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On the representation of the thermal and visual behavior of a roller shade material: comparison between different simulation models

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2016 Purdue Conferences
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MAIN AIM & METHOD

Roller shades can **improve internal environmental quality** and **reduce** the energy consumption due to **cooling needs**

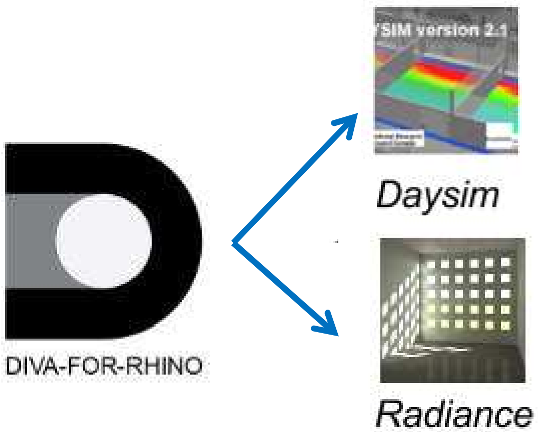
A **common and standardized method** to simulate the **roller shades thermal and visual behavior** still misses:

- non angular model → perfect diffusers
- angular/semi-angular model → dependent of solar radiation incident angle

Simulation Results VERSUS Measured Data

MODELS & SOFTWARE SELECTION

EnergyPlus



WindowMaterial:Shade

- shades = perfect diffusers → τ and ρ independent of incidence angle

WindowMaterial:Shade:EquivalentLayer

- solar $\tau_{b\text{-}b}$ → function of the Openess Factor (Kotey et al. 2009)
- visible spectrum properties → not used yet

trans

- $\tau_{b\text{-}b}$ and $\tau_{b\text{-}d}$ → independent of incidence angle
- beam/diffuse ratio → be defined

transdata

- $\tau_{b\text{-}b}$ or $\tau_{b\text{-}d}$ → modelled according to the incidence angle

MODELS & SOFTWARE SELECTION

EnergyPlus

WindowMaterial:Shade (A)

- thermal and visual behaviour

WindowMaterial:Shade:EquivalentLayer (B)

- only thermal behaviour

DIVA-FOR-RHINO

Daysim

Radiance

trans (C_1) (C_2)

- only visual behaviour

transdata (D_1) (D_2)

- only visual beahviour

SIMULATION RESULTS COMPARISON WITH MEASURED DATA

Validation aspect	Shade's model	Model	Software
Internal air temperature and transmitted solar radiation	WindowMaterial:Shade	A	Energy Plus
	WindowMaterial:Shade :EquivalentLayer	B	Energy Plus
Work-plane illuminance	WindowMaterial:Shade	A	Energy Plus
	trans	C_1 C_2	DIVA (Radiance+Daysim)
	transdata	D_1 D_2	DIVA (Radiance+Daysim)
Vertical eye illuminance	*trans*	C_1 C_2	DIVA(Radiance+Daysim)
	transdata	D_1 D_2	DIVA (Radiance+Daysim)

EXPERIMENTAL SETUP

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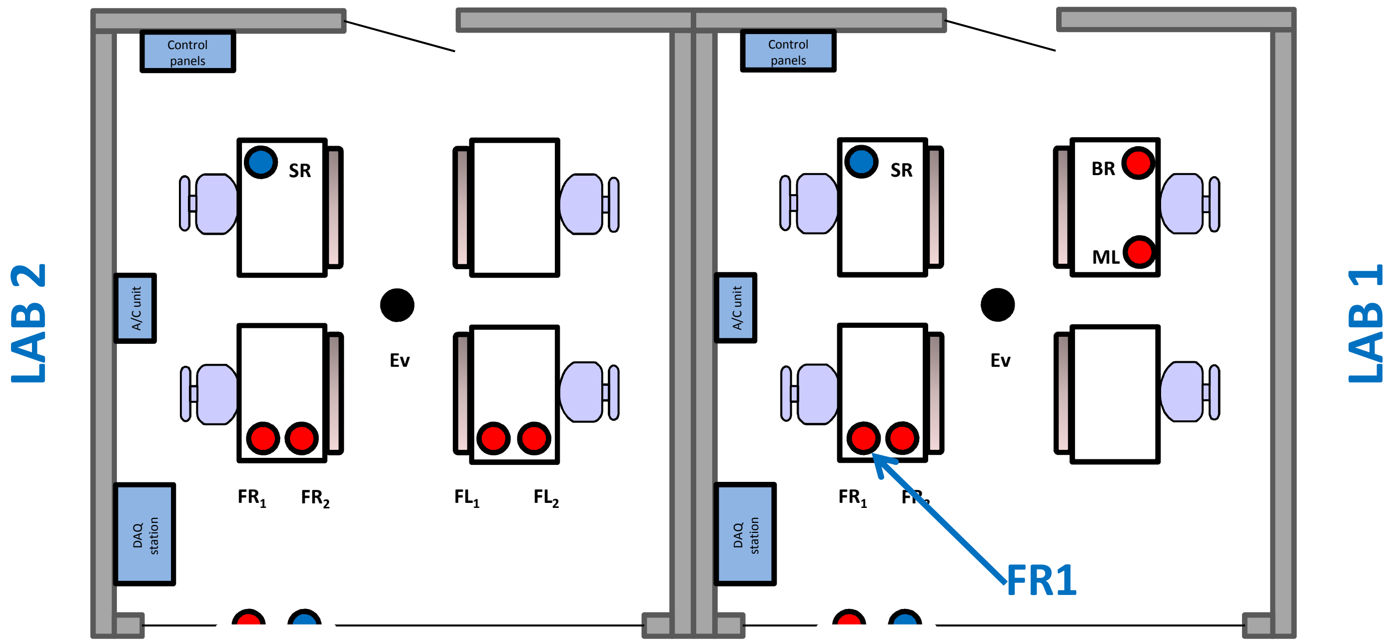
- **MEASUREMENTS PERIOD:** 02-08 Jun 2015
- **MEASUREMENTS TIME-STEP:** 1 minute
- **LAB 1:** shades always closed
- **LAB 2:** shades always open
- Free-floating environment

EXPERIMENTAL SETUP



transmitted or work-plane illuminance

vertical illuminance

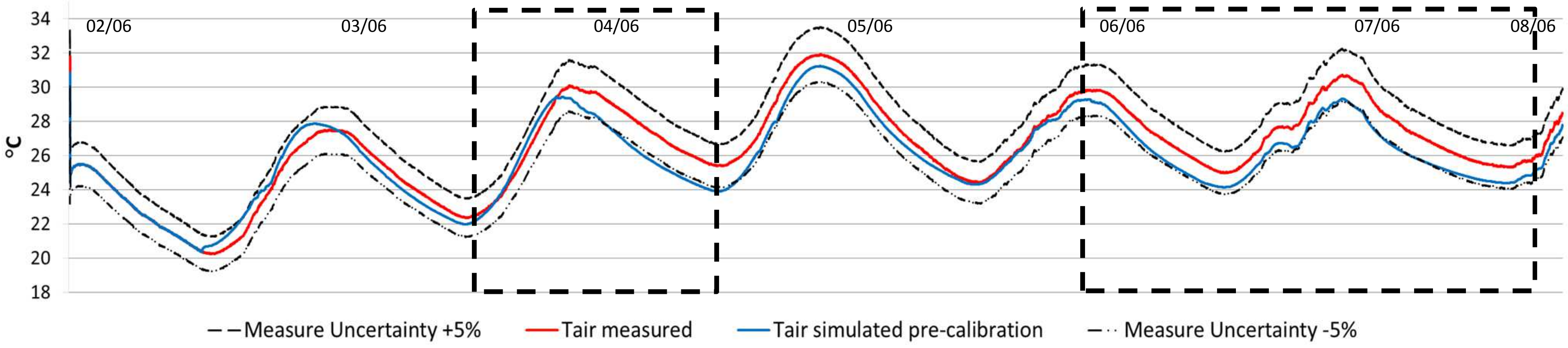
transmitted or work-plane solar radiation

THERMAL MODEL CALIBRATION AND VALIDATION WITH OPEN SHADES

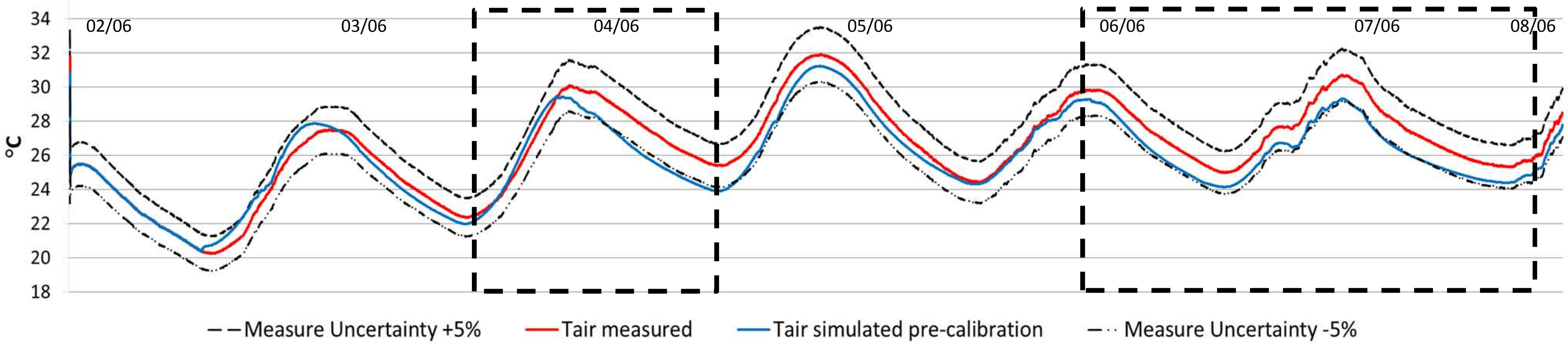
je+EA → **Objective function: internal T_{air} LAB 2**

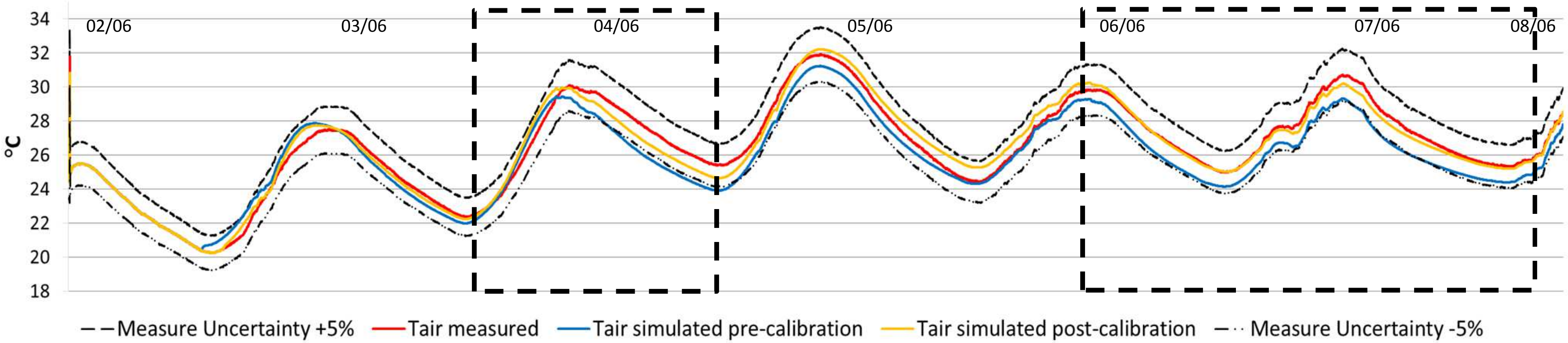
Input parameters	Material	Nominal value	Range value (*levels)	Unit measure
Specific heat	Concrete	840	672-1000	$J\ kg^{-1}\ K^{-1}$
	Acoustic Tile	590	472-708	
	Gypsum	1090	872-300	
Infiltration airchanges		0.1	0.05-0.20	ACH
Thermal conductivity	Concrete	0.53	0.42-0.64	$W\ m^{-1}\ K^{-1}$
	Acoustic Tile	0.06	0.048-0.072	
	Gypsum	0.16	0.13-0.19	
Internal gains (electric equipment)		36	40;50;60*	W

THERMAL MODEL CALIBRATION AND VALIDATION WITH OPEN SHADES



THERMAL MODEL CALIBRATION AND VALIDATION WITH OPEN SHADES





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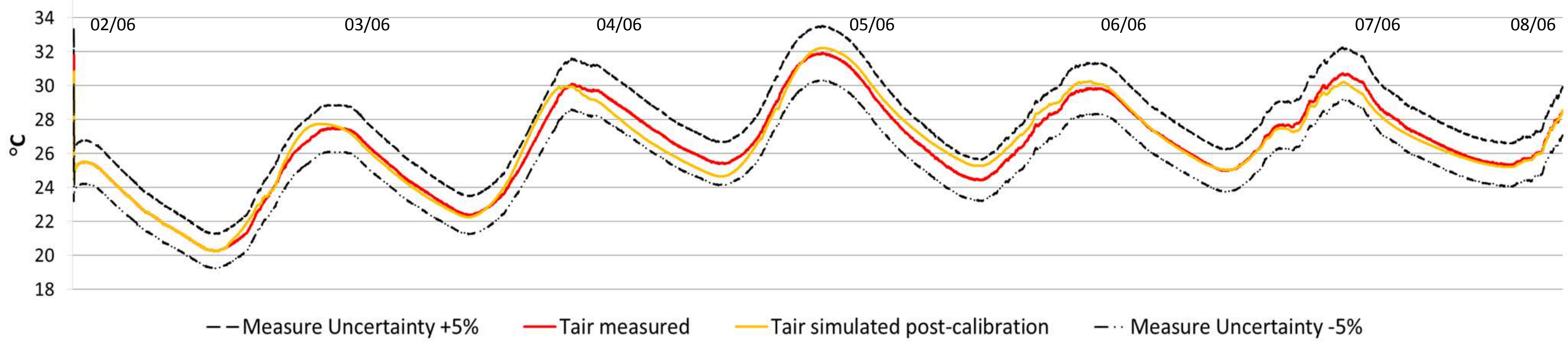
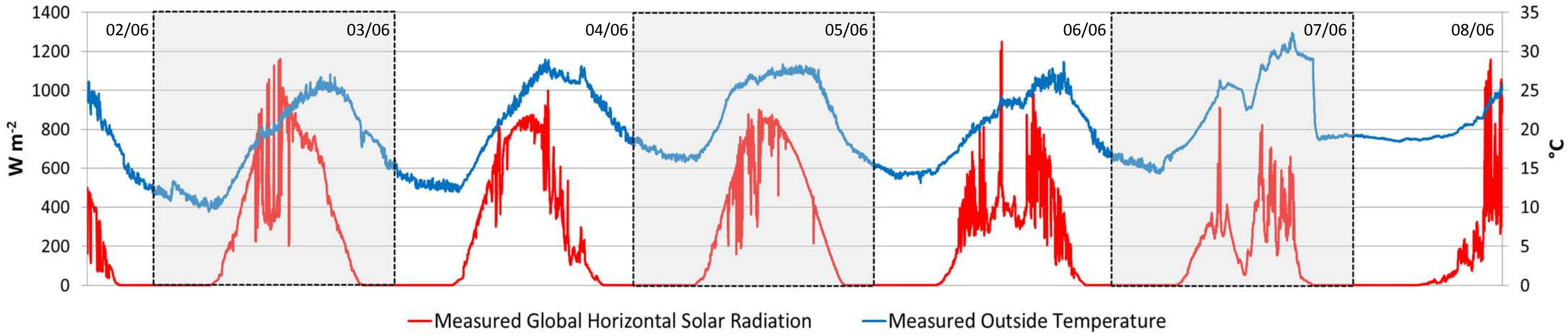
THERMAL MODEL CALIBRATION AND VALIDATION WITH OPEN SHADES

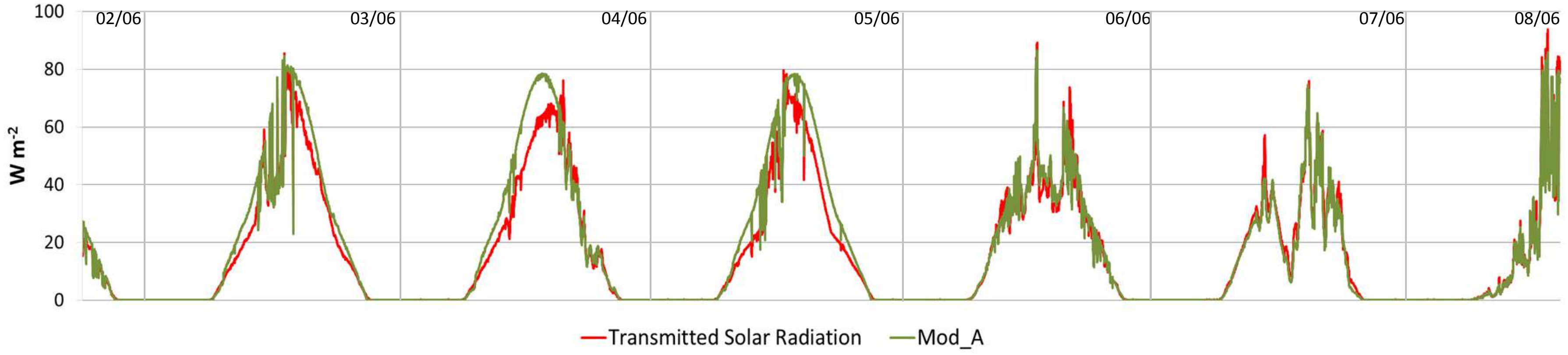




METHOD

THERMAL SIMULATION RESULTS: SOLAR RADIATION

Both the models A and B provide a **good response** for the entering solar radiation calculation with a bare window



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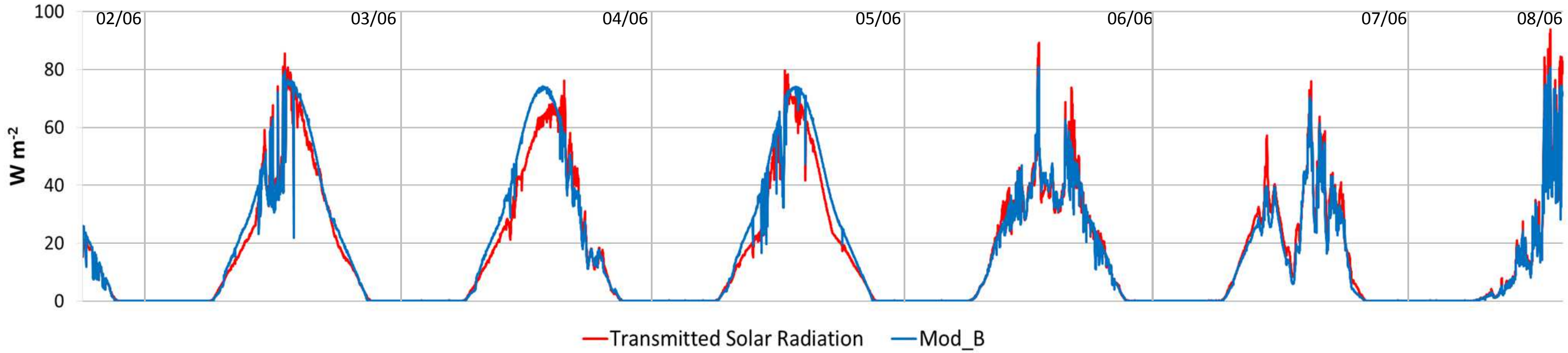

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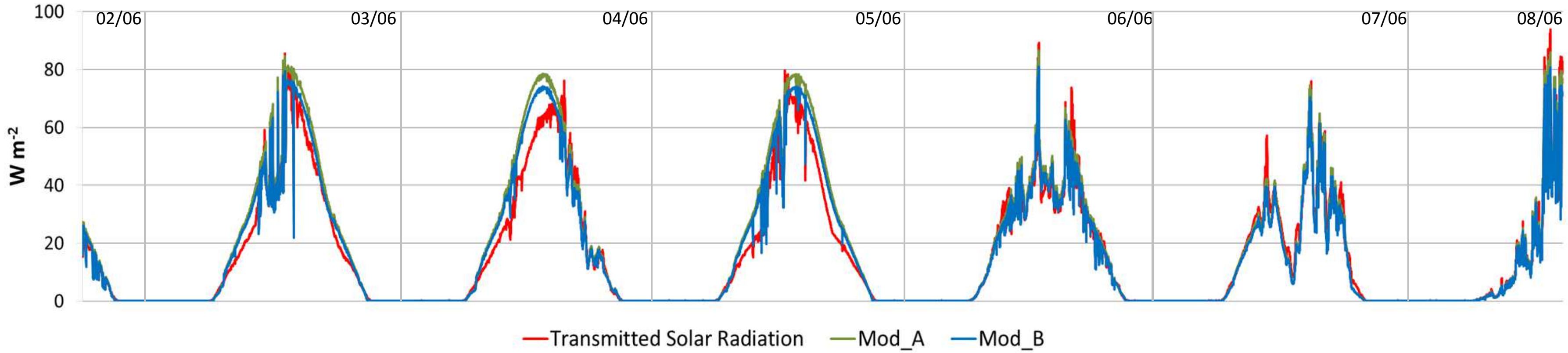
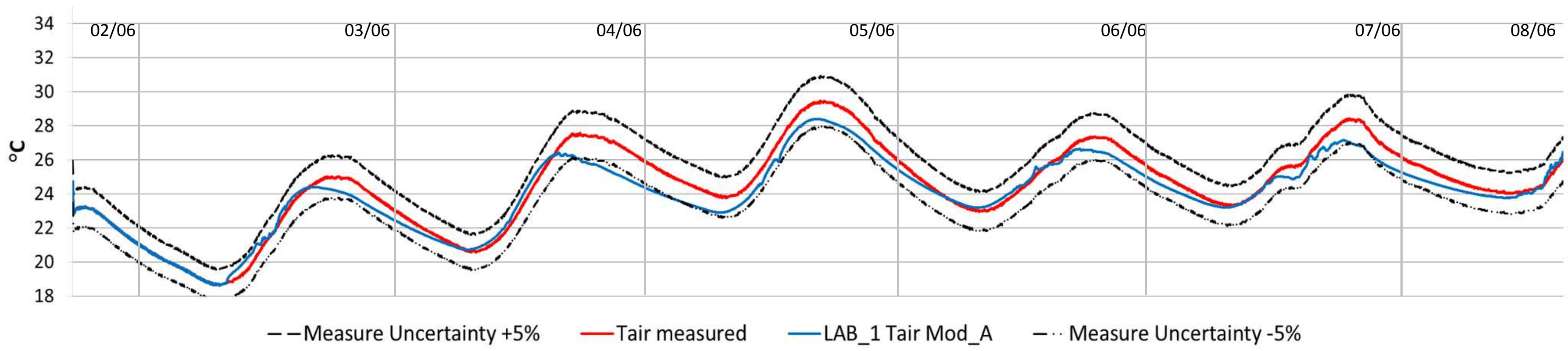


THERMAL SIMULATION RESULTS: INTERNAL AIR TEMPERATURE

When **adding shades (Model A)** the **performance remains** quite **good**



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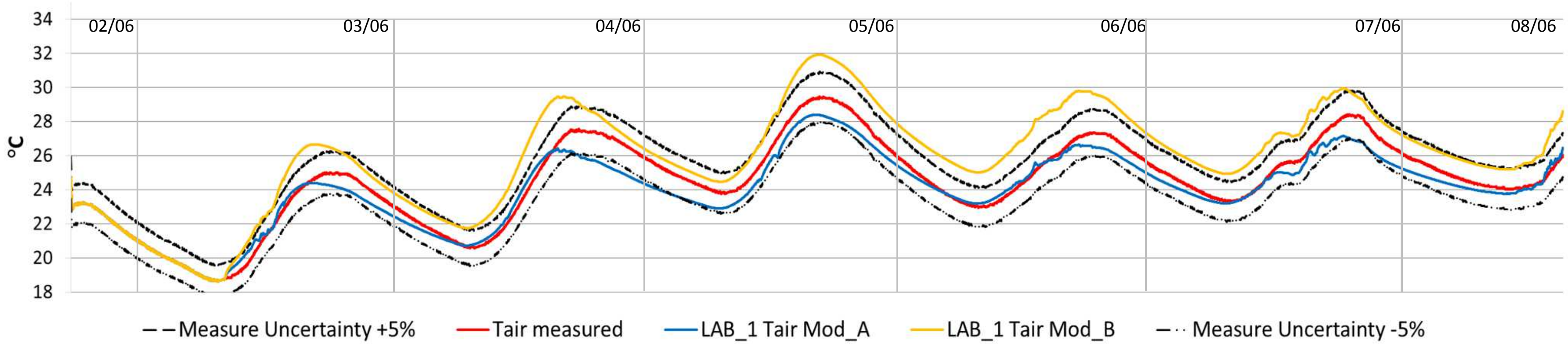
THERMAL SIMULATION RESULTS: INTERNAL AIR TEMPERATURE

When **adding shades (Model A)** the **performance remains** quite **good** even if the **Model B** seems to **overestimate** the temperature profile

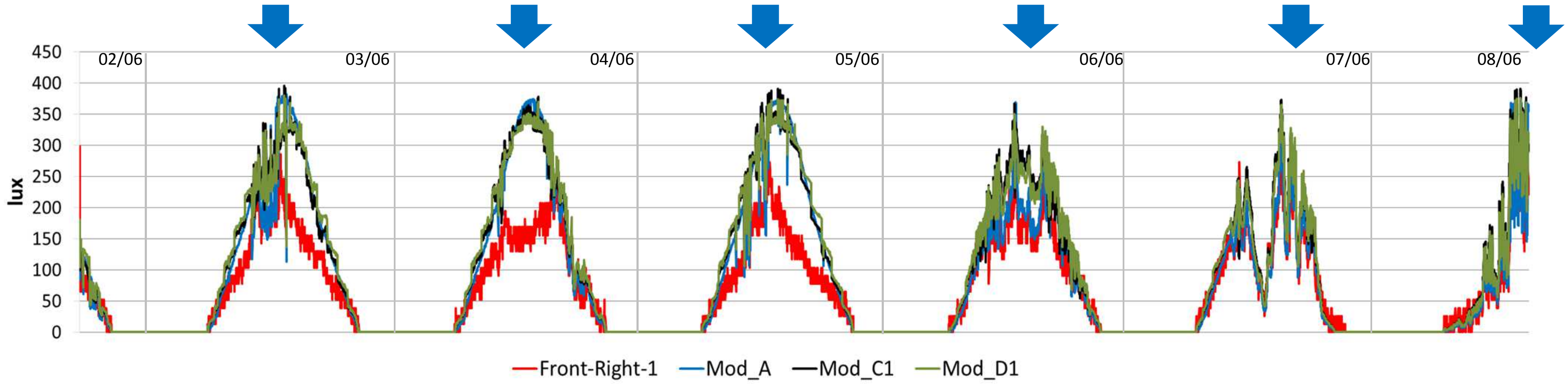


WORK-PLANE ILLUMINANCE RESULTS

Poor agreement using **Model A**, **Model C_1** or **Model D_1** when the **direct-direct component prevails**

- overestimation of the available natural light
- wrong evaluation of glare occurrence
- underestimation of artificial light consumptions

Good agreement when the **direct-diffuse component prevails**



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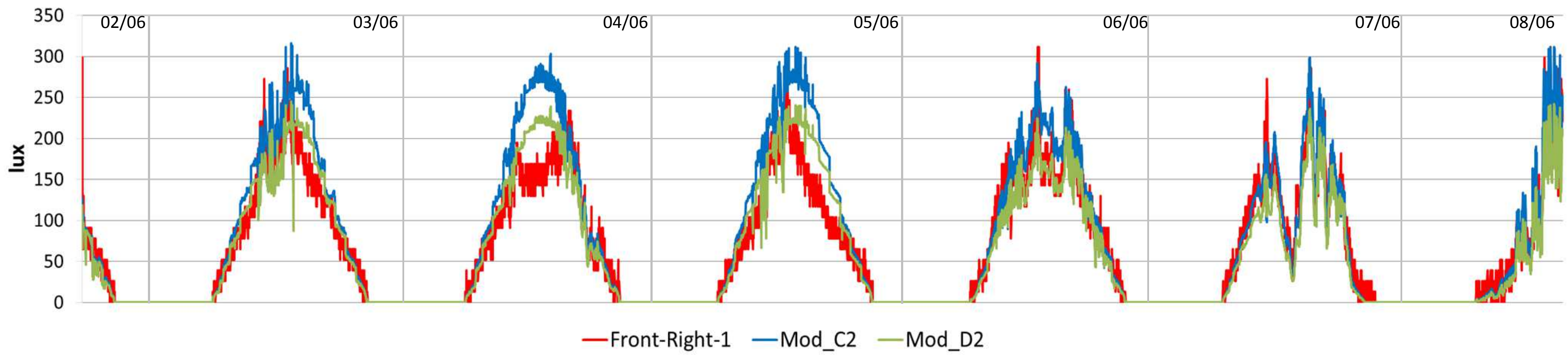
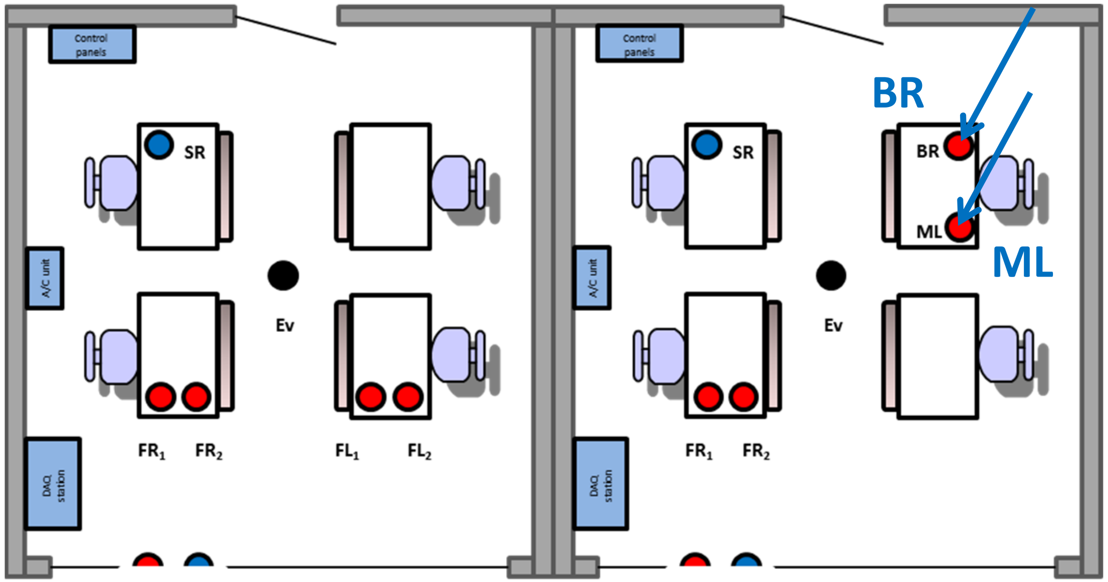
WORK-PLANE ILLUMINANCE RESULTS

Good agreement using **Model C_2** and **Model D_2** when the

direct-direct or the direct-diffuse component prevails



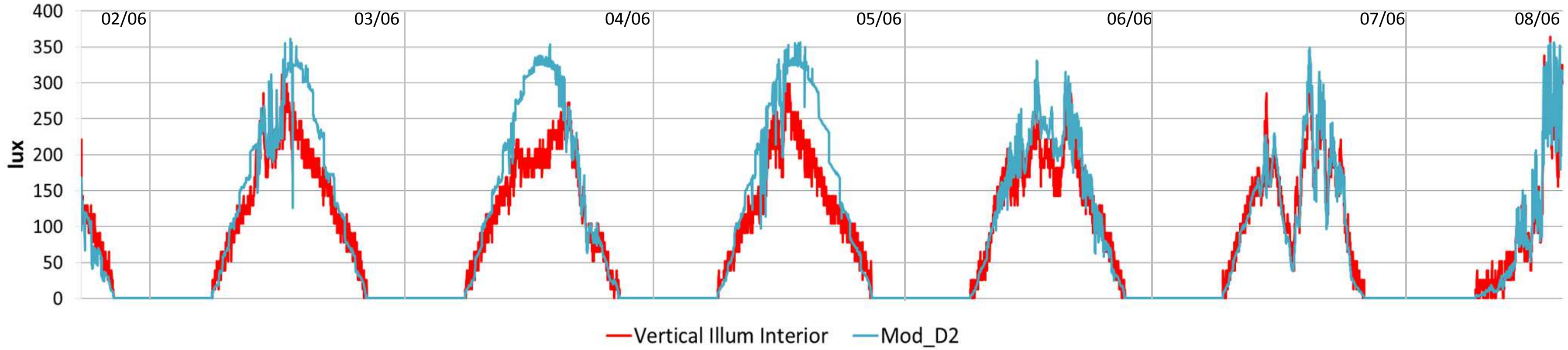
WORK-PLANE ILLUMINANCE RESULTS



- the other sensors show the same trends
- the greater the distance between sensor and window the lesser the discrepancy between measured and simulated values

E_V ILLUMINANCE RESULTS

Best agreement between simulated and measured vertical eye illuminance is found using **Model D_2**



CONCLUSIONS - THERMAL SIMULATIONS

Adding the shades the simulation performance remains good with both the models even if the **Model B overestimates the temperature profile**

↓

This inaccuracy could be **particularly critic** when the aim of the analysis consists in assessing **internal thermal comfort conditions** and/or calculating **heating or cooling consumptions**

CONCLUSIONS - VISUAL SIMULATIONS

Strong correlation between the solar radiation incidence angle and the amount of visible light able to pass through the fabric material

↓

Semi-angular models (C_2 and D_2) show a **good agreement** with measured quantities considering $\boldsymbol{\rho_{b\text{-}b} \neq 0}$

Non-angular (A) **or semi-angular models** $\boldsymbol{\rho_{b\text{-}b} = 0}$ (C1, D1) **overestimate** the daylight contribution during clear days

THANKS FOR YOUR ATTENTION!

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SIMULATION RESULTS COMPARISON WITH MEASURED DATA

	Sol	Opt	Sol	Opt	Sol	Opt	Sol	Opt	Sol	Opt	
	Normal		15°		30°		45°		60°		Side
$\tau_{b\text{-}tot}$	5.0	5.0	5.1	4.9	5.1	5.0	4.3	4.1	2.9	2.7	
$\tau_{b\text{-}b}$	4.2	4.2	3.8	3.1	3.1	3.0	1.7	1.7	0.6	0.6	
$\tau_{b\text{-}d}$	0.8	0.8	1.3	1.0	2.0	2.0	2.6	2.4	2.3	2.1	
$\rho_{b\text{-}tot}$	74.5	72.3	74.0	71.7	74.9	72.2	74.8	72.4	75.9	74.2	ext
	28.3	28.3									int

SIMULATION RESULTS COMPARISON WITH MEASURED DATA

A

Quantity	Value
τ_{sol}	0.050
ρ_{sol}	0.745
τ_{vis}	0.050
ρ_{vis}	0.723

SIMULATION RESULTS COMPARISON WITH MEASURED DATA

A

Quantity	Value
τ_{sol}	0.050
ρ_{sol}	0.745
τ_{vis}	0.050
ρ_{vis}	0.723

B

Quantity	Value
τ_{b-b}	0.042
τ_{b-d} Front	0.008
τ_{b-d} Back	0.008
ρ_{b-d} Front	0.723
ρ_{b-tot} Back	0.283

SIMULATION RESULTS COMPARISON WITH MEASURED DATA

A

Quantity	Value
τ_{sol}	0.050
ρ_{sol}	0.745
τ_{vis}	0.050
ρ_{vis}	0.723

C_1 + D_1

Quantity	Value
$col_{red;}col_{green;}col_{blue}$	0.773
spec	0
roughness	0
trans	0.065
tspec C_1/D_1	0.84/1

B

Quantity	Value
τ_{b-b}	0.042
τ_{b-d} Front	0.008
τ_{b-d} Back	0.008
ρ_{b-d} Front	0.723
ρ_{b-tot} Back	0.283

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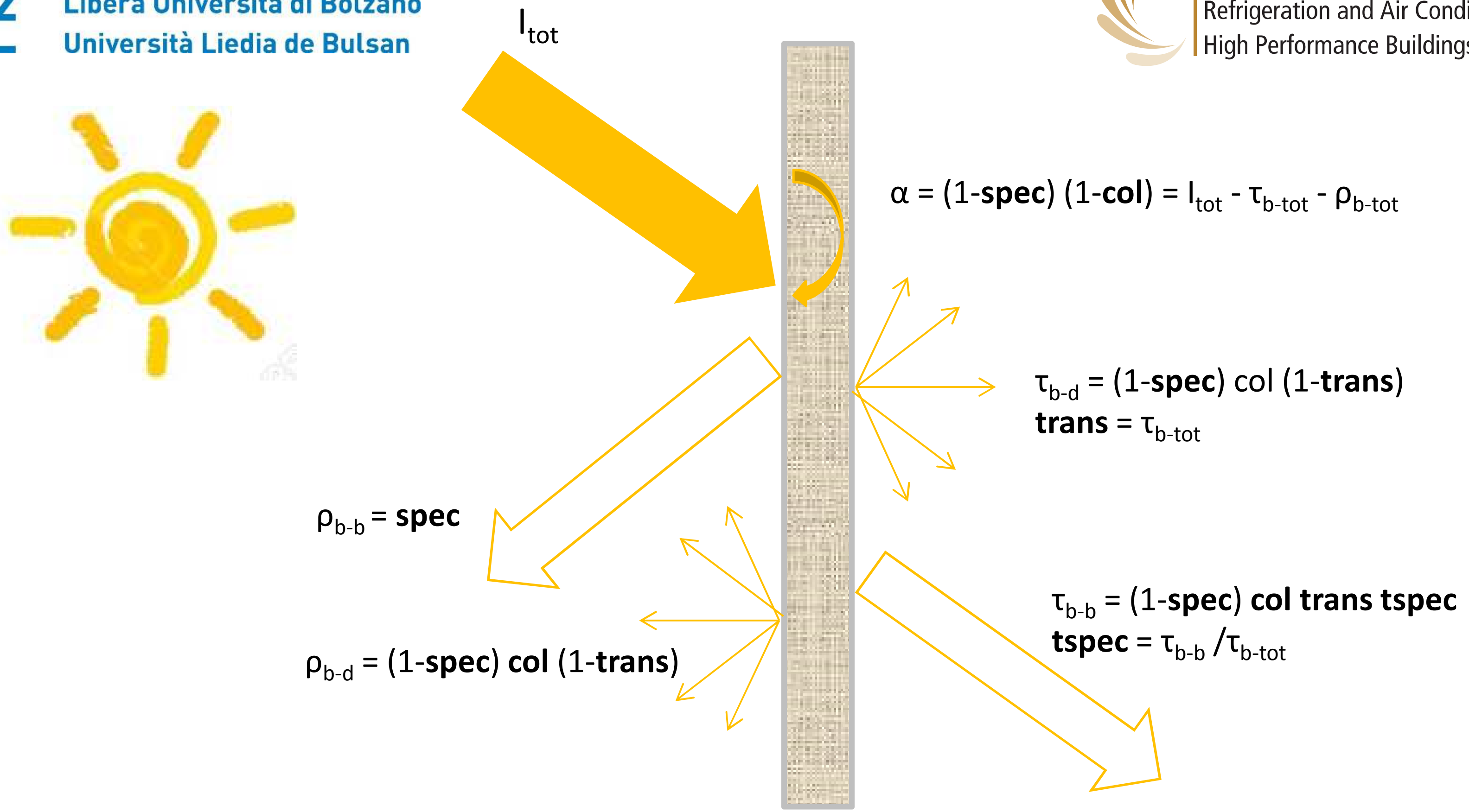
B

Quantity	Value
τ_{b-b}	0.042
τ_{b-d} Front	0.008
τ_{b-d} Back	0.008
ρ_{b-d} Front	0.723
ρ_{b-tot} Back	0.283

C_2 + D_2

Quantity	Value
$col_{red;}col_{green;}col_{blue}$	0.434; 0.523; 0.589
spec	0.33
roughness	0
trans	0.113
tspec C_2/D_2	0.84/1




```
# Translucent material for Bowen shade LAB1
# OF=5%; τb-d= 0.8%;  τb-b= 4.2%
void trans shade
0
0
7 col col col spec roughness trans tspec
```

```
# Transdata material for Bowen shade LAB1
void transdata SilverGreyBowen
4 noop SilverGreyBowen.dat rang.cal rang
0
6 col col col spec trans 1
```

This value changes according to the incidence angle

$I_{tot} = 1$
$\rho_{b\text{-}b}$ = spec = 0 according to *Kotey et al (2009)*
α = (1-spec) (1-color) = $I_{tot} - \rho_{b\text{-}tot} - \tau_{b\text{-}tot} = 0.227$
color = 0.773
$\tau_{b\text{-}tot} = 0.05$ according to measured data
$\rho_{b\text{-}tot} = \rho_{b\text{-}d} = 0.723$ according to measured data
$\tau_{b\text{-}tot}$ = (1-spec) color trans
trans = 0.065
$\rho_{b\text{-}d}$ = diffuse reflectance = (1-spec) color (1-trans) = 0.723 as results from measured data
t_{spec} = specular transmission = $\tau_{b\text{-}tot} / \tau_{b\text{-}b}$
$\tau_{b\text{-}d}$ = diffuse transmission = (1-spec) color trans (1-t_{spec}) = 0.008 as results from measured data

```
# Translucent material for Bowen shade LAB1
# light total transmittance: 5%
# diffused part : 0.8%
# direct part : 4.2%
void trans shade
0
0
7 col col col spec roughness trans tspec
```

→

```
# Translucent material for Bowen shade LAB1
# light total transmittance: 5%
# diffused part : 0.8%
# direct part : 4.2%
void trans shade
0
0
7 0.773 0.773 0.773 0 0 0.065 0.84
```

RAL color for silver gray: $Y=0.298$ $x=0.311$ $y=0.321$

$X = x\ (Y7y) = 0.2887$ $Z = (1-x-y)\ (Y/y) = 0.3416$

$Cr = 2.565X - 1.167Y - 0.398Z = 0.256$

$Cg = -1.022X + 1.978Y + 0.044Z = 0.309$

$Cb = 0.075X - 0.252Y + 1.177Z = 0.348$

$\rho_{b-d} = 0.39$

$\rho_{b-d} = \rho_{b-tot} - \rho_{b-d} = 0.333$

$trans = \tau_{b-tot} / \rho_{b-d} * \tau_{b-tot} = 0.113$

$col1 = Cr/(1- \rho_{b-d})\ (1-trans) = 0.434$

$col2 = Cg/(1- \rho_{b-d})\ (1-trans) = 0.523$

$col3 = Cb/(1- \rho_{b-d})\ (1-trans) = 0.589$

```
# Translucent material for Bowen shade LAB1
# light total transmittance: 5%
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# direct part : 4.2%
void trans shade
0
0
7 col col col spec roughness trans tspec
```

→

```
# Translucent material for Bowen shade LAB1
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0
0
7 0.434 0.523 0.589 0.33 0.113 0.84
```