvered Kapton as a function of temperature, T	147
Figure 6-27: Normal spectral absorptance, α'_λ , of Aluminium as a function of wavelength, λ	148
Figure 6-28: Normal solar absorptance, α_s , of Aluminium as a function of temperature, T	149
Figure 6-29: Normal spectral absorptance, α'_λ , of Copper as a function of wavelength λ	150
Figure 6-30: Normal solar absorptance, α_s , of Copper as a function of temperature T	151
Figure 6-31: Normal spectral absorptance, α'_λ , of Gold as a function of wavelength λ	152
Figure 6-32: Normal solar absorptance, α_s , of Gold as a function of temperature T	153
Figure 6-33: Normal spectral absorptance, α'_λ , of Molybdenum as a function of wavelength λ	154
Figure 6-34: Normal solar absorptance, α_s , of Molybdenum as a function of temperature T	155
Figure 6-35: Normal spectral absorptance, α'_λ , of Nickel as a function of wavelength λ	156
Figure 6-36: Normal solar absorptance, α_s , of Nickel as a function of temperature, T	158
Figure 6-37: Normal spectral absorptance, α'_λ , of Incoel as a function of wavelength λ	159
Figure 6-38: Normal solar absorptance, α_s , of Incoel as a function of the temperature, T , to which samples had been previously heated.	160
Figure 6-39: Normal spectral absorptance, α'_λ , of Platinum as a function of wavelength λ	161
Figure 6-40: Normal solar absorptance, α_s , of Platinum as a function of temperature, T	162
Figure 6-41: Normal spectral absorptance, α'_λ , of Silver as a function of wavelength, λ	163
Figure 6-42: Normal solar absorptance, α_s , of Silver as a function of temperature, T	164

CEN/CLC/TR 17603-31-07:2021 (E)

Figure 6-43: Linear thermal expansion, $\Delta L/L$, of two nominally identical specimens of $6,35 \times 10^{-6}$ m thick Mylar Double-Goldized as a function of temperature, T	172
Figure 6-44: Linear thermal expansion, $\Delta L/L$ of $6,35 \times 10^{-6}$ - $7,62 \times 10^{-6}$ m thick Kapton Double-Goldized, with Dacron Flocking, as a function of temperature, T	173
Figure 6-45: Coating thickness, t_c , given by several methods, compared with that gives by the electrical resistance method, $t_{c\Omega}$	181
Figure 6-46: Thickness, $t_{c\Omega}$, of metallic coatings as a function of film electrical resistance, R . Calculated by the compiler.....	183
Figure 6-47: Apparent emittance, ε_a , of a gray V-Groove as a function of surface emittance, ε , illustrating the effect of embossing or crinkling on the optical properties of the shield. Calculated by the compiler.	186
Figure 6-48: Effective thermal conductivity, k_{eff} , of several fibrous spacers as a function of mean temperature, T	199
Figure 6-49: Effective thermal conductivity, k_{eff} , of Fiber-glass batting as a function of Nitrogen gas pressure, p	200
Figure 6-50: Effective thermal conductivity, k_{eff} , of Dexiglas as a function of warm-boundary temperature, T_H	201
Figure 6-51: Effective thermal conductivity, k_{eff} , of Tissuglas as a function of warm-boundary temperature, T_H	202
Figure 6-52: Effective thermal conductivity, k_{eff} , of Refrasil as a function of warm-boundary temperature, T_H	203
Figure 6-53: Effective thermal conductivity, k_{eff} , of several spacer materials as a function of bulk density, ρ	204
Figure 6-54: Specific Heat, c , of several spacer materials as a function of temperature, T	205
Figure 6-55: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t	211
Figure 6-56: Compressive mechanical load, P , on the multilayer insulation vs. the number of radiation shields per unit thickness, N/t	212
Figure 6-57: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t	215
Figure 6-58: Effective thermal conductivity, k_{eff} , as a function of the characteristic temperature, T	216
Figure 6-59: Heat flux, Q/A , across a single-aluminized Mylar, crinkled, MLI on different substrate plates, as a function of the number of radiation shields, N . $T = 195$ K, $p = 2 \times 10^{-3}$ Pa. $N/t = 1100 \pm 200$ m ⁻¹	217
Figure 6-60: Effective thermal conductivity, k_{eff} , of a single-aluminized Mylar, crinkled, MLI on two different substrate plates, as a function of the number of radiation shields, N	218
Figure 6-61: Heat flux, Q/A , across a single-aluminized Mylar, crinkled, MLI on different substrate plates, as a function of the pressure, p . $T = 195$ K. Layer density, $N/t = 1100 \pm 200$ m ⁻¹ in any case.....	219

CEN/CLC/TR 17603-31-07:2021 (E)

Figure 6-62: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t	220
Figure 6-63: Effective thermal conductivity, k_{eff} , as a function of the characteristic temperature, T	221
Figure 6-64: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t	222
Figure 6-65: Compressive mechanical load, P , on the multilayer insulation vs. the number of radiation shields per unit thickness, N/t	223
Figure 6-66: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. number of radiation shields per unit thickness, N/t	224
Figure 6-67: Compressive mechanical load, P , on the multilayer insulation vs. the number of radiation shields per unit thickness, N/t	225
Figure 6-68: Effective thermal conductivity, k_{eff} , as a function of the characteristic temperature, T	225
Figure 6-69: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t . Arrows in curves indicate whether the system is being loaded or unloaded.	228
Figure 6-70: Compressive mechanical load, P , on the multilayer insulation vs. the number of radiation shields per unit thickness, N/t	229
Figure 6-71: Effective thermal conductivity, k_{eff} , as a function of the characteristic temperature, T	229
Figure 6-72: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t	231
Figure 6-73: Compressive mechanical load, P , on the multilayer insulation vs. the number of radiation shields per unit thickness, N/t	232
Figure 6-74: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t	234
Figure 6-75: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t . Complete loading-unloading history of system (Δ).	235
Figure 6-76: Compressive mechanical load, P , on the multilayer insulation vs. the number of radiation shields per unit thickness, N/t	236
Figure 6-77: Compressive mechanical load, P , on the multilayer insulation vs. the number of radiation shields per unit thickness, N/t . Complete loading-unloading history of system (Δ).	236
Figure 6-78: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t	239
Figure 6-79: Effective thermal conductivity, k_{eff} , as a function of the characteristic temperature, T	240

CEN/CLC/TR 17603-31-07:2021 (E)

Figure 6-80: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t	243
Figure 6-81: Effective thermal conductivity, k_{eff} , as a function of the characteristic temperature, T	244
Figure 6-82: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t	245
Figure 6-83: Compressive mechanical load, P , on the multilayer insulation vs. the number of radiation shields per unit thickness, N/t	246
Figure 6-84: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t	247
Figure 6-85: Compressive mechanical load, P , on the multilayer insulation vs. the number of radiation shields per unit thickness, N/t	248
Figure 6-86: Effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff} , vs. the number of radiation shields per unit thickness, N/t	249
Figure 6-87: Compressive mechanical load, P , on the multilayer insulation vs. the number of radiation shields per unit thickness, N/t	250
Figure 6-88: Effective thermal conductivity, k_{eff} , as a function of the characteristic temperature, T	250
Figure 6-89: Lateral effective thermal conductivity, k_{eff} , as a function of characteristic temperature, T	252
Figure 6-90: Lateral effective thermal conductivity, k_{eff} , as a function of characteristic temperature, T	253
Figure 6-91: Lateral effective thermal conductivity, k_{eff} , as a function of characteristic temperature, T	255
Figure 6-92: Lateral effective thermal conductivity, k_{eff} , as a function of characteristic temperature, T	256
Figure 6-93: Effective emittance, $\Delta\epsilon_{eff}$, vs. overlap, I	267
Figure 6-94: Length, L^* , vs. overlap, I , of alternate layers.	267
Figure 6-95: Length, L^* , vs. underlap, I	268
Figure 6-96: Length, L^* , vs. k_{eff} . Edge rejection.....	268
Figure 6-97: Heat loss, ΔQ , due to stitching vs. the length of Stitch, L	270
Figure 6-98: Heat loss, ΔQ , due to stitch patching vs. the number of patch layers, N . Undisturbed system and test method as in Figure 6-97.....	271
Figure 6-99: Effect of perforations on the effective thermal conductivity of a multilayer insulation formed by 24 Radiation Shields $6,35 \times 10^{-6}$ m thick Mylar Double-Aluminized, and 23 Spacers $7,11 \times 10^{-4}$ m thick Polyurethane Foam.	272
Figure 6-100: Effect of perforations on the effective thermal conductivity of a multilayer insulation formed by 10 Radiation Shields $6,35 \times 10^{-6}$ m thick by 0,279 m diameter Mylar Double-Aluminized, and 22 Spacers $2,54 \times 10^{-5}$ m thick by 0,305 m diameter Glass Fabric.	273

CEN/CLC/TR 17603-31-07:2021 (E)

Figure 6-101: Effect of percentage of perforations, τ , on the heat flux through a multilayer insulation.....	274
Figure 6-102: Effect of Meteoroid-Bumper debris damage on the effective thermal conductivity, k_{eff} , and product of apparent density and effective thermal conductivity, ρk_{eff}	276
Figure 6-103: Effective thermal conductivity, k_{eff} , as a function of gas pressure, p	278
Figure 6-104: Effective thermal conductivity, k_{eff} , as a function of gas pressure, p	280
Figure 6-105: Effective thermal conductivity, k_{eff} , as a function of gas pressure, p	281
Figure 6-106: Effective thermal conductivity, k_{eff} , as a function of gas pressure, p	283
Figure 6-107: Effective thermal conductivity, k_{eff} , as a function of gas pressure, p	284
Figure 6-108: Permeability, κ , of several multilayer insulation configurations as a function of the layer density, N/t	287
Figure 6-109: Pressure differential, $p(0,t)-p_o(t)$. Vs. time, t	290
Figure 6-110: Knudsen Diffusion Coefficient, D_K , as a function of gas molecular mass, M . From Coston (1967) [13], p. 4,3-31.	292
Figure 6-111: Outgassing rate, Q , as a function of pumping time, t , for Mylar Double-Aluminized. Effect of preconditioning. From Glassford (1970) [24].	293
Figure 6-112: Outgassing rate, Q , as a function of pumping time, t , for Mylar Double-Aluminized. Effect of prepumping. From Glassford (1970) [24].....	294
Figure 6-113: Outgassing rate, Q , as a function of pumping time, t , for Mylar Double-Aluminized, as received. Effect of test temperature.....	295
Figure 6-114: Outgassing rate, Q , as a function of pumping time, t , for several shielding materials, as received.	297
Figure 6-115: Outgassing rate, Q , as a function of pumping time, t , for several spacing materials.	298
Figure 6-116: Outgassing rate, Q , as a function of pumping time, t , for an MLI system and for its components. No preconditioning. From Glassford (1970) [24].	299
Figure 6-117: Main characteristics of the different self-evacuated MLIs and experimental methods used to obtain the results summarized in Table 6-25....	303
Figure 6-118: Model for a guarded two-dimensional MLI. (a) Geometry. (b) Boundary conditions for the calculations.	317
Figure 6-119: Ratio of lateral to total heat transfer rate, $Q_x/(Q_x+Q_y)$, in an anisotropic two-dimensional continuous medium subject to the boundary conditions indicated in Figure 6-118:.....	318

Tables

Table 4-1: Relevant Properties of Ceramic Foams	25
Table 4-2: Properties of Ceramic Foams	29
Table 4-3: Characterization of Foams Whose Properties Will Be Given Later	38
Table 4-4: Average Tensile Data of Polyurethane and Polystyrene Foams	39
Table 4-5: Average Tensile Data of Polyurethane and Polystyrene Foams at $T = 76$ K T: Transverse; L: Longitudinal	40

CEN/CLC/TR 17603-31-07:2021 (E)

Table 4-6: Average Tensile Data of Polyurethane and Polystyrene Foams at $T = 195$ K T: Transverse; L: Longitudinal	41
Table 4-7: Average Tensile Data of Polyurethane and Polystyrene Foams at $T = 300$ KT: Transverse; L: Longitudinal	42
Table 4-8: Average Compressive Data of Polyurethane and Polystyrene Foams	42
Table 4-9: Average Compressive Data of Polyurethane and Polystyrene Foams at $T =$ 76 K T: Transverse; L: Longitudinal	43
Table 4-10: Average Compressive Data of Polyurethane and Polystyrene Foams at $T =$ 195 K T: Transverse; L: Longitudinal	44
Table 4-11: Average Compressive Data of Polyurethane and Polystyrene Foams at $T =$ 300 K T: Transverse; L: Longitudinal	45
Table 4-12: Information Concerning Processing	60
Table 4-13: Information Concerning Processing of Fiberfil Products Recommendations for Molding	63
Table 5-1: Available Densities, ρ , and Thicknesses, t , of B & W Kaowool Blanket. X denotes available.	90
Table 5-2: Available Thicknesses, t , and Lengths, L , of Fiberfrax Lo-Con Blanket and Felt for densities of 64 kg.m^{-3} and 96 kg.m^{-3} and roll widths 0,3 m, 0,61 m, and 1,22 m.	91
Table 5-3: Thermal Conductivity, k , [$\text{W.m}^{-1}.\text{K}^{-1}$], of J-M Thermoflex Felt for different values of Density, ρ , [kg.m^{-3}], and Mean Temperature, T_m , [K].	92
Table 5-4: Available Densities, ρ , [kg.m^{-3}], and Thicknesses, $t \times 10^3$ [m], of J-M Thermoflex.	95
Table 5-5: Available Densities, ρ , and Thicknesses, t , of J-M Micro-Quartz	96
Table 5-6: Available Forms of J-M Min-K 1301	102
Table 5-7: Available Forms of J-M Min-K 2000	102
Table 5-8: Available Thicknesses of B&W Kaowool Paper	104
Table 5-9: Available Thicknesses of Fiberfrax 970 Paper	105
Table 5-10: Available Roll Sizes of Fiberfrax 970 Paper	105
Table 5-11: Available Thicknesses and Corresponding Mass/Area of Fiberfrax Paper H880; Hi-Fi 660, and 550.	105
Table 6-1: Properties of Metallic Foils	166
Table 6-2: Properties of Polymeric Films	168
Table 6-3: Properties of Several Marketed Polycarbonate Resins	169
Table 6-4: Tensile Strength of Mylar and Kapton H for Different. Values of the Temperature.	170
Table 6-5: Properties of Coated Plastic Films	170
Table 6-6: Flammability of Several Radiation Shields in Oxygen and in Air	174
Table 6-7: Outgassing Characteristics of Non-Metallized and Metallized Plastic Films	175
Table 6-8: Procurement Data	177
Table 6-9: ρ and $3\lambda\rho/8$ for Aluminium, Copper, Gold and Silver	182

CEN/CLC/TR 17603-31-07:2021 (E)

Table 6-10: Absorption and Scattering Coefficients for Spacer Materials	188
Table 6-11: Properties of Staple Fibers Data is available for the following Staple Fibers	190
Table 6-12: Properties of Staple Fibers	191
Table 6-13: Properties of Staple Fibers	192
Table 6-14: Effect of Heat on Several Fibers	193
Table 6-15: Moisture Regain of Several Fibers.....	193
Table 6-16: Effect of Exposure Temperature, Pressure and Time on the Strength of Fabrics, $T = 450$ K.....	194
Table 6-17: Fiber Strength after 10 min Exposure to Temperature	195
Table 6-18: Effect of Cycling vs. Continuous Exposure to Temperature of Two Fibers in Woven Forms.....	196
Table 6-19: Thermal Properties of Fabrics Woven of Several Fibers	197
Table 6-20: Flammability per Vertical Flame Tests	206
Table 6-21: Flammability of Several Spacers in Oxygen and in Air.....	206
Table 6-22: Outgassing Characteristics of Several Spacers	207
Table 6-23: Thermal Effects of Joints	259
Table 6-24: Characteristics of Self-Pumping MLIs the performances of which are given in Table 6-25	302
Table 6-25: Characteristics of Several Self-Pumping Multilayer Insulations.....	304
Table 6-26: Summary of the Best and Worst Cases Reached by the Different Investigators.....	314

European Foreword

This document (CEN/CLC/TR 17603-31-07:2021) has been prepared by Technical Committee CEN/CLC/JTC 5 “Space”, the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-31.

This Technical report (TR 17603-31-07:2021) originates from ECSS-E-HB-31-01 Part 7A.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any TR covering the same scope but with a wider domain of applicability (e.g.: aerospace).

1

Scope

There are 3 main categories of insulators used in spacecrafts:

1. foams: organic and inorganic;
2. fibrous insulations: for internal and external insulation and for high temperature environments
3. multilayer insulations (MLI): layers of radiation reflecting shields.

Properties, thermal behaviour and application areas of the insulation materials used in spacecrafts are detailed in this Part 7.

The Thermal design handbook is published in 16 Parts

TR 17603-31-01	Thermal design handbook – Part 1: View factors
TR 17603-31-02	Thermal design handbook – Part 2: Holes, Grooves and Cavities
TR 17603-31-03	Thermal design handbook – Part 3: Spacecraft Surface Temperature
TR 17603-31-04	Thermal design handbook – Part 4: Conductive Heat Transfer
TR 17603-31-05	Thermal design handbook – Part 5: Structural Materials: Metallic and Composite
TR 17603-31-06	Thermal design handbook – Part 6: Thermal Control Surfaces
TR 17603-31-07	Thermal design handbook – Part 7: Insulations
TR 17603-31-08	Thermal design handbook – Part 8: Heat Pipes
TR 17603-31-09	Thermal design handbook – Part 9: Radiators
TR 17603-31-10	Thermal design handbook – Part 10: Phase – Change Capacitors
TR 17603-31-11	Thermal design handbook – Part 11: Electrical Heating
TR 17603-31-12	Thermal design handbook – Part 12: Louvers
TR 17603-31-13	Thermal design handbook – Part 13: Fluid Loops
TR 17603-31-14	Thermal design handbook – Part 14: Cryogenic Cooling
TR 17603-31-15	Thermal design handbook – Part 15: Existing Satellites
TR 17603-31-16	Thermal design handbook – Part 16: Thermal Protection System

2 References

EN Reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS System - Glossary of terms

All other references made to publications in this Part are listed, alphabetically, in the **Bibliography**.

koniec náhľadu – text ďalej pokračuje v platenej verzii STN