# Modeller's Report

# Validation Carnot

# IEA Task34 Empirical validations of shading/daylighting/load interactions in building energy simulation tools

**Index:**



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2009/2010

# Summary

Buildings with highly glazed façades are becoming increasingly popular around the world. Shading devices are vital components for preventing overheating in buildings during the summer and reducing and/or eliminating the need for active cooling. Building energy simulation programs are tools which can be used to predict and optimize energy performance in buildings. However, successful application of a program requires careful and thorough validations. This is especially true when assessing solar gain and daylighting models

Therefore a suite of experiments was performed in the Swiss Federal Laboratories for Materials Testing and Research (EMPA) outdoor facility in Dübendorf, Switzerland that focused on evaluating solar gain modelling.

Results from the experiments were used to carry out empirical validation exercises in several building energy simulation programs. These experiments and according validations are described in Report for the International Energy Agency's SHC Task 34/ ECBCS Annex 43 Project C, August 2007, by Peter Loutzenhiser and Heinrich Manz, Laboratory for Building Technologies at Swiss Federal Laboratories for Materials Testing and Research (EMPA)

Therefore this study not only allowed comparative validation (program-to-program comparisons) but also empirical validation (comparing results with an actual experiment) of the Carnot blockset. Validation and modelling steps are subsequently increased in complexity in each experiment.

1. Test cell transient characterization (Experiment 2):
   To assure identical passive behaviour of the model the exact profile of internal gains, and measured inner surface temperatures are given onto the walls.

2. Evaluation of irradiation models on tilted facades (Experiment 3):
   As for the solar gain experiments the model of solar radiation on tilted surface is very important, a new algorithm for the Perez model was implemented beside Isotropic sky and Hay Davies. The Perez model showed best accordance to measured values. All models lay within the benchmark results.

3. Glazing unit only (Experiment 3):
   Optical properties of the glazing unit were precalculated using Optics and WIS software with the given spectral data.
   Cooling profile shows good agreement to measured data and also corresponds to the results of the benchmark programs. Transmitted solar power is identical to benchmark programs which indicates that all window models are very similar.

4. Glazing unit with external shading screen (Experiment 4):
   Solar Transmittance of Shading screen is used as factor to reduce incoming solar irradiance. Although back reflectance, absorption as well as shielding against wind and rain is not taken into account, this simple method of modelling exterior screen shading shows a surprising accuracy.

5. Glazing unit with internal shading screen (Experiment 5):
   Inner shading needs to also respect for absorption and influence of g-value of the whole glazing unit dependent on type of glazing. A shading model is implemented which allows for comfortable input of properties

6. Glazing unit with external Venetian blinds (Experiment 6):
   Shading factors analogue to view factor method based on geometrical and optical input are defined for shading of direct and diffuse irradiance. Because of complex geometrical dependencies as on sun position, blind angle and dimensions etc. calculation of shading factors is implemented within a Matlab script file.

Validation shows good accordance to measured values and is absolutely comparable to the benchmark programs. This validation only has been done with four other programs

7. Glazing unit with internal mini-blinds (Experiment 7):
   Experiment is not performed with Carnot

8. Window (i.e. glazing unit with a window frame) (Experiment 8):
   Unfortunately the weather data of this exercise was corrupted (Angles of sun position). As in Experiment 3 Optical properties of the glazing unit was precalculated using Optics and WIS software with the given spectral data. In addition the ration of frame area is taken into account.
   Compared to the other experiment the resulting cooling profile is not as close to measured values than in other experiments, but lie within the results of the benchmark programs. Unlike in the other experiments already the profile for solar irradiance on tilted surface, on tilted surface differs quite much from measured values. As this calculation is done in the Surfrad block, which is independent from the model itself, it seems that there is a problem with the corrupted weather data.

Generally several changes and new modelling approaches have been implemented.

- Calculation of global Irradiance in the surface irradiance function block was enhanced with the Perez algorithm. There are now 3 irradiance model available:
  1. Isotropic sky
  2. Hay Davies
  3. Perez
- Equation of wind dependent heat transfer coefficient on vertical outer wall is adapted (4*u+4)
- heat transfer coefficient of ceiling and floor is improved to detect up- or down going heat flux with different temperature dependent heat transfer coefficients
- Window shading function as described

# Exercises with results

## *Exercise 1 (Transient characterization experiment)*

**Task34_Ex_1_32**

**Modelling of thermal bridges:**
The influence of Thermal bridges and edge effects are implemented by adapting the conductivity of the isolation layer (foam) of each wall, by manual iteration, such as to fit the "Overall Thermal Transmittance (incl. Edge effects and thermal bridges)" of the steady-state experiment, specified in the IEA Task34/Annex 43 Project C Report, page 10.
Errata: Obviously the values for South-, resp. East-Wall in table 3.3 has been confounded.

**Modelling of thermal mass (200kJ/K):**
The thermal mass inside the test cell is considered as interior wall with one thin steel layer of appropriate area to correspond to the specification in the experiment.

**Application of internal load:**
Hourly values of internal load were extracted from the excel file experiment2 and applied onto the model via workspace.

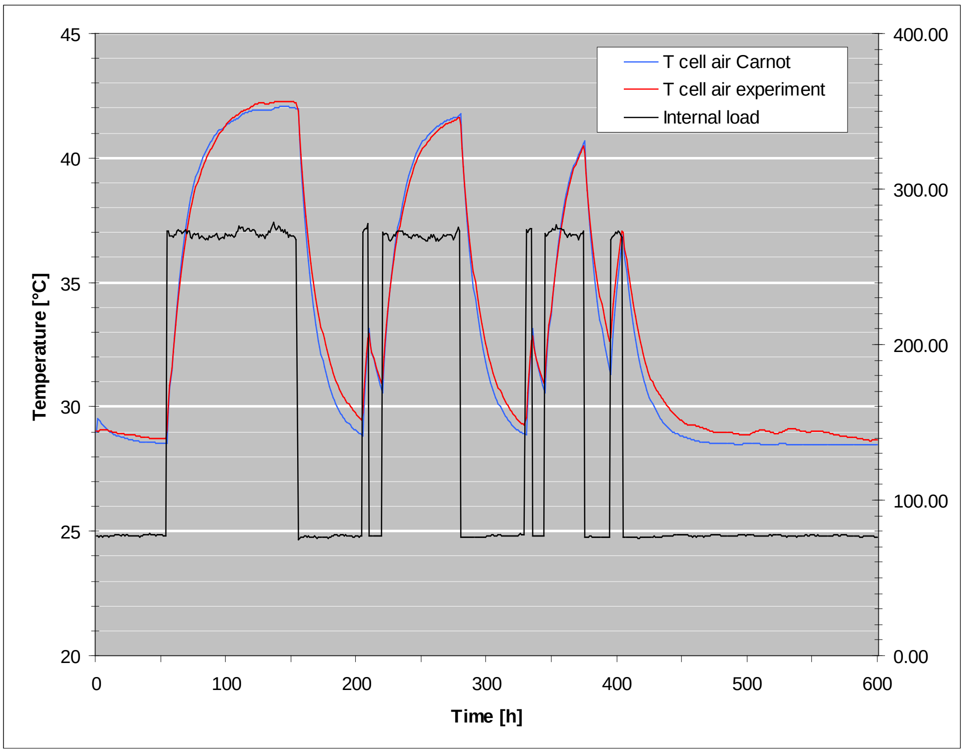
All the walls from Carnot blockset provide temperature dependent convective heat transfer coefficients on the inner surface and Wind speed dependency on the outer surface. Convective heat transfer coefficients of roof/ceiling are additionally depend on flow direction

**Weather data:**
Simple model with constant temperature.

Steady-state results:

| **Steady state experiment** | | | |
|---|---|---|---|
| | *Phase1* | *Phase2* | *state condition exercise 1* |
| Heat input W | 282.26 | 145.04 | 77 |
| Air Temp test cell | 43.13 | 36.45 | 28.7 |
| Temp guarded zone | 23.5 | 23.33 | 23 |
| Temp ext. Chamber | 23.24 | 43.74 | 23 |
| mean wall temp ext. Chamber | 36.6 | 31.6 | |
| mean wall temp guarded zone | 36.6 | 31.6 | |
| Carnot | 42.97 | 36.11 | 28.48 |
| ΔT Experiment-Carnot | 0.16 | 0.34 | 0.22 |

Transient profile according Experiment1:



**Task34_Ex_1_33**

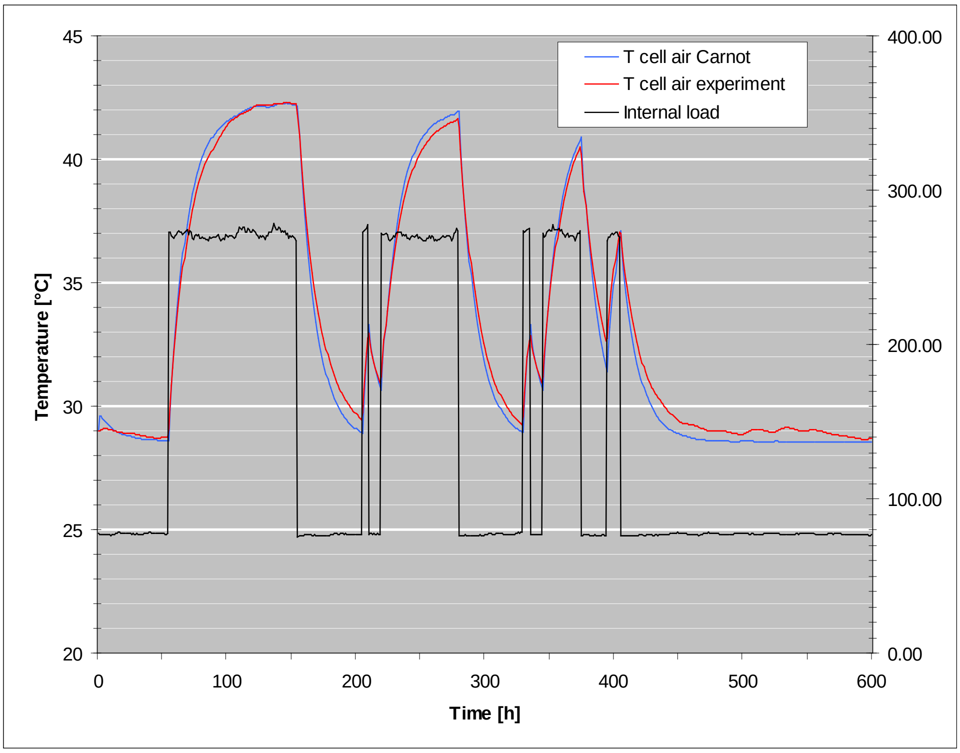
Based on model Task34_Ex_1_32 with following adjustments:

All exterior walls were interchanged with blocks for interior walls, apart from the south wall which needed to rest an exterior wall for further testing of window influence.
“Exterior” side of these walls were linked to a constant AIV vector with the specified temperatures from the experiments.

Steady-state results:

| **Steady state experiment** | Phase1 | Phase2 | state condition exercise 1 |
|---|---|---|---|
| Heat input W | 282.26 | 145.04 | 77 |
| Air Temp test cell | 43.13 | 36.45 | 28.7 |
| Temp guarded zone | 23.5 | 23.33 | 23 |
| Temp ext. Chamber | 23.24 | 43.74 | 23 |
| mean wall temp ext. Chamber | 36.6 | 31.6 | |
| mean wall temp guarded zone | 36.6 | 31.6 | |
| Carnot | 43.08 | 36.01 | 28.55 |
| ΔT Experiment-Carnot | 0.05 | 0.44 | 0.15 |

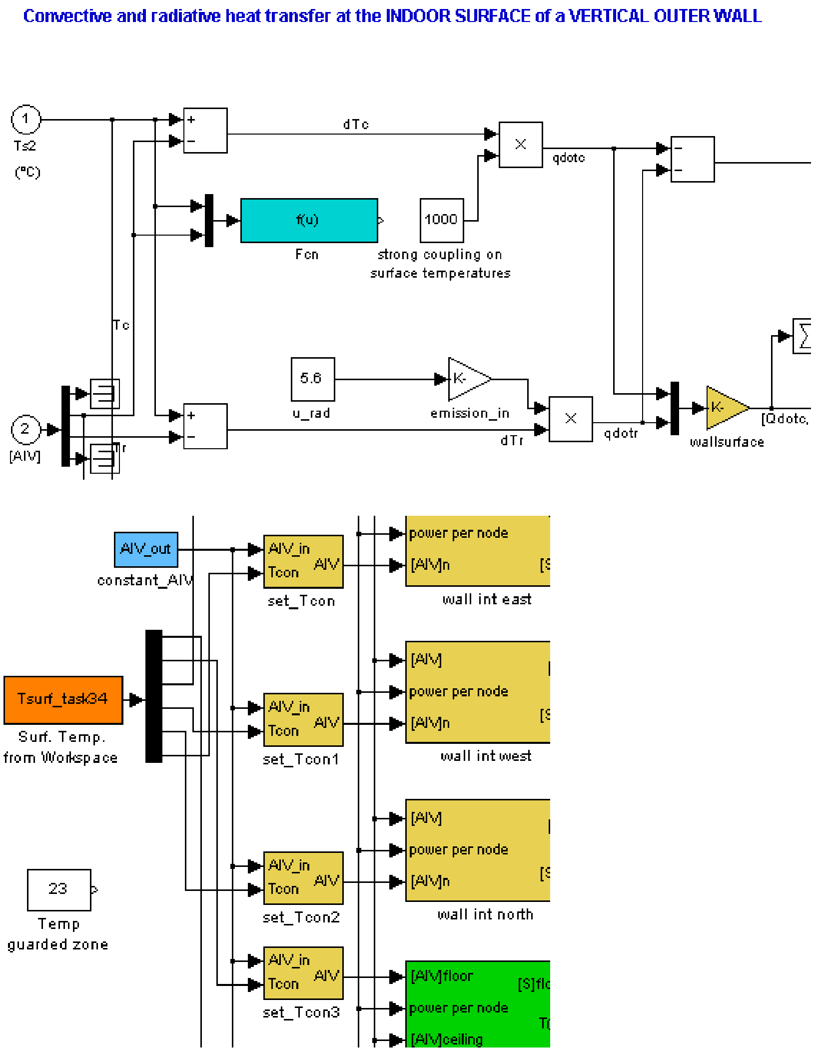
Transient profile according Experiment1:



**Task34_Ex_1_34**

Based on model Task34_Ex_1_33 with following adjustments:

To get better approximation of air temperature behaviour between experiment and simulation, the measured wall surface temperatures are linked directly onto the surface of each wall in the model. Therefore the measured surface temperatures are implemented in the constant AIV vector and the block calculating heat transfer coefficient is detached and replaced by a factor (1000) which means a very high heat transfer rate between air and wall surface, which results in identical surface temperatures.



Steady-state results:

| Steady state experiment | | | |
|---|---|---|---|
| | *Phase1* | *Phase2* | *state condition exercise 1* |
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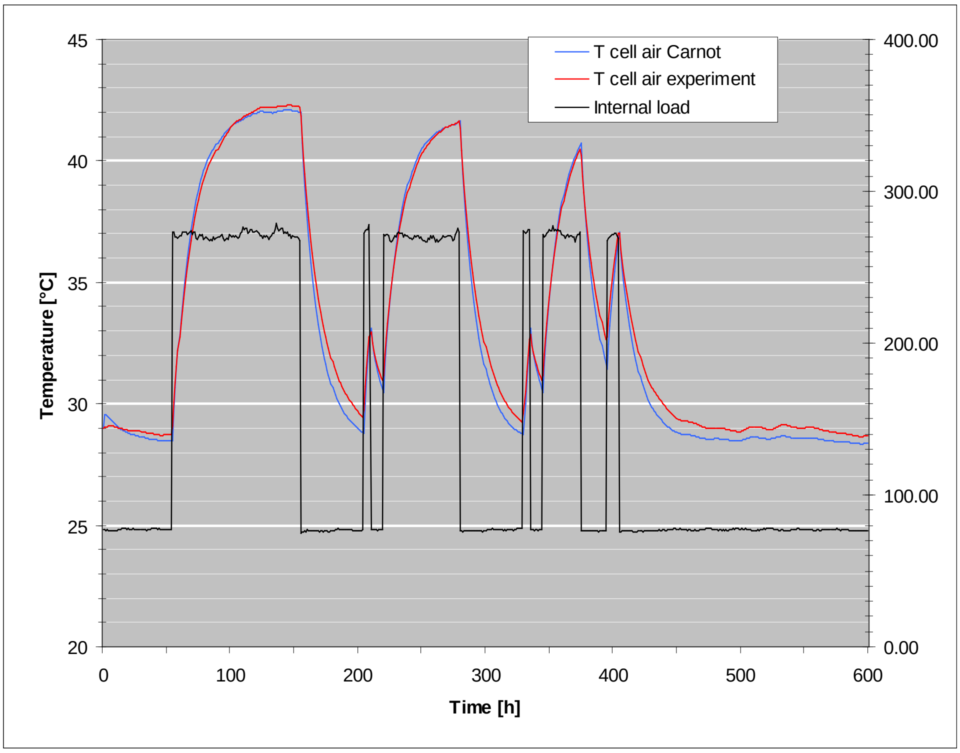
Transient profile according Experiment1:

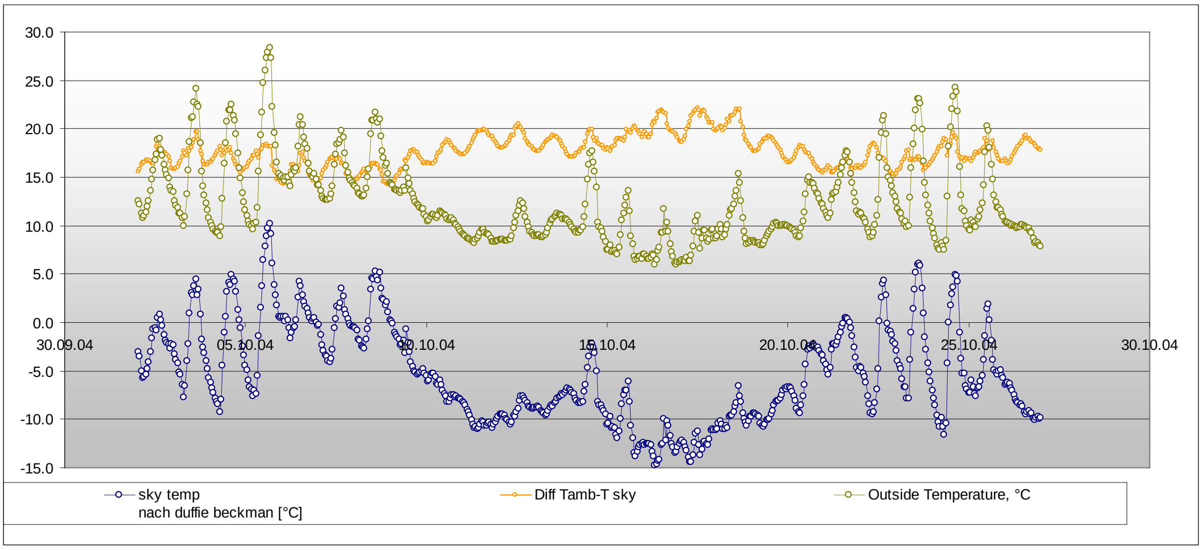


## *Exercise 2 (Evaluation of irradiation models on tilted facades)*

**Tas34_Ex_2**

Sky temperature
Evaluation is done according Duffie Beckman:
Solar engineering of thermal processes, page 158
Ts=Ta*(0.711+0.0056Tdp+0.000073Tdp^2+0.0013*cos(15t))^(1/4)

Ts: Temperature sky, Kelvin
Ta: Temperature air environment, Kelvin
Tdp : Dew point temperature, Celsius
t: Time from midnight hour




Ground reflectance
Ground reflectance is set to 13.4% → input in Carnot 0.134
Ref. Empirical validation of models to compute solar irradiance on inclined surfaces for building energy simulation; by P.G. Loutzenhiser et all; 2007

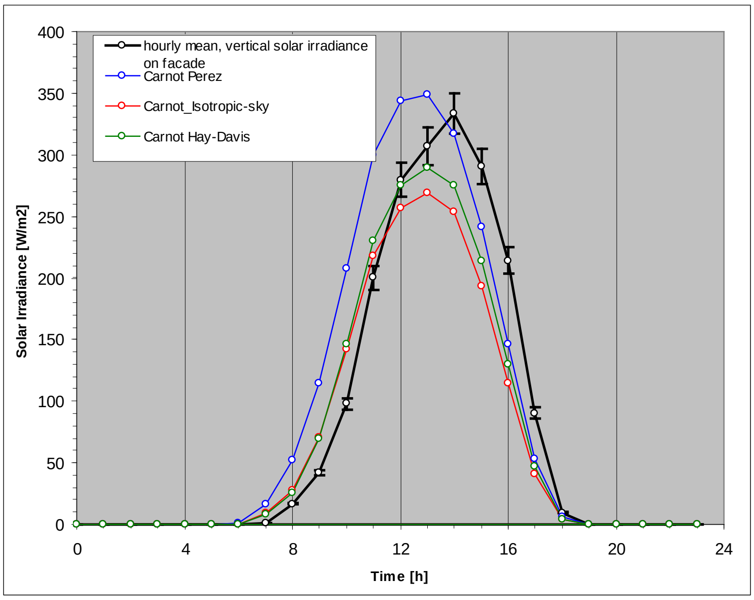
## Carnot weather output

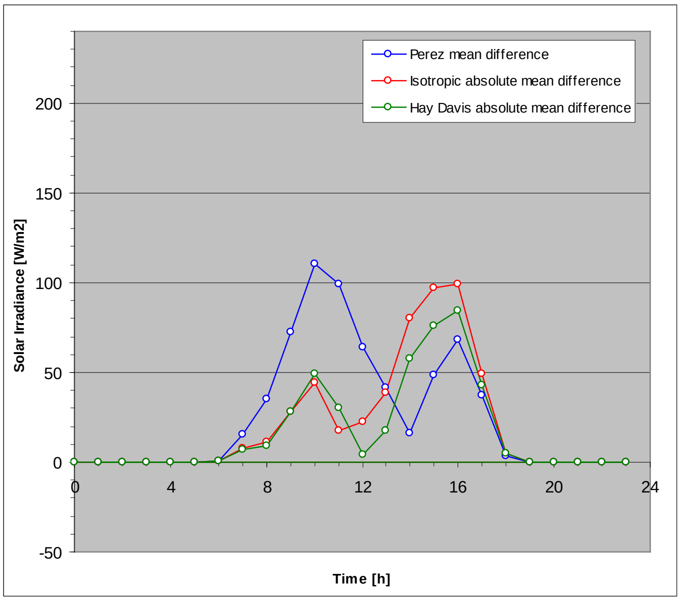
Time steps: Start at t0=0h, t2=0.5h, t3=1.5h,…
Extrapolation of data

Task34_ex2_wetter_carnot.dat - Editor

Datei Bearbeiten Format Ansicht ?

| %1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| 0 | -9999 | 90.0 | -101.6 | -9999 | 0.0 | 0.0 | 12.5 | -3.098 |
| 1800 | -9999 | 90.0 | -101.6 | -9999 | 0.0 | 0.0 | 12.5 | -3.098 |
| 5400 | -9999 | 90.0 | -153.1 | -9999 | 0.0 | 0.0 | 12.2 | -3.562 |
| 9000 | -9999 | 90.0 | -135.1 | -9999 | 0.0 | 0.0 | 11.2 | -5.040 |
| 12600 | -9999 | 90.0 | -120.0 | -9999 | 0.0 | 0.0 | 10.7 | -5.764 |
| 16200 | -9999 | 90.0 | -107.1 | -9999 | 0.0 | 0.0 | 11.0 | -5.578 |
| 19800 | -9999 | 90.0 | -95.5 | -9999 | 0.0 | 0.0 | 11.3 | -5.387 |
| 23400 | -9999 | 88.5 | -84.4 | -9999 | 0.0 | 2.4 | 11.9 | -4.764 |
| 27000 | -9999 | 79.5 | -73.1 | -9999 | 0.0 | 21.4 | 12.6 | -4.154 |



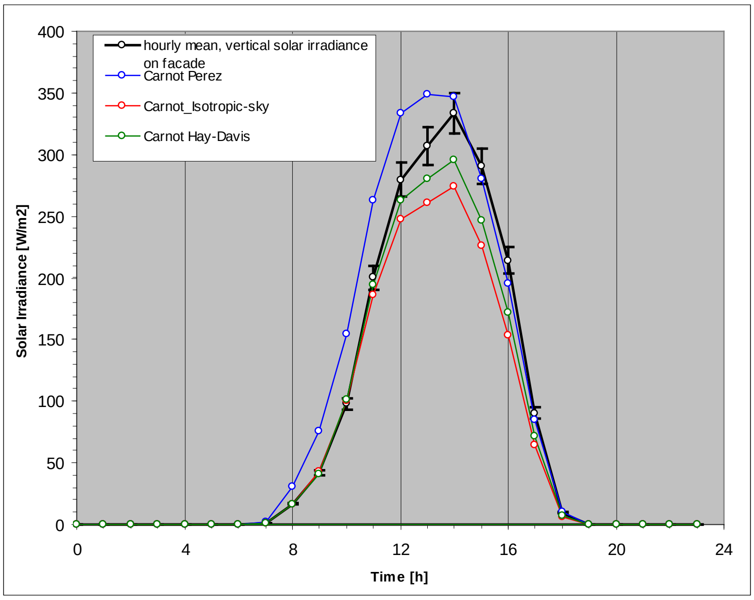

Interpolation of weather input values beginning at time 0, first step 0.5h and then 1h steps, the output radiation seems to create a left-shifted profile compared to measured values.

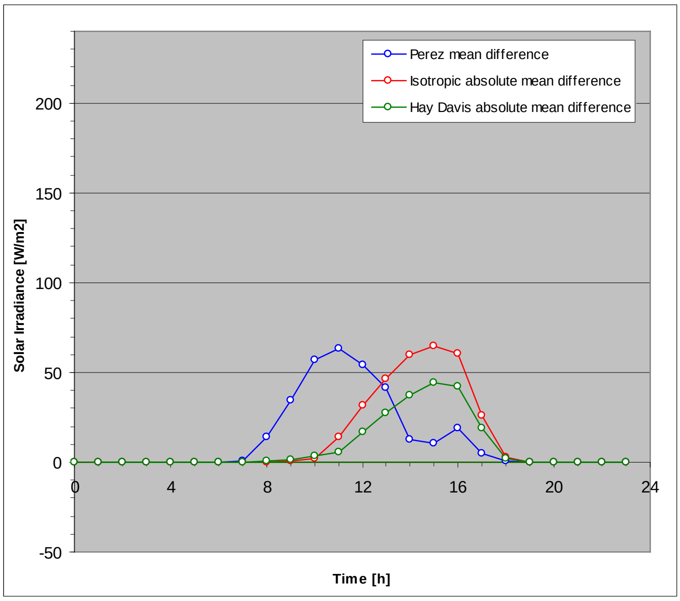
Time steps: Start at t0=0h, t2=1h, t3=2h,…
Extrapolation of data

Task34_ex2_wetter_carnot.dat - Editor

Datei Bearbeiten Format Ansicht ?

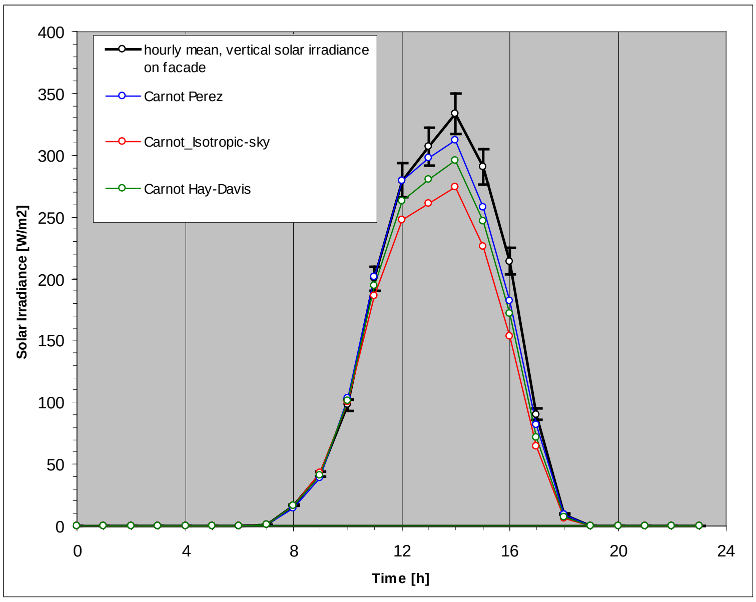
| % 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 0 | -9999 | 90.0 | -101.6 | -9999 | 0.0 | 0.0 |
| 3600 | -9999 | 90.0 | -101.6 | -9999 | 0.0 | 0.0 |
| 7200 | -9999 | 90.0 | -153.1 | -9999 | 0.0 | 0.0 |
| 10800 | -9999 | 90.0 | -135.1 | -9999 | 0.0 | 0.0 |
| 14400 | -9999 | 90.0 | -120.0 | -9999 | 0.0 | 0.0 |
| 18000 | -9999 | 90.0 | -107.1 | -9999 | 0.0 | 0.0 |
| 21600 | -9999 | 90.0 | -95.5 | -9999 | 0.0 | 0.0 |
| 25200 | -9999 | 88.5 | -84.4 | -9999 | 0.0 | 2.4 |
| 28800 | -9999 | 79.5 | -73.1 | -9999 | 0.0 | 21.4 |
| 32400 | -9999 | 70.2 | -60.9 | -9999 | 0.1 | 54.5 |
| 36000 | -9999 | 62.0 | -47.2 | -9999 | 0.4 | 99.3 |

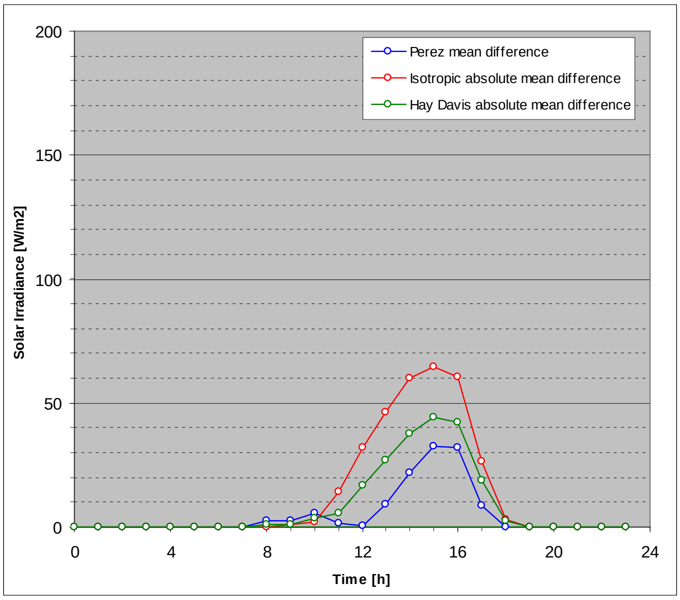



With adapted time steps t0=0, t1=1h the radiation profiles of Hay Davis and isotropic models seem to match the measured values very well. For the Perez model still a certain mismatch of the up going slope is present.

The surfrad.dll S-Function in the weather calculation block in the original Carnot-Blockset seems to create above described difference in the shifted profile. With updated surfrad function from the Carnot_add_lib following improved radiation profile for the Perez model is calculated.




Highest deviation can be observed during afternoon until sunset. Therefore solar angles were checked for errors. Calculation of solar angle Elevation to zenith and azimuth angle shows no deviation.

However, the mean differences of all three models are now in the range of the benchmark Programs evaluated in the EMPA report Task34.

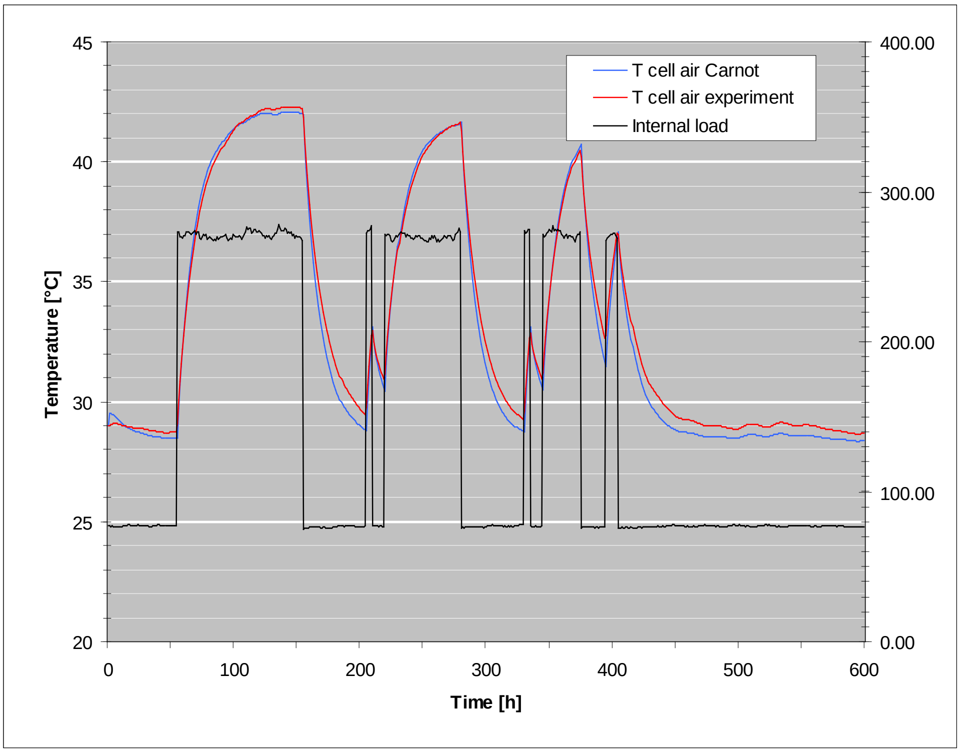
## *Exercise 3 (Glazing unit only)*

### Task34_Ex_3_1

Based on model Task34_Ex_1_34 with following adjustments:

External wall south is interchanged with an exterior wall with window, while maintaining all adjustments and properties of the original wall from Task34_Ex_1_34.
Window size is set to area=0 to proof if changes were done correctly.

Results according Experiment1:




Behaviour is identical to Task34_Ex_1_34, which assures changes are correct.

**Task34_Ex_3_2**

Based on model Task34_Ex_3_1 with following adjustments:

Thermal conductivity values of the PU-foam layer are slightly different. The changes are not taken into account because thermal bridge effects are implemented in the conductivity of this layer as described in model Task34_Ex_1_32.

Orientation of wall with window is 29°.

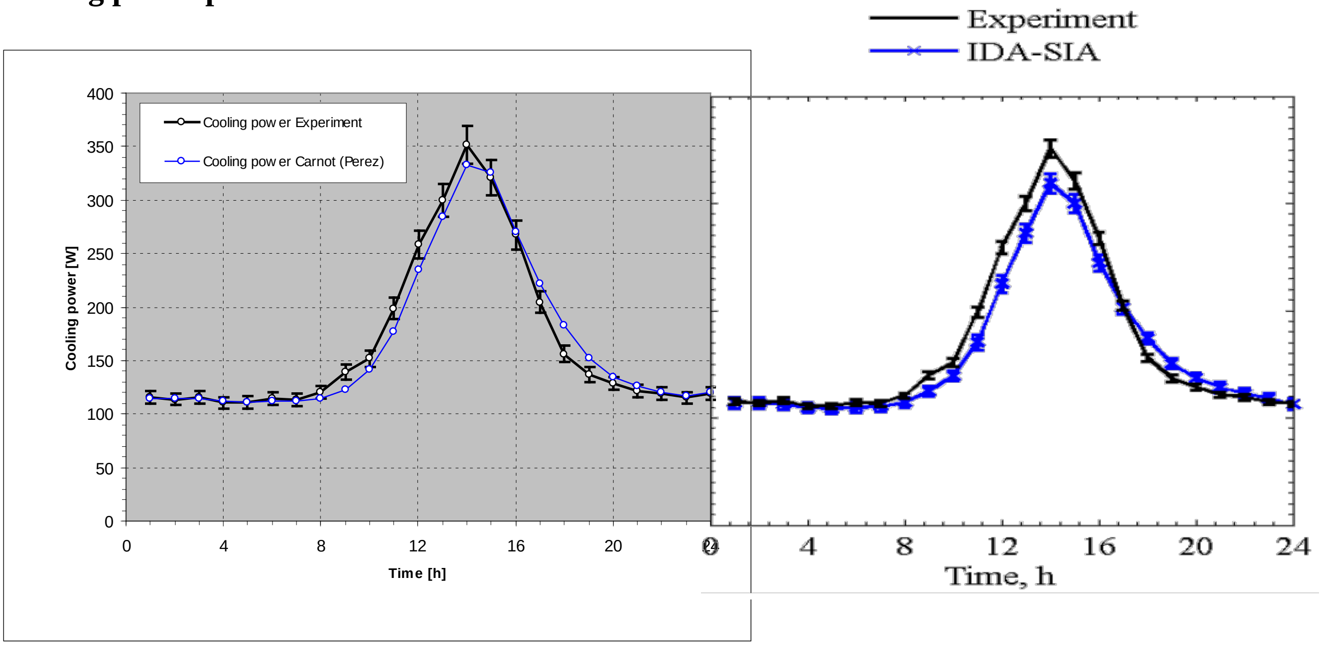
Optical properties of window glazing are set to following specifications:

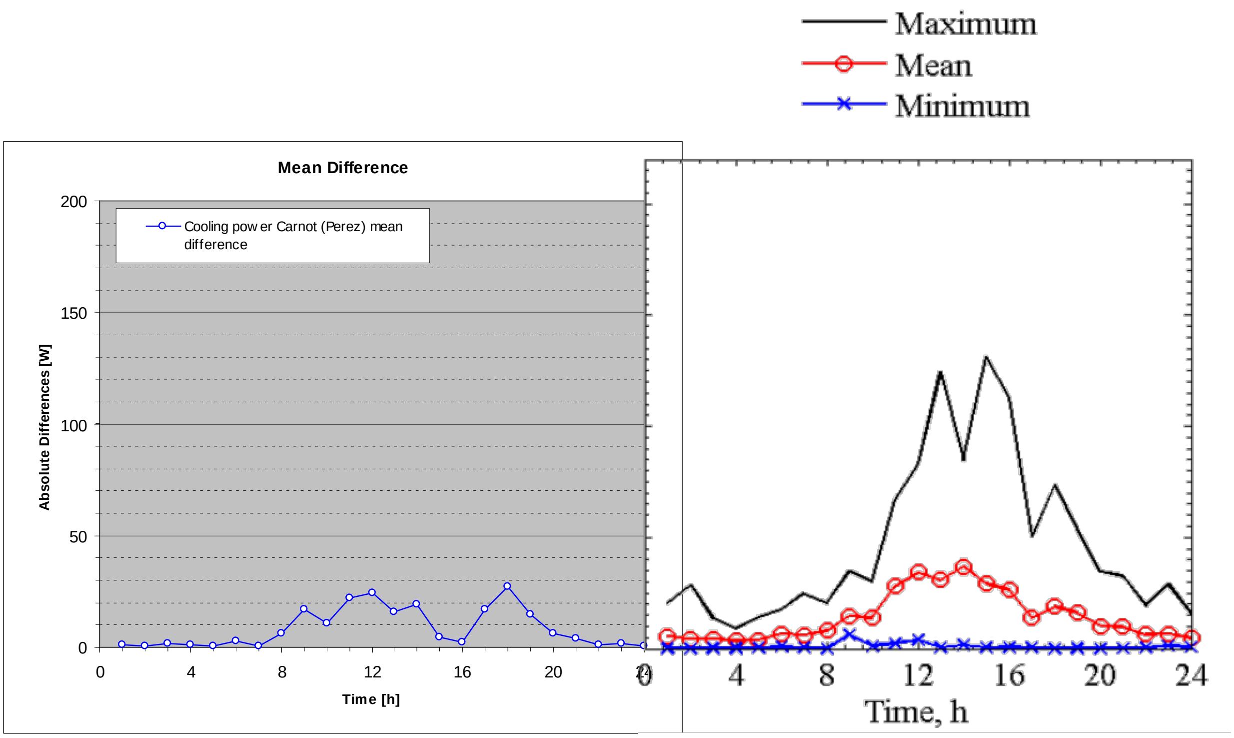
Calculation of g-value with WIS software by integration of measured transmittance reflectance and emittance over the solar spectrum.
Software Optics was used to create database file for WIS software.

- g-value = 0.483 (WIS)
- Transmission of glass = 0.429
- Emission out = 0.894
- Emission in = 0.887
- Absorption out = 0.319 (estimated value so far)
- U_value = 1.05

- Addition of cooling unit. Cell air temperatures from experiment are set as target temperatures for the thermostat that are to maintain during simulation.
  This method showed some disadvantages concerning thermostat behaviour.
- Optionally the measured cell air temperatures are set onto the room-node by selecting “ideal profile (for heating demand)” for air temperature. This method generates cooling energy profile very close to measured data.
- Internal gains specified in the Task34 excel file are applied through purely convective heating unit, acting directly on room node.

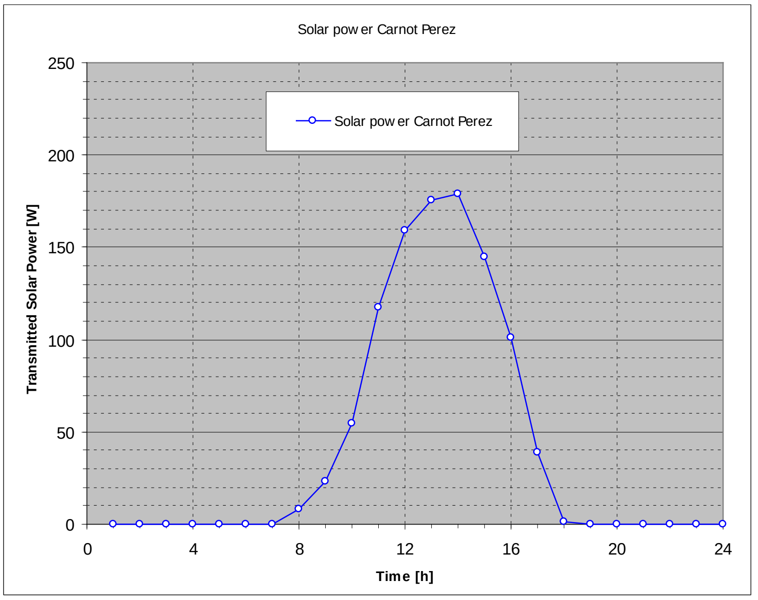
## Cooling power profile

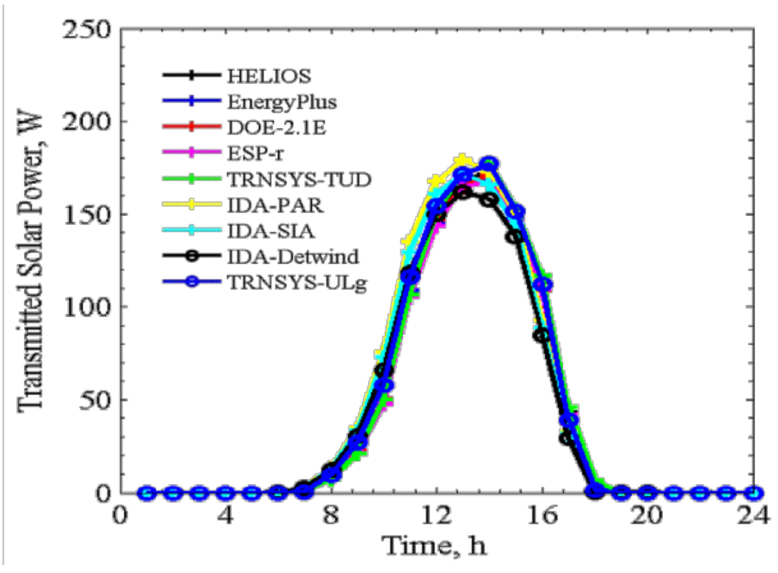



Cooling profile shows good agreement to measured data and also corresponds to the results of the benchmark programs (eq. IDA-SIA).

## Transmitted solar power



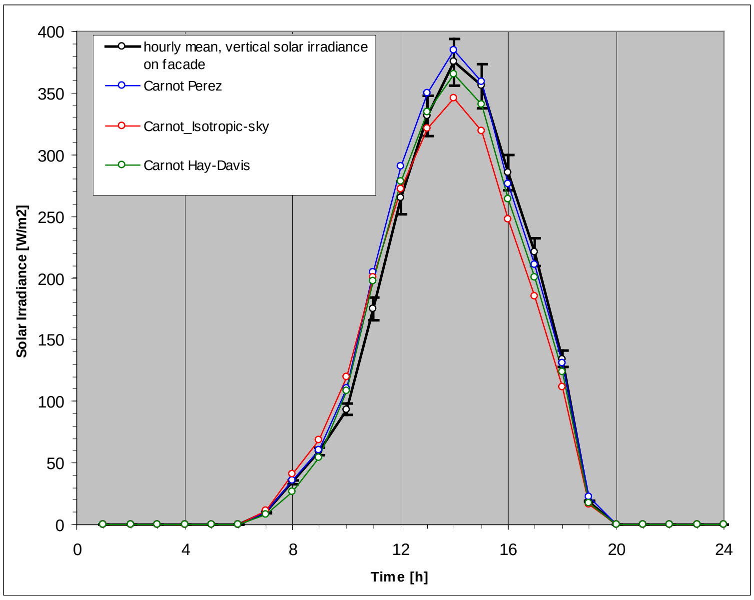

Transmitted solar power profile is very similar to benchmark simulation programs.

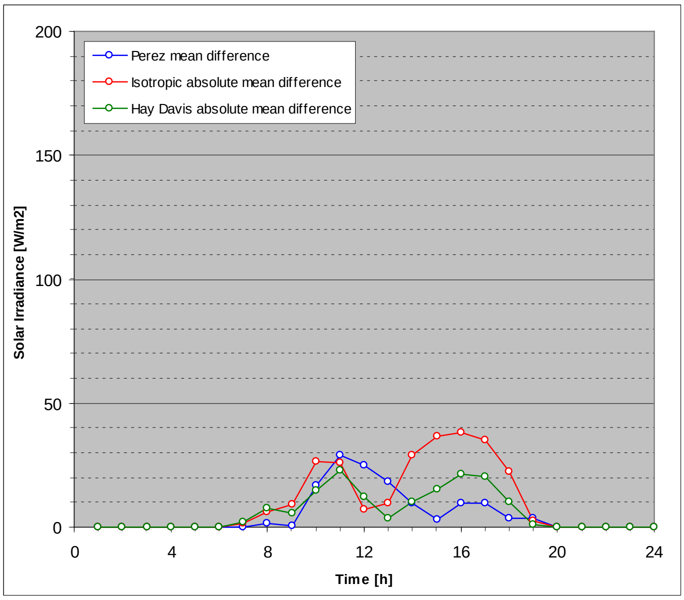
## *Exercise 4 (Glazing unit with exterior shading screen)*

### Carnot_Task34_Ex_4_1.mdl

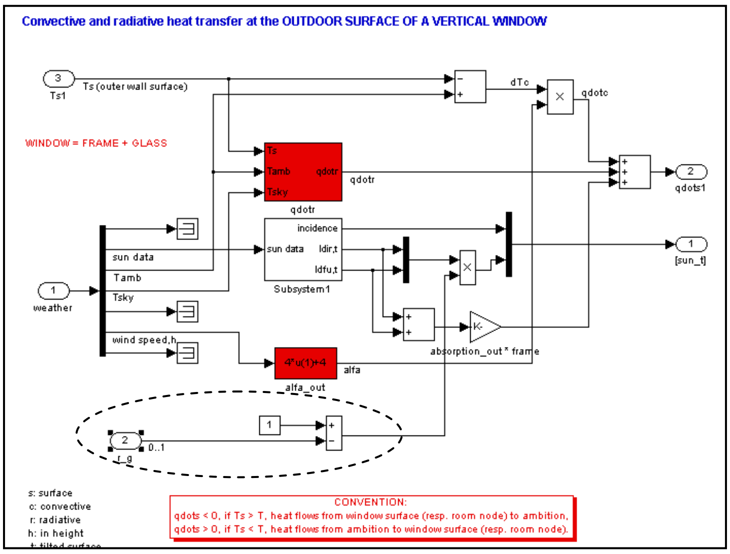
Based on model Task34_Ex_3_2 with most recent input values described in Task34_Ex_3_2

Weather Data:
Weather data is computed analogically to exercise 2 with the following results

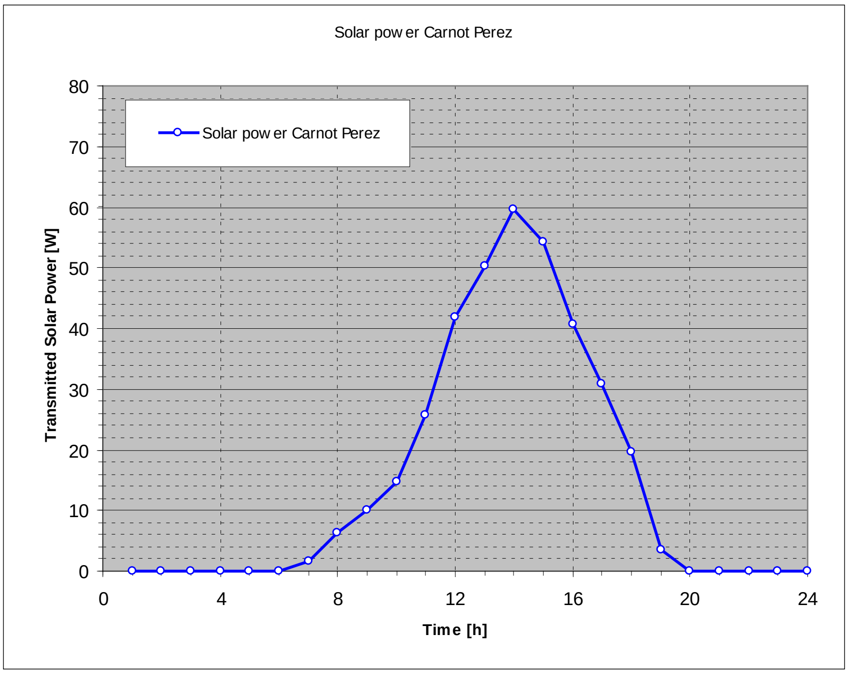


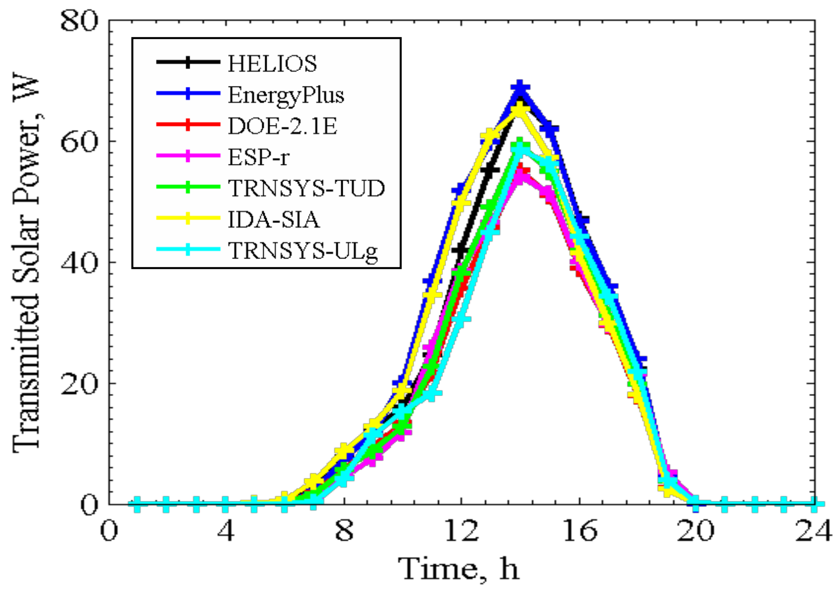



Simple shading model which only reduces incoming solar irradiance (direct + diffuse) by a factor (1-R) R = 0.215, which corresponds to normal solar transmittance of the exterior shading element.

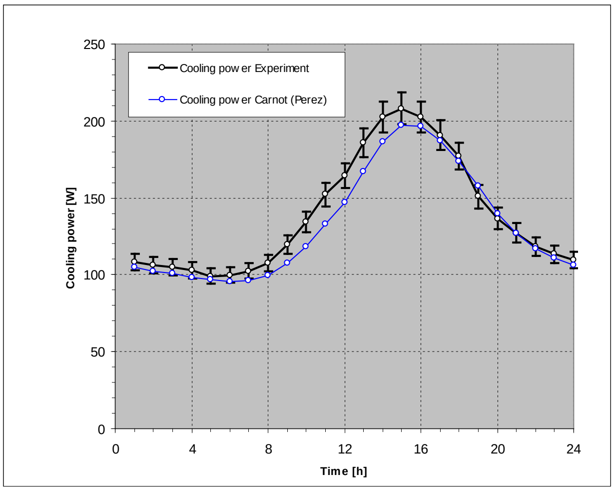


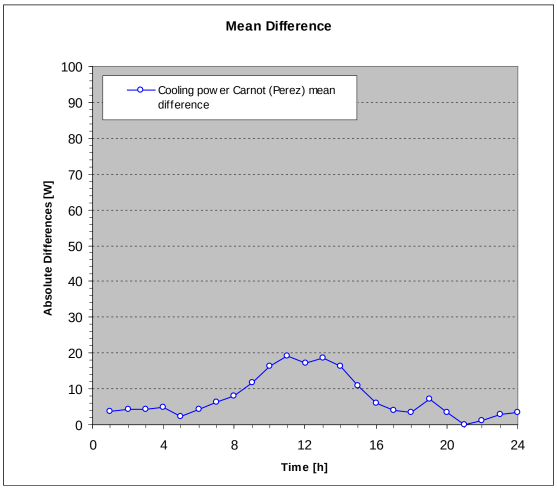

Transmitted solar power

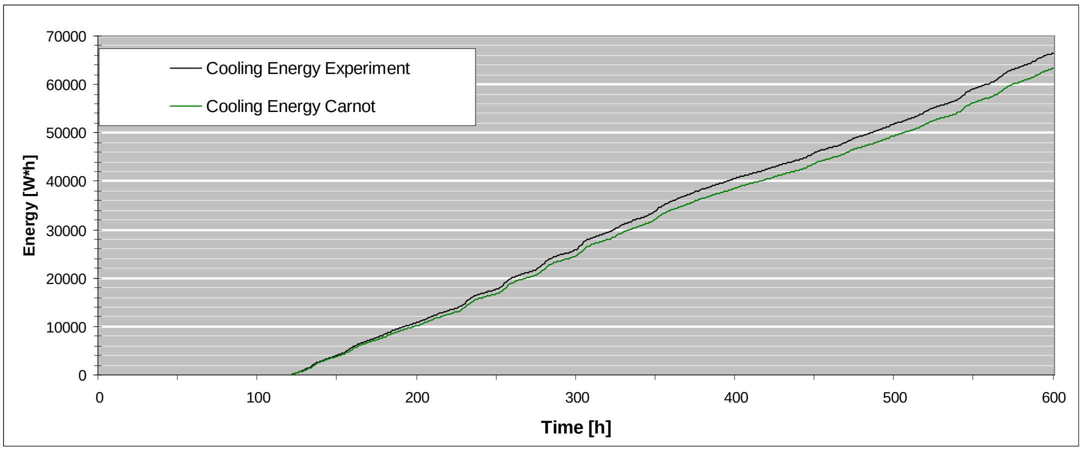


## Cooling power profile




Compared to benchmark programs this simple method for modelling exterior shading shows a surprising accuracy.
Overall difference of cooling energy during considered period is below 5%.

Effects that are not considered in the model that might influence cooling power demand are:

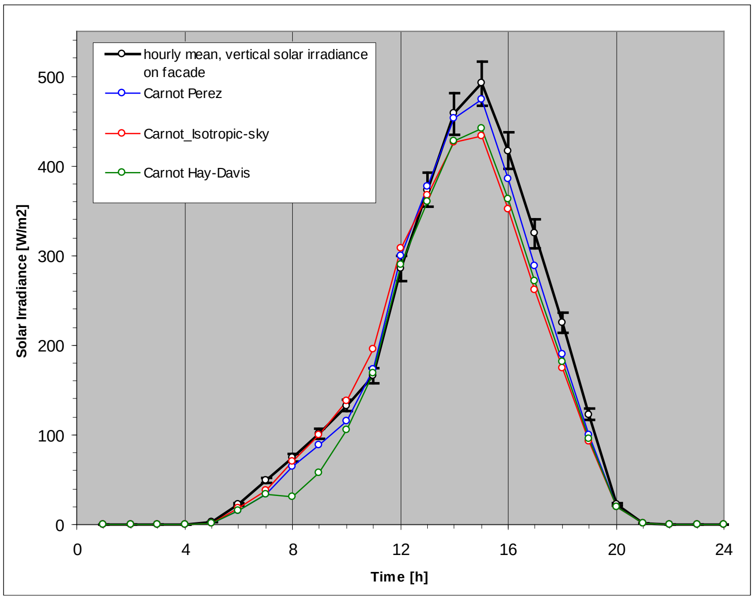
- Shading screen shields the window also against weather (Wind, rain)
- Shading screen reflects back reflected irradiance from the window.
- Solar absorption in the shading screen resulting in infrared emission to the window.

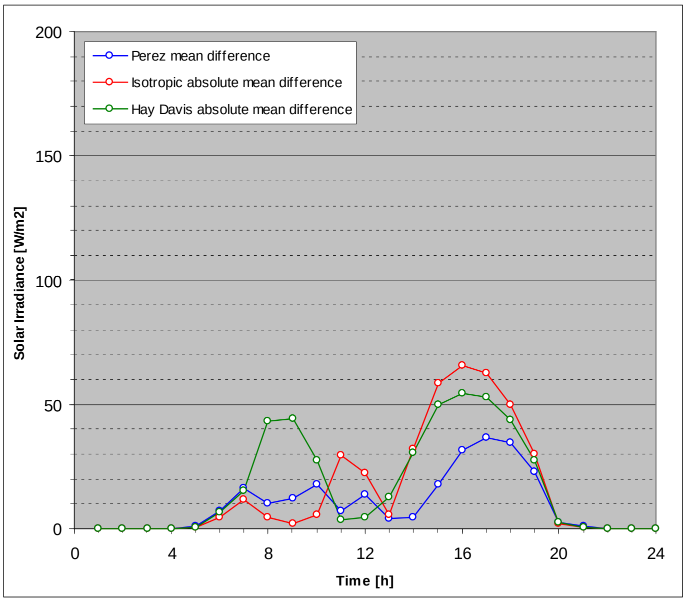
## *Exercise 5 (Glazing unit with interior shading screen)*

### Carnot_Task34_Ex_5_1.mdl

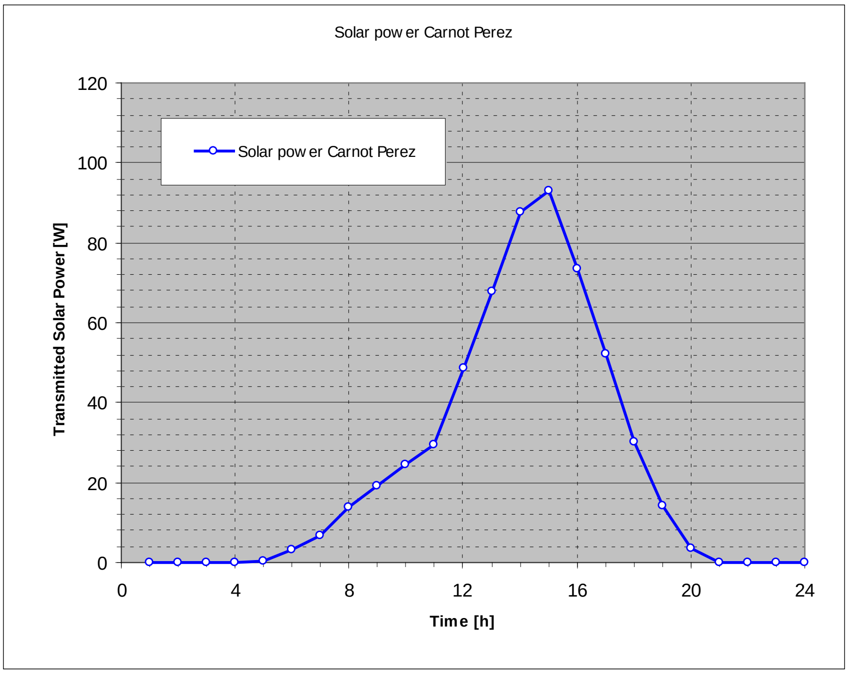
Based on model Task34_Ex_4_1

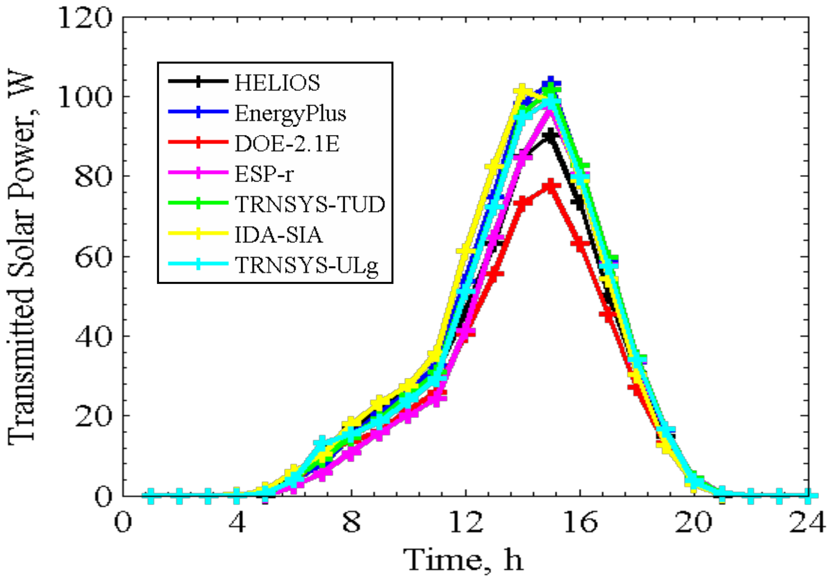
Weather Data:
Weather data is computed analogically to exercise 2 with the following results



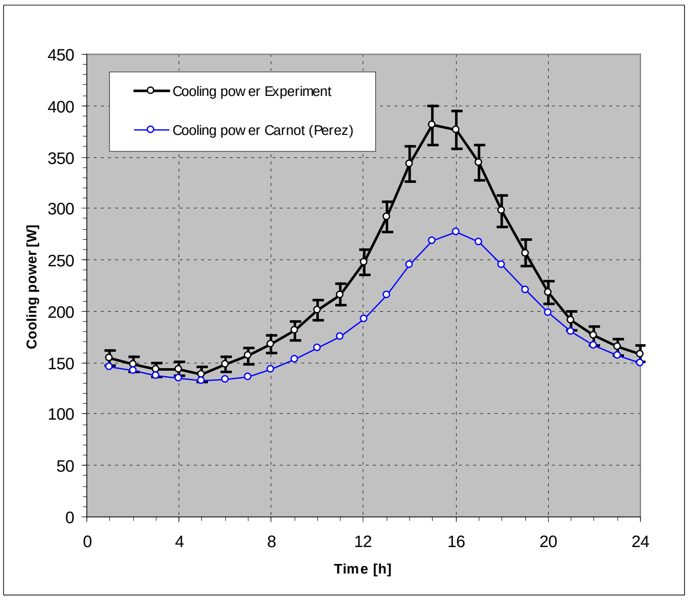
## Transmitted solar power



Cooling power profile with simple shading model which only reduces incoming solar irradiance (direct + diffuse) by a factor (1-R)
R = 0.304, which corresponds to normal solar transmittance of the exterior shading element.

### Cooling power profile

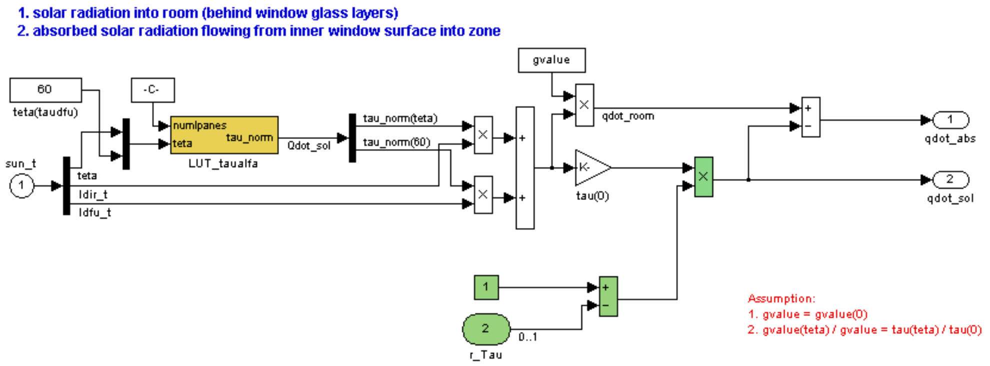



The very simple shading model only respects reducing of solar transmittance into the room. Because of interior mounted shading the absorbed solar power on the shading, is delivered into the room via convection and infrared emission. Also a part of the reflected irradiance from the shading back to the window is absorbed in the window and/or once again reflected onto the shading screen.
As these effects are not taken into account a much too low cooling demand is calculated, although transmitted solar power corresponds with benchmark programs.

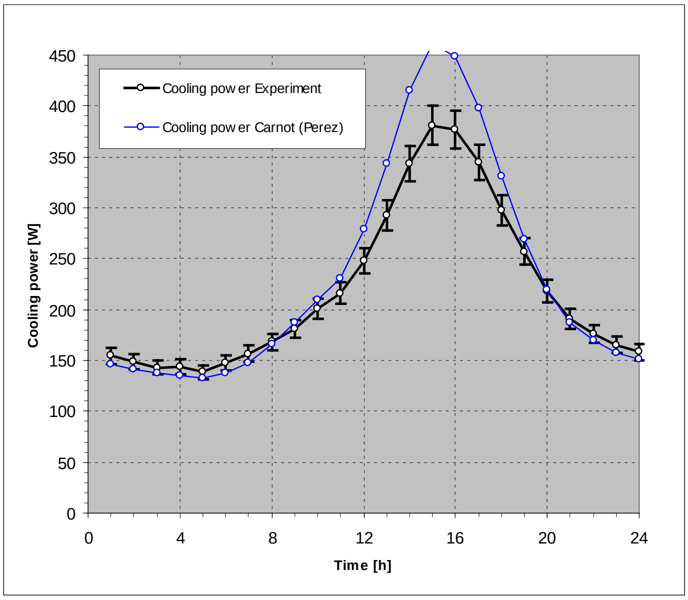
### Carnot_Task34_Ex_5_2.mdl

Based on model Task34_Ex_5_1

Shading model which adjusts solar transmittance and absorption of inner window pane by factor (1-R) (green elements).
R = 0.304, which corresponds to integral normal solar transmittance of the exterior shading element.




### Cooling power profile



**Carnot_Task34_Ex_5_3.mdl**

Based on model Task34_Ex_5_2

Improved shading model which adjusts also g-value of window by a special factor

Tabelle 32 Solare und thermische Kennwerte typischer Verglasungen

| Verglasung | $U_g$ in W/m²·K | $\tau_v$ | $\rho_v$ | $\tau_e$ | $q_i$ | $g$ |
|---|---|---|---|---|---|---|
| Einfachglas normal | > 5 | 0,89 | 0,08 | 0,83 | 0,02 | 0,85 |
| Einfach-Wärmeschutzglas (hartbeschichtet) | 3,7 | 0,82 | 0,11 | 0,68 | 0,06 | 0,74 |
| Zweifachglas normal | 2,9 | 0,82 | 0,15 | 0,73 | 0,04 | 0,77 |
| Zweifach-Wärmeschutzglas | 1,3 | 0,76 | 0,12 | 0,53 | 0,11 | 0,64 |
| Zweifach-Wärmeschutzglas | 1,0 | 0,75 | 0,13 | 0,45 | 0,12 | 0,57 |
| Zweifach-Kombiglas 73/41 | 1,2 | 0,73 | 0,12 | 0,41 | 0,03 | 0,44 |
| Zweifach-Kombiglas 50/24 | 1,1 | 0,50 | 0,12 | 0,24 | 0,03 | 0,27 |
| Dreifachglas normal | 2,0 | 0,75 | 0,20 | 0,63 | 0,06 | 0,69 |
| Dreifach-Wärmeschutzglas | 0,7 | 0,71 | 0,14 | 0,42 | 0,09 | 0,51 |
| Dreifach-Wärmeschutzglas | 0,5 | 0,66 | 0,14 | 0,36 | 0,11 | 0,47 |

$U_g$ Wärmedurchgangskoeffizient der Verglasung
$\tau_v$ Lichttransmissionsgrad
$\rho_v$ Lichtreflexionsgrad
$\tau_e$ direkter solarer Transmissionsgrad
$q_i$ sekundärer Wärmeabgabegrad der Verglasung
$g$ Gesamtenergiedurchlassgrad

Tabelle 33 Solare Kennwerte typischer Verglasungen mit Sonnenschutz

| Verglasung | Sonnenschutz | Farbe | $\tau_{e,B}$ | $\tau_v$ | $g$ |
|---|---|---|---|---|---|
| Zweifachglas normal | aussen | pastell | 0,1 | 0,09 | 0,13 |
| Zweifachglas normal | innen | hell | 0,1 | 0,09 | 0,37 |
| Zweifach-Wärmeschutzglas | aussen | pastell | 0,1 | 0,08 | 0,09 |
| Zweifach-Wärmeschutzglas | innen | hell | 0,2 | 0,16 | 0,40 |
| Zweifach-Kombiglas 73/41 | innen | hell | 0,2 | 0,15 | 0,32 |
| Zweifach-Kombiglas 50/24 | innen | hell | 0,2 | 0,11 | 0,23 |
| Dreifachglas normal | aussen | pastell | 0,1 | 0,08 | 0,11 |
| Dreifachglas normal | innen | hell | 0,1 | 0,09 | 0,37 |
| Dreifach-Wärmeschutzglas | aussen | pastell | 0,1 | 0,07 | 0,07 |
| Dreifach-Wärmeschutzglas | innen | pastell | 0,2 | 0,15 | 0,40 |
| Dreifach-Wärmeschutzglas | innen | hell | 0,2 | 0,15 | 0,36 |

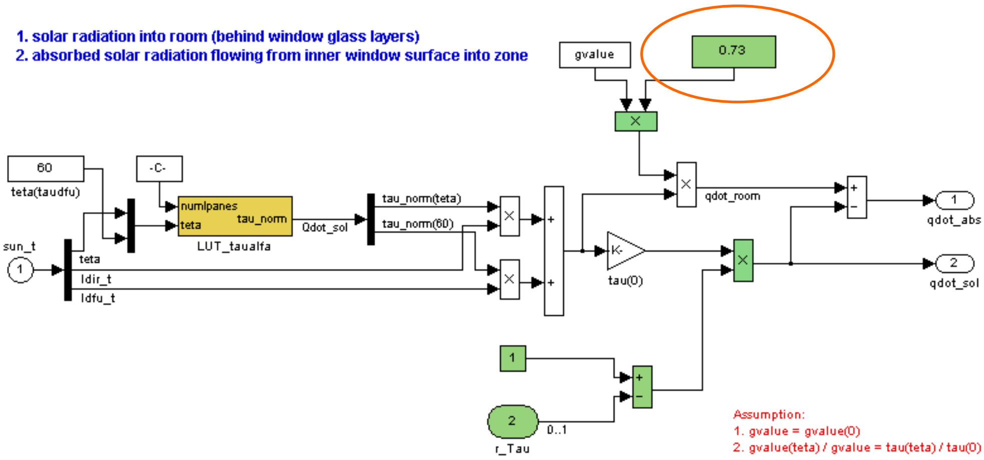
$\tau_{e,B}$ solarer Transmissionsgrad des Sonnenschutzes

(Extracted from SIA 382-1-2007, page 70,

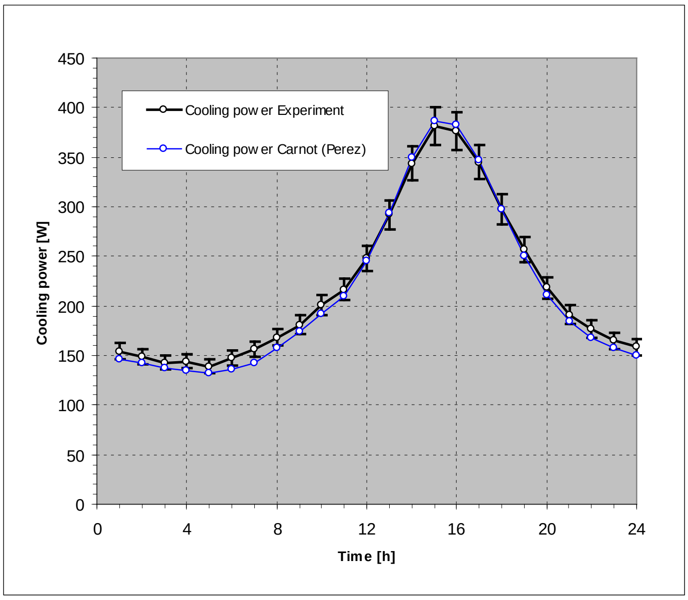
Derivation of factor:

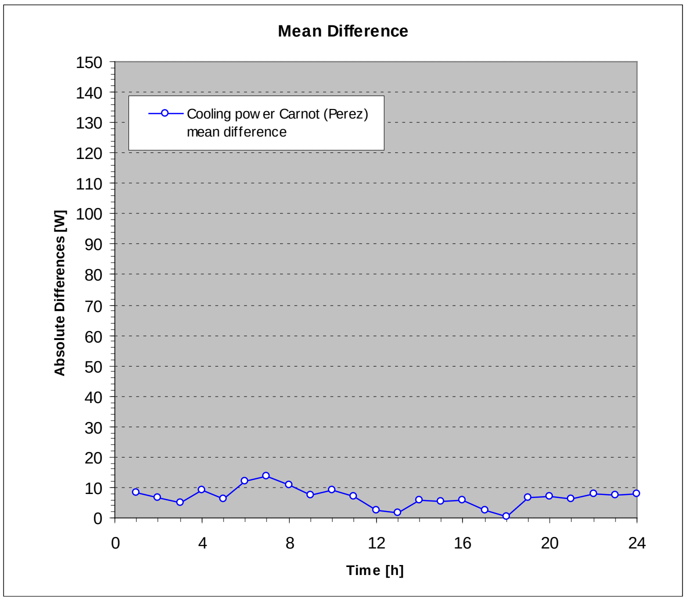
- Relation of corresponding g-values of unshaded window to shaded window.
  G-value of unshaded window was calculated with WIS software by integration of measured optical and emittance values over the solar spectrum. (exercise 3)
  g-value = 0.483
  → calculated g-value corresponds to “Zweifach-Kombiglas 73/41” with g-value = 0.44
  → inner shaded (hell) “Zweifach-Kombiglas 73/41” g-value = 0.32

$$factor = \frac{0.32}{0.44} = 0.73$$


1. solar radiation into room (behind window glass layers)
2. absorbed solar radiation flowing from inner window surface into zone
gvalue
0.73
60
teta(taudfu)
-C-
numlpanes
teta
tau_norm
LUT_taualfa
Qdot_sol
tau_norm(teta)
tau_norm(60)
sun_t
teta
Idir_t
Idfu_t
qdot_room
tau(0)
1
qdot_abs
2
qdot_sol
r_Tau
0..1
Assumption:
1. gvalue = gvalue(0)
2. gvalue(teta) / gvalue = tau(teta) / tau(0)

## Cooling power profile




Compared to benchmark programs this method for modelling interior shading shows a surprising accuracy.
Overall difference of cooling energy profile to experiment during considered period is below 3%.

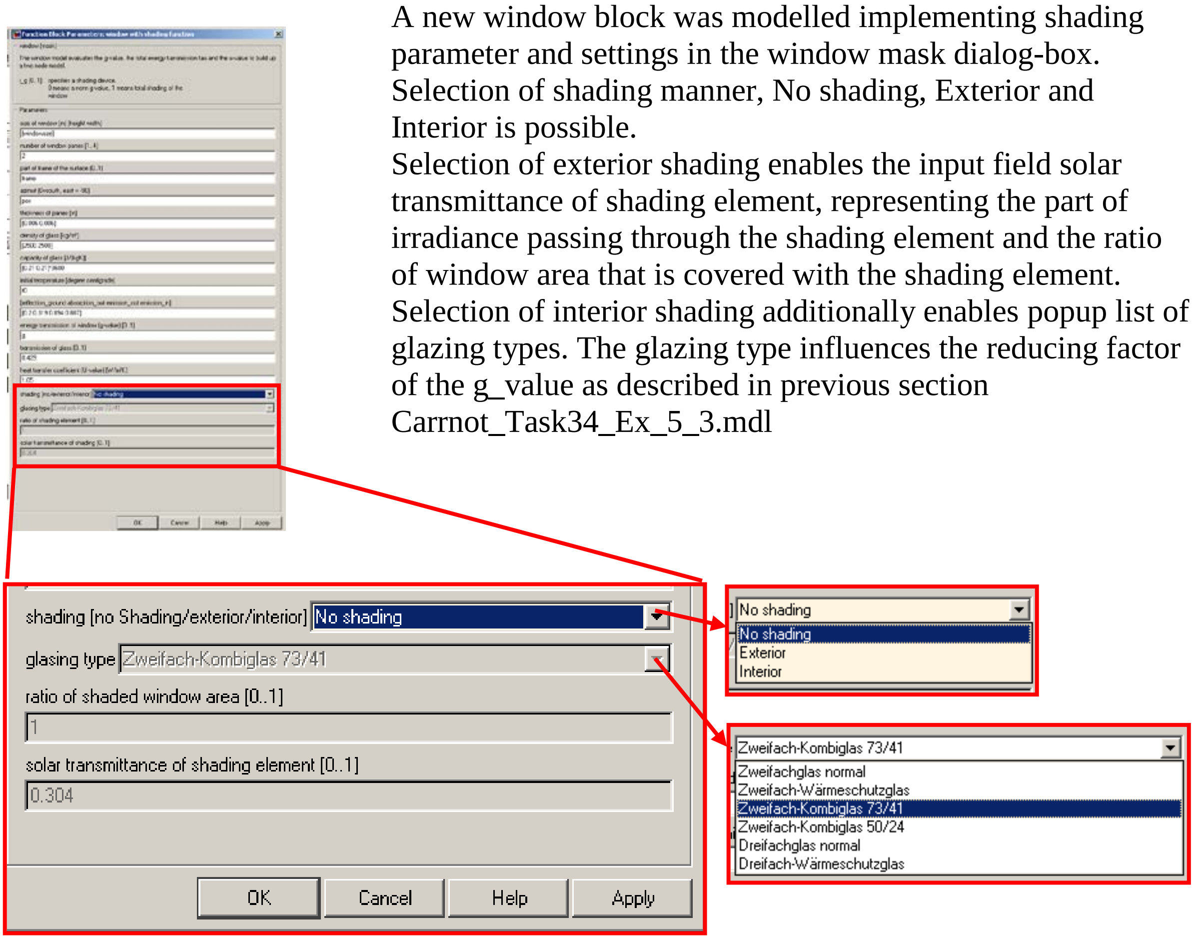
Effects that are not considered in the model that might influence cooling power demand are:

- Influence on dynamics of heat transfer due to convection is not considered
- Reflectance back out of the window

## Carnot_Task34_Ex_5_4.mdl

Based on model Task34_Ex_5_3

A new window block was modelled implementing shading parameter and settings in the window mask dialog-box. Selection of shading manner, No shading, Exterior and Interior is possible.
Selection of exterior shading enables the input field solar transmittance of shading element, representing the part of irradiance passing through the shading element and the ratio of window area that is covered with the shading element.
Selection of interior shading additionally enables popup list of glazing types. The glazing type influences the reducing factor of the g_value as described in previous section Carrnot_Task34_Ex_5_3.mdl




Simulation results analogue to previous section Carnot_Task34_Ex_5_3.mdl.

## *Exercise 6 (Glazing unit with exterior Venetian blind)*

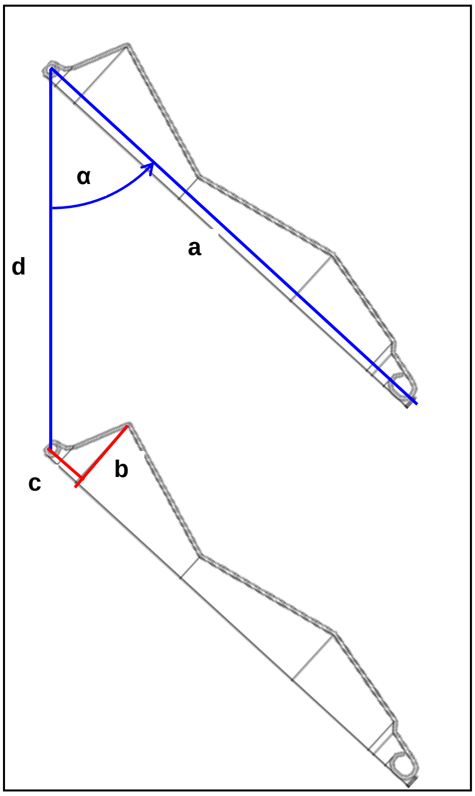
### Venetian blind

Shading factors are defined to count for shading of direct and diffuse irradiance.

Geometrical properties of blinds:

| | | | |
|---|---|---|---|
| Blind blade depth | **a** | 91.65 | mm |
| Blind blade height | **b** | 11.15 | mm |
| Blind blade | **c** | 9 | mm |
| Blind blade offset | **d** | 62 | mm |

α = 0 --> closed blinds
α = 90 --> horizontal blinds

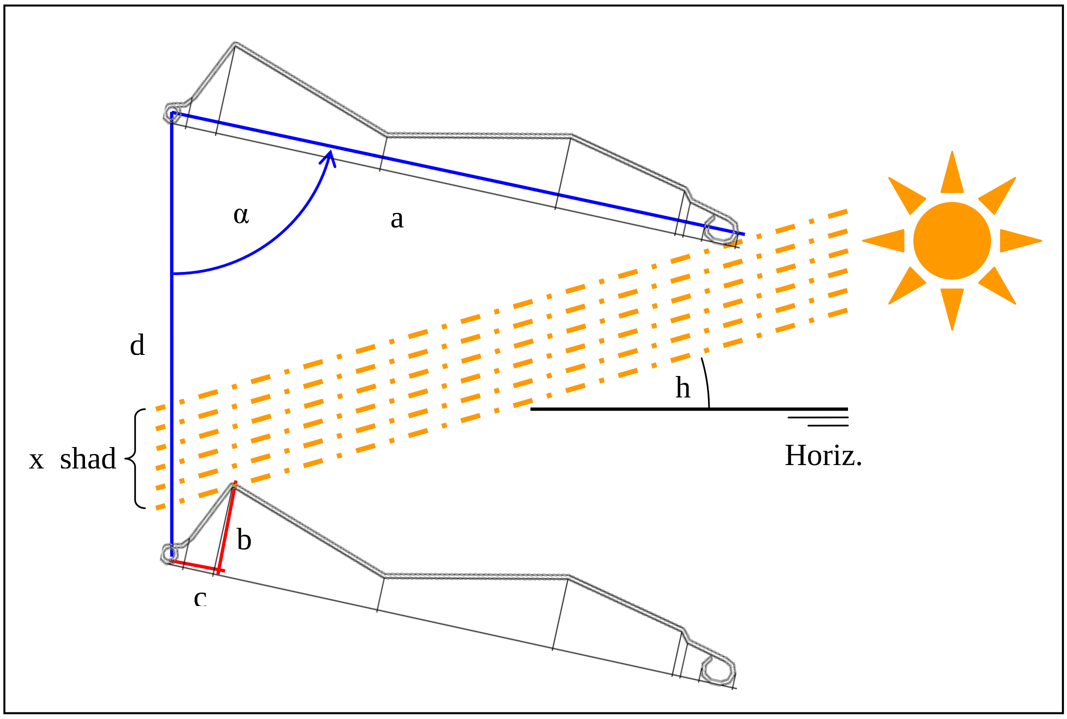


Shading method of direct beam irradiance:

Shading of direct beam is regarded as shading factor which reduces direct solar irradiance passing through window surface. The “view factor” is build as ratio of distance between the blind blades remaining open to the blinds’ offset distance.

- x_shad = function(a, b, c, d, h, α)
- F_Shad_dir = x_shad / d
- Shading_factor = 1 - F_Shad_dir

See appendix for detailed calculation method in Matlab m-script file

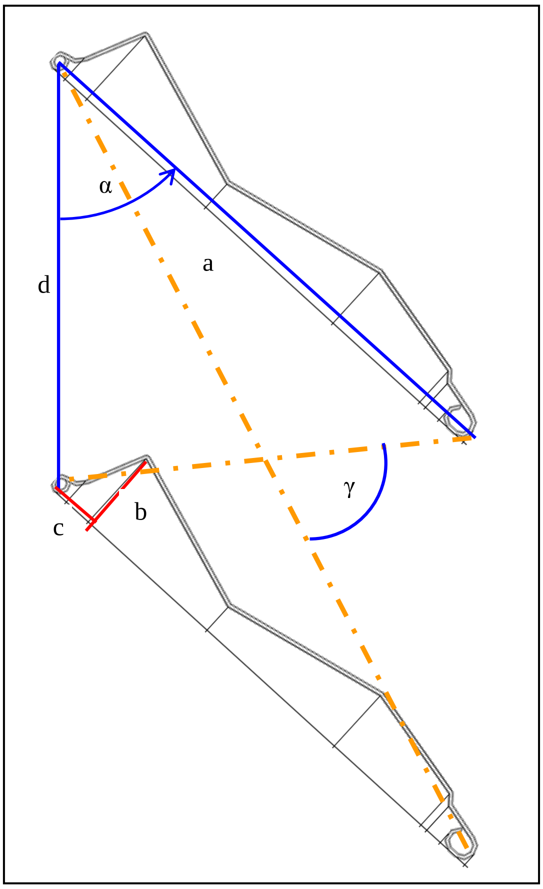



This method also corresponds to that of H. Simmler et al. “Experimental and numerical determination of the total solar energy transmittance of glazing with venetian blind shading”

Shading method of diffuse irradiance:

Assuming that diffuse irradiance is distributed evenly around the window in an angle of 180° the Venetian blind lets the window only see part of it. This part is described as open angle “γ” which depends on blind geometrics.
Similar to the view factor method the angle γ which is left open by the blinds is therefore set in relation to the maximal possible view angle of 180°.

- $\gamma$ = function(a, d, $\alpha$)
- F_Shad_dfu = $\gamma$ / pi




Reflectance of diffuse irradiance seems to have a not negligible effect on solar gain and is therefore modelled in the following way.

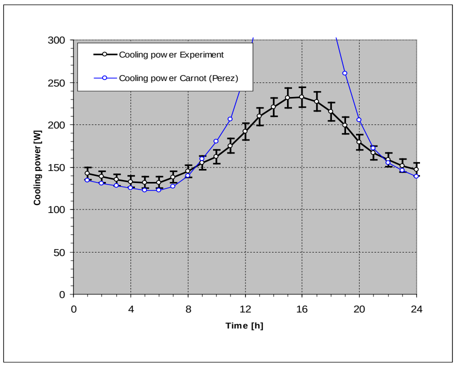
| | |
|---|---|
| • refl = 0.441 | Geometrical reflectance of blind surface |
| • A = 1.3 | Weight factor of reflectance empirically evaluated with task34 empa measurements |
| • Refl_alpha = 1-sin(pi/2+ $\alpha$) | Term that creates 0..1 (1=no Reflection with $\alpha$=0° / 0=Total Reflection with $\alpha$=90°) as a function of blind angle $\alpha$ |
| • D_refl = (1-refl* Refl_alpha)*A_corr | Reflectance factor which is used to reduce shading factor |

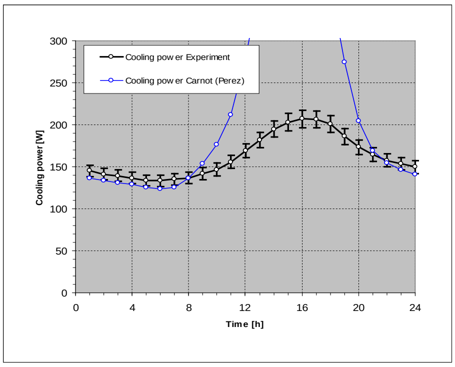
- Shading_factor = 1 - F_Shad_dfu* D_refl

See appendix for detailed calculation method in Matlab m-script file

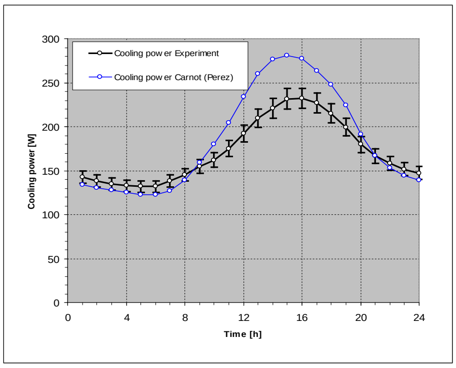
Comparison of different modelling steps for both periods

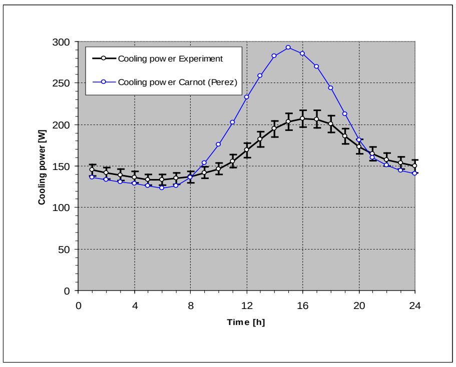
**Period a (Blinds 90°)** **Period b (Blinds 45°)** **Model**



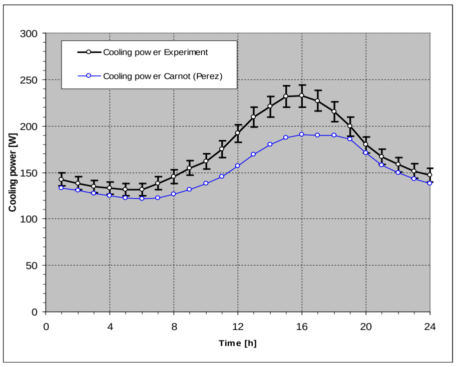



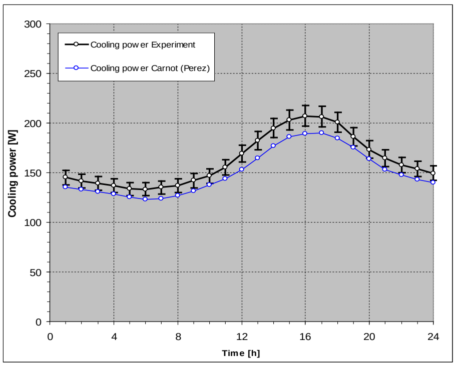

No Shading



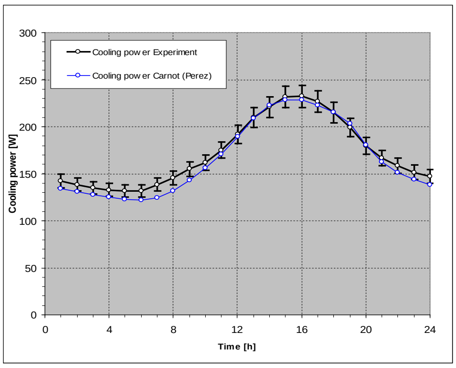



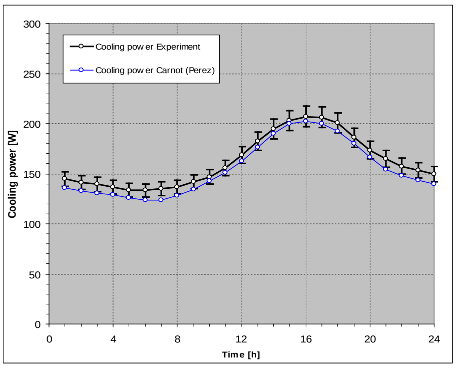

Shading of direct irradiance



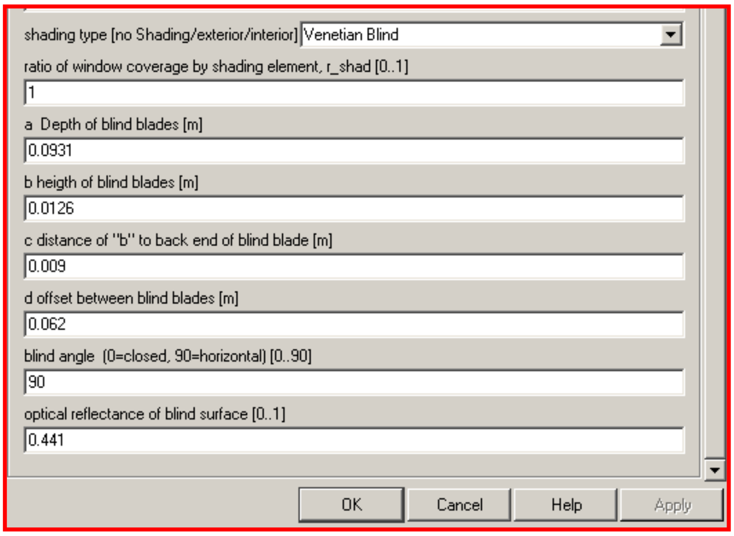

Shading of direct and diffuse irradiance

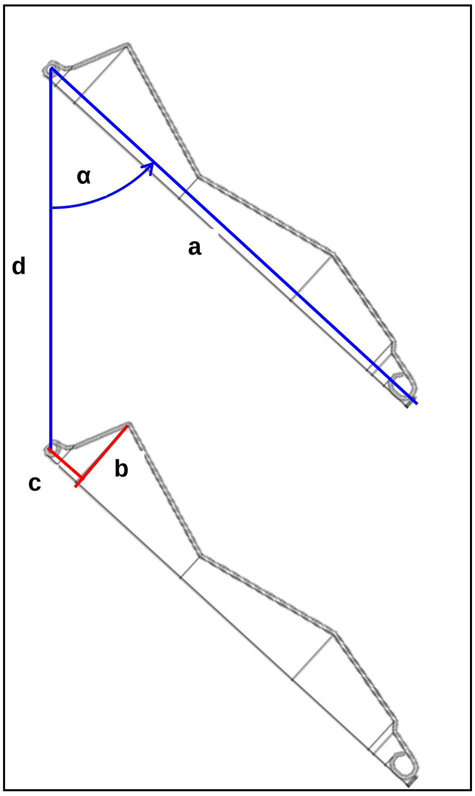



Shading of direct and diffuse irradiance respecting reflectance of diffuse irradiance on blind surfaces

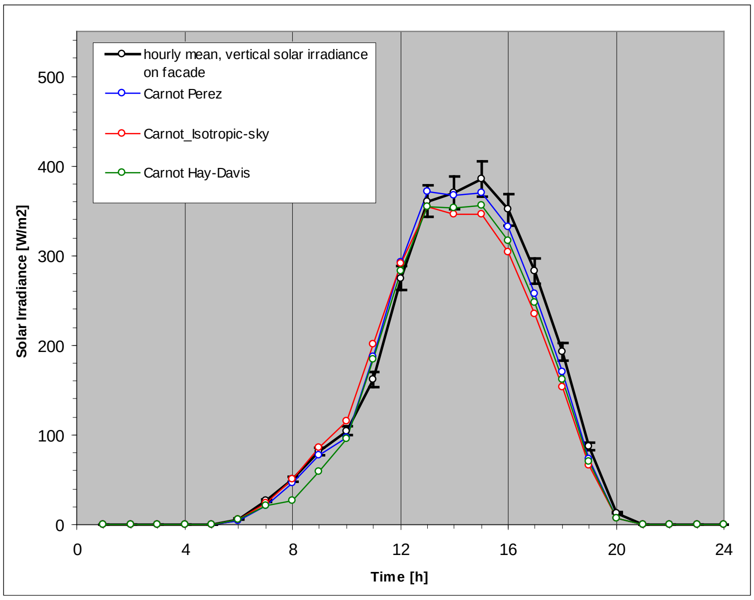
The new window block is enhanced allowing needed input of geometrical and optical properties for the shading calculation.

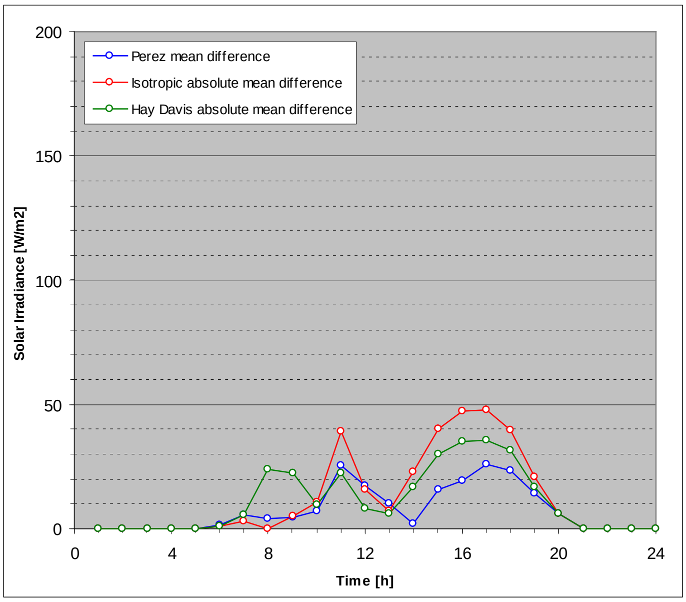


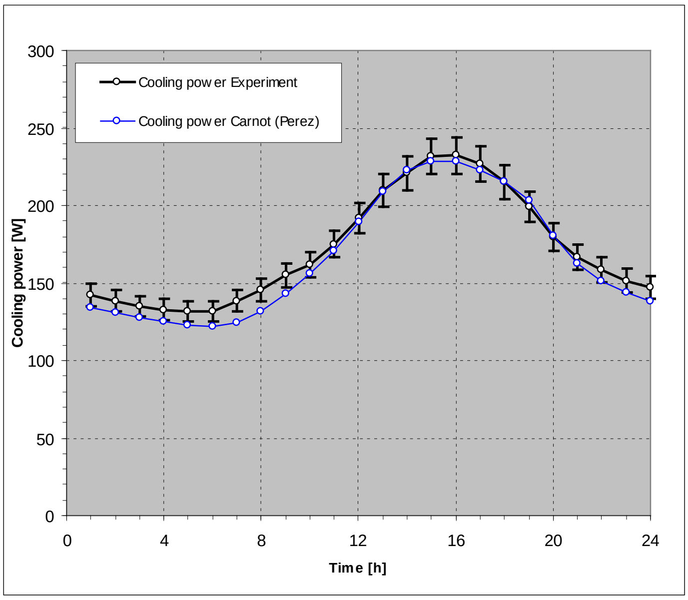
## Period a

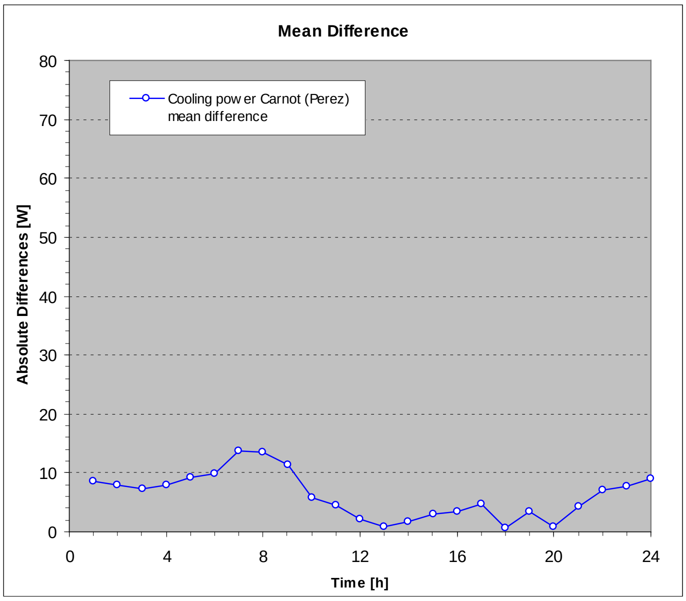
### Solar Irradiance



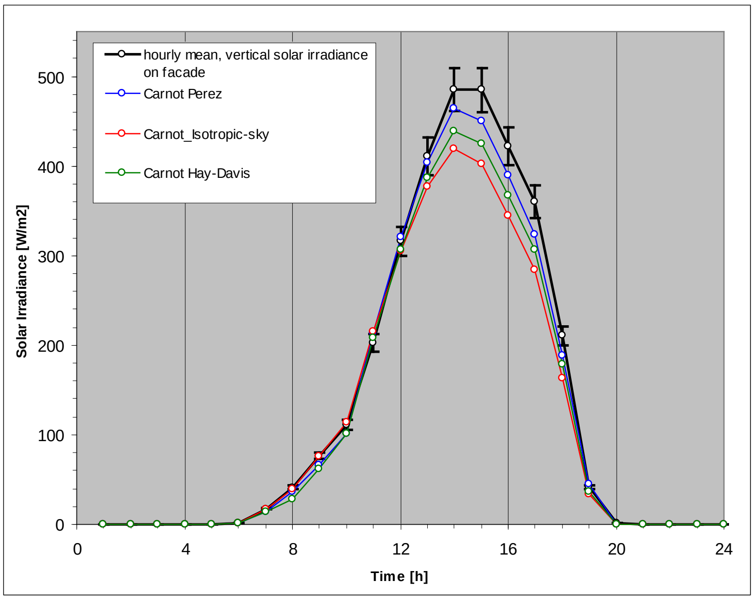



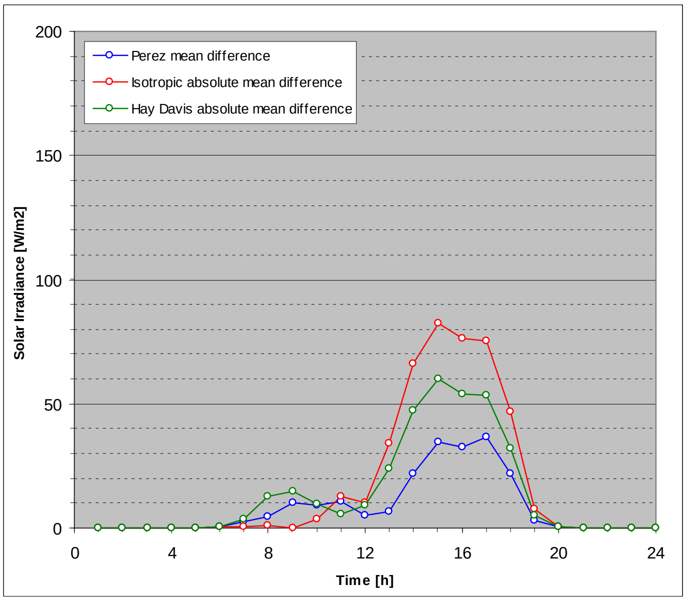
## Cooling power profile



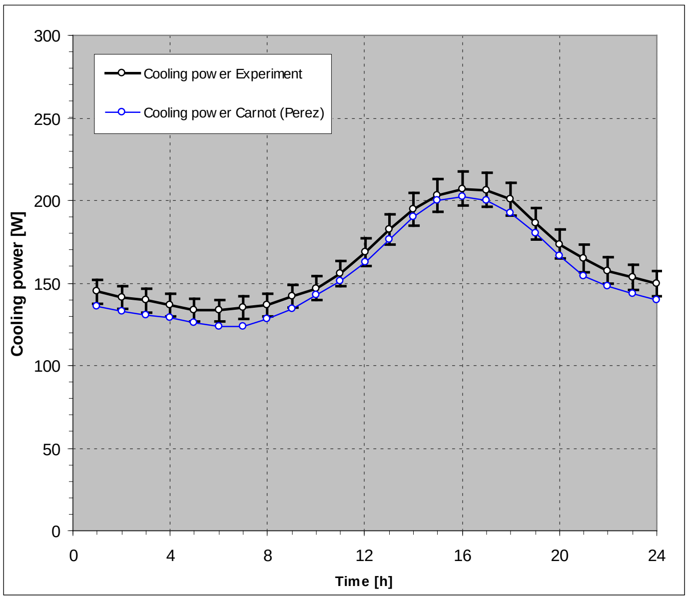



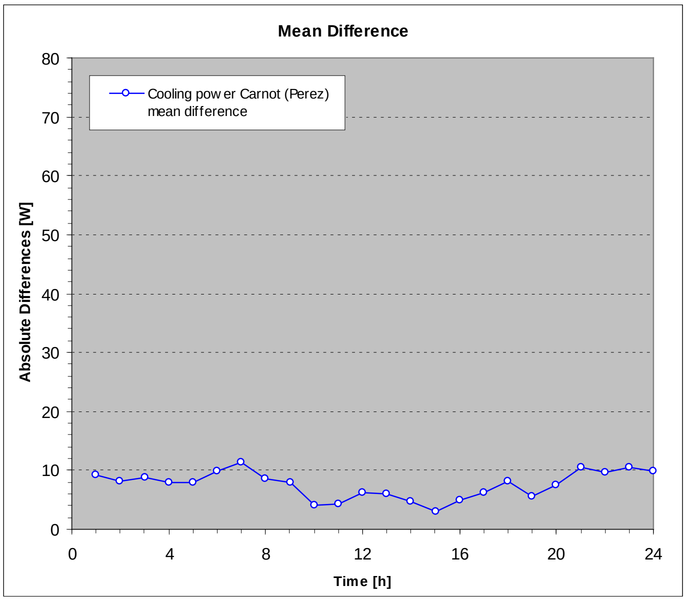
## Period b


hourly mean, vertical solar irradiance on facade
Carnot Perez
Carnot_Isotropic-sky
Carnot Hay-Davis
Solar Irradiance [W/m2]
Time [h]
0
100
200
300
400
500
0
4
8
12
16
20
24


Perez mean difference
Isotropic absolute mean difference
Hay Davis absolute mean difference
Solar Irradiance [W/m2]
Time [h]
0
50
100
150
200
0
4
8
12
16
20
24

# Cooling power profile



## *Exercise 8 (Glazing unit with frame)*

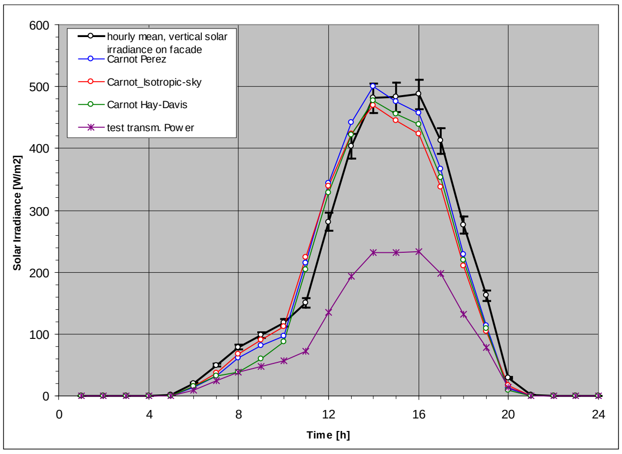
Errata: The weather file (excel: Experiment 8.xls) for exercise 8 shows corrupted data for azimuth angle.

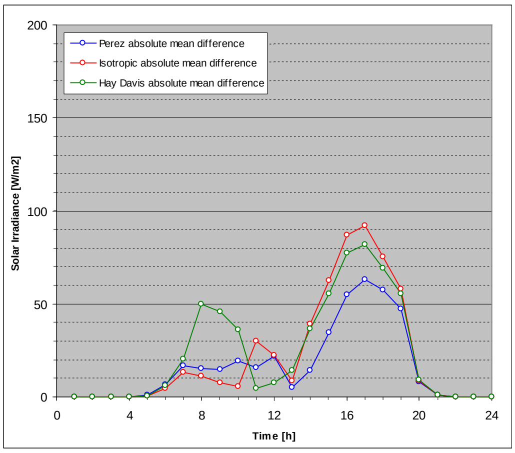
Several methods of implementing azimuth angle into the calculation are tried for best fit to the measured irradiance on tilted façade.

Irradiance with azimuth angles from sunpos calculation method from Carnot library with position input as described in the table for simulation time (4200*3600sec to 4800*3600sec)

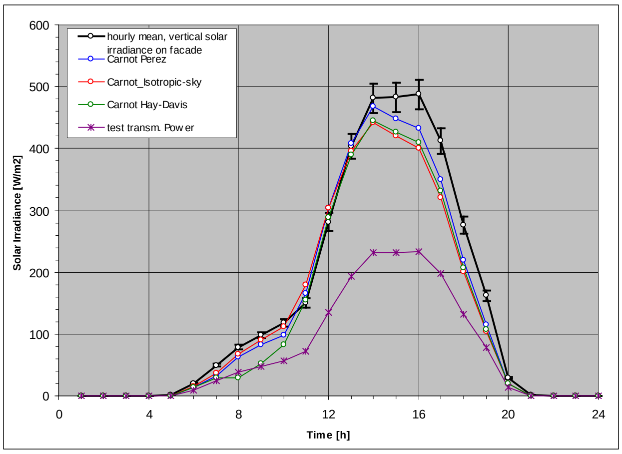
Table 3.1. Location of the EMPA test cell.

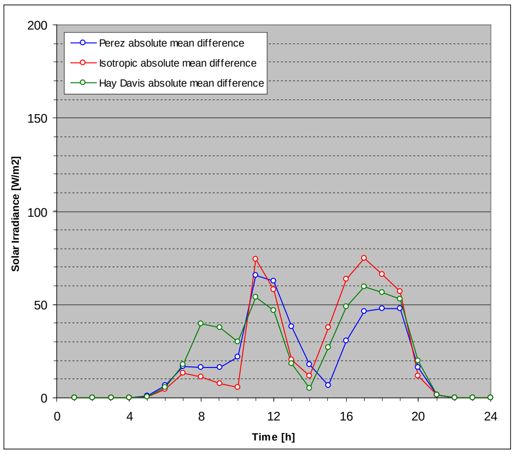
| | |
|---|---|
| Degrees of longitude | 8.6° East |
| Degrees of latitude | 47.7° North |
| Altitude above sea-level | 430 m |
| Time Zone | Central European Time (GMT + 1 h) |
| Orientation of external wall | 29° (south = 0°, west =90°) |



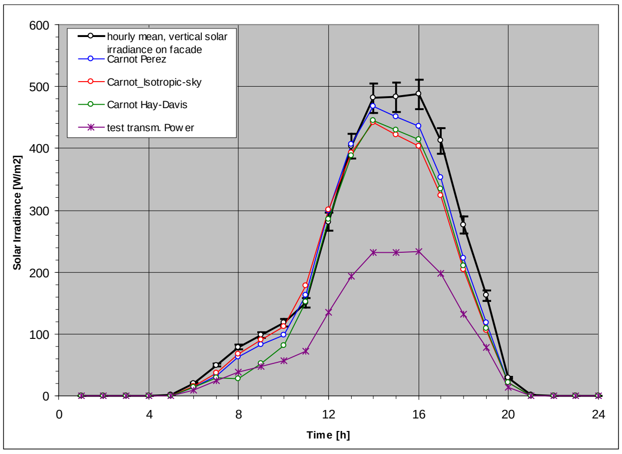



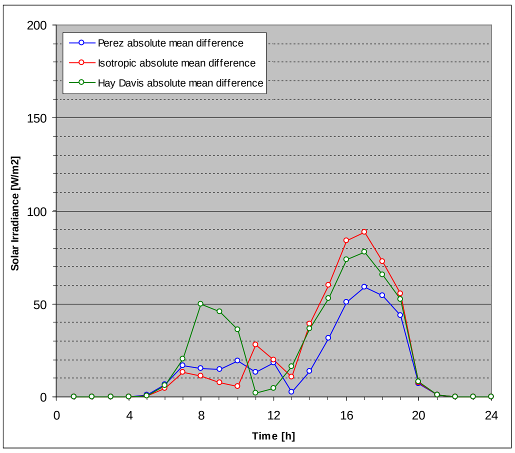

Irradiance with azimuth angles from similar period of precedent year (June 8 to July 2, 2005)



Irradiance with periodically repeated azimuth angles from July 1, 2005




Calculated Solar irradiance on tilted surface seem to show the best fit to Irradiance with periodically repeated azimuth angles from July 1, 2005.
As the difference to measured irradiance are displayed as absolute values, it is possible that the total irradiance over 24 averaged hours is closer to measured values with the azimuth angles from sunpos calculation, which calculates partially too high, partially too low irradiance during the day.

Further simulation is done with azimuth angles from sunpos calculation.

**Window properties:**

An overall window thermal transmittance is calculated using center-pane thermal transmittance of glazing unit, linear thermal transmittance for spacer and thermal conductance of the window frame given in table 11.3. in the IEA Task34 documentation U-value window

| | | | | |
|---|---|---|---|---|
| **Rahmen:** | Holz-, Holz/Metall | **Uf-Wert** | 1.64 | $W/m^2K$ |
| **Glas*:** | 2-fach WS | **Ug-Wert** | 1.16 | $W/m^2K$ |
| **Marke/Typ:** | | | | |
| | | **g-Wert** | 0.55 | |
| **Glasrandverbund:** | CNS | **Psi-Wert** | 0.073 | W/mK |
| **$U_w$-Wert Fenster** | | | **1.51** | **$W/m^2K$** |

Calculated with Excel SIA tool (090715_Ref-Geb-ME_sia380-1(2009)_dor.xls)

U-value window = 1.51W/m2K

g-value = 0.55 (SIA default for 2-fach Wärmeschutzglas)

Dimensions:

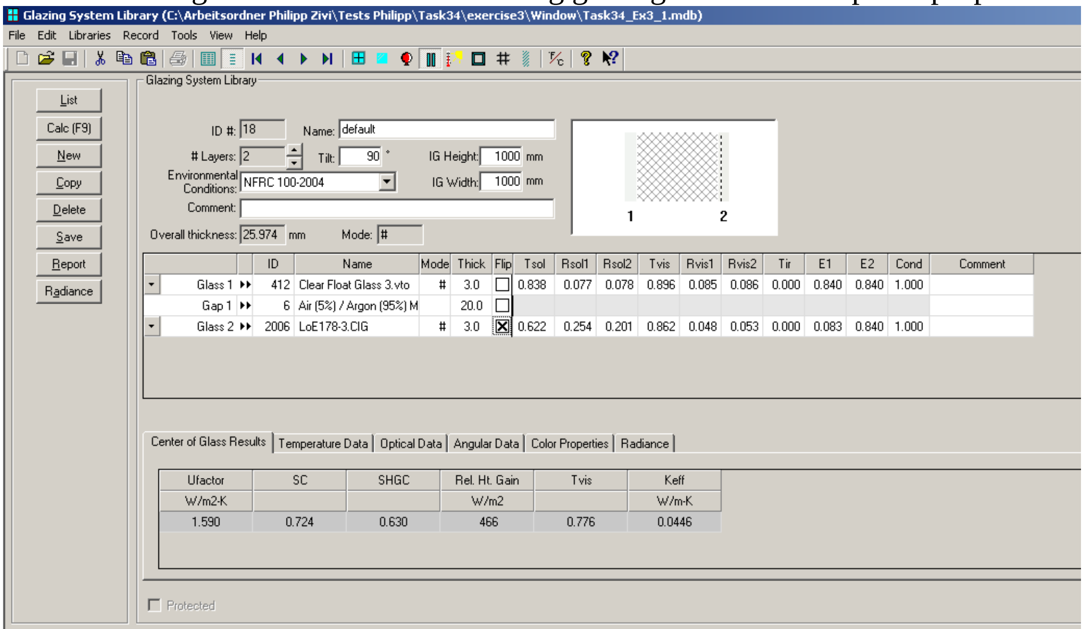
| **Abmessungen** | **Norm** | **Individuell** |
|---|---|---|
| Fläche Fenster $A_w$ [$m^2$] | | 1.820 |
| Fläche Glas $A_g$ [$m^2$] | | 1.170 |
| Breite d (Glas) [m] | | 0.96 |
| Höhe a (Glas) [m] | | 1.21 |
| Fläche Rahmen $A_f$ [$m^2$] | | 0.650 |
| Umfang Glas L [$m^1$] | | 4.36 |
| Breite b (Fenster) [m] | | 1.23 |
| Höhe h (Fenster) [m] | | 1.48 |
| Rahmenanteil ff [%] | | 36% |

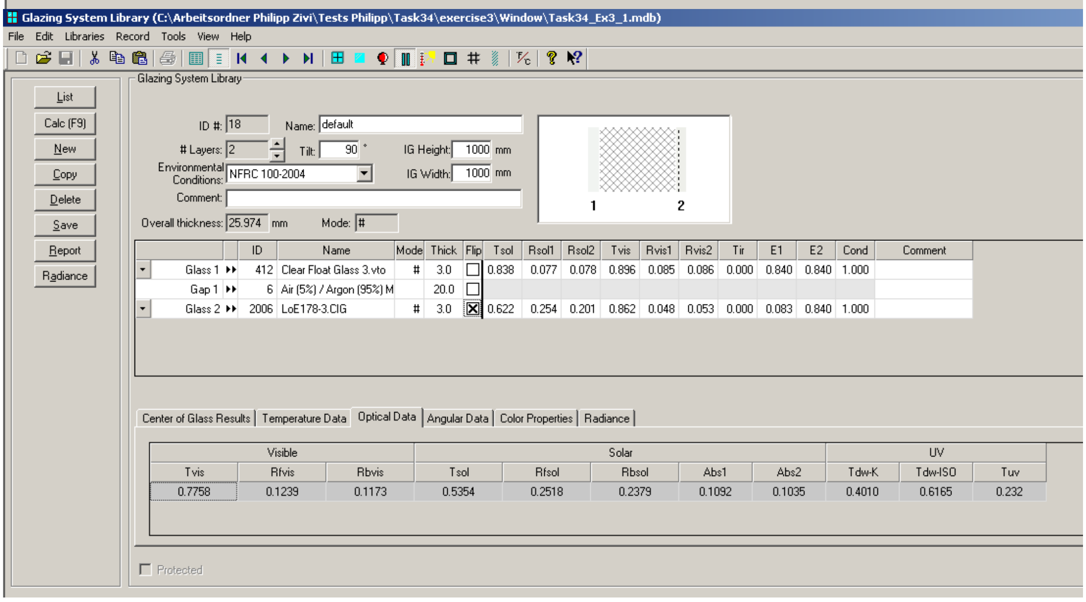
Part of frame of window surface = 35.7%

Evaluation of g-Value:

g-value = 0.55 (SIA default for 2-fach Wärmeschutzglas)

Calculation of g-value with Window6 using glazing with similar optical properties

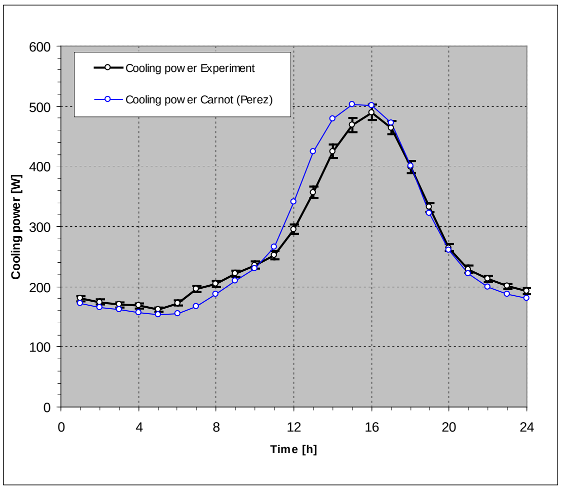


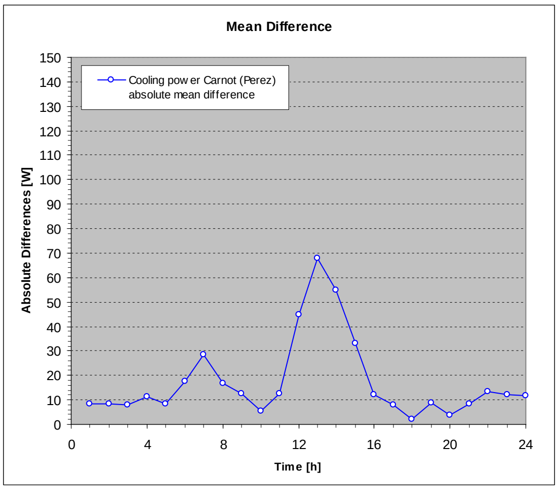




g-value = 0.63 (Window6)

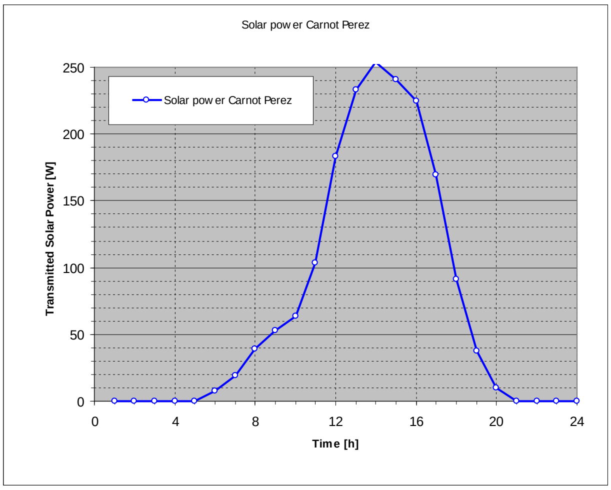
Calculation of g-value with WIS software by integration of measured transmittance reflectance and emittance over the solar spectrum.
Software Optics was used to create database file for WIS software.
g-value = 0.63 (WIS)

## **Cooling power profile** (Azimuth angle from sunpos)

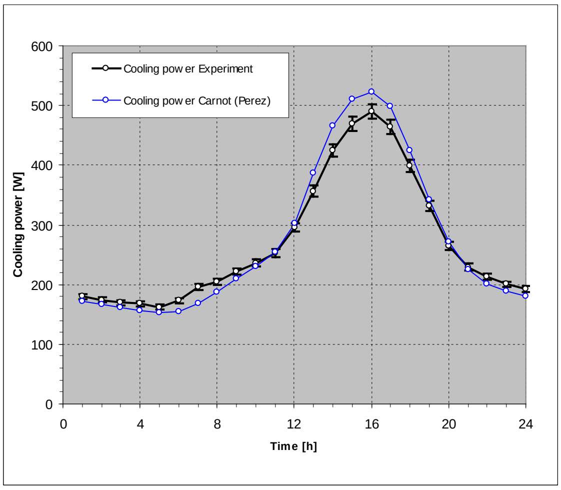


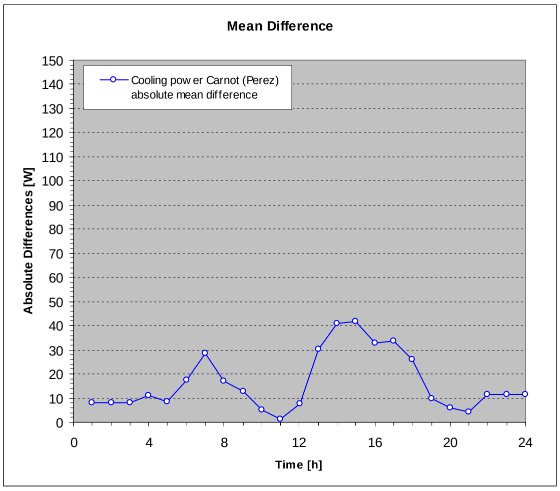




## **Transmitted solar power**

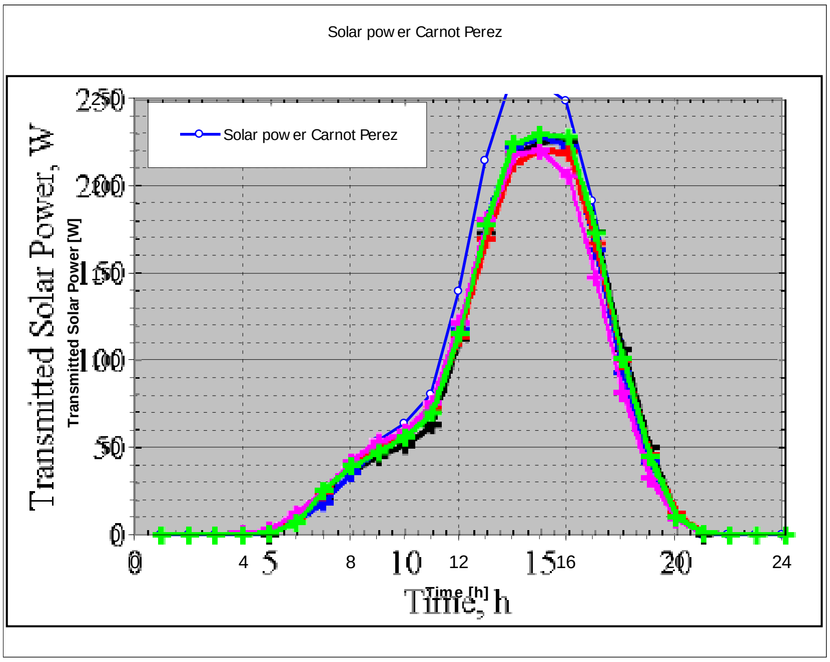



## **Cooling power profile** (Azimuth angle from July 1, 2005 periodically repeated)

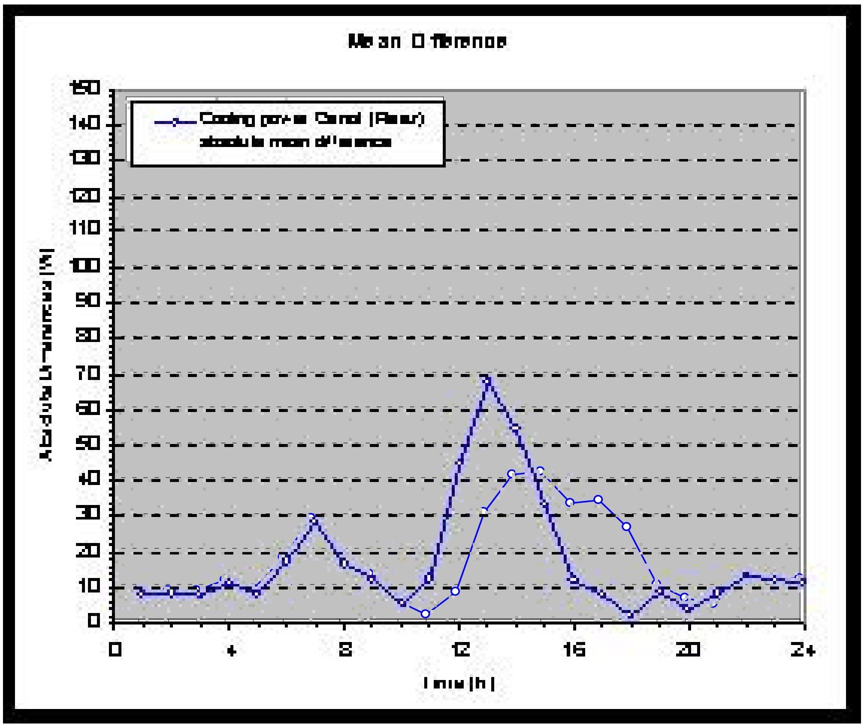


## Transmitted solar power




Transmitted Solar power of benchmark programs




Comparison of cooling power absolute mean difference of both azimuth angle methods

Compared to the other experiment the resulting cooling profile is not as close to measured values than in other experiments, but lie within the results of the benchmark programs. Unlike in the other experiments already the profile for solar irradiance on tilted surface, on tilted surface differs quite much from measured values. As this calculation is done in the Surfrad block, which is independent from the model itself, it seems that there is a problem with the corrupted weather data.

## General model changes

During validation of Carnot simulation tool with IEA Task 34 measurements several changes and new modelling approaches have been implemented.

- Calculation of global Irradiance in the wall surface irradiance function block was enhanced with the Perez algorithm. There are now 3 irradiance model available:
  4. Isotropic sky
  5. Hay Davies
  6. Perez

- Equation of wind dependent heat transfer coefficient on vertical outer wall is improved (4*u+4)
- heat transfer coefficient of ceiling and floor is improved to detect up- or down going heat flux with different temperature dependent heat transfer coefficients
- Window shading function as described in accordant sections

# Appendix

Matlab m-script for window block with shading function

WindowShading.m

```
%############################################################################
%#
%#  Matlab script corresponds to Carnot block "Window with shading
function"
%#
%#  Written by Zivi Philipp Seiler, February/March, 2010
%#
%############################################################################

function [OutputShading] = WindowShading(Zen_Angle, Azim_Angle, shad_type,
type_glazing, r_shad, tau_shad, bli_a, bli_b, bli_c, bli_d, bli_alpha,
bli_refl)

    switch shad_type

        case 1 % 'No shading'
            %-----------------
            f_dir_rad_win_out=1;
            f_dfu_rad_win_out=1;
            f_g_win_in=1;
            f_tau_win_in=1;

        case 2 % 'Exterior Screen'
            %-----------------
            f_dir_rad_win_out=1-r_shad*(1-tau_shad);
            f_dfu_rad_win_out=f_dir_rad_win_out;
            f_g_win_in=1;
            f_tau_win_in=1;

        case 3 % 'Interior Screen'
            switch type_glazing %shading: Selection of glasing type,
setting appropriate reducing factor for g value
                case 1
                 f_g = 0.48;
                case 2
                 f_g = 0.66;
                case 3
                 f_g = 0.73;
                case 4
                 f_g = 0.85;
                case 5
                 f_g = 0.54;
                case 6
                 f_g = 0.74;
                otherwise
                 f_g = 1;
            end
            %-----------------
            f_dir_rad_win_out=1;
            f_dfu_rad_win_out=1;
            f_g_win_in=1-((1-f_g)*r_shad);
            f_tau_win_in=1-(r_shad*(1-tau_shad));

        case 4 % 'Venetian Blind'
            el_h=90-Zen_Angle;
```

```
            el_h_rad=el_h*pi/180;
            % Parameter from Mask Window for test applications
            % bli_a=;
            % bli_b=;
            % bli_c=;
            % bli_d=;
            % bli_alpha=;
            bli_alpha_rad=bli_alpha*pi/180;
            epsilon_rad=atan(bli_b/bli_c);
            epsilon=epsilon_rad/pi*180;

            %*** Shading of direct beam irradiance ***
            %shading through element b
            if (bli_alpha+epsilon) > (el_h+90)
                bli_r=(bli_c^2+bli_b^2)^0.5;
                Z1=sin(bli_alpha_rad+atan(bli_b/bli_c)-pi/2-el_h_rad);
                N1=sin(pi/2+el_h_rad);
                X_shad_b=bli_r*Z1/N1;
            else
                 X_shad_b=0;
            end
            %shading through element a % Calculation is identical to method
            %by H. Simmler
            X_shad_a =
bli_a*(cos(bli_alpha_rad)+sin(bli_alpha_rad)*tan(el_h_rad));
            if X_shad_a<0
                X_shad_a=1;
            end
            %shading factor
            X_shad=X_shad_a+X_shad_b;

            if (X_shad) > bli_d
                F_Shad_dir=1;
            else
                F_Shad_dir=(X_shad)/bli_d;
            end

%              %*** Reflection of direct beam *** not active ! ***
%              refl=0.441;
%              k_refl=bli_a*sin(el_h_rad+pi/2-bli_alpha_rad)/cos(el_h_rad);
%              if k_refl>bli_d
%                  k_refl=bli_d;
%              end
%              % number of reflections
%              n_refl=bli_a/bli_d/sin(bli_alpha_rad)*tan(pi/2-
bli_alpha_rad+el_h_rad);
%              if n_refl<0
%                  Nue_refl=0;
%              elseif n_refl>100
%                  Nue_refl=0;
%              else
%              Nue_refl=refl^n_refl;
%              end
%              if n_refl<2
%                  test=1;
%              end
%              %einstrahlwinkel
%              gamma_rad=el_h_rad+pi/2-bli_alpha_rad;
%              if gamma_rad<pi/2
%                 if gamma_rad>0
%                     B_refl=k_refl/bli_d*Nue_refl*cos(gamma_rad);
%                 else
%                     B_refl=k_refl/bli_d*Nue_refl;
%                 end
%              else
```

```
%                   B_refl=k_refl/bli_d*Nue_refl;
%               end
            B_refl=0;

            %*** Shading of diffuse irradiance ***
            % Modelling with view factor method:
            % Calculation of " left open angle" gamma
            f_para=sqrt(bli_d^2+bli_a^2-
2*bli_d*bli_a*cos(bli_alpha_rad))/2;

e_para=sqrt(bli_d^2+bli_a^2+2*bli_d*bli_a*cos(bli_alpha_rad))/2;
            gamma = acos((f_para^2+e_para^2-bli_d^2)/2/f_para/e_para);
            F_Shad_dfu = 1-gamma/pi; % View Factor for geometrical shading
of diffuse irradiance

            % Reflectance
            A_corr=1.3; % weight factor empirically evaluated with task34
empa measurments
            refl_alpha=(1-sin(pi/2+bli_alpha_rad)); % 1=no Reflection
0=Total Reflection (Reflectance of diffuse irradiance
            D_refl = (1-bli_refl*refl_alpha)*A_corr;
            F_Shad_dfu = F_Shad_dfu*D_refl; % reducing shading factor with
Reflectance factor

            %-----------------
            f_dir_rad_win_out= (1-r_shad*(F_Shad_dir))+(r_shad*B_refl);
            f_dfu_rad_win_out= 1-r_shad*F_Shad_dfu;
            f_g_win_in=1;
            f_tau_win_in=1;

    end
    % handover output-factors to Carnot block
    OutputShading(1)=f_dir_rad_win_out;
    OutputShading(2)=f_dfu_rad_win_out;
    OutputShading(3)=f_g_win_in;
    OutputShading(4)=f_tau_win_in;
end
```