Application of multipurpose heat pumps in museums

A case study

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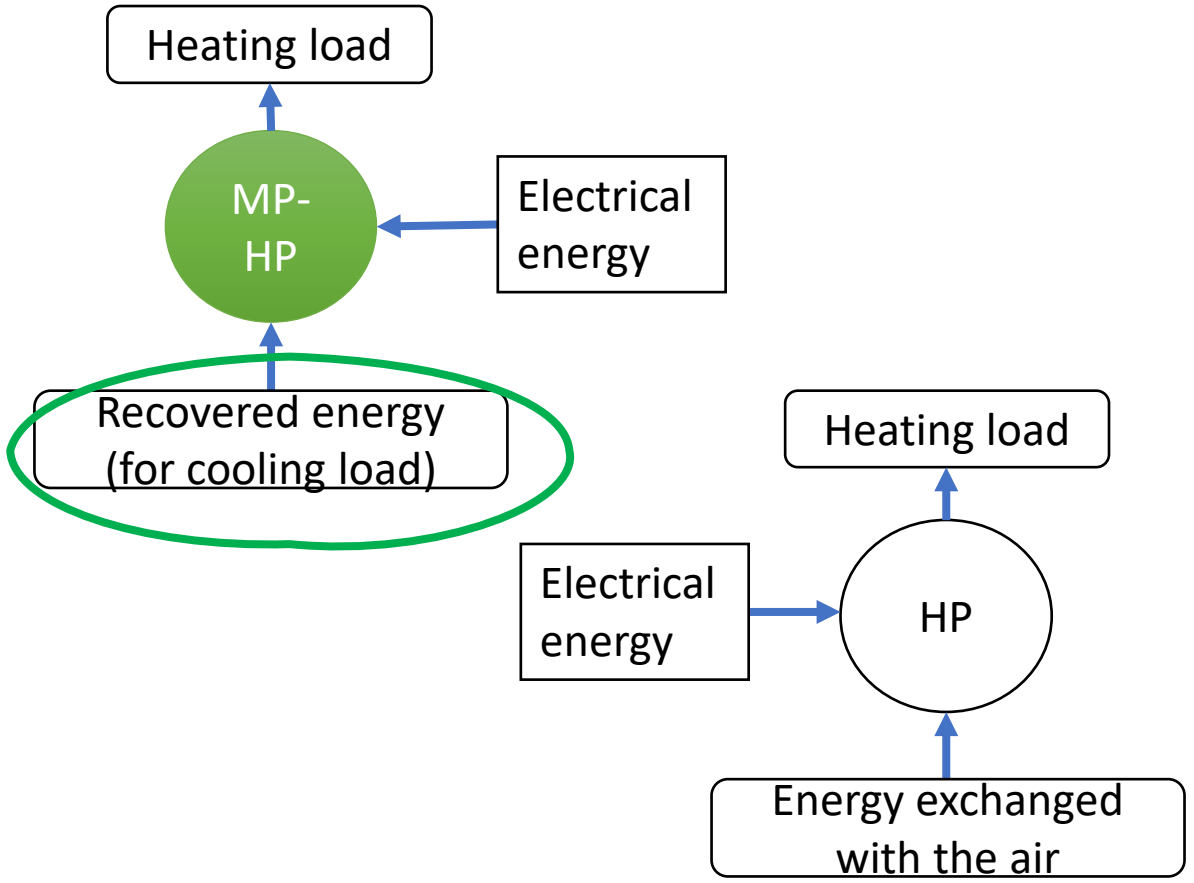
Aim of the work

WHAT

- Quantify the energy savings obtainable by using a **multipurpose heat pump** compared to a separate configuration with two generators (chiller + heat pump) when both heating and cooling are needed



Also known as: multi-heat pump, total recovery chiller, multifunctional heat pump

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WHAT

- Quantify the energy savings obtainable by using a **multipurpose heat pump** compared to a separate configuration with two generators (chiller + heat pump) when both heating and cooling are needed

WHY

- Explore the potential of a multipurpose heat pump, a not-yet widespread generator in building application

Aim of the work

WHAT

- Quantify the energy savings obtainable by using a **multipurpose heat pump** compared to a separate configuration with two generators (chiller + heat pump) when both heating and cooling are needed

HOW

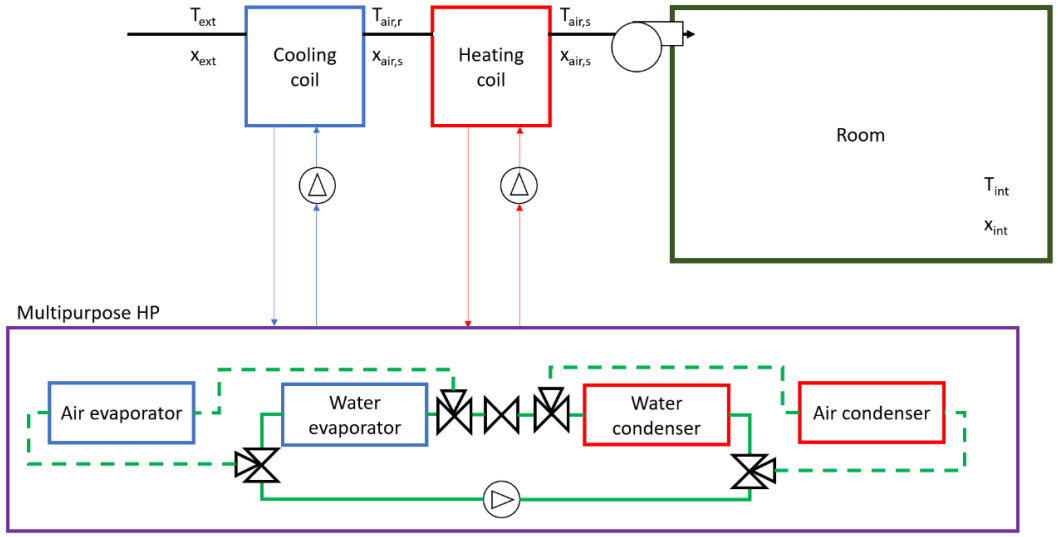
- Dynamic energy simulation of a case study (Italian museum)

WHY

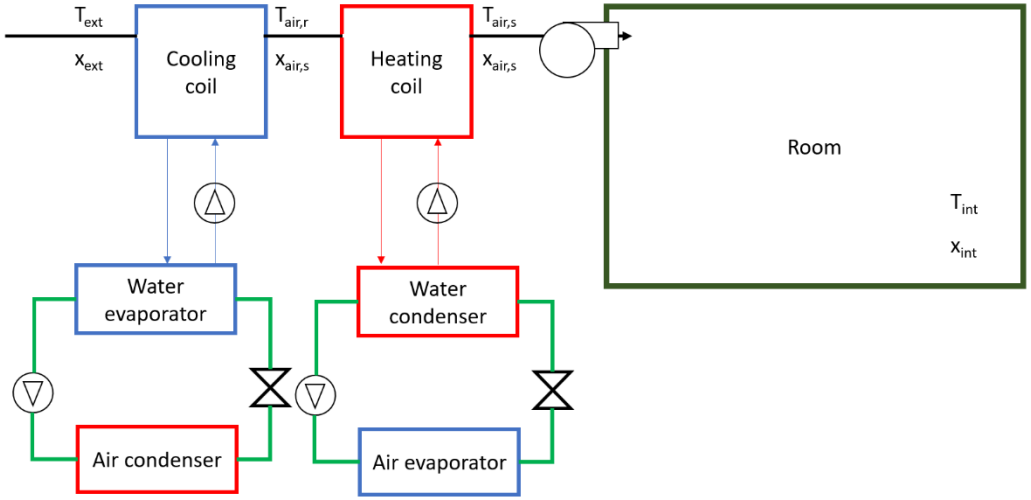
- Explore the potential of a multipurpose heat pump, a not-yet widespread generator in building application

Configurations

Multipurpose HP (MP-HP)



Separate configuration (SP)



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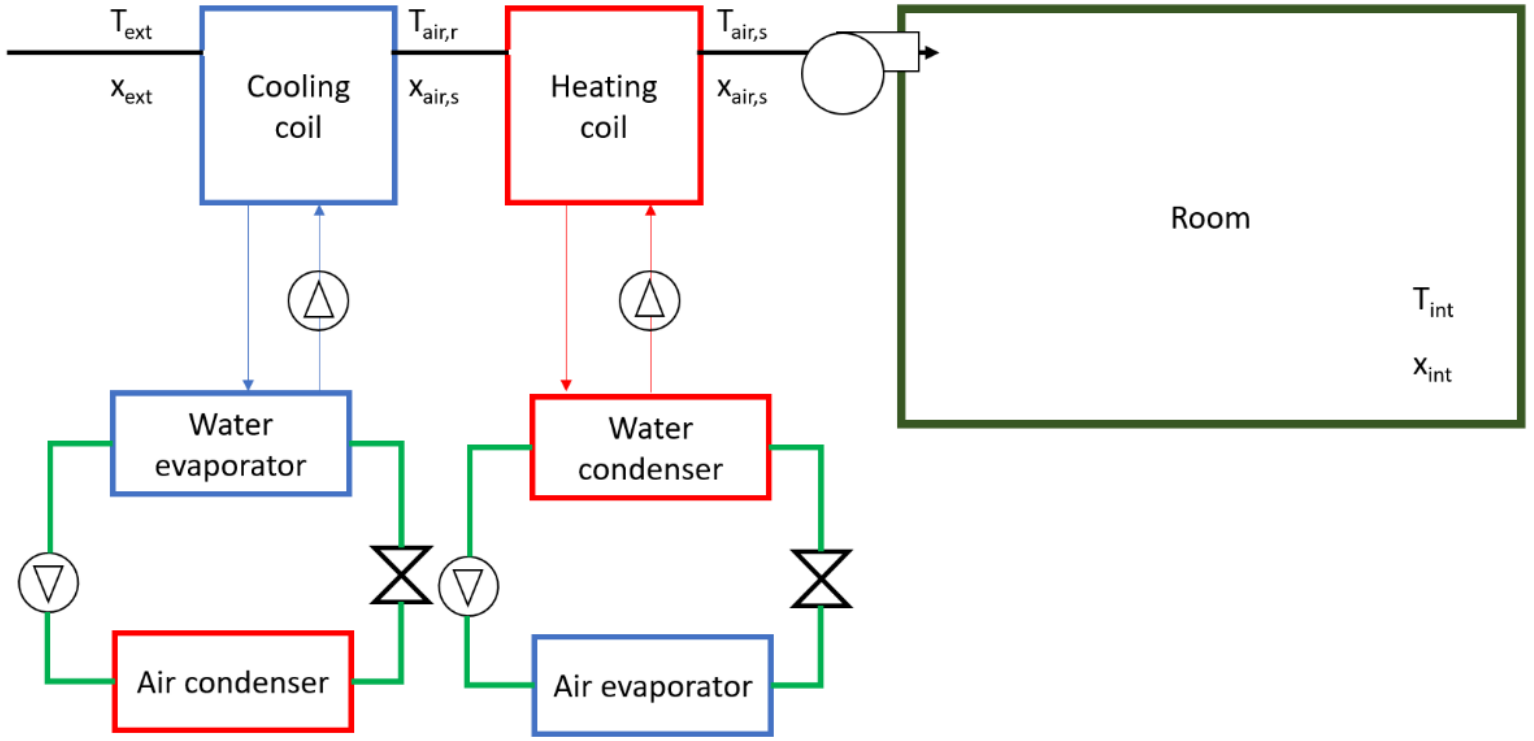

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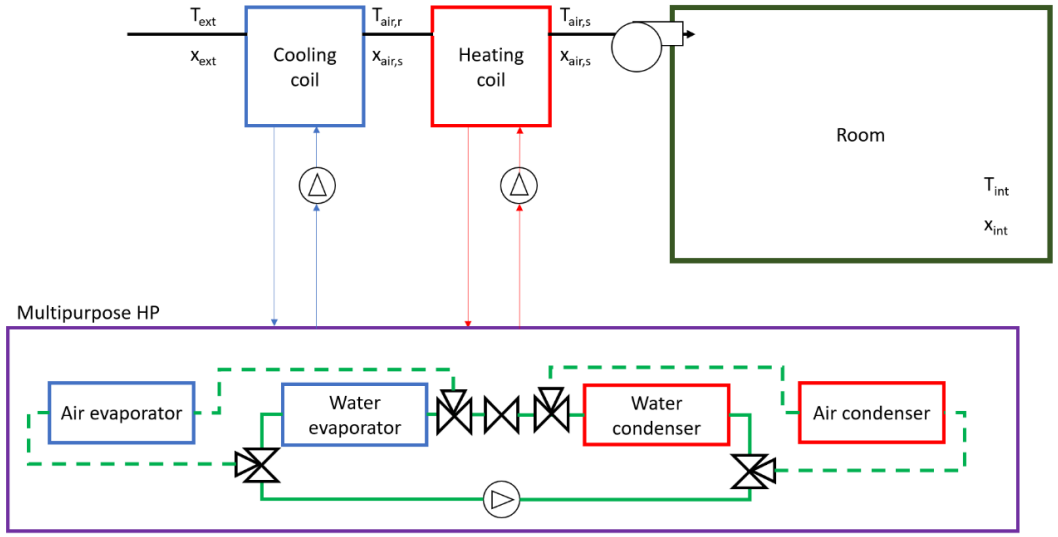

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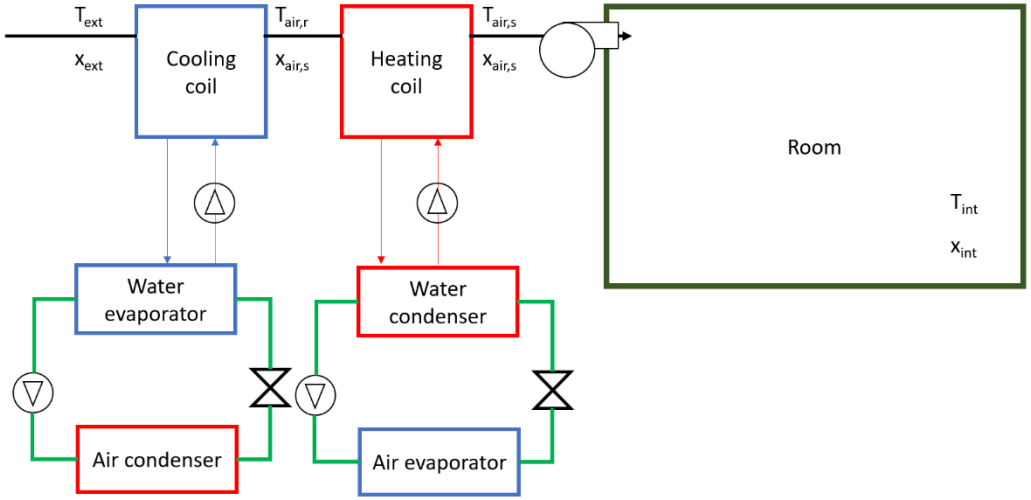

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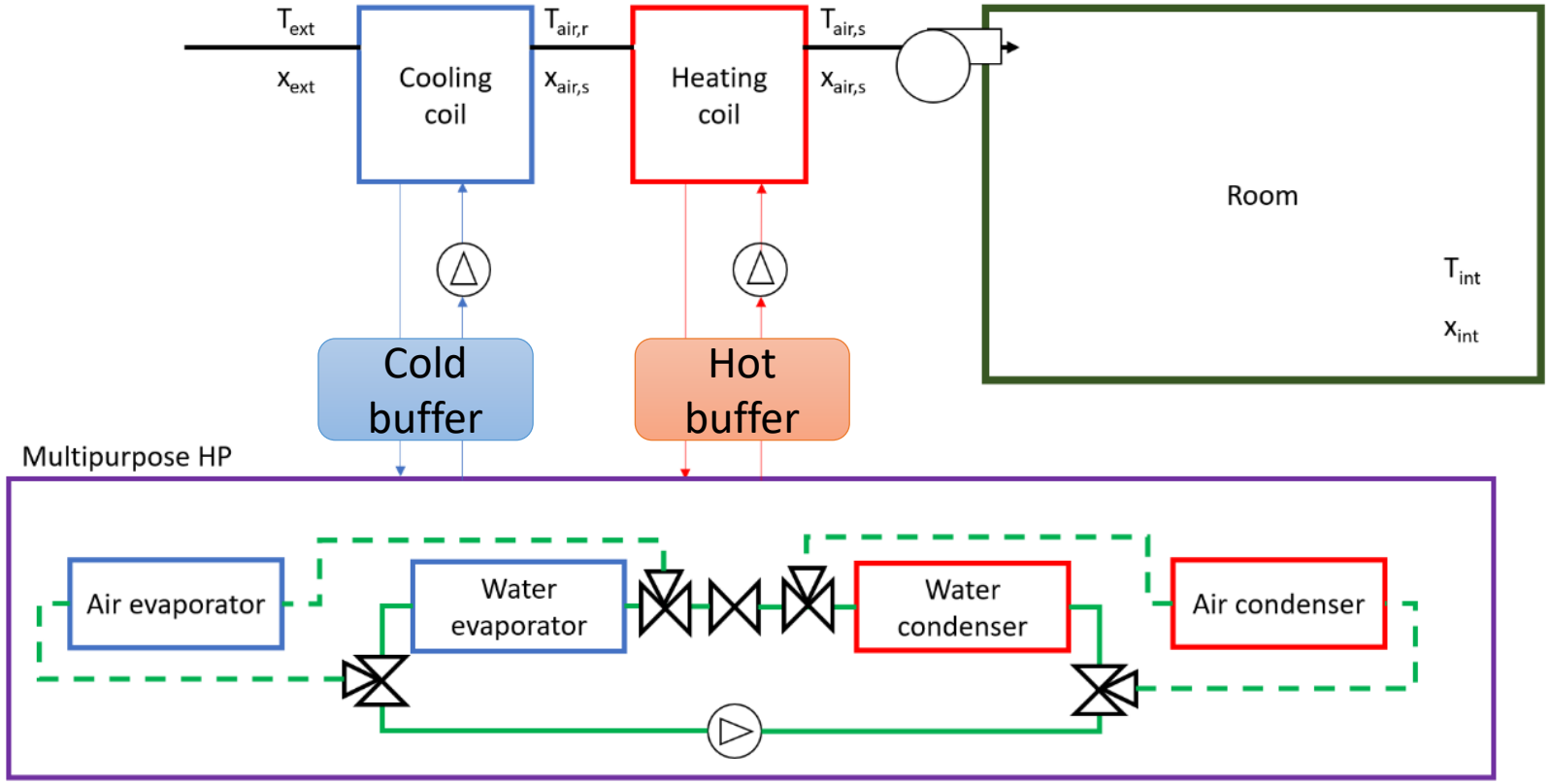


Case study

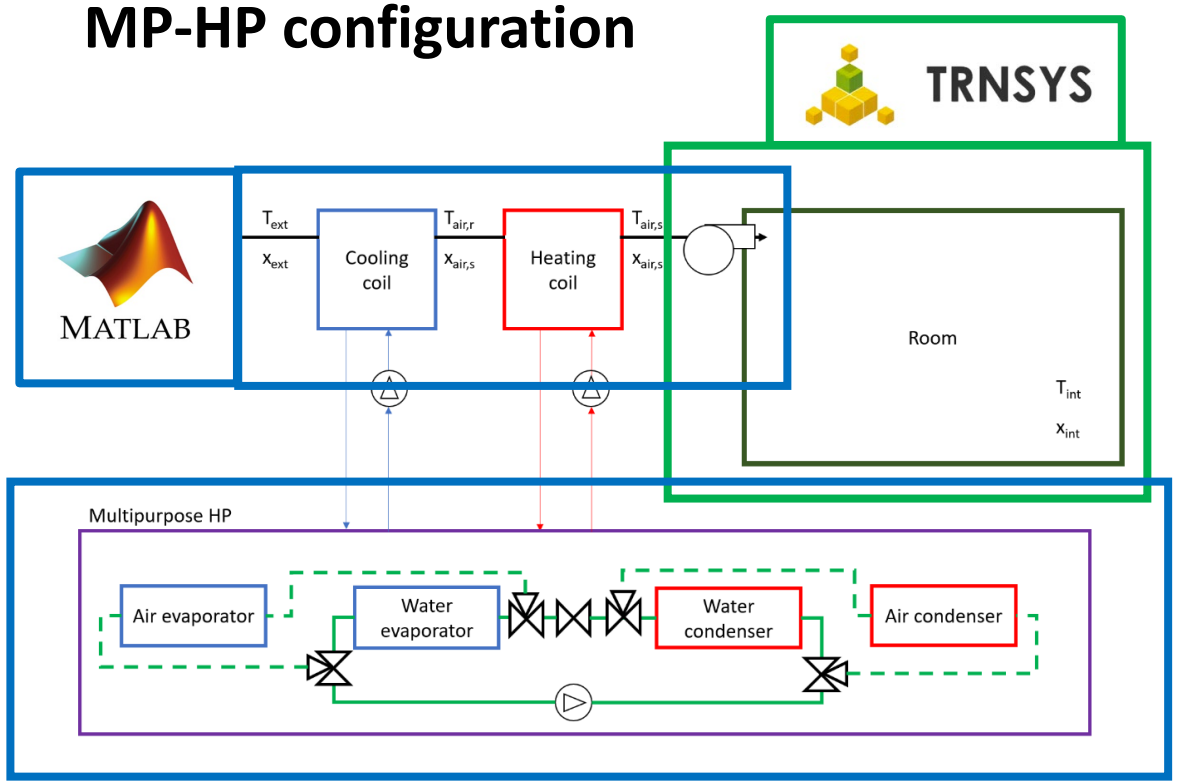
The case study: two rooms of a museum in Pisa, Italy

- Floor area: *100 m^2*
- Volume: *500 m^3*
- Walls: *bricks and masonry (U = 1.1 W/(m^2 K))*
- Period: *July 1st – August 31st*
- Timestep: *one hour*
- External climate data: Pisa, IT *(TMY)*
- Visitors: *hourly profile*
- Indoor temperature setpoint: *25 °C (DB ±1K)*
- Indoor relative humidity setpoint: *50% (DB ± 2%)*
- HVAC operating period: *24/7*

For artwork preservation

Case study modeling

MP-HP configuration



KEY POINTS OF THE MODEL

- Room → TRNSYS → Hourly dynamic heating and cooling loads
- AHU → MATLAB (e-NTU and BF/straight line models) → Thermal loads at both heating and cooling coils
- MP-HP/HP&Chiller → MATLAB (Polynomial fitting using manufacturers' data) → Efficiency based on source (water/air) temperatures and capacity ratio

MP-HP model

Both heating and cooling

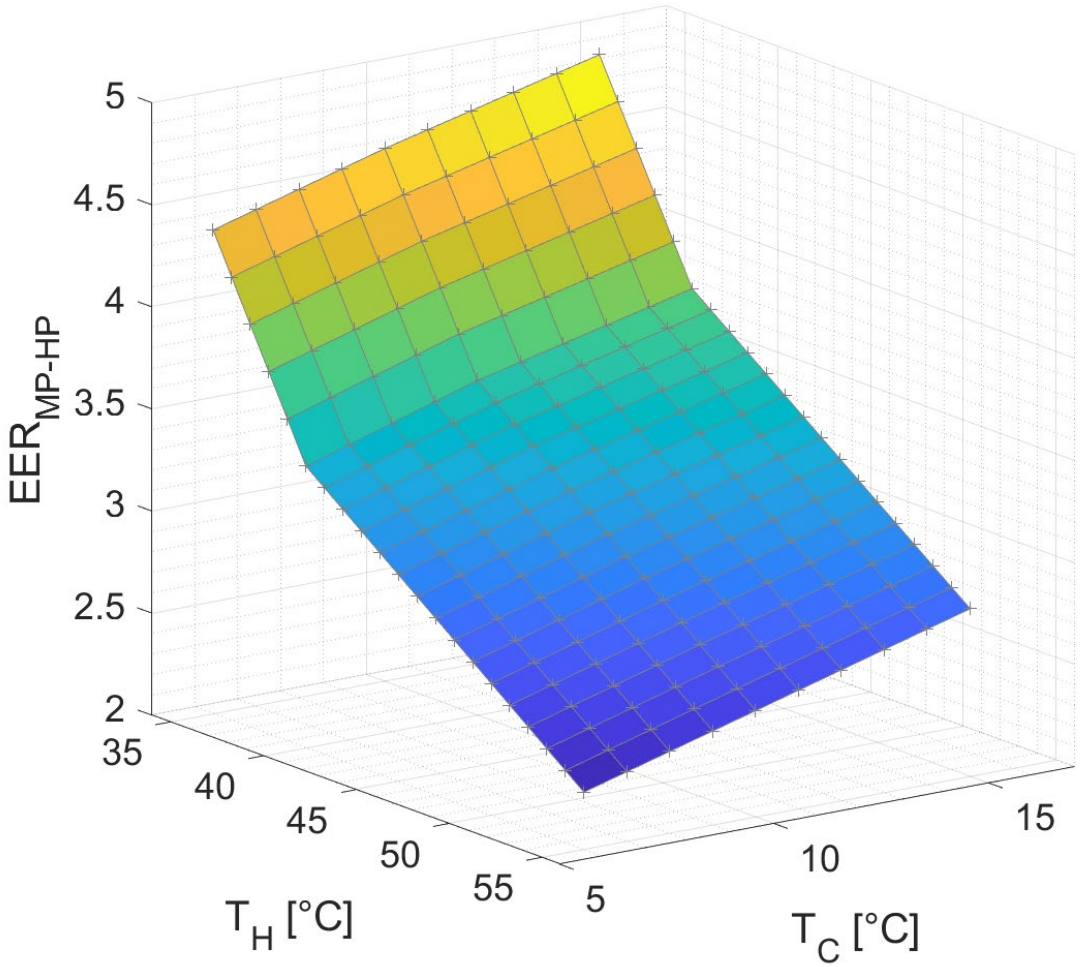
- Following heating load
- Following cooling load

Heating only

- Working as a «classical» heat pump

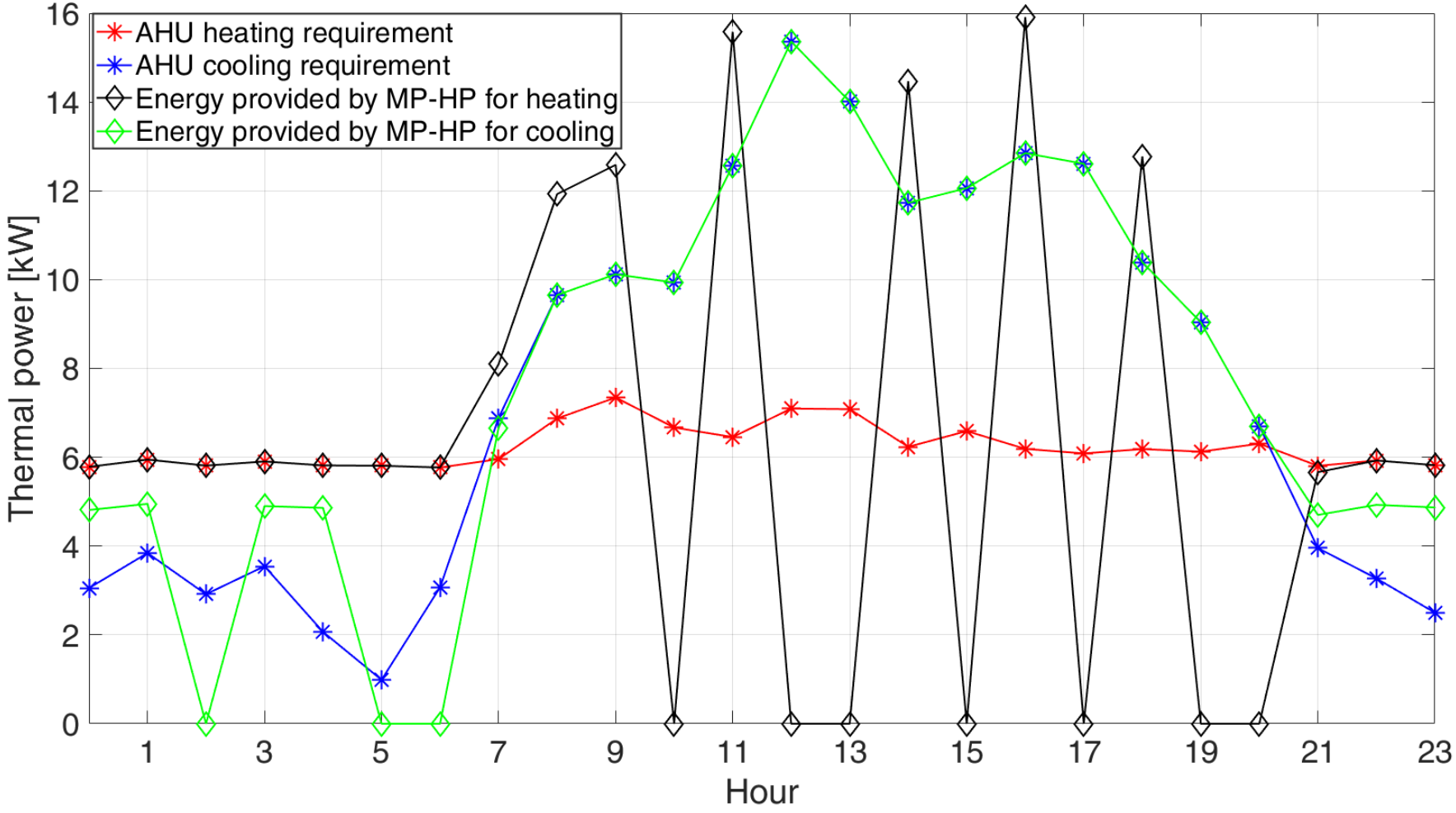
Cooling only

- Working as a «classical» chiller



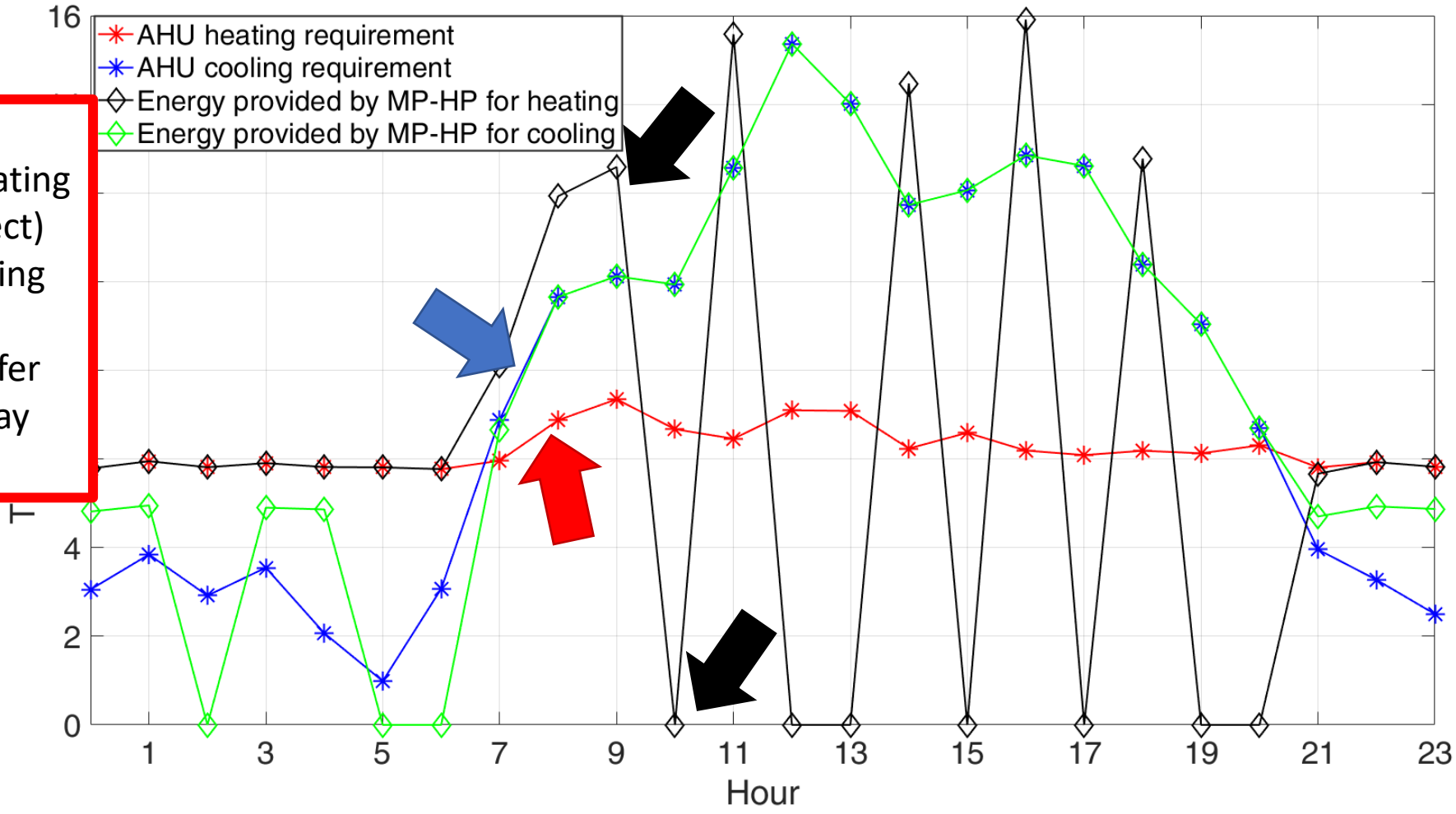
Results

Comparison MP-HP vs SC



Comparison MP-HP vs SC

Daylight hours:
cooling load > heating load (visitors' effect)
→ Following cooling load
→ Use of hot buffer (yellow and gray surfaces)



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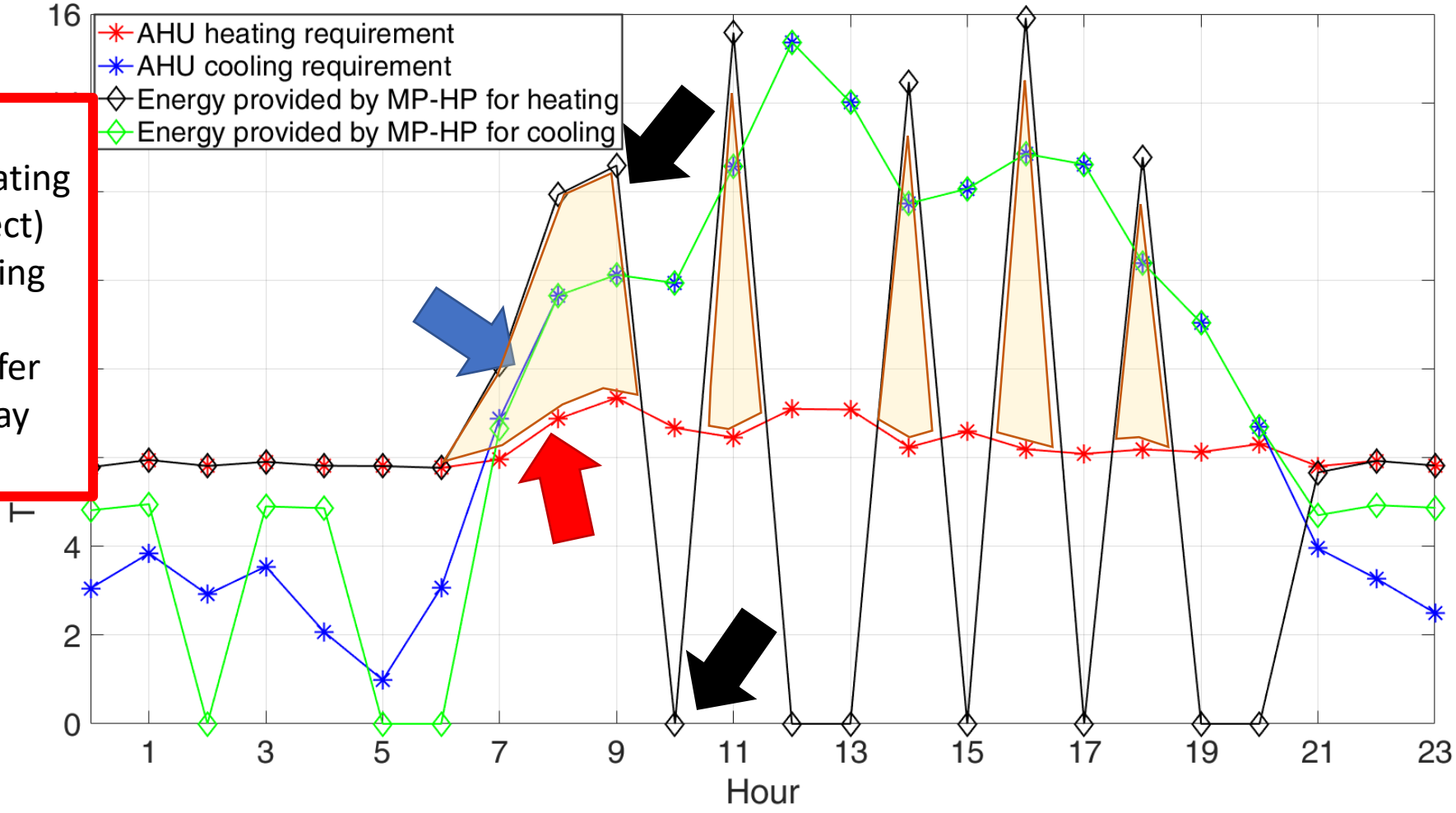

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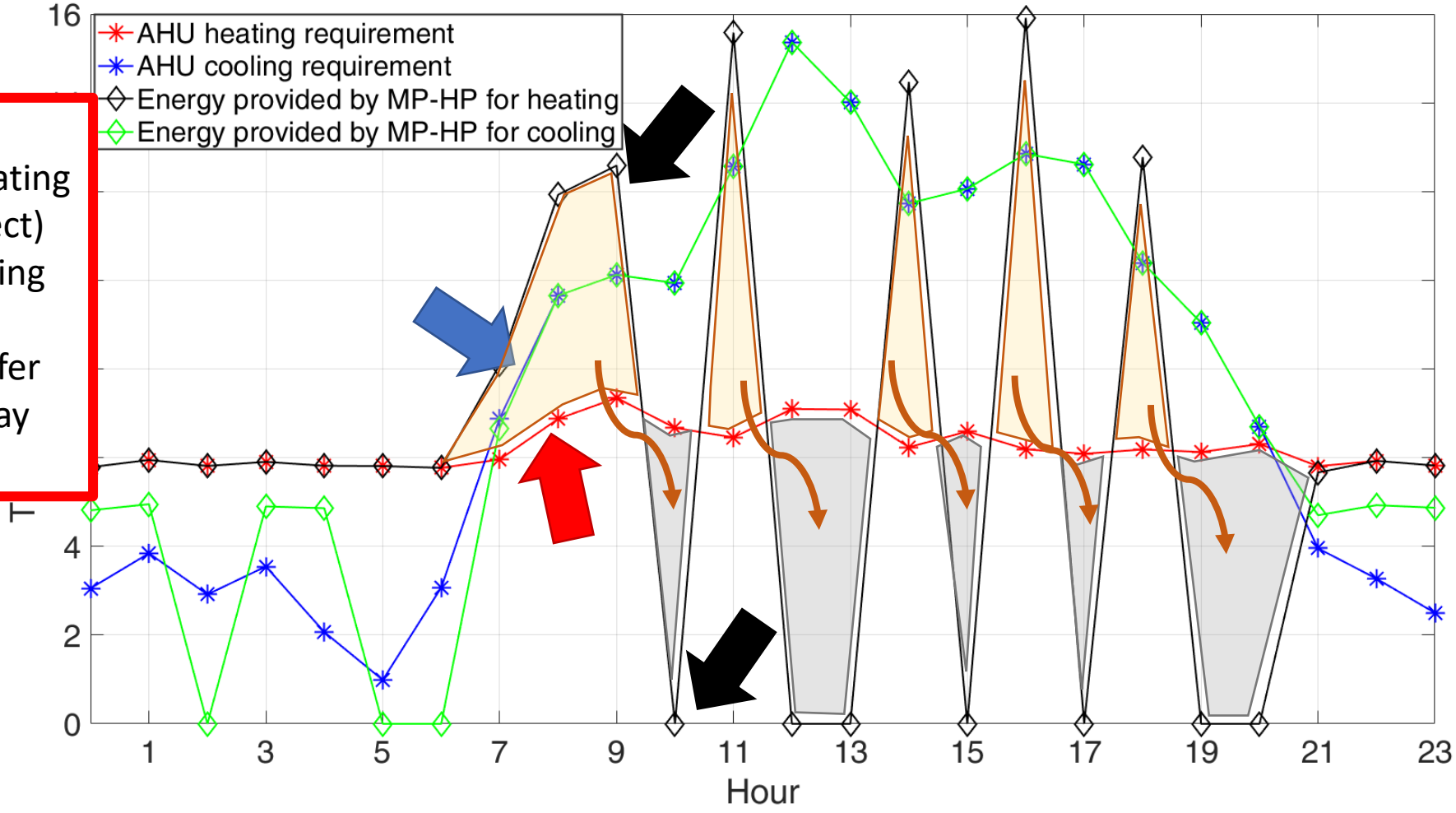
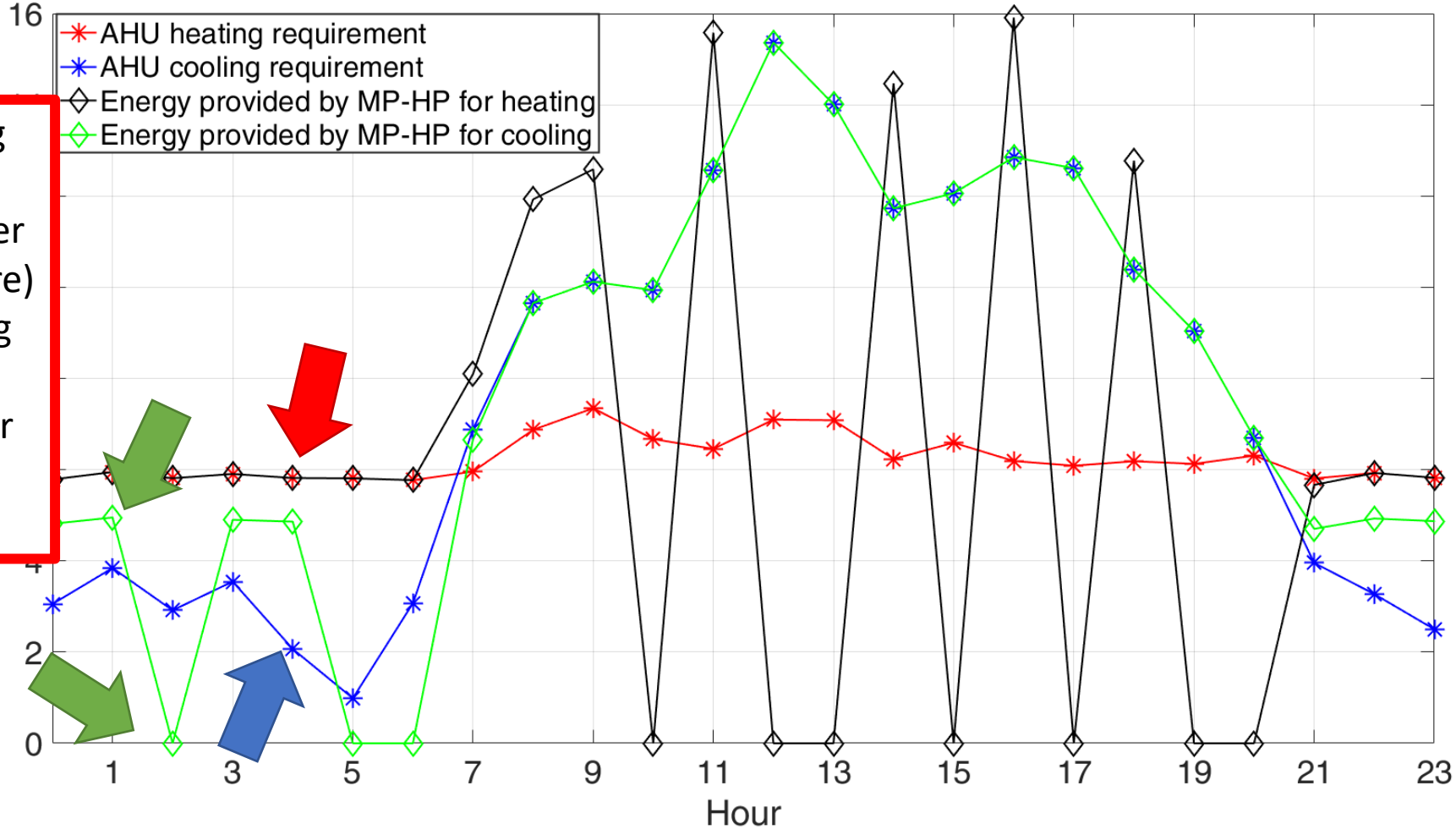


Comparison MP-HP vs SC

Night hours: heating load > cooling load (no visitors and lower external temperature)

→ Following heating load

→ Use of cold buffer (orange and blue areas)



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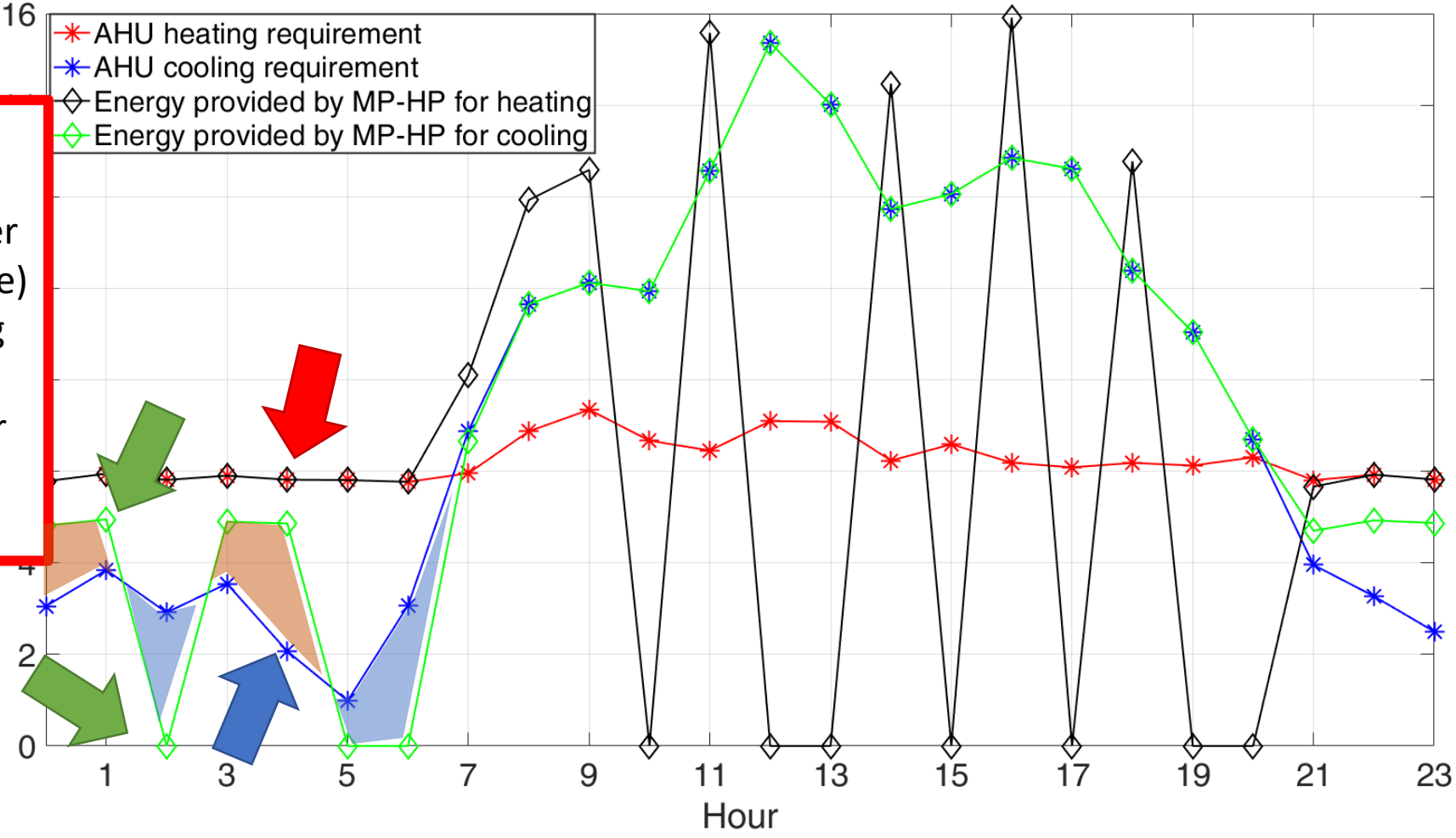

Comparison MP-HP vs SC

	MP-HP	SC
Total cooling load at AHU [MWh]	13.9	13.9
Total heating load at AHU [MWh]	8.8	8.8
Total electrical energy input [MWh] -25 %	3.2	4.3
Seasonal coefficient of performance («Cooling only» mode)	4.63	5.00
Seasonal coefficient of performance («Heating only» mode)	5.20	5.70
Seasonal coefficient of performance («MP-HP» mode)	4.11	NA
Share of cooling load provided in «MP-HP» mode [%]	47	NA
Share of heating load provided in «MP-HP» mode [%]	92	NA

Conclusions

Conclusions and future prospects

- Effectiveness of MP-HP use in buildings where heating and cooling are required at the same time
- 25%-reduction of electrical energy compared to separate configuration
- Importance of energy buffer to store surplus energy

- Accurate analysis of thermal buffer (sizing + management)
- Simulation on a whole-year period and different climates

Any questions?

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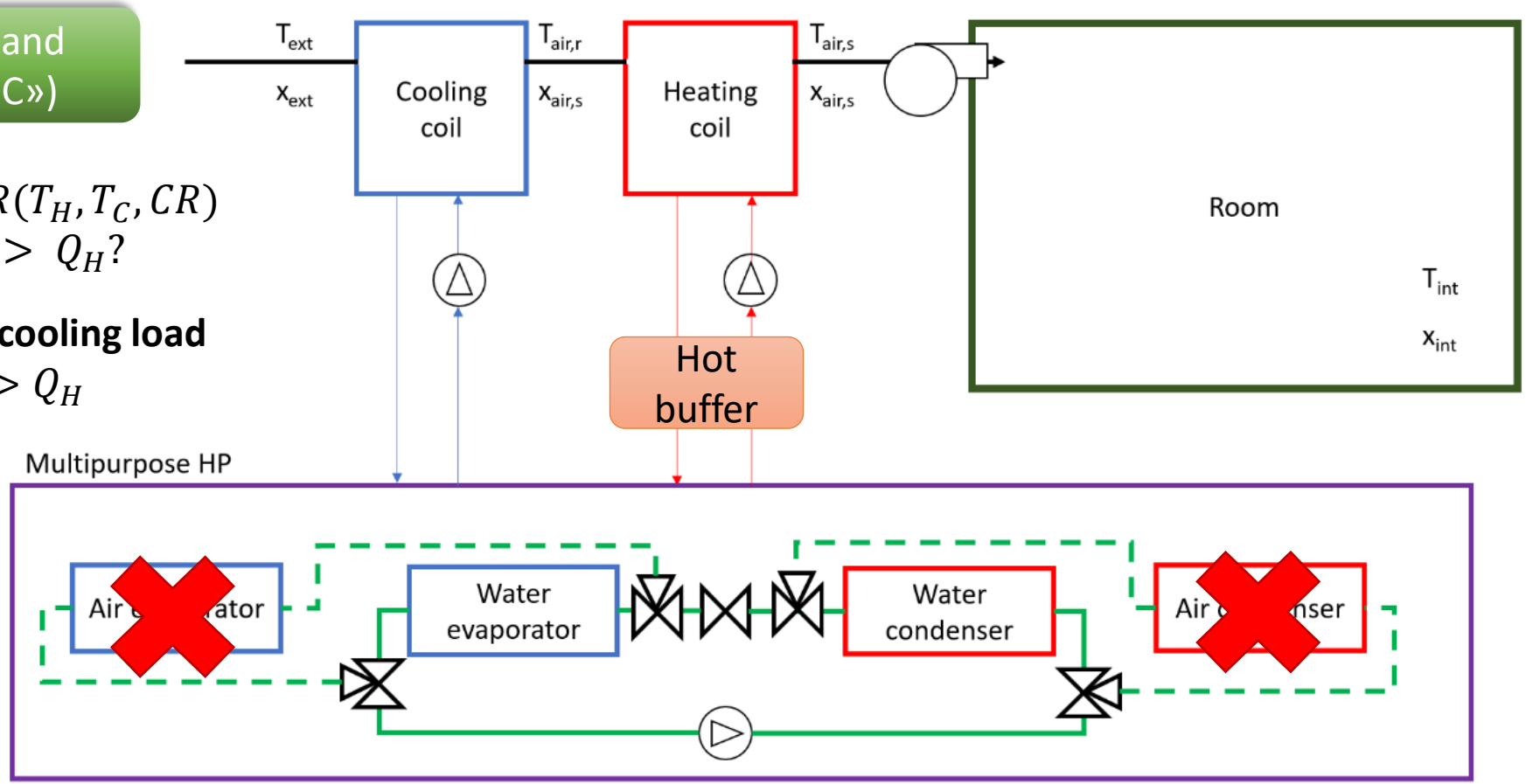
MP-HP model

Both heating and cooling («H&C»)

$$E_{el} = Q_C/EER(T_H, T_C, CR)$$
$$Q_C + E_{el} > Q_H?$$

YES: Following cooling load

$$Q_{H,eff} > Q_H$$



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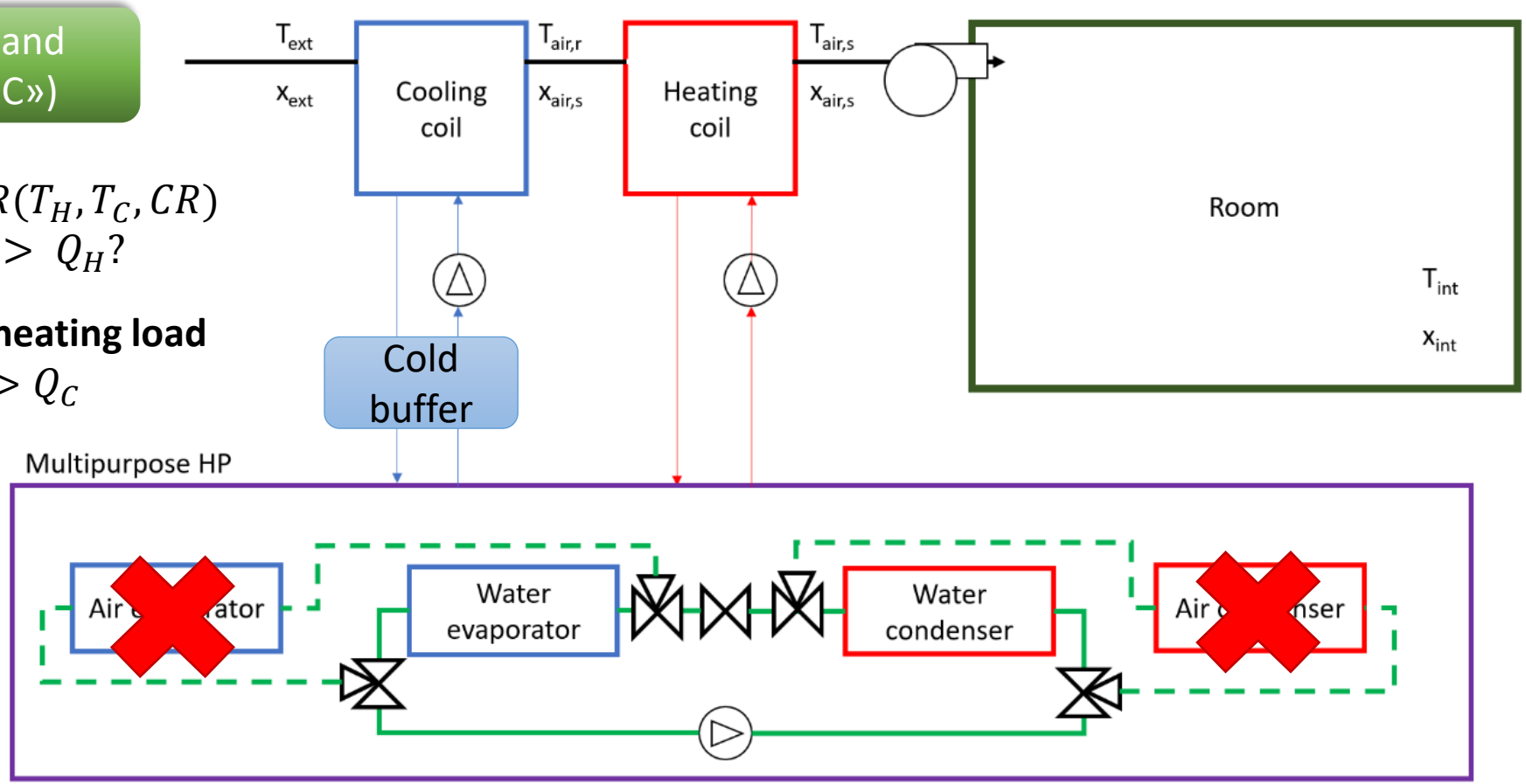
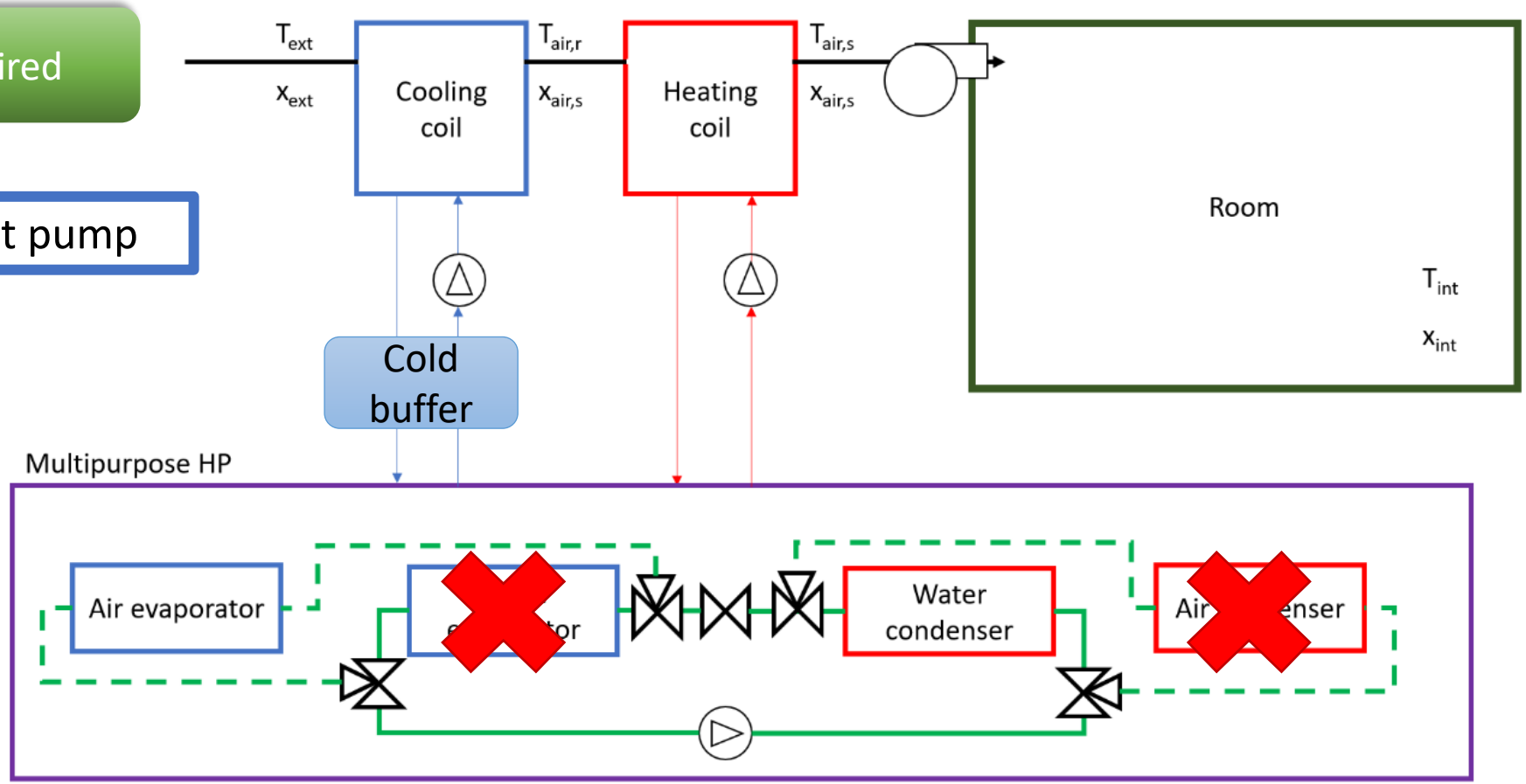


MP-HP model

Heating required

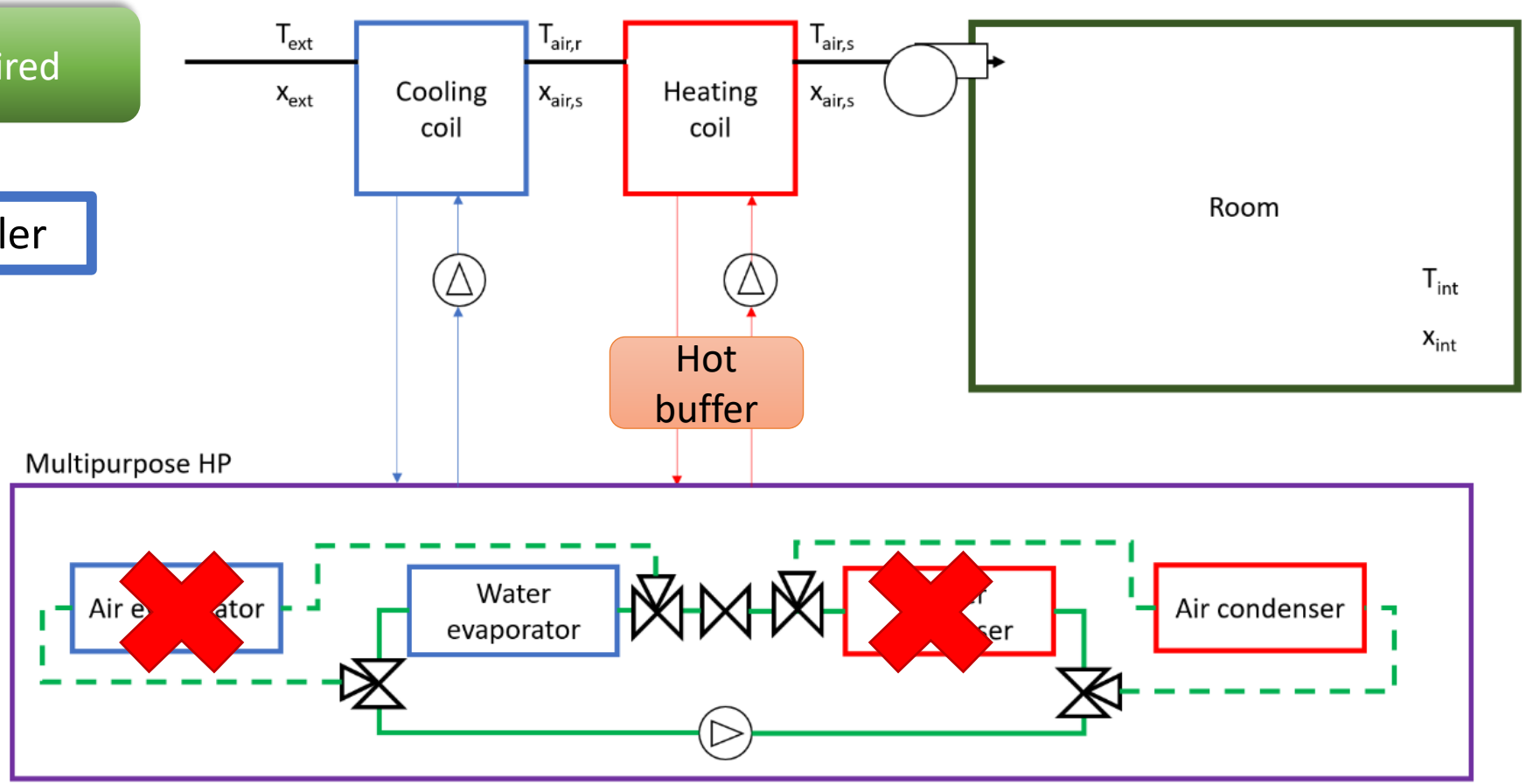
«Classical» heat pump



MP-HP model

Cooling required

«Classical» chiller

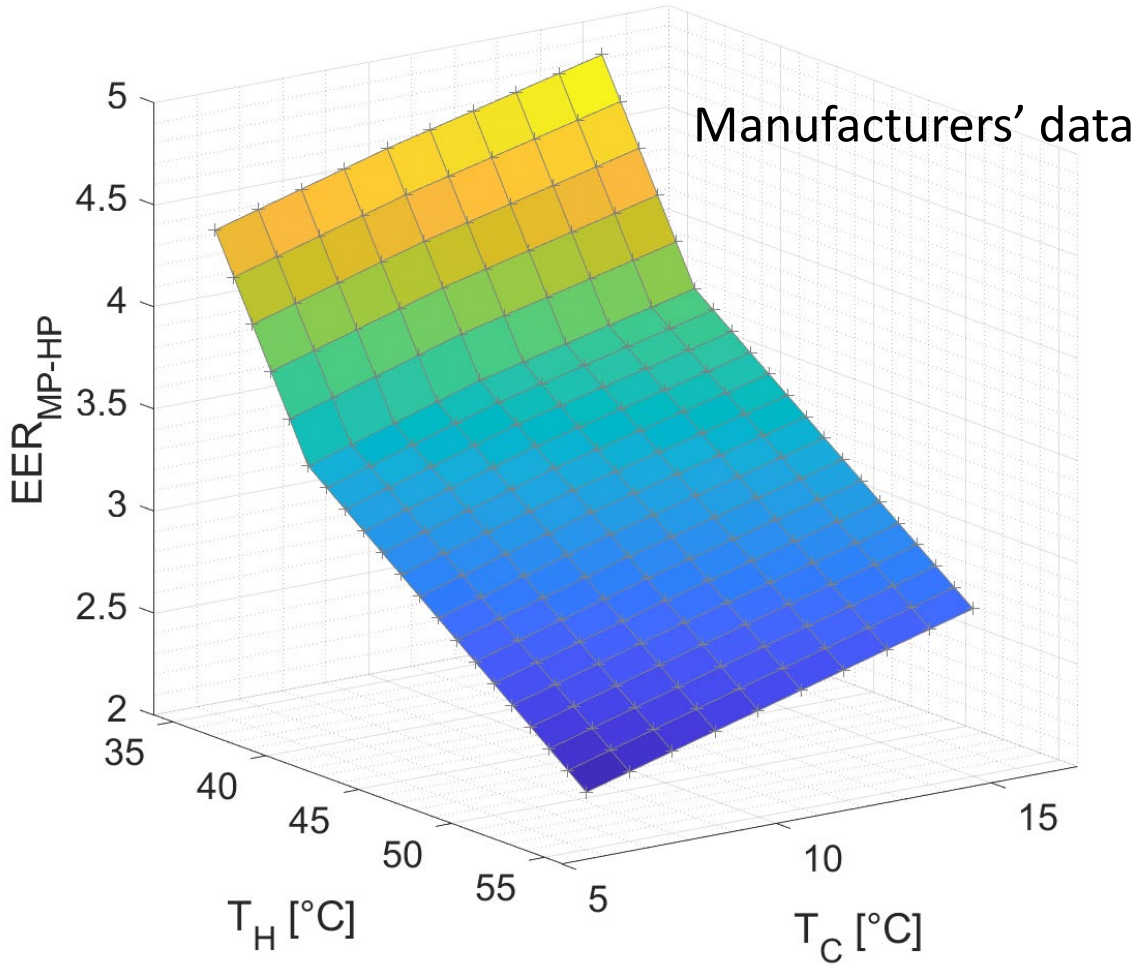


MP-HP model

$$TR = \frac{T_{H,s}+273.15}{T_{C,s}+273.15}$$

$$CR = \frac{\dot{Q}_{C,r}}{\dot{Q}_{C,NOM,MP-HP}}$$

$$EER_{H\&C,MP-HP}(T_{H,s}, T_{C,s}, CR) = [\alpha_0 + \alpha_1 \times TR + \alpha_2 \times CR + \alpha_3 \times TR^2 + \alpha_4 \times TR \times CR] \times \left(\frac{T_{C,s}+273.15}{T_{H,s}-T_{C,s}}\right)$$



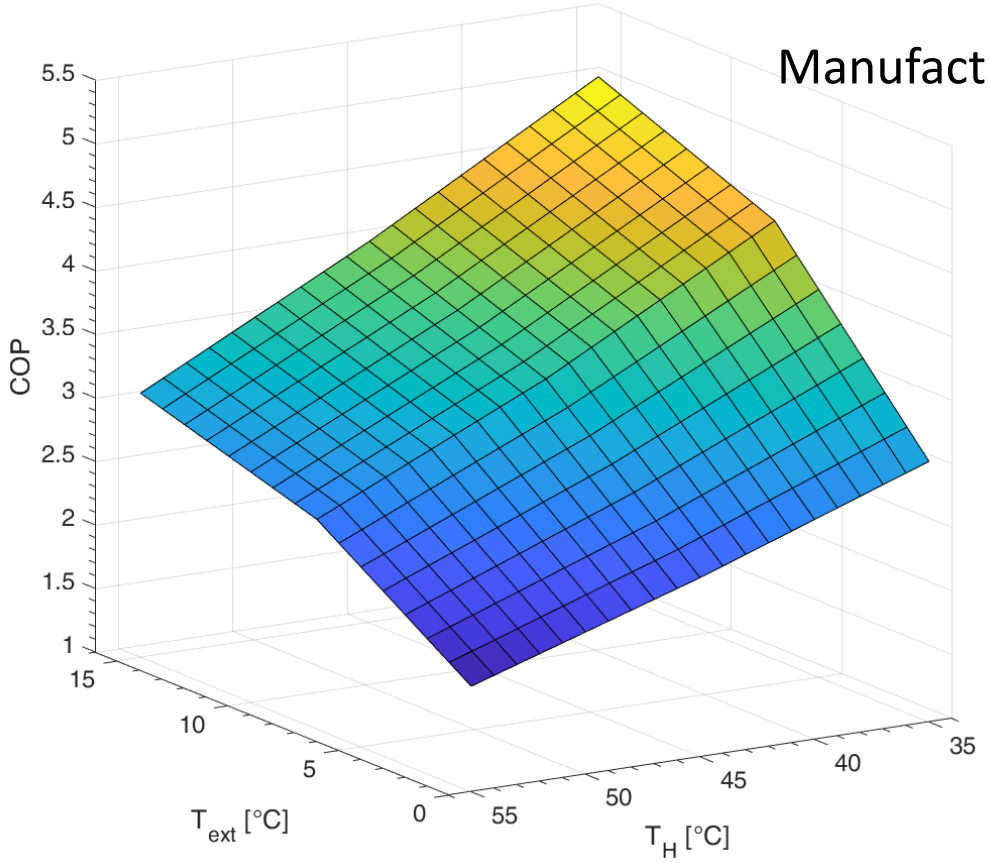
MP-HP in «Heating only» mode & HP model

$$TR = \frac{T_{H,s}+273.15}{T_{ext}+273.15}$$

$$CR = \frac{\dot{Q}_{H,r}}{\dot{Q}_{H,NOM}}$$

$$COP_H(T_{H,s}, T_{ext}, CR) = [\alpha_0 + \alpha_1 \times TR + \alpha_2 \times CR + \alpha_3 \times TR^2 + \alpha_4 \times TR \times CR] \times \left(\frac{T_{H,s}+273.15}{T_{H,s}-T_{ext}}\right)$$

Manufacturers' data



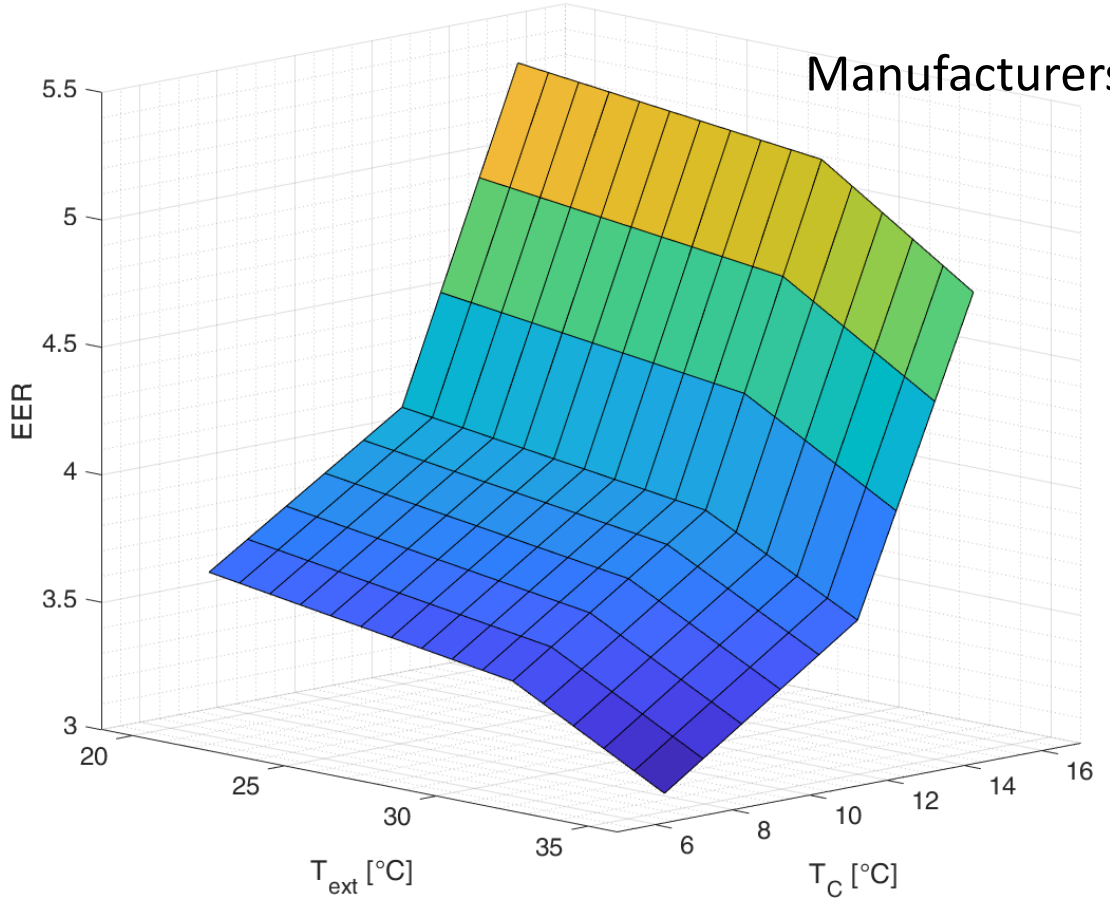
MP-HP in «Cooling only» mode & Chiller model

$$TR = \frac{T_{ext}+273.15}{T_{C,s}+273.15}$$

$$CR = \frac{\dot{Q}_{C,r}}{\dot{Q}_{C,NOM}}$$

$$EER_C\left(T_{ext}, T_{C,s}, CR\right) = [\alpha_0 + \alpha_1 \times TR + \alpha_2 \times CR + \alpha_3 \times TR^2 + \alpha_4 \times TR \times CR] \times \left(\frac{T_{C,s}+273.15}{T_{ext}-T_{C,s}}\right)$$

Manufacturers' data

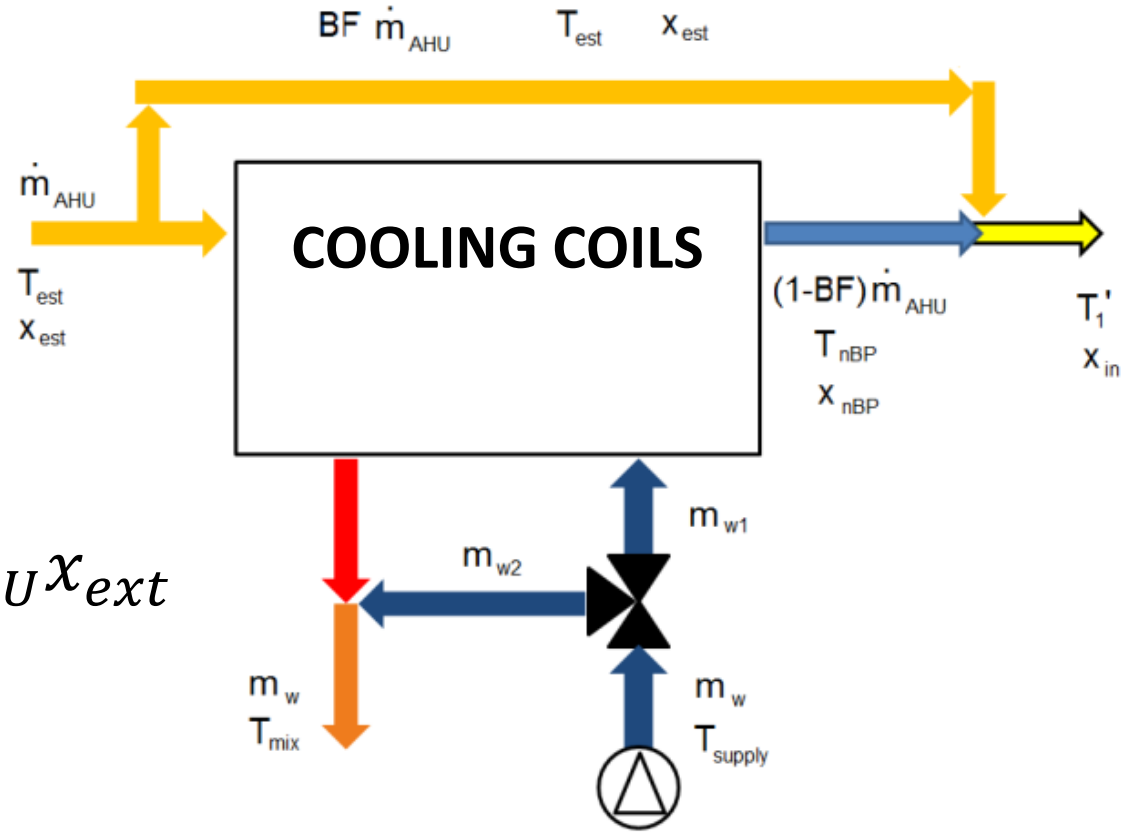


Regression coefficients for the polynomial fitting

	α_1	α_2	α_3	α_4	α_5
$EER_{H\&C,MP-HP}$	-13.46	24.56	0.65	-10.78	-0.72
EER	-45.8	83.39	1.57	-37.58	-1.57
COP	-20.15	36.86	-0.40	-16.49	0.31

AHU modeling

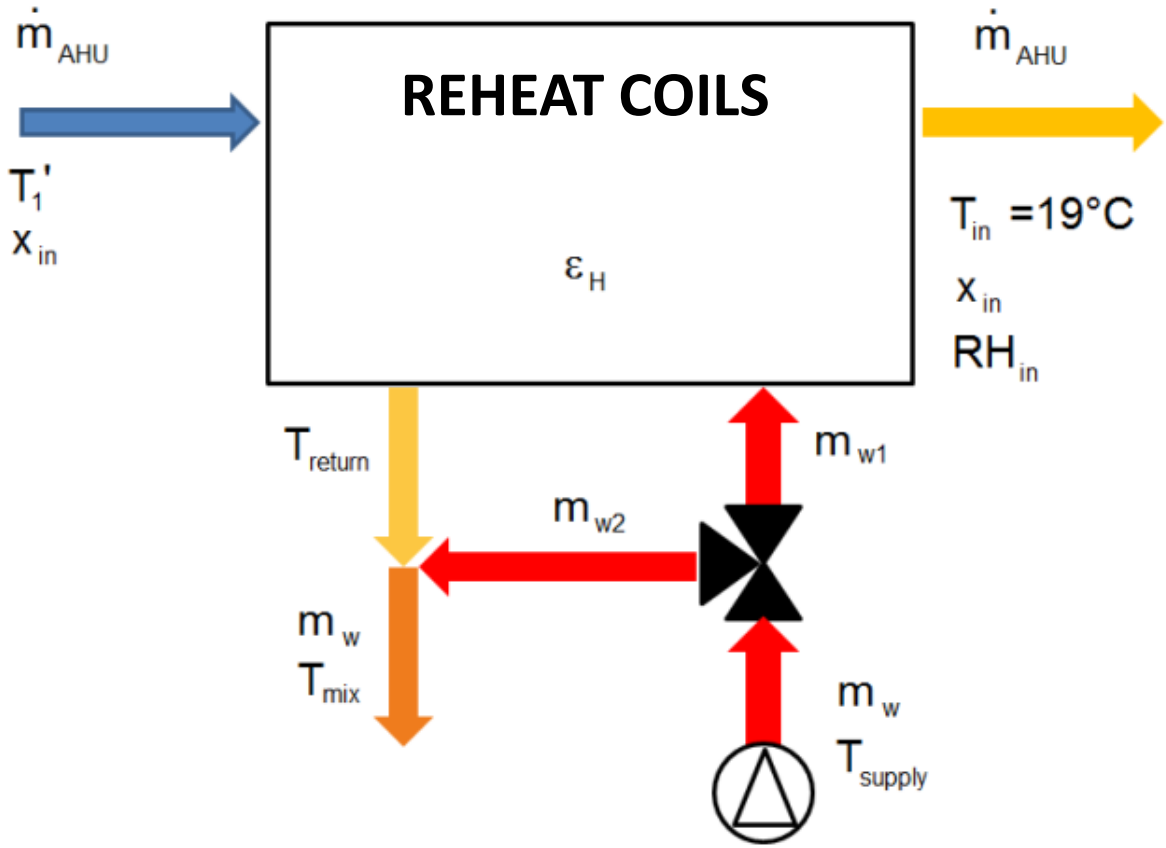
- Bypass factor method
- BF=0.05 (experimental data)



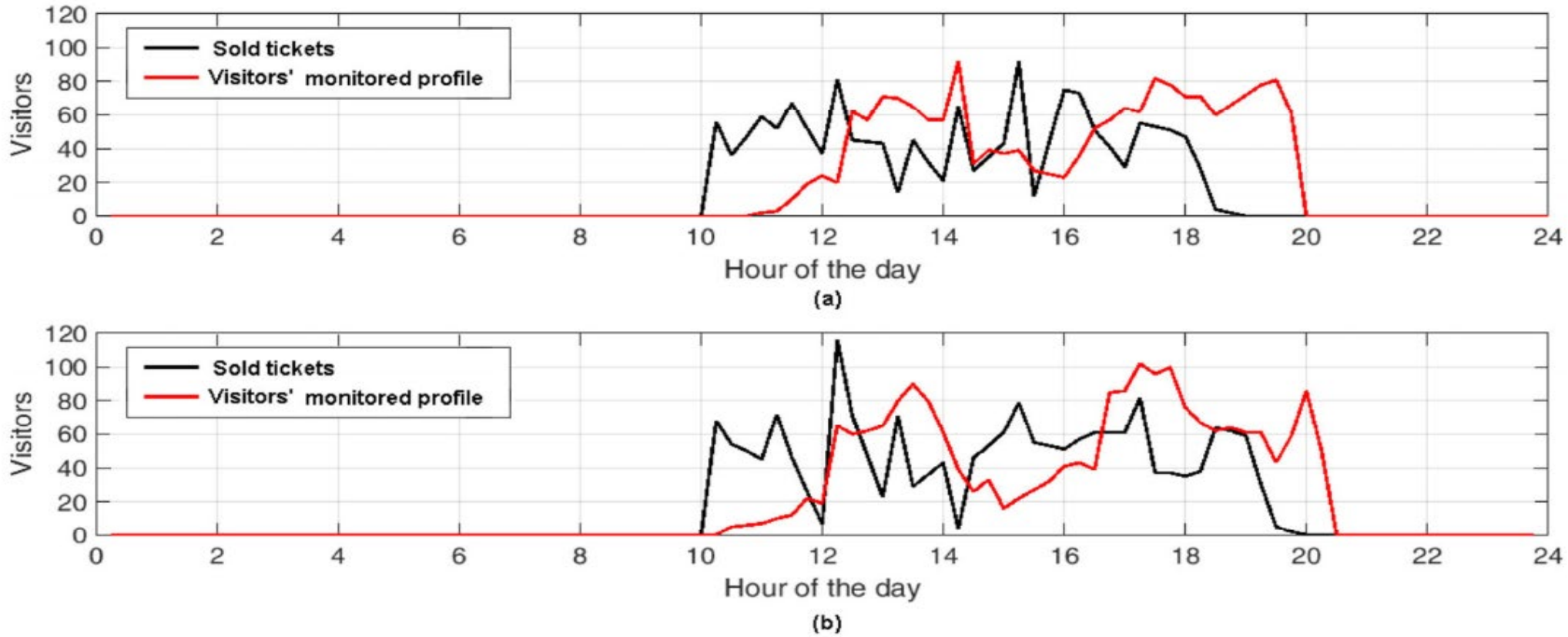
$$(1 - BF)\dot{m}_{AHU}x_{nBP} + BF\dot{m}_{AHU}x_{ext} = \dot{m}_{AHU}x_{in}$$

AHU modeling

- ϵ-NTU method for cross-flow heat exchanger



Visitors' model



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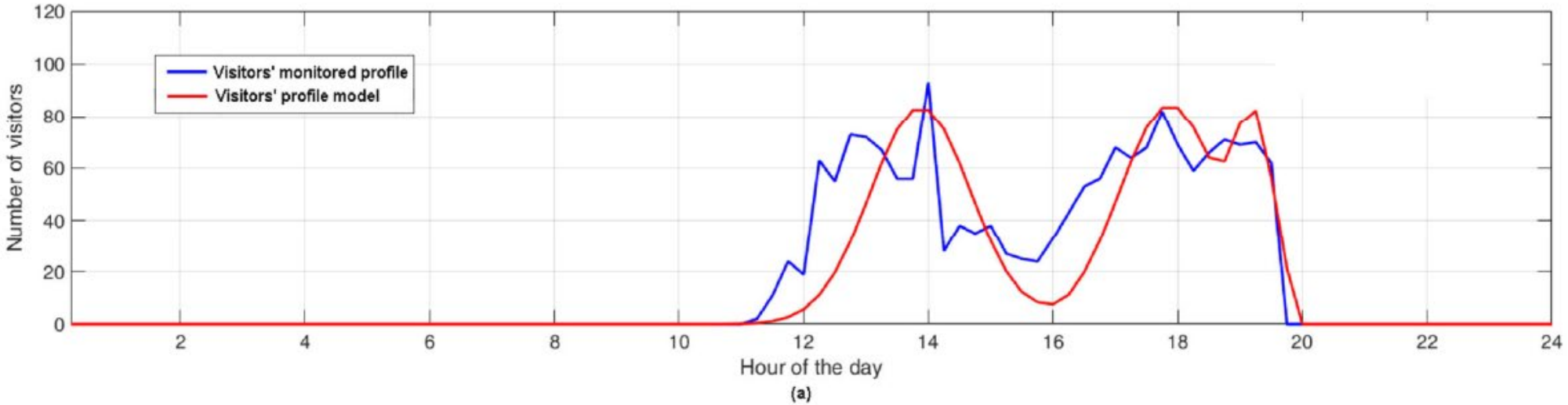

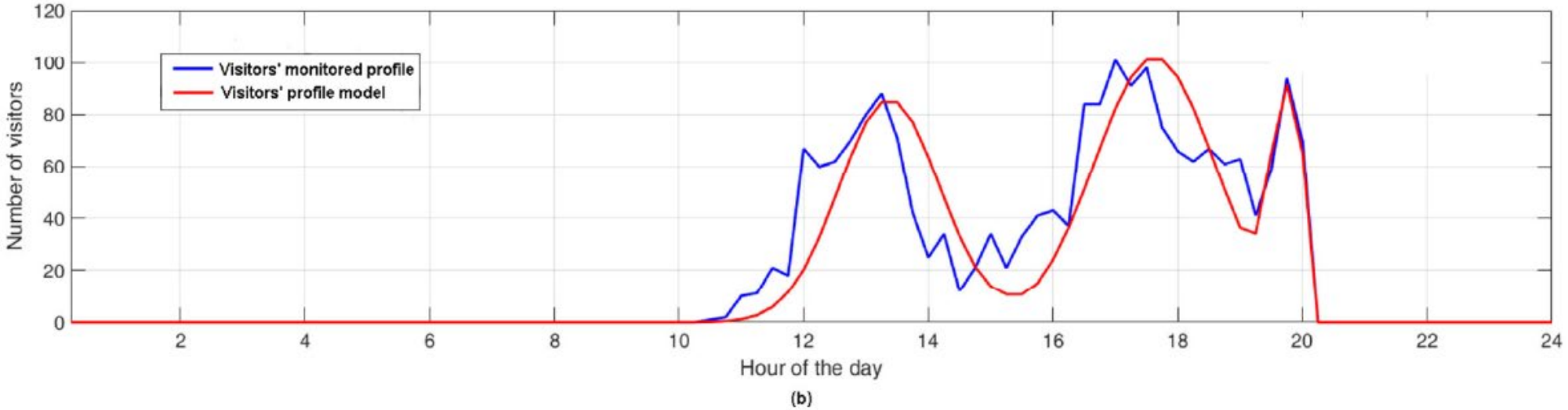

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Share of cooling load provided in «H&C» mode [%]	47	NA
Share of heating load provided in «H&C» mode [%]	92	NA

- Lower performance of MP-HP in "separate" modes
- Working in "H&C" mode for the majority of time

Comparison MP-HP vs SC