Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

The second part is the experimental radiation heat transfer fitting

Report date	Jan 3, 2024, 7:07:20 PM

Contents

1 Global Definitions

Date	Sep 13, 2023, 3:51:58 PM

GLOBAL SETTINGS

Name	The second part is the experimental radiation heat transfer fitting. mph
Path	C:\Users\Administrator\Desktop\11.mph
Version	COMSOL Multiphysics 6.1 (Build: 252)
Unit system	SI

USED PRODUCTS

Heat Transfer Module
CAD Import Module
COMSOL Multiphysics

COMPUTER INFORMATION

CPU	Intel(R) Core (TM) i5-5200U CPU @ 2.20GHz, 2 cores, 15.9 GB RAM
Operating system	Windows 10

2 components 1

Date	Sep 13, 2023, 3:34:57 PM

SETTINGS

Description	Value
Unit system	Same as global system (SI)
Geometry shape function	Automatic

SPATIAL FRAME COORDINATES

First	Second	Third
x	y	z

MATERIAL FRAME COORDINATES

First	Second	Third
X	Y	Z

GEOMETRY FRAME COORDINATES

First	Second	Third
Xg	Yg	Zg

MESH FRAME COORDINATES

First	Second	Third
Xm	Ym	Zm

2.1 DEFINITIONS

2.1.1 Variables

Indicator. Inner Sphere

SELECTION

Geometric entity level	Boundary
Name	Film
Selection	Named geom1_csel2_bnd: Geometry geom1: Dimension 2: Boundaries 6–11

Name	Expression	Unit	Description
ext	0		
int	1		

Indicator, outer sphere

SELECTION

Geometric entity level	Boundary
Name	Aluminum foil
Selection	Named geom1_csel1_bnd: Geometry geom1: Dimension 2: Boundaries

	1–5, 12

Name	Expression	Unit	Description
ext	1		
int	0		

2.1.2 Nonlocal Couplings

Integral, Inner Sphere

Coupling type	Integration
Operator name	intop_int

SELECTION

Geometric entity level	Boundary
Name	Film
Selection	Named geom1_csel2_bnd: Geometry geom1: Dimension 2: Boundaries 6–11

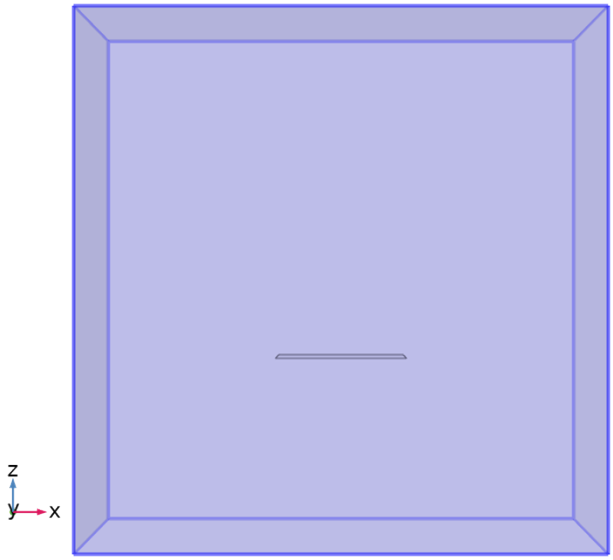
Selection

Integral, outer sphere

Coupling type	Integration
Operator name	intop_ext

SELECTION

Geometric entity level	Boundary
Name	Aluminum foil
Selection	Named geom1_csel1_bnd: Geometry geom1: Dimension 2: Boundaries 1–5, 12



Selection

2.1.3 Coordinate Systems

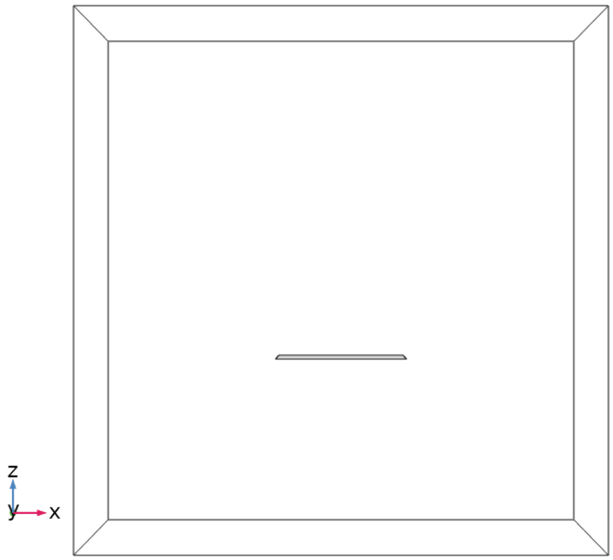
Boundary coordinate system 1

Coordinate system type	Boundary system
Tag	sys1

COORDINATE NAMES

First	Second	Third
t1	t2	n

2.2 GEOMETRY 1



Geometry 1

UNITS

Length unit	m
Angular unit	deg

GEOMETRY STATISTICS

Description	Value
Space dimension	3
Number of domains	0
Number of boundaries	12
Number of edges	24
Number of vertices	16

2.2.1 **cuboid 1** (blk1)

SELECTIONS OF RESULTING ENTITIES

Description	Value
Contribute to	Aluminum foil

POSITION

Description	Value
Position	{0, 0, 0}

OBJECT TYPE

Description	Value
Type	Surface

AXIS

Description	Value
Axis type	z - axis

SIZE AND SHAPE

Description	Value
Width	0.195
Depth	0.295
Height	0.2

2.2.2 cuboid 2 (blk2)

SELECTIONS OF RESULTING ENTITIES

Description	Value
Contribute to	Film

POSITION

Description	Value
Position	{0.0725, 0.0975, 0.07}

OBJECT TYPE

Description	Value
Type	Surface

AXIS

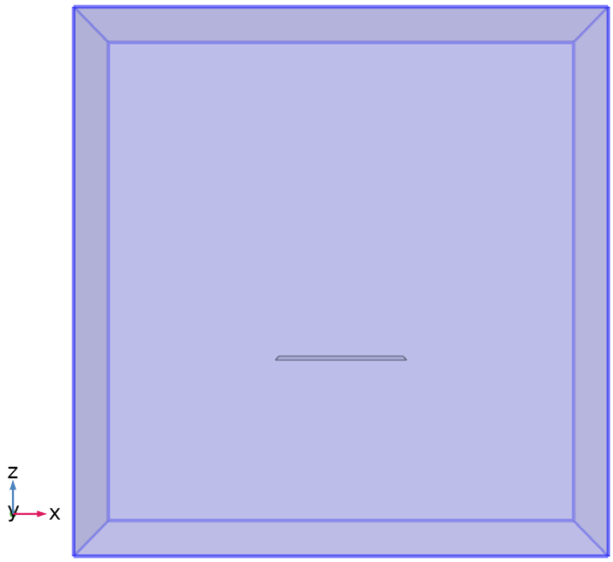
Description	Value
Axis type	z - axis

SIZE AND SHAPE

Description	Value
Width	0.05
Depth	0.1
Height	1E-4

2.3 MATERIALS

2.3.1 Aluminum



Aluminum

SELECTION

Geometric entity level	Boundary
Name	Aluminum foil
Selection	Named geom1_csel1_bnd: Geometry geom1: Dimension 2: Boundaries 1–5, 12

MATERIAL PARAMETERS

Name	Value	Unit	Property group
Surface emissivity	0.09	1	Basic

BASIC

Description	Value
Surface emissivity	0.09

2.3.2 material 2

Material 2

SELECTION

Geometric entity level	Boundary
Name	Film
Selection	Named geom1_csel2_bnd: Geometry geom1: Dimension 2: Boundaries 6–11

MATERIAL PARAMETERS

Name	Value	Unit	Property group
Surface emissivity	0.9	1	Basic

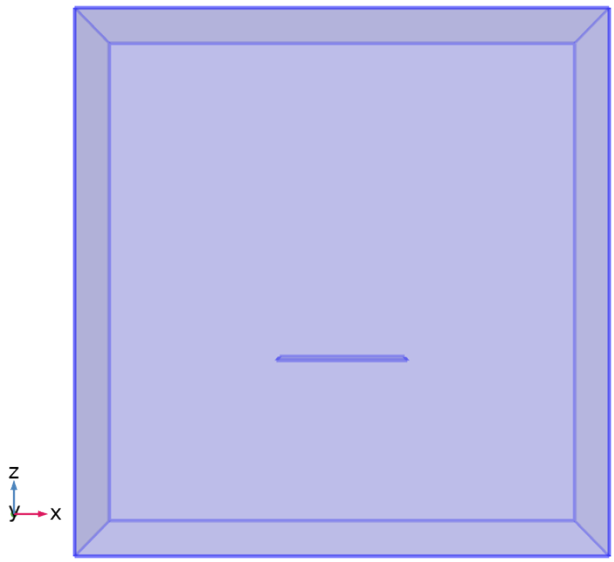
BASIC

Description	Value
Surface emissivity	0.9

2.4 SURFACE-TO-SURFACE RADIATION

USED PRODUCTS

Heat Transfer Module
COMSOL Multiphysics



surface-to-surface radiation

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 2: All boundaries

EQUATIONS

$$J = \varepsilon e_b(T) + \rho_d G$$
$$G = G_m + G_{amb} + G_{ext}$$
$$G_{amb} = F_{amb}\varepsilon_{amb}e_b(T_{amb})$$
$$e_b(T) = n^2\sigma T^4$$

2.4.1 Interface Settings

Discretization

SETTINGS

Description	Value
Surface radiosity	Linear

SETTINGS

Description	Value
Equation form	Study controlled

Radiation Settings

SETTINGS

Description	Value
Jacobian contribution	Only local contributions to radiosity
Use radiation groups	Off
Surface-to-surface radiation method	Hemicube

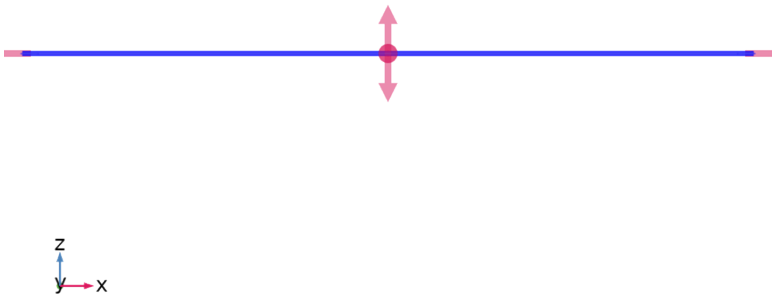
Description	Value
Radiation resolution	256
Transparent media refractive index	1
Wavelength dependence of radiative properties	Constant
Check consistency	On
Store view factors on disk	Off
View factors update threshold	Every nonlinear iteration

2.4.2 Variables

Name	Expression	Unit	Description	Selection	Details
rad.nx	dnx	1	Normal vector, x-component	Boundaries 1–12	
rad.ny	dny	1	Normal vector, y-component	Boundaries 1–12	
rad.nz	dnz	1	Normal vector, z-component	Boundaries 1–12	
rad.dnx	dnx	1	Normal vector down direction, x-component	Boundaries 1–12	
rad.dny	dny	1	Normal vector down direction, y-component	Boundaries 1–12	
rad.dnz	dnz	1	Normal vector down direction, z-component	Boundaries 1–12	
rad.unx	unx	1	Normal vector up direction, x-component	Boundaries 1–12	
rad.uny	uny	1	Normal vector up direction, y-component	Boundaries 1–12	
rad.unz	unz	1	Normal vector up direction, z-component	Boundaries 1–12	
rad.nS2S	1	1	Transparent media refractive index	Global	
rad.q0su	0	W/m²	Source heat flux	Global	+ operation
rad.q0sd	0	W/m²	Source heat flux	Global	+ operation
rad.dfltopaque	-1	1	Opaque	Boundaries 1–12	
rad.dfltopaque	-1	1	Opaque	Domains -2–0	
rad.opaque	rad.dfltopaque	1	Opaque	Boundaries 1–12	
rad.opaque	rad.dfltopaque	1	Opaque	Domains -2–0	
rad.lambdainf	1[mm]	m	Upper bound for integrations	Boundaries 1–12	

Name	Expression	Unit	Description	Selection	Details
rad.Ts	5780[K]	K	Sun blackbody temperature	Boundaries 1–12	

2.4.3 diffuse reflective surface 1



diffuse reflective surface 1

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 2: All boundaries

EQUATIONS

$$J = \varepsilon e_b(T) + \rho_d G$$
$$\varepsilon + \rho_d = 1$$
$$G = G_m + G_{amb} + G_{ext}$$
$$G_{amb} = F_{amb} e_b(T_{amb})$$
$$G_{ext} = q_s$$
$$e_b(T) = n^2 \sigma T^4$$
$$q_{r,net} = \varepsilon\left(G - e_b(T)\right)$$

Radiation Direction

SETTINGS

Description	Value
Emitted radiation direction	Positive normal direction

Ambient

SETTINGS

Description	Value	Unit

Description	Value	Unit
Define ambient temperature on each side	Off	
Ambient temperature	User defined	
Ambient temperature	293.15	K
Define ambient emissivity on each side	Off	
Ambient emissivity	Blackbody	
Include diffuse irradiance	Off	

Surface Emissivity

SETTINGS

Description	Value
Define properties on each side	Off
Emissivity	From material

Constraint Settings

SETTINGS

Description	Value
Use weak constraints	Off
Constraint method	Elemental

Model Input

SETTINGS

Description	Value	Unit
Temperature	User defined	
Temperature	293.15	K

PROPERTIES FROM MATERIAL

Property	Material	Property group
Surface emissivity	Material 2	BASIC

Variables

Name	Expression	Unit	Description	Selection	Details
rad.Tradu	rad.Trad	K	Upside temperature	Boundaries 6–11	
rad.Tradd	rad.Trad	K	Downside temperature	Boundaries 6–11	
rad.Tamb	293.15[K]	K	Ambient temperature	Boundaries 6–11	
rad.Famb	rad.Fambu	1	Ambient view factor	Boundaries 6–11	
rad.Gamb	rad.Gambu	W/m²	Ambient irradiation	Boundaries 6–11	
rad.Gext	rad.Gextu	W/m²	External irradiation	Boundaries 6–11	

Name	Expression	Unit	Description	Selection	Details
rad.Gm	rad.Gmu	W/m²	Mutual surface irradiation	Boundaries 6–11	
rad.Grad_band	rad.Gradu	W/m²	Surface irradiation	Boundaries 6–11	
rad.Grad	rad.Grad_band	W/m²	Surface irradiation	Boundaries 6–11	
rad.J	rad.J_band	W/m²	Surface radiosity	Boundaries 6–11	
rad.J_band	rad.Ju_band	W/m²	Surface radiosity	Boundaries 6–11	
rad.lambda	1	m	Wavelength	Boundaries 6–11	
rad.q0s	rad.q0su	W/m²	Source heat flux	Boundaries 6–11	
rad.rflux	rad.rflux_band	W/m²	Radiative heat flux	Boundaries 6–11	
rad.rflux_band	rad.rfluxu_band+rad.rfluxd_band	W/m²	Radiative heat flux	Boundaries 6–11	
rad.zeta	1	1	Intermediate variable	Boundaries 6–11	
rad.fep	rad.fepu	1	Fractional emissive power	Boundaries 6–11	
rad.fepamb	rad.fepambu	1	Fractional emissive power	Boundaries 6–11	
rad.fepdiff	rad.fepdiffu	1	Fractional emissive power	Boundaries 6–11	
rad.T_band	rad.Tu_band	K	Temperature	Boundaries 6–11	
rad.T	rad.T_band	K	Temperature	Boundaries 6–11	
rad.Trad	rad.dsurf1.minput_temperature	K	Temperature	Boundaries 6–11	
rad.Gm_gp	gpeval(2,rad.Gm)	W/m²	Mutual surface irradiation	Boundaries 6–11	
rad.Gmu_gp	gpeval(2,rad.Gmu)	W/m²	Mutual surface irradiation, upside	Boundaries 6–11	
rad.Gmd_gp	0	W/m²	Mutual surface irradiation, downside	Boundaries 6–11	
rad.Famb_gp	gpeval(2,rad.Famb)	1	Ambient view factor, Gauss point evaluation	Boundaries 6–11	
rad.Fambu_gp	gpeval(2,rad.Fambu)	1	Ambient view factor, Gauss point evaluation, upside	Boundaries 6–11	

Name	Expression	Unit	Description	Selection	Details
rad.Fambd_gp	0	1	Ambient view factor, Gauss point evaluation, downside	Boundaries 6–11	
rad.diru	1	1	Radiation direction, upside	Boundaries 6–11	
rad.ebu	rad.nS2S^2*sigma_const*rad.Tu_band^4*rad.fepu	W/m²	Blackbody emissive power, upside	Boundaries 6–11	
rad.ebambu	rad.nS2S^2*sigma_const*rad.Tambu^4*rad.fepambu	W/m²	Blackbody emissive power, upside	Boundaries 6–11	
rad.fepu	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zeta,eps,eps,1.0E-6)/pi^4	1	Fractional emissive power, upside	Boundaries 6–11	
rad.fepambu	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zeta,eps,eps,1.0E-6)/pi^4	1	Fractional emissive power, upside	Boundaries 6–11	
rad.fepdiffu	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zeta,eps,eps,1.0E-6)/pi^4	1	Fractional emissive power, upside	Boundaries 6–11	
rad.Tu_band	0.5*((1+rad.opaque)*rad.Tradu+(1-rad.opaque)*rad.Tradd)	K	Upside temperature	Boundaries 6–11	
rad.Gambu	rad.Fambu*rad.epsilon_ambu_band*rad.ebambu	W/m²	Ambient irradiation, upside	Boundaries 6–11	
rad.Gextu	rad.q0su	W/m²	External irradiation, upside	Boundaries 6–11	+ operation
rad.Gradu	nojac(rad.Gmu+rad.Gambu+rad.Gextu)	W/m²	Surface irradiation, upside	Boundaries 6–11	
rad.Ju	rad.Ju_band	W/m²	Surface radiosity, upside	Boundaries 6–11	
rad.Ju_band	rad.dsurf1.Ju_band	W/m²	Surface radiosity, upside	Boundaries 6–11	
rad.rfluxu	rad.rfluxu_band	W/m²	Radiative heat flux, upside	Boundaries 6–11	
rad.rfluxu_band	rad.epsilonu_band*(rad.Gradu-rad.ebu)	W/m²	Radiative heat flux, upside	Boundaries 6–11	
rad.Idiff	0	W/m²	Diffuse	Boundaries	

Name	Expression	Unit	Description	Selection	Details
			irradiance	6–11	
rad.Idiff_band	rad.Idiffu_band	W/m²	Diffuse irradiance	Boundaries 6–11	
rad.Idiffu_band	0	W/m²	Diffuse irradiance, upside	Boundaries 6–11	
rad.Idiffd_band	0	W/m²	Diffuse irradiance, downside	Boundaries 6–11	
rad.Tambu	rad.Tamb	K	Ambient temperature, upside	Boundaries 6–11	
rad.dird	0	1	Radiation direction, downside	Boundaries 6–11	
rad.ebd	rad.nS2S^2*sigma_const*rad.Td_band^4*rad.fepd	W/m²	Blackbody emissive power, downside	Boundaries 6–11	
rad.ebambd	rad.nS2S^2*sigma_const*rad.Tambd^4*rad.fepambd	W/m²	Blackbody emissive power, downside	Boundaries 6–11	
rad.fepd	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zeta,eps,eps,1.0E-6)/pi^4	1	Fractional emissive power, downside	Boundaries 6–11	
rad.fepambd	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zeta,eps,eps,1.0E-6)/pi^4	1	Fractional emissive power, downside	Boundaries 6–11	
rad.fepdiffd	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zeta,eps,eps,1.0E-6)/pi^4	1	Fractional emissive power, downside	Boundaries 6–11	
rad.Td_band	0.5*((1+rad.opaque)*rad.Tradd+(1-rad.opaque)*rad.Tradu)	K	Downside temperature	Boundaries 6–11	
rad.Gambd	rad.Fambd*rad.epsilon_ambd_band*rad.ebambd	W/m²	Ambient irradiation, downside	Boundaries 6–11	
rad.Gextd	rad.q0sd	W/m²	External irradiation, downside	Boundaries 6–11	+ operation
rad.Gradd	nojac(rad.Gmd+rad.Gambd+rad.Gextd)	W/m²	Surface irradiation, downside	Boundaries 6–11	
rad.Jd	rad.Jd_band	W/m²	Surface radiosity,	Boundaries	

Name	Expression	Unit	Description	Selection	Details
			downside	6–11	
rad.Jd_band	rad.dsurf1.Jd_band	W/m²	Surface radiosity, downside	Boundaries 6–11	
rad.rfluxd	rad.rfluxd_band	W/m²	Radiative heat flux, downside	Boundaries 6–11	
rad.rfluxd_band	0	W/m²	Radiative heat flux, downside	Boundaries 6–11	
rad.Tambd	rad.Tamb	K	Ambient temperature, downside	Boundaries 6–11	
rad.epsilon	rad.epsilon_band	1	Emissivity	Boundaries 6–11	
rad.epsilonu	subst(material.epsilon_rad,rad.dsurf1.minput_temperature,rad.Tradu,rad.dsurf1.minput_length,rad.lambda)	1	Emissivity, upside	Boundaries 6–11	Meta
rad.epsilond	subst(material.epsilon_rad,rad.dsurf1.minput_temperature,rad.Tradd,rad.dsurf1.minput_length,rad.lambda)	1	Emissivity, downside	Boundaries 6–11	Meta
rad.epsilon_band	0.5*((1+rad.opaque)*rad.epsilonu_band+(1-rad.opaque)*rad.epsilond_band)	1	Emissivity	Boundaries 6–11	
rad.epsilonu_band	integrate(rad.epsilonu,rad.lambda,0[m]*(1+0.25*eps),rad.lambdainf*(1-0.25*eps),1.0E-6)/max(rad.lambdainf*(1-0.25*eps)-0[m]*(1+0.25*eps),eps)	1	Emissivity, upside	Boundaries 6–11	
rad.epsilond_band	integrate(rad.epsilond,rad.lambda,0[m]*(1+0.25*eps),rad.lambdainf*(1-0.25*eps),1.0E-6)/max(rad.lambdainf*(1-0.25*eps)-0[m]*(1+0.25*eps),eps)	1	Emissivity, downside	Boundaries 6–11	
rad.epsilon_amb	rad.epsilon_amb_band	1	Ambient emissivity	Boundaries 6–11	
rad.epsilon_ambu	1	1	Ambient	Boundaries	

Name	Expression	Unit	Description	Selection	Details
			emissivity, upside	6–11	
rad.epsilon_ambd	1	1	Ambient emissivity, downside	Boundaries 6–11	
rad.epsilon_amb_band	0.5*((1+rad.opaque)*rad.epsilon_ambu_band+(1-rad.opaque)*rad.epsilon_ambd_band)	1	Ambient emissivity	Boundaries 6–11	
rad.epsilon_ambu_band	integrate(rad.epsilon_ambu,rad.lambda,0[m]*(1+0.25*eps),rad.lambdainf*(1-0.25*eps),1.0E-6)/max(rad.lambdainf*(1-0.25*eps)-0[m]*(1+0.25*eps),eps)	1	Ambient emissivity, upside	Boundaries 6–11	
rad.epsilon_ambd_band	integrate(rad.epsilon_ambd,rad.lambda,0[m]*(1+0.25*eps),rad.lambdainf*(1-0.25*eps),1.0E-6)/max(rad.lambdainf*(1-0.25*eps)-0[m]*(1+0.25*eps),eps)	1	Ambient emissivity, downside	Boundaries 6–11	

Shape functions

Name	Shape function	Unit	Description	Shape frame	Selection	Details
rad.dsurf1.Ju_band	Lagrange (Linear)	W/m²	Surface radiosity, upside	Spatial	Boundaries 6–11	
rad.dsurf1.Ju_band	Lagrange (Linear)	W/m²	Surface radiosity, upside	Spatial	Edges 9–20	Slit
rad.dsurf1.Jd_band	Lagrange (Linear)	W/m²	Surface radiosity, downside	Spatial	Boundaries 6–11	
rad.dsurf1.Jd_band	Lagrange (Linear)	W/m²	Surface radiosity, downside	Spatial	Edges 9–20	Slit

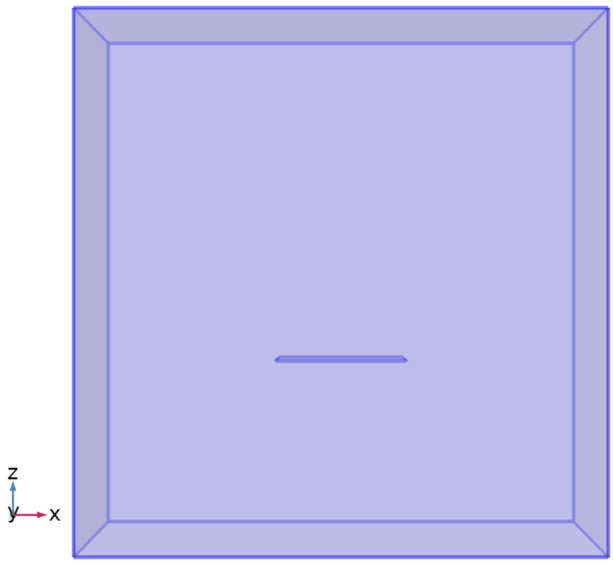
Weak Expressions

Weak expression	Integration order	Integration frame	Selection
((1-rad.epsilonu_band)*rad.Gradu+rad.epsilonu_band*rad.ebu-rad.Ju_band)*test(rad.Ju_band)	2	Spatial	Boundaries 6–11

Constraints

Constraint	Constraint force	Shape function	Selection	Details
-rad.Jd_band+rad.Ju_band	-test(rad.dsurf1.Jd_band)	Lagrange (Linear)	Boundaries 6–11	Elemental

2.4.4 initial value 1



initial value 1

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 2: All boundaries

EQUATIONS

$$J_{init} = \varepsilon e_b(T_{init}) + (1 - \varepsilon) e_b(T_{amb})$$

Initial Values

SETTINGS

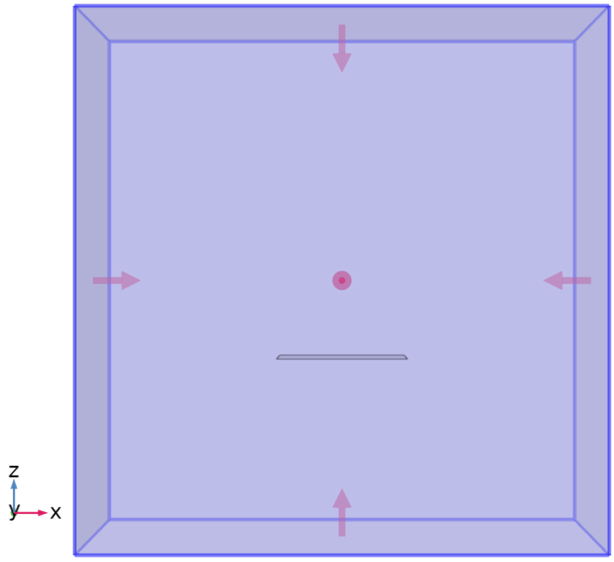
Description	Value	Unit
Initial value	Blackbody/Graybody	
Initial temperature	User defined	
Initial temperature	293.15	K

Variables

Name	Expression	Unit	Description	Selection	Details
rad.init1.Tinit	model.input.Tinit	K	Initial temperature	Boundaries 1–12	Meta
rad.Juinit	subst(rad.epsilonu_ban	W/m²	Initial surface	Boundaries	

Name	Expression	Unit	Description	Selection	Details
	d,rad.Tradu,rad.init1.Tinit,rad.Tradd,rad.init1.Tinit)*rad.nS2S^2*sigma_const*rad.init1.Tinit^4+(1-subst(rad.epsilonu_band,rad.Tradu,rad.Tambu,rad.Tradd,rad.Tambd))*rad.ebambu*rad.fepambu		radiosity	1–12	
rad.Jdinit	subst(rad.epsilond_band,rad.Tradd,rad.init1.Tinit,rad.Tradu,rad.init1.Tinit)*rad.nS2S^2*sigma_const*rad.init1.Tinit^4+(1-subst(rad.epsilond_band,rad.Tradd,rad.Tambd,rad.Tradu,rad.Tambu))*rad.ebambd*rad.fepambd	W/m²	Initial surface radiosity	Boundaries 1–12	
rad.init1.Tinit0	293.15	K	Default initial temperature	Boundaries 1–12	
rad.Tinit	rad.init1.Tinit0	K	Initial temperature	Boundaries 1–12	

2.4.5 diffuse reflective surface 2



diffuse reflective surface 2

SELECTION

Geometric entity level	Boundary
Name	Aluminum foil

Selection	Named geom1_csel1_bnd: Geometry geom1: Dimension 2: Boundaries 1–5, 12

EQUATIONS

$$J = \varepsilon e_b(T) + \rho_d G$$
$$\varepsilon + \rho_d = 1$$
$$G = G_m + G_{amb} + G_{ext}$$
$$G_{amb} = F_{amb} e_b(T_{amb})$$
$$G_{ext} = q_s$$
$$e_b(T) = n^2 \sigma T^4$$
$$q_{r,net} = \varepsilon(G - e_b(T))$$

Radiation Direction

SETTINGS

Description	Value
Emitted radiation direction	Negative normal direction

Ambient

SETTINGS

Description	Value	Unit
Define ambient temperature on each side	Off	
Ambient temperature	User defined	
Ambient temperature	293.15	K
Define ambient emissivity on each side	Off	
Ambient emissivity	Blackbody	
Include diffuse irradiance	Off	

Surface Emissivity

SETTINGS

Description	Value
Define properties on each side	Off
Emissivity	From material

Constraint Settings

SETTINGS

Description	Value
Use weak constraints	Off
Constraint method	Elemental

Model Input

SETTINGS

Description	Value	Unit
Temperature	User defined	

Description	Value	Unit
Temperature	293.15	K

PROPERTIES FROM MATERIAL

Property	Material	Property group
Surface emissivity	Aluminum	Basic

Variables

Name	Expression	Unit	Description	Selection	Details
rad.Tradu	rad.Trad	K	Upside temperature	Boundaries 1–5, 12	
rad.Tradd	rad.Trad	K	Downside temperature	Boundaries 1–5, 12	
rad.Tamb	293.15[K]	K	Ambient temperature	Boundaries 1–5, 12	
rad.Famb	rad.Fambd	1	Ambient view factor	Boundaries 1–5, 12	
rad.Gamb	rad.Gambd	W/m²	Ambient irradiation	Boundaries 1–5, 12	
rad.Gext	rad.Gextd	W/m²	External irradiation	Boundaries 1–5, 12	
rad.Gm	rad.Gmd	W/m²	Mutual surface irradiation	Boundaries 1–5, 12	
rad.Grad_band	rad.Gradd	W/m²	Surface irradiation	Boundaries 1–5, 12	
rad.Grad	rad.Grad_band	W/m²	Surface irradiation	Boundaries 1–5, 12	
rad.J	rad.J_band	W/m²	Surface radiosity	Boundaries 1–5, 12	
rad.J_band	rad.Jd_band	W/m²	Surface radiosity	Boundaries 1–5, 12	
rad.lambda	1	m	Wavelength	Boundaries 1–5, 12	
rad.q0s	rad.q0sd	W/m²	Source heat flux	Boundaries 1–5, 12	
rad.rflux	rad.rflux_band	W/m²	Radiative heat flux	Boundaries 1–5, 12	
rad.rflux_band	rad.rfluxu_band+rad.rfluxd_band	W/m²	Radiative heat flux	Boundaries 1–5, 12	
rad.zeta	1	1	Intermediate variable	Boundaries 1–5, 12	
rad.fep	rad.fepd	1	Fractional emissive power	Boundaries 1–5, 12	
rad.fepamb	rad.fepambd	1	Fractional emissive power	Boundaries 1–5, 12	
rad.fepdiff	rad.fepdiffd	1	Fractional emissive power	Boundaries 1–5, 12	

Name	Expression	Unit	Description	Selection	Details
rad.T_band	rad.Td_band	K	Temperature	Boundaries 1–5, 12	
rad.T	rad.T_band	K	Temperature	Boundaries 1–5, 12	
rad.Trad	rad.dsurf2.minput_temperature	K	Temperature	Boundaries 1–5, 12	
rad.Gm_gp	gpeval(2,rad.Gm)	W/m²	Mutual surface irradiation	Boundaries 1–5, 12	
rad.Gmu_gp	0	W/m²	Mutual surface irradiation, upside	Boundaries 1–5, 12	
rad.Gmd_gp	gpeval(2,rad.Gmd)	W/m²	Mutual surface irradiation, downside	Boundaries 1–5, 12	
rad.Famb_gp	gpeval(2,rad.Famb)	1	Ambient view factor, Gauss point evaluation	Boundaries 1–5, 12	
rad.Fambu_gp	0	1	Ambient view factor, Gauss point evaluation, upside	Boundaries 1–5, 12	
rad.Fambd_gp	gpeval(2,rad.Fambd)	1	Ambient view factor, Gauss point evaluation, downside	Boundaries 1–5, 12	
rad.diru	0	1	Radiation direction, upside	Boundaries 1–5, 12	
rad.ebu	rad.nS2S^2*sigma_const*rad.Tu_band^4*rad.fepu	W/m²	Blackbody emissive power, upside	Boundaries 1–5, 12	
rad.ebambu	rad.nS2S^2*sigma_const*rad.Tambu^4*rad.fepambu	W/m²	Blackbody emissive power, upside	Boundaries 1–5, 12	
rad.fepu	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zeta,eps,eps,1.0E-6)/pi^4	1	Fractional emissive power, upside	Boundaries 1–5, 12	
rad.fepambu	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zeta,eps,eps,1.0E-6)/pi^4	1	Fractional emissive power, upside	Boundaries 1–5, 12	
rad.fepdiffu	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zeta,eps,eps,1.0E-6)/pi^4	1	Fractional emissive power, upside	Boundaries 1–5, 12	
rad.Tu_band	0.5*((1+rad.opaque)	K	Upside	Boundaries	

Name	Expression	Unit	Description	Selection	Details
	*rad.Tradu+(1-rad.opaque)*rad.Tradd)		temperature	1–5, 12	
rad.Gambu	rad.Fambu*rad.epsilon_ambu_band*rad.ebambu	W/m²	Ambient irradiation, upside	Boundaries 1–5, 12	
rad.Gextu	rad.q0su	W/m²	External irradiation, upside	Boundaries 1–5, 12	+ operation
rad.Gradu	nojac(rad.Gmu+rad.Gambu+rad.Gextu)	W/m²	Surface irradiation, upside	Boundaries 1–5, 12	
rad.Ju	rad.Ju_band	W/m²	Surface radiosity, upside	Boundaries 1–5, 12	
rad.Ju_band	rad.dsurf2.Ju_band	W/m²	Surface radiosity, upside	Boundaries 1–5, 12	
rad.rfluxu	rad.rfluxu_band	W/m²	Radiative heat flux, upside	Boundaries 1–5, 12	
rad.rfluxu_band	0	W/m²	Radiative heat flux, upside	Boundaries 1–5, 12	
rad.Idiff	0	W/m²	Diffuse irradiance	Boundaries 1–5, 12	
rad.Idiff_band	rad.Idiffd_band	W/m²	Diffuse irradiance	Boundaries 1–5, 12	
rad.Idiffu_band	0	W/m²	Diffuse irradiance, upside	Boundaries 1–5, 12	
rad.Idiffd_band	0	W/m²	Diffuse irradiance, downside	Boundaries 1–5, 12	
rad.Tambu	rad.Tamb	K	Ambient temperature, upside	Boundaries 1–5, 12	
rad.dird	-1	1	Radiation direction, downside	Boundaries 1–5, 12	
rad.ebd	rad.nS2S^2*sigma_const*rad.Td_band^4*rad.fepd	W/m²	Blackbody emissive power, downside	Boundaries 1–5, 12	
rad.ebambd	rad.nS2S^2*sigma_const*rad.Tambd^4*rad.fepambd	W/m²	Blackbody emissive power, downside	Boundaries 1–5, 12	
rad.fepd	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zeta,eps,eps,1.0E-6)/pi^4	1	Fractional emissive power, downside	Boundaries 1–5, 12	
rad.fepambd	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zet	1	Fractional emissive power,	Boundaries 1–5, 12	

Name	Expression	Unit	Description	Selection	Details
	a,eps,eps,1.0E-6)/pi^4		downside		
rad.fepdiffd	1+15*integrate(rad.zeta^3/(1-exp(rad.zeta)),rad.zeta,eps,eps,1.0E-6)/pi^4	1	Fractional emissive power, downside	Boundaries 1–5, 12	
rad.Td_band	0.5*((1+rad.opaque)*rad.Tradd+(1-rad.opaque)*rad.Tradu)	K	Downside temperature	Boundaries 1–5, 12	
rad.Gambd	rad.Fambd*rad.epsilon_ambd_band*rad.ebambd	W/m²	Ambient irradiation, downside	Boundaries 1–5, 12	
rad.Gextd	rad.q0sd	W/m²	External irradiation, downside	Boundaries 1–5, 12	+ operation
rad.Gradd	nojac(rad.Gmd+rad.Gambd+rad.Gextd)	W/m²	Surface irradiation, downside	Boundaries 1–5, 12	
rad.Jd	rad.Jd_band	W/m²	Surface radiosity, downside	Boundaries 1–5, 12	
rad.Jd_band	rad.dsurf2.Jd_band	W/m²	Surface radiosity, downside	Boundaries 1–5, 12	
rad.rfluxd	rad.rfluxd_band	W/m²	Radiative heat flux, downside	Boundaries 1–5, 12	
rad.rfluxd_band	rad.epsilond_band*(rad.Gradd-rad.ebd)	W/m²	Radiative heat flux, downside	Boundaries 1–5, 12	
rad.Tambd	rad.Tamb	K	Ambient temperature, downside	Boundaries 1–5, 12	
rad.epsilon	rad.epsilon_band	1	Emissivity	Boundaries 1–5, 12	
rad.epsilonu	subst(material.epsilon_rad,rad.dsurf2.minput_temperature,rad.Tradu,rad.dsurf2.minput_length,rad.lambda)	1	Emissivity, upside	Boundaries 1–5, 12	Meta
rad.epsilond	subst(material.epsilon_rad,rad.dsurf2.minput_temperature,rad.Tradd,rad.dsurf2.minput_length,rad.lambda)	1	Emissivity, downside	Boundaries 1–5, 12	Meta
rad.epsilon_band	0.5*((1+rad.opaque)*rad.epsilond_band+(1-rad.opaque)*rad.epsilonu_band)	1	Emissivity	Boundaries 1–5, 12	

Name	Expression	Unit	Description	Selection	Details
rad.epsilonu_band	integrate(rad.epsilonu,rad.lambda,0[m]*(1+0.25*eps),rad.lambdainf*(1-0.25*eps),1.0E-6)/max(rad.lambdainf*(1-0.25*eps)-0[m]*(1+0.25*eps),eps)	1	Emissivity, upside	Boundaries 1–5, 12	
rad.epsilond_band	integrate(rad.epsilond,rad.lambda,0[m]*(1+0.25*eps),rad.lambdainf*(1-0.25*eps),1.0E-6)/max(rad.lambdainf*(1-0.25*eps)-0[m]*(1+0.25*eps),eps)	1	Emissivity, downside	Boundaries 1–5, 12	
rad.epsilon_amb	rad.epsilon_amb_band	1	Ambient emissivity	Boundaries 1–5, 12	
rad.epsilon_ambu	1	1	Ambient emissivity, upside	Boundaries 1–5, 12	
rad.epsilon_ambd	1	1	Ambient emissivity, downside	Boundaries 1–5, 12	
rad.epsilon_amb_band	0.5*((1+rad.opaque)*rad.epsilon_ambd_band+(1-rad.opaque)*rad.epsilon_ambu_band)	1	Ambient emissivity	Boundaries 1–5, 12	
rad.epsilon_ambu_band	integrate(rad.epsilon_ambu,rad.lambda,0[m]*(1+0.25*eps),rad.lambdainf*(1-0.25*eps),1.0E-6)/max(rad.lambdainf*(1-0.25*eps)-0[m]*(1+0.25*eps),eps)	1	Ambient emissivity, upside	Boundaries 1–5, 12	
rad.epsilon_ambd_band	integrate(rad.epsilon_ambd,rad.lambda,0[m]*(1+0.25*eps),rad.lambdainf*(1-0.25*eps),1.0E-6)/max(rad.lambdainf*(1-0.25*eps)-0[m]*(1+0.25*eps),eps)	1	Ambient emissivity, downside	Boundaries 1–5, 12	

Shape functions

Name	Shape function	Unit	Description	Shape frame	Selection	Details
rad.dsurf2.Ju_band	Lagrange (Linear)	W/m²	Surface radiosity, upside	Spatial	Boundaries 1–5, 12	
rad.dsurf2.Ju_band	Lagrange (Linear)	W/m²	Surface radiosity, upside	Spatial	Edges 1–8, 21–24	Slit
rad.dsurf2.Jd_band	Lagrange (Linear)	W/m²	Surface radiosity, downside	Spatial	Boundaries 1–5, 12	
rad.dsurf2.Jd_band	Lagrange (Linear)	W/m²	Surface radiosity, downside	Spatial	Edges 1–8, 21–24	Slit

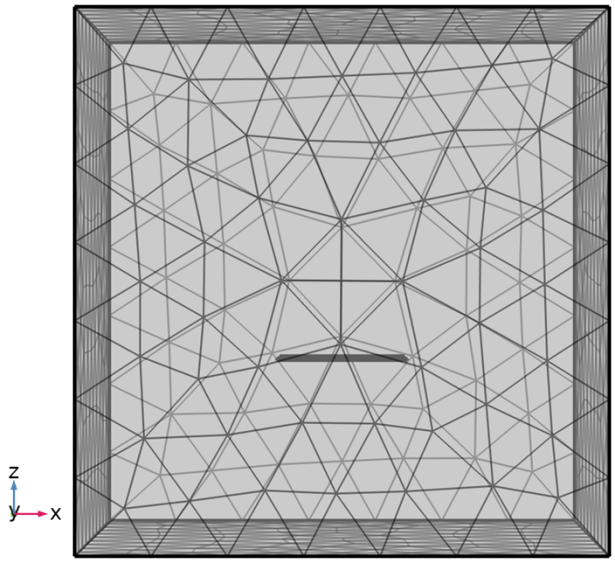
Weak Expressions

Weak expression	Integration order	Integration frame	Selection
((1-rad.epsilond_band)*rad.Gradd+rad.epsilond_band*rad.ebd-rad.Jd_band)*test(rad.Jd_band)	2	Spatial	Boundaries 1–5, 12

Constraints

Constraint	Constraint force	Shape function	Selection	Details
rad.Ju_band-rad.Jd_band	test(rad.dsurf2.Ju_band)	Lagrange (Linear)	Boundaries 1–5, 12	Elemental

2.5 GRID 1



grid 1

MESH STATISTICS

Description	Value
Status	Complete mesh
Mesh vertices	974
Triangles	1940
Edge elements	296
Vertex elements	16
Number of elements	1940
Minimum element quality	0.01801
Average element quality	0.7649
Element area ratio	2.7947E-5
Mesh face area	0.3211 m²

2.5.1 size

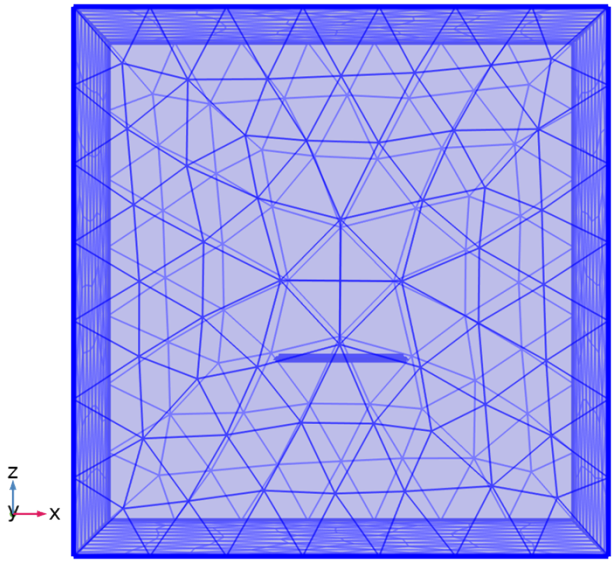
SETTINGS

Description	Value
Maximum element size	0.0295
Minimum element size	0.00531
Curvature factor	0.6
Resolution of narrow regions	0.5
Maximum element growth rate	1.5

2.5.2 (ftri1)

SELECTION

Geometric entity level	Boundary
Selection	Geometry geom1: Dimension 2: Boundaries 1–12



ftri1

SETTINGS

Description	Value
Last build time	0
Built with	COMSOL 6.1.0.252 (win64)|2023 - 09 - 13T15:40:57.196446700

3 study 1

COMPUTATION INFORMATION

Computation time	

3.1 STEADY STATE

STUDY SETTINGS

Description	Value
Include geometric nonlinearity	Off

PHYSICS AND VARIABLES SELECTION

Physics interface	Discretization
Surface-to-surface radiation (rad)	physics

MESH SELECTION

Geometry	Mesh
geom1	mesh1

3.2 SOLVER CONFIGURATIONS

3.2.1 solution 1

Compile Equations: Steady state (st1)

STUDY AND STEP

Description	Value
Use study	Study 1
Use study step	Steady state

LOG

<---- Study on “Compiler equation: steady state” in 1/solution 1(SOL1)” ----------
It started at 3:40:59 p.m. on September 13,2009, at the 2023.
Geometric functions: linear Joseph-Louis Lagrange elements.
Run on an Intel (R) Core (TM) i5-5200U CPU at 2.20 GHz.
Use 1 slot in the following location: win-m7 VEOE2JIB2(2 kernels total).
Available memory: 16.28 GB.
Time: 2.
Physical memory: 1.37 GB
Virtual memory: 1.43 GB
End 2023: September 13,3:41 p.m.
----- Study on “ Compiler equation: steady state” in 1/solution 1(SOL1)” ---------->

Dependent variable 1 (v1)

GENERAL

Description	Value
Defined by study step	Steady state

LOG

<---- Study the dependent variable 1 in 1/solution 1(SOL1)" ----------
It began at 3:41:01 p.m. on September 13,2009, at the 2023.
Solve time：0 s.
Physical memory: 1.37 GB
Virtual memory: 1.43 GB
End 2023: September 13,3:41 p.m.
----- Study "Dependent variable 1" in 1/solution 1(SOL1)" ---------->

Surface Radiance, lower side (comp1.rad.dsurf1.Jd_band) (comp1_rad_dsurf1_Jd_band)

GENERAL

Description	Value
Field components	comp1.rad.dsurf1.Jd_band

SCALING

Description	Value
Method	Initial value based

Surface Radiance, upper side (comp1.rad.dsurf1.Ju_band) (comp1_rad_dsurf1_Ju_band)

GENERAL

Description	Value
Field components	comp1.rad.dsurf1.Ju_band

SCALING

Description	Value
Method	Initial value based

Surface Radiance, lower side (comp1.rad.dsurf2.Jd_band) (comp1_rad_dsurf2_Jd_band)

GENERAL

Description	Value
Field components	comp1.rad.dsurf2.Jd_band

SCALING

Description	Value
Method	Initial value based

Surface Radiance, upper side (comp1.rad.dsurf2.Ju_band) (comp1_rad_dsurf2_Ju_band)

GENERAL

Description	Value
Field components	comp1.rad.dsurf2.Ju_band

SCALING

Description	Value
Method	Initial value based

Steady State Solver 1 (s1)

GENERAL

Description	Value
Defined by study step	Steady state

Separation 1 (se1)

GENERAL

Description	Value
Tolerance factor	0.1
Stabilization and acceleration	Anderson acceleration

Radiation (ss1)

GENERAL

Description	Value
Variables	{Surface Radiance, upper side (comp1.rad.dsurf1.Ju_band), Surface Radiance, lower side (comp1.rad.dsurf1.Jd_band), Surface Radiance, upper side (comp1.rad.dsurf2.Ju_band), Surface Radiance, lower side (comp1.rad.dsurf2.Jd_band)}
Linear solver	Direct radiation variable

METHOD AND TERMINATION

Description	Value
Damping factor	0.8

Direct radiation variable (d1)

GENERAL

Description	Value
Solver	PARDISO
Pivoting perturbation	1E-13

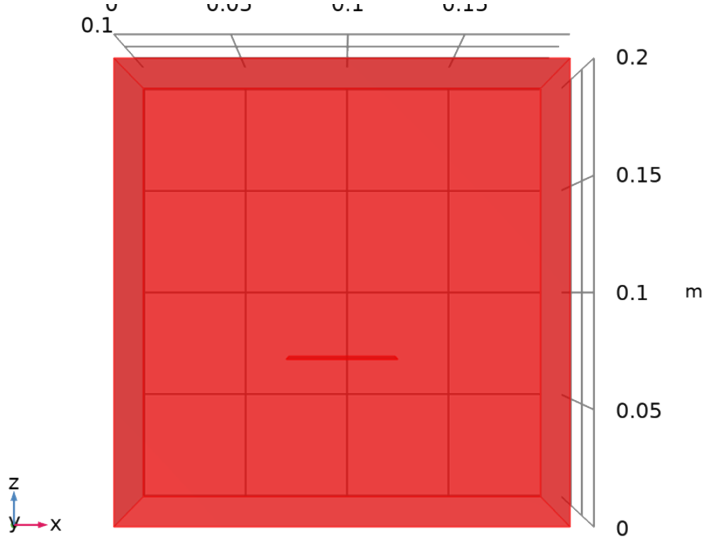
4 results

4.1 DATA SET

4.1.1 study 1/solution 1

SOLUTION

Description	Value
Solution	Solution 1
Component	comp1



Dataset: *Study 1/Solution 1*

4.2 DERIVED VALUES

4.2.1 global calculation 1

OUTPUT

Evaluated in	Form 1

DATA

Description	Value
Dataset	Study 1/Solution 1

EXPRESSIONS

Expression	Unit	Description
intop_int(comp1.rad.radopu(int,0))/intop_int(1)		Inside to inside
intop_ext(comp1.rad.radopd(int,0))/intop_int(1)		Inside to outside
intop_ext(comp1.rad.radopd(0,ext))/intop_ext(1)		Outside to outside
intop_int(comp1.rad.radopu(0,ext))/intop_ext(1)		Outside to inside

4.3 FORM

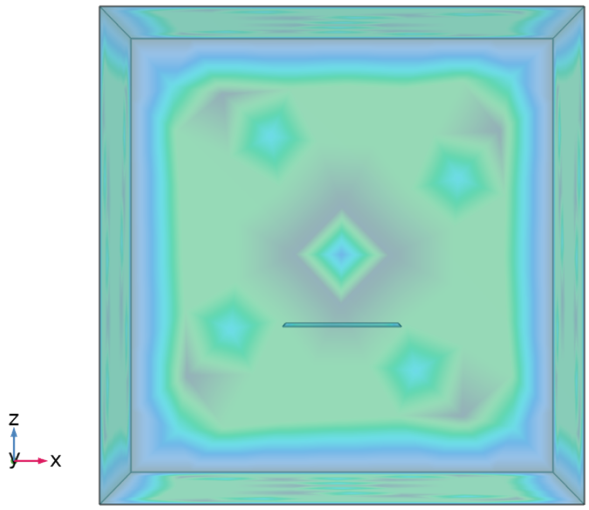
4.3.1 Form 1

Global Calculation 1

Time	Inside to inside	Inside to outside	Outside to outside	Outside to inside
0	0	0.90245	0.96775	0.032246

4.4 PLOT GROUPS

4.4.1 surface radiance (rad)



Surface Slit: Surface Radiance, upper side (W/m2) Surface Radiance, lower side (W/m²)