DYNAMISCHE SIMULATIE VAN GEBOUWEN

BIJEENKOMST VAN ATIC
OP 15 JANUARI 2020

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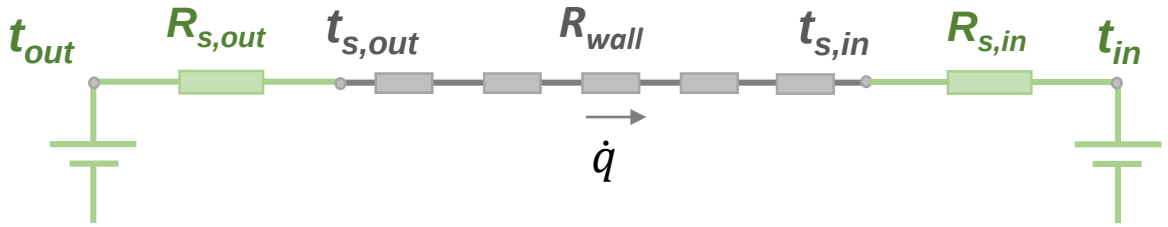
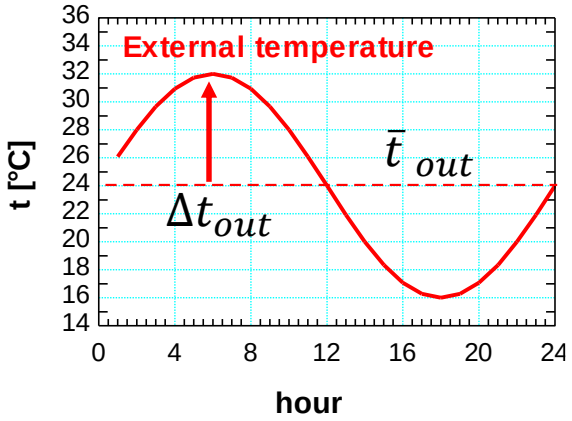
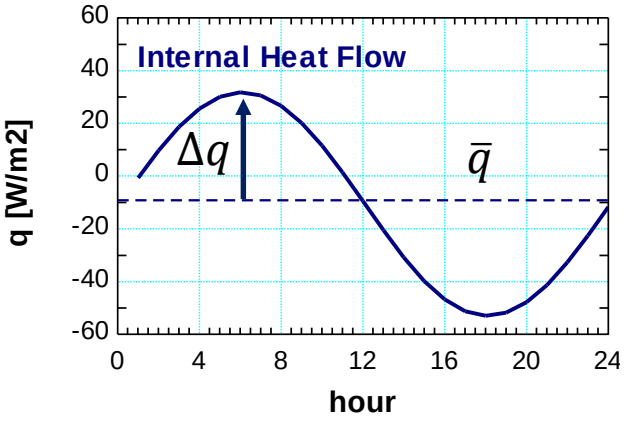
Atic
for HVAC professionals

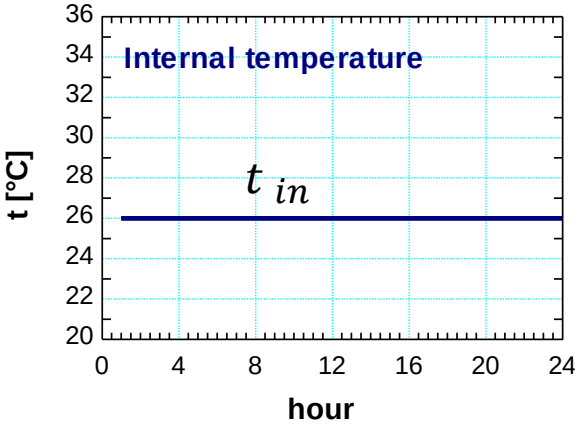
Statisch systeem



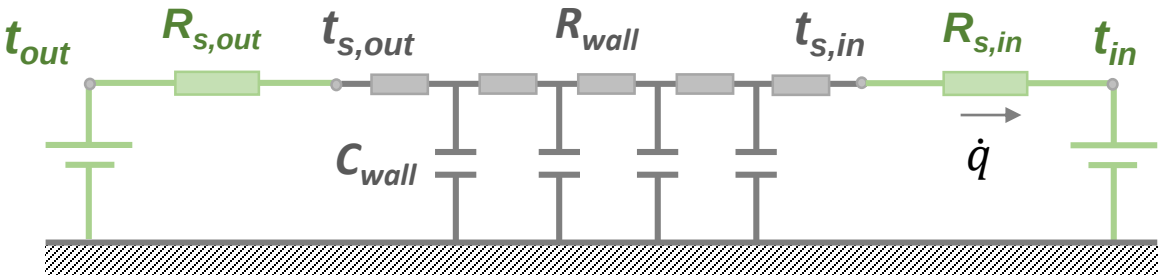
$$\dot{q} = U(t_{out} - t_{in}) \qquad \bar{q} = U(\bar{t}_{out} - t_{in}) \qquad \Delta q = U(\Delta t_{out} - t_{in})$$



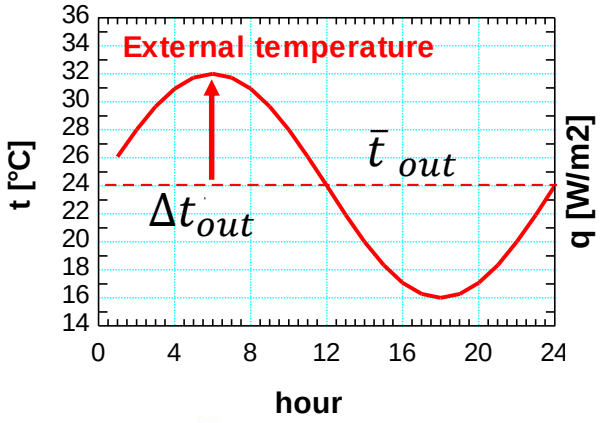


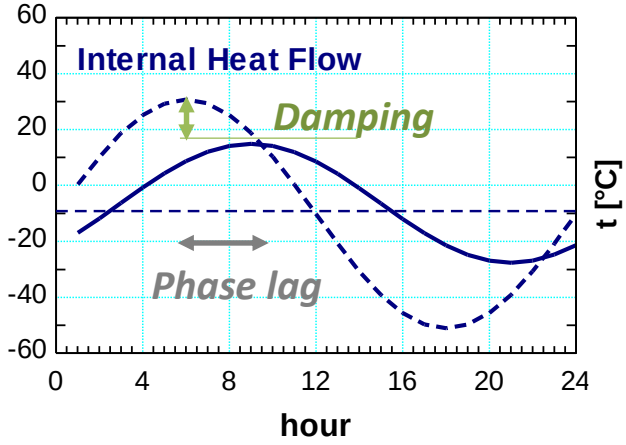


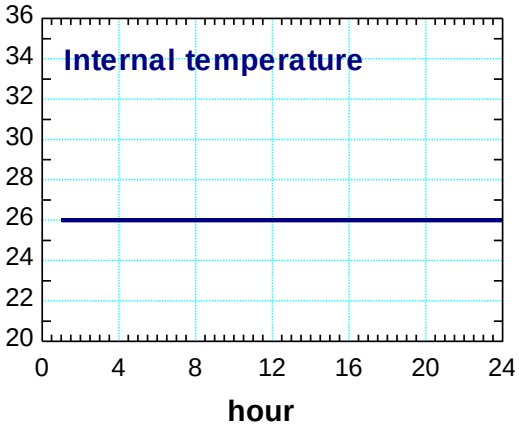
Dynamisch systeem



$$\Delta t_{eq} = \frac{\dot{q}}{U}$$





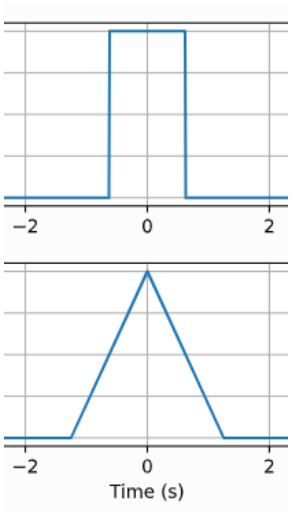


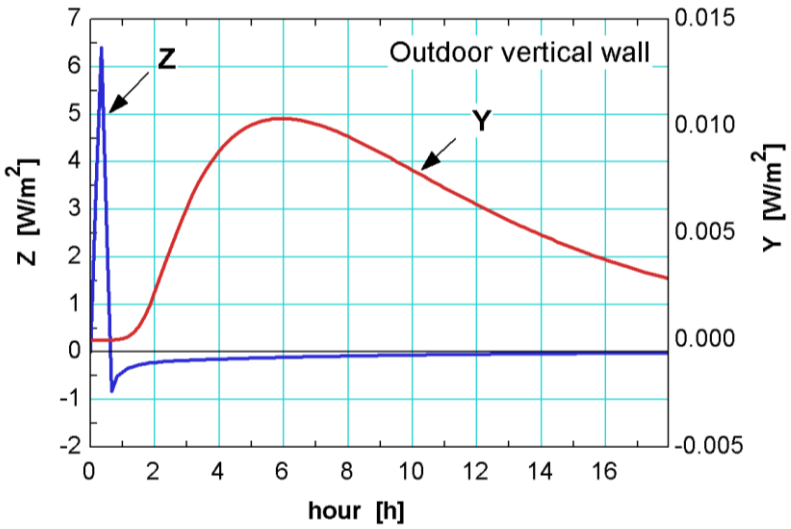
DYNAMISCHE SIMULATIE - BEGINSEL

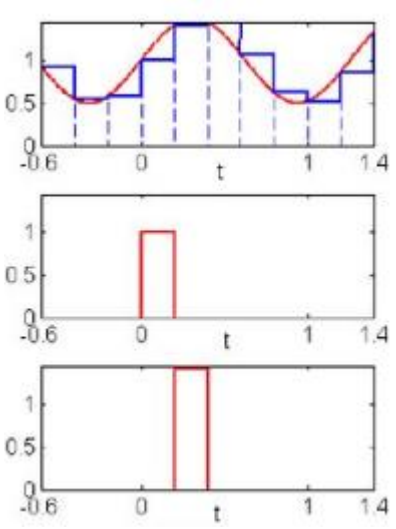
- Differentiaalvergelijkingen

$$\begin{bmatrix} \frac{dT_1}{dt} \\ \frac{dT_2}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{1}{RC} - \frac{hA}{C} & \frac{1}{RC} \\ \frac{1}{RC} & -\frac{1}{RC} - \frac{hA}{C} \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \end{bmatrix} + \begin{bmatrix} \frac{hA}{C} & 0 \\ 0 & \frac{hA}{C} \end{bmatrix} \begin{bmatrix} T_o \\ T_i \end{bmatrix}$$

- Convolutiemodel op basis van responsfactoren







DYNAMISCHE SIMULATIESOFTWARES

TRNSYS 18

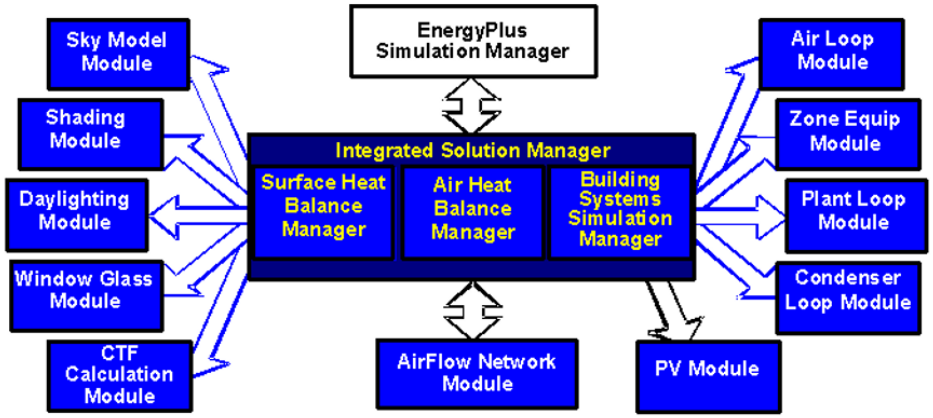
BEMS team, ULg

Web : http://www.bems.ulg.ac.be

Library energy system components

- **Solar** Thermal Processes
- **Ground** Coupled Heat Transfer
- **Heat Pump** Systems
- Coupled Multizone Thermal/**Airflow** Modeling
- **Power Plant**s (Biomass,Cogeneration)
- Hydrogen **Fuel Cell** Systems
- **Wind and Photovoltaic** Systems
- **HVAC** systems
- Emerging Technology **Assessment**
- Energy System **Research**
- Data and Simulation **Calibration**
- **Optimization**

EnergyPlus



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DYNAMISCHE SIMULATIE - TOEPASSINGEN

Systeem dimensionering

Energieverbruik

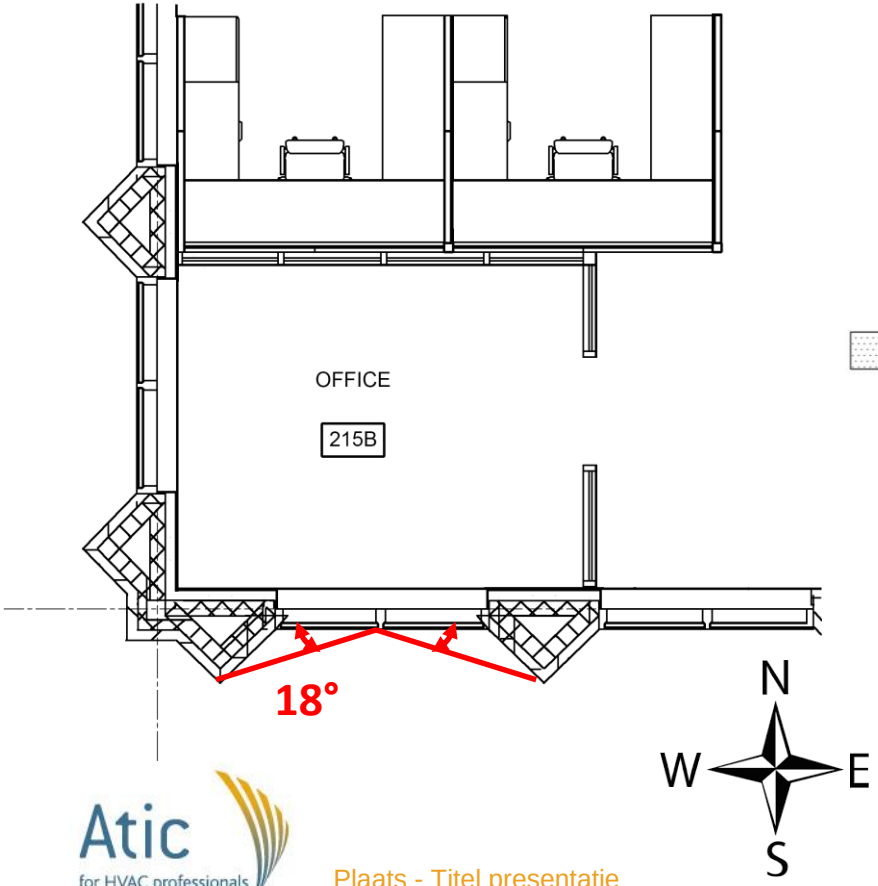
Bevestiging

Parametrische identificatie

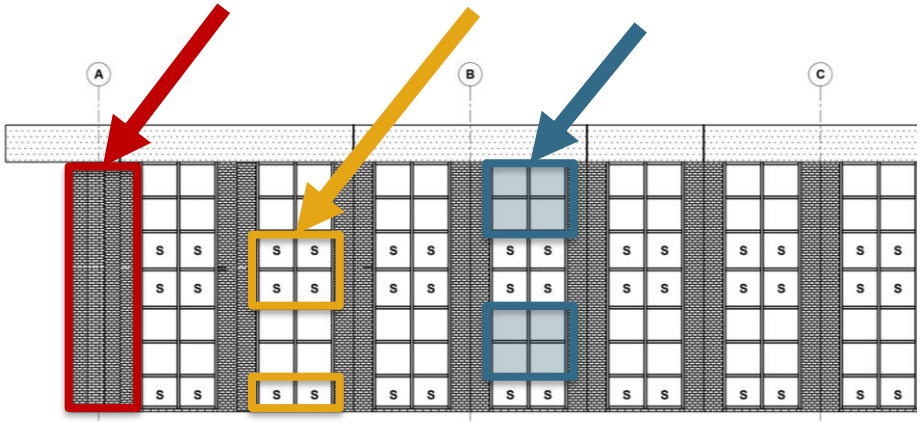
CASE STUDY

Glazing : U_w = 1,8 W/m^2-K, SHGC = 0.49 frame factor 10 %

Bricks	U = 0,24 W/m^2-K
Sprandel walls	U = 0,24 W/m^2-K
Roof	U = 0,18 W/m^2-K

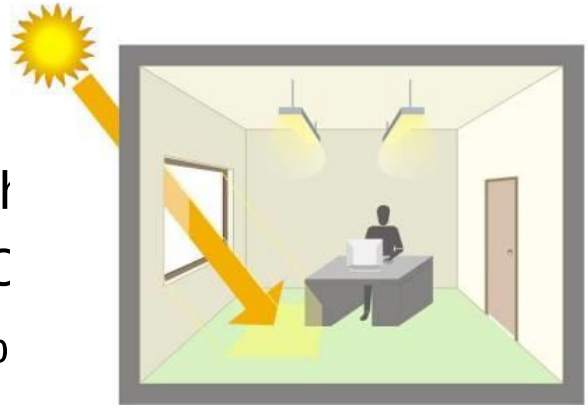


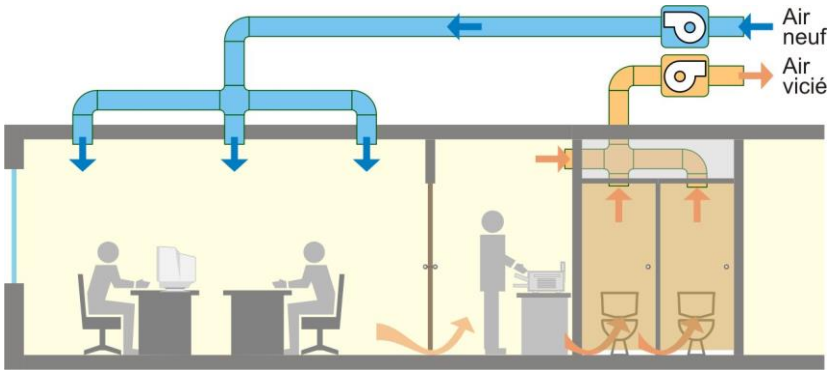
Bricks – Sprandel walls - Windows

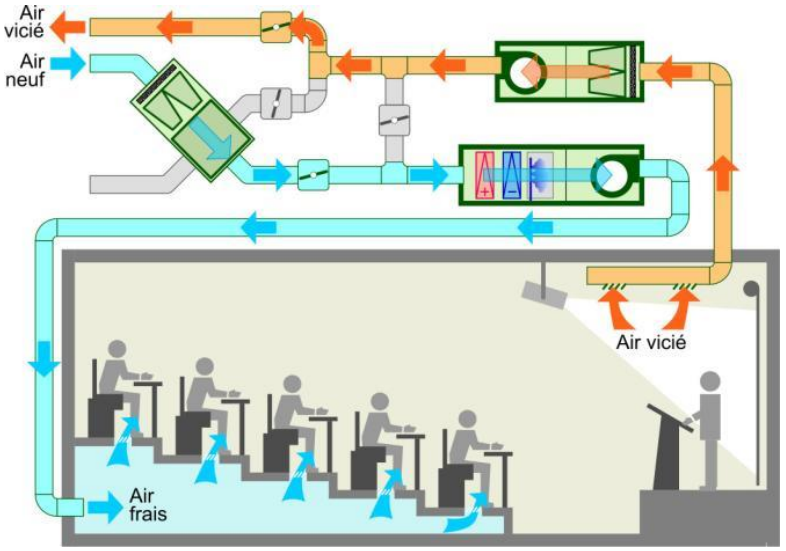


COMFORT EISEN

- Frisse luchtstroom per inzittende: 40-50 m³/h
- Interne temperatuur: 20 à 26 °C
- Interne relatieve vochtigheid : 40 à 60 %

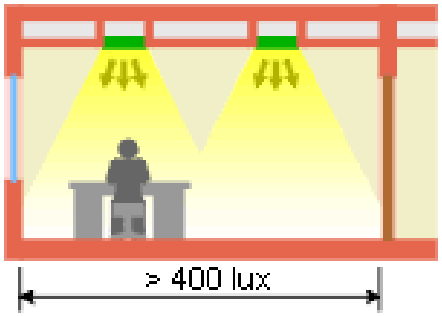




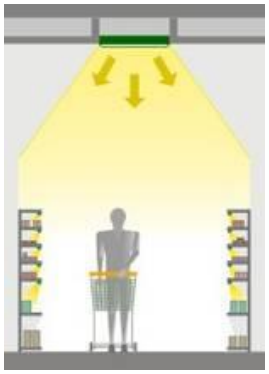


Source: www.energieplus-lesite.be

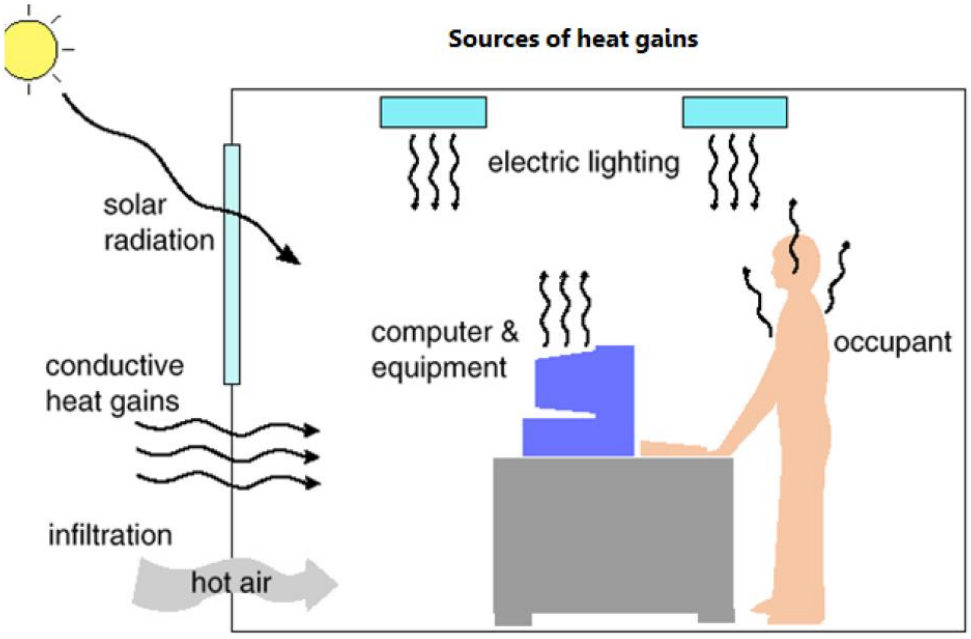
WARMTE WINSTEN

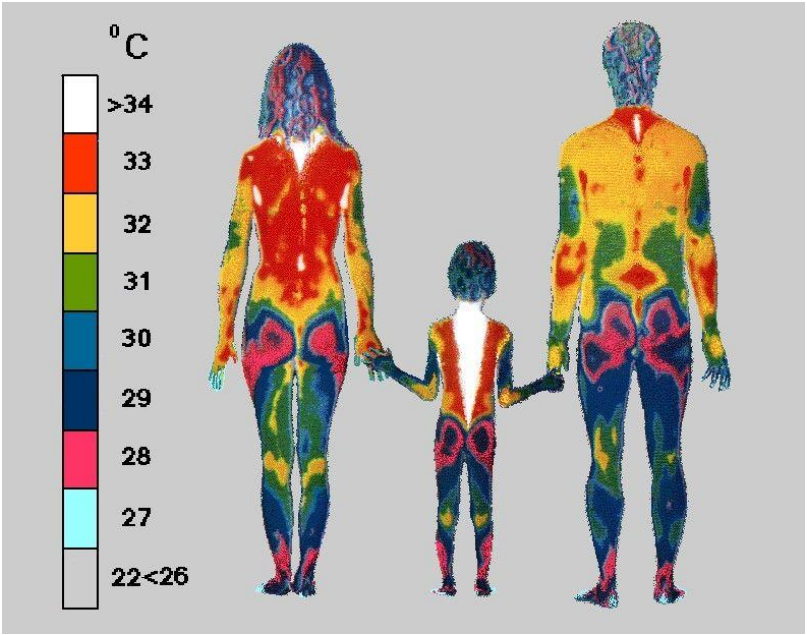


Uniforme: 10 W/m^2



Général: 20 W/m^2

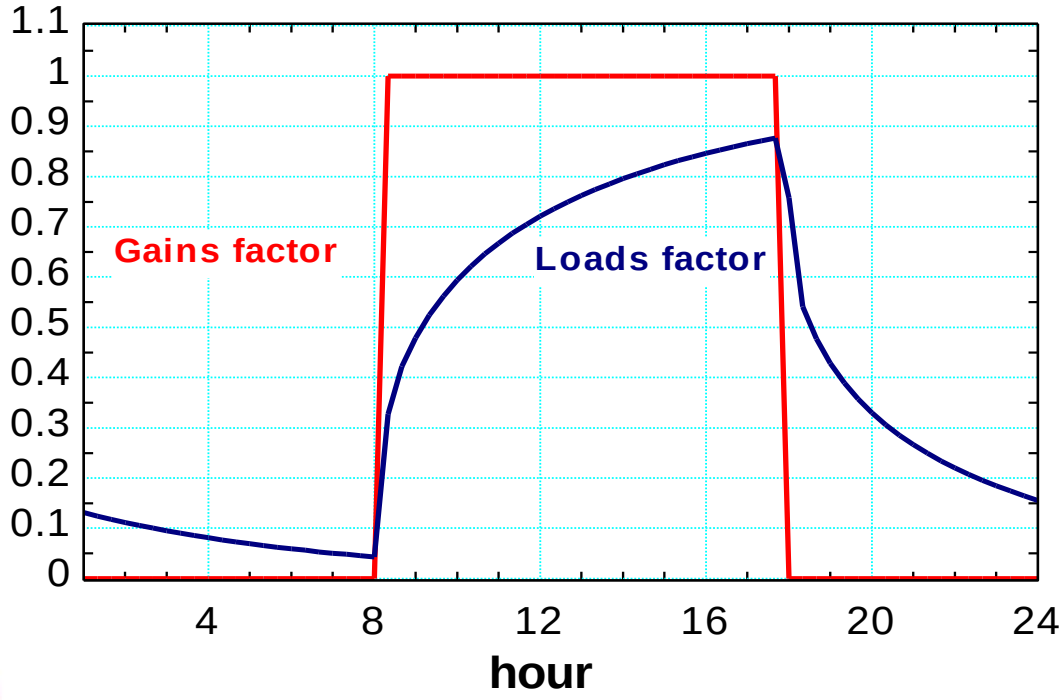




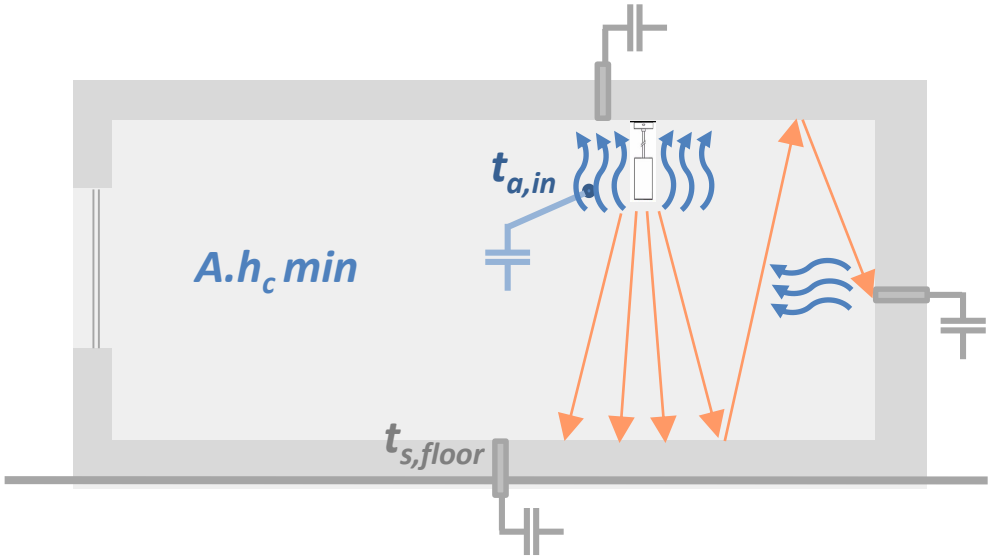
WARMTE WINSTEN versus WARMTEBELASTINGEN

$$\dot{Q}_l = f_{ad} \cdot \dot{Q}_{l,m}$$

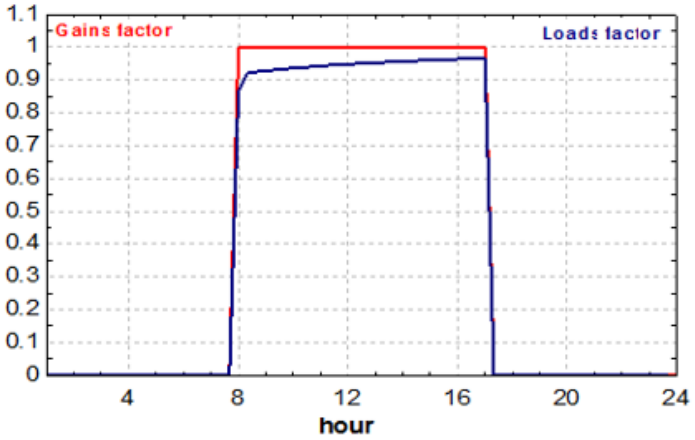
$\dot{Q}_l$	Warmtewinsten	W
f_{ad}	Cooling Load Factor (uur voor uur)	-
$\dot{Q}_{l,m}$	Warmtebelasting	W



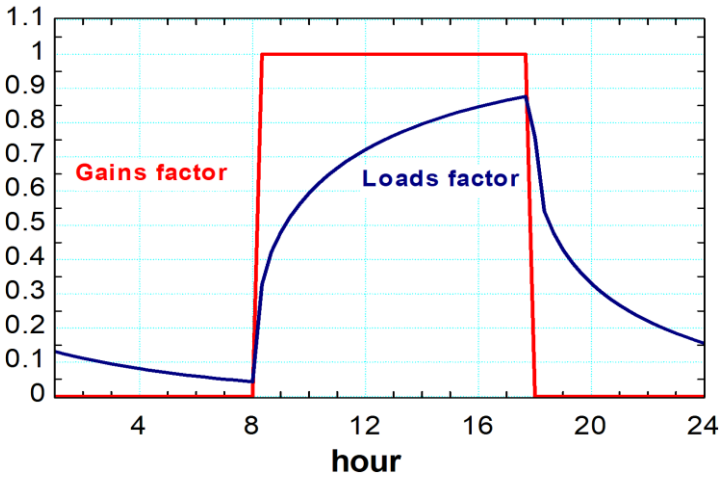
CONVECTIEF versus RADIATIEF WARMTEWINSTEN



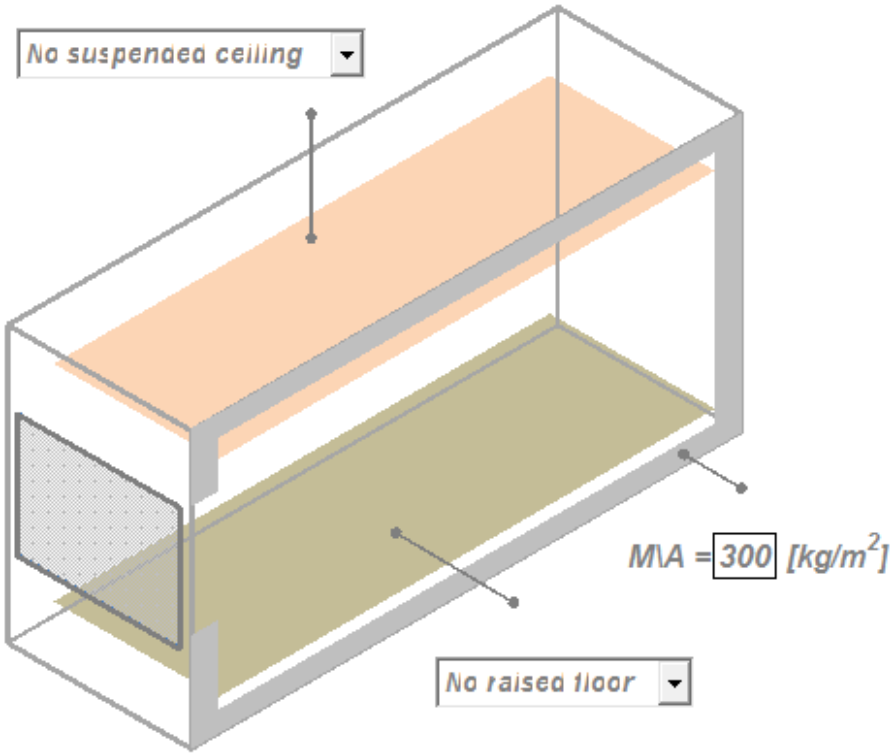
Convectief warmtewinst



Radiatief warmtewinst



VERLICHTING EN BEZETTINGSBELASTINGEN

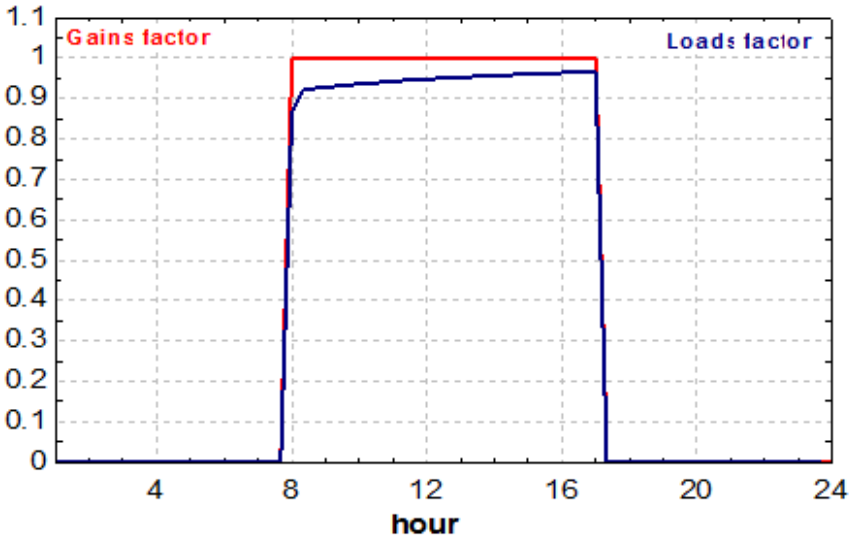


Radiative fraction of Heat gains 0

Heat gains from 8 AM to 5 PM

Plant working from 8 AM to 5 PM

Calculate **Maximum load factor: 0.97**



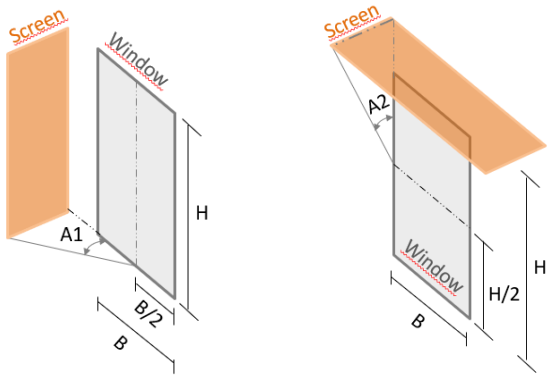
Load_factors

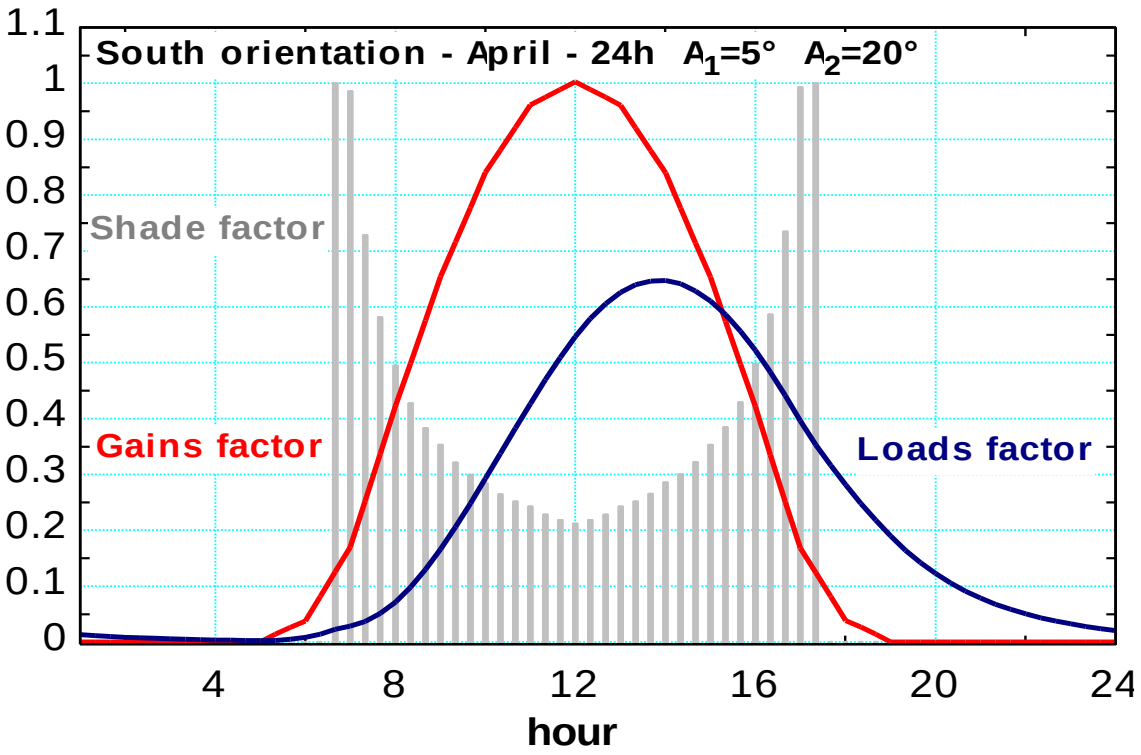
	1 $f_{ad,0}$	2 $f_{ad,1}$	3 $f_{ad,2}$	4 $f_{ad,3}$	5 $f_{ad,4}$	6 $f_{ad,5}$	7 $f_{ad,6}$	8 $f_{ad,7}$	9 $f_{ad,8}$	10 $f_{ad,9}$	11 $f_{ad,10}$	12 $f_{ad,11}$	13 $f_{ad,12}$	14 $f_{ad,13}$	15 $f_{ad,14}$	16 $f_{ad,15}$	17 $f_{ad,16}$	18 $f_{ad,17}$
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.87	0.93	0.94	0.94	0.95	0.95	0.96	0.96	0.96	0.97

ZONNEWARMTEBELADINGEN - VENSTERS

$$\dot{Q}_s = f_{ad,gl} . g . A_{gl} . \Phi_{t\,max}$$

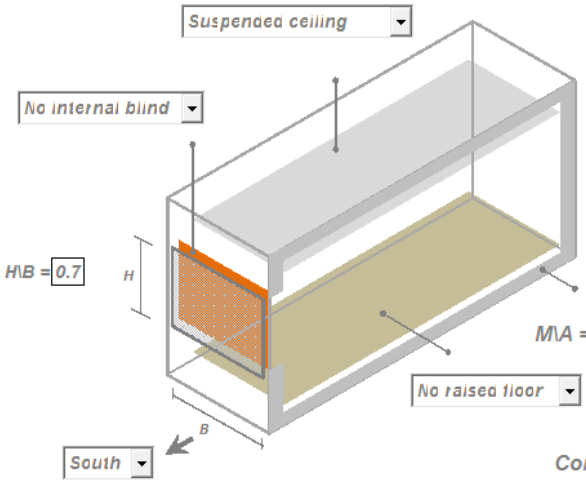
$\dot{Q}_s$	Warmtewinsten	*W*
$f_{ad,gl}$	Cooling Load Factor, schaduweffect inbegrepen	
$\Phi_{t\,max}$	Max totale zonnestraling	*W/m²*

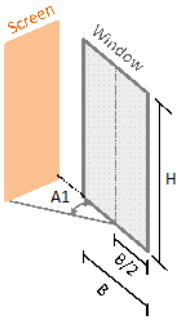


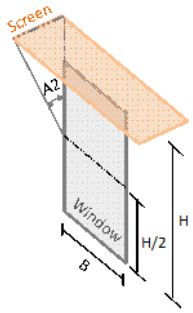


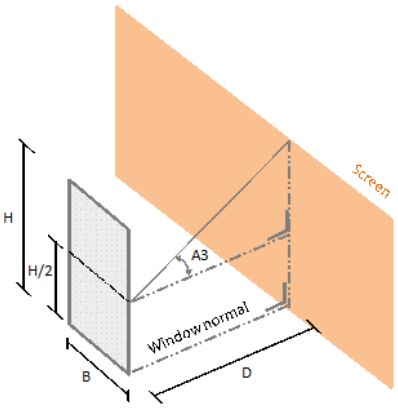
ZONNEWARMTEBELADINGEN - VENSTERS

Loads Values Evaluation









M\A = 500 [kg/m^2]

A1 = 0 [deg]

A2 = 0 [deg]

D\H = 0

A3 = 0 [deg]

No vertical screen

Convection heat exchange coefficient 7 [W/m^2-K]

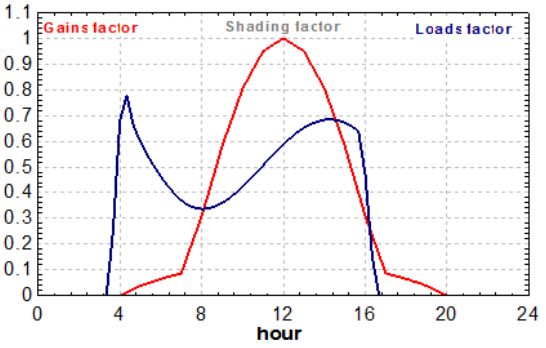
Plant working from 4 AM to 4 PM

Calculate

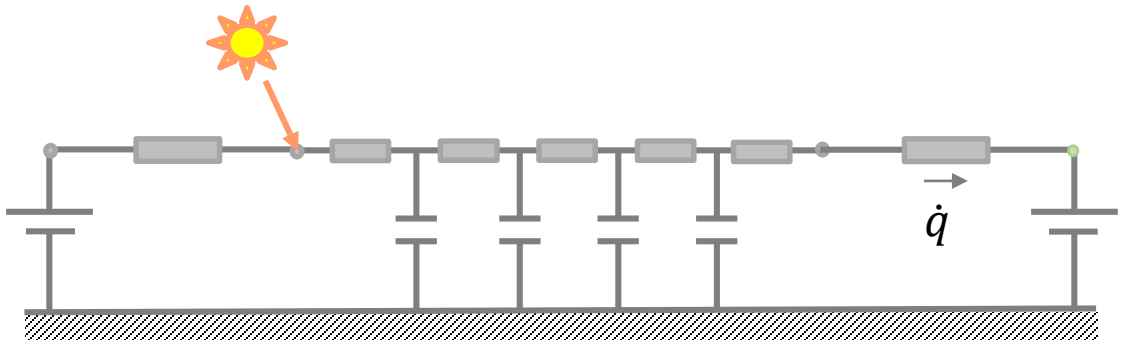
Maximum solar intensity on window: 507 [W/m^2]

Maximum hourly average load factor: 0.73

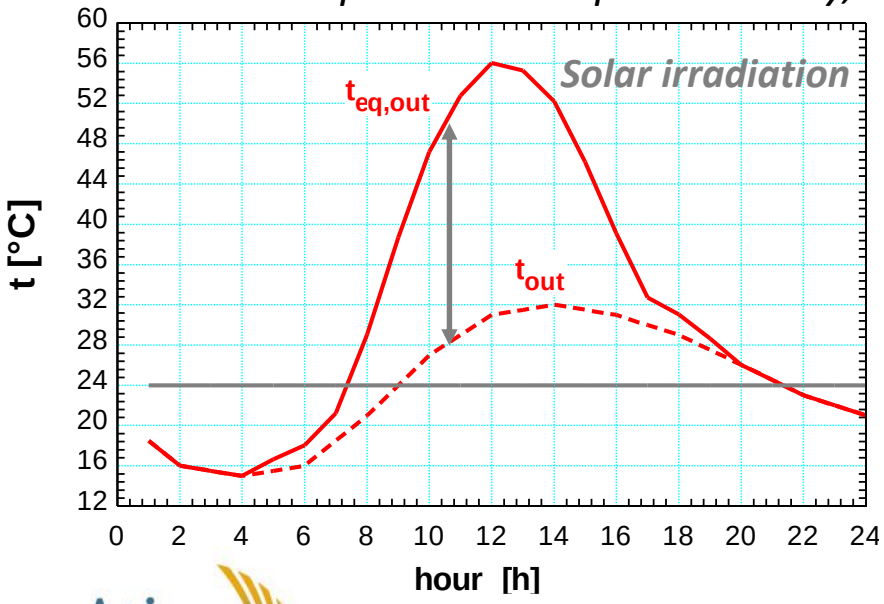
Maximum intensity times load factor: 370.1 [W/m^2]

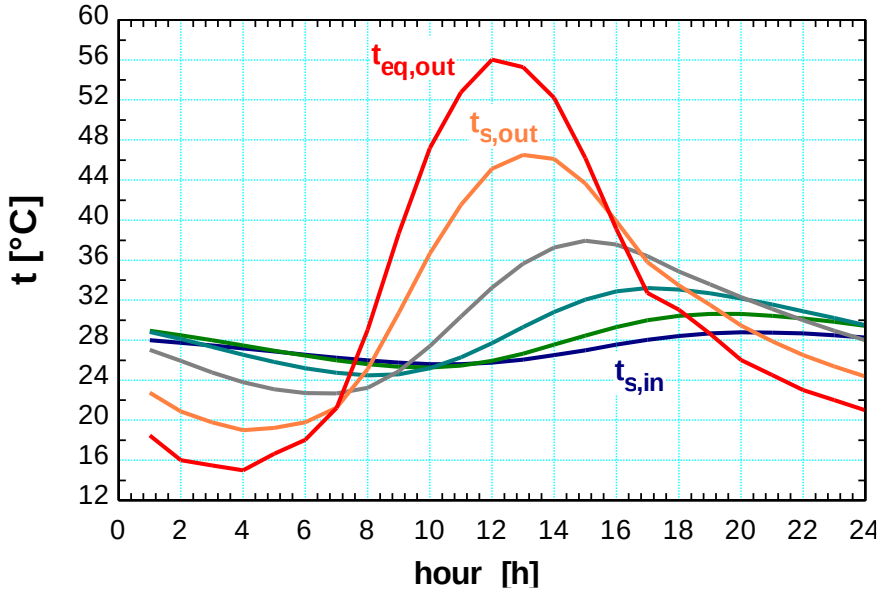


ZONNEWARMTEBELADINGEN - OPAQUE WANDEN



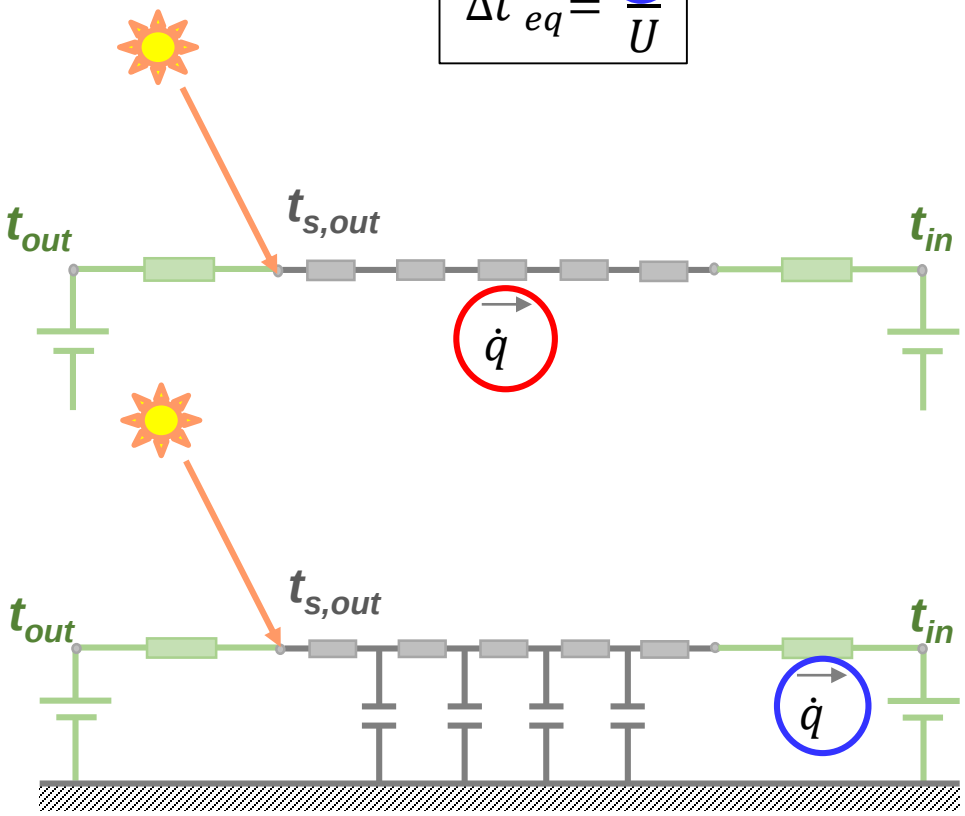
External equivalent temperature July, South

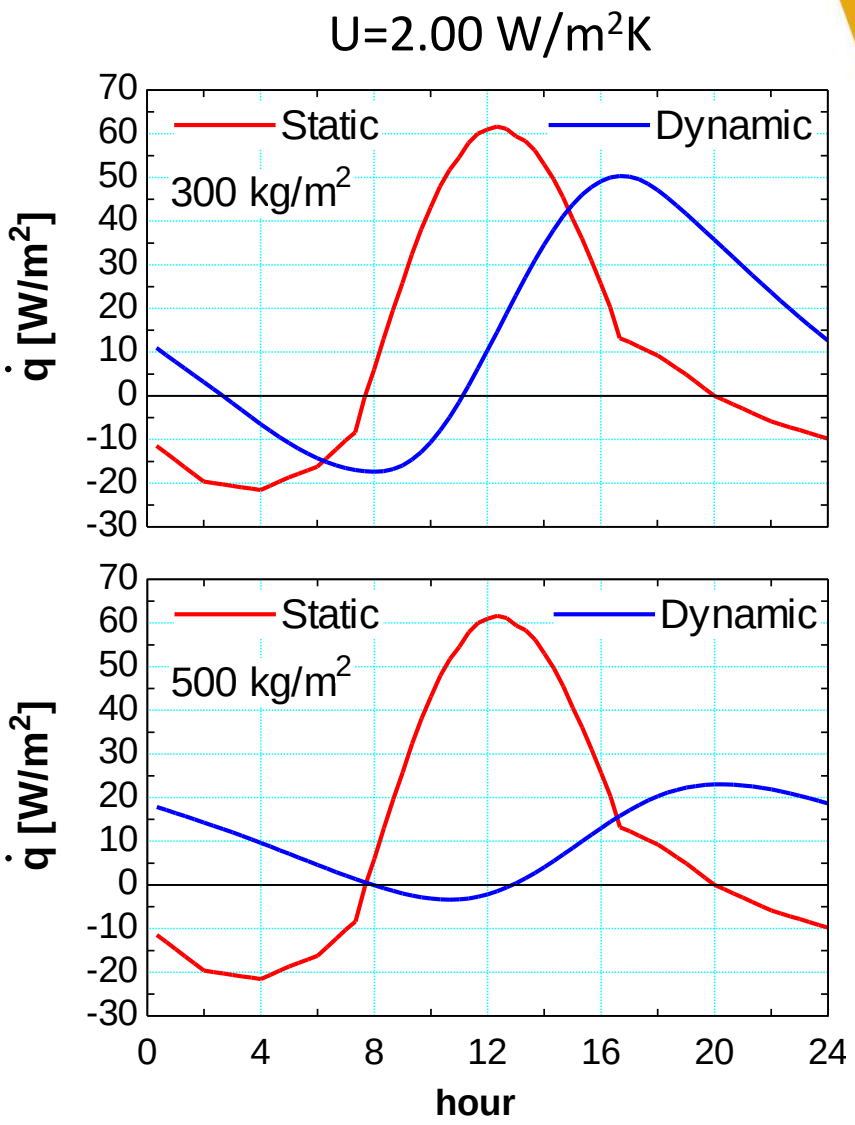




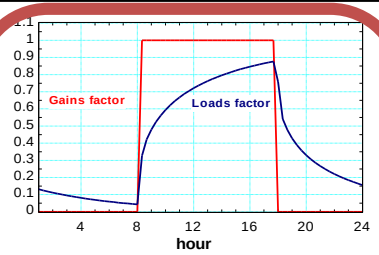
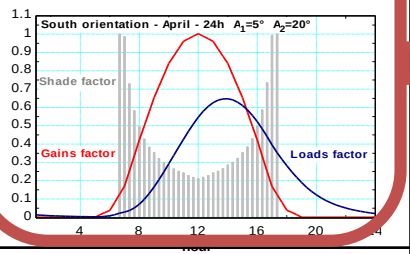
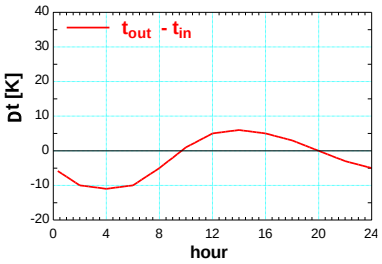
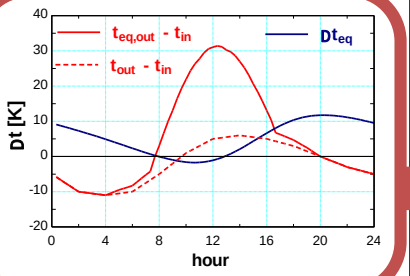
ZONNEWARMTEBELADINGEN - OPAQUE WANDEN

$$\Delta t_{eq} = \frac{\dot{q}}{U}$$





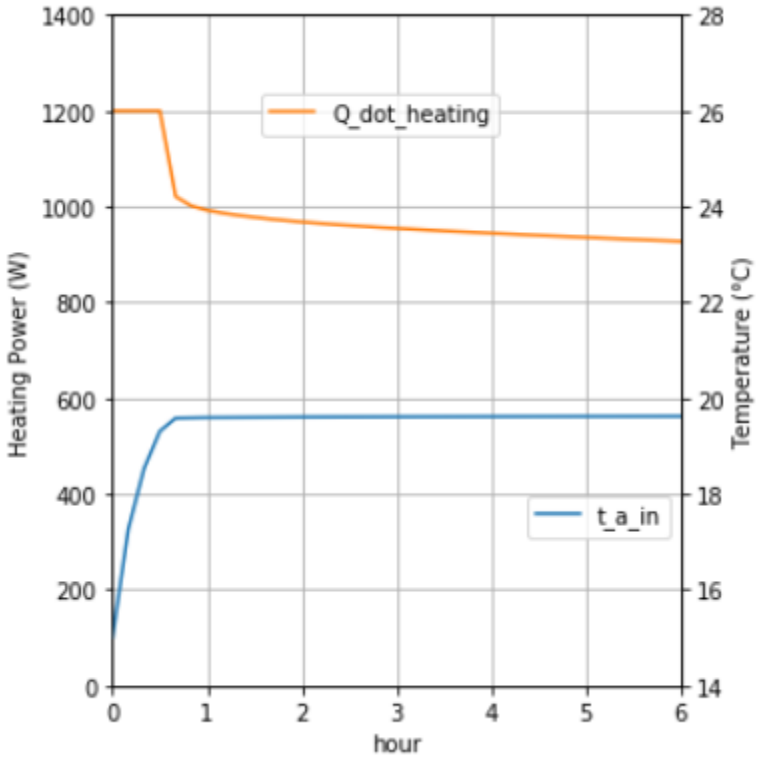
WARMTE WINSTEN

	Heat Gains	Load Factor	Heat Loads
Occupants **Lighting** **Equipment**	Radiative		$\dot{Q} = f_{ad} . \dot{Q}_{rad,max}$
	Convective		$\dot{Q} = f_{ad} . \dot{Q}_{conv,max}$
Windows	Radiative		**Internally accessible mass** $\dot{Q} = f_{ad,gl} . g . A_{gl} . \phi_{s,max}$
	Transmission		$\dot{Q}_{tr} = AU(t_{out} - t_{in})$
Opaque walls	Radiative + Transmission		$\dot{Q}_{tr} = AU\Delta t_{eq}$ **Total mass**

KOELSYSTEEM DIMENSIONERING

Hour (summer)		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	0	1
Hour (solar time)		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Step 100% radiative CLF		0,18	0,14	0,11	0,09	0,07	0,07	0,28	0,43	0,54	0,63	0,7	0,75	0,8	0,83	0,86	0,88	0,9	0,91	0,73	0,57	0,45	0,36	0,28	0,23	0,18
Light & occ radiative loads (W)	144	26	20	16	13	10	10	40	62	78	91	101	108	115	120	124	127	130	131	105	82	65	52	40	33	26
Step 100 % convective CLF		0,09	0,07	0,06	0,04	0,04	0,25	0,65	0,72	0,78	0,82	0,85	0,88	0,9	0,92	0,93	0,94	0,95	0,96	0,36	0,28	0,22	0,17	0,14	0,11	0,09
Light & occ convective loads (W)	216	19	15	13	9	9	54	140	156	168	177	184	190	194	199	201	203	205	207	78	60	48	37	30	24	19
South Solar CLF - July		0,01	0	0	0	0	0	0,02	0,04	0,06	0,08	0,09	0,1	0,11	0,11	0,11	0,11	0,11	0,11	0,1	0,08	0,06	0,04	0,02	0,01	0,01
South Solar heat loads (W)	832	8	0	0	0	0	0	17	33	50	67	75	83	91	91	91	91	91	91	83	67	50	33	17	8	8
West Solar CLF - July		0,04	0,02	0,01	0,01	0	0	0,01	0,03	0,04	0,06	0,07	0,07	0,08	0,08	0,08	0,08	0,08	0,11	0,22	0,31	0,32	0,22	0,12	0,07	0,04
West Solar heat loads (W)	1094	44	22	11	11	0	0	11	33	44	66	77	77	88	88	88	88	88	120	241	339	350	241	131	77	44
South brick wall DTE- July (K)		6,4	5,9	5,2	4,4	3,5	2,6	1,6	0,5	-0,4	-1,3	-1,9	-2,3	-2,1	-1,5	-0,4	1	2,5	4,1	5,4	6,4	7	7,3	7,2	7	6,5
South brick wall (W)	1,34	9	8	7	6	5	3	2	1	-1	-2	-3	-3	-3	-2	-1	1	3	5	7	9	9	10	10	9	9
South spandrel wall DTE- July (K)		-4,7	-6,8	-9,3	-10,3	-10,9	-10,2	-9,1	-6,8	-1,7	6	13,2	18,4	21,8	22,4	20,8	17	12	6,4	4,5	2,7	0,6	-1,1	-2,6	-3,7	-4,7
South spandrel wall (W)	1,34	-6	-9	-12	-14	-15	-14	-12	-9	-2	8	18	25	29	30	28	23	16	9	6	4	1	-1	-3	-5	-6
West brick wall DTE- July (K)		9,6	9,1	8,4	7,5	6,4	5,2	4	2,7	1,6	0,5	-0,3	-1	-1,3	-1,4	-1,2	-0,8	0	1,2	2,7	4,5	6,3	7,9	9,1	9,7	9,6
West brick wall (W)	0,89	9	8	7	7	6	5	4	2	1	0	0	-1	-1	-1	-1	-1	0	1	2	4	6	7	8	9	9
West spandrel wall DTE- July (K)		-4,7	-6,8	-9,3	-10,3	-10,9	-10,2	-9,1	-6,8	-4	-1	2,1	4,4	6,4	12,7	20	25,2	28	27,6	23,8	16,1	3,1	-1	-2,6	-3,7	-4,7
West spandrel wall (W)	1,34	-6	-9	-12	-14	-15	-14	-12	-9	-5	-1	3	6	9	17	27	34	37	37	32	22	4	-1	-3	-5	-6
Roof DTE - July (K)		-4,3	-6	-8,4	-9,9	-10,6	-8,8	-3,1	5,7	16,3	27	36,6	44,1	48,9	50,6	49,2	44,9	38,3	29,9	20,6	11,4	4,1	0	-1,9	-3,3	-4,3
Roof (W)	1,51	-7	-9	-13	-15	-16	-13	-5	9	25	41	55	67	74	77	74	68	58	45	31	17	6	0	-3	-5	-7
External dry temperature (°C)		21	18,5	16	15,5	15	15,5	16	18,5	21	24	27	29	31	31,5	32	31,5	31	30	29	27,5	26	24,5	23	22	21
DT dry- July (K)		-5	-7,5	-10	-10,5	-11	-10,5	-10	-7,5	-5	-2	1	3	5	5,5	6	5,5	5	4	3	1,5	0	-1,5	-3	-4	-5
Windows transmission gains (W)	12,05	-60	-90	-121	-127	-133	-127	-121	-90	-60	-24	12	36	60	66	72	66	60	48	36	18	0	-18	-36	-48	-60
Infiltration sensible gains (W)	11,00	-55	-83	-110	-116	-121	-116	-110	-83	-55	-22	11	33	55	61	66	61	55	44	33	17	0	-17	-33	-44	-55
Total heat load (W)		-20	-127	-214	-239	-270	-210	-46	104	243	400	532	620	712	744	769	761	744	740	655	638	539	342	157	53	-20

VERWARMINGSSYSTEEM DIMENSIONERING



- Transmissieverliezen :
  - 400 W
- Ventilatie & Infiltratie :
  - 180 W met warmtewisselaar
  - 720 W zonder warmtewisselaar
- Verwarming herstart
  - 620 W
- Totaal
  - 1200 W met warmtewisselaar
  - 1700 W zonder warmtewisselaar

DYNAMISCHE SIMULATIE - TOEPASSINGEN

Systeem dimensionering

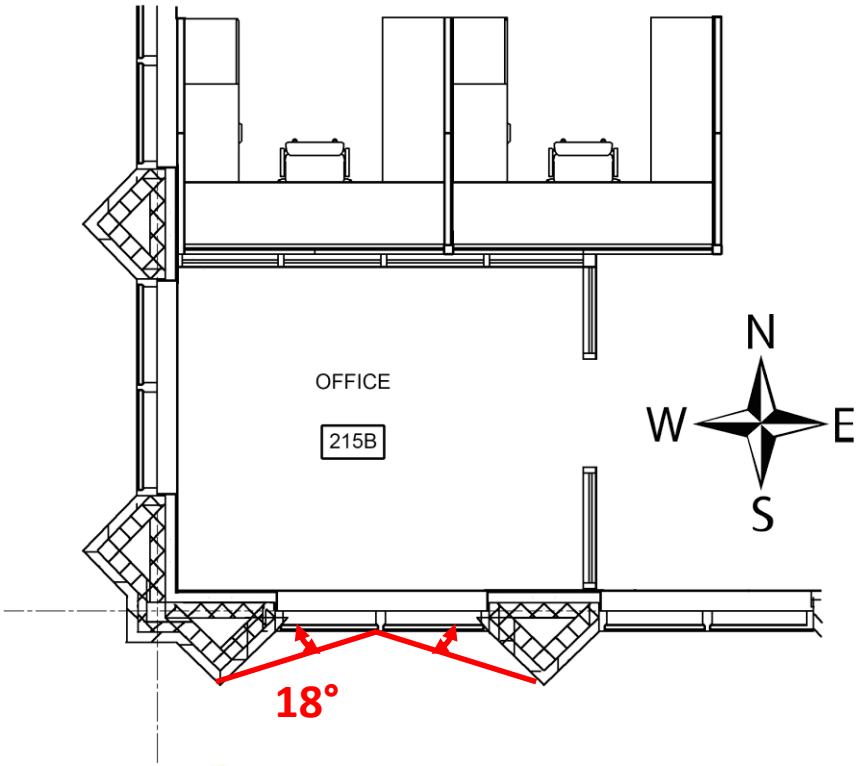
Energieverbruik

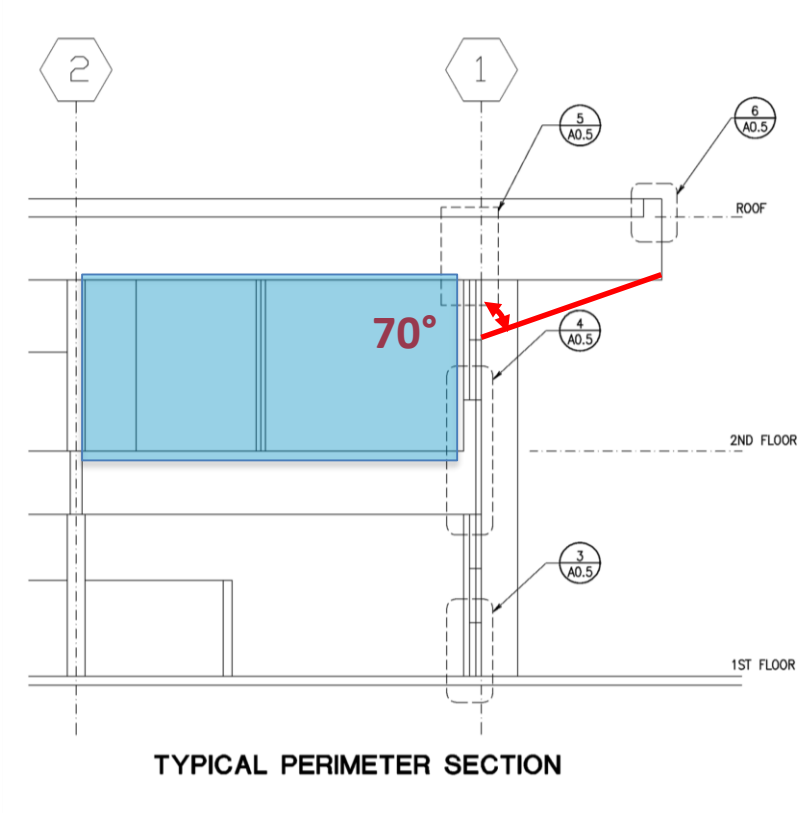
Bevestiging

Parametrische identificatie

CASE STUDY

Glazing : U_w = 1,8 W/m2-K, SHGC = 0.49 frame factor 10 %



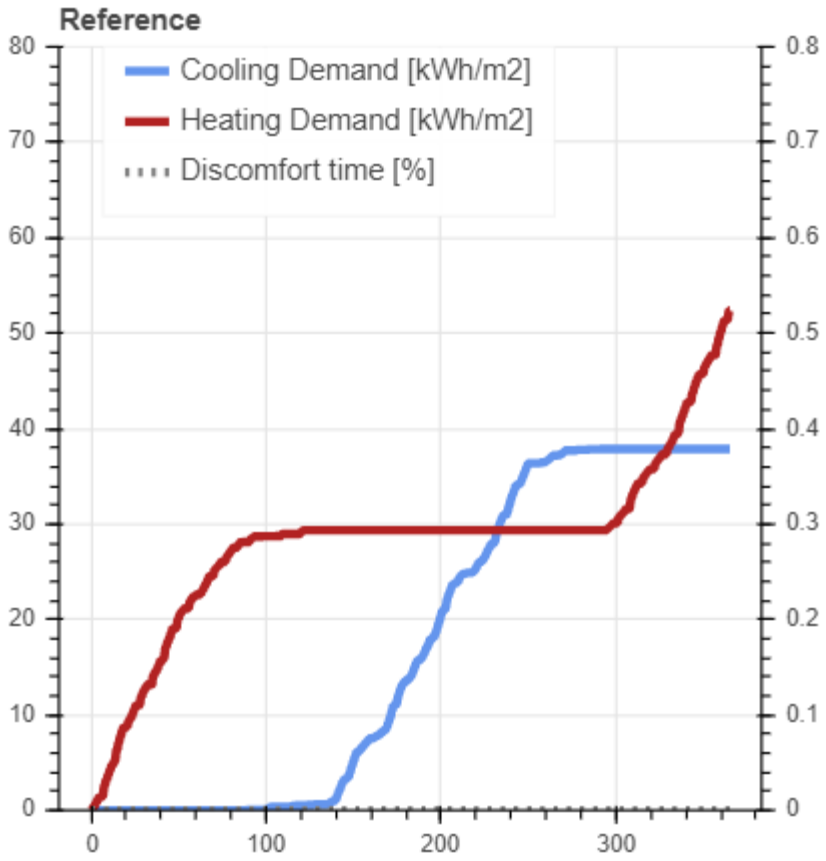


TYPICAL PERIMETER SECTION

VERBETERINGSSTAPPEN

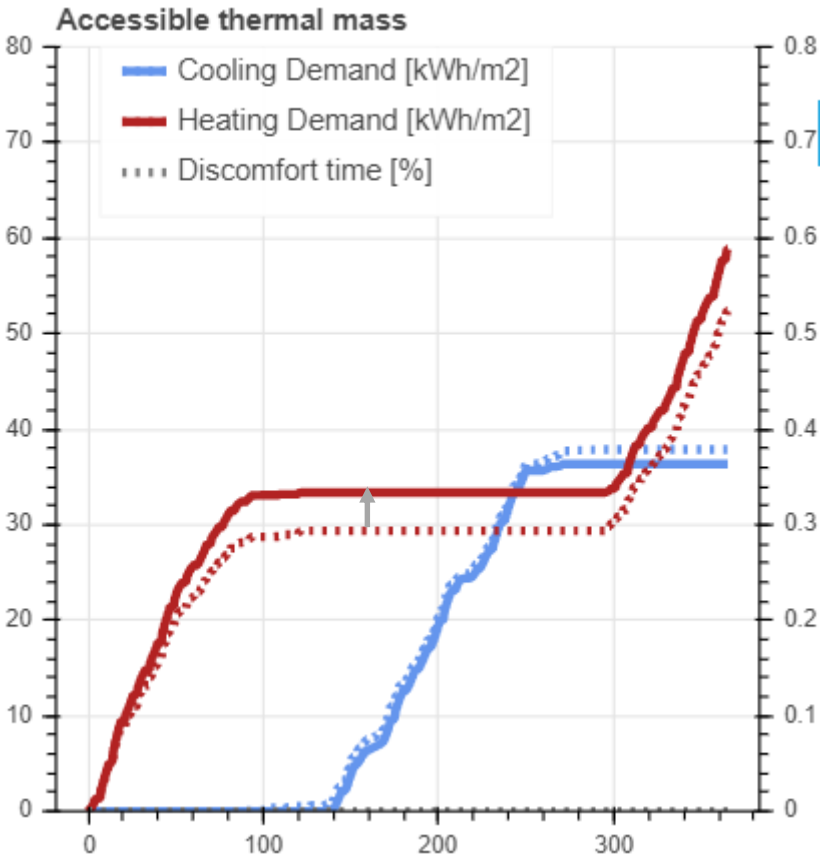
- Referentie:
  - Verlaagd plafond en ondervloer, geen zonneschermen
- Gebouw envelop :
  - Toegankelijke thermische massa
  - Zonwering
- System control improvement:
  - Daytime free cooling : bypass van de warmtewisselaar
  - Night free cooling
  - Geoptimaliseerde regeling voor free cooling
- Gebouw envelop :
  - Extra isolatiedikte voor buitenwanden (+ 5 cm)

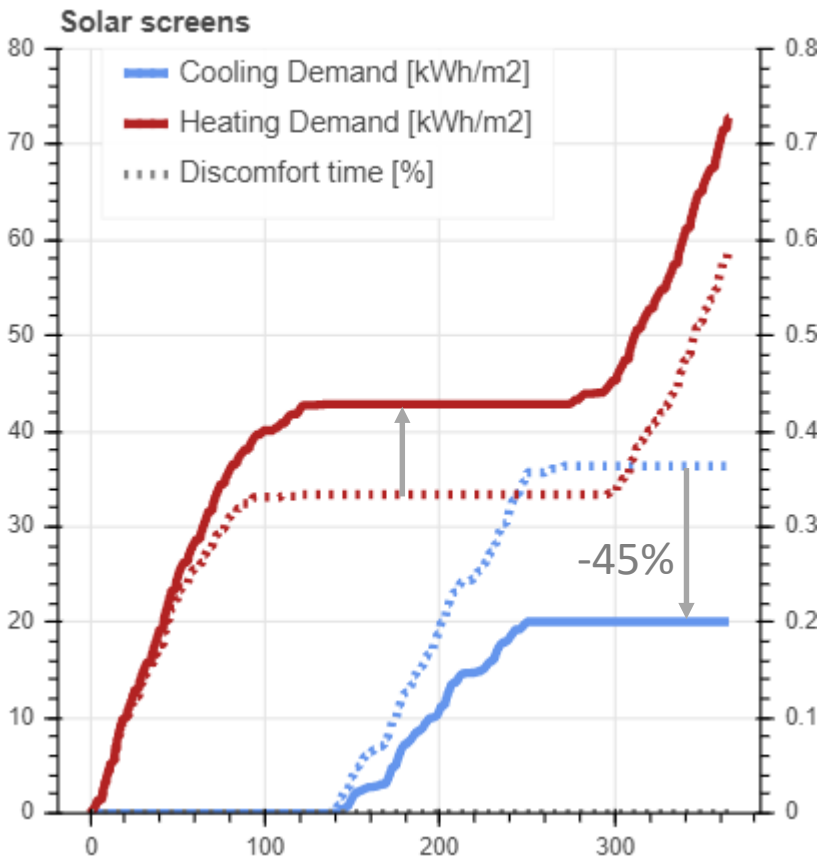
REFERENTIE



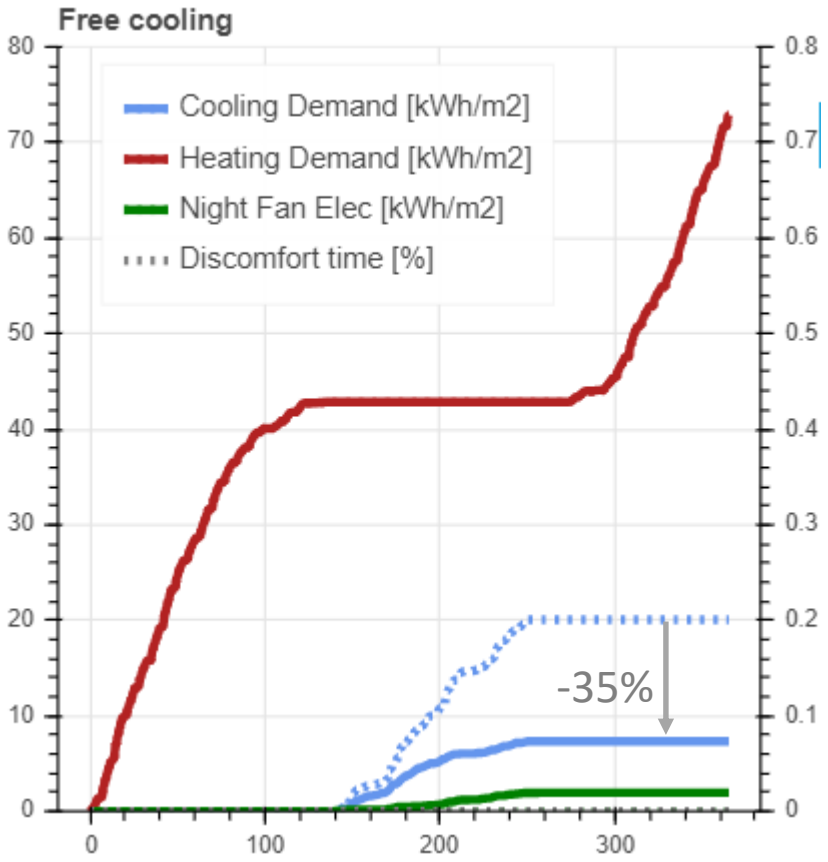
- Typisch weergegevens
- Temperatuur instelpunten :
  - Zomer 26°C / 30°C
  - Winter 21°C / 16°C
- Bewoning :
  - 8 h – 18 h
  - 7.5 m^2/occ
  - 40 m^3/h.occ frisse lucht
  - 6 W/m^2 verlichting
  - 10 W/m^2 apparaten
- Warmteterugwinwisselaar

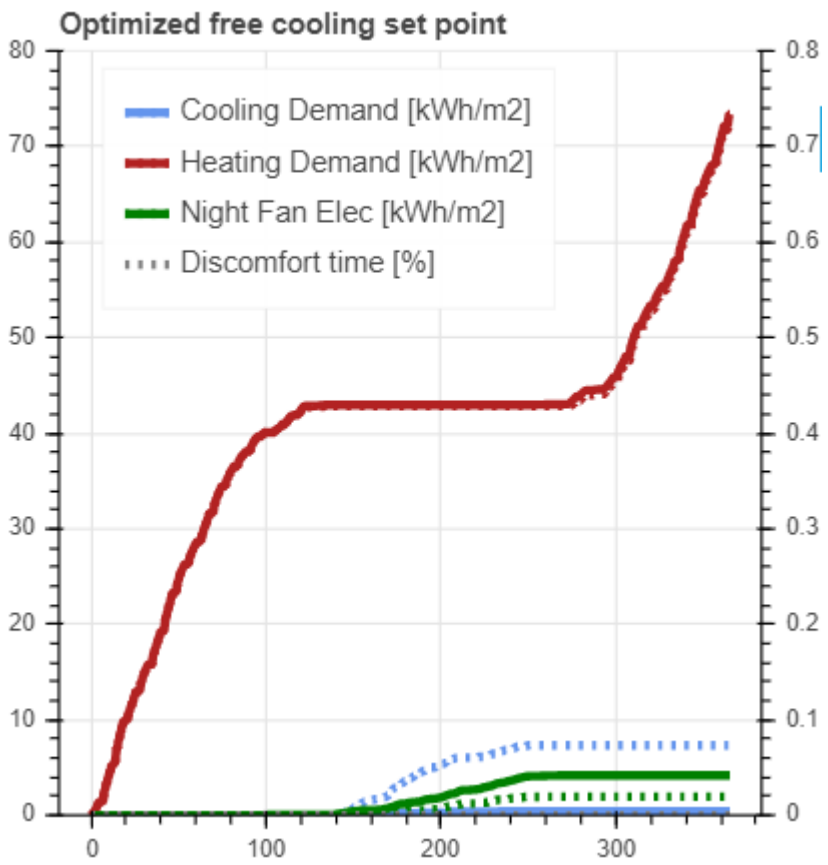
VERBETERINGEN VAN DE ENVELOP



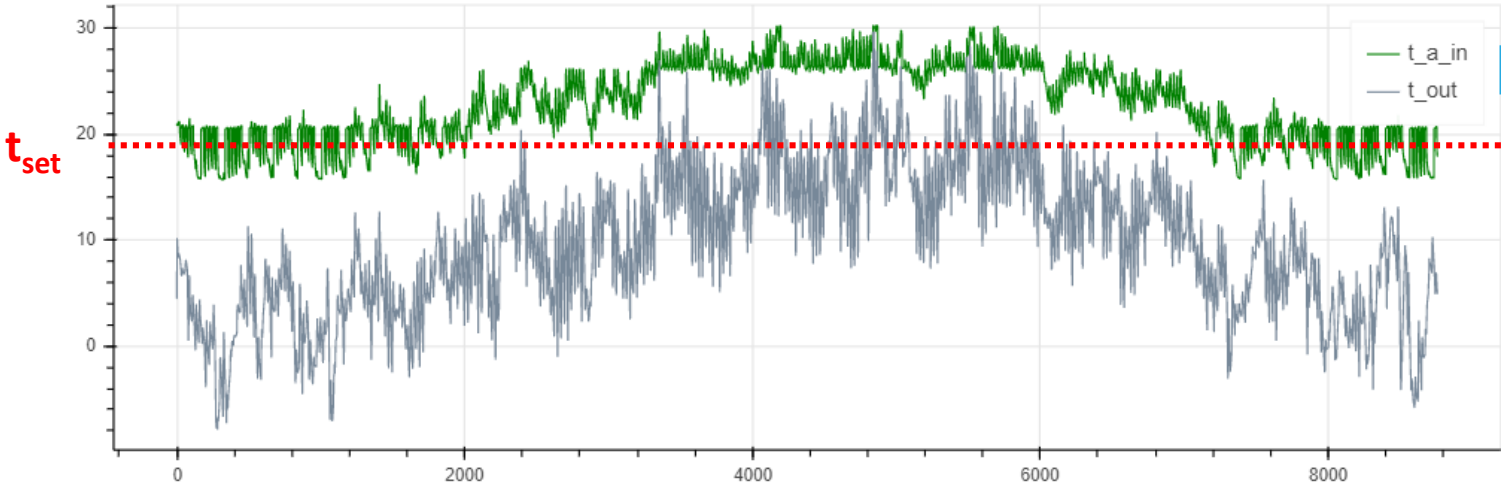


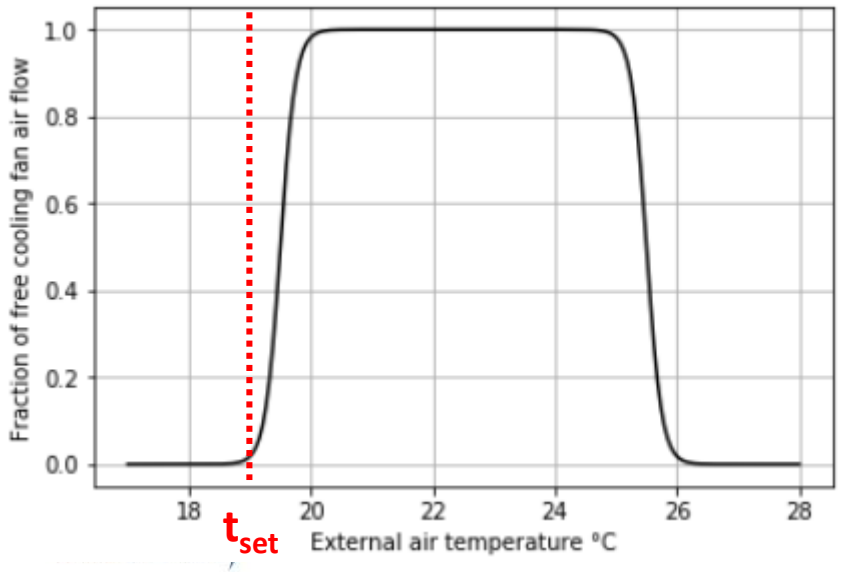
SYSTEEMCONTROLE VERBETERING



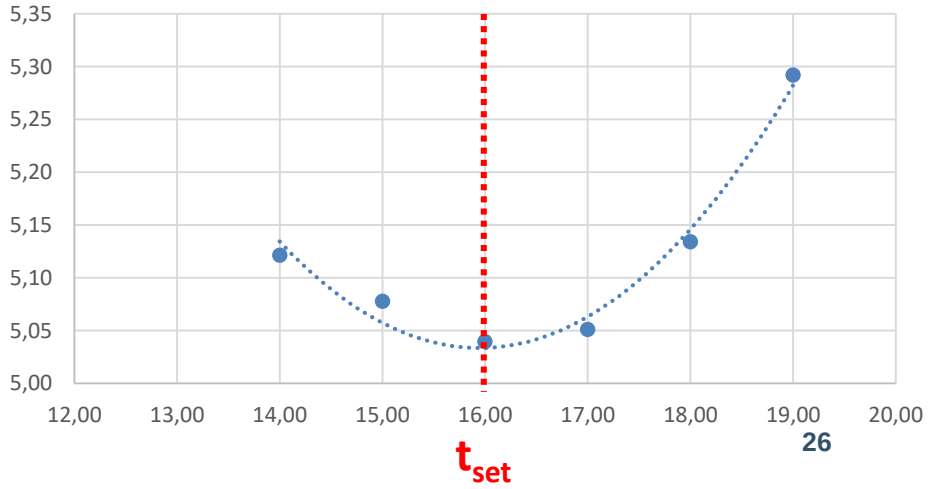


OPTIMALISATIE FREE COOLING INSTELPUNT

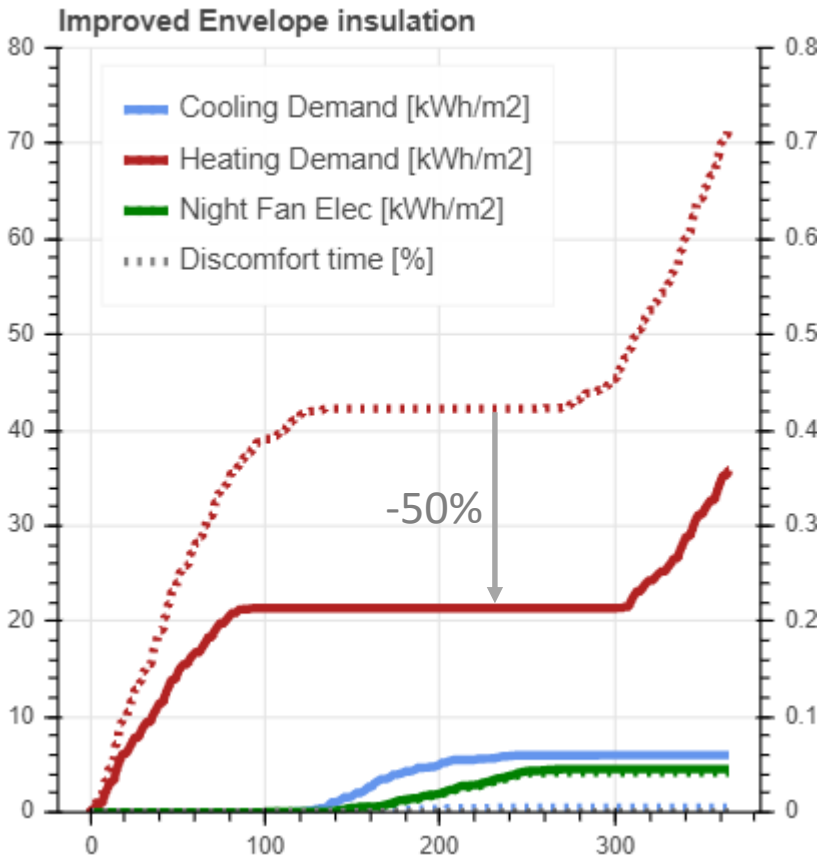


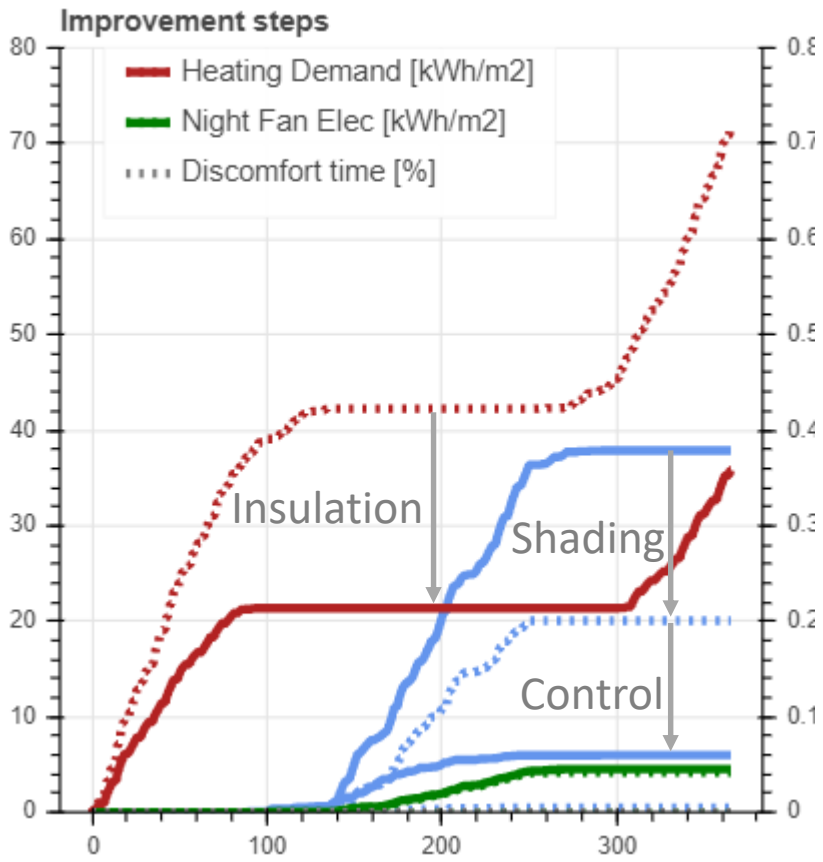


Energy Cost vs free cooling temperature set point (EUR/m2)

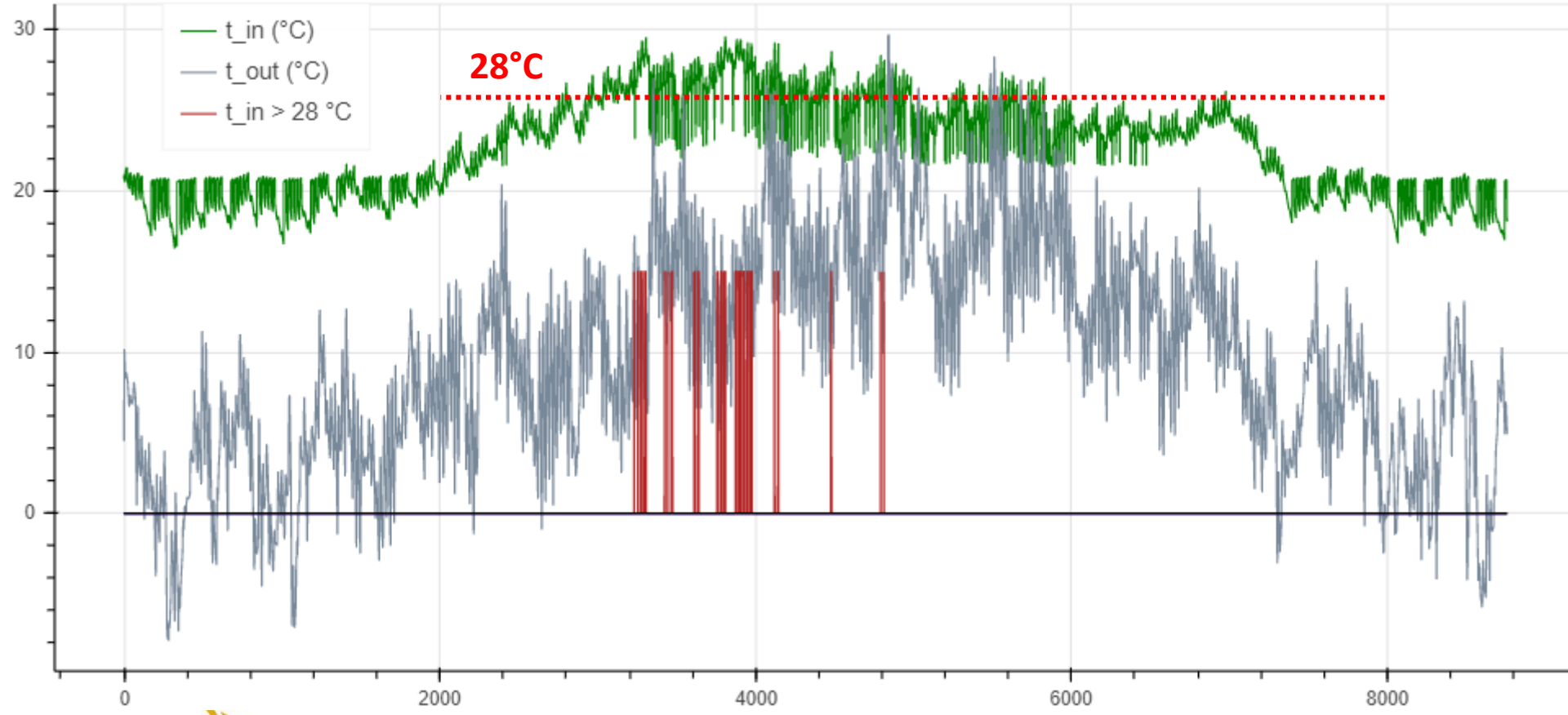


EXTRA ISOLATIEDIKTE VOOR BUITENWANDEN

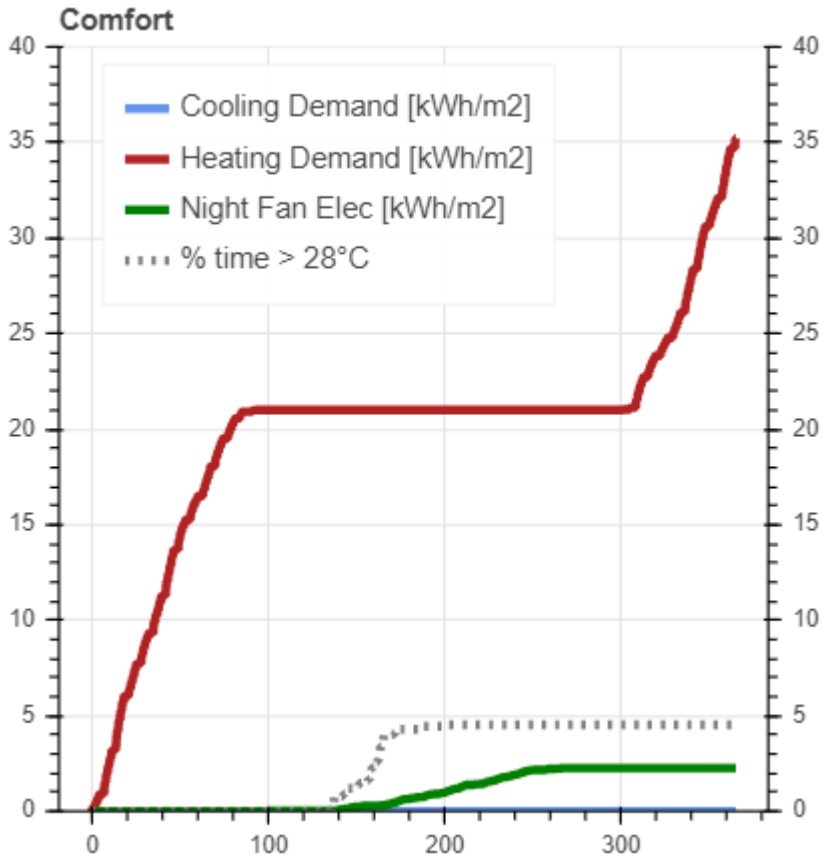


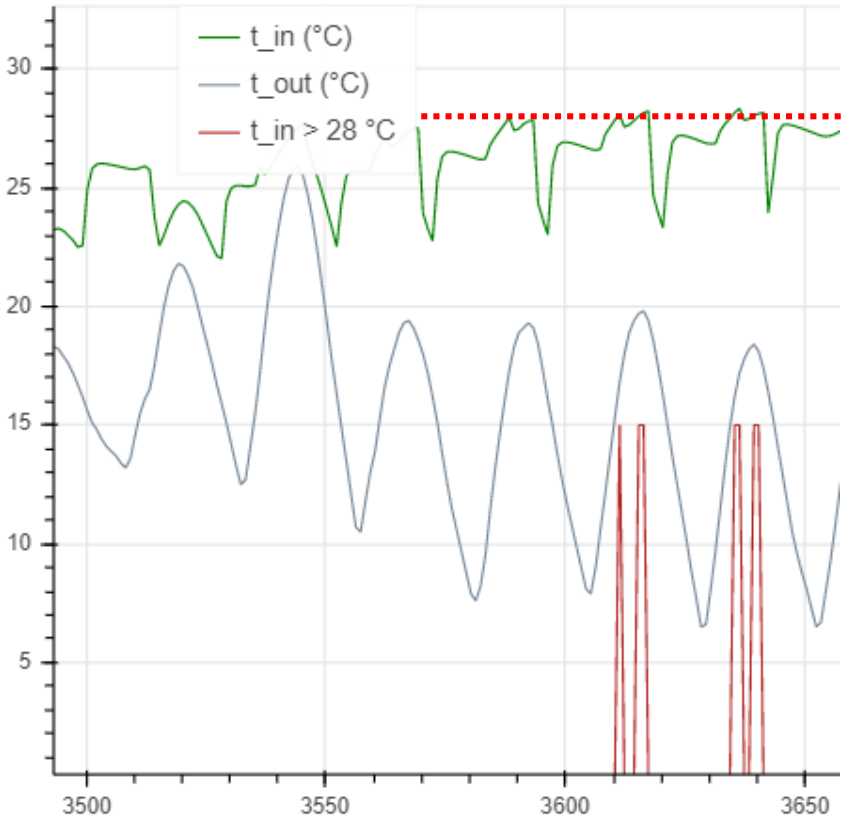


THERMISCH COMFORT - GEEN CHILLER



THERMISCH COMFORT - GEEN CHILLER





CONCLUSIE

- Toepassingen van dynamische simulatie :
  - Dimensionering van verwarmings- en koelsystemen
  - Schatting van het energieverbruik
  - Verificatie van thermisch comfort

- Verbeteringen opties :
  - Shading systemen
  - Optimalisatie van controle >>> ROI < 15 years
  - Isolatie van gebouwen >>> ROI > 15 years

DYNAMISCHE SIMULATIE - TOEPASSINGEN

Systeem dimensionering

Energieverbruik

Bevestiging

Parametrische identificatie

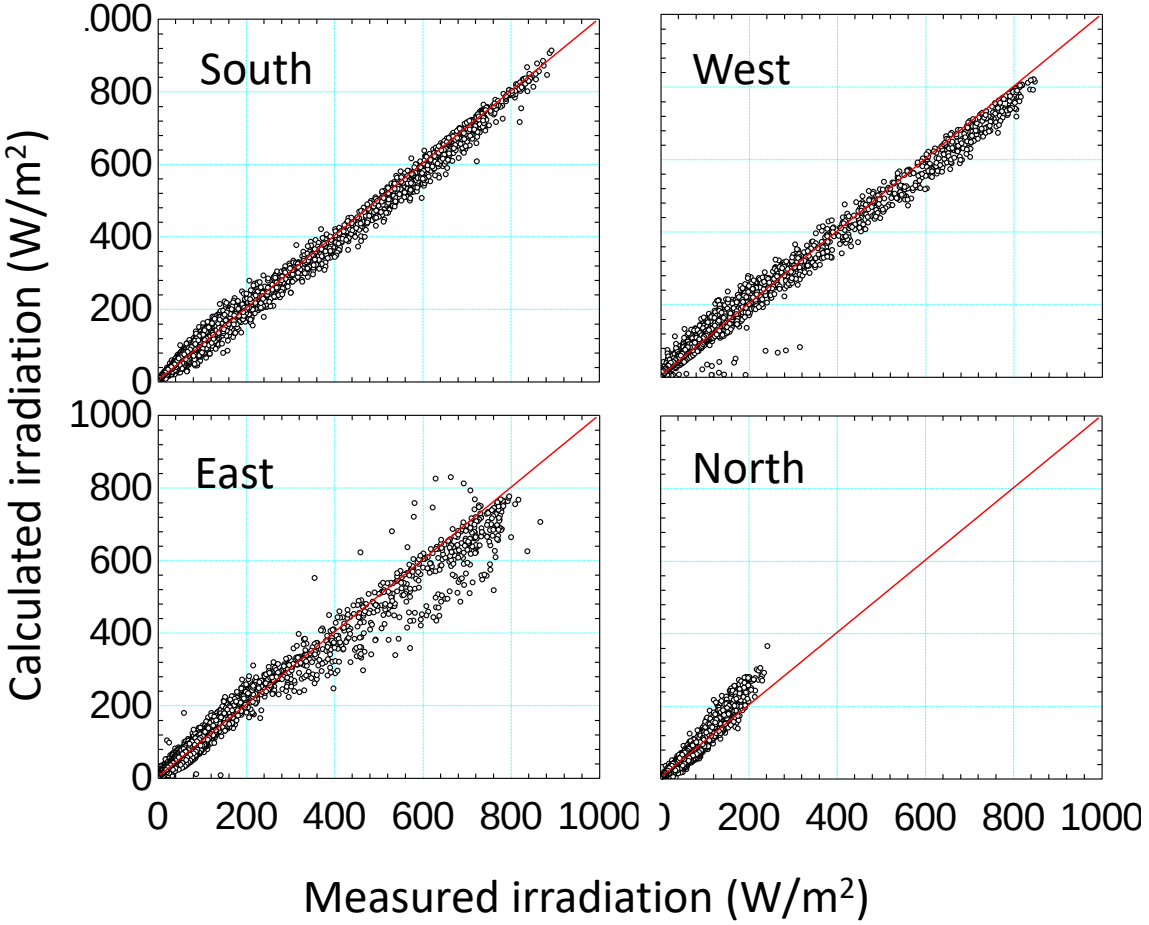
VALIDATIE VAN SIMULATIE INSTRUMENTEN

IEA EBC Annex 71 Holzkichen Twin Test Houses

VALIDATIE VAN SIMULATIE INSTRUMENTEN

Berekend versus gemeten zonnestraling op gevels

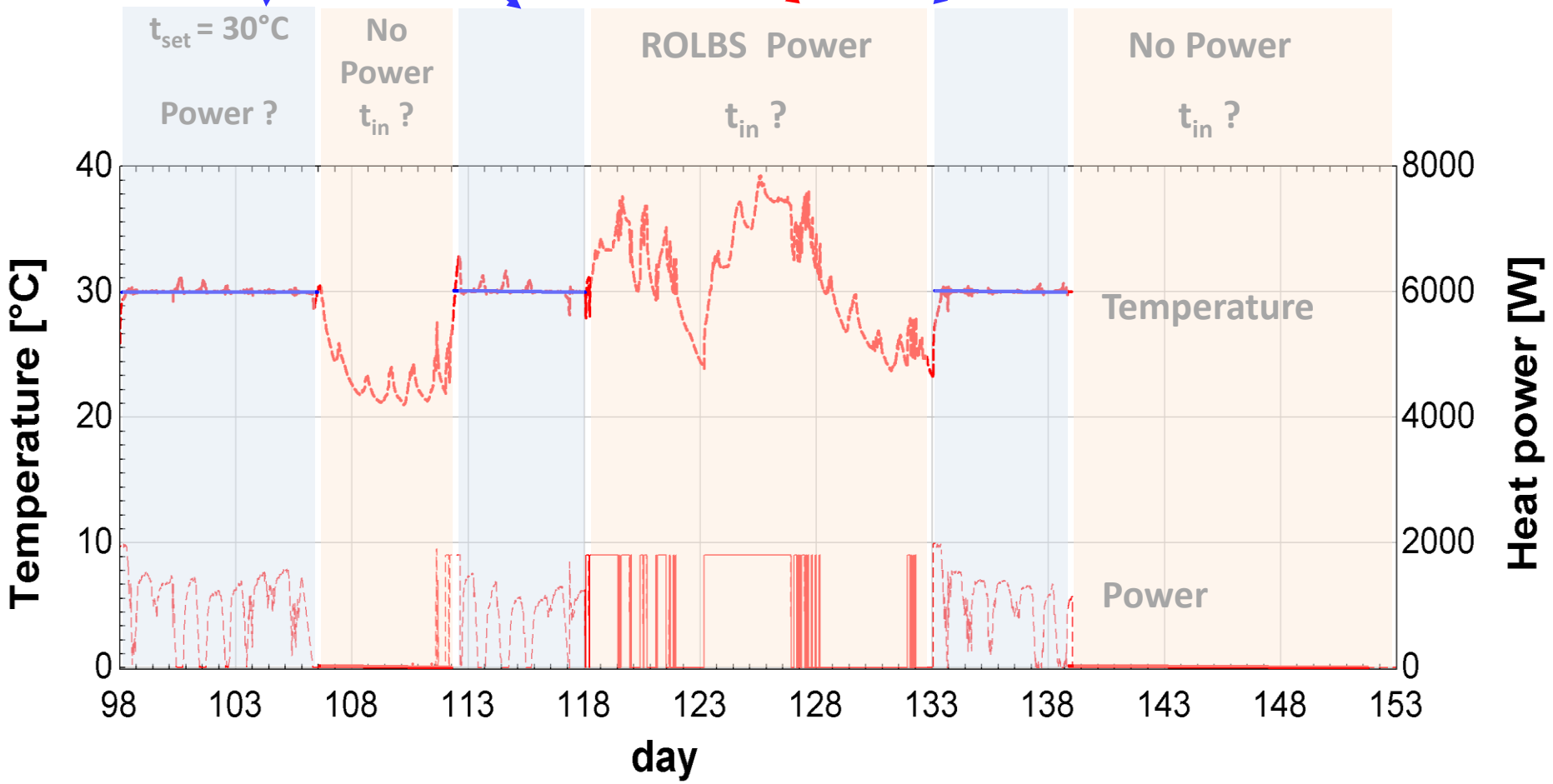
IEA EBC Annex 71 Holzkichen



BLIND EXPERIMENT

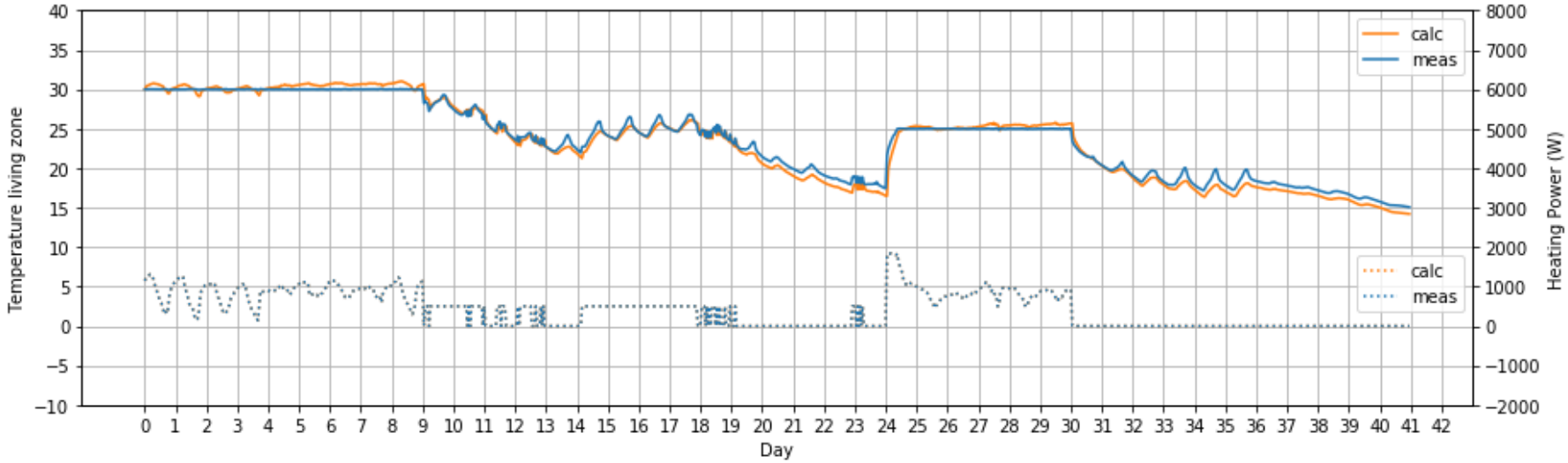
Temperature set point > Heating Power ?

Measured Heating power > temperature ?



VALIDATIE VAN SIMULATIE INSTRUMENTEN

IEA EBC Annex 71 Holzkichen Twin Test Houses



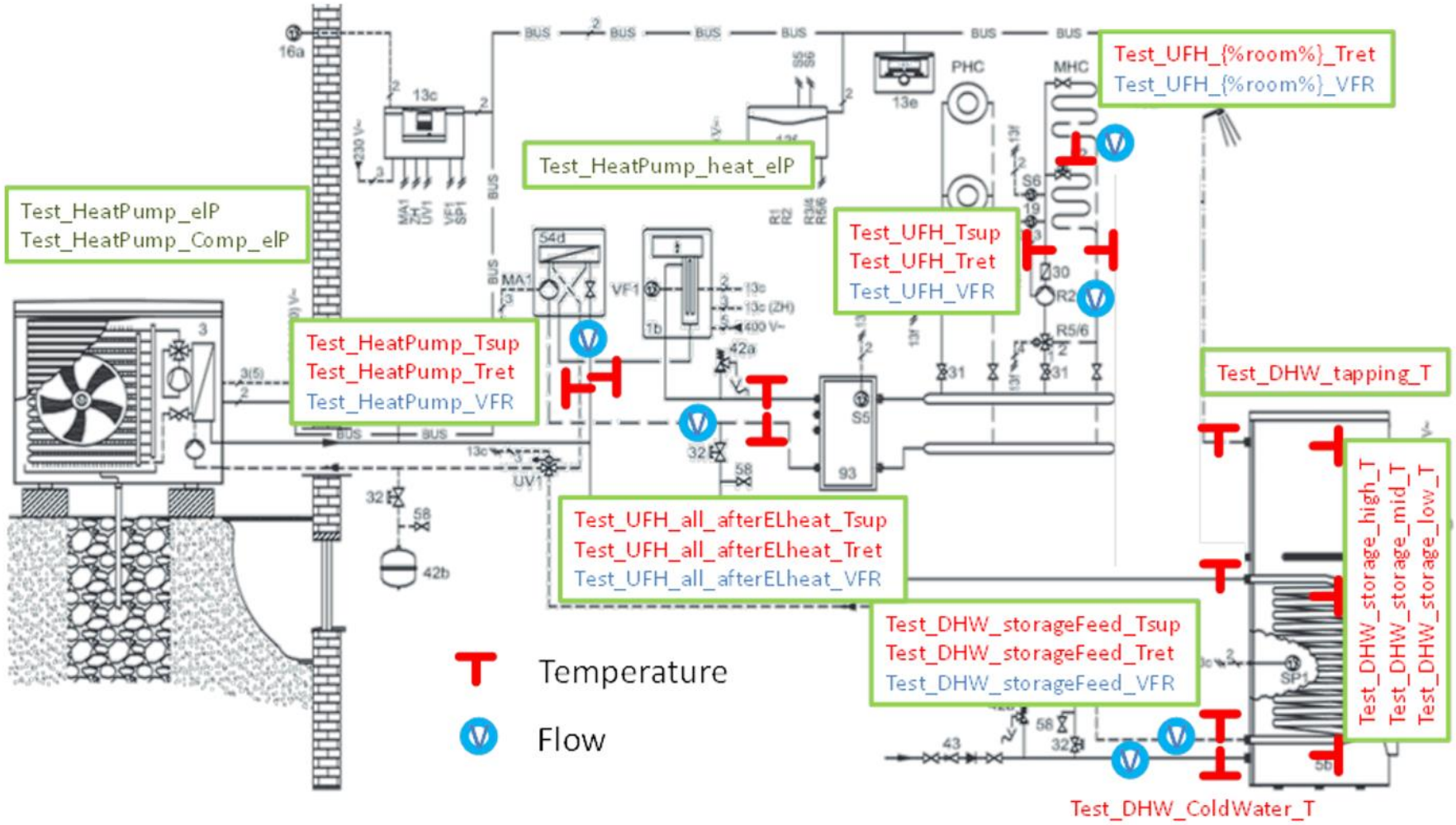
VALIDATIE VAN SIMULATIE INSTRUMENTEN

IEA EBC Annex 71
Holzkichen Twin Test Houses

Figure 21: External installation of the Twin Houses Vaillant "aroTHERM VWL 55/2 A" air source heat pump, left in summer, right in winter.

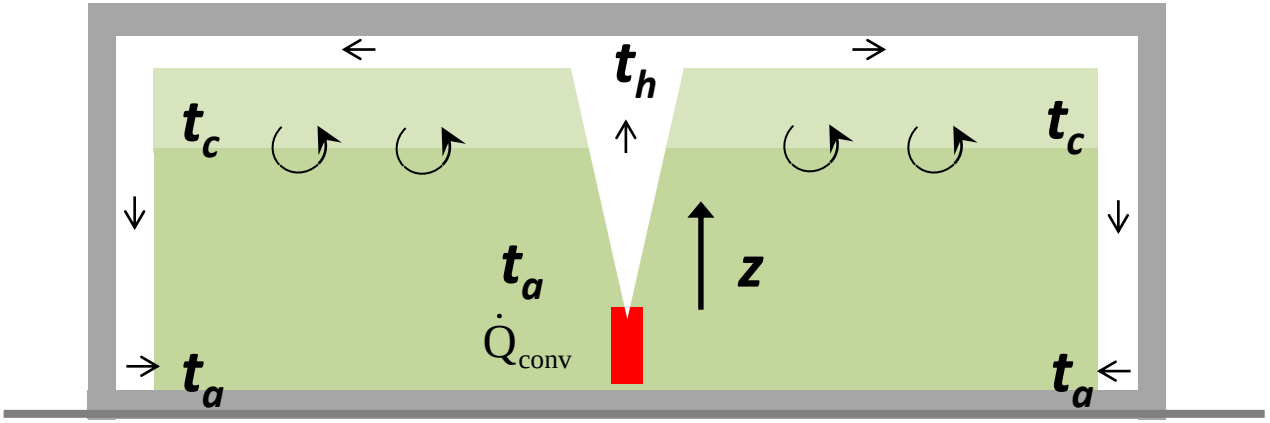
VALIDATIE VAN SIMULATIE INSTRUMENTEN

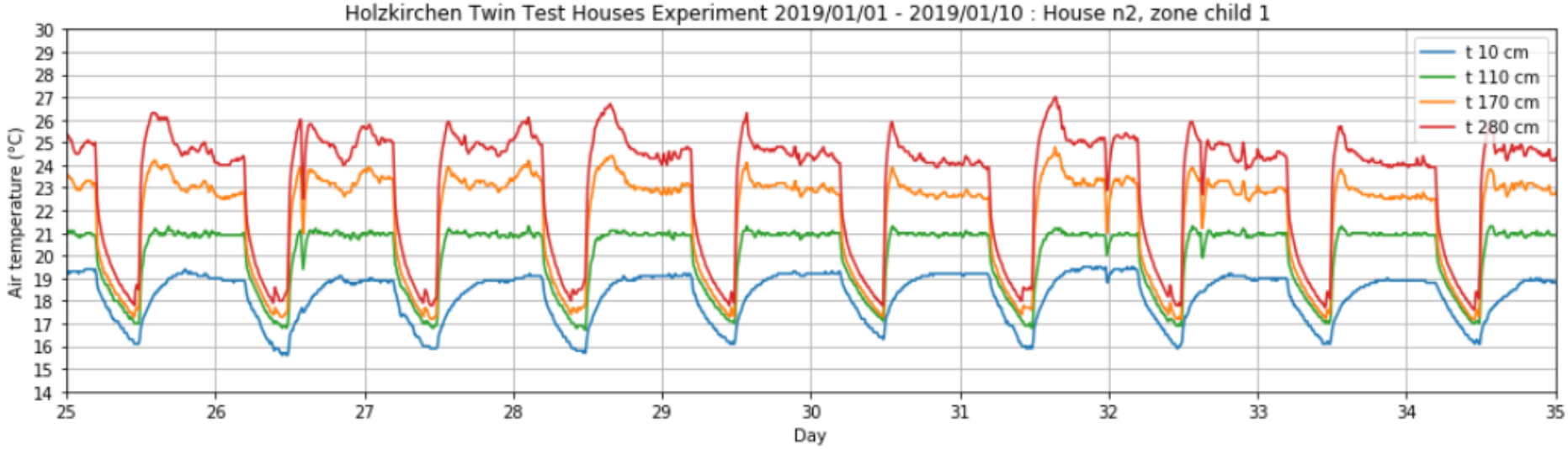
IEA EBC Annex 71 Holzkichen Twin Test Houses

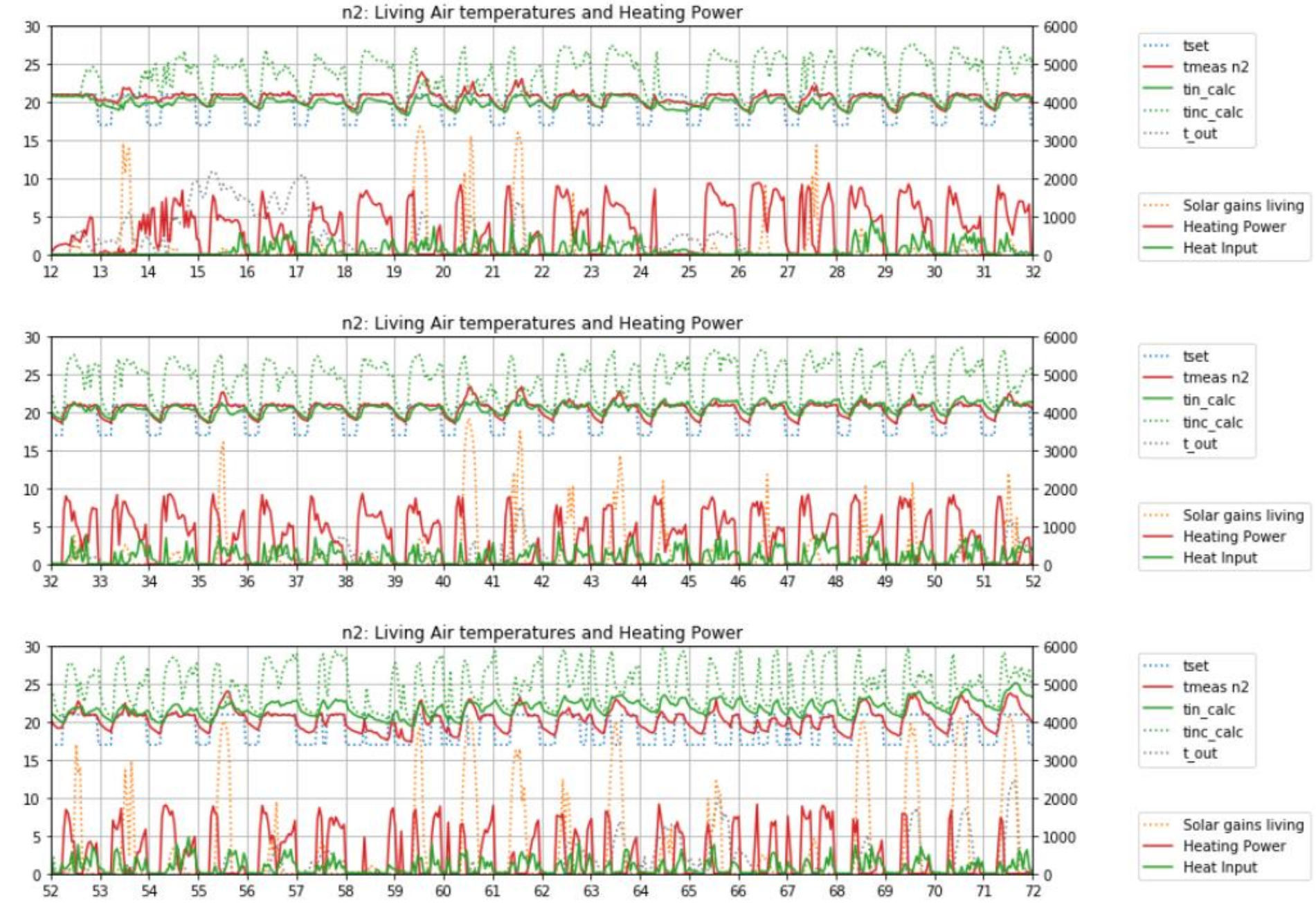


STRATIFICATIE EFFECT

- Child1 zone electric radiators : 5 °C on average, 10°C maximum

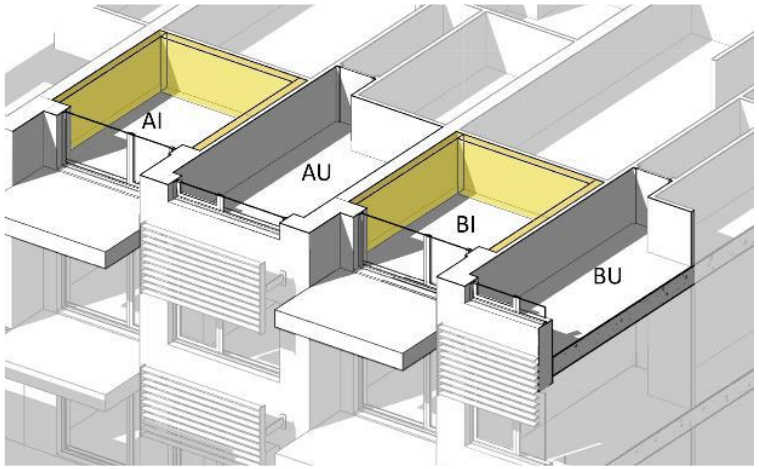


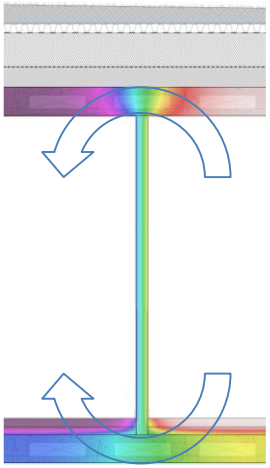


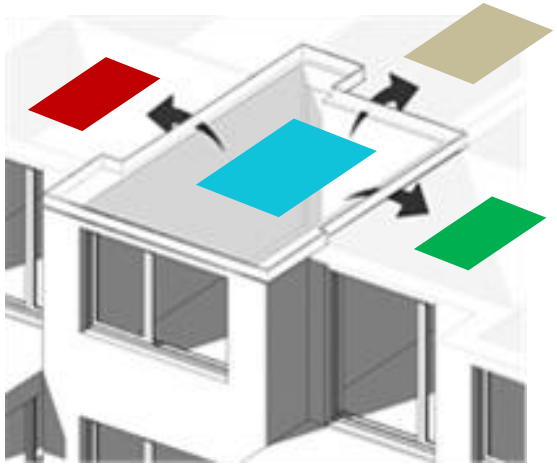

n2: Living Air temperatures and Heating Power
tset
tmeas n2
tin_calc
tinc_calc
t_out
Solar gains living
Heating Power
Heat Input
n2: Living Air temperatures and Heating Power
tset
tmeas n2
tin_calc
tinc_calc
t_out
Solar gains living
Heating Power
Heat Input
n2: Living Air temperatures and Heating Power
tset
tmeas n2
tin_calc
tinc_calc
t_out
Solar gains living
Heating Power
Heat Input

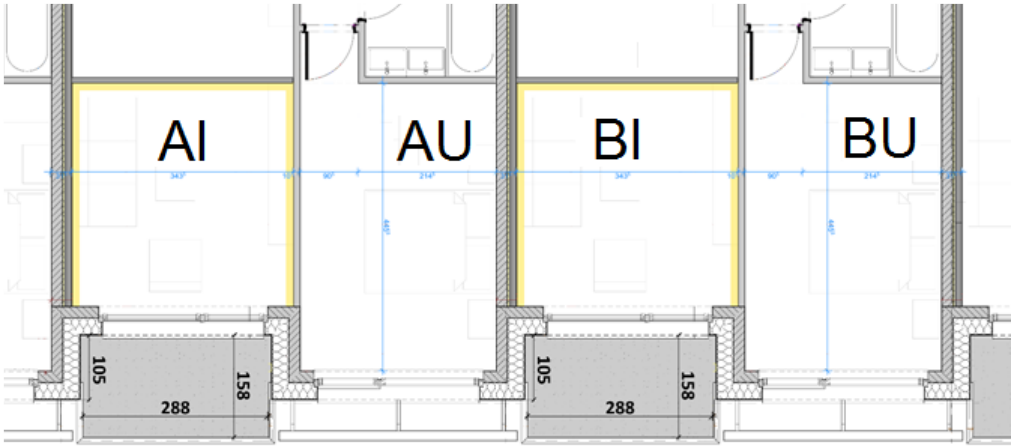
INTERNE THERMISCHE BRUGGEN

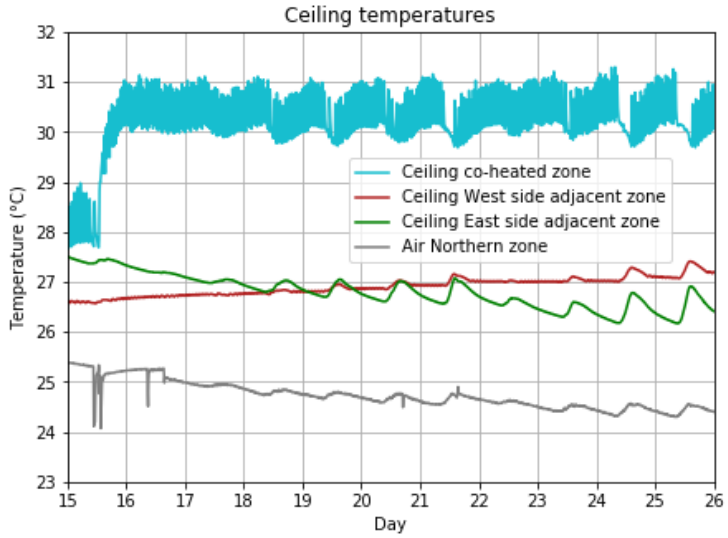
Saints Pierre et Paul, Neder-Hover-Heembeek, Cam(b)bridge Project supported by innoviris











DYNAMISCHE SIMULATIE - TOEPASSINGEN

Systeem dimensionering

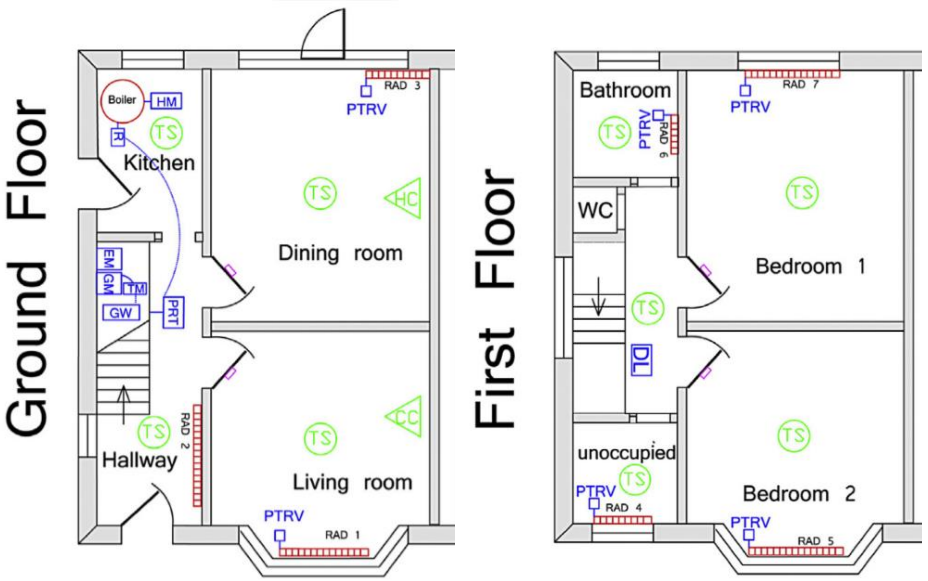
Energieverbruik

Bevestiging

Parametrische identificatie

PARAMETRISCHE IDENTIFICATIE

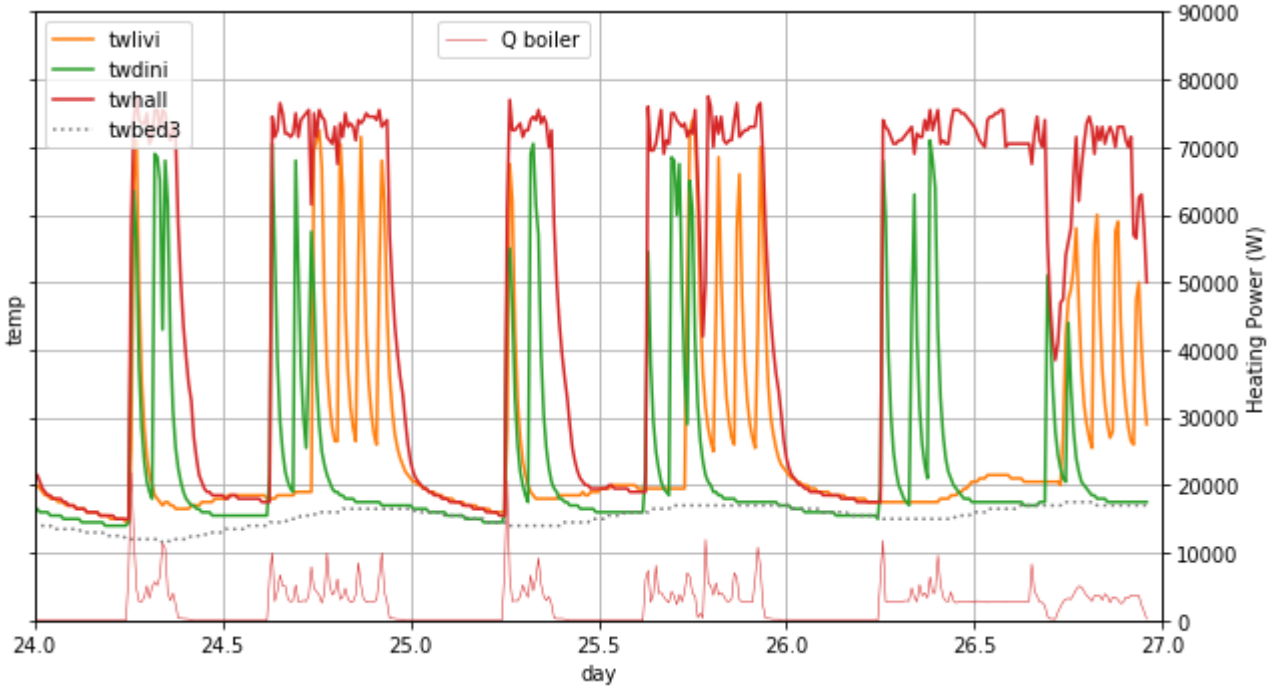
IEA EBC Annex 71 Loughborough case

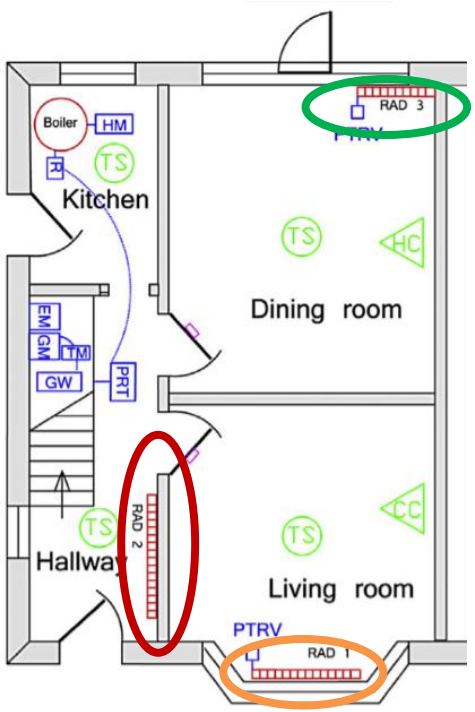


- Gebruik van de gemeten radiatortemperaturen om de warmteafgifte van de ketel op te splitsen in de verschillende gebouwzones
- Multi-zone modelling op basis van interne temperaturen gemeten per zone

PARAMETRISCHE IDENTIFICATIE

Gebruik van de gemeten radiatortemperaturen om de warmteafgifte van de ketel op te splitsen in de verschillende gebouwzones





Morning Afternoon & Evening

Ordinary day Week-end

Radiators AU's – 4 days static analysis

$$\dot{Q}_{rad} = m_w \frac{d\theta_w}{dt} + AU\,(\theta_w - \theta_{in})^n$$

$$m_w = 0.011\,\dot{Q}_n \qquad \dot{Q}_n = AU\left(\theta_{w,n} - \theta_{in,n}\right)^n$$

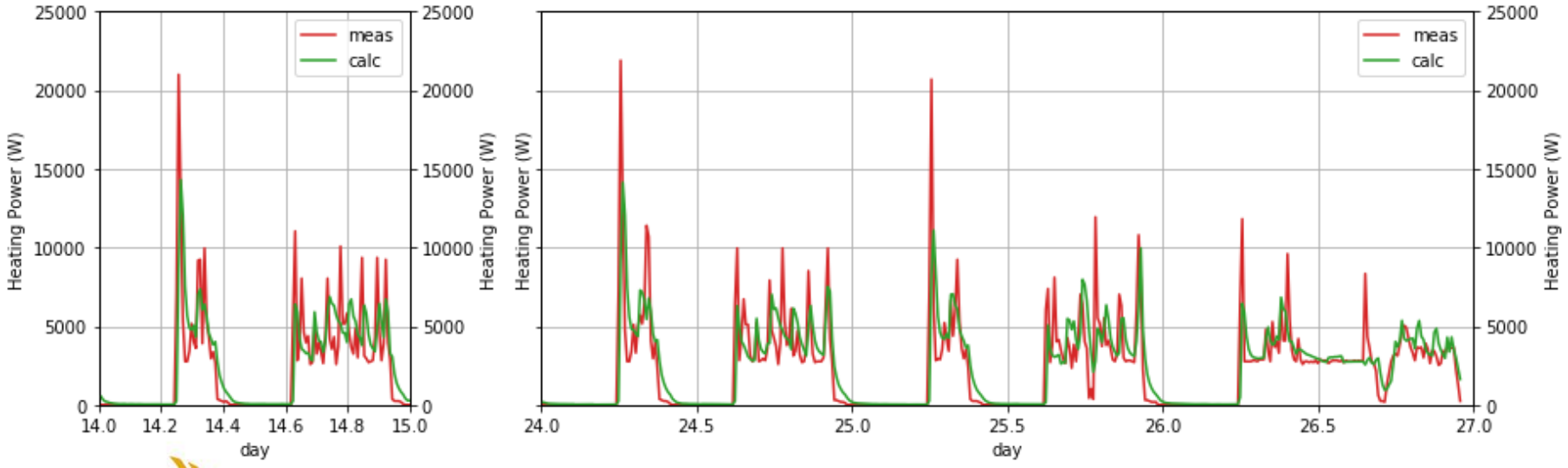
$$\dot{Q}_{rad} = AU\left(0.011\,.\left(\theta_{w,n} - \theta_{in,n}\right)^n \frac{d\theta_w}{dt} + \left(\theta_w - \theta_{in}\right)^n\right)$$

$$n = 1.3$$

$$\theta_{w,n} = 70\,°$$

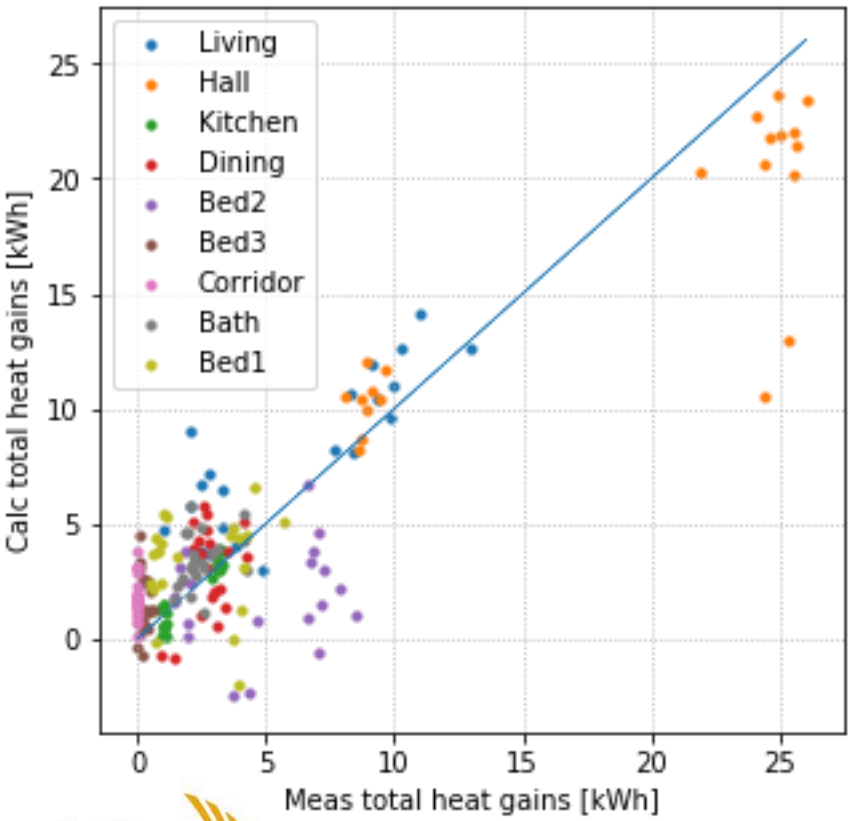
$$\theta_{in,n} = 20\,°$$

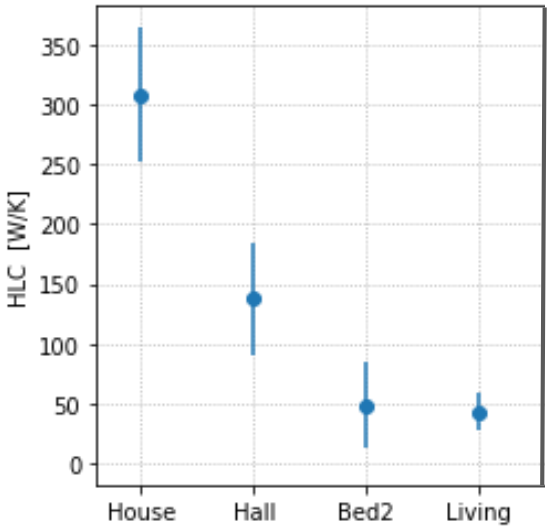
Radiator	AU [W/K]	$Q_{rad,n}$ [W]
Living	15.39	2488
Hall	17.13	2770
Dining	16.13	2608
Bed2	17.6	2846
Bath	9.94	1608
Bed1	12.96	2095



Zones HLC's – 10 days static analysis

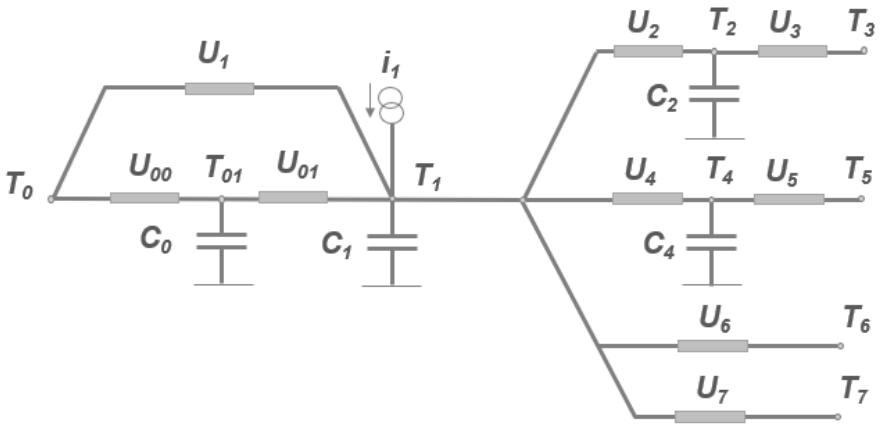
$$\dot{Q}_{rad} + \dot{Q}_{in} + \dot{Q}_{sol} = HLC\ (\theta_{in} - \theta_{out})$$





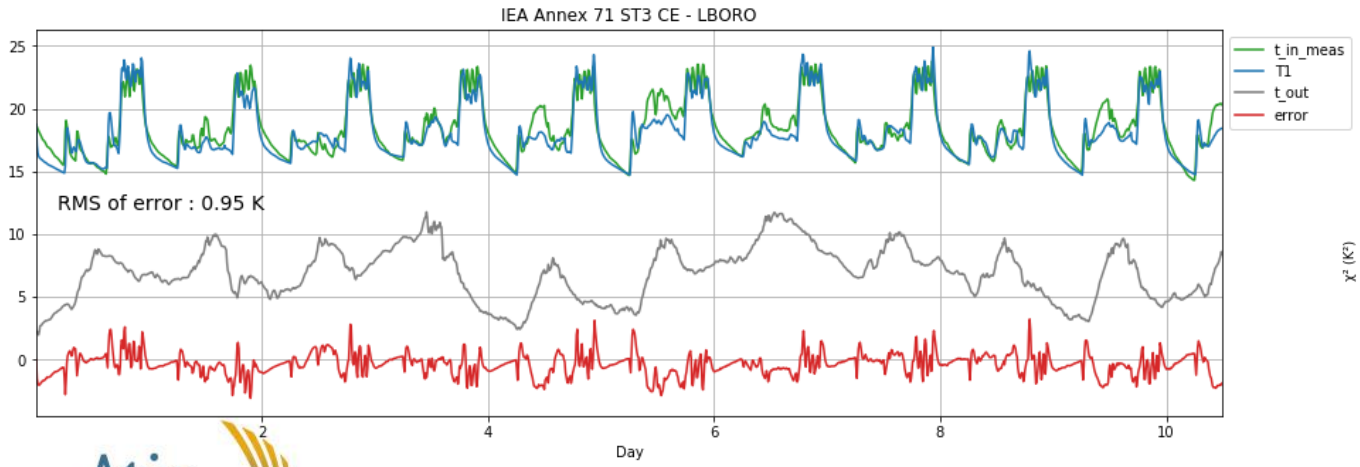
Zone	HLC [W/K]	HLC std [W/K]
House	308.04	56.38
Hall	137.88	47.17
Bed2	48.64	35.83
Living	43.11	15.21

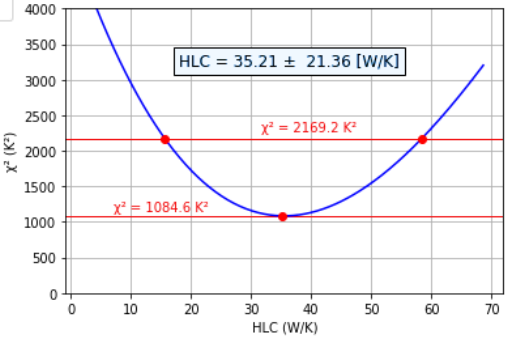
Living zone – 10 days dynamic analysis



T0	External
T1	Living
T3	Hall and Dining
T5	Neighbor 18°C
T6	Bed2
T7	Hall
facs	Solar gains factor
fach	Heat input factor
facm	Ventilation coupling factor

U00	[W/K]	0.02
U01	[W/K]	296.01
U1	[W/K]	35.21
tau0	[h]	18155
tau1	[h]	0.17
tau2	[h]	46.81
facs	[-]	1.51
fach	[-]	1.50
facm	[-]	2





CONCLUSION

- Validatie van dynamische simulatietools :
  - Evaluatie van zonnewarmtewinsten
  - Modellering van het stratificatie-effect van lucht
  - Aanwezigheid van interne thermische bruggen

- Parametrische identificatie :
  - Naar Effective Performance Assessment
    - Building Envelope Heat Loss Coefficient
    - Systeemefficiënties
    - Evaluatie van onzekerheden van metingen