Exergy analysis of cooling systems and strategies

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Relevance

- The demand for ventilation and cooling of buildings is an increasing share of Europe's total energy use in buildings

- The performance of HVAC systems is usually evaluated based on the first law of thermodynamics. Exergy-optimized systems make use of low temperature differences, which makes it possible to put to use renewable sources.

- Aim of this paper is to show the potential for optimization of three hybrid cooling systems

- This potential is addressed performing an exergy analysis of the cooling demand of a generic office building and of three supply systems, which use chillers in conjunction with evaporative cooling

Building model

Office building

Floor area : 1200 m^2
Walls area: 500 m^2, U-value of 0.15 $W/(m^2\ K)$
Windows area : 250 m^2, U-value 1 $W/(m^2\ K)$
Internal loads: 10 W/m^2
External loads: 15 W/m^2
Set-point temperature, indoor environment : 26 °C
Outdoor temperature: 30°C

Reference conditions

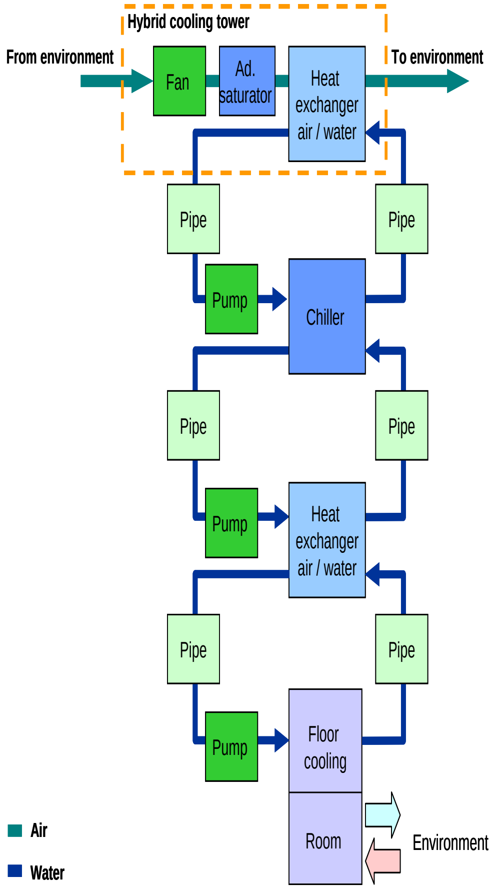
Environment temperature: 30 °C
Environment pressure : 110 kPa.
Humidity ratio: 0.01 kg_w/kg_a, RH= 40%.

Calculation of the cooling load, steady-state

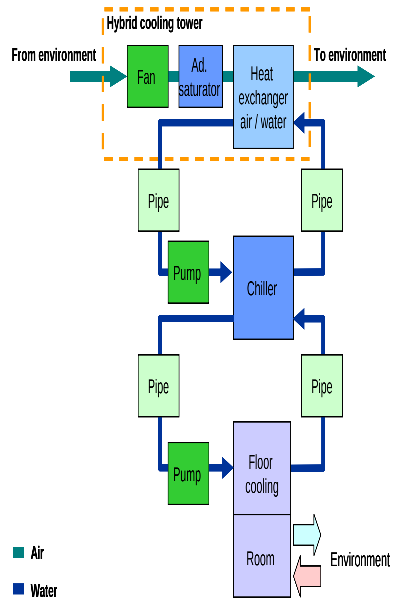
$$Q_{cooling} = U_{windows}A_{windows}(T_{in}-T_{out})+U_{walls}A_{walls}(T_{in}-T_{out})+Q_{int}+Q_{ext}$$

The obtained cooling load has been in all the three cases 31,500 W, delivered cooling power : 26 W/m^2

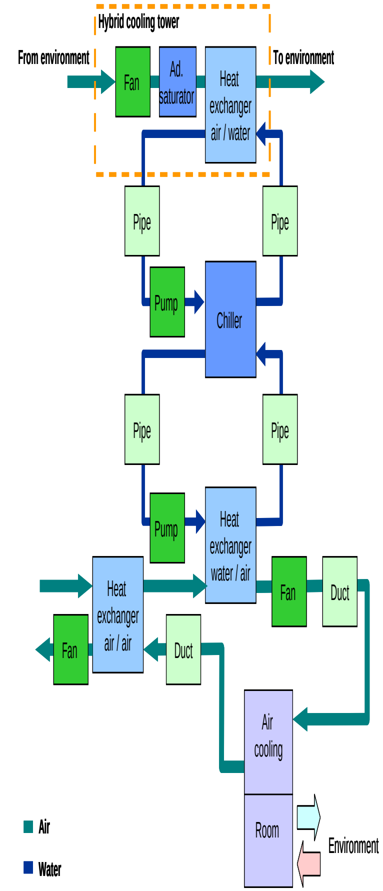
Cooling systems description



System 1

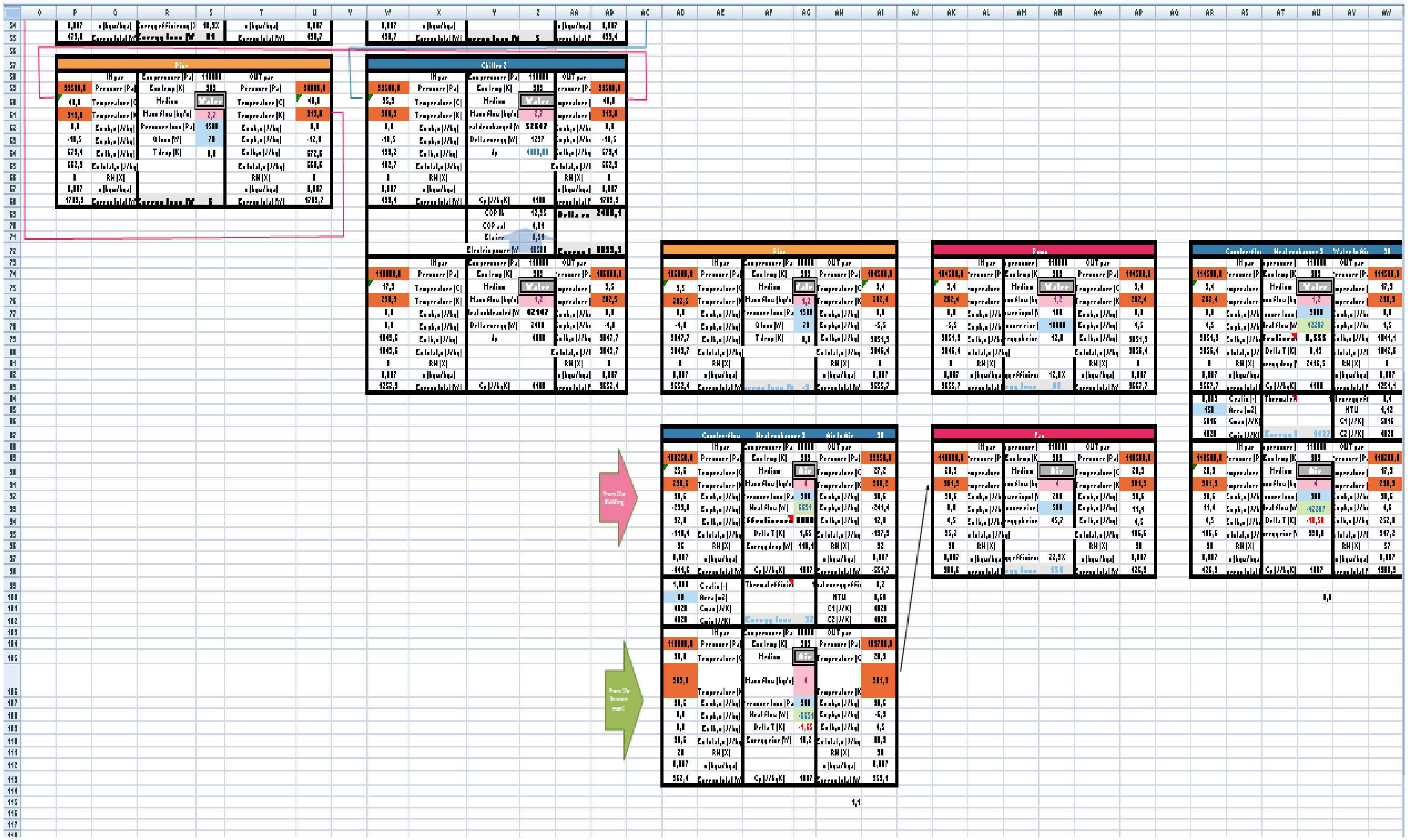


System 2

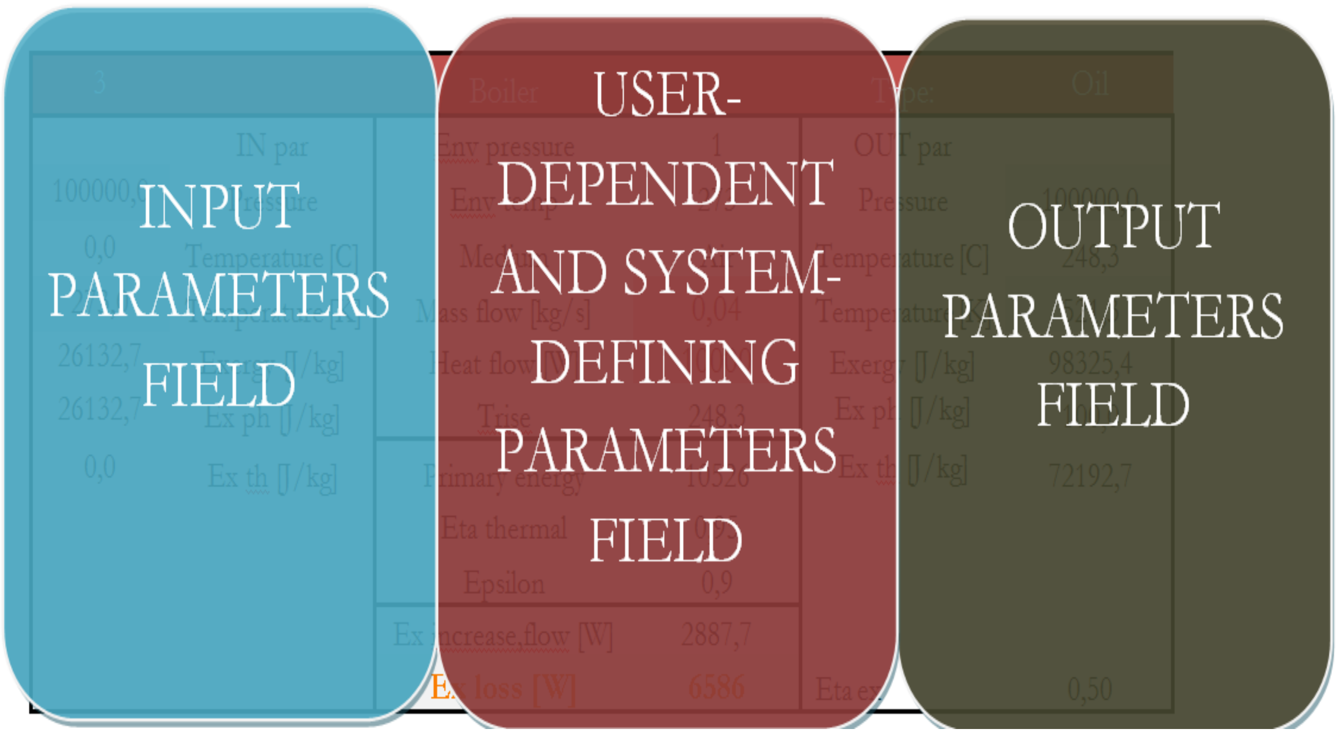


System 3

Software tool: SEPE



Components


INPUT PARAMETERS FIELD
USER-DEPENDENT AND SYSTEM-DEFINING PARAMETERS FIELD
OUTPUT PARAMETERS FIELD

Nodes description

Chiller

	IN par	Env pressure [Pa]	110000	OUT par	
99500,0	Pressure [Pa]	Env temp [K]	303	Pressure [Pa]	99500,0
38,1	Temperature [C]	Medium	Water	emperature [C	41,5
311,1	Temperature [K]	Mass flow [kg/s]	2,5	emperature [K	314,5
0,0	Ex ch,s [J/kg]	Heat descharged [W]	35186	Ex ch,s [J/kg]	0,0
-10,5	Ex ph,s [J/kg]	Delta exergy [W]	1105	Ex ph,s [J/kg]	-10,5
449,2	Ex th,s [J/kg]	dp	4000,00	Ex th,s [J/kg]	891,1
438,7	Ex total,s [J/kg]			Ex total,s [J/kg	880,6
0	RH [%]			RH [%]	0
0,007	x [kgw/kga]			x [kgw/kga]	0,007
1096,7	Exergy total [W]	Cp [J/kgK]	4180	xergy total [W	2201,4
		COP th	16,04	Delta exergy	1023,7
		COP act	8,02		
		Eta irr	0,5		
		Electric power [W]	3900	Exergy loss ['	2876,3

	IN par	Env pressure [Pa]	110000	OUT par	
100000,0	Pressure [Pa]	Env temp [K]	303	Pressure [Pa]	96000,0
22,1	Temperature [C]	Medium	Water	emperature [C	18,5
295,1	Temperature [K]	Mass flow [kg/s]	2,1	emperature [K	291,5
0,0	Ex ch,s [J/kg]	Heat subtracted [W]	31286	Ex ch,s [J/kg]	0,0
-10,0	Ex ph,s [J/kg]	Delta exergy [W]	1024	Ex ph,s [J/kg]	-14,0
437,1	Ex th,s [J/kg]	dp	4000	Ex th,s [J/kg]	928,6
427,1	Ex total,s [J/kg]			Ex total,s [J/kg	914,6
0	RH [%]			RH [%]	0
0,007	x [kgw/kga]			x [kgw/kga]	0,007
896,9	Exergy total [W]	Cp [J/kgK]	4180	xergy total [W	1920,6

Pipe

	IN par	Env pressure [Pa]	110000	OUT par	
96000,0	Pressure [Pa]	Env temp [K]	303	Pressure [Pa]	94500,0
18,5	Temperature [C]	Medium	Water	Temperature [C]	18,5
291,5	Temperature [K]	Mass flow [kg/s]	2,1	Temperature [K]	291,5
0,0	Ex ch,s [J/kg]	Pressure loss [Pa]	1500	Ex ch,s [J/kg]	0,0
-14,0	Ex ph,s [J/kg]	Q loss [W]	0	Ex ph,s [J/kg]	-15,5
928,6	Ex th,s [J/kg]	T drop [K]	0,0	Ex th,s [J/kg]	928,6
914,6	Ex total,s [J/kg]			Ex total,s [J/kg]	913,1
0	RH [%]			RH [%]	0
0,007	x [kgw/kga]			x [kgw/kga]	0,007
1920,6	Exergy total [W]	Exergy loss [W]	3	Exergy total [W]	1917,4

-AdSat-Fc | 2 Ch-AdSat-Fc | 3 Ch-AdSat-AHU

Exergy calculations

$$Ex_{,spec} = f(T, T_0, P, P_0, \omega, \omega_0)$$

$$Exergy\ flow_i = \dot{m} \bullet ex_{spec}$$

$$\Delta Exergy\ flow =$$

$$= Exergy\ flow_{i+1} - Exergy\ flow_i$$

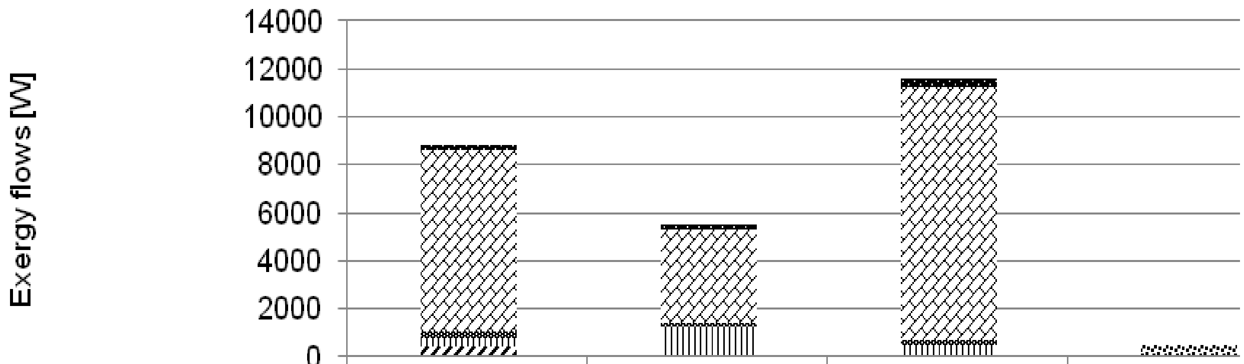
$$Ex_{spec} = Ex_{th} + Ex_{pr} + Ex_{ch}$$

$$Ex_{th} = c_p \left[(T - T_0) - T \ln \frac{T}{T_0} \right]$$

$$Ex_{pr} = T_0 R \ln \frac{P}{P_0}$$

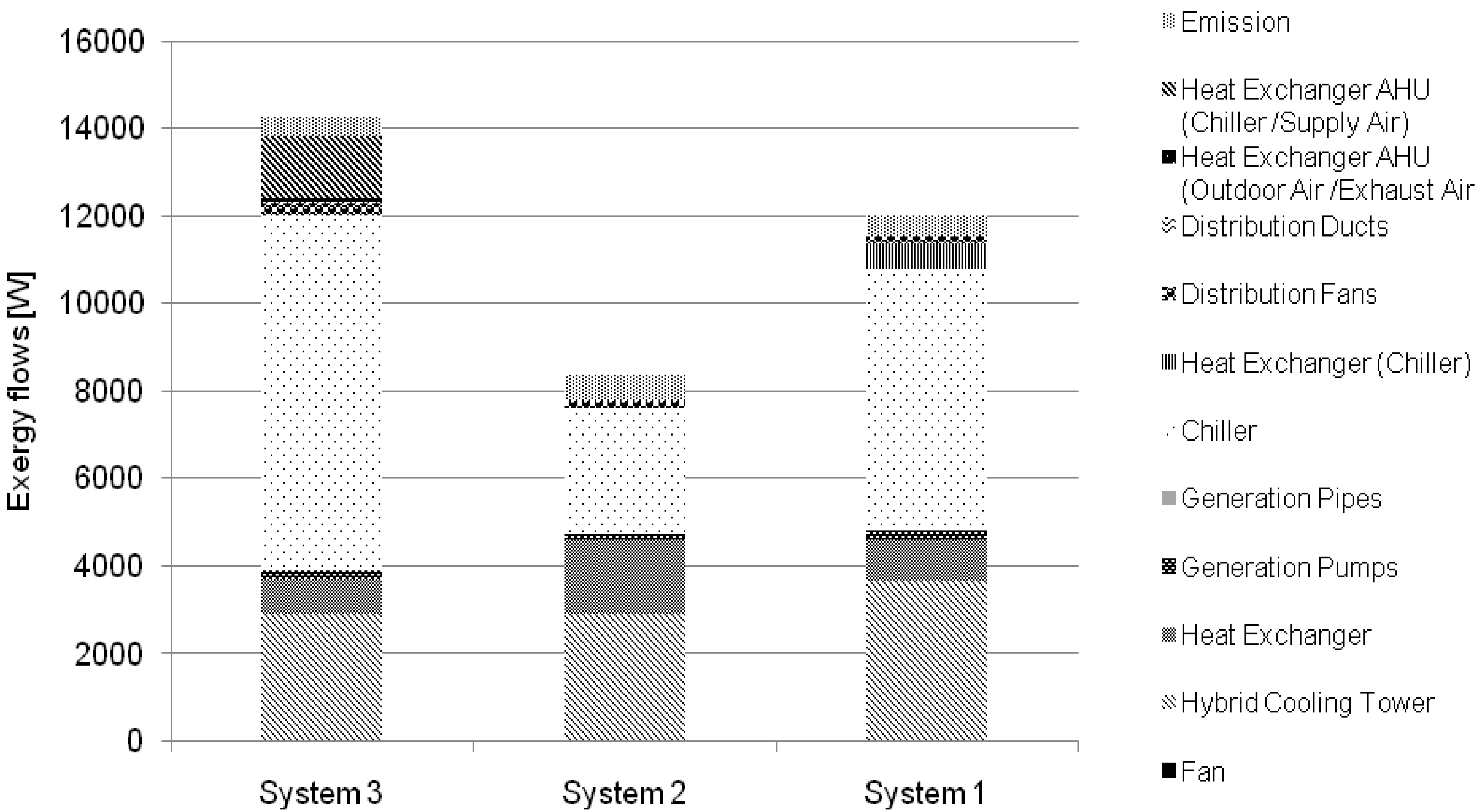
$$Ex_{ch} = R\,T_0 \left(1 + 1.608\omega_i \ \ln\left(\frac{1 + 1.608\omega_0}{1 + 1.608\omega_i}\right) + 1.608\omega_i \ln\left(\frac{\omega_i}{\omega_0}\right) \right)$$

Exergy supply and demand of the analyzed systems



	System 1	System 2	System 3	Building demand
Building demand				460
Distribution pumps/fans	200	200	400	
Chiller	7600	3900	10500	
Generation pumps	250	150	200	
Hybrid cooling tower	400	1100	375	
Hybrid cooling tower fan	400	150	150	

Exergy losses in the cooling systems



Conclusions

- All three systems have a low exergy efficiency. The exergy demand for the building is low.
- The main losses occur in the generation systems, chillers and hybrid cooling tower, and in the heat exchangers.
- The system with the highest exergy efficiency in the analysis is the System 2.
  - Water: lower temperature difference
  - No heat exchanger
- Direct distribution of the chiller output to the emission system doubles the exergy efficiency in comparison with a system where an intermediate heat exchanger is necessary.
- Exergy potential in the outdoor air at mid European humidity conditions: for System 2, the exergy gained from the outdoor air is in the level of the losses from the chiller.

References

- Karlström, Petra, and Gudni Jóhannesson. "A general procedure to model the exergy performance of hybrid HVAC systems in buildings." *Bausim 2006.*
- Molinari, Marco. ”SEPE: an excel calculation tool for exergy-based optimizations.” *ECBCS Annex 49 Newsletter 6*, 2009.
- Molinari, M. 2009. A pressure and thermal exergy analysis of a waterborne and an airborne system, Proceedings of the 15th „Building Services, Mechanical and Building Industry Days” International Conference, Debrecen.

Aknowledgements

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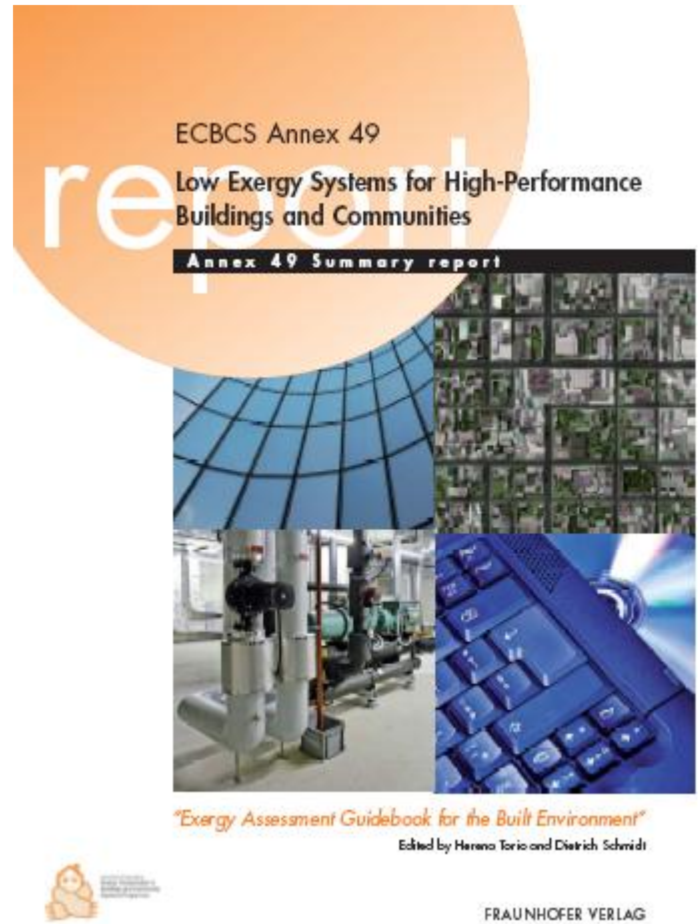

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Thank you for your attention!