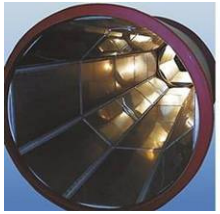
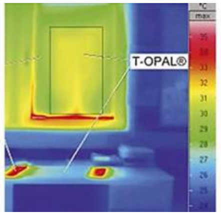


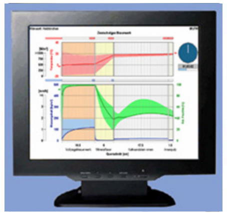
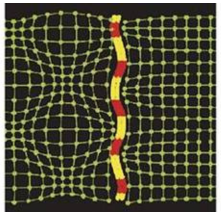


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Radiation Effects On Exterior Surfaces

Manfred Kehrer

IBP
Fraunhofer Institut Bauphysik

Content:

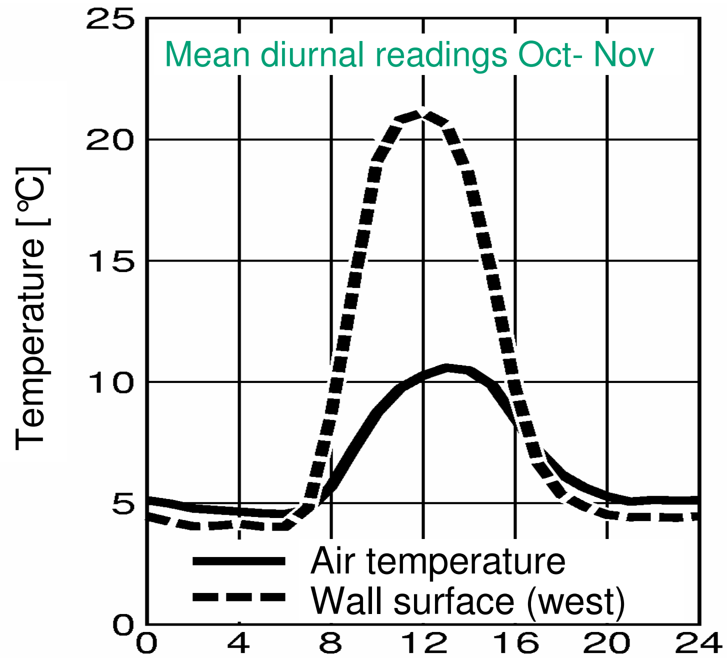
Fraunhofer Institut Bauphysik

Radiation Effects on Exterior Surfaces

Radiation: energy source and sink

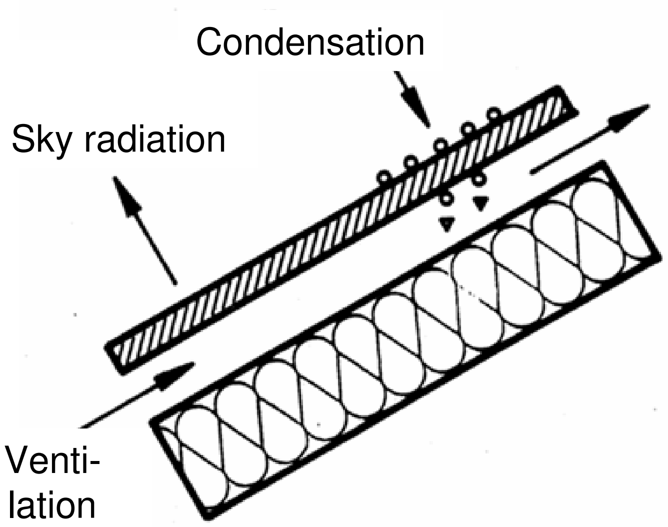
The exterior surface temperature of a building envelope component depends on:

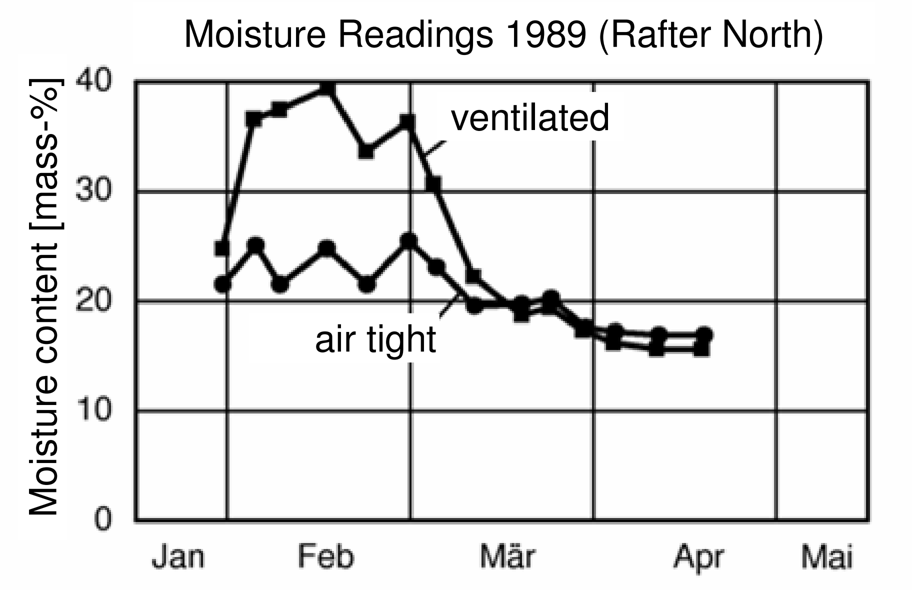
- ambient air temperature and surface transfer
- absorption of short-wave radiation from the sun
- emission/absorption of long-wave radiation

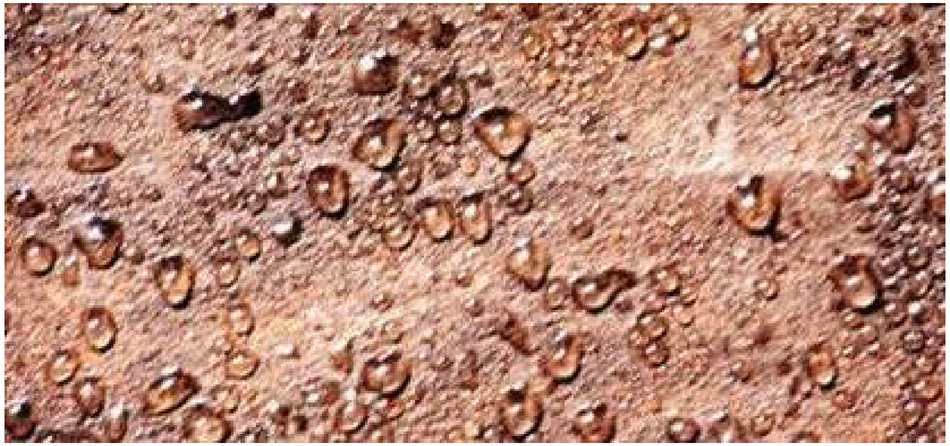


Radiation Effects on Exterior Surfaces

Condensation in ventilation planes







Radiation Effects on Exterior Surfaces

Result: Condensation yields to Mould and Algee Growth on Exterior Surfaces.

No Insulation EIFS

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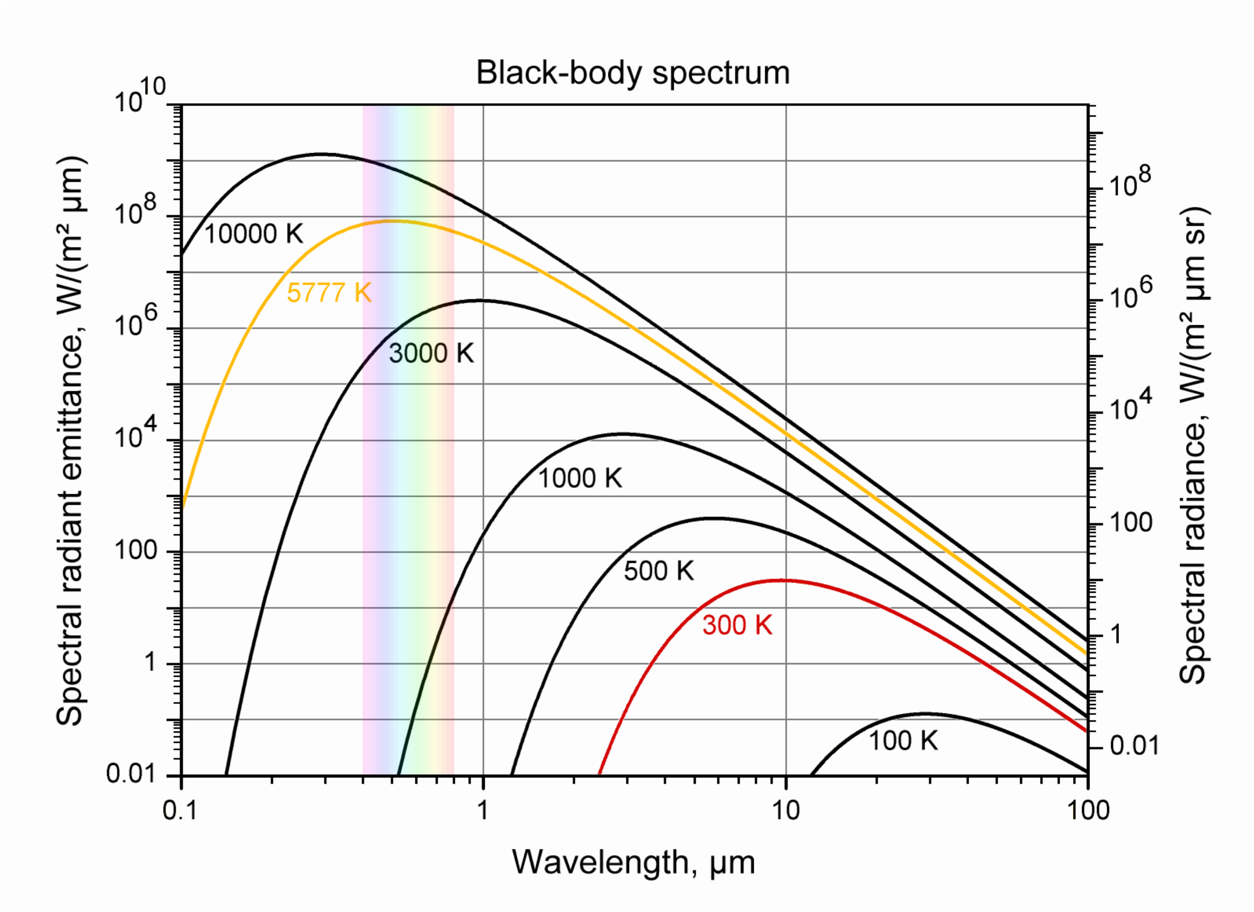
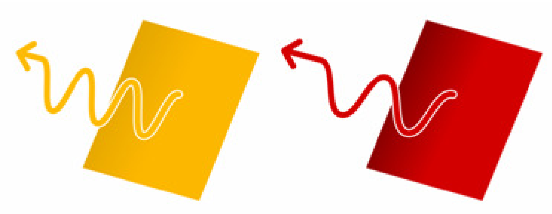
Radiation Effects on Exterior Surfaces

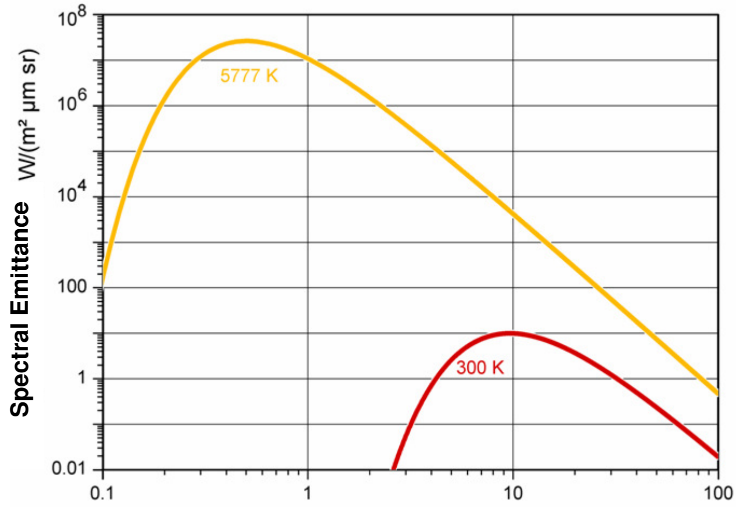
Every body has an radiant emittance according to the law from Max Planck,depending on Temperature and Wave Length.



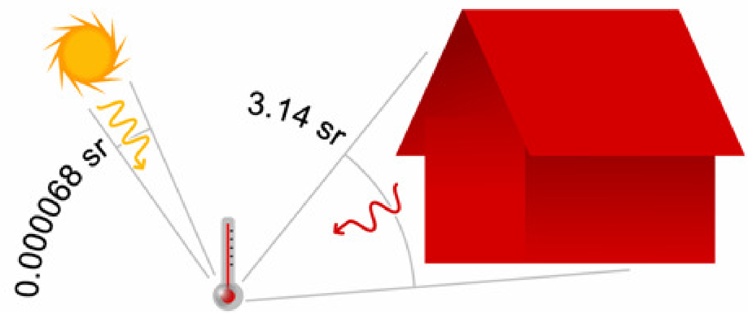
Radiation Effects on Exterior Surfaces

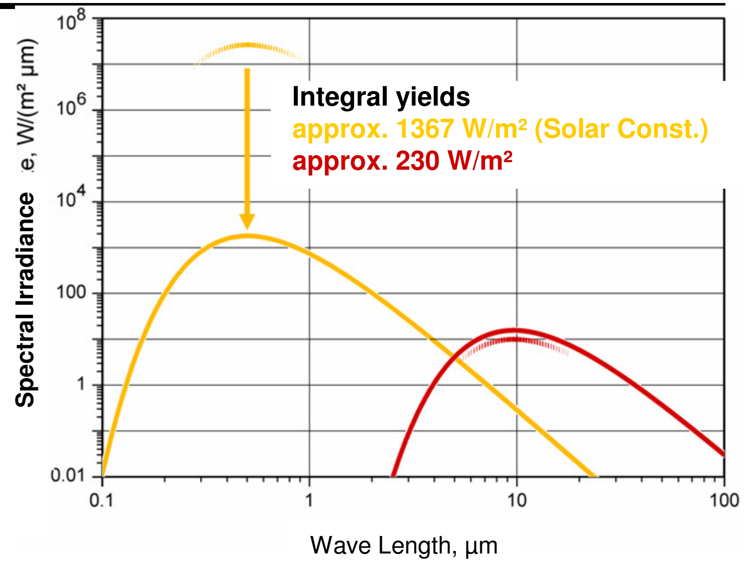
Emittance of a Surface





Radiation to a Recipient Surface (Irradiance)

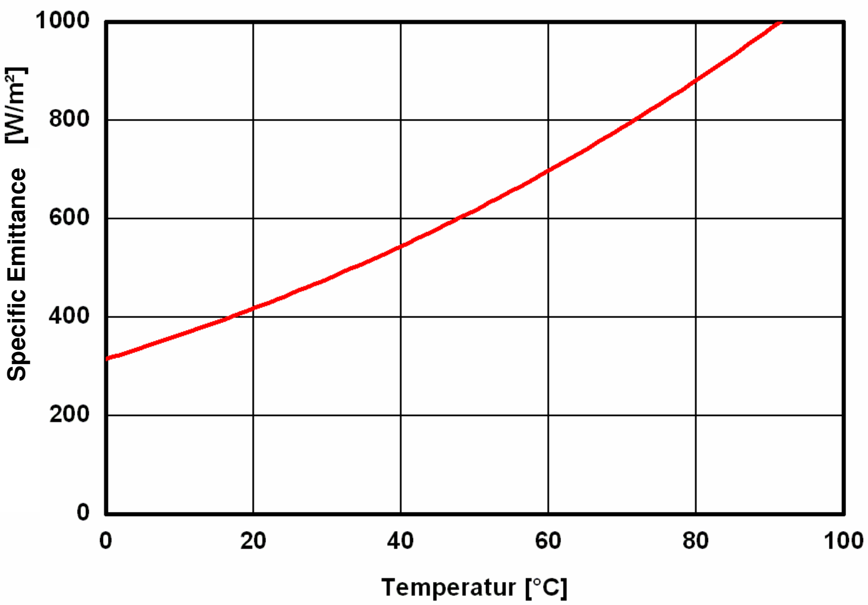




Radiation Effects on Exterior Surfaces

Integration of the Planck Law over all Wave Length over the half space yields to the Specific Emittance of a black body according to Stefan-Boltzmann-Law.

$$M_e = \sigma \cdot T^4$$



M_e : Specific Emittance $\left[\frac{W}{m^2}\right]$

σ : Stefan – Boltzmann – Constant; $5{,}67 \cdot 10^{-8} \frac{W}{m^2 K^4}$

T : absolute Temperature [K]

For Gray Radiators gilt:

$$M_e = \varepsilon \cdot \sigma \cdot T^4$$

ε : Emissivity $[-]$

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Radiation Effects on Exterior Surfaces

Example for the Emittance:

A Human Being has the follwing Properties:

Mass: 80 kg (basicaly Water)
Surface: 1,8 m²
Surface Temperature: 34 °C

The Emittance of about 900 W yields to a body temperature 25 °C in 1 hour and this Human Being will die.

To avoid this he must eat 17000 kcal a day.

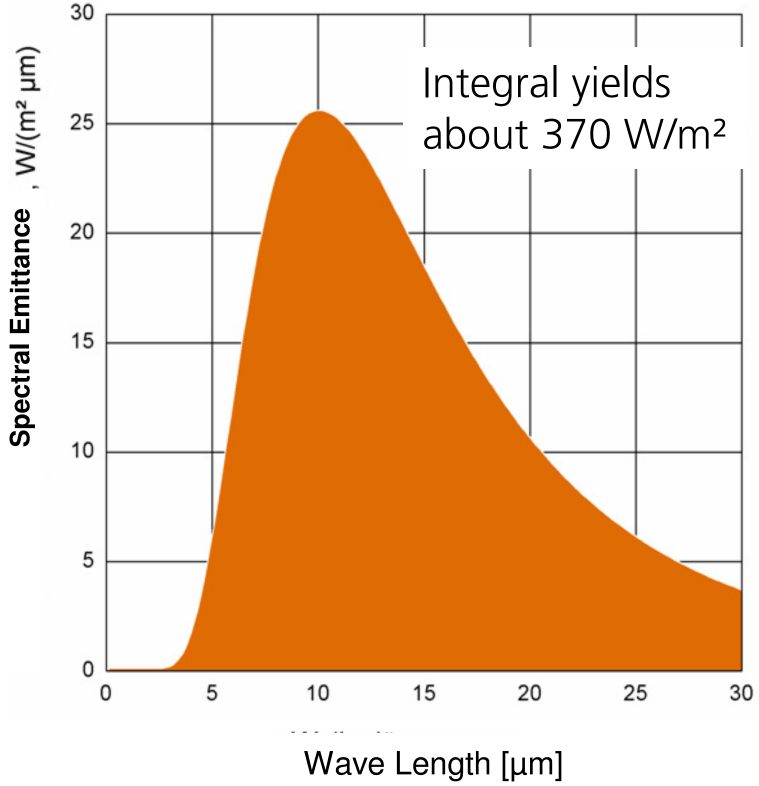
Where is the fault ?

This Human Being has not only an Emittance of 900 W, he does also absorb the Irradiation of the surrounding Environment (about. 750 W at 20°C).

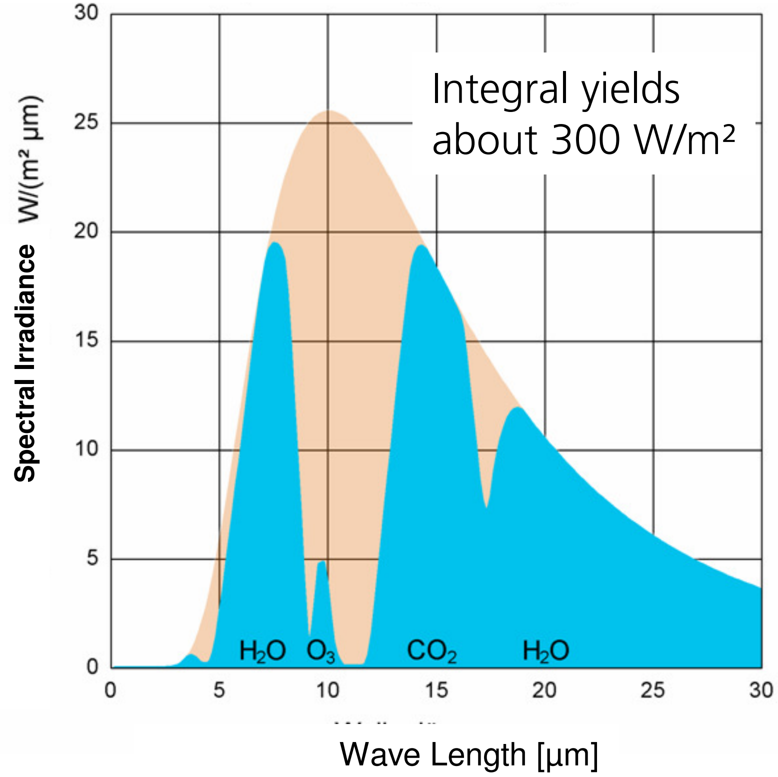
Radiation Effects on Exterior Surfaces

The Atmosphere is not a solid body and has another Radiation Behavior.

Emittance of the Ground at 15℃



Irradiance from the Atmosphere at 15℃



Difference (about. 70 W/m²) ist the reason for night-time overcooling.

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Radiation Effects on Exterior Surfaces

How is long-wave Radiation typically taken into account?

- German Standard DIN EN ISO 6946: Bauteile – Wärmedurchlasswiderstand und Wärmedurchgangskoeffizient - Berechnungsverfahren

$$R_s = \frac{1}{h_c + h_r}$$

R_s: Heat Transfer Resistance [m²K/W]
h_c: Heat Transfer Coefficient, Convection [W/m²K]
h_r: Heat Transfer Coefficient, long-wave Radiation [W/m²K]

$$q = \frac{1}{R_s} \cdot \Delta T$$

q : Heat Flux [W/m²]
ΔT : Temperature Difference Surface - Air [K]

- Consequence: Surface Temperature can not sink below Air Temperature.

- Conclusion: This Method is applicable for thermal long term calculation. It is not applicable to model real physical processes on Exterior Surfaces.

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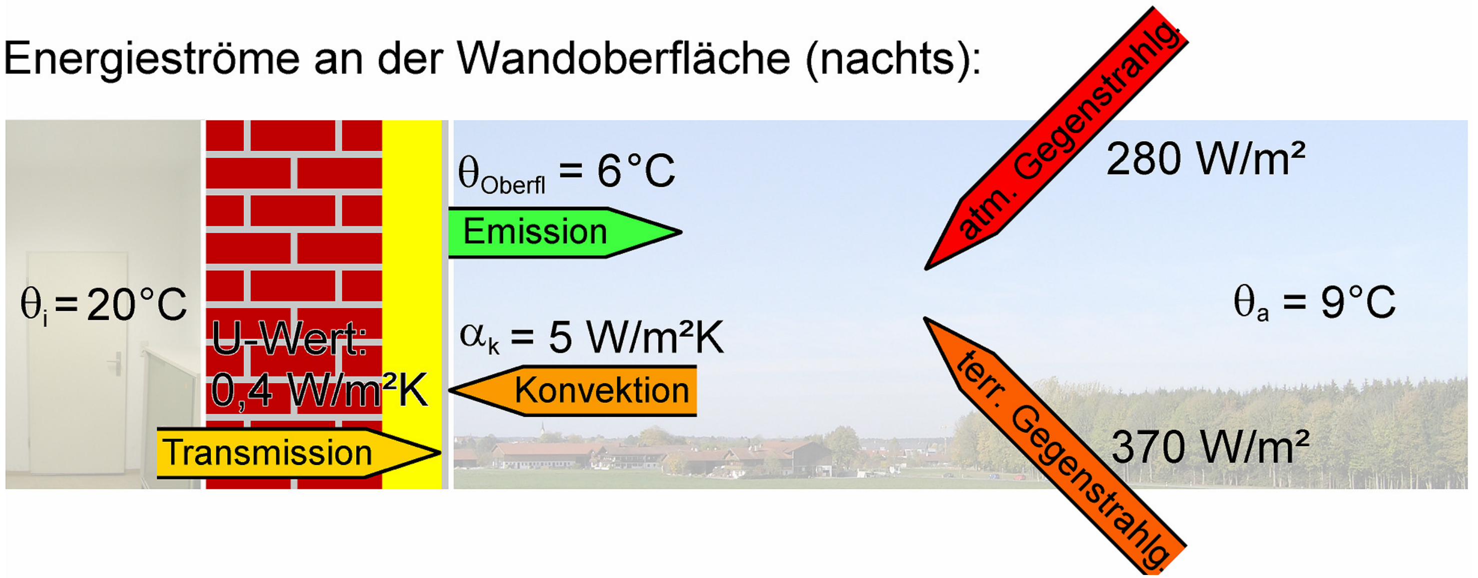
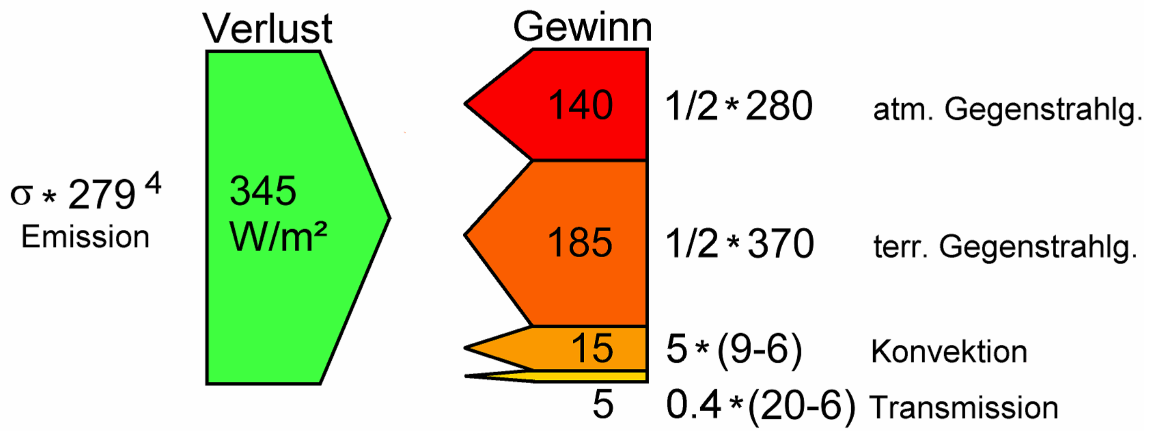
Radiation Effects on Exterior Surfaces

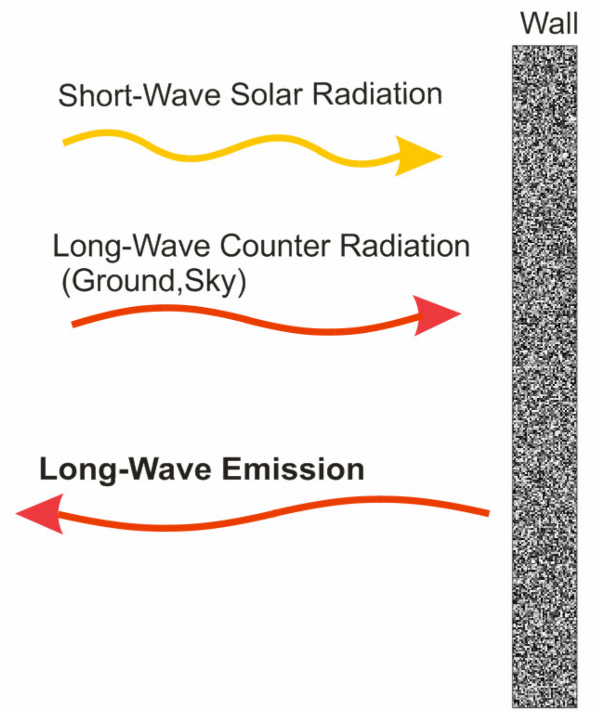
Energieströme an der Wandoberfläche (nachts):



Nächtliche Energiebilanz an der Wandoberfläche:



Radiation Effects on Exterior Surfaces



Radiation Model in WUFI® 4.1

Explicit Radiation Balance at Exterior Surfaces

$$I = a \cdot I_s + \epsilon \cdot I_l - I_e$$

I	$[W/m^2]$	balanced net radiation at the component's surface
a	$[-]$	short-wave absortion coefficient of the component's surface
I_s	$[W/m^2]$	normal short-wave solar radiation incident onto the component's surface
ϵ	$[-]$	long-wave emission coefficient (=absorption coefficient) of the component's surface
I_l	$[W/m^2]$	normal long-wave radiation incident onto the component's surface
I_e	$[W/m^2]$	long-wave emission radiation of the component's surface

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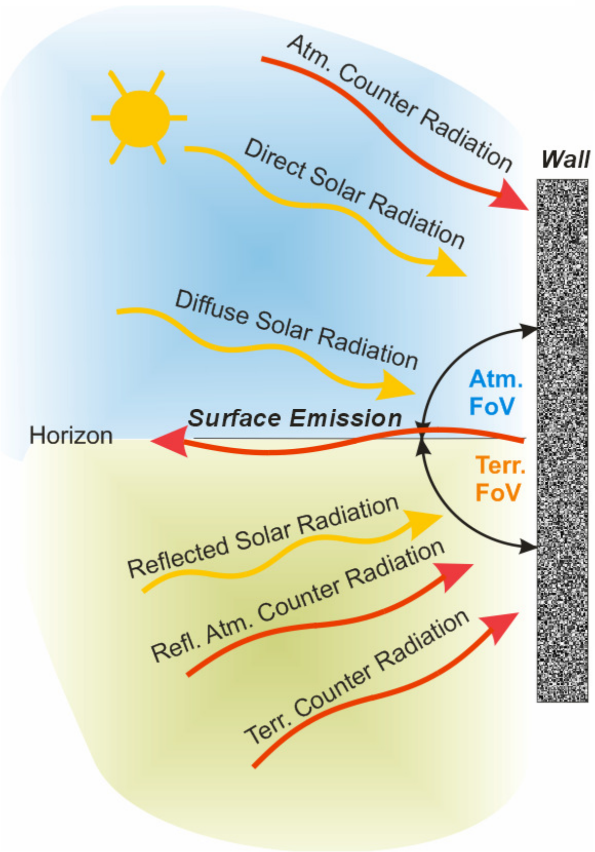
Radiation Effects on Exterior Surfaces

Further Splitting yields 7 Radiation Parts



$$I_s = I_{s,\,dir.} + g_{atm.} \cdot I_{s,\,diff.} + g_{terr.} \cdot I_{s,\,refl.}$$

$I_{s,\,dir.}$	$[W/m^2]$	direct solar radiation
$g_{atm.}$	$[-]$	atmospheric field of view factor
$I_{s,\,diff.}$	$[W/m^2]$	diffuse solar radiation
$g_{terr.}$	$[-]$	terrestrial field of view factor
$I_{s,\,refl.}$	$[W/m^2]$	solar radiation reflected by the ground

$$I_l = g_{atm.} \cdot I_{l,\,atm.} + g_{terr.} \cdot (I_{l,\,terr.} + I_{l,\,refl.})$$

$I_{l,\,atm.}$	$[W/m^2]$	atmospheric long-wave counter radiation
$I_{l,\,terr.}$	$[W/m^2]$	terrestrial long-wave counter radiation
$I_{l,\,refl.}$	$[W/m^2]$	atmospheric long-wave counter radiation reflected by the ground

$$I_e = \epsilon \cdot \sigma \cdot T_{sur}^4$$

σ	$[W/m^2K^4]$	Stefan-Boltzmann-Constant, $5,67 \cdot 10^{-8}$
T_{sur}	$[K]$	temperature of the component's surface

Radiation Effects on Exterior Surfaces

If your meteorological data-set does not include atm. counter radiation but cloud cover N, WUFI will use the following empirical equations:

$$I_{l,\,atm} = N \cdot I_{cloud} + (1-N) \cdot I_{air}$$

$$I_{air} = \sigma \cdot T^4 \,(0.79 - 0.174 \cdot 10^{\,-0.041 \cdot p})$$

T: air temperature at station [K]

p: vapor pressure at station [hPa]

$$I_{cloud} = \sigma \cdot T^4_D$$

T_D: = Dewpoint temp. at station

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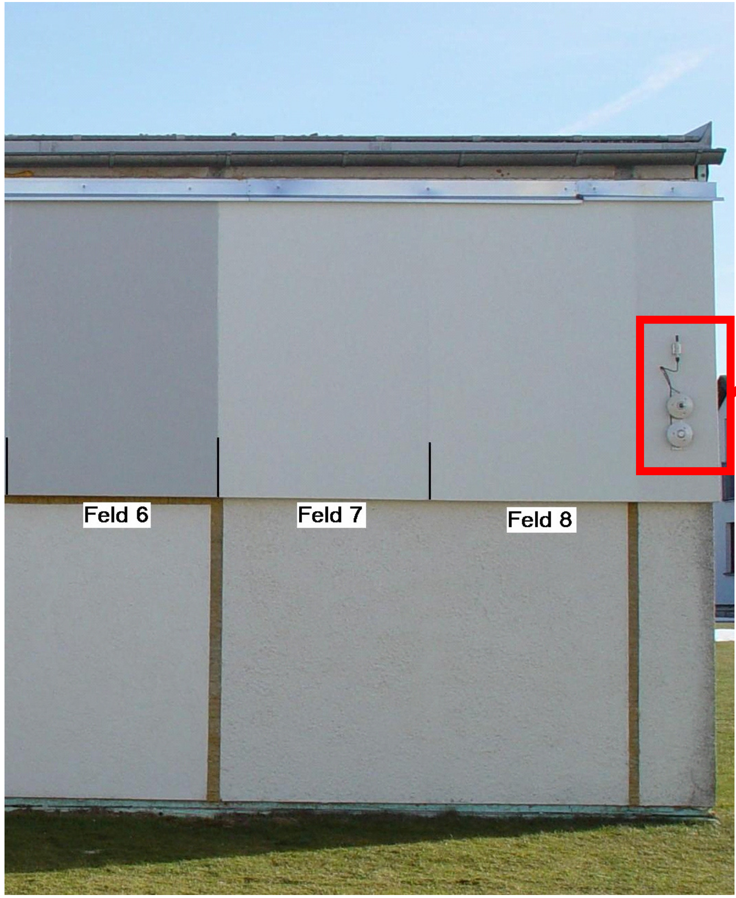
Radiation Effects on Exterior Surfaces

Validation of the Radiation Model



Solarimeter

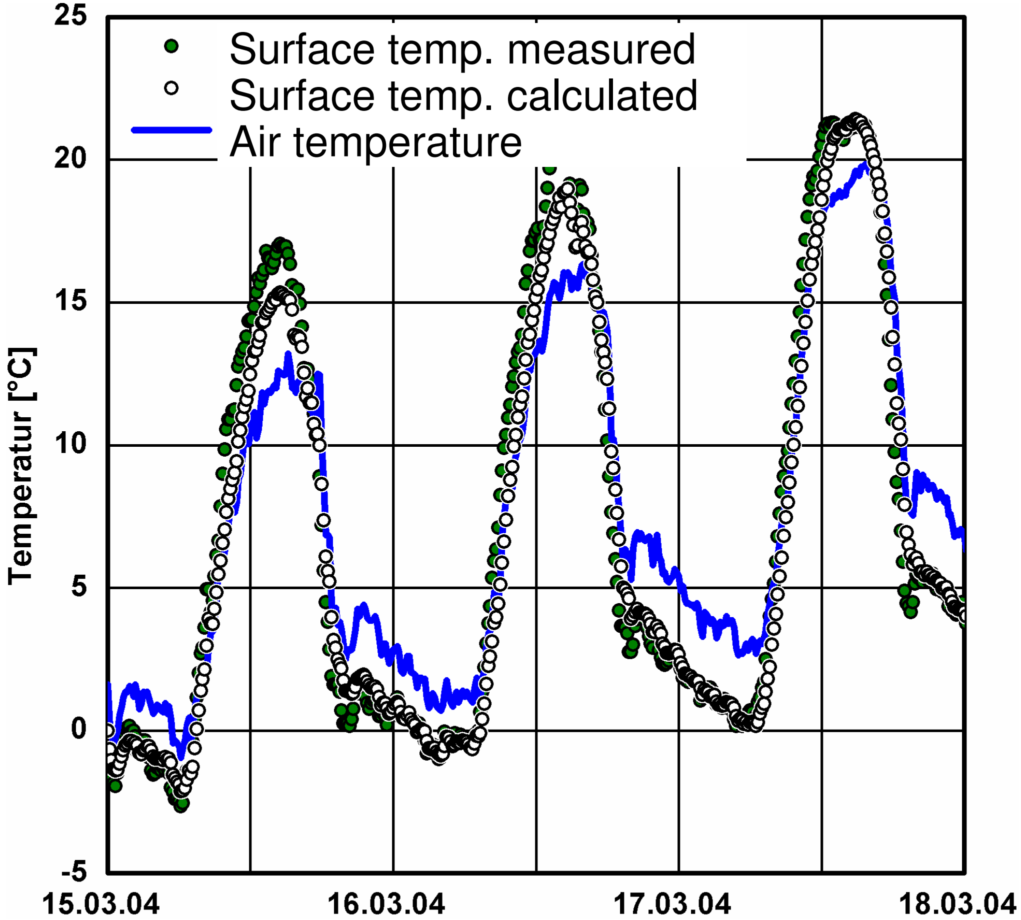
(short-wave range 0.3 – 2.8 µm)

Pyrgeometer

(long-wave range 5 – 25 µm)

- Brick wall EIFS (10 cm EPS; 5 mm Plaster)
- Oriented to the North.
- Measurement of long-wave and short-wave radiation and Surface Temperature
- Measurement of Temparature and RH of the Air.
- Measurment short-wave Absorptivity (a_{short}=0,39) and long-wave Emissivity (ε_{long}=0,96) of the Surface at IBP laboratory.

Comparison of measured and calculated Surface Temperature



Note: Without „Explicit Radiation Balance“ the Surface Temperature will remain beyond Air Temperature !!!

But: Conversion to walls or inclined Surfaces is not validated here

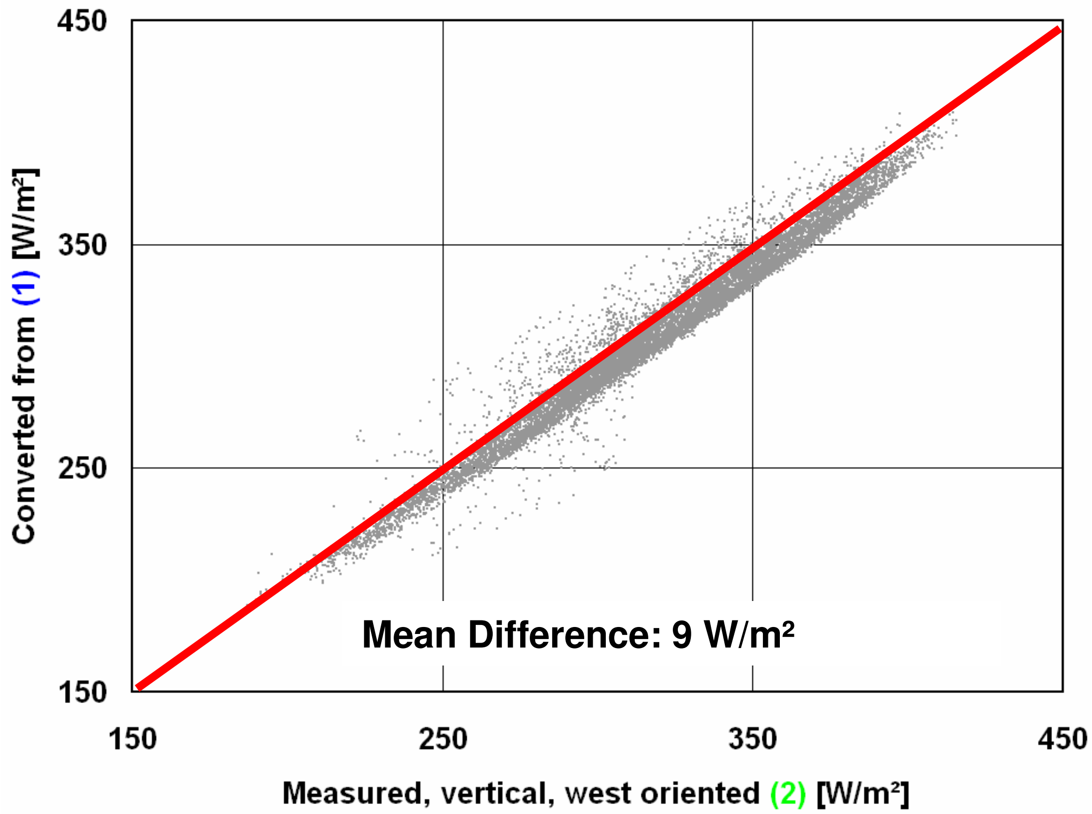
Radiation Effects on Exterior Surfaces

Validation of Conversion to inclined Surfaces

(1) Measurement of the Long-Wave Radiation to the Horizontal at IBP
(2) Measurement of the Long-Wave Radiation to a west oriented vertical Surface at IBP

(1)

(2)



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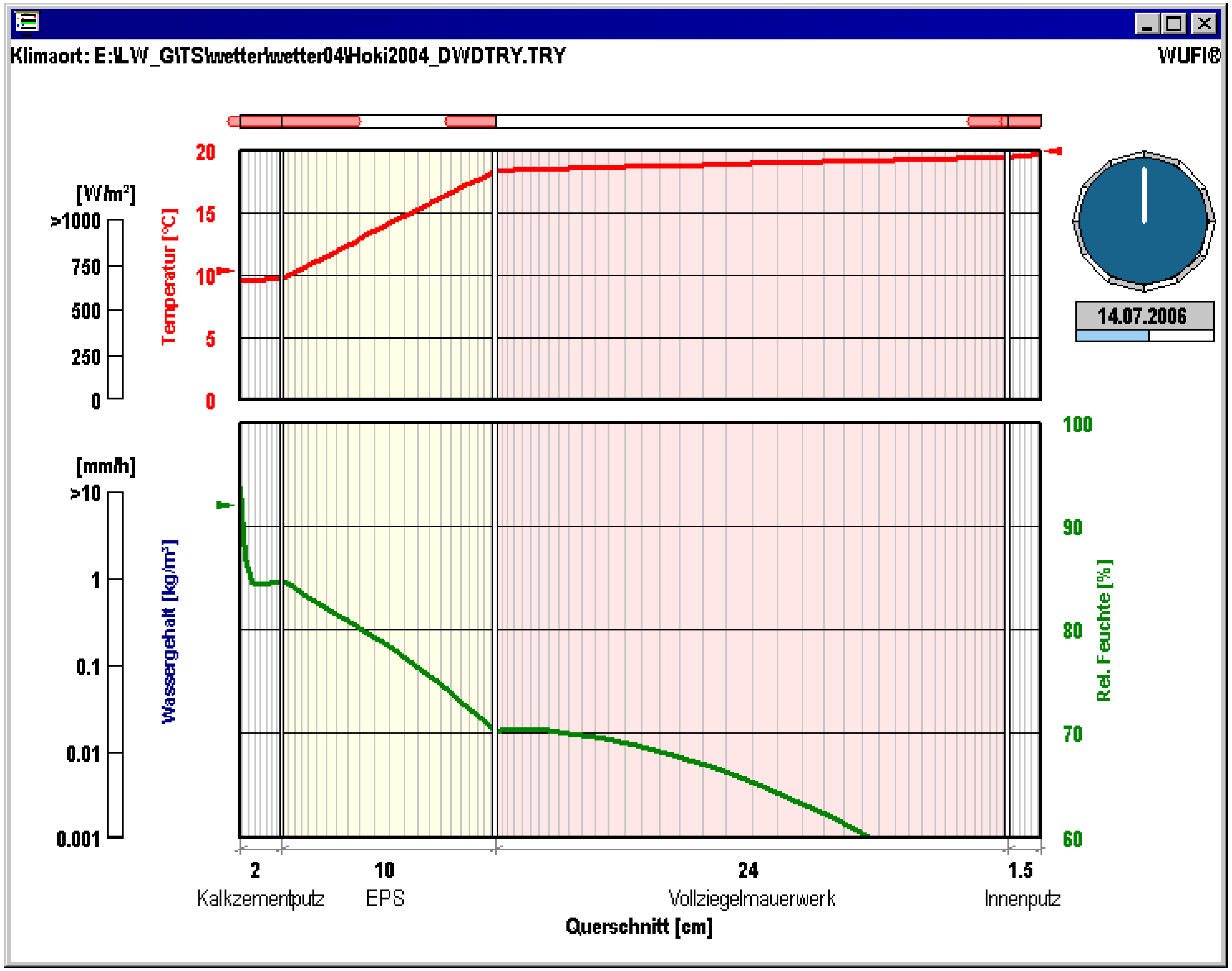
Radiation Effects on Exterior Surfaces



WUFI®-Pro 4.1 hygrothermal simulation with radiation balance

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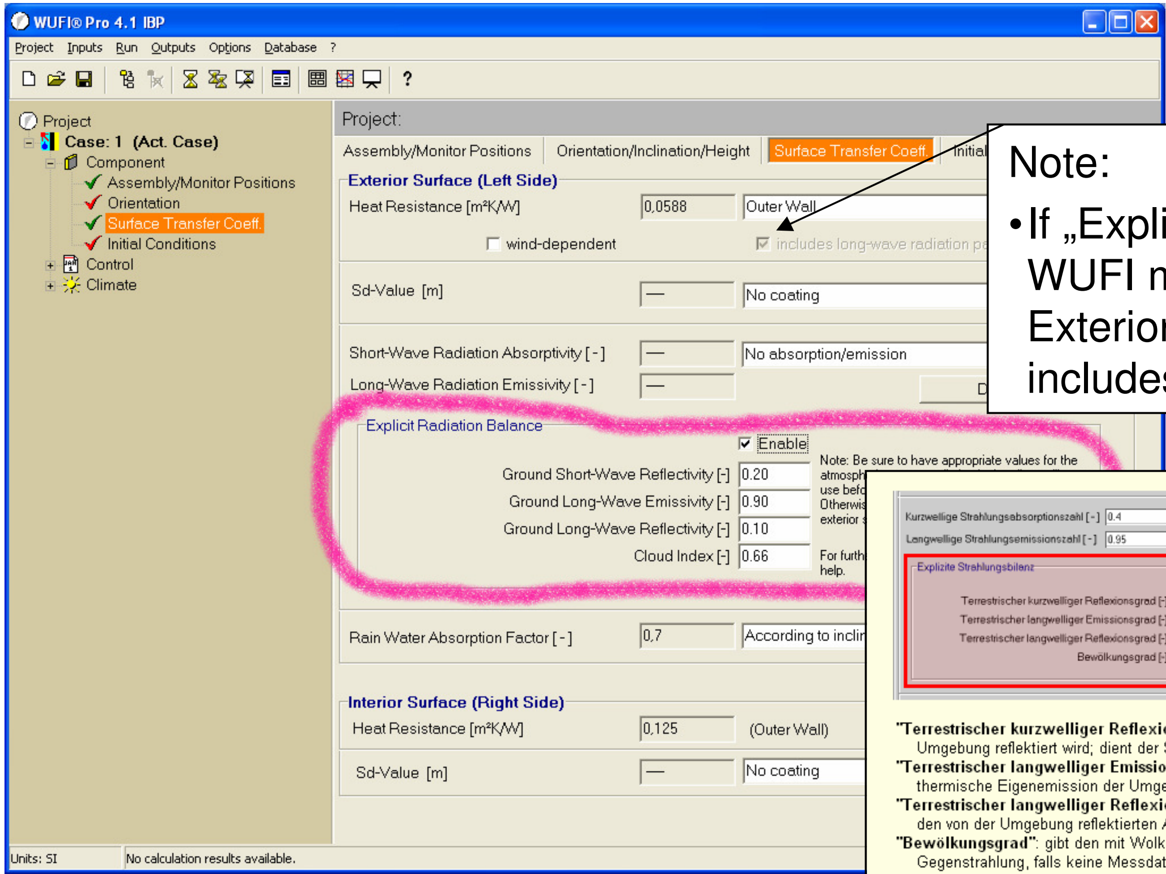
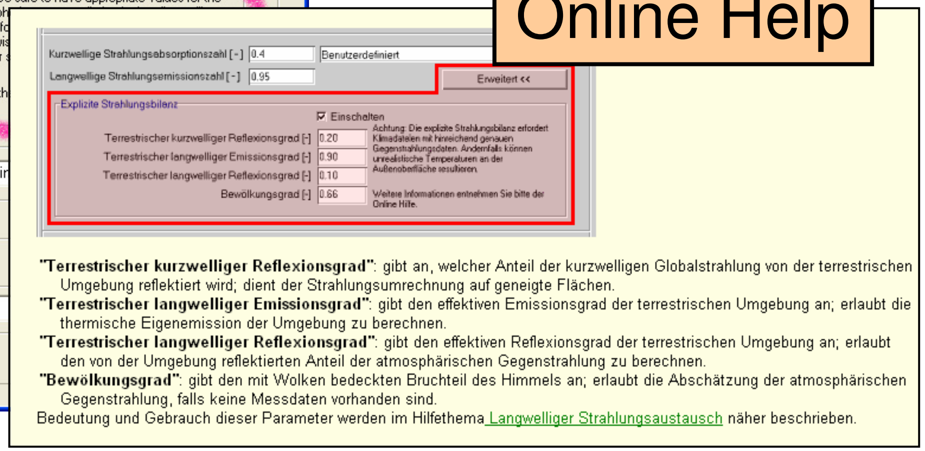
How to use this Radiation Model in WUFI® 4.1



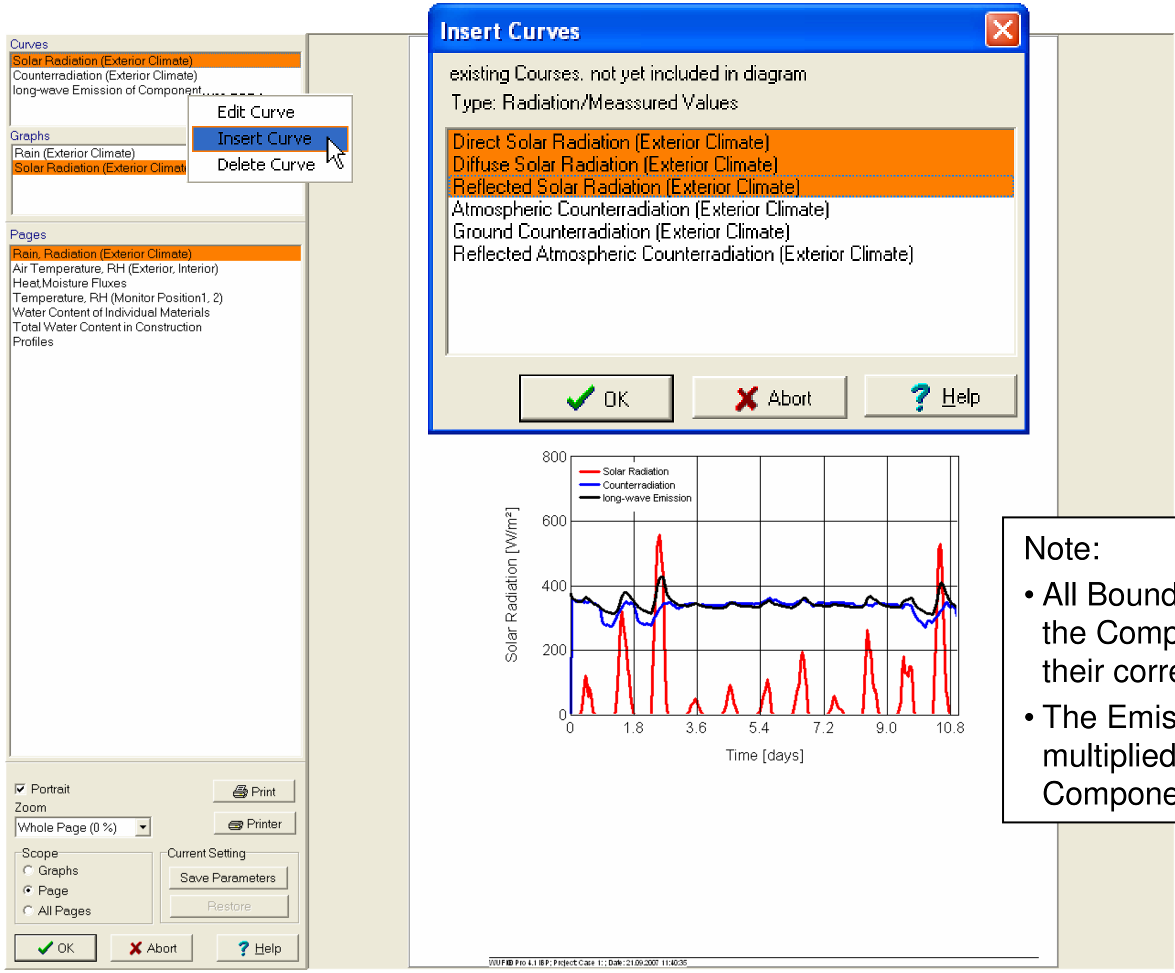
Note:

- If „Explicit Radiation Balance“ is used WUFI must know whether the Exterior Surface Transfer Resistance includes long-wave radiation parts !!!

Online Help



View of all Radiation Parts in the WUFI®-Results



Note:

- All Boundary Conditions (und thus all Irradiations to the Components Surface) are **not** multiplied with their corresponding Surface Transfer Coefficient!!!
- The Emission from the Components Surface is multiplied with the long-wave Emissivity of the Components Surface.

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Radiation Effects on Exterior Surfaces

Additional Report in „Input Data / Summary“

WUFI Output:

Printer | Print | Page Width | Options | Close

Rain Water Absorption Factor	[-]	0,7	According to inclination and construc

Interior (Right Side)

Name	Unit	Value	Description
Heat Resistance	[m²K/W]	0,125	Outer Wall
Sd-Value	[m]	----	No coating

Explicit Radiation Balance

Exterior (Left Side)

Name	Value
Enabled	yes
Heat Transfer Coefficient includes long-wave radiation	yes
Terrestrial Short-Wave Reflectivity [-]	0.20
Terrestrial Long-Wave Emissivity [-]	0.90
Terrestrial Long-Wave Reflectivity [-]	0.10
Cloud Index [-]	0.66

WUFI® Pro 4.1 IBP; Project: Case 1: ; Date: 21.09.2007 11:46:29 Page : 3

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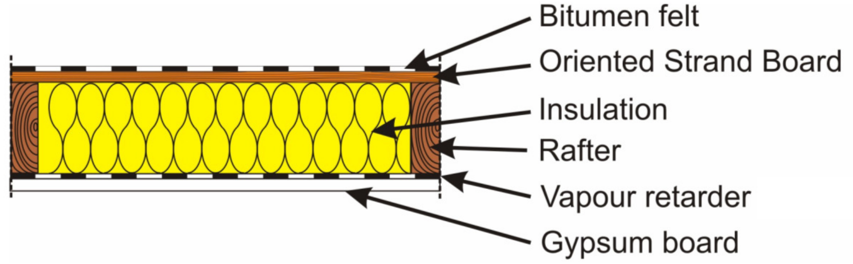
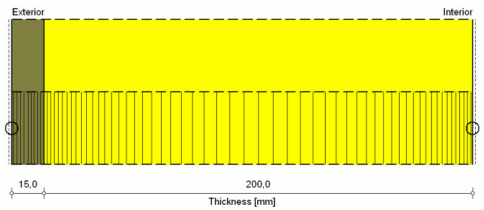
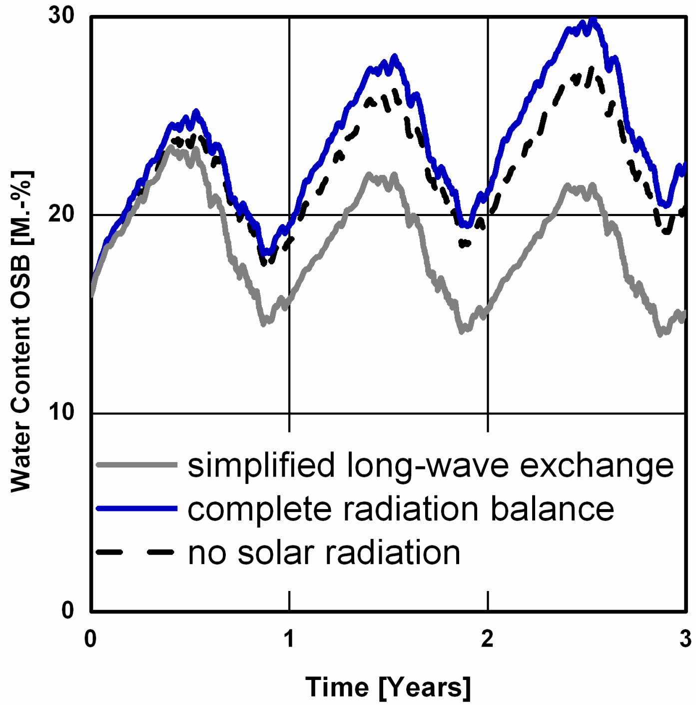
Radiation Effects on Exterior Surfaces

WUFI simulation of a white flat roof at IBP Holzkirchen (Year 2003)

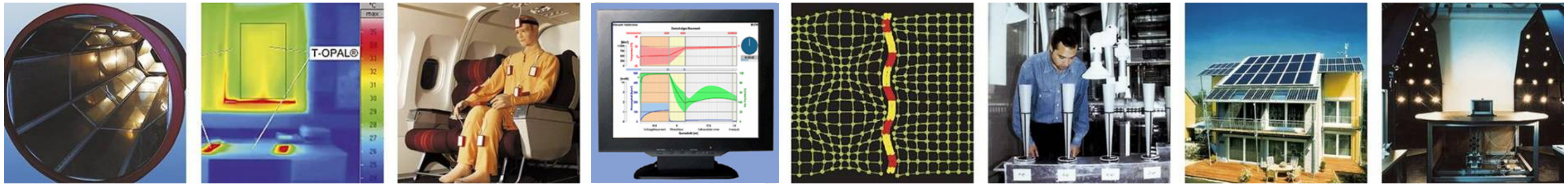






- Simplified approach yields „It performs well“, but it probably will fail.

- Negelcting all radiation as supposed to produce results „on the safe side“ is problematic, too



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