TEAM DTU

Conditioning of a Plus-energy House Using Solar Systems for Both Production of Heating and Nighttime Radiative Cooling

Master thesis presentation – September 11th

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DTU Civil Engineering
Department of Civil Engineering

ICIEE

Solar Decathlon Europe 2014 EN FRANCE

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Agenda

Solar Decathlon Europe 2014

1. Architecture	120 pts
2. Engineering and Construction	80 pts
3. Electrical Energy Balance	120 pts
4. Energy Efficiency	80 pts
5. Comfort Conditions	120 pts
6. House Functioning	120 pts
7. Communication and Social Awareness	80 pts
8. Urban Design, Transportation and Affordability (UDTA)	120 pts
9. Innovation	80 pts
10. Sustainability	80 pts

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Solar Decathlon Europe 2014

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→ Indoor temperature range: $T_{av}-1 < T_{indoor} < T_{av}+1$

\+ Humidity, CO_2, VOCs and formaldehyde criteria

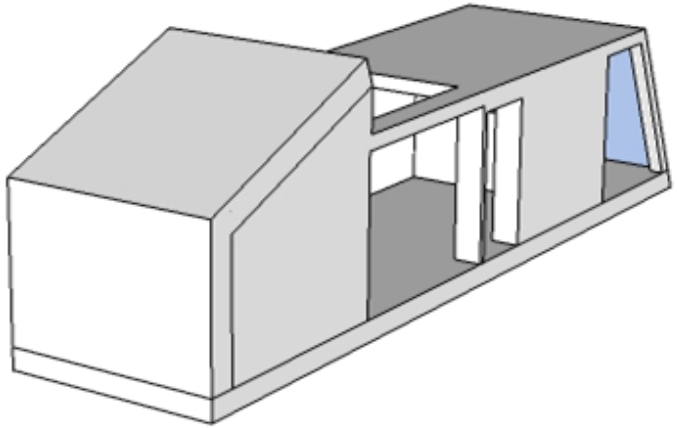
SDE2014 – EMBRACE

Solar Decathlon Europe 2014
Cité du Soleil - Versailles

EMBRACE
Team DTU

Envelope

- Integration on rooftops to densify cities
- Small dwelling
- Thermal envelope: 4 modules
- Sheltered garden acting as a buffer zone



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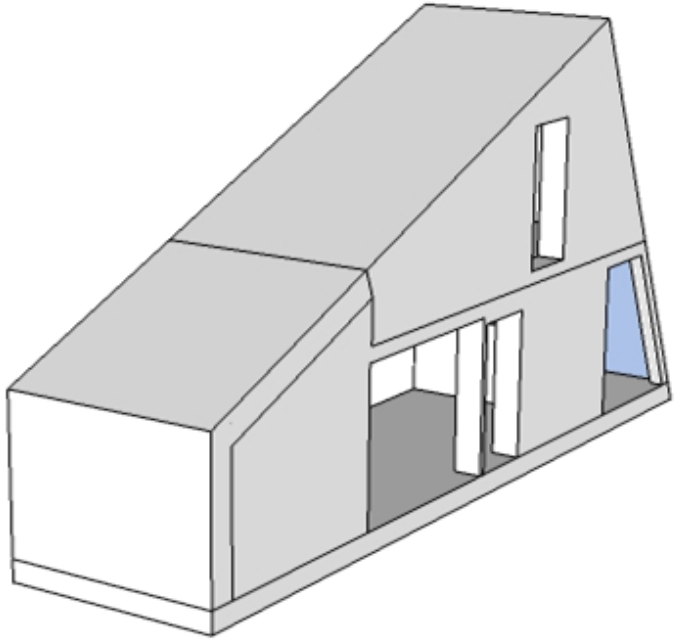

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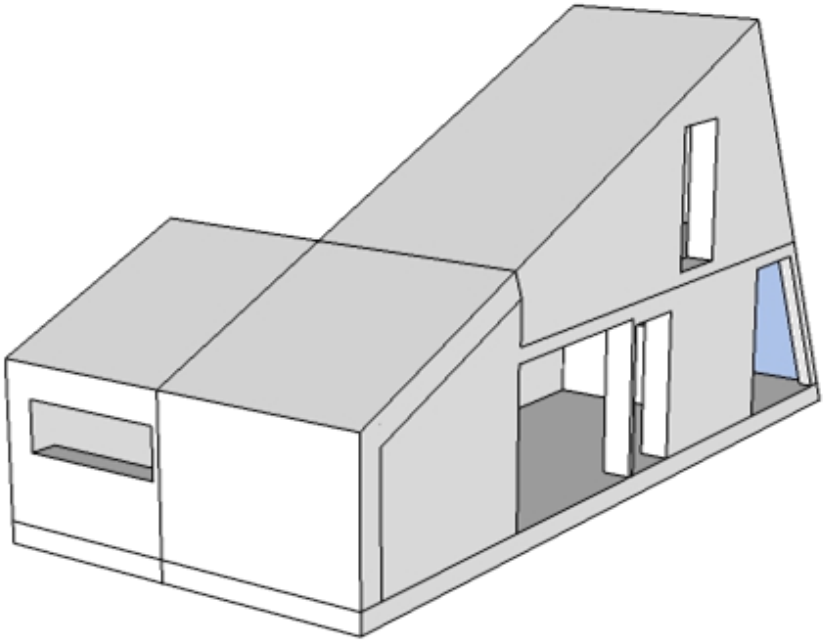

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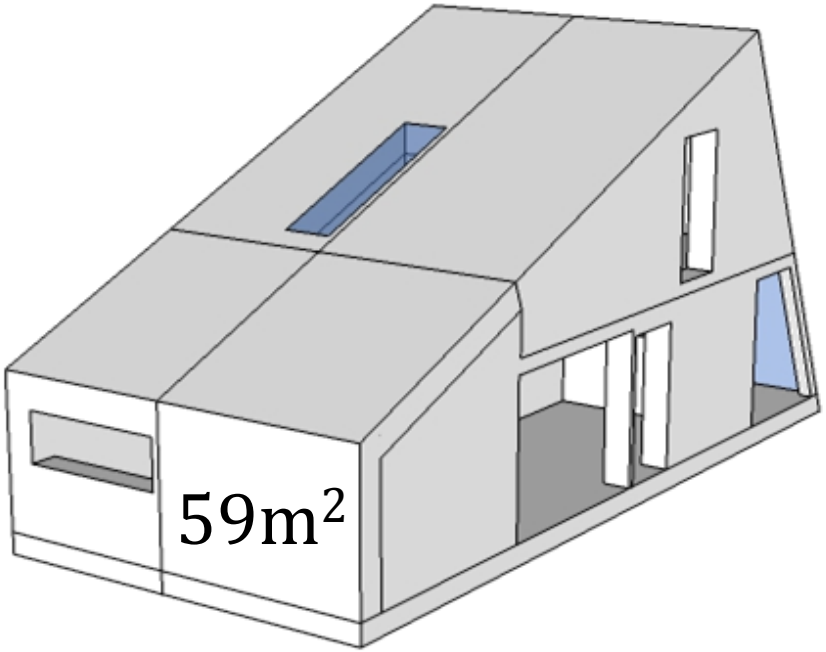

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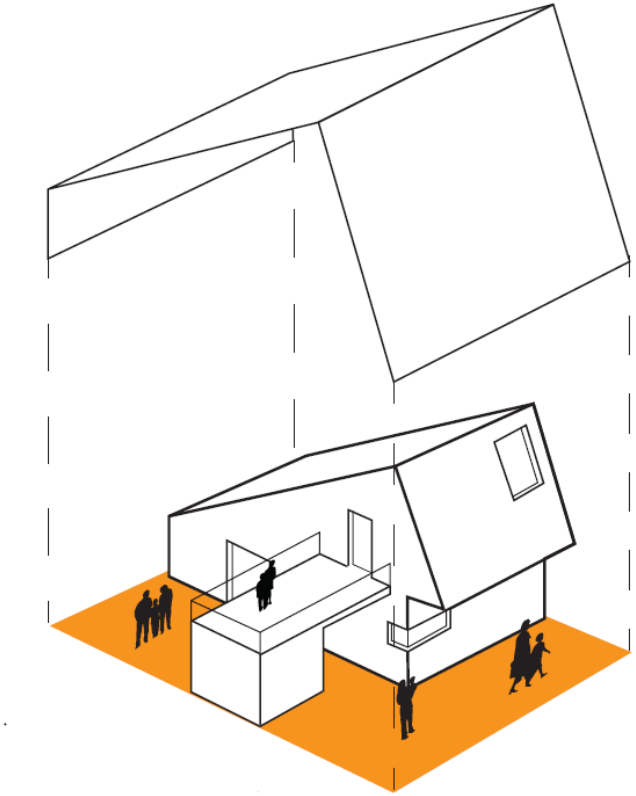
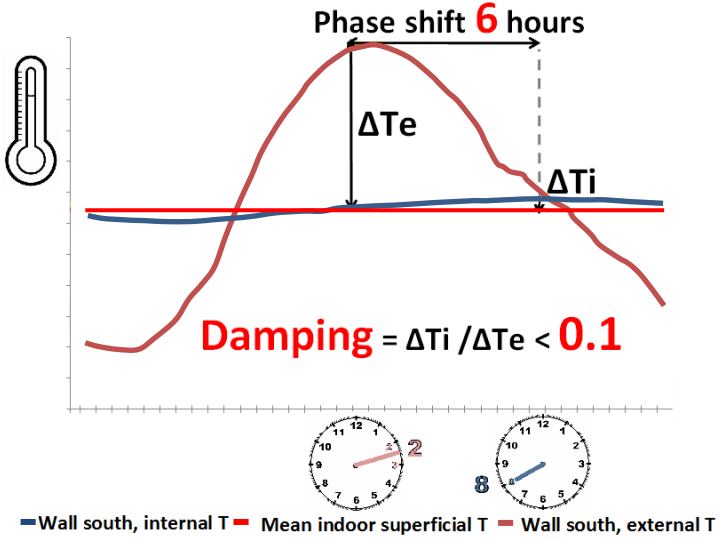


Envelope

Construction	U-value (W/m^2K)
External wall	0,08
Roof	0,085
External floor	0,1
Internal walls	0,38
Internal floor	0,25
Glazing 1st type	U-window 0,83
Glazing 2nd type	U-window 0,79



HVAC overview – heating and cooling sources

Active heat recovery from ventilation

Solar collectors

External Heat Pump

Domestic Hot Water (DHW)

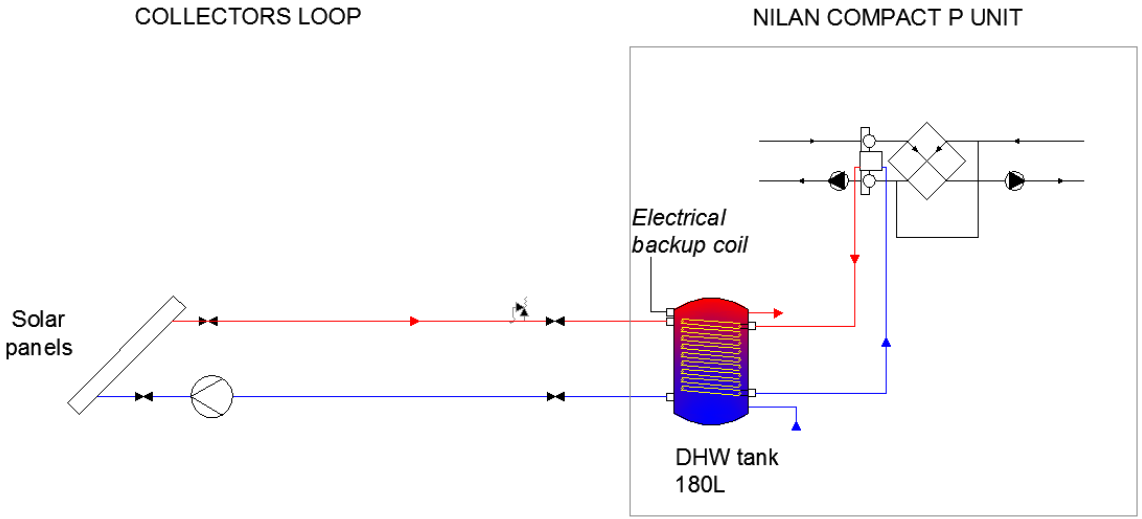
Space heating (SH)

Nighttime radiative cooling

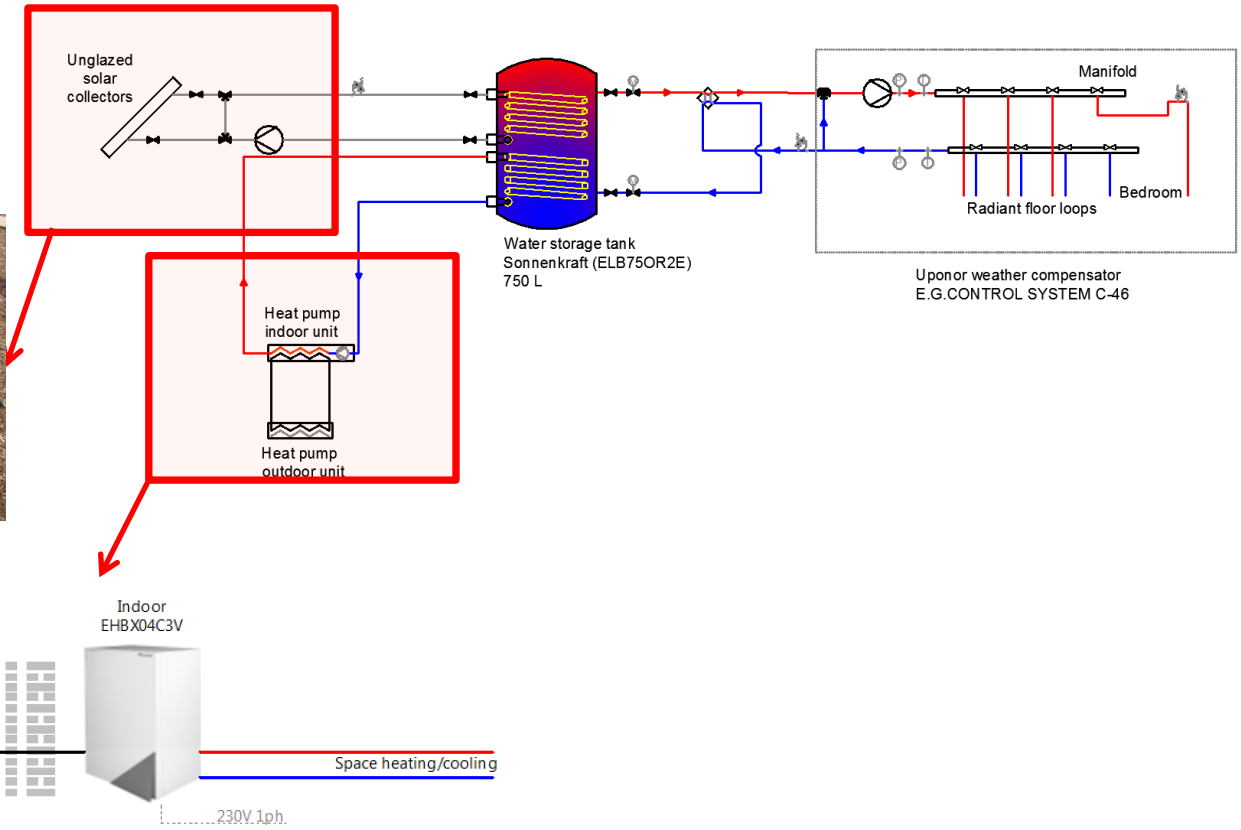
External heat pump

Cooling production

Realized system: DHW/Ventilation

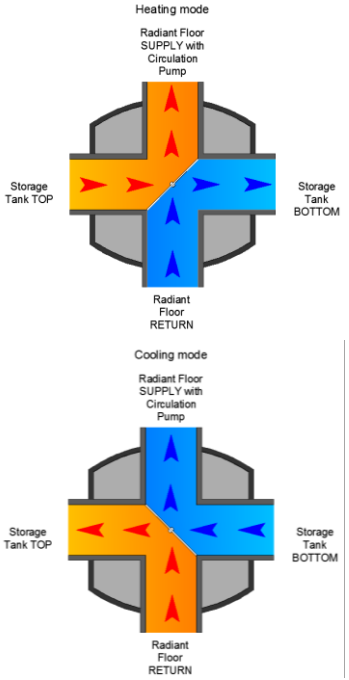


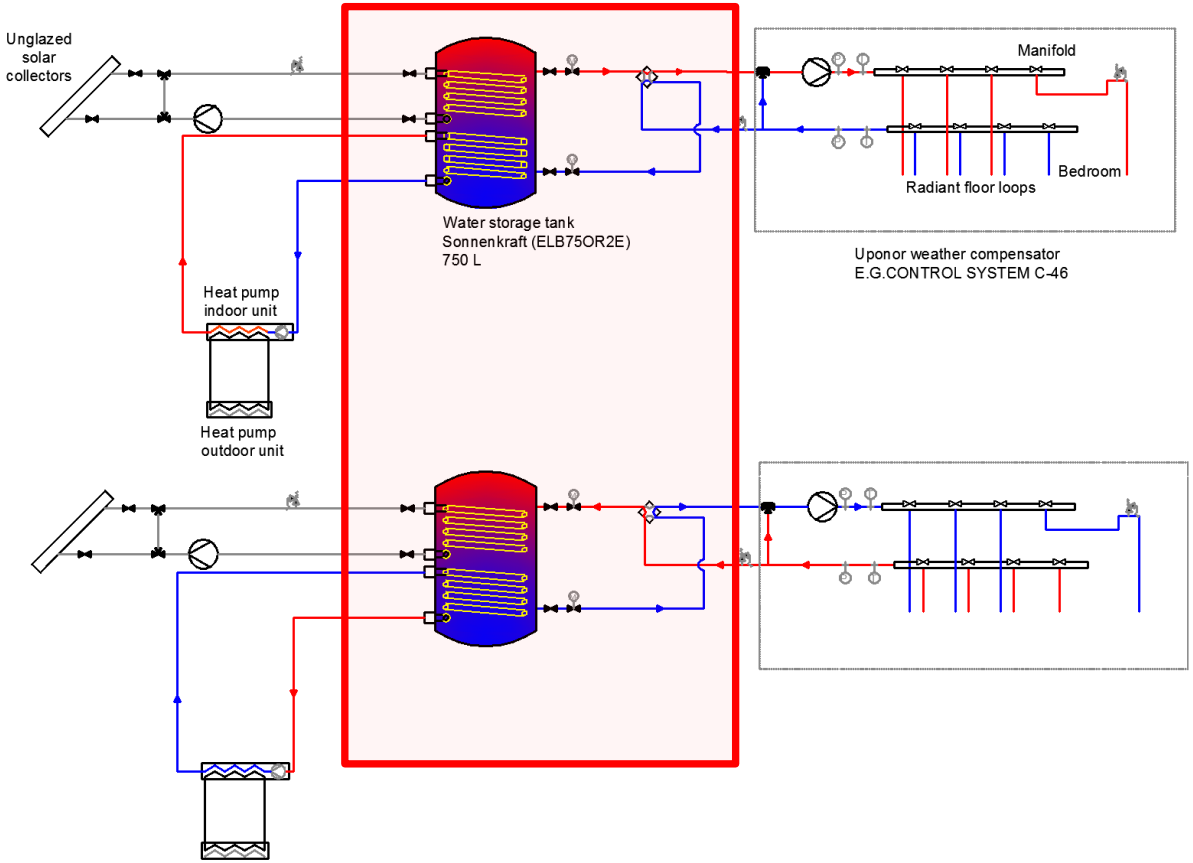
Realized system: sources



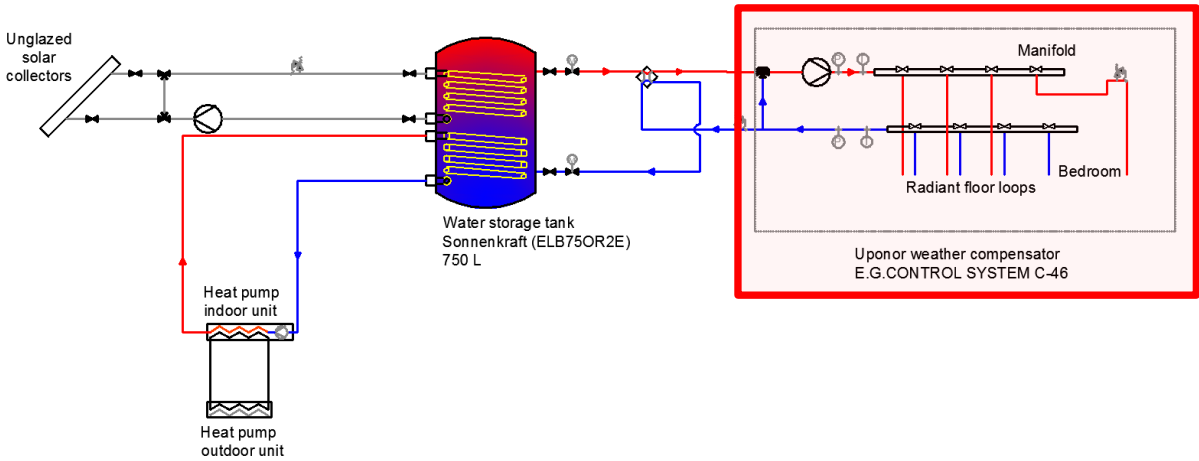
Realized system: storage/delivery

4-way valve

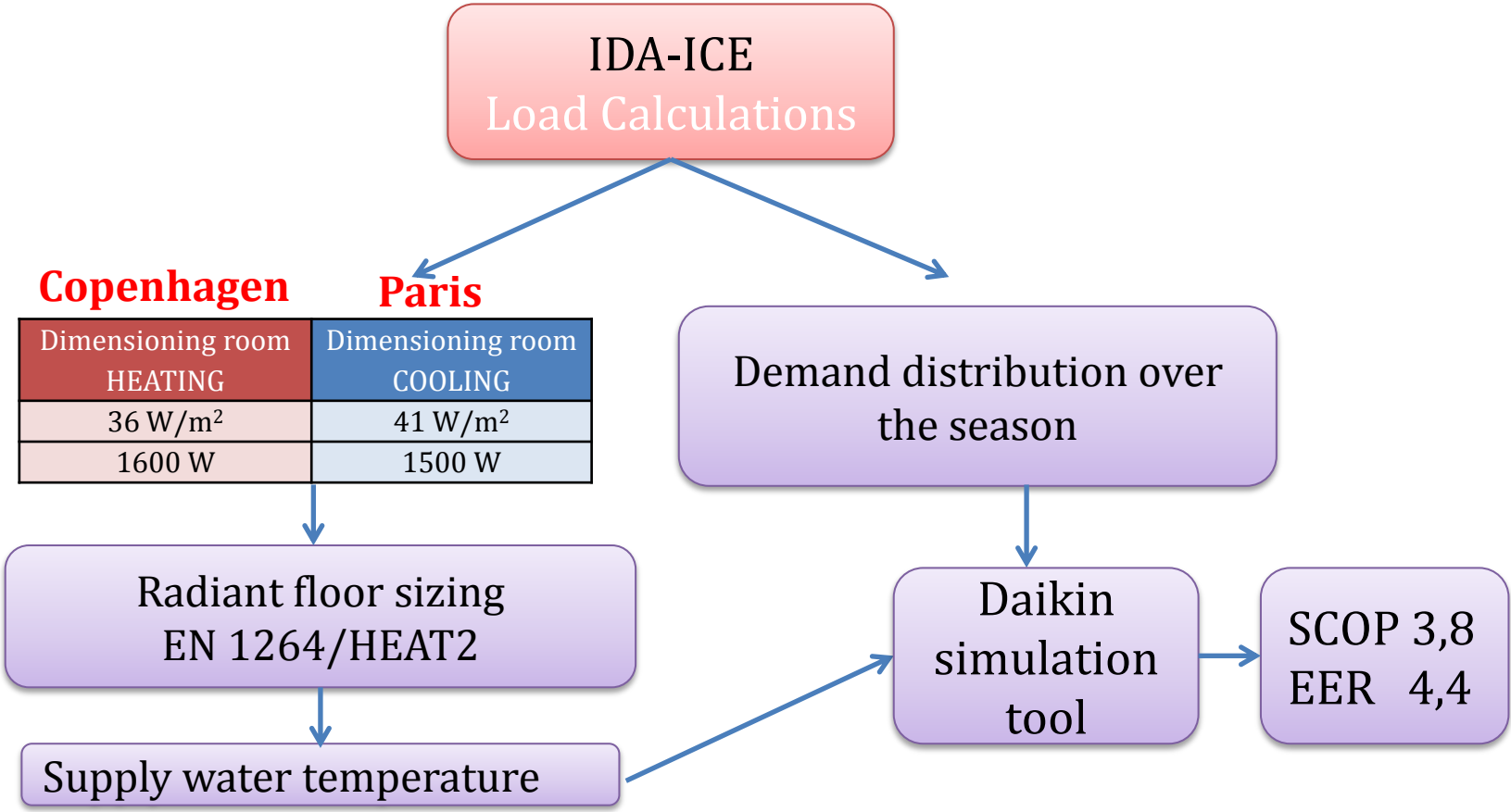




Realized system: emission/regulation



Sizing process



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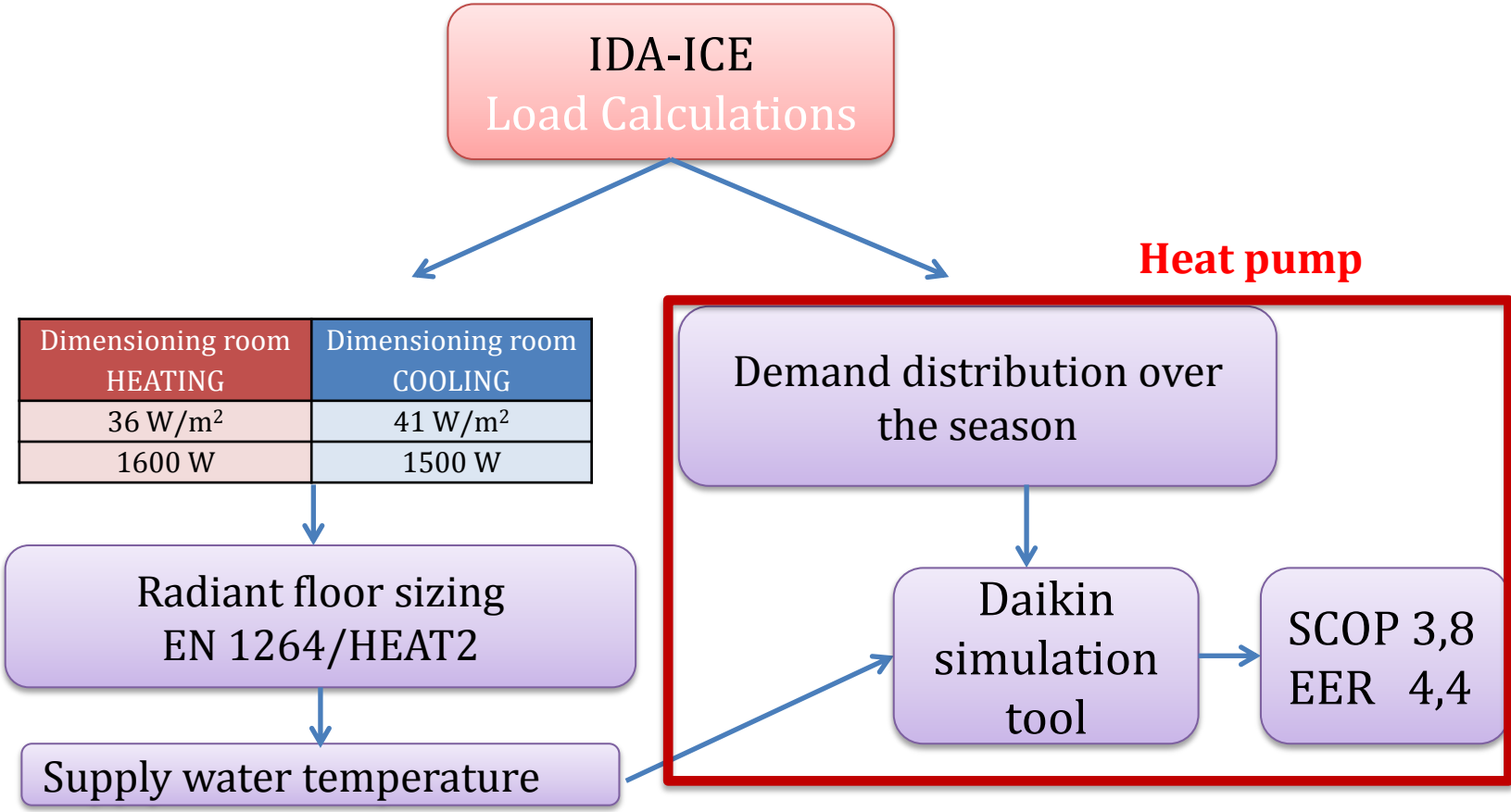
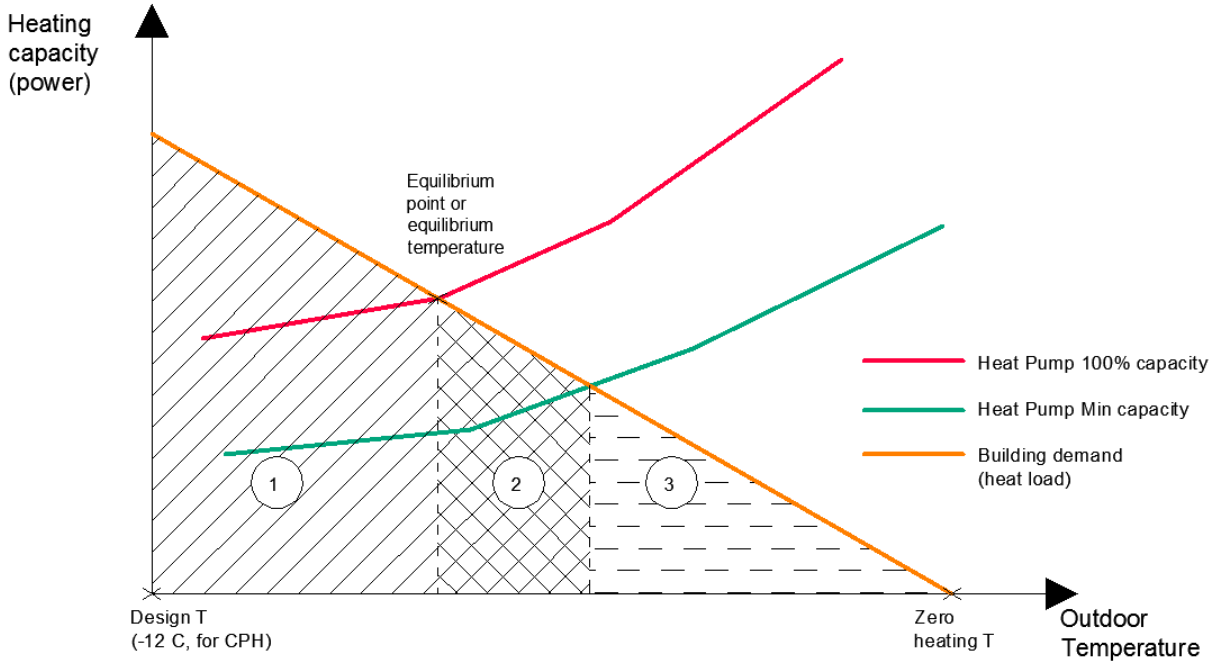
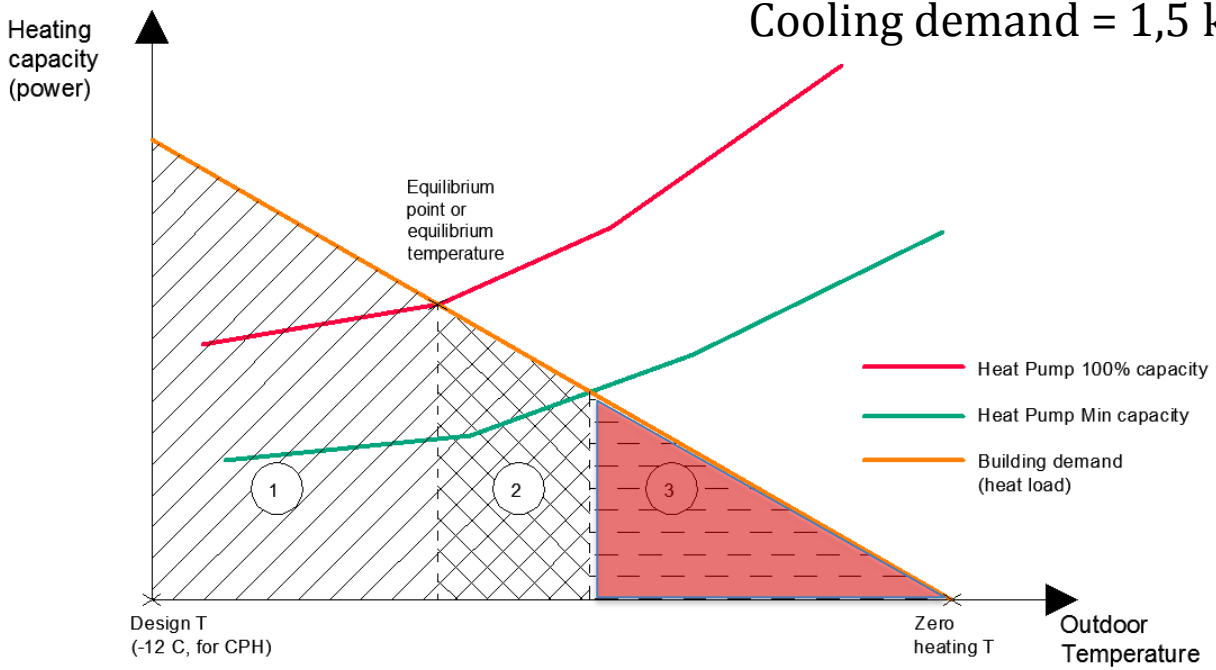


Heat pump



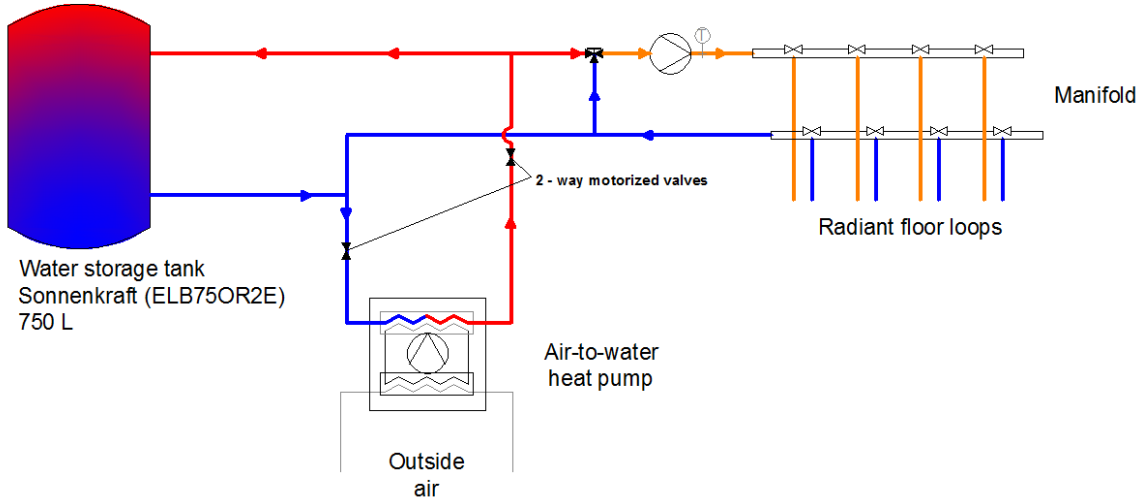
Heat pump

Heating demand =1,6 kW
Cooling demand = 1,5 kW

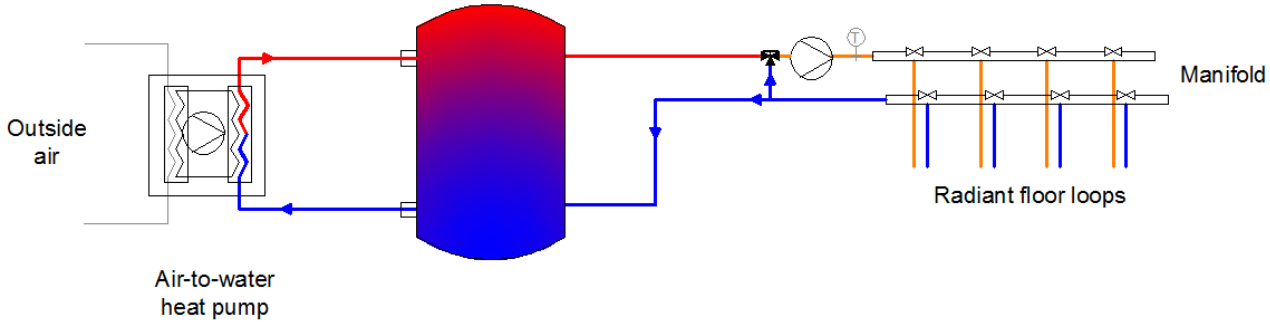


Heat pump

1ST preferred



2ND realized



Sizing process

IDA-ICE
Load Calculations

Dimensioning room HEATING	Dimensioning room COOLING
36 W/m²	41 W/m²
1600 W	1500 W

Demand distribution over the season

Radiant floor

Radiant floor sizing
EN 1264/HEAT2

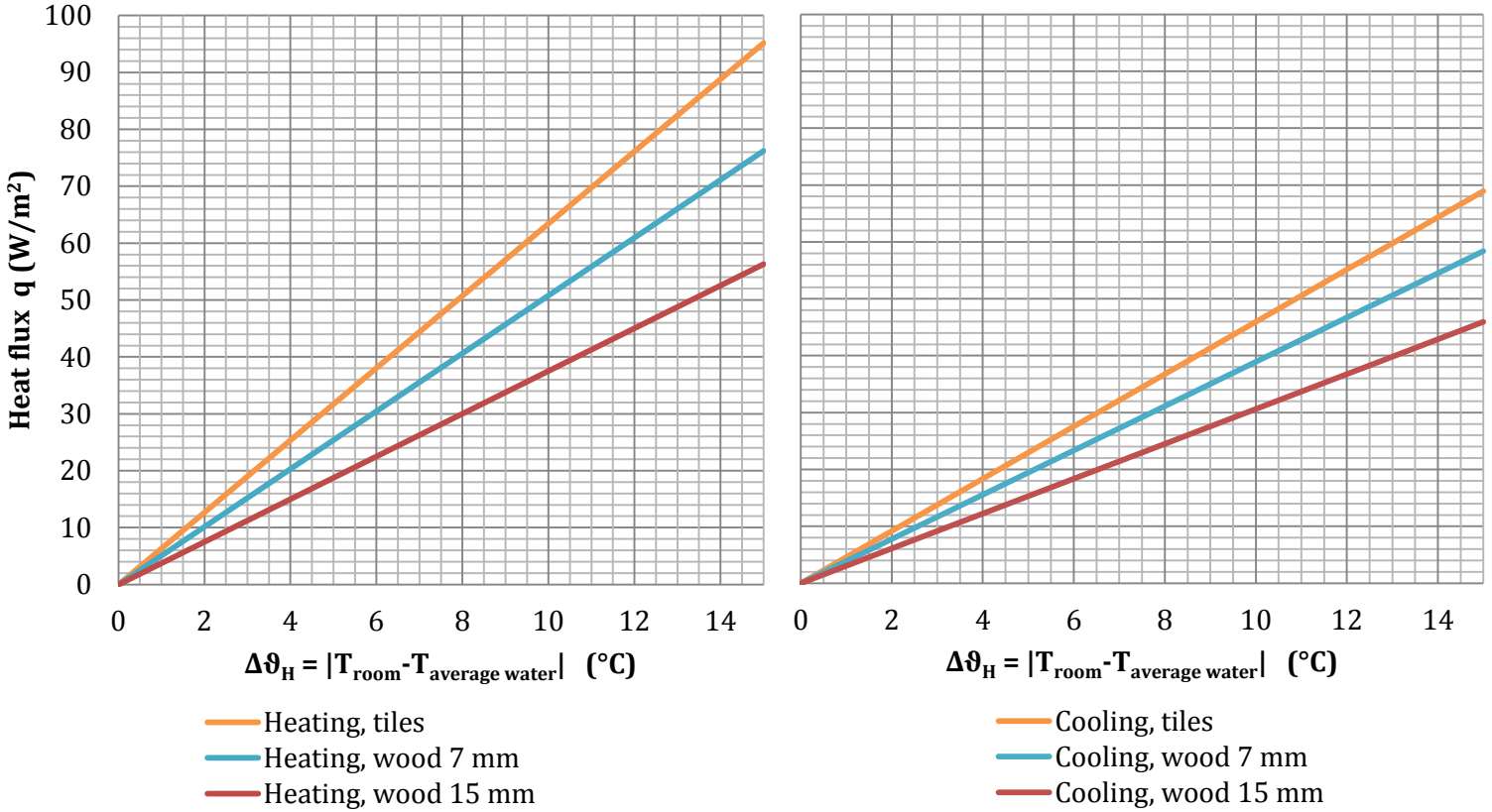
Supply water temperature

Daikin simulation tool

SCOP 3,8
EER 4,4

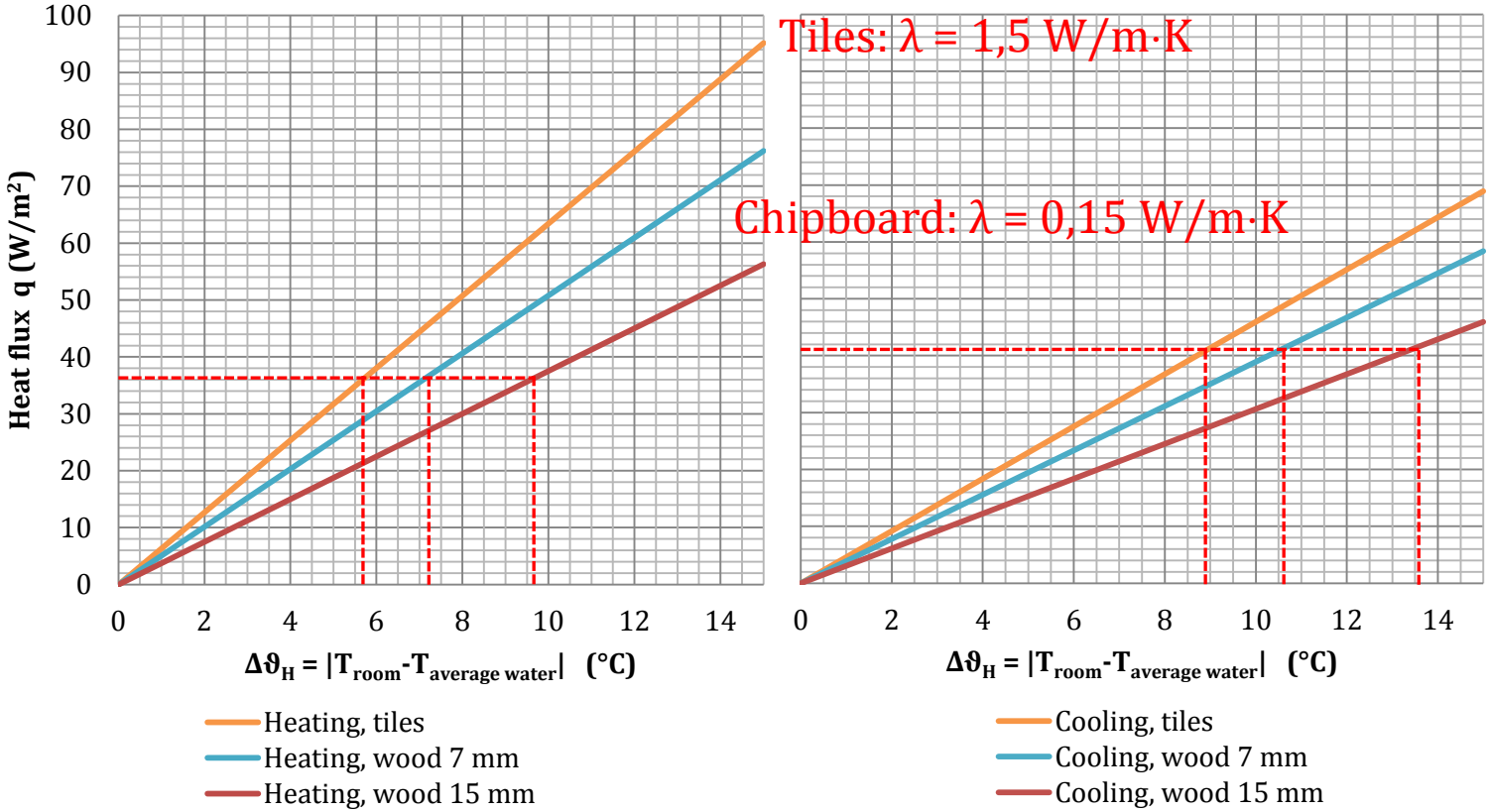
Radiant floor – EN 1264 – Type B

Single power equation – Characteristic curves



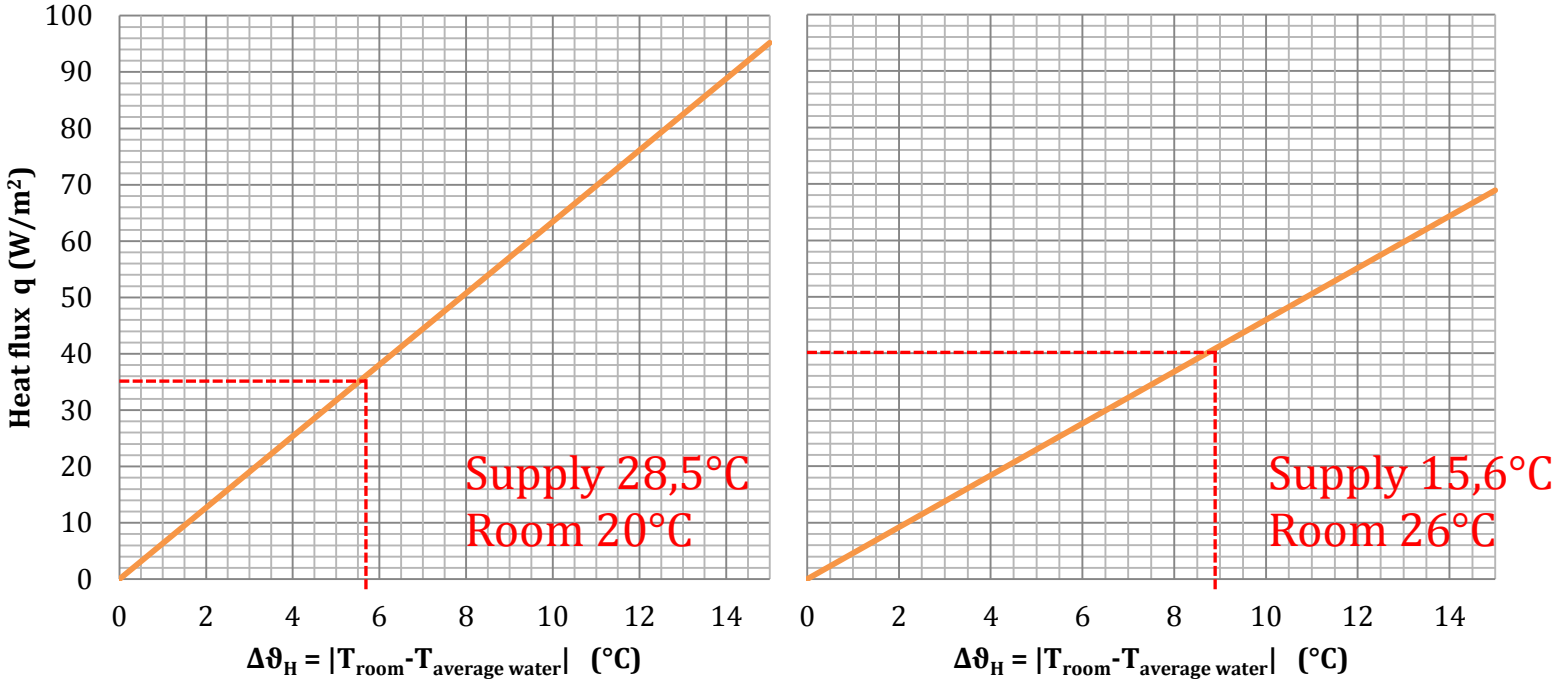
Radiant floor – EN 1264

Choice of the floor covering



Radiant floor – EN 1264

Determination of the water supply temperature



Surface temperature in the range 20-24°C, no condensation problem

Comparison standard – HEAT2

Case of the tiles as floor covering

q (W/m^2)	$\Delta\vartheta$ heating = 7,9°C	$\Delta\vartheta$ cooling = 8,6°C
EN 1264	50,1	39,5
HEAT2	46	39,9

8%

1%

Results – Yearly Electricity consumption

IDA-ICE Simulation + SCOP; EER

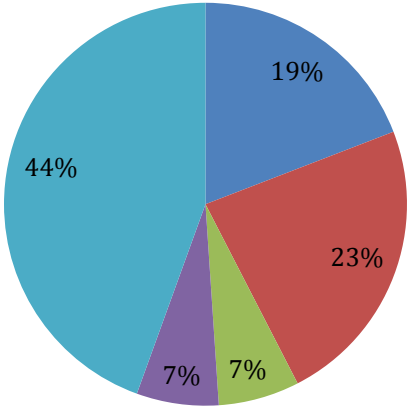
Paris	32 kWh/m²/year (net area)
Copenhagen	38 kWh/m²/year (net area)

13 kWh/m² for appliances

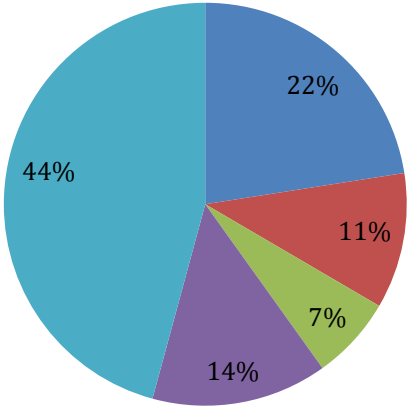
Results – Energy consumption: cooling mode

Simulation

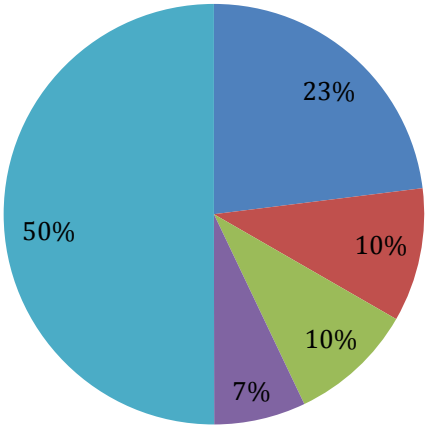
Copenhagen (%)



Paris (%)

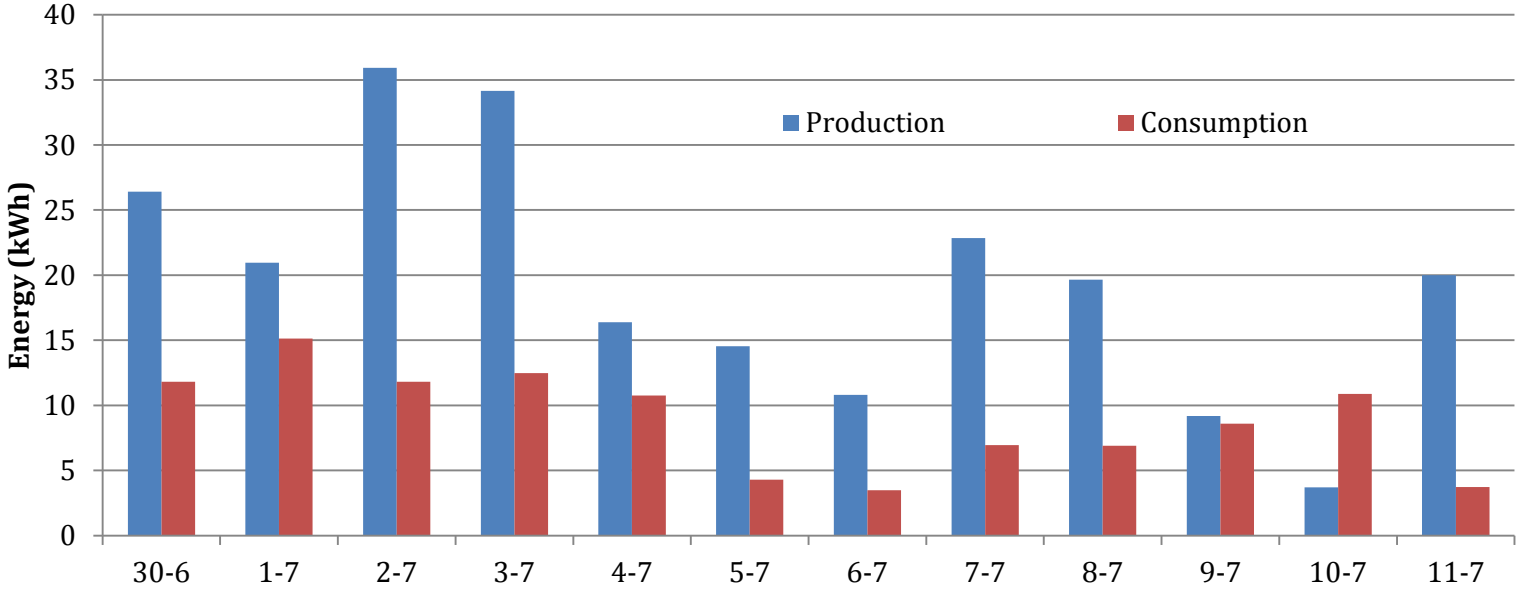


Competition



Appliances Ventilation + DHW Rad. Fl. Cooling Lights Pumps

Results – Energy production



=> Plus-energy house

Results – Comfort Conditions

	Operative Temperature	
Range	Competition range (±1°C) based on EN15251	Lower limit not considered
Percentage of time outside the range	27 %	2 %

	Relative Humidity	CO_2 level
Range	40% < RH < 55%	< 800 ppm
Percentage of time outside the range	6%	11 %

Competition rankings

Sub contest	Points earned by Team DTU	Ranking of Team DTU
Electrical Energy Balance	79,22 / 120	#7
Energy Efficiency	71,84 / 80	#9
Comfort Conditions	99,23 / 120	#8
• • •		
TOTAL	780,01 / 1000	#8

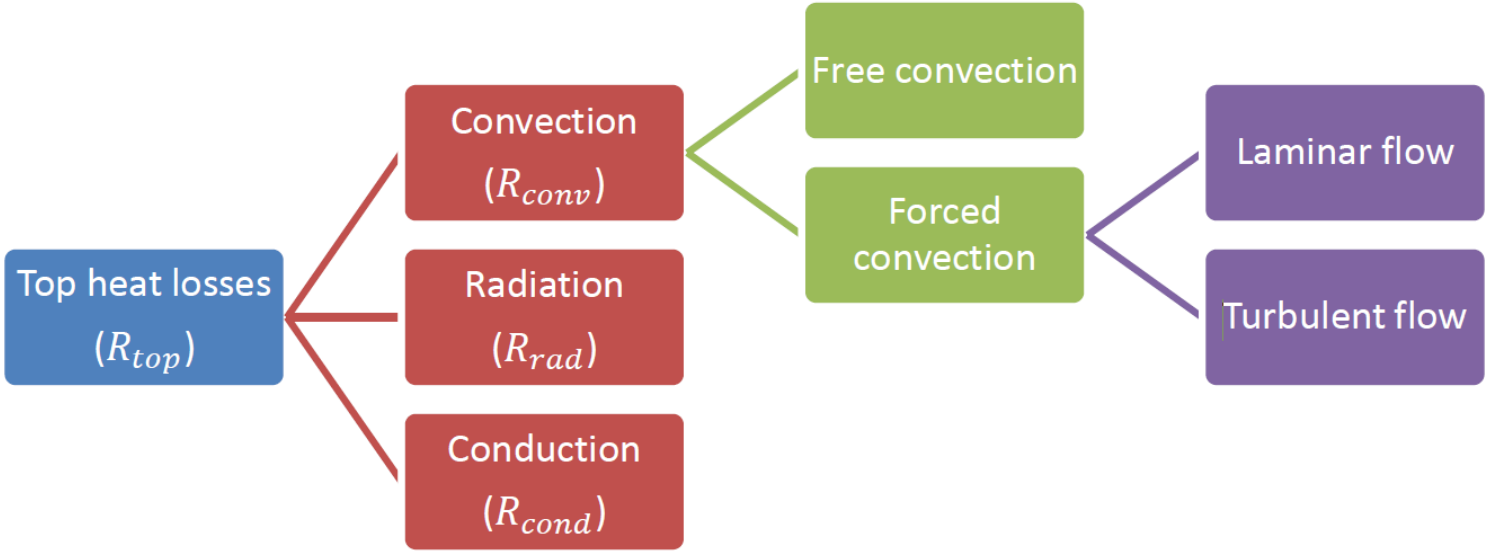
Nighttime radiative cooling

Unglazed collector vs. photovoltaic thermal (PVT)

Outputs:

cooling power (W/m^2), energy (kWh), COP (-)

Theory – Heat losses



Theory – Longwave thermal radiation

Stefan-Boltzmann law $q = \sigma \cdot \varepsilon \cdot T^4$

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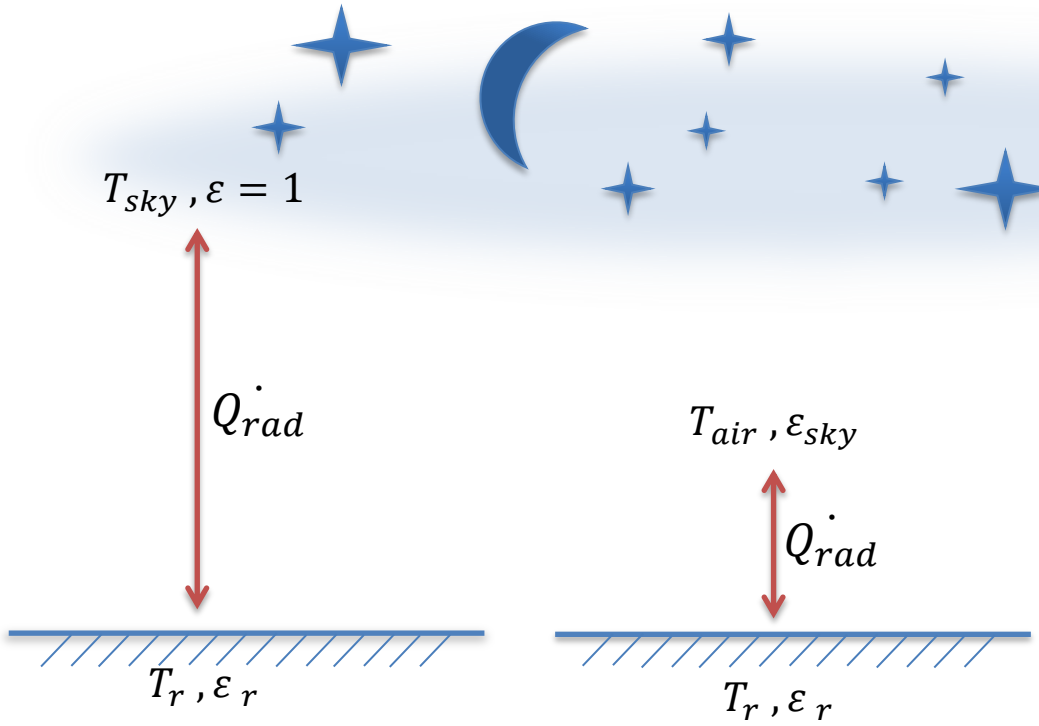

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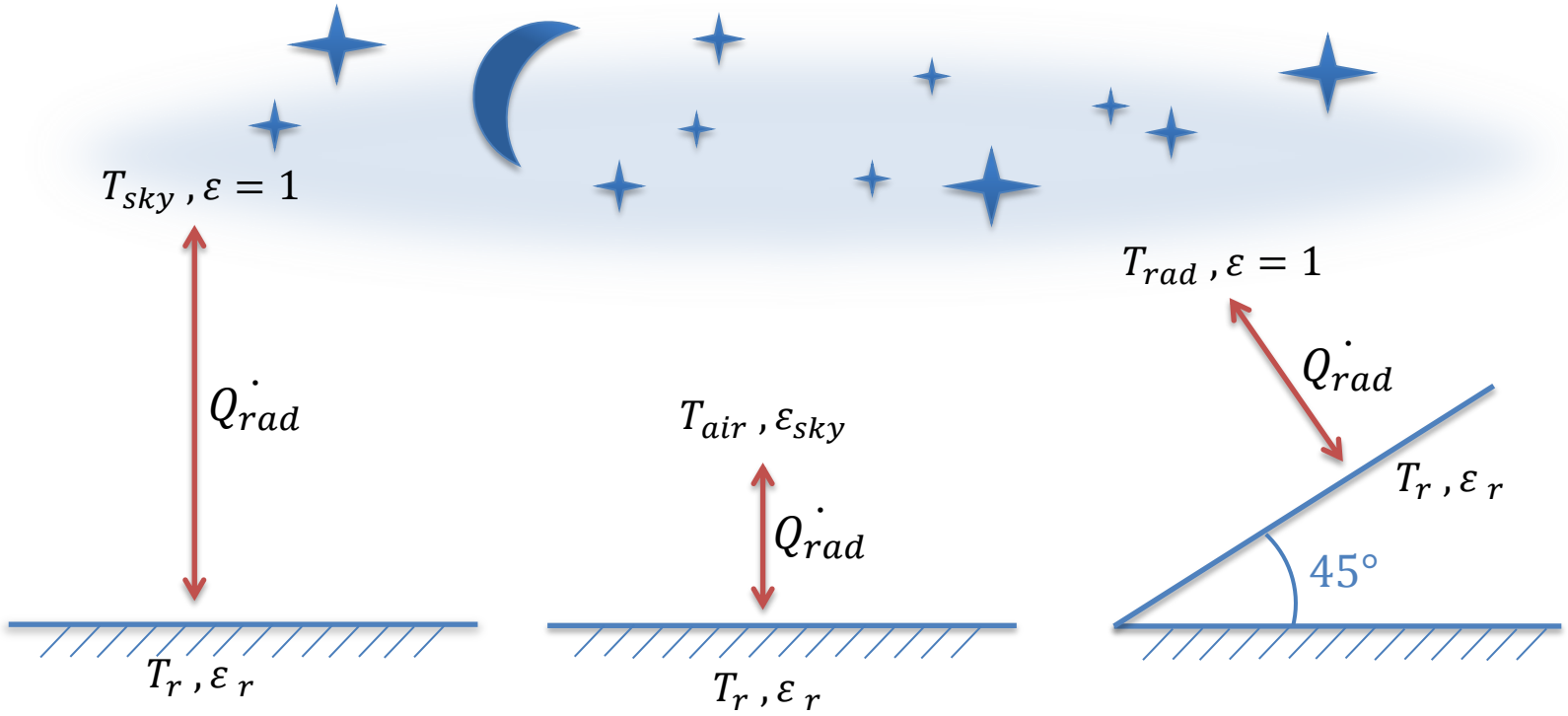

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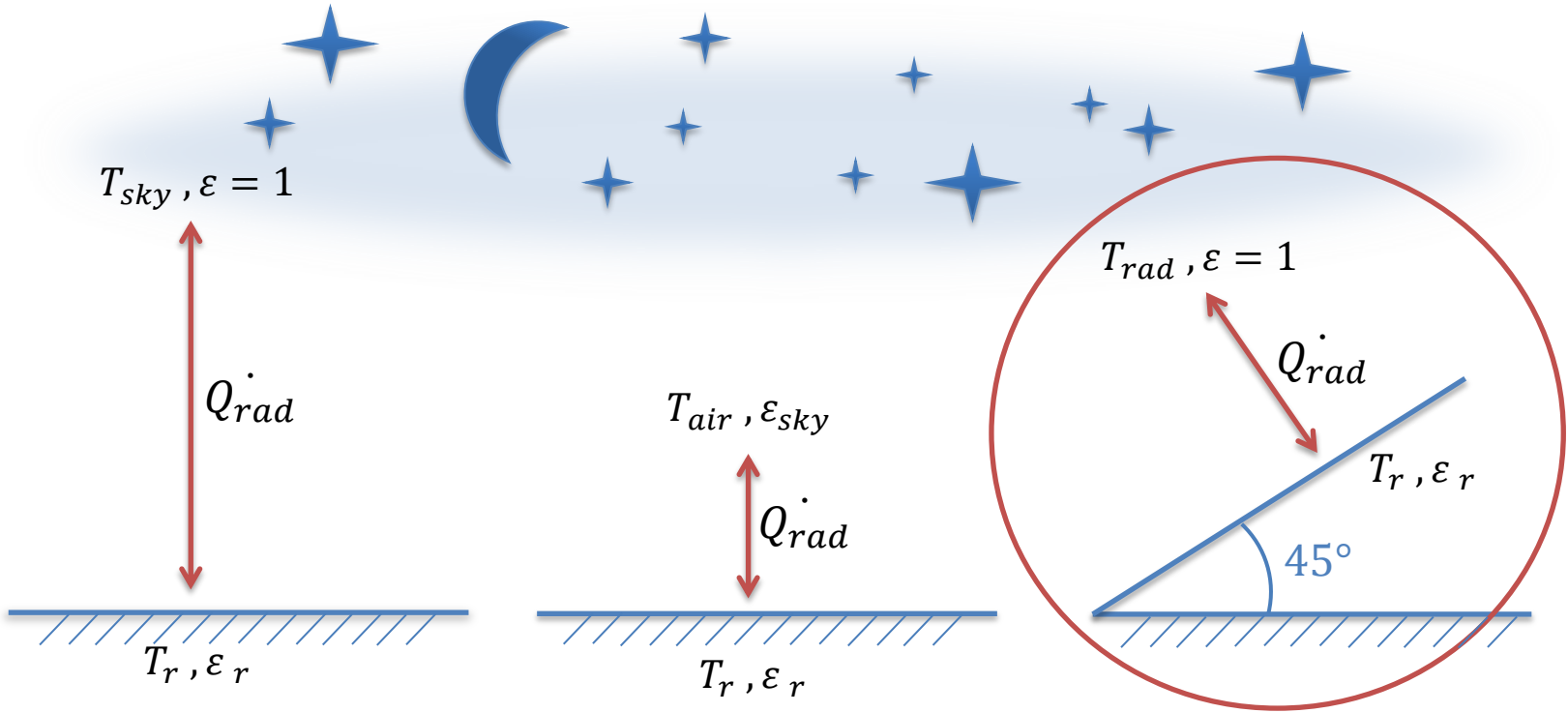
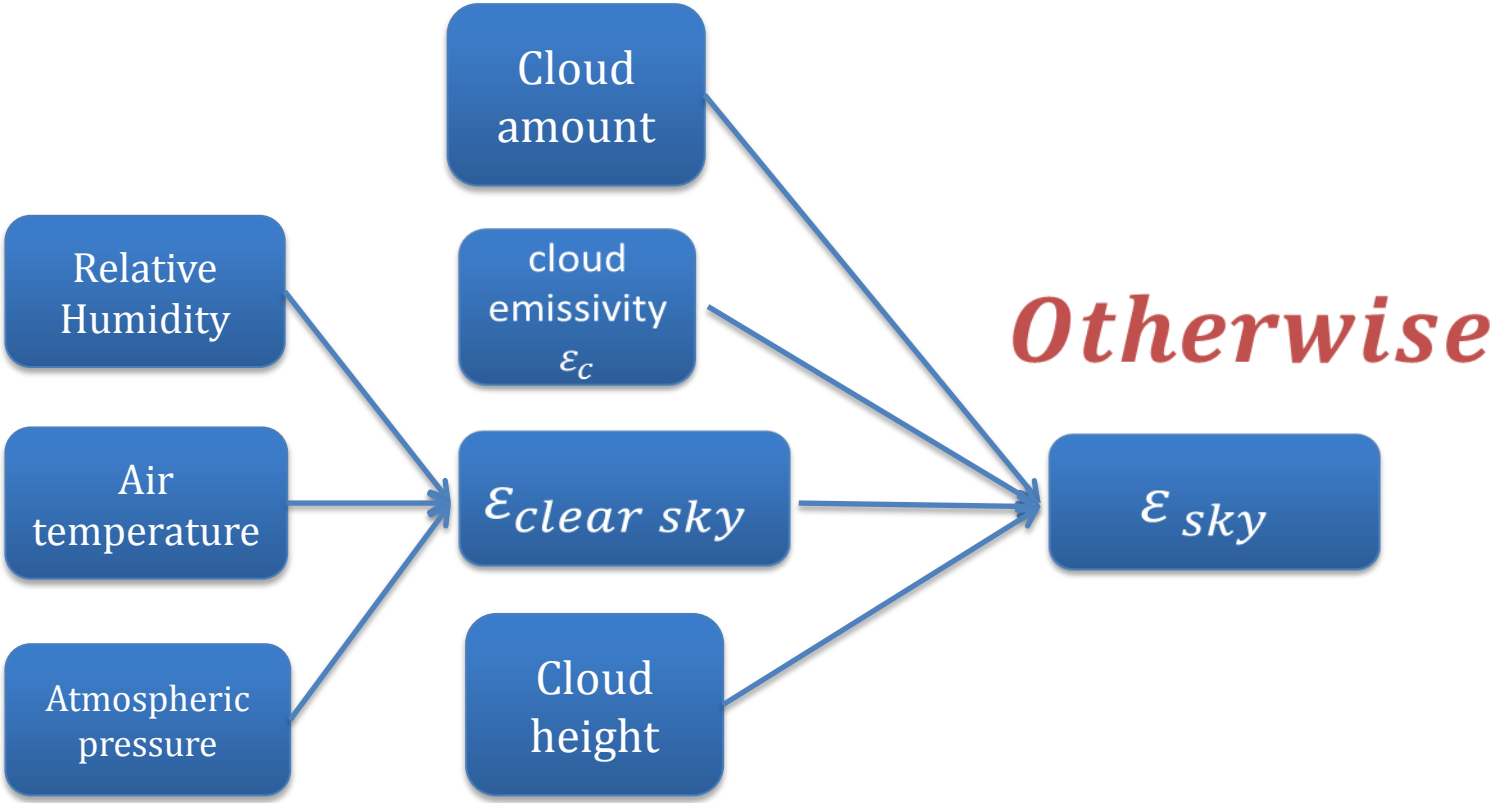


Theory – Longwave thermal radiation

Otherwise

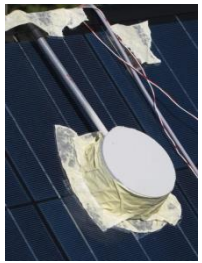
ε_{sky}

Theory – Longwave thermal radiation



Cooling powers

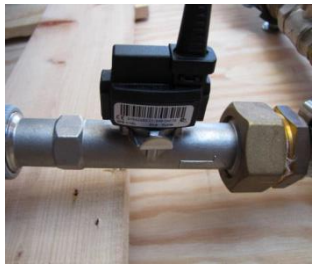
Theory



Plane radiant & surface temperatures

Weather data

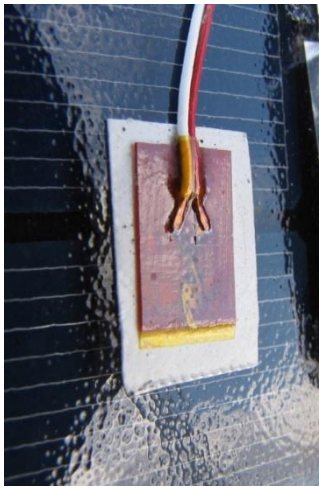
VFS - Water



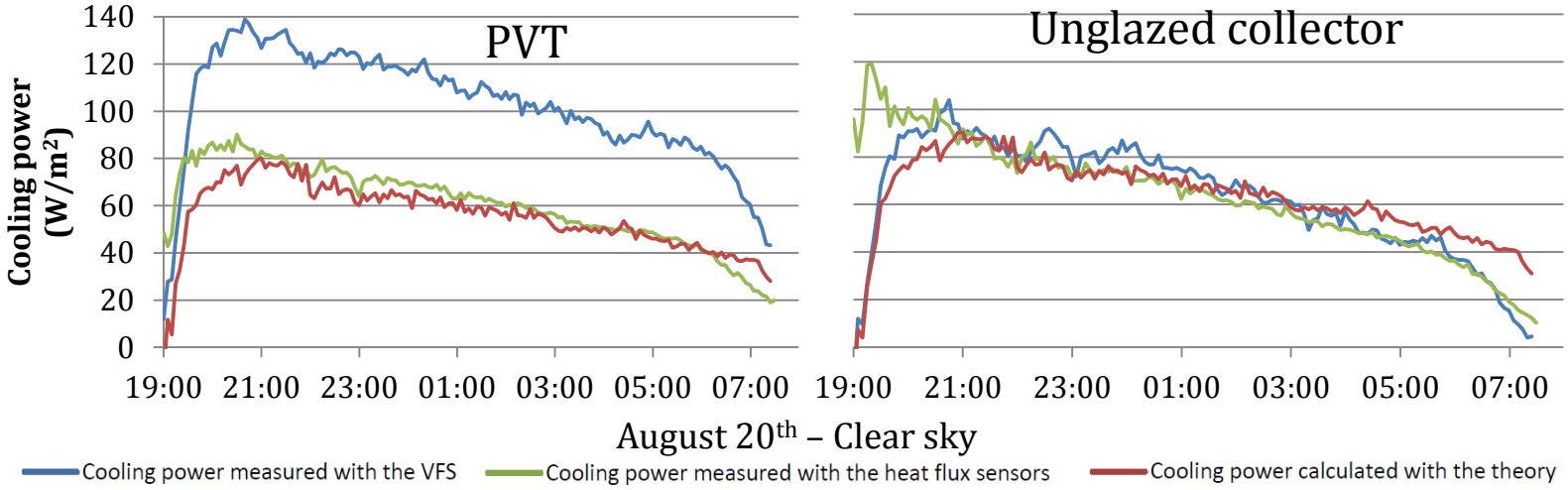
Supply flow and temperature

Returns flows and temperatures

Heat flux sensors



Experiment results



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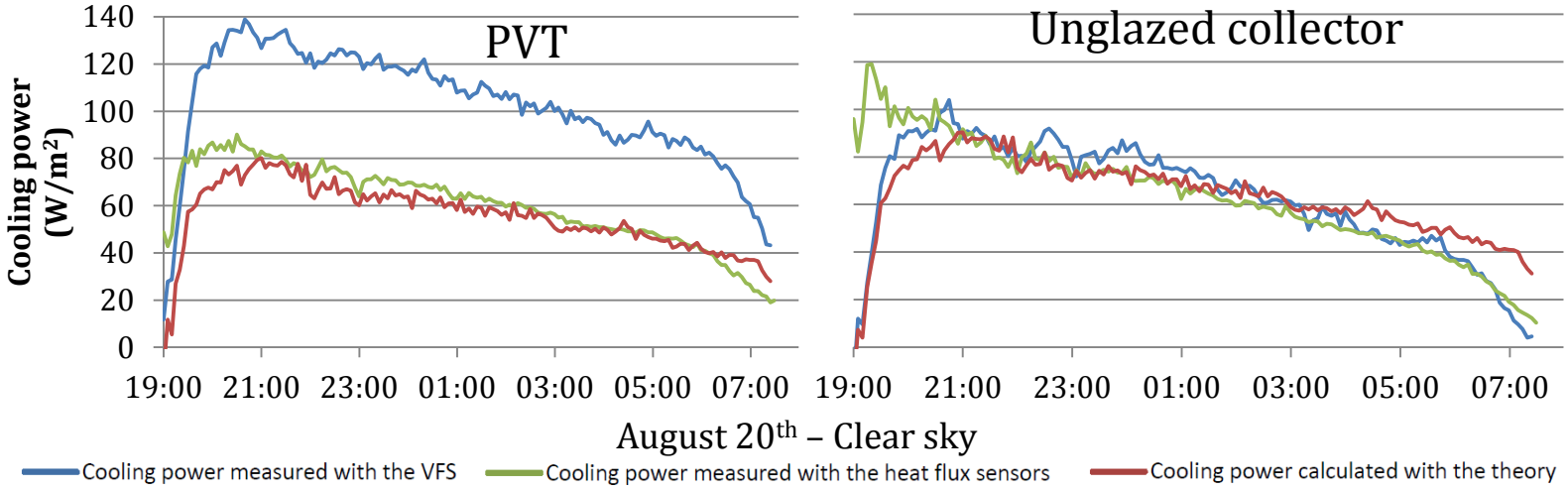
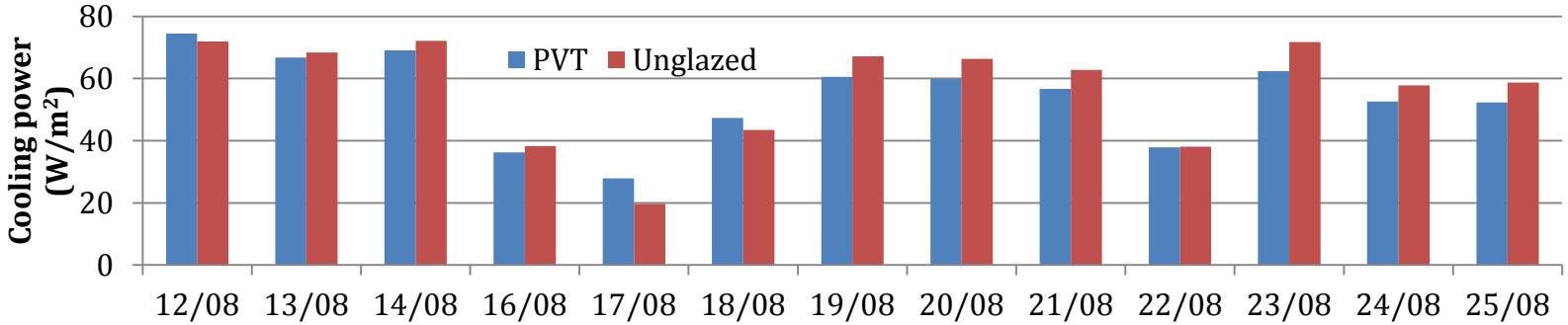
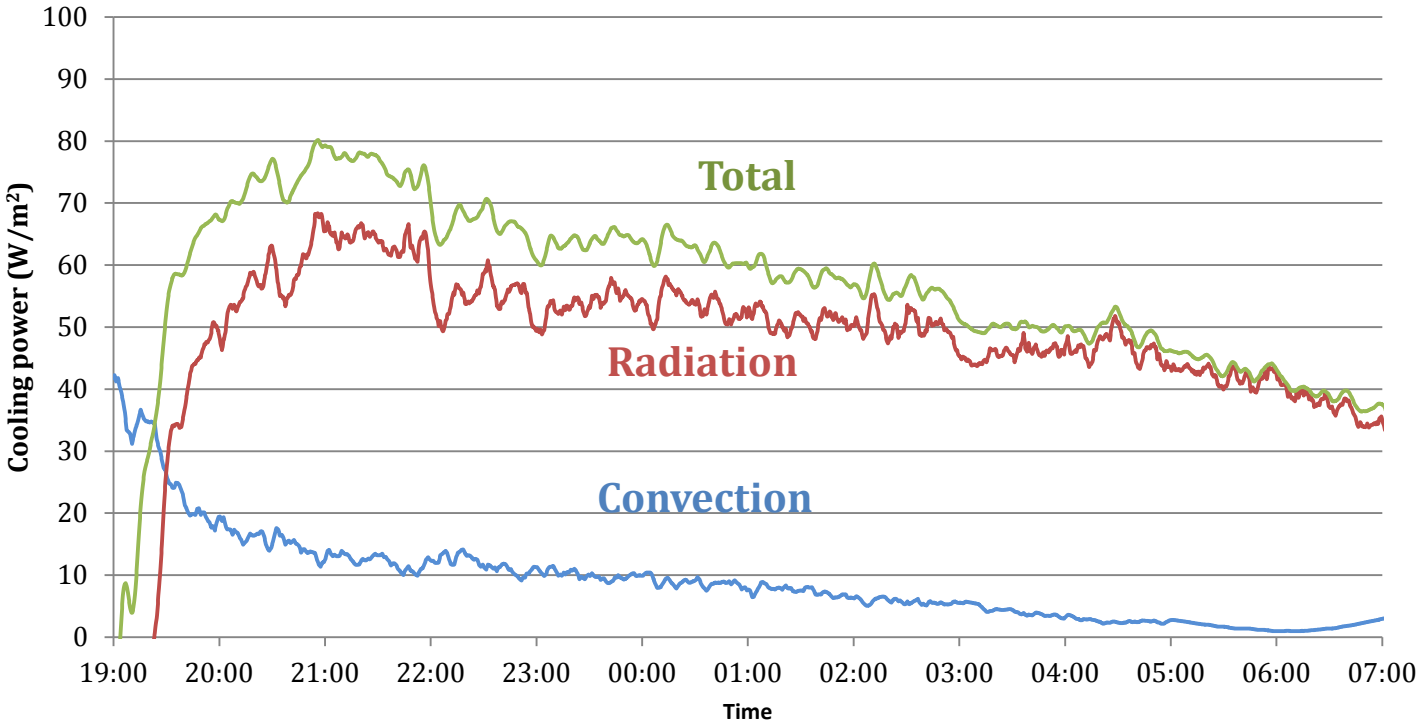




Experiment results: Radiation vs. Convection



August 20th – Clear sky

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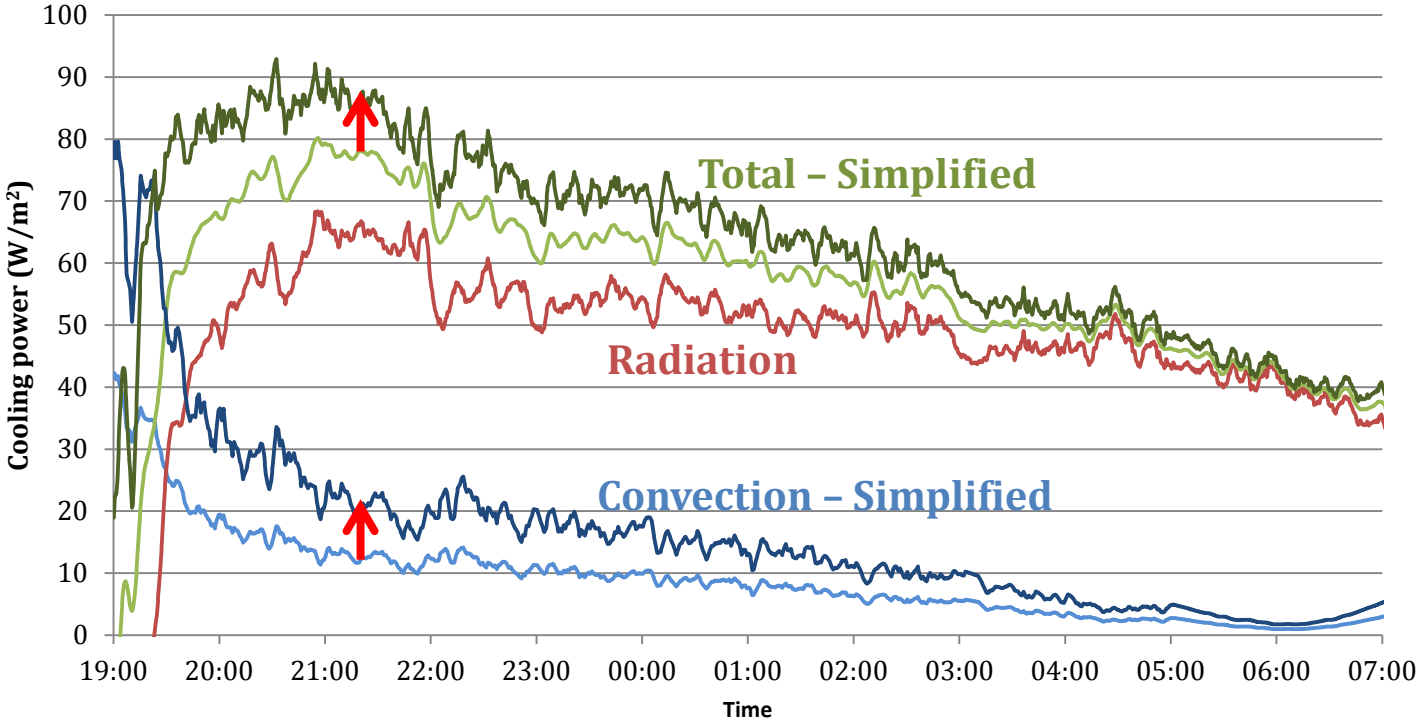


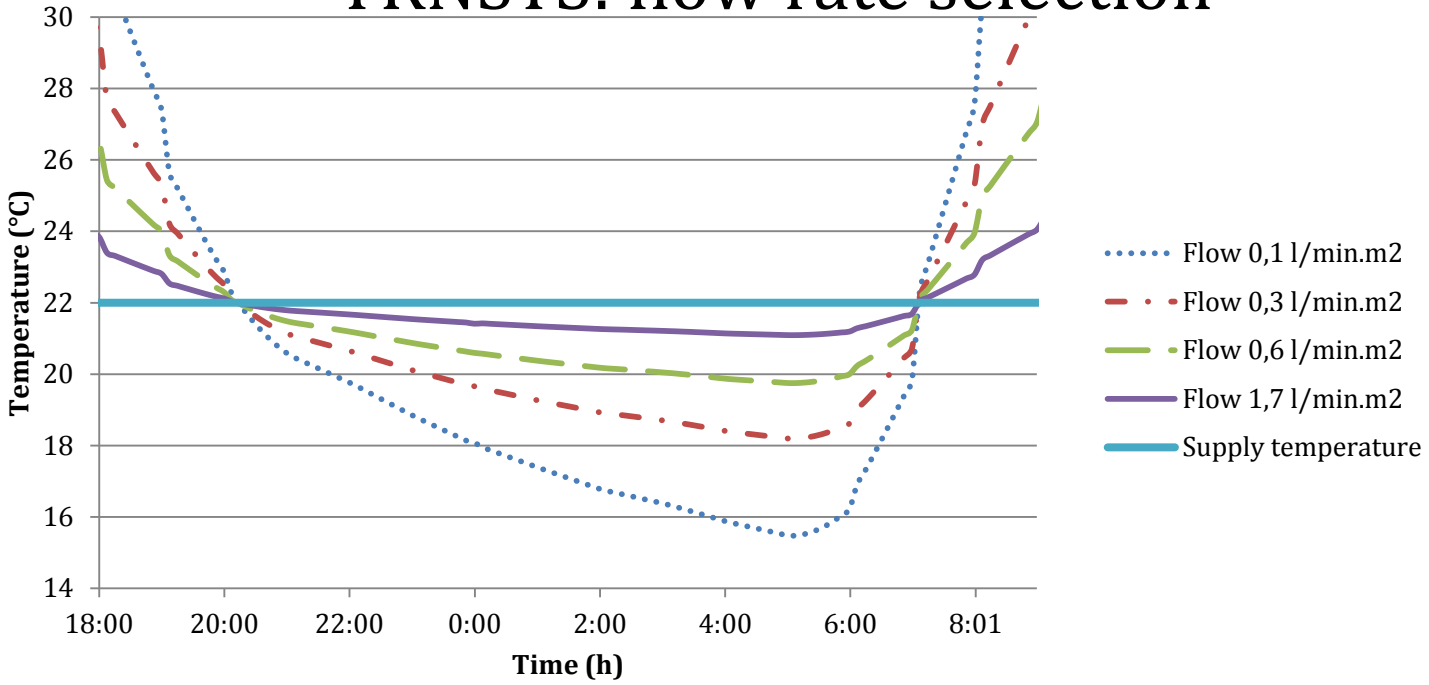
August 20th – Clear sky

Experiment results

	PVT	Unglazed collector
Cooling power (average per night)	28 to 74 W/m^2	20 to 72 W/m^2
Cooling power (literature)	60 to 65 W/m^2	~50 W/m^2
Cooling COP	19 to 58	

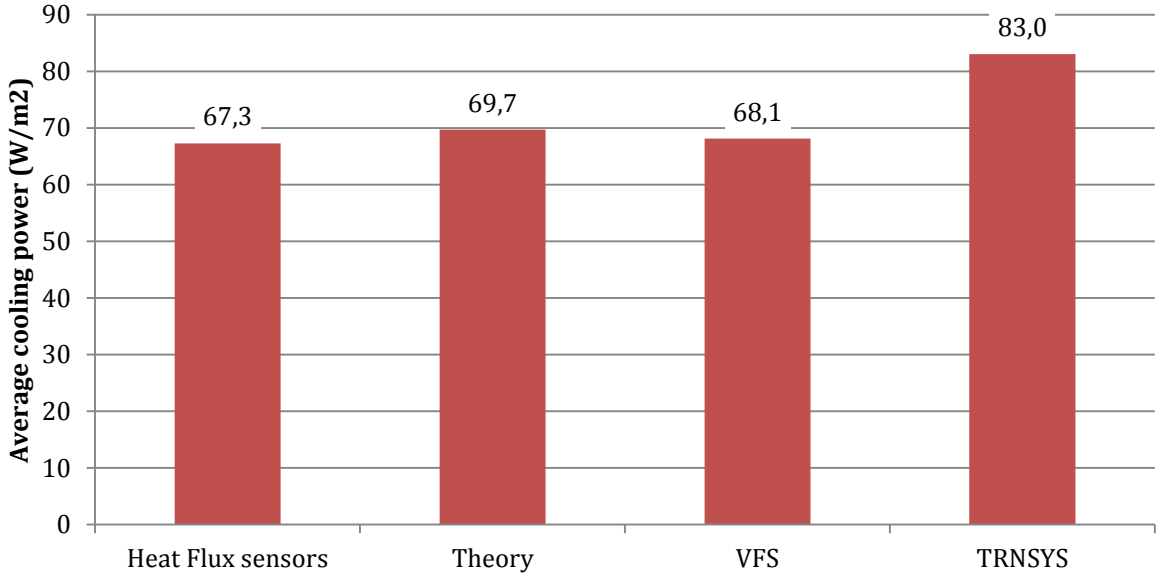
Heating power (average Aug 28th)	247 W/m^2	241 W/m^2
Heating energy (Aug 28th)	9,25 kWh	5,74 kWh

TRNSYS: flow rate selection



Inlet temperature fixed at 22°C				
Flow rate (l/min.m^2)	0,1	0,3	**0,6**	1,7
Cooling power per average night (W/m^2)	30	53	**63**	72

TRNSYS vs. Experiment



Comparison for August 13th

Discussion

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- Reliability of simulations ➔ supported by Standards-Experiment
- Time issues/ difficult central control ➔changes
- Competition rules
- High consumption per m^2 ➔ consumption per person

Nighttime radiative cooling

- Inaccuracies in the measurements (VFS, rain)
- Limited potential in Denmark

Conclusion

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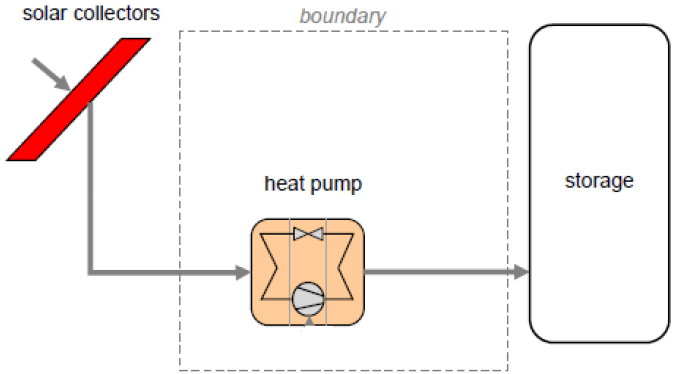
- EMBRACE ranking: #8
- Good performance in Comfort Conditions, Energy Efficiency and Electrical Energy Balance

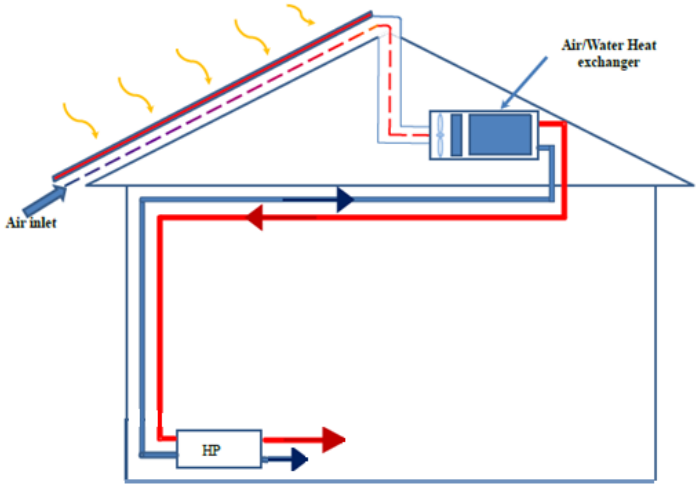
Nighttime radiative cooling

- High savings potential in cooling (high COP)
- Economical potential (PVT, unglazed)
  - Possibility of utilizing existing solar installations
  - Residential use in Southern climates
  - Public buildings use in Denmark

Future research

- Sheltered garden
- Potential of nighttime radiative cooling in different climates
- Coupling with PCM
- Coupling with heat pump condenser



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THANKS FOR THE
GREAT EXPERIENCE!
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