Validation of the Building Simulation Program IDA-ICE According to CEN 13791 „Thermal Performance of Buildings - Calculation of Internal Temperatures of a Room in Summer Without Mechanical Cooling - General Criteria and Validation Procedures“

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Summary

The European Standard prEN 13791 defines test cases, by which calculation methods for the determination of hourly room temperature values shall be validated. The present report describes the application of this standard to the building simulation program IDA-ICE. The test cases are described, the implementation of the geometries and boundary conditions to IDA-ICE explained and the results of the simulation presented.

Overview of the Test Cases

Summary of the Results

Most of the differences between the resuts from IDA-ICE and the values given in prEN 13791 are not attributed to uncertainties in the program, but to the fact that the model forming the basis of these values contents stronger simplification assumptions than the accuracy required by the standard allows. Especially in the area of caculation of the internal heat transfer coefficient and of the distribution of pentrating solar radiation to the different surfaces the prEN 13791 model is too rough.

IDA-ICE gives – after adapting simplification of the model – the results as demanded by prEN 13791. Only for test case 4a (subcase a: small air exchange rate) an unexplainable difference of up to 2 °C remains.

A clear weakness of IDA-ICE was at the time of performance of the tests, that only shoe box shaped zones were allowed which only could consist of 6 surfaces which could only have one neighbouring zone each. In the present standard this weakness only affects test case 2.4, where one half of one zone surface is in contact with exterior climate. IDA-ICE was not able to calculate this case. The current version of IDA-ICE does not show this limitation any more.

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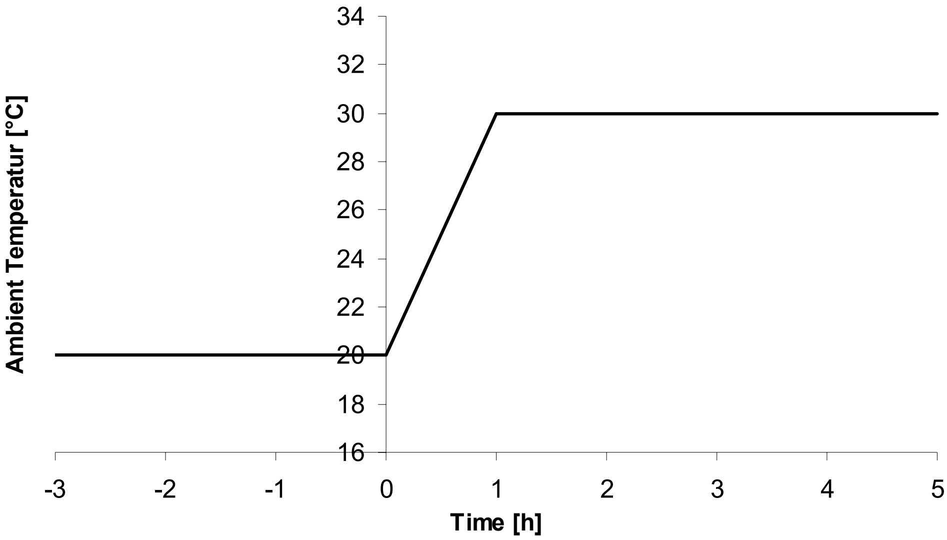
1. Heat Conduction through Opaque Walls

Description of the test case:

- The test room is a cube with inner dimensions of 1 m x 1 m x 1 m without windows.
- The short wave radiation is zero.
- The long wave radiation exchange is neglected.
- The air exchenge rate is zero.
- The heat capacity of the air in the test room is zero.
- The convective surface coefficients on all 6 surfaces are 2.5 W/(m^2K) inside and 8 W/(m^2K) outside.

Boundary conditions

The exterior temperature steps from constantly 20°C to 30°C within one hour and then remains constant again.



Test

Es interessiert das Verhalten der Innenraum-Temperatur beim Einpendeln in den neuen stationären Zustand. Es sind vier Unterfälle mit verschiedenen Wandkonstruktionen definiert:

Test case Layers	thickness s [m]	conductivity λ [W / (m K)]	density ρ [kg / m^3]	Heat capacity c [J / (kg K)]
1.1. 1 layer	0.2	1.2	2'000	1'000
1.2. 1 layer	0.1	0.04	50	1'000
1.3. outside	0.2	1.2	2'000	1'000
	0.1	0.04	50	1'000
inside	0.005	0.14	800	1'500
1.4. outside	0.005	0.14	800	1'500
	0.1	0.04	50	1'000
inside	0.2	1.2	2'000	1'000

Inplementation in IDA-ICE (essential parameters)

Climatic file:

1	20.00	50.00	0.00	0.00	0.00	0.00
:						
744	20.00	50.00	0.00	0.00	0.00	0.00
745	30.00	50.00	0.00	0.00	0.00	0.00
:						
8760	30.00	50.00	0.00	0.00	0.00	0.00

Simulation data: Startup: dynamic 2000-01-01 to 2000-01-31
Calculation: dynamic 2000-01-01 to 2000-02-29

Buidling: 1 m x 1 m x 1 m

Zone: 1 m x 1 m x 1 m

Exhaust air for CAV: 10^{-6} l / (s m^2)

Contoller setpoints: office, basic control

Weight/Area with furniture: 10^{-6} kg/m^2

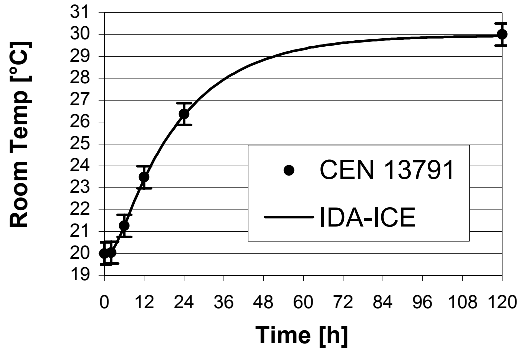
Wall constructions: These values can be entered 1:1. But one has to be aware of the fact that the order of the layers is from inside to outside for walls, however from top to bottom for floors and ceilings. Therefore the order of layers is the opposite of that of the walls.

Wall surfaces: Longwave emissivity 10^{-6}

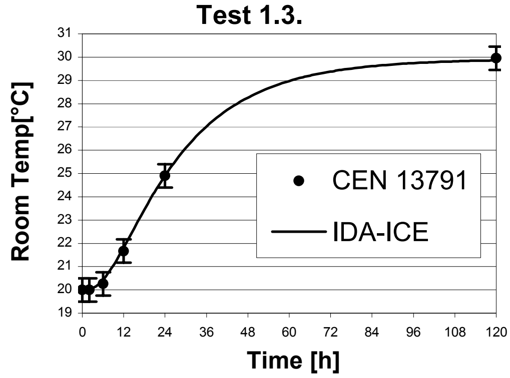
Results:

Although the heat transfer coefficients cannot be enterd because they are calculated by the program (dependent of the tilt angle of the wall and the suface and air temperatures), the resuts agree very well with the values given in CEN 13791:

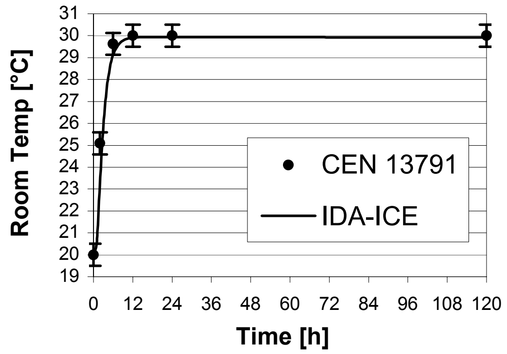
Test 1.1.



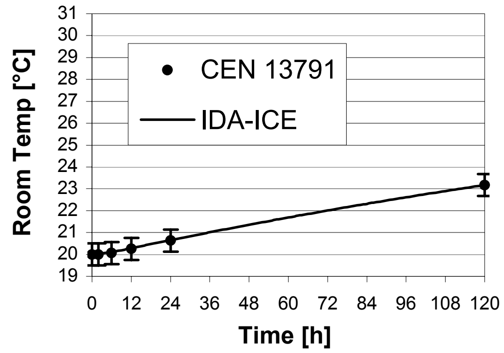
Test 1.3.



Test 1.2.



Test 1.4.



2. Internal long wave radiation exchange

Description of the test case

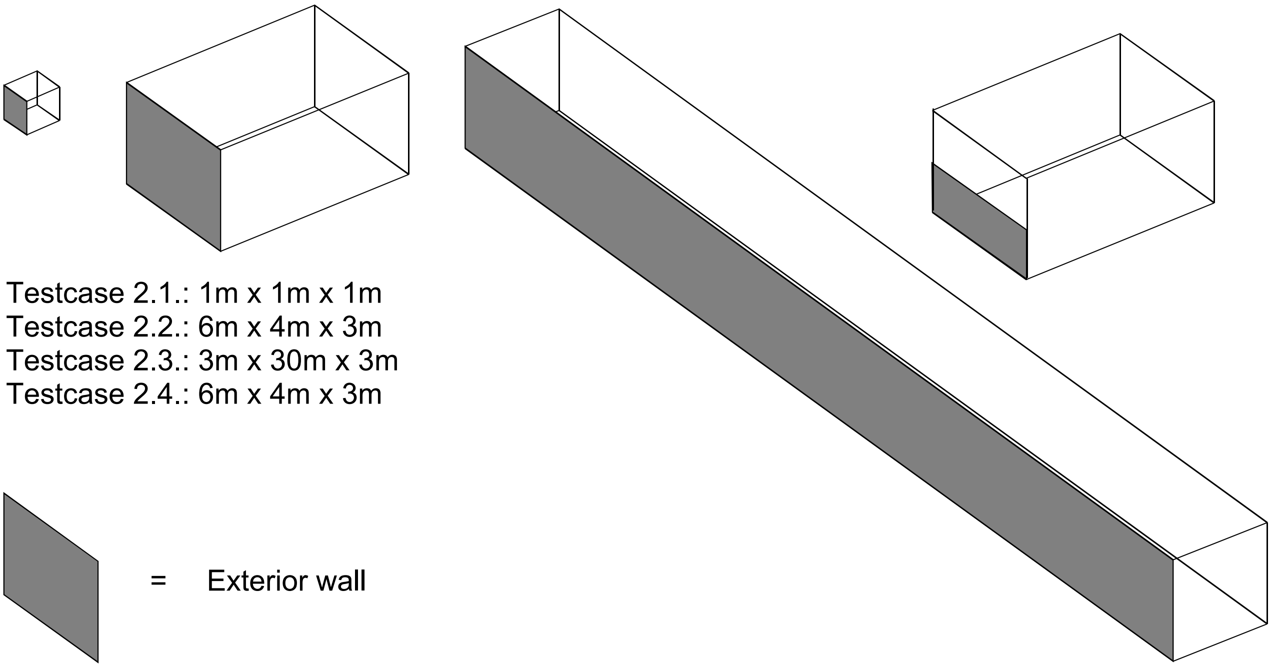
- The test room consists of 6 walls (floor and ceiling included), where 5 are identical (interior walls), but different from the 6th (exterion wall).
- The short wave radiation on the interior surfaces is zero.
- The air exchange rate is zero.
- The heat capacity of the air in the test room is zero.
- The heat transfer coefficient of the interior walls is 1.0 W/(m^2 K), for the exterior wall it is 5.0 W/(m^2 K).
- The long wave radiation emission of the exterior sufaces is described by a linear heat transfer coefficient of 5.5 W/(m^2 K).
- The long wave radiation exchange between the interior surfaces is calculated by the Stefan-Boltzmann law. The emissvity of all interior surfaces is 0.9.
- The convective surface coefficients on all 6 surfaces are 2.5 W/(m^2K) inside and 8 W/(m^2K) outside.

Boundary conditions

The outward surfaces of the walls (floor and ceilings included) are exposed to predefined air temperatures of 20°C (interior walls) or 30°C (exterior wall). In addition, the inner surface of the eterior wall absorbs a short wave radiation of 100 W / m^2.

Test

The air temperature i steady state conditions is to be calculated. Four test cases with different geometries are defined:



Inplementation in IDA-ICE (essential parameters)

Climatic file:	not important
Simulationsdaten:	Startup: dynamic 2000-01-01 to 2000-01-01 Calculation: dynamic 2000-01-01 to 2000-01-15
Building:	Dimensions of the test room
Zone:	Dimensions of the test room
Contoller setpoints:	office, basic control
Exhaust air for CAV:	10^{-6} l / (s m^2)
Leak area at 4 Pa:	10^{-6} m^2
Air velocity in the occupied zone:	10^{-6} m / s
Covered part of the floor	0.01
Weight/Area with furniture:	10^{-6} kg / m^2
Wall constructions:	All walls are defined with fix outside surface temperatures. Interior wall: Thickness 0.1 m; Conductivity 0.1 W/mK; density 1'000 kg/m^3; specific heat 1'000 J/kgK. Exterior wall: Thickness 0.1m; Conductivity 0.5 W/mK; density 1'000 kg/m^3; specific heat 1'000 J/kgK. The outside boundary layer is defined as an additional wall layer which represents the combined heat transfer (convection and radiation) on the exterior surface. Boundary layer: Thickness 0.001m; Conductivity 0.0135 W/mK; density 1'000 kg/m^3; specific heat 1'000 J/kgK. Again it is important that the order of the layers is from inside to outside for walls, however from top to bottom for floors and ceilings. Therefore the order of layers is the opposite of that of the walls.
Interior wall surfaces:	Longwave emissivity 0.9.
Radiative input:	IDA-ICE is not designed to define a heat input on an interior wall surface. Therefore a simple component was modelled, which was put between the the exterior wall and the zone component and which influences the heat balance accordingly ($Q_{wall-in} + Q_{zone-in} = Q_{injected}$ instead of $Q_{wall-in} + Q_{zone-in} = 0$).
"Bisected" wall in Test 2.4.:	IDA-ICE only allows for 6 walls for each zone. Therefore for test 2.4 the whole wall hat to be defined as an exterior wall (with exterior temperature of 30 °C). The heat input was halved accordingly, but distributed on the whole wall despite.

Results

The zone temperatures calculated by are all tightly (for test case 2.4 clearly) above the tolerance of 0.5 °C given in prEN 13791:

	Test 2.1.	**Test 2.2.**	**Test 2.3.**	**Test 2.4.**
prEN 13791	34.4 °C	30.4 °C	38.5 °C	25.5 °C
IDA-ICE	35.0 °C	31.2 °C	39.2 °C	27.0 °C

Unfortunately, prEN 13791 only gives the zone temperature, and not the respective surface temperatures of the walls or some radiation exchange values. This makes the search for the reasons for the discrepancies difficult. It could be that the fact that the heat transfer coefficients cannot be determined in IDA-ICE plays a more important role in this test than in test 1. By way of trial the tilt angle of the floor and ceiling was changed from 0° or 180°, respectively, to 90° to enlarge the heat transfer coefficient. But this also influenced the radiation exchange:

Test 2.1. with different tilt angles of floor and ceiling:

Tilt angle		T_{Zone} °C	convective heat transfer coefficient [W/m^{2}K]						Emission from wall [W]					
Floor	Cei-ling		Floor	Cei-ling	Wall	Wall	Wall	Wall	Floor	Cei-ling	Wall	Wall	Wall	Wall
0°	180°	35.0	0.58	2.60	2.31	2.31	2.31	3.26	-10.79	-7.96	-8.31	-8.31	-8.31	43.67
90°	180°	34.8	2.23	2.52	2.23	2.23	2.23	3.28	-8.71	-8.40	-8.71	-8.71	-8.71	43.22
0°	90°	35.0	0.58	2.32	2.32	2.32	2.32	3.25	-10.77	-8.25	-8.25	-8.24	-8.25	43.75
90°	90°	34.9	2.24	2.24	2.24	2.24	2.24	3.28	-8.66	-8.66	-8.66	-8.66	-8.66	43.28

The heat transfer coefficient of the floor grows in fact, which lowers the room temperature. But simultaneously the radiative absorption gets lower, which raises the room temperature again. Thus, the surface coefficient has to be enlarged without changing the tilt angle.

This is only possible by changng the equation for the heat transfer coefficient in the nmf-Code of the zone model (cedetzon.nmf):

```
h[i] := IF LINEARIZE(1) THEN
          1.
        ELSE
          U_film (TAirSurf[i], TSurf[i], slopeSurf[i])
        END_IF;
```

replace by:

```
h[i] := 2.5
```

In fact this leads to a decisively better agreement of the results with the values given in prEN 13791:

	Test 2.1.	**Test 2.2.**	**Test 2.3.**	**Test 2.4.**
CEN 13791	34.4 °C	30.4 °C	38.5 °C	25.5 °C
IDA-ICE	34.3 °C	30.4 °C	38.6 °C	26.6 °C

Test case 2.4 clearly could not be calculated in a satisfying way, because the possibility to split a zone wall into wall parts was missing at tha time of performing the tests. Basically this was possible in IDA, but not within the application IDA-ICE. Meanwhile this was changed and in the new version this can be done. The test will be repeated.

3. Shading of Windows by External Constructions

Description of the test case

An external construction is put in front of a window to protect it from direct solar radiation.

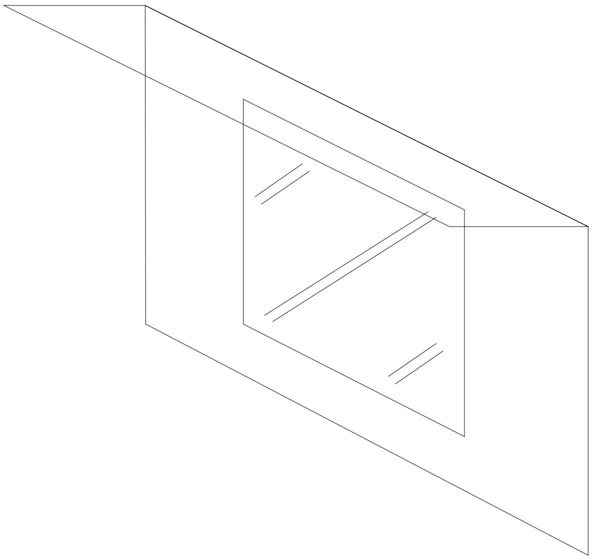
Boundary conditions

The 30 min values of the solar azimuth and elevation angles between 4:30 und 12:00 are given:

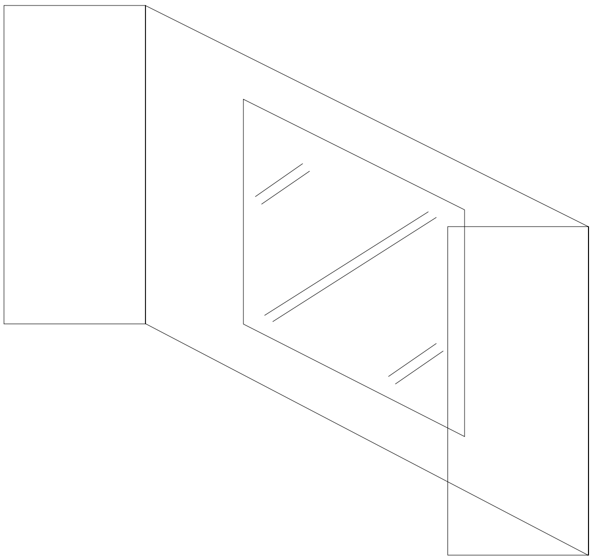
Time	Solar elevation [°]	Solar azimuth (deviation from south towards east) [°]	Time	Solar elevation [°]	Solar azimuth (deviation from south towards east) [°]
4:30	2.90	120.60	8:30	40.16	74.97
5:00	7.25	115.06	9:00	44.73	67.82
5:30	11.70	109.61	9:30	79.05	59.80
6:00	16.31	104.22	10:00	53.02	50.64
6:30	21.04	98.79	10:30	56.40	40.10
7:00	25.83	93.26	11:00	59.15	28.01
7:30	30.65	87.54	11:30	60.91	14.46
8:00	35.44	81.49	12:00	61.51	0.00

Test

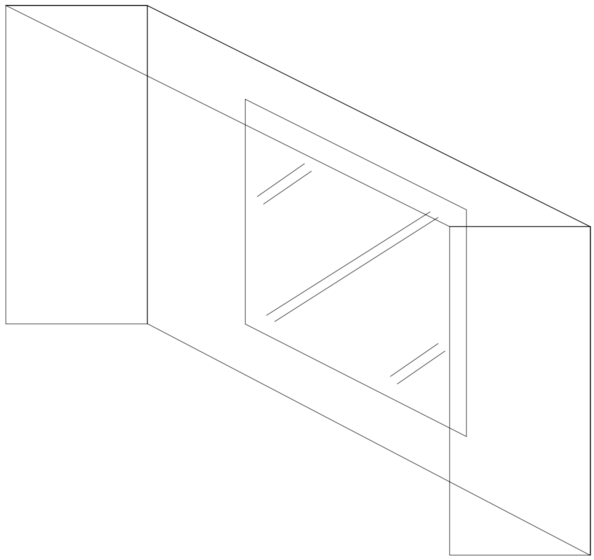
The so called "sunlit factor" is to be calculated, the portion of the window area which is hit by direct sunlight. Frou different external constructions are described, two of which are applied to the south façade, two for the south and east façade:



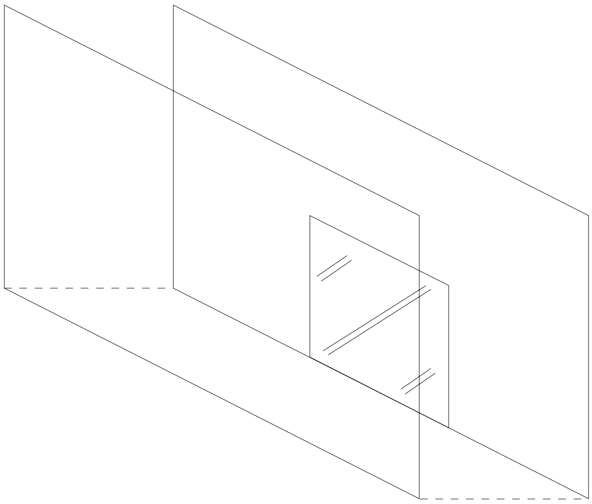
Test case 3.1.: **Overhang south facade**
Window: 2 m x 2 m
0.5 m above floor
Overhang: 4 m wide
1 m deep
0.5 m above wind.



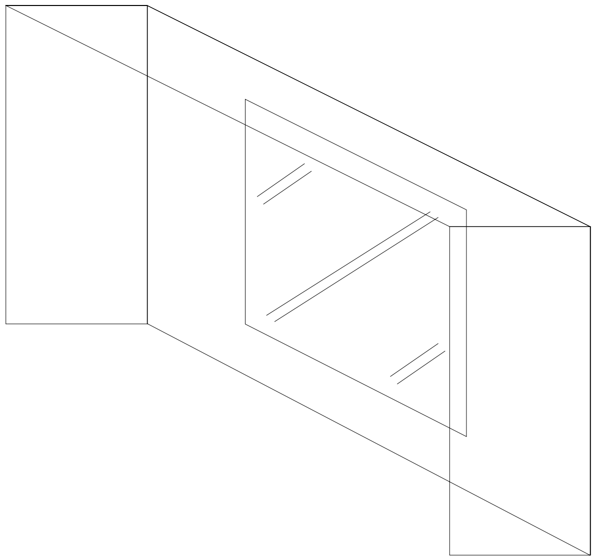
Test case 3.2.: **Fin south facade**
Window: 2 m x 2 m
0.5 m above floor
Fins: 3 m high
1 m deep
1 m from window



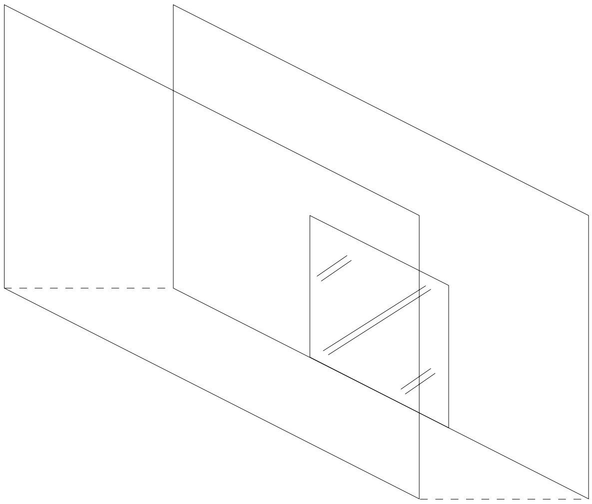
Test case 3.3: **Overhang and fins south**
Window: 2 m x 2 m
0.5 m above floor
Overhang: like test case 3.1
Fins: like test case 3.2



Test case 3.4: **Wall in front of south facade**
Window: 5 m x 5 m
0 m above floor
Wall: 15 m wide
10m high
5 m from facade



Test case 3.5: **Overhang and fins east**
like test case 3.3, but for east facade



Test case 3.6: **Wall in front of east facade**
like test case 3.4, but for east facade

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Inplementation in IDA-ICE (essential parameters)

Climatic file:	not important	
Simulationsdaten:	Startup:	dynamic 2000-01-01 to 2000-01-01
	Calculation:	dynamic 2000-01-01 to 2000-01-15
Building:	Large enough for window and external construction	
Zone:	like building	
Contoller setpoints:	office, basic control	
Weight/Area with furniture:	unimportant, e.g. 1 kg / m^2	
External construction:	This can very easily be entered under "external window shading" (overhangs and walls in front under "simple screens" and fins under "side fins").	
Solar position:	Source-File with hourly values (only every second value from prEN 13791).	

Source-File for south facade:

0	00.00	-180.00
1	00.00	-160.00
2	00.00	-140.00
3	00.00	-120.00
4	00.00	-115.06
5	07.25	-115.06
6	16.31	-104.22
7	25.83	-93.26
8	35.44	-81.49
9	44.37	-67.82
10	53.02	-50.64
11	59.15	-28.01
12	61.51	-00.00
13	59.15	28.01
14	53.02	50.64
15	44.37	67.82
16	35.44	81.49
17	25.83	93.26
18	16.31	104.22
19	07.25	115.06
20	00.00	115.06
21	00.00	120.00
22	00.00	140.00
23	00.00	160.00
24	00.00	180.00

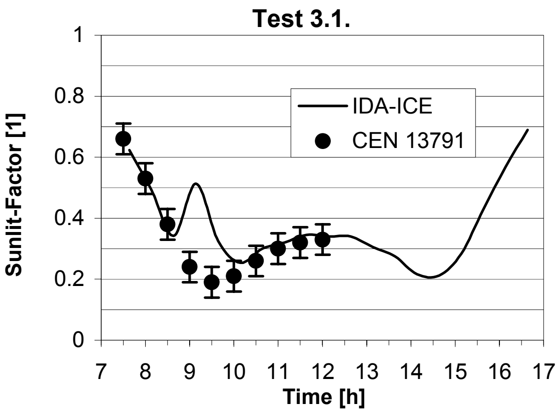
Source-File for east facade:

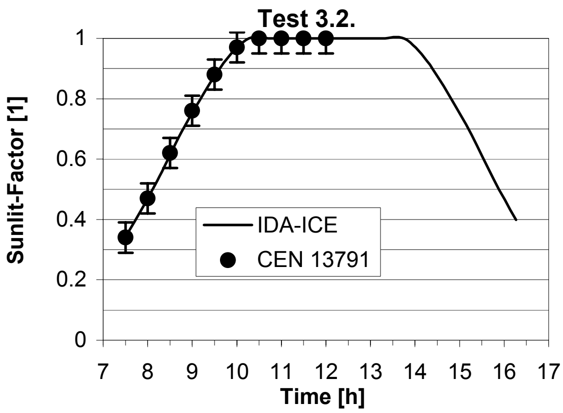
0	00.00	-90.00
1	00.00	-70.00
2	00.00	-50.00
3	00.00	-30.00
4	00.00	-25.06
5	07.25	-25.06
6	16.31	-14.22
7	25.83	-3.26
8	35.44	8.51
9	44.37	22.18
10	53.02	39.36
11	59.15	61.99
12	61.51	90.00
13	59.15	118.01
14	53.02	140.64
15	44.37	157.82
16	35.44	171.49
17	25.83	-176.74
18	16.31	-165.87
19	07.25	-154.94
20	00.00	-154.94
21	00.00	-150.00
22	00.00	-130.00
23	00.00	-110.00
24	00.00	-90.00

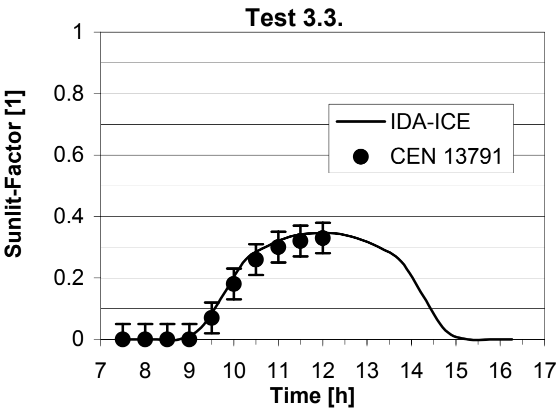
Links to Face 3:	The link from the climatic file to face 3 must be deleted. Instead, the variables PAIR, TAIR, XAIR, HUMAIR, TTGROUND, TSKY, WINDDIR, WINDVEL, IDIRNORM and IDIFFHOR must be defined separately einzeln (e.g. constant to starting value). The variables ELEVSUN and AZIMUTSUN must be linked to the respective variables of the source file.
Sunlit-Factor	This can be found in the component "WindShade" as variable TRANSP_RES.

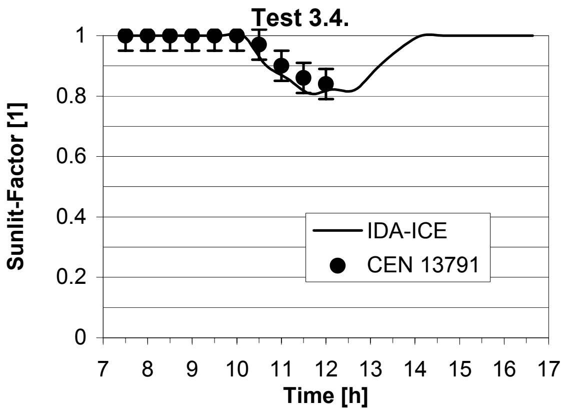
Results

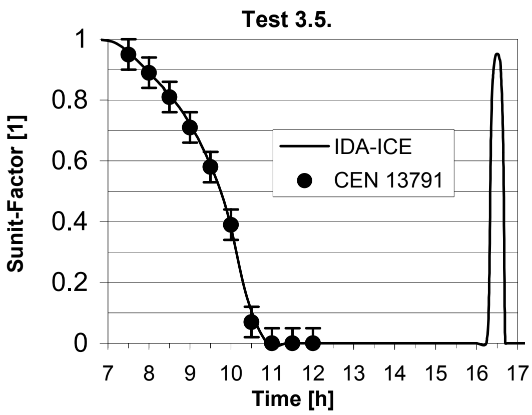
Apart from an unexplainable peak at 9:00 in test case 3.1, all values calculated by IDA-ICE agree very accurately with the values given in prEN 13791:

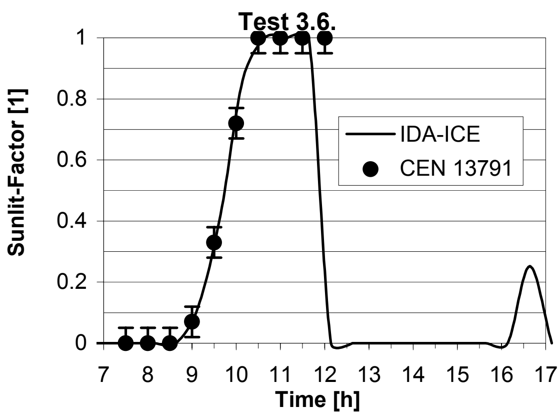












The sunlit factor is calculated in a FORTRAN subroutine (calcshad.for). With high probability the reason for the deviation in test 3.1 (and unimportant in test 3.4) is a mistake in this routine. In addition, the peaks at 16:30 in the tests 3.5 and 3.6 are impossible, but also not important, because in this case the east facade is not sunlit at all.

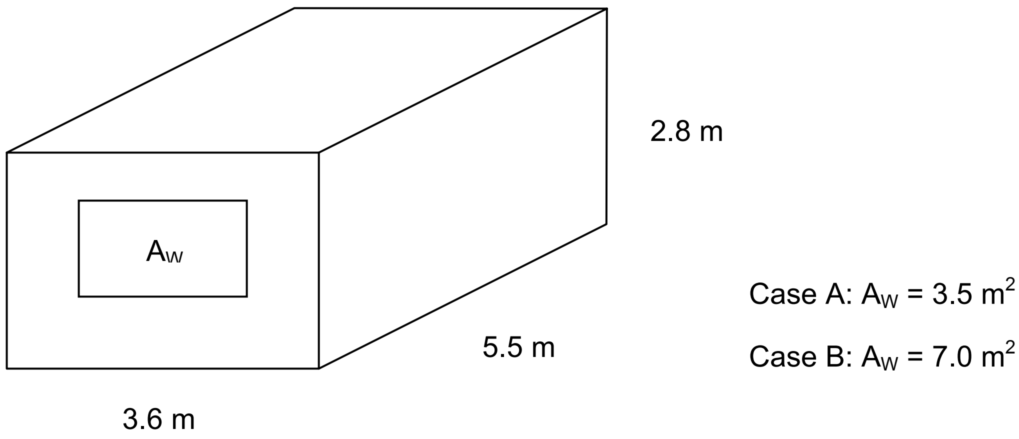
4. Test Case for the Whole Calculation Method

Description of the Test Case

A test room has a west oriented exterior wall with a window. All other walls and floor and ceiling are in contact with neighbouring rooms of the same type. Exception: ceiling in case 3.

4.1. Room geometry

Boundary conditions



Implementation in IDA-ICE

Building: 6.5 m x 5.6 m x 4.8 m
Zone: 5.5 m x 3.6 m x 2.8 m with origin in (0,1,1)
Window: e.g. 2.5 m x 1.4 m (case A), 2.8 m x 2.5 m (case B)

4.2. Thermophysical properties of the opaque walls

Boundary conditions

Layers of the exterior wall from ouside to inside:

Layer	**Thickness [m]**	**Conductivity [W/m.K]**	**Density [kg/m^3]**	**Specific heat [J/kg.K]**
Exterior layer	0.115	0.99	1'800	850
Insulation	0.06	0.04	30	850
Masonry	0.175	0.79	1'600	850
Internal plastering	0.015	0.70	1'400	850

Layers of the interior walls:

Layer	**Thickness [m]**	**Conductivity [W/m.K]**	**Density [kg/m^3]**	**Specific heat [J/kg.K]**
Gypsum plaster	0.012	0.21	900	850
Insulation	0.10	0.04	30	850
Gypsum plaster	0.012	0.21	900	850

Layers of floors and ceilings from top to bottom for case 1:

Layer	**Thickness [m]**	**Conductivity [W/m.K]**	**Density [kg/m^3]**	**Specific heat [J/kg.K]**
Plastic covering	0.004	0.23	1'500	1'500
Cement floor	0.06	1.40	2'000	850
Insulating layer	0.04	0.04	50	850
Concrete	0.18	2.10	2'400	850
Insulating layer	0.10	0.04	50	850
Acoustic board	0.02	0.06	400	840

Layers of floors and ceilings from top to bottom for case 2:

Layer	Thickness [m]	Conductivity [W/m.K]	Density [kg/m^3]	Specific heat [J/kg.K]
Plastic covering	0.004	0.23	1'500	1'500
Cement floor	0.06	1.40	2'000	850
Insulating layer	0.04	0.04	50	850
Concrete	0.18	2.10	2'400	850

Layers of ceiling (exterior roof) from top to bottom for case 3 (floor like case 2):

Layer	Thickness [m]	Conductivity [W/m.K]	Density [kg/m^3]	Specific heat [J/kg.K]
Rain protection	0.004	0.23	1'500	1'300
Insulating layer	0.08	0.04	50	850
Concrete	0.20	2.1	2'400	850

Implementation in IDA-ICE

Wall 4 (west wall) is exterior wall. The values can be entered 1:1.

4.3. Window Properties

Boundary conditions

Case A: Single glazing
Case B: Double glazing
Semitransparent external shading

Solar values of the different layers (for short wave radiation):

Layer	Transmission	Reflection	Absorption
Glass	0.84	0.08	0.08
Shading	0.20	0.50	0.30

Values for all layers:

Case	direct transmission	total transmission	U-Value [W/m^2.K]
A (Single glazing)	0.168	0.175	3.584
B (Double glazing)	0.1411	0.1525	2.212

Implementation in IDA-ICE

In IDA-ICE the reflection at the window is angle dependent and the influece of the external shading is considered separately. The model is based on reference glazings. For these a transmission value of 0.87 (single glazing) or 0.76 (double glazing) is valid.

Glazing:

	Case A	Case B
	Single pane reference	Double pane reference
	Sc = 0.2651 / 0.87 = 0.3047	F1 = 0.2195 / 0.76 = 0.2888
	Ssc = 0.1750 / 0.87 = 0.2011	F2 = 0.1525 / 0.76 = 0.2007
	U = 3.584 W/m^2.K	U = 2.212 W/m^2.K
	Internal Emissivity = 10^{-6}	Internal Emissivity = 10^{-6}
	External Emissivity = 10^{-6}	External Emissivity = 10^{-6}

Opening schedule: Never open

Frame fraction of total window area: 10^{-6}

Frame U-value: unimportant

Internal window shading device: No interal shading

Internal window shading control: None

Internal window shading schedule: unimportant

External window shading device: No external shading

4.4. Distribution of the solar radiation and its absorption at the building

Boundary conditions

Solar-air-factor: 0.10
solar loss factor: 0.00
solar distribution factors: floor 0.5; ceilings 0.1; all walls (without windows) 0.4
Absorptivity of solar radiation on facade: 0.6
Absorptivity of solar radiation on roof: 0.9

Implementaton in IDA-ICE

Here prEN 13791 gives a very simplified model how the radiation incident on the window penetrates into the room (4.3) and is distributed there. IDA-ICE calculates with a much more detailed radiation exchange between all involved surfaces.
External surface of the exterior wall: Shortwave reflectance := 0.4
External surface of roof in case 3: Shortwave reflectance := 0.1

4.5. Heat transfer coefficients and climatic data

Boundary conditions

Convective heat transfer coefficient on all external surfaces: 8.0 W/(m^2.K)
Convective heat transfer coefficient on all internal wall surfaces: 2.5 W/(m^2.K)
Convective heat transfer coefficient on floor (heat flux upwards): 5.0 W/(m^2.K)
Convective heat transfer coefficient on ceiling (heat flux downwards): 0.7 W/(m^2.K)
Radiative heat transfer coefficient on external walls
(calculated with □ = 0.93 and T_m = 303K): 5.5 W/(m^2.K)

	Climatic data for case A (40° north lattitude)						Climatic data for case B (52° north lattitude)					
Zeit	T_{Amb}	direct horiz.	diffuse horiz.	direct west	diffuse west	refl. west	T_{Amb}	direct horiz.	diffuse horiz.	direct west	diffuse west	refl. west
1	23.6	0	0	0	0	0	14.1	0	0	0	0	0
2	23.0	0	0	0	0	0	13.3	0	0	0	0	0
3	22.5	0	0	0	0	0	12.6	0	0	0	0	0
4	22.1	0	0	0	0	0	12.2	0	0	0	0	0
5	22.0	1	3	0	2	0	12.0	35	34	0	15	7
6	22.2	106	62	0	45	17	12.3	153	73	0	33	23
7	22.8	278	91	0	78	37	13.1	295	93	0	42	39
8	23.9	452	105	0	103	56	14.6	435	104	0	47	54
9	25.8	606	112	0	122	72	16.6	558	110	0	50	67
10	27.3	725	117	0	137	84	19.0	654	114	0	51	77
11	29.3	801	119	0	145	92	21.8	714	116	0	52	83
12	31.2	827	120	0	160	95	24.3	735	117	0	64	85
13	32.7	801	119	209	172	92	26.2	714	116	204	78	83
14	33.6	725	117	396	180	84	27.5	654	114	387	94	77
15	34.0	606	112	539	181	72	28.0	558	110	529	107	67
16	33.6	452	105	616	172	56	27.5	435	104	609	115	54
17	32.8	278	91	595	146	37	26.4	295	93	606	111	39
18	31.5	106	62	418	93	17	24.6	153	73	492	89	23
19	29.9	1	3	17	3	0	22.6	35	34	223	41	7
20	28.4	0	0	0	0	0	20.5	0	0	0	0	0
21	27.0	0	0	0	0	0	18.7	0	0	0	0	0
22	25.8	0	0	0	0	0	17.1	0	0	0	0	0
23	24.9	0	0	0	0	0	15.8	0	0	0	0	0
24	24.2	0	0	0	0	0	14.9	0	0	0	0	0

Implementation in IDA-ICE

IDA-ICE calculates all convective heat transfer cefficients. Only for the external surfaces of the building envelope the variable (UFACE for the facade, HEXT for the window) can be set to a constant value after building the model.

The climatic data are needed in a different form IDA-ICE. All other hourly values are calculated from the hourly values for direct normal and diffuse horizontal radiation. Therefore, also here an intervention in the linking of the variables (after the model is created) is necessary.:

Climatic file:	1	23.60	50.00	0.00	0.00	0.00	0.00
	:						
	12	31.20	50.00	0.00	0.00	0.00	255.00
	13	32.70	50.00	0.00	0.00	209.00	264.00
	:						
	24	24.20	50.00	0.00	0.00	0.00	0.00

ExtWallTQFace_4 (external surface of the exterior wall of the zone):

The link "AMBIENT" is disconected, instad the parameters concerned are linked as follows:

TAMBIENT <--- Face4.TAIRWAL
PDIR <--- Climate.IDIRNORM2
PDIFF <--- Climate.IDIFFHOR2
TSKY <--- Face4.TSKYWAL
TGROUND <--- Face4.TGROUNDWAL
UFACE <--- 8 W/(m^2 K)

Window_1 (window of the zone):

The link "OUTSIDE" is disconected, instad the parameters concerned are linked as follows:

AZIMUTTHRU <--- Face4.AZSUN2FACE
ELEVTHRU <--- Face4.ELEVSUNWDW
ANGLEINC <--- Face4.ANGLEINCFACE
IDIFFINC <--- Climate.IDIFFHOR2
IDIRINC <--- Climate.IDIRNORM2
TAMB <--- Face4.TAIRWDW
TGROUND <--- Face4,TGROUNDWDW
TSKY <--- Face4.TSKYWDW
HEXT <--- 8 W/(m^2 K)

4.6. Internal heat sources

Boundary conditions

For internal heat sources the following schedule is given (in W/m^2 floor area):

Zeit	Wärme-abgabe	Zeit	Wärme-abgabe	Zeit	Wärme-abgabe	Zeit	Wärme-abgabe
0 - 1	0	6 - 7	0	12 - 13	10	18 - 19	15
1 - 2	0	7 - 8	1	13 - 14	10	19 - 20	15
2 - 3	0	8 - 9	1	14 - 15	10	20 - 21	15
3 - 4	0	9 - 10	1	15 - 16	1	21 - 22	15
4 - 5	0	10 - 11	1	16 - 17	1	22 - 23	10
5 - 6	0	11 - 12	10	17 - 18	1	23 - 24	0

The heat is emitted to the room to 50 % each by radiation and convection.

Implementation in IDA-ICE

Equipment:	Number of units:	1		
	Schedule:	Profile:	0:00	0.0
			7:00	0.0
			7:00	0.01
			11:00	0.01
			11:00	0.1
			15:00	0.1
			15:00	0.01
			18:00	0.01
			18:00	0.15
			22:00	0.15
			22:00	0.1
			23:00	0.1
			23:00	0.0
			24:00	0.0
	Emitted heat per unit:	1980.0 W		
	Long wave radiation fraction:	0.5		
	Moisture emission per unit:	0.0		
	CO2 per unit	0.0		

4.7. Ventilation

Boundary conditions

For the air exchange rate 3 cases shall be calculated:

Case a: Constant air exchange rate of 1 h^{-1}.

Case b: Air exchange rate daytime (6-18 h) 0.5 h^{-1} and nighttime (18-6 h) 10 h^{-1}.

Case c: Constant air exchange rate of 10 h^{-1}.

Implementation in IDA-ICE

	Case a	Case b	Case c
System type	CAV	VAV	CAV
Exhaust air for CAV	0.777778 l/s m^2	unimportant	7.777778 l/s m^2
Gradient calculation	Well-mixed	Well-mixed	Well-mixed
Suppl. air / exh. air	1.0	1.0	1.0
Leak area at 4 Pa	10^{-6} m^2	10^{-6} m^2	10^{-6} m^2
Air vel. in the occ. z.	0.1 m/s	0.1 m/s	0.1 m/s
AHU:	Shed_AHU: Always on Setpoint for supply air temperature: Schedule, Always off sf.TRISE := 0.0		
Plant:	Boiler schedule: Always off Chiller schedule: Always off		

4.8. Tests

The daily mean value as well as the minimum and maximum value of the operative temperature, which is defined as the average of room air temperature and area-weighted suface temperatures of all surfaces shall be calculated:

$\theta_{op} = (\theta_{Room\ air} + \theta_{Surface})/2$ with $\theta_{Surface}$ = area weighted surface temperature

In total 18 test cases are defined:

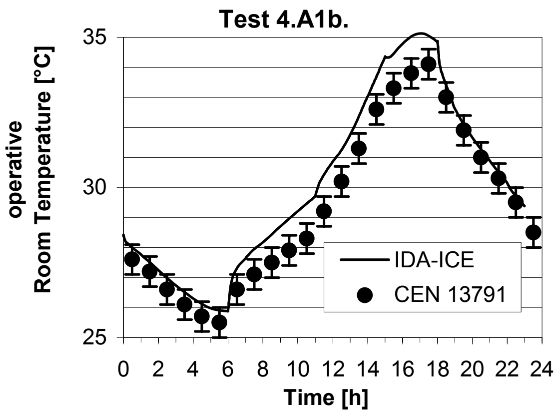
2 differnt climatic conditions: A: warm with small window and single glazing
B: mild with large window and double glazing

3 different foor/ceiling combinations: 1: Floor and ceiling double insulated
2: Floor and ceiling single insulated
3: Floor and (external) roof single insulated

3 different ventilation cases: a: constant air exchange rate 1 h^{-1}
b: daytime 0.5 h^{-1}, nighttime 10 h^{-1}
c: constant air exchange rate 10 h^{-1}

Results with original IDA-ICE code

The resuts are mostly ouside of the tolerances given in prEN 13791. As an eample, the result of test case 4.A1b. is presented here:



Values in °C	min	mean	max
CEN 13791	25.5	29.4	34.1
IDA-ICE	25.9	30.1	35.1

The daily minimum is in enough good agreement in this case. But in general the daily profile is above the one given in prEN 13791. In addition, the daily maximum is learly outside the tolerance band.

Again the zone model has to be simplified and adapted to the standard prEN 13741. But this time it is not sufficient to set the film cefficients to constant values, also the distribution of the solar radiation pentrating through the window has to be adapted. The changes in the nmf-code (cedetzon.nmf) are as follows:

1. Heat transfer coefficient at the internal surfaces:

```
h[i] := IF LINEARIZE(1) THEN
          1.
        ELSE
          U_film (TAirSurf[i], TSurf[i], slopeSurf[i])
        END_IF;
```

replace by:

```
h[i] := IF i >= 3 THEN
          2.5
        ELSE_IF i == 2 THEN
          IF TSurf[i] >= TAir THEN
            0.7
          ELSE
            5.0
          END_IF
        ELSE_IF i == 1 THEN
          IF TSurf[i] >= TAir THEN
            5.0
          ELSE
            0.7
          END_IF
        ELSE
          2.5
        END_IF;
```

2. Distribution of the incomming solar radiation to the internal sufaces:

```
QSw2Surf[i] := psiSw[i, nLite] * QSwLite +
               SUM k = 1, nWind
                 psiSw[i, nLite + k] * QSwWind2Zone[k]
               END_SUM;
```

replace by:

```
QSw2Surf[i] := SUM k = 1, nWind
                 0.9 *
                 IF i == 1 THEN 0.5
                 ELSE_IF i == 2 THEN 0.1
                 ELSE_IF i <= 6 THEN 0.4 * ASurf[i] / AWall
                 ELSE 0
                 END_IF
                 * QSwWind2Zone[k]
               END_SUM;
```

The new parameter AWall has to be defined in addition:

```
PARAMETERS
/* CALCULATED PARAMETERS */
 Area        AWall                C_P   "Total wall surface area for
zone"
PARAMETER_PROCESSING
    AWall := SUM i=3, 6
              ASurf[i]
             END_SUM;
```

Besides that the energy balance of the zone air:

```
massAir * ((CP_Air + XHumLoc*CP_Vap) * TAir' + HF_Vap * XHumLoc')
  =  QFurn2Zone + QCvOcc2Zone + QCvEquip2Zone + QCv2Zone +
     Q_0 + SUM i = 1, nTerminal Q[i] END_SUM +
     SUM i = 1, nLocUnit QLocalUnit[i] END_SUM +
     HF_VAP * (VapFOcc2Zone +
               SUM i = 1, nUnit
                 schedEquip[i] * VapFSrcEquip[i]
               END_SUM) ;
```

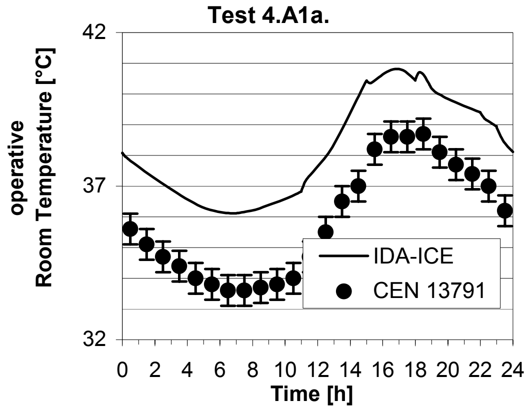
add a term:

```
  =  ...
     ...
     ...                +
     0.1 * SUM i = 1, nWind QSwWind2Zone[i] END_SUM;
```

Results with IDA-ICE with changed source code for the zone model

After this adaption of the model the resuts are mostly in agreement with the given values in standard prEN 13791 within the tolerance band (Exception: Sub case a: small air exchange rate):

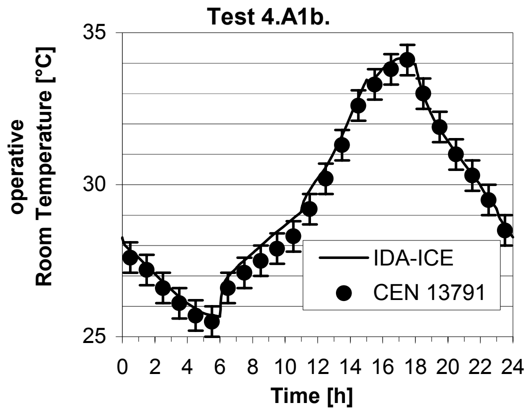
Result of test 4.A1a.



Values in °C	min	mean	max
prEN 13791	33.6	35.9	38.7
IDA-ICE	36.1	38.2	40.8

The results only changed only little and the calculated curve is still above the profile given by prEN 13791 by more than 2 °C.

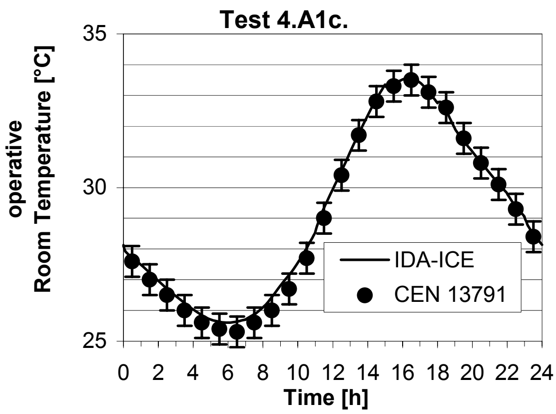
Result of test 4.A1b.



Values in °C	min	mean	max
prEN 13791	25.5	29.4	34.1
IDA-ICE	25.7	29.6	34.2

The values are in sufficiently good agreement with the given values..

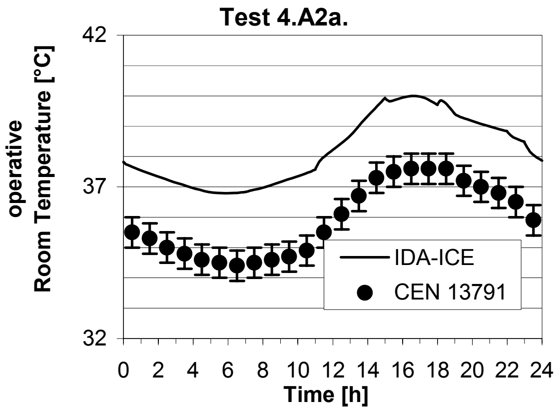
Result of test 4.A1c.



Values in °C	min	mean	max
prEN 13791	25.4	29.0	33.5
IDA-ICE	25.6	29.2	33.5

Here the resullt could be additionally enhanced.

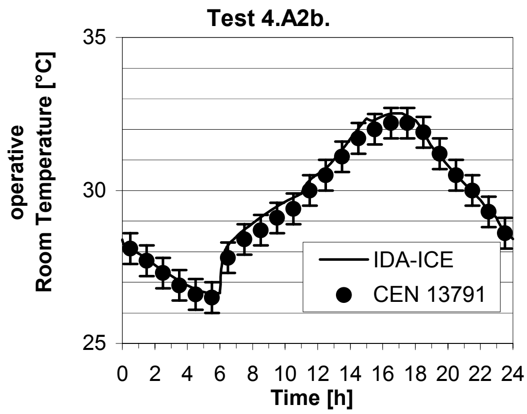
Result of test 4.A2a.



Values in °C	min	mean	max
prEN 13791	34.4	35.9	37.6
IDA-ICE	36.8	38.2	40.0

Again the values from IDA-ICE are higher than the given values from prEN 13791 by more than 2 °C.

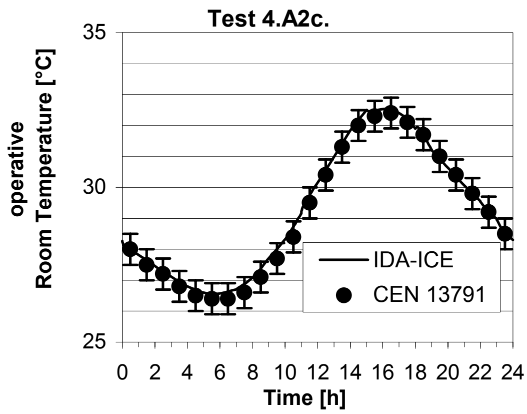
Result of test 4.A2b.



Values in °C	min	mean	max
prEN 13791	26.5	29.5	32.2
IDA-ICE	26.6	29.7	32.5

Very good agreement.

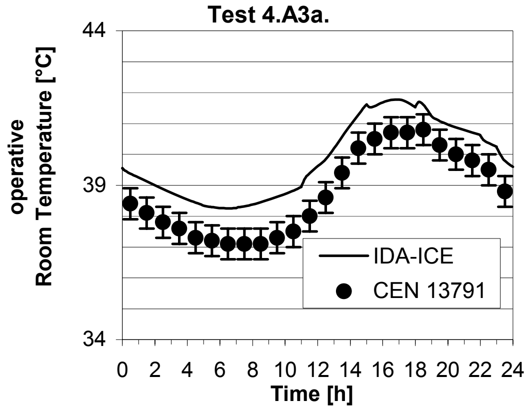
Result of test 4.A2c.



Values in °C	min	mean	max
prEN 13791	26.4	29.1	32.4
IDA-ICE	26.6	29.3	32.5

Very good agreement.

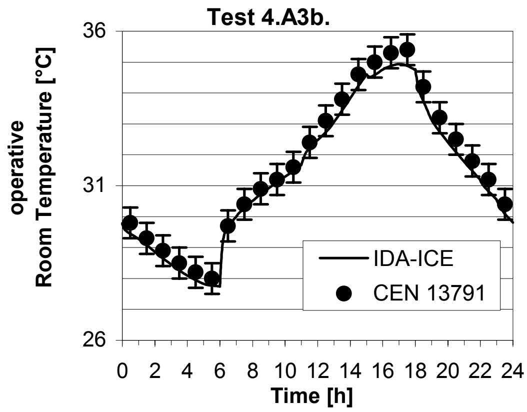
Resultat Test 4.A3a.



Values in °C	min	mean	max
prEN 13791	37.1	38.7	40.8
IDA-ICE	38.3	39.8	41.8

The values calculated by IDA-ICE are higher than the values given by prEN 13791 by about 1 °C.

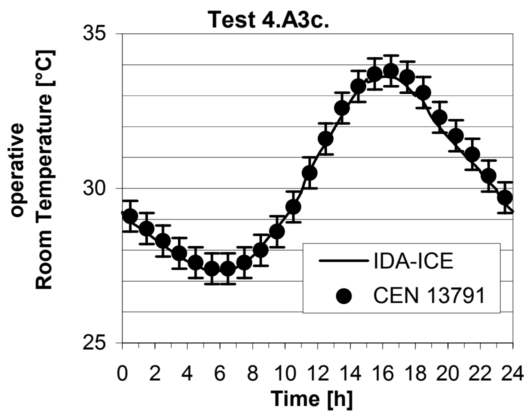
Result of test 4.A3b.



Values in °C	min	mean	max
prEN 13791	28.0	31.6	35.4
IDA-ICE	27.7	31.3	34.9

Good agreement.

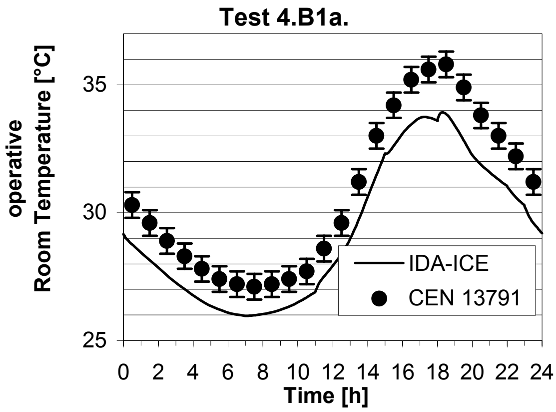
Result of test 4.A3c.



Values in °C	min	mean	max
prEN 13791	27.4	30.3	33.8
IDA-ICE	27.3	30.2	33.6

Very good agreement.

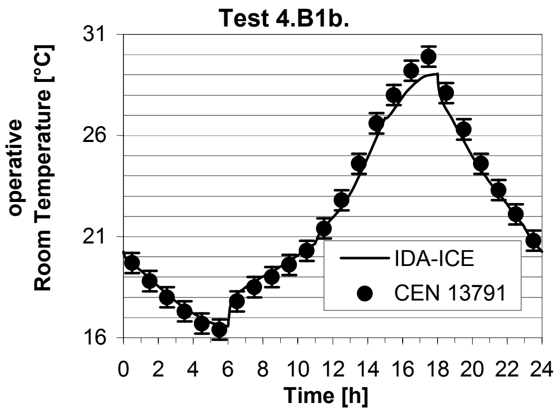
Result of test 4.B1a.



Values in °C	min	mean	max
prEN 13791	27.2	30.7	35.9
IDA-ICE	26.0	29.3	33.9

This time the results from IDA-ICE are below the given vaues of prEN 13791 by up to 2 °C.

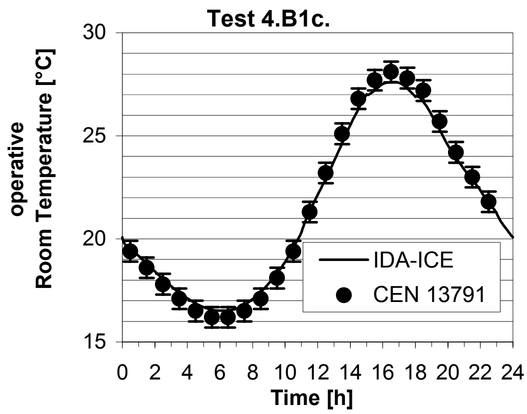
Result of test 4.B1b.



Values in °C	min	mean	max
prEN 13791	16.4	22.1	29.9
IDA-ICE	16.6	21.9	29.1

Good agreement except for the daily maximum which is calculated by IDA-ICE as 0.8°C lower than given by prCEN 13791.

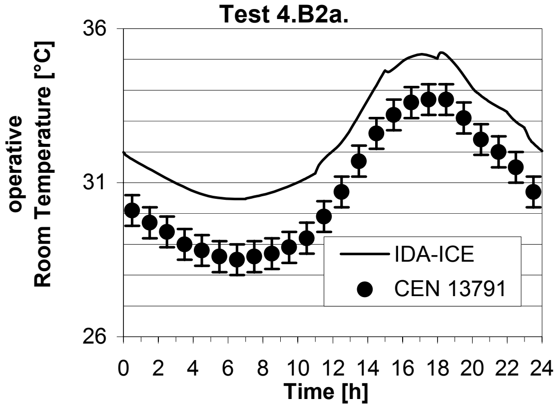
Result of test 4.B1c.



Values in °C	min	mean	max
prEN 13791	16.2	21.5	28.1
IDA-ICE	16.5	21.8	27.6

Good agreement.

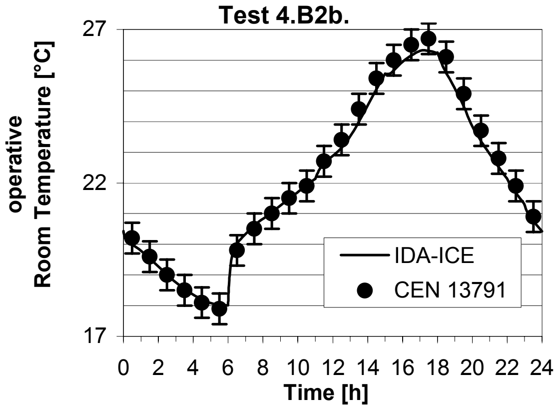
Result of test 4.B2a.



Values in °C	min	mean	max
prEN 13791	28.5	30.8	33.7
IDA-ICE	30.5	32.4	35.2

The values calculated by IDA-ICE higher than the values given in prEN 13791 by up to 2 °C.

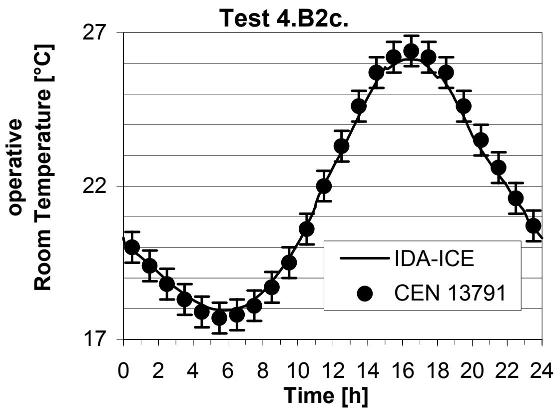
Result of test 4.B2b.



Values in °C	min	mean	max
prEN 13791	17.9	22.2	26.7
IDA-ICE	18.0	22.1	26.3

Good agreement.

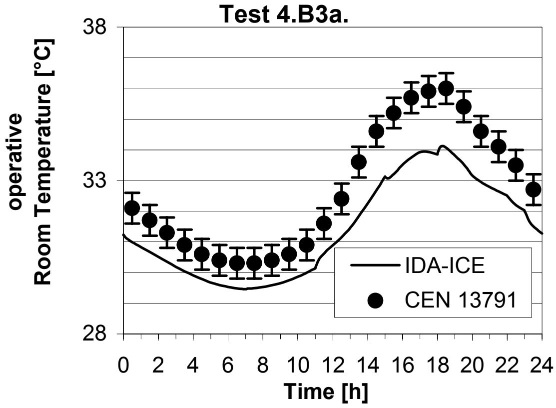
Result of test 4.B2c.



Values in °C	min	mean	max
prEN 13791	17.7	21.7	26.4
IDA-ICE	18.0	21.6	26.1

Good agreement.

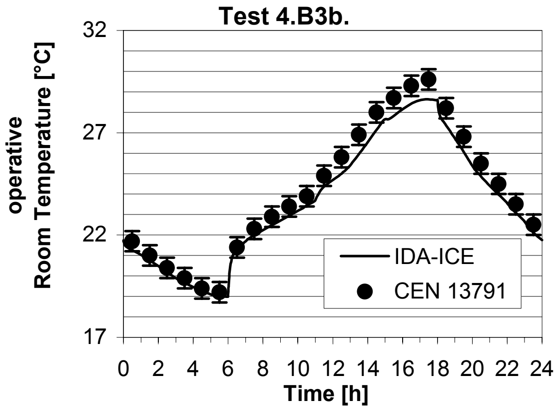
Result of test 4.B3a.



Values in °C	min	mean	max
prEN 13791	30.3	32.7	36.0
IDA-ICE	29.5	31.4	34.1

The values calculated by IDA-ICE are deeper than the values given in prEN 13791 by up to 2 °C.

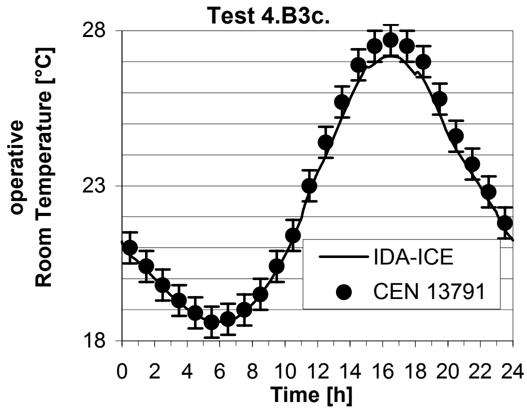
Result of test 4.B3b.



Values in °C	min	mean	max
prEN 13791	19.2	24.2	29.6
IDA-ICE	19.0	23.6	28.6

The values calculated by IDA-ICE are slightly deeper than the values given in prEN 13791.

Result of test 4.B3c.



Values in °C	min	mean	max
prEN 13791	18.6	22.7	27.7
IDA-ICE	18.6	22.5	27.2

Good agreement.