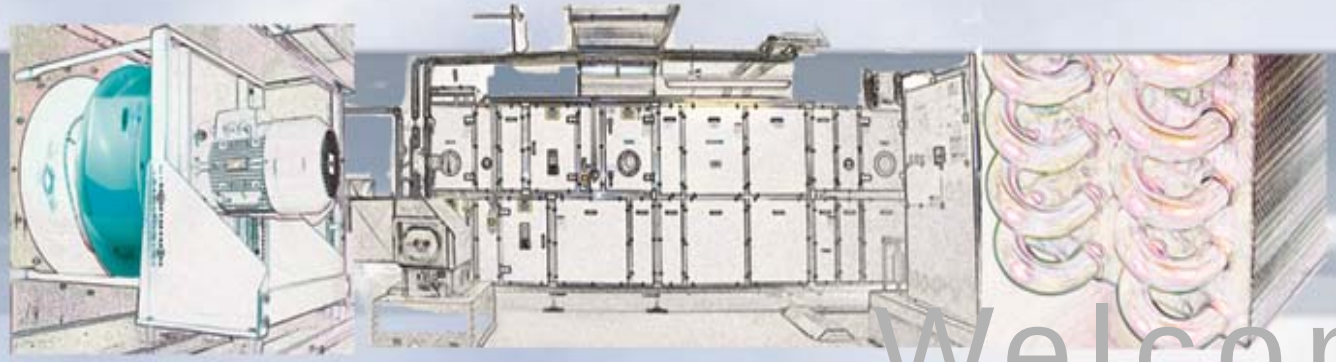
Willkommen



Welcome

Bienvenue

Heatrecovery in Europe

Economic and environmental study 2019

Prof. Dr.-Ing. **Christoph Kaup**
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UNIKASSEL VERSITÄT

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld
Umwelt macht Karriere.

Statistics for germany

HOCHSCHULE TRIER
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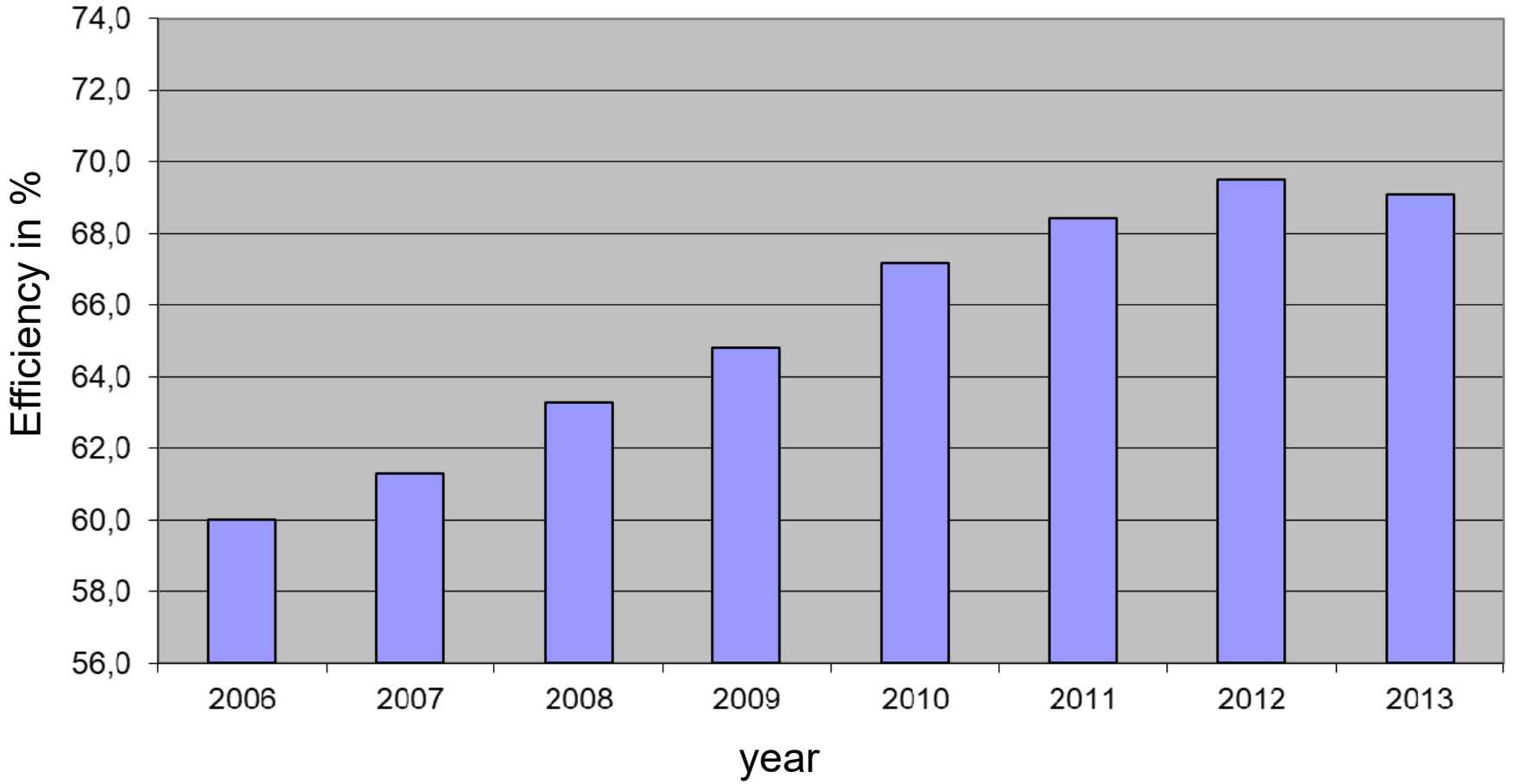
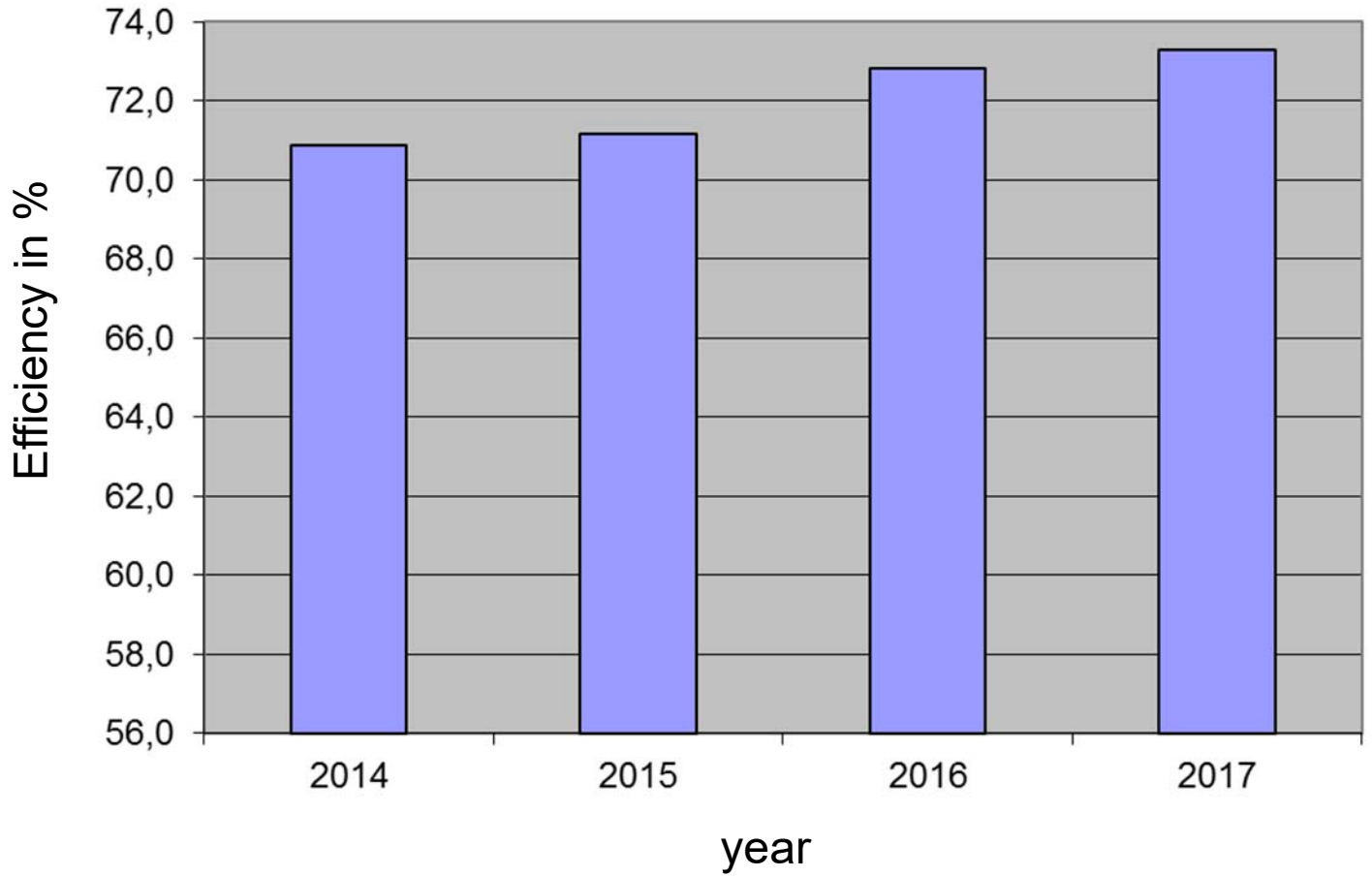


heatrecovery efficiency 2006 to 2013

Statistics for germany



heatrecovery efficiency 2014 to 2017

Statistics for germany

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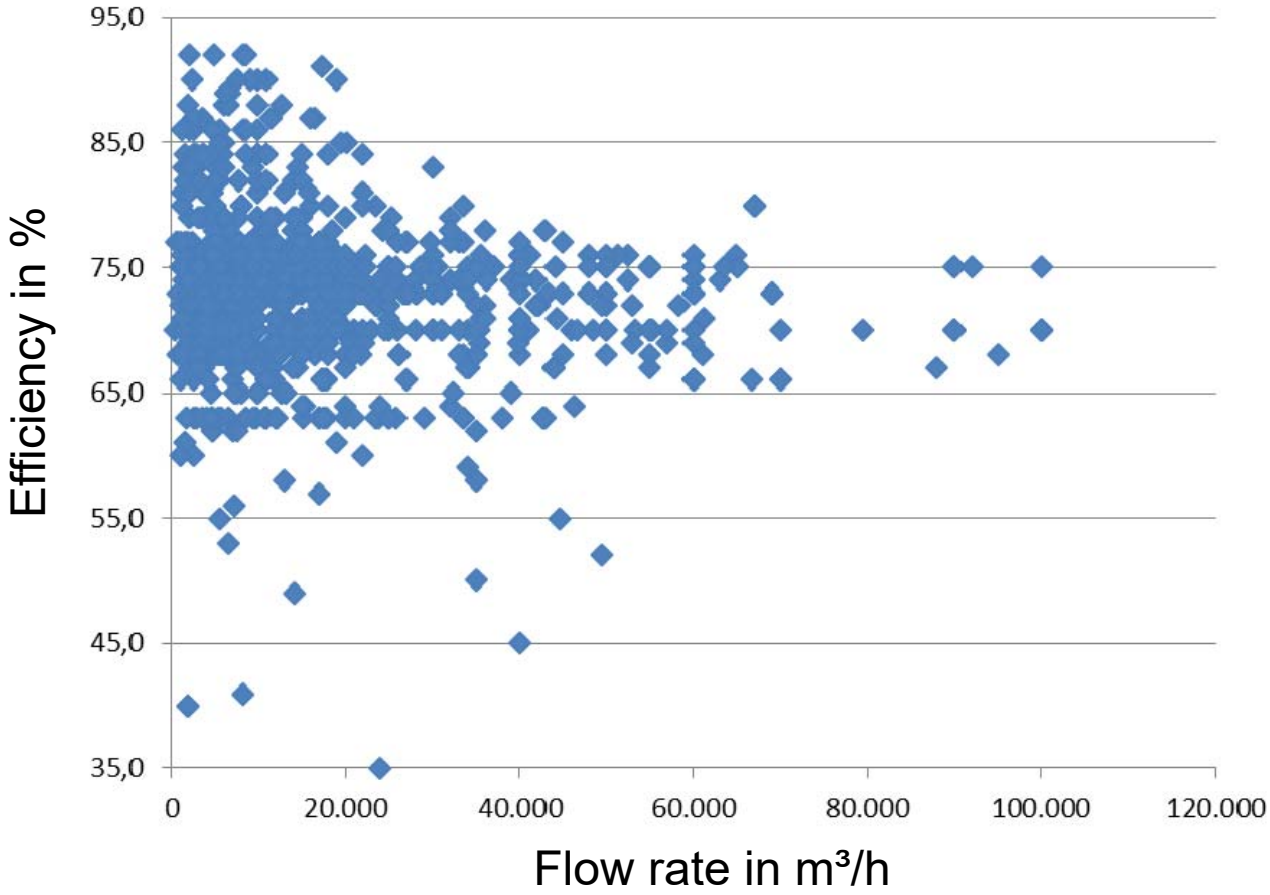
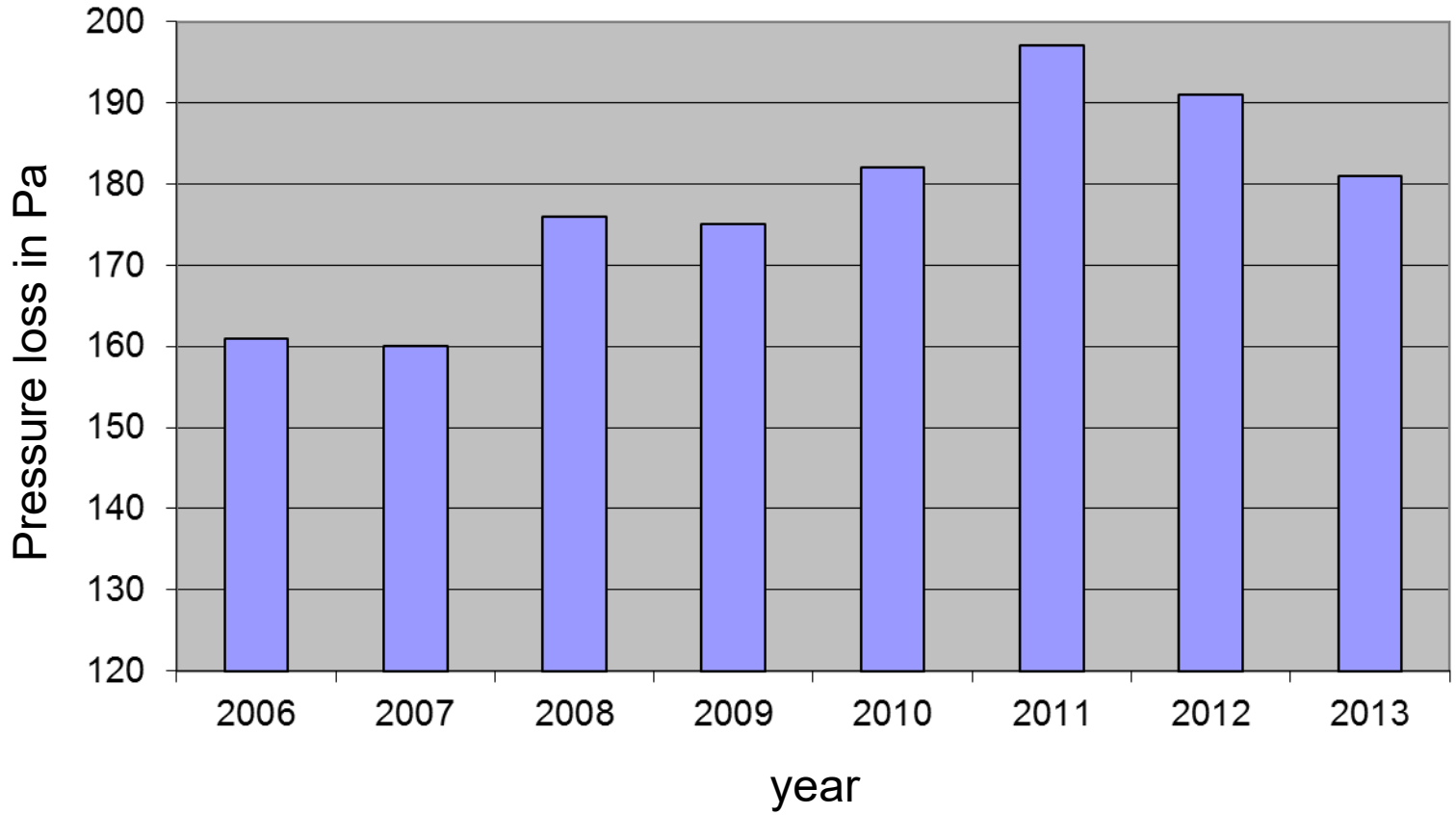


heatrecovery efficiencies 2016

Statistics for germany



heatrecovery pressure losses 2006 to 2013

Statistics for germany

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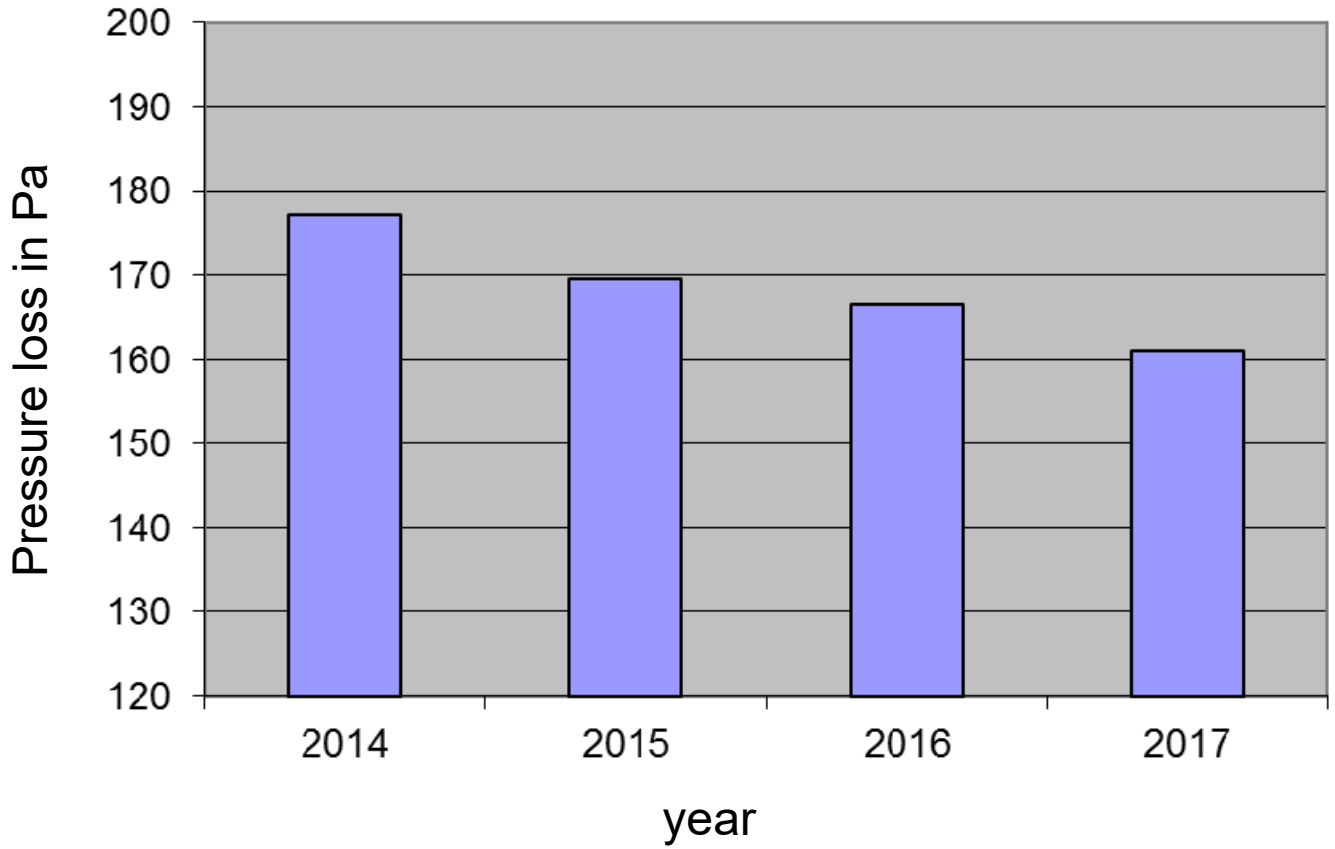
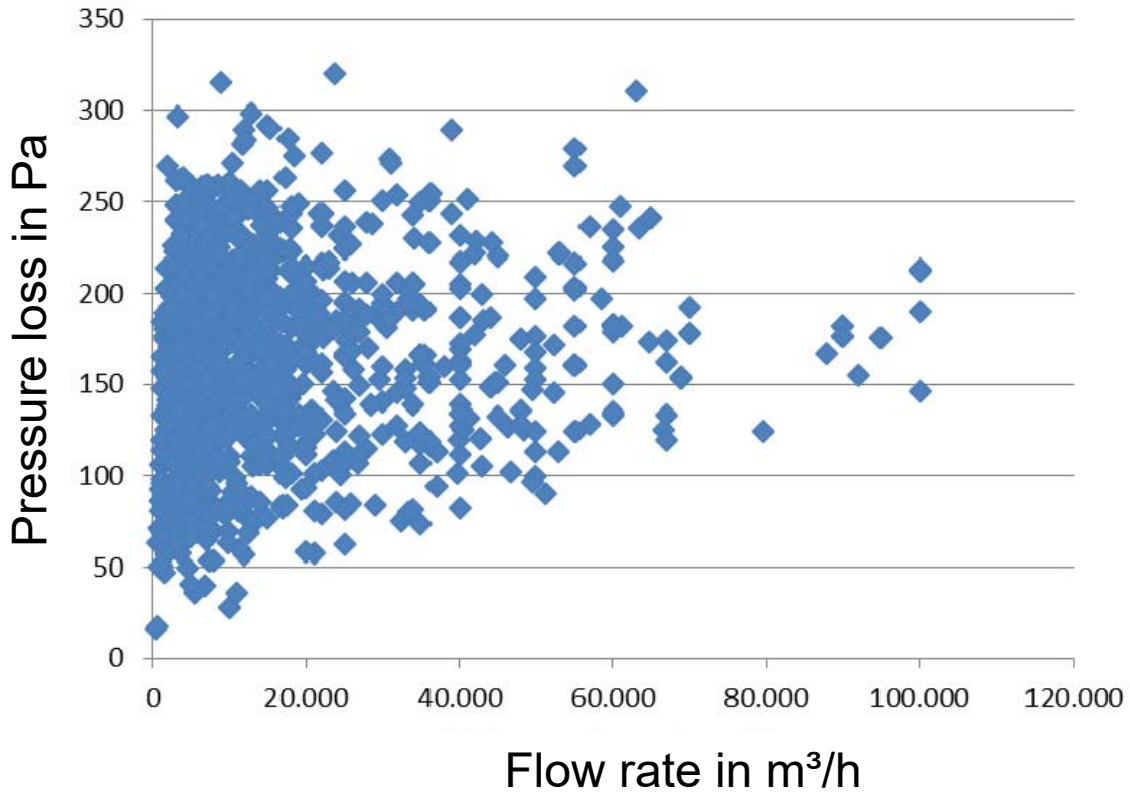


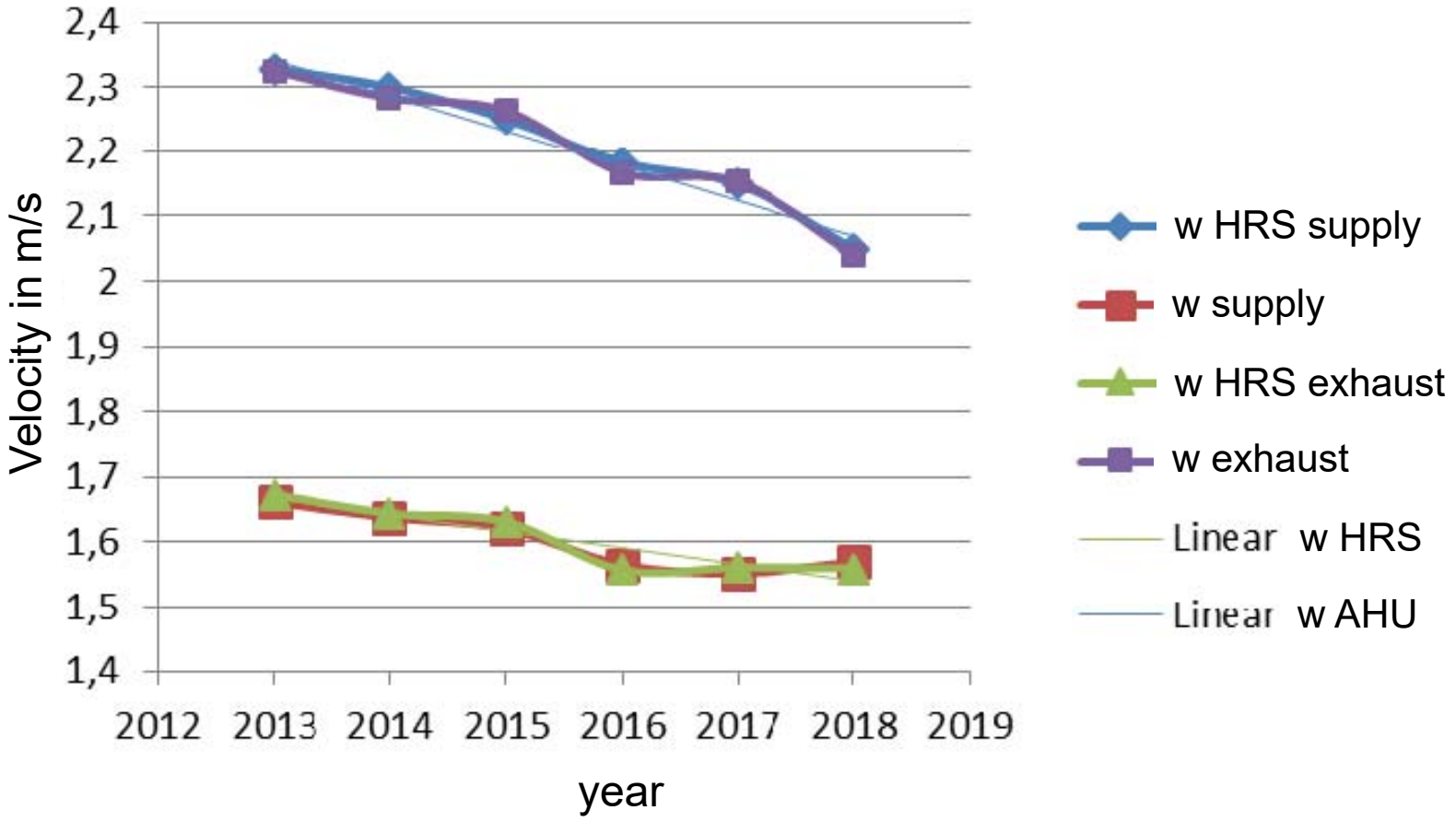
heatrecovery pressure losses 2014 to 2017

Statistics for germany



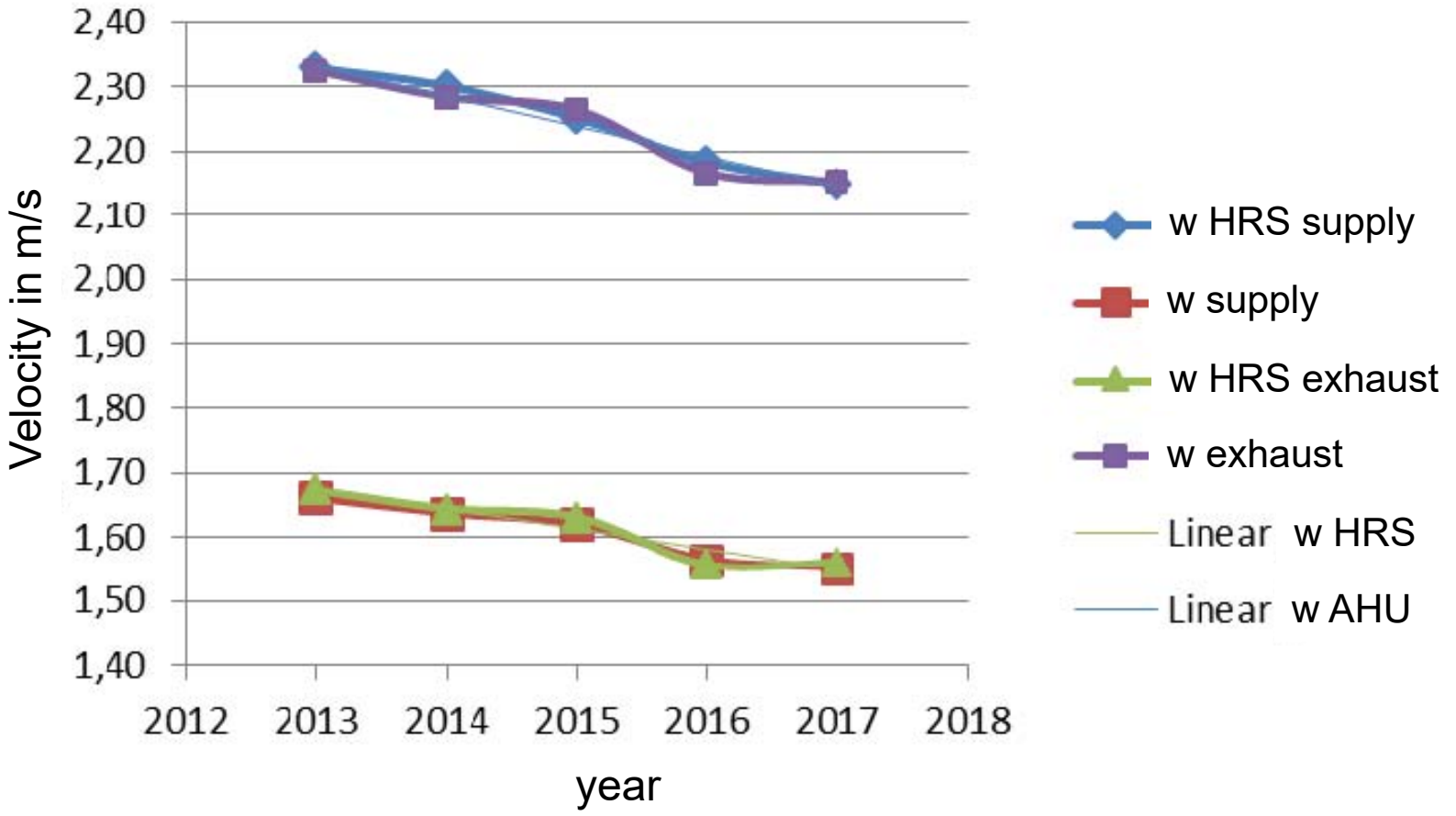
heatrecovery pressure losses 2016

Statistics for germany



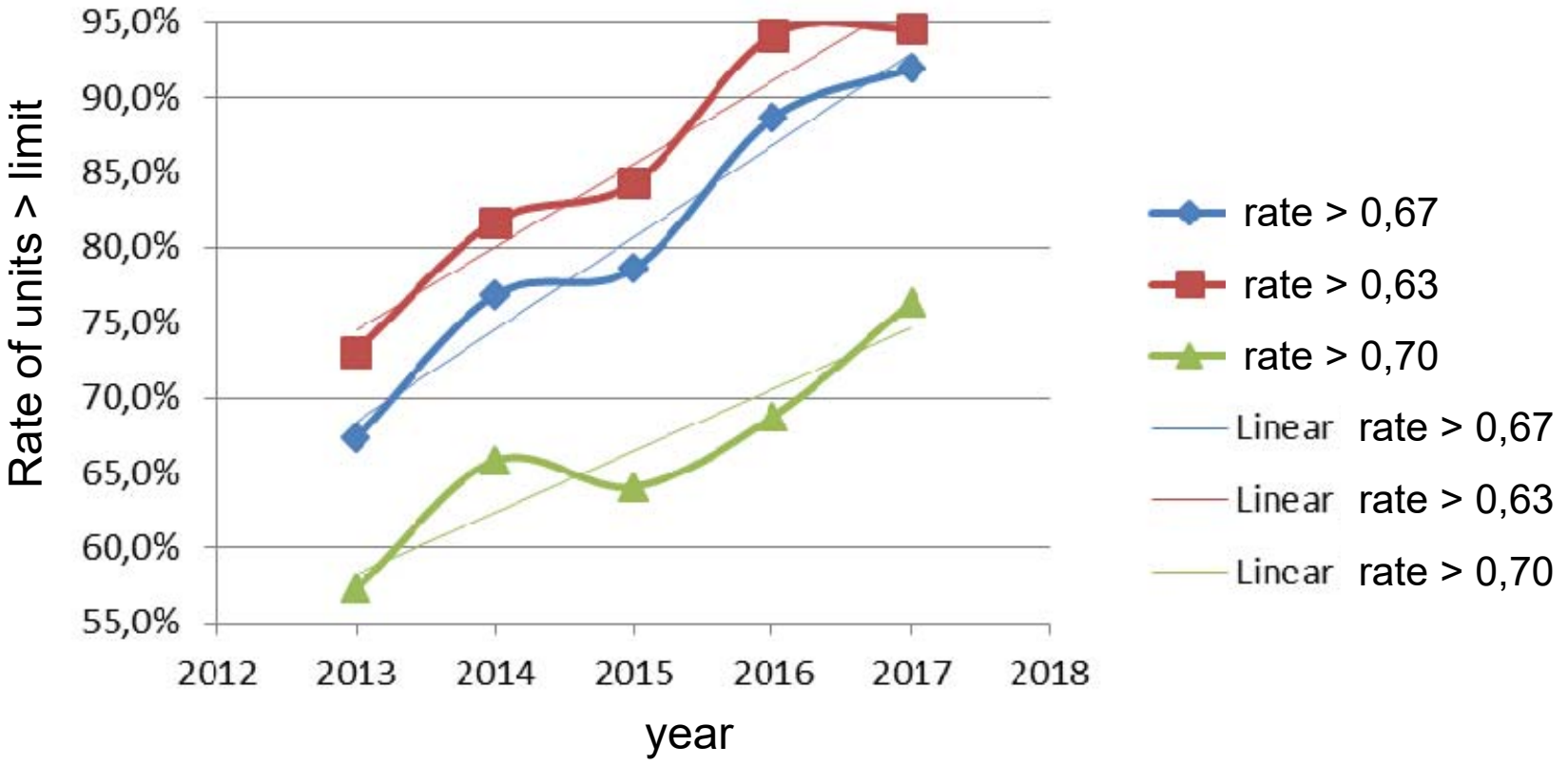
air velocities (units and heat recovery)

Statistics for germany



air velocities (units and heat recovery)

Statistics for germany



rate of selections

RLT P_{el} in NWG in Deutschland

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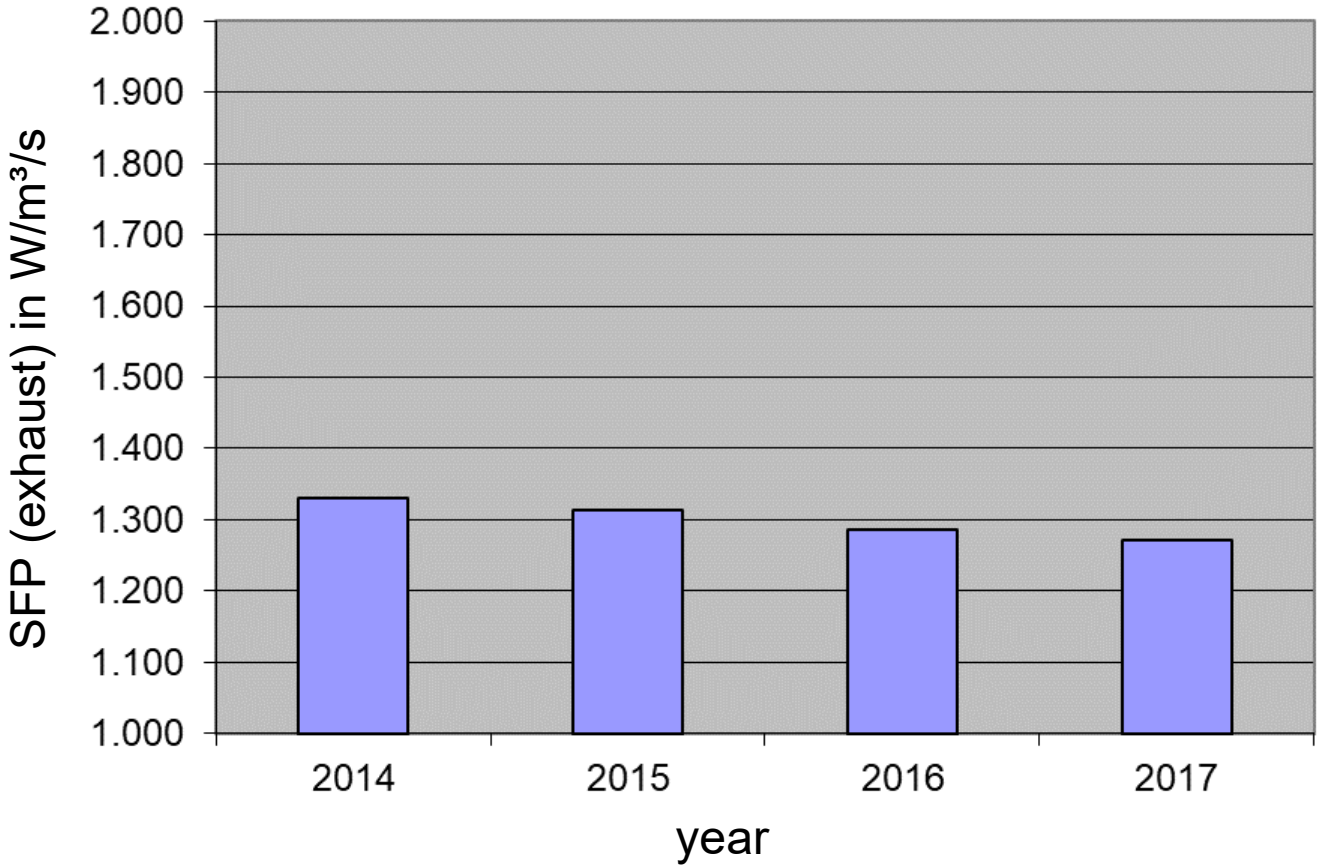

development of SFP exhaust

Simulation base values

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Boundary conditions

- Approx. 3.300 units where analyzed
- Real units from 2015 to 2015
- Calculated with project related values
- Simulated with general values like:
  - costs of heating 0,043 €/kWh (average EU 28 from 2008 to 2017 without VAT)
  - costs of cooling 0,041 €/kWh (average EU 28 from 2008 to 2017 without VAT)
  - electro costs 0,091 €/kWh (average EU 28 from 2008 to 2017 without VAT)
  - interest rate 2,4 % (average from 2008 to 2017)
  - price increase rate 1,7 % (average from 2008 to 2017)
  - life span 15 a
  - exhaust temperature 20°C (winter) and 26°C (summer)
  - supply air temperature 20°C
  - load at day time 100 % and 50 % during night time and partload (70 % / 40 %)
  - running hours between 2.350 and 8.760 h/a
  - 3 locations in Europe acc. Meteonorm 7.1 (Lissabon / Helsinki and Mannheim)

Heat prdoction in germany

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

		Emission	rate germany		costs	
electricity	germany	**0,520**				
	EU 15	**0,460**		https://www.kea-bw.de/service/emissionsfaktoren/		
		kg/kWh	%	kg/kWh	€/kWh	€/kWh
Heating	oil	0,315	24,0	0,076	0,091	0,0219
	gas	0,202	46,7	0,094	0,045	0,0210
	district heating	0,341	9,2	0,031	0,101	0,0093
	renewable	0,030	16,7	0,005	0,038	0,0063
	electricity	0,460	1,8	0,008	0,118	0,0021
	carbon	0,429	1,6	0,007	0,080	0,0013
	mix values		100,0	**0,222** kg/kWh		**0,062** €/kWh
Policy officer Delaunoy Oliver				**0,299** kg/kWh	x 1,35	**0,084** €/kWh

Simulation base values

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

eurostat

gas prices (0,043 €/kWh industry or **0,081 €/kWh** incl. VAT - Consumer**)**

Table ▾ Graph ▾ Map ▾

Gas prices by type of user
EUR per gigajoule
This indicator presents the natural gas prices charged to final consumers. Natural gas ... more

indic_en: Medium size industries

geo \ time	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
EU (28 countries)	:	:	8.9300	9.3700	7.9000	8.5300	9.5800	10.5400	9.9800	9.1900	7.6400	7.1100

eurostat

electricity prices (0,091 €/kWh industry or **0,204 €/kWh** incl. VAT - Consumer**)**

Tabelle ▾ Grafik ▾ Karte ▾

Strompreise nach Art des Benutzers
EUR je kWh
Dieser Indikator stellt die Strompreise dar, die den Endverbrauchern in Rechnung gestellt ... Mehr

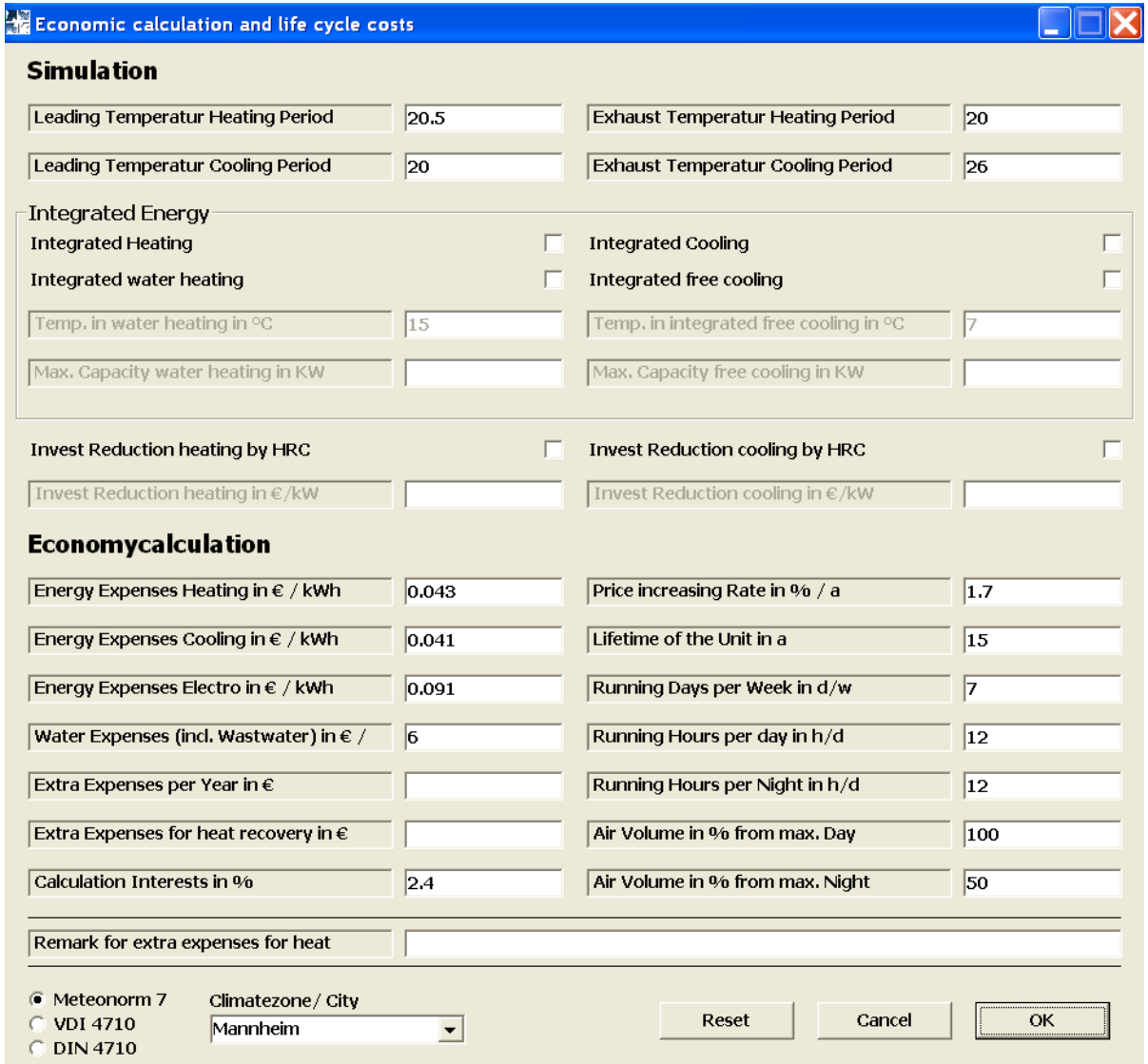
indic_en: Industrielle Unternehmen mittlerer Größe

geo \ time	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
EU (28 Länder)	:	:	0,0875	0,0950	0,0911	0,0926	0,0960	0,0942	0,0924	0,0877	0,0819	0,0788

year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	average
intrest-rate	4,0	3,3	3,4	3,3	3,1	2,3	1,7	1,3	1,0	0,7	**2,4**%
inflation rate EU	3,7	1,0	2,1	3,1	2,6	1,5	0,5	0,0	0,4	1,7	**1,7**%

Simulation Economic calculation

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



Simulation Economic calculation

HOCHSCHULE TRIER
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FA °C	RA °C	ETA %	HRC °C	SA °C	dT °C	Q WRG kW	Q int. kW	Q ext. kW	Status
-10,5	20,0	65,6	9,5	20,5	20,0	99,2	54,6	0,0	I
-9,5	20,0	67,8	10,5	20,5	20,0	99,2	49,6	0,0	I
-8,5	20,0	68,0	10,9	20,5	19,4	96,1	47,7	0,0	
-7,5	20,0	68,0	11,2	20,5	18,7	92,8	46,1	0,0	
-6,5	20,0	68,0	11,5	20,5	18,0	89,4	44,6	0,0	
-5,5	20,0	68,0	11,8	20,5	17,3	86,0	43,0	0,0	
-4,5	20,0	68,0	12,2	20,5	16,7	82,7	41,4	0,0	
-3,5	20,0	68,0	12,5	20,5	16,0	79,3	39,8	0,0	
-2,5	20,0	68,0	12,8	20,5	15,3	75,9	38,2	0,0	
-1,5	20,0	68,0	13,1	20,5	14,6	72,5	36,6	0,0	
-0,5	20,0	68,0	13,4	20,5	13,9	69,2	35,0	0,0	
0,5	20,0	68,0	13,8	20,5	13,3	65,8	33,4	0,0	
1,5	20,0	68,0	14,1	20,5	12,6	62,4	31,9	0,0	
2,5	20,0	68,0	14,4	20,5	11,9	59,0	30,3	0,0	
3,5	20,0	68,0	14,7	20,5	11,2	55,7	28,7	0,0	
4,5	20,0	68,0	15,0	20,5	10,5	52,3	27,1	0,0	
5,5	20,0	68,0	15,4	20,5	9,9	48,9	25,5	0,0	
6,5	20,0	68,0	15,7	20,5	9,2	45,5	23,9	0,0	
7,5	20,0	68,0	16,0	20,5	8,5	42,2	22,3	0,0	
8,5	20,0	68,0	16,3	20,5	7,8	38,8	20,7	0,0	
9,5	20,0	68,0	16,6	20,5	7,1	35,4	19,2	0,0	
10,5	20,0	68,0	17,0	20,5	6,5	32,0	17,6	0,0	
11,5	20,0	68,0	17,3	20,5	5,8	28,7	16,0	0,0	
12,5	20,0	68,0	17,6	20,5	5,1	25,3	14,4	0,0	
13,5	20,0	68,0	17,9	20,5	4,4	21,9	12,8	0,0	
14,5	20,0	68,0	18,2	20,5	3,7	18,6	11,2	0,0	
15,5	20,0	68,0	18,6	20,5	3,1	15,2	9,6	0,0	
16,5	20,0	68,0	18,9	20,5	2,4	11,8	8,0	0,0	
17,5	20,0	68,0	19,2	20,5	1,7	8,4	6,4	0,0	
18,5	20,0	68,0	19,5	20,5	1,0	5,1	4,9	0,0	
19,5	20,0	68,0	19,8	20,5	0,3	1,7	3,3	0,0	
20,5	20,5	0,0	20,5	0,0	0,0	0,0	0,0	0,0	OUT
21,5	21,5	0,0	21,5	21,5	0,0	0,0	-7,4	0,0	OUT
22,5	22,5	0,0	22,5	22,5	0,0	0,0	-12,4	0,0	OUT
23,5	23,5	0,0	23,5	23,5	0,0	0,0	-17,4	0,0	OUT
24,5	24,5	0,0	24,5	24,5	0,0	0,0	-22,3	0,0	OUT
25,5	25,5	0,0	25,5	25,5	0,0	0,0	-27,3	0,0	OUT
26,5	26,0	68,0	26,2	20,0	-0,3	-1,7	-30,6	0,0	
27,5	26,0	68,0	26,5	20,0	-1,0	-5,1	-32,1	0,0	
28,5	26,0	68,0	26,8	20,0	-1,7	-8,4	-33,7	0,0	
29,5	26,0	68,0	27,1	20,0	-2,4	-11,8	-35,3	0,0	
30,5	26,0	68,0	27,4	20,0	-3,1	-15,2	-36,9	0,0	
31,5	26,0	68,0	27,8	20,0	-3,7	-18,6	-38,5	0,0	
32,5	26,0	68,0	28,1	20,0	-4,4	-21,9	-40,1	0,0	
33,5	26,0	68,0	28,4	20,0	-5,1	-25,3	-41,7	0,0	

I = Iceprotect / H = Heating / C = Cooling / S = Hum. stage(s) / F = free cooliing / W = service water
P = Powercontrol / FA = Fresh air temp. / RA = Room air temp. (after hum.) / SA = Supply air temp.
Simulation only dry under const. Conditions !

Simulation Economic calculation

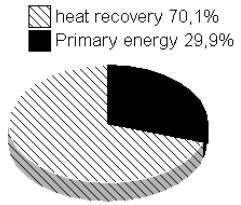
HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

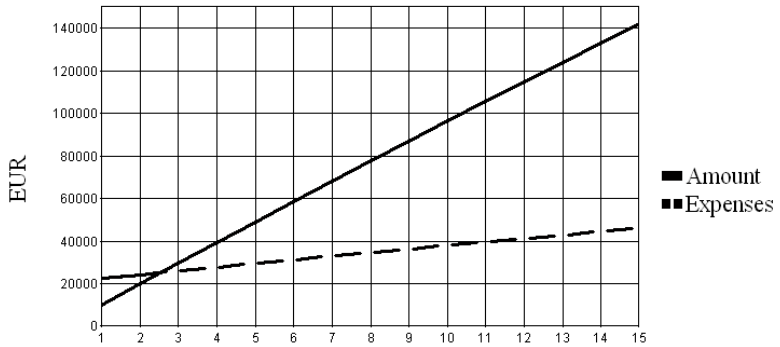
AL	Q WRG	Hours Day	Hours Night	Heating total	Cooling total	HRC +	HRC -	FC +	SW -	Water
°C	kW	h/°C	h/°C	kWh	kWh	kWh	kWh	kWh	kWh	m³
< -9,5	99,2		1	77		66				
-9,5	99,2	2	7	818		661				
-8,5	96,1	16	9	2.950		2.114				
-7,5	92,8	4	10	1.250		990				
-6,5	89,4	8	23	2.613		2.086				
-5,5	86,0	23	17	4.064		2.953				
-4,5	82,7	29	29	5.394		3.997				
-3,5	79,3	27	64	7.027		5.525				
-2,5	75,9	61	59	10.326		7.615				
-1,5	72,5	84	91	14.128		10.488				
-0,5	69,2	77	137	15.161		11.649				
0,5	65,8	94	155	17.013		12.985				
1,5	62,4	117	150	18.106		13.541				
2,5	59,0	127	146	17.860		13.236				
3,5	55,7	116	180	17.366		13.145				
4,5	52,3	133	215	19.096		14.452				
5,5	48,9	165	183	19.084		14.034				
6,5	45,5	162	233	19.356		14.439				
7,5	42,2	181	218	18.705		13.771				
8,5	38,8	165	213	16.154		11.912				
9,5	35,4	180	220	15.834		11.564				
10,5	32,0	201	211	15.202		10.933				
11,5	28,7	172	199	12.136		8.744				
12,5	25,3	182	193	11.056		7.860				
13,5	21,9	156	185	8.623		6.117				
14,5	18,6	176	194	8.135		5.679				
15,5	15,2	149	159	5.667		3.876				
16,5	11,8	173	161	5.019		3.308				
17,5	8,4	155	131	3.285		2.036				
18,5	5,1	164	122	2.228		1.251				
19,5	1,7	156	117	1.073		398				
20,5	0,0	169	103							
21,5	0,0	166	86		1.547					
22,5	0,0	144	54		2.120					
23,5	0,0	135	35		2.654					
24,5	0,0	117	25		2.888					
25,5	0,0	63	15		1.925					
26,5	-1,7	33	14		1.288		72			
27,5	-5,1	28	7		1.172		167			
28,5	-8,4	21	4		971		199			
29,5	-11,8	16	4		848		220			
30,5	-15,2	17	1		912		269			
31,5	-18,6	10			571		186			
32,5	-21,9	3			186		66			
> 32,5	-25,3	3			201		76			
Total Year	**Meteon. Mannheim**	**4.380**	**4.380**	**314.792**	**17.275**	**231.411**	**1.249**			
						7.487 h	**1.001 h**			

Simulation Economic calculation

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

Energy Cost Heating	0,043 € / kWh
Energy Cost Colling	0,041 € / kWh
Energy Cost Electro	0,091 € / kWh
Water Costs (incl. Waste Water)	6,00 € / m³
Calculation Interests	2,40 %
Price increasing Rate	1,70 %
Climate Zone/ City	Mannheim
Life Time	15 a
Running Days per Week	7 d / w
Running Hours at Day	12 h / d
Running Hours per Night	12 h / d
Load in % at Day (V max)	100 % / V max
Load in % at Night (V max)	50 % / V max
Invest for the Heat Recovery	20.766 €
Extra Invest HRC	0 €
Reduction Heating	0 € / (0 € / kW)
Reduction Cooling	0 € / (0 € / kW)
Extra Expenses	0 €
Heat Recovery	9.951 € / a
Cooling Recovery	51 € / a
Electro Consumption for Heat Recovery	1.381 € / a
Capital Costs for the Heat Recovery	1.665 € / a
Service- and Maintenance Costs	415 € / a
Diff. Costs per Year	6.540 € / a
Capital Value of Saving	95.792 €
Calculation Interests	41,7 %
Amorisation	2,6 a
Eff. of use per Year (based on energy)	70,1 %
COP acc. EN 13053 based on energies	15,3
COP acc. EN 13053 based on capacities	21,9
Effective yearly efficiency acc. EN 13053	64,9 %





Simulation Economic calculation

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

HRC SYSTEMS / OPTIMIZING (based on money / HRS faced aerea const.)

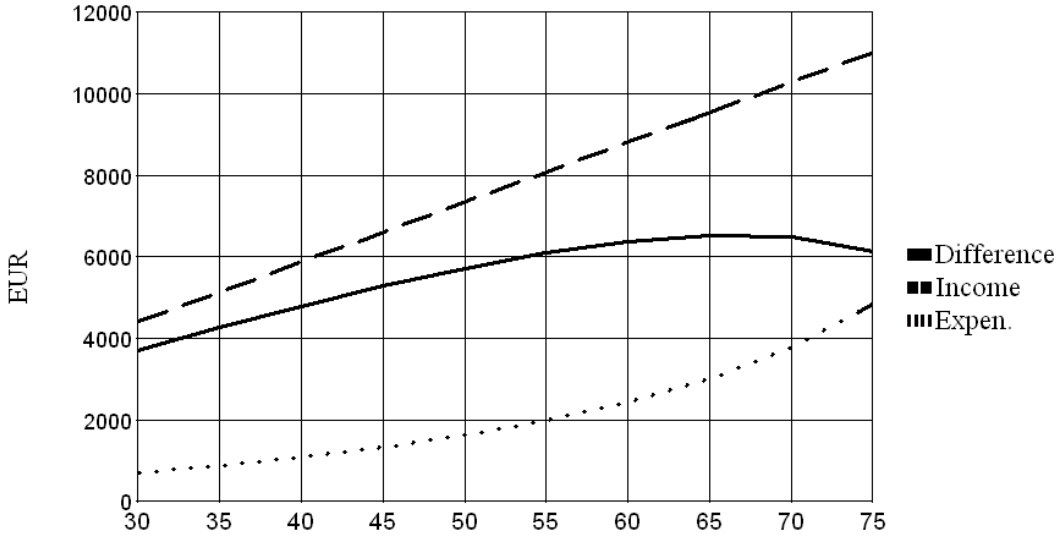
Efficiency	Depth HRS	Benefit €/a	Expenditure €/a	Difference costs €/a
30,0 %	20,2 %	4412,6 €	698,1 €	3714,5 €
35,0 %	25,3 %	5148,0 €	877,1 €	4270,9 €
40,0 %	31,4 %	5883,5 €	1086,0 €	4797,5 €
45,0 %	38,5 %	6618,9 €	1332,8 €	5286,1 €
50,0 %	47,1 %	7354,3 €	1629,0 €	5725,4 €
55,0 %	57,5 %	8089,8 €	1990,9 €	6098,8 €
60,0 %	70,6 %	8825,2 €	2443,4 €	6381,8 €
65,0 %	87,4 %	9560,6 €	3025,2 €	6535,4 €
67,0 %	**95,5 %**	**9854,8 €**	**3307,3 €**	**6547,5 €**
70,0 %	109,8 %	10296,1 €	3800,9 €	6495,2 €
75,0 %	141,2 %	11031,5 €	4886,9 €	6144,6 €

Costs of heat recovery calculated per year

selection with a Velocity (supply - and exhaust air unit) 1,90 m /s - 68,0 %

optimized efficiency of HRC **67 % (63 - 70 %)**

Calculation based on economic calculation (toleranc ± 1 % costs)



Simulation Economic calculation

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

HRC SYSTEMS / OPTIMIZING (based on money / HRS debth const.)

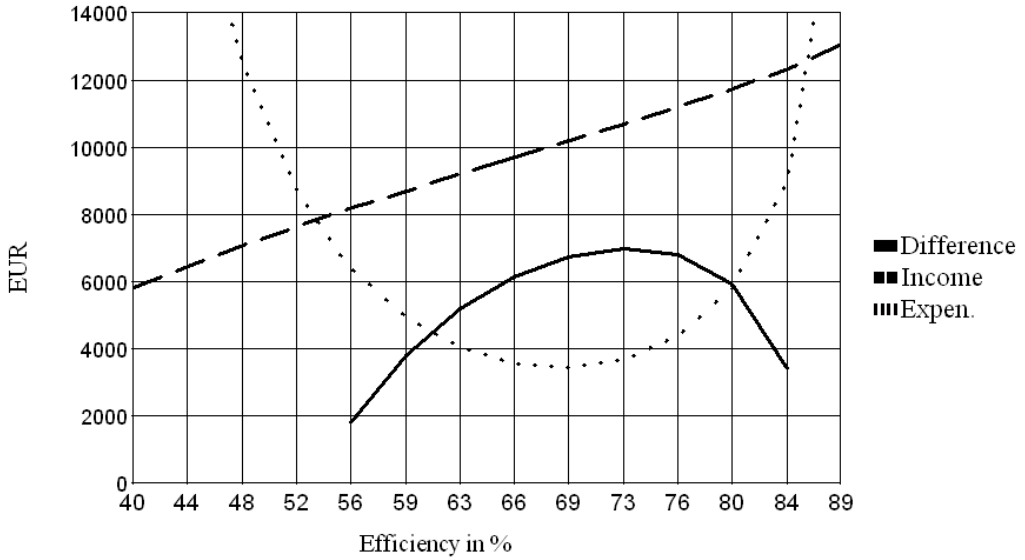
Efficiency	square area (base 2 m/s)	w in m/s	Benefit €/a	Expenditure €/a	Difference costs €/a
55,7 %	62,3 %	3,21 m/s	8191,0 €	6391,3 €	1799,8 €
59,2 %	71,9 %	2,78 m/s	8710,3 €	4913,7 €	3796,7 €
62,6 %	83,1 %	2,41 m/s	9213,8 €	4025,5 €	5188,3 €
66,0 %	96,2 %	2,08 m/s	9707,6 €	3565,8 €	6141,8 €
69,3 %	112,0 %	1,79 m/s	10198,2 €	3459,7 €	6738,4 €
72,7 %	131,9 %	1,52 m/s	10693,1 €	3705,0 €	6988,1 €
73,4 %	**136,6 %**	**1,46 m/s**	**10793,5 €**	**3801,9 €**	**6991,5 €**
76,2 %	158,3 %	1,26 m/s	11202,7 €	4394,0 €	6808,7 €
79,8 %	196,1 %	1,02 m/s	11742,4 €	5821,2 €	5921,2 €
83,9 %	258,2 %	0,77 m/s	12341,2 €	8944,2 €	3396,9 €

Area in % of the selcted Area. Costs of heat recovery calculated per year. Exponent for dP calc. 1,6

selection with a Velocity (supply - and exhaust air unit) 1,90 m /s - 68,0 %

optimized efficiency of HRC **73,4 % (71,3 - 74,8 %)**

Calculation based on economic calculation (toleranc ± 1% costs)



Simulation Economic calculation

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

HRC SYSTEMS / OPTIMIZING (based on money / multidimensional)

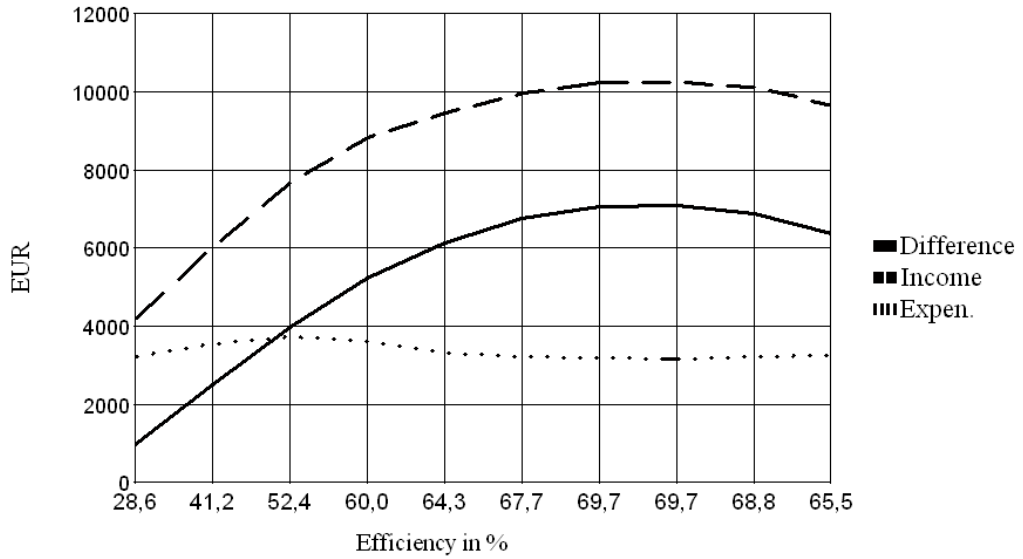
Efficiency	square area (base 2 m/s)	w in m/s	Depth HRS	Benefit €/a	Expenditure €/a	Difference costs €/a
28,6 %	53,7 %	3,73 m/s	28,2 %	4202,5 €	3232,0 €	970,4 €
41,2 %	62,3 %	3,21 m/s	45,1 %	6056,5 €	3559,9 €	2496,6 €
52,4 %	71,9 %	2,78 m/s	65,0 %	7704,5 €	3722,1 €	3982,4 €
60,0 %	83,1 %	2,41 m/s	81,4 %	8825,2 €	3601,0 €	5224,1 €
64,3 %	96,2 %	2,08 m/s	89,4 %	9455,6 €	3306,5 €	6149,0 €
67,7 %	112,0 %	1,79 m/s	95,2 %	9963,9 €	3213,4 €	6750,5 €
69,7 %	131,9 %	1,52 m/s	94,5 %	10251,5 €	3200,0 €	7051,5 €
69,7 %	**146,7 %**	**1,36 m/s**	**88,7 %**	**10251,5 €**	**3147,2 €**	**7104,2 €**
69,7 %	158,3 %	1,26 m/s	84,7 %	10251,5 €	3162,8 €	7088,7 €
68,8 %	196,1 %	1,02 m/s	71,3 %	10112,2 €	3235,1 €	6877,1 €
65,5 %	258,2 %	0,77 m/s	52,2 %	9636,7 €	3260,1 €	6376,6 €

Area in % of the selcted Area. Costs of heat recovery calculated per year. Exponent for dP calc. 1,6

selection with a Velocity (supply - and exhaust air unit) 1,90 m /s - 68,0 %

max usefull efficiency of HRC **69,7 %**

Calculation based on economic calculation (toleranc aprox. 2% of max. benefit)



Simulation Ecologic calculation

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

HRC SYSTEMS / OPTIMIZING (based on CO2 / HRS faced area const.)

Efficiency	Depth HRS	Saving kg CO2/a	Expenditure kg CO2/a	Difference kg CO2/a
30,0 %	20,2 %	27638	1576	26061
35,0 %	25,3 %	32244	1980	30264
40,0 %	31,4 %	36850	2452	34398
45,0 %	38,5 %	41456	3009	38447
50,0 %	47,1 %	46063	3678	42385
55,0 %	57,5 %	50669	4495	46174
60,0 %	70,6 %	55275	5516	49759
65,0 %	87,4 %	59881	6830	53051
70,0 %	109,8 %	64488	8581	55906
75,0 %	141,2 %	69094	11033	58061
80,0 %	**188,2 %**	**73700**	**14711**	**58990**
85,0 %	266,7 %	78306	20840	57467
90,0 %	423,5 %	82913	33099	49814

CO2 Emissions of heat recovery calculated

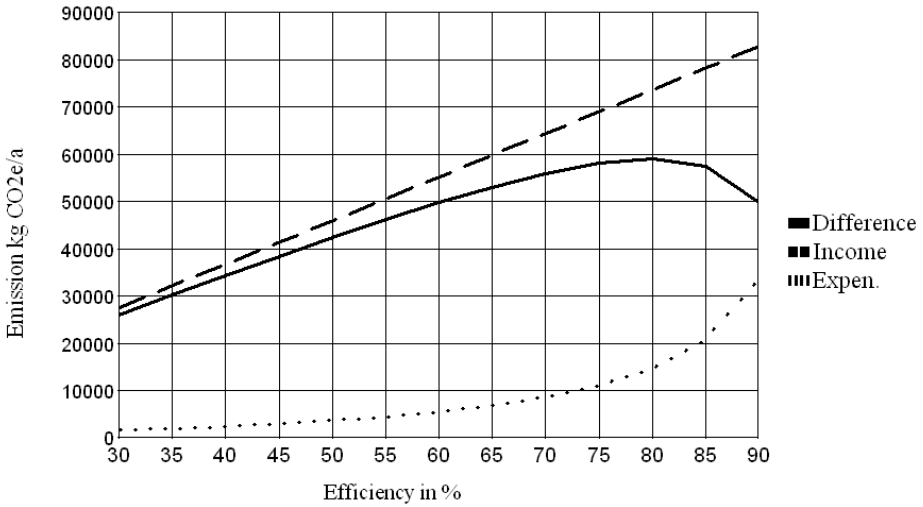
CO2-Emissionen calc. per year with 270 g/kWh heat, 460 g/kWh electricity and 500 g/€ HRS Invest und additional running costs 200 g/€

selection with a Velocity (supply - and exhaust air unit) 1,90 m /s - 68,0 %

selection with a CO2 reduction of 54,8 to/a

optimized efficiency of HRC **80 % (77 - 83 %)**

Calculation based on economic calculation (tolerance ± 1% CO2 Emission)



Simulation Ecologic calculation

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

HRC SYSTEMS / OPTIMIZING (based on CO2 / multidimensional)

Efficiency	square area (base 2 m/s)	w in m/s	Depth HRS	Saving kg CO2/a	Expenditure kg CO2/a	Difference kg CO2/a
9,1 %	53,7 %	3,73 m/s	7,0 %	8375	8100	275
28,6 %	62,3 %	3,21 m/s	25,8 %	26321	19067	7254
44,4 %	71,9 %	2,78 m/s	47,3 %	40945	22794	18150
56,5 %	83,1 %	2,41 m/s	70,5 %	52071	22287	29784
66,7 %	96,2 %	2,08 m/s	99,4 %	61417	20614	40803
74,4 %	112,0 %	1,79 m/s	131,5 %	68503	17860	50644
80,0 %	131,9 %	1,52 m/s	164,4 %	73700	14623	59077
84,6 %	158,3 %	1,26 m/s	202,6 %	77952	12014	65938
87,8 %	196,1 %	1,02 m/s	233,3 %	80890	9918	70972
89,5 %	258,2 %	0,77 m/s	233,5 %	82428	8724	73704
89,6 %	**323,3 %**	**0,62 m/s**	**206,4 %**	**82529**	**8624**	**73904**
89,1 %	395,6 %	0,51 m/s	174,4 %	82112	8904	73208

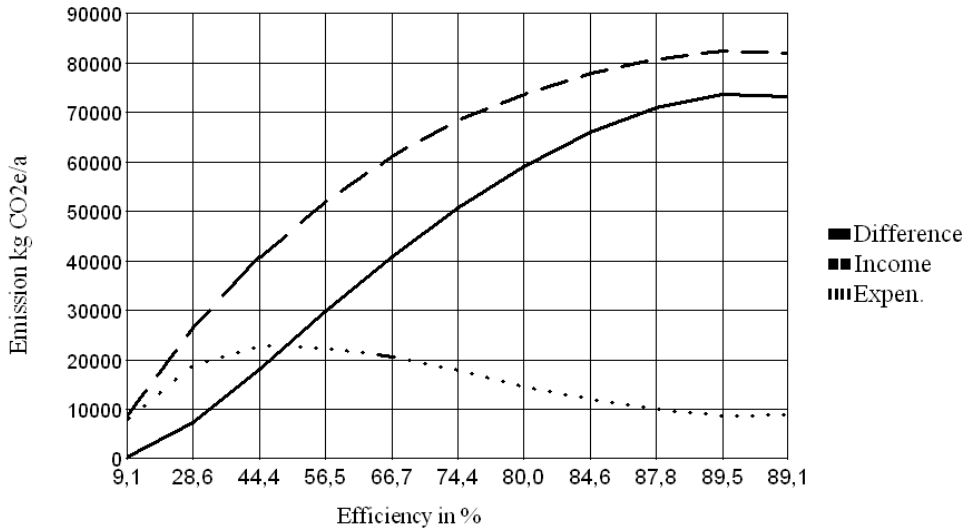
Area in % of the selcted Area. Costs of heat recovery calculated per year. Exponent for dP calc. 1,6

selection with a Velocity (supply - and exhaust air unit) 1,90 m /s - 68,0 %

selection with a CO2 reduction of 54,8 to/a

max usefull efficiency of HRC **89,6 %**

Calculation based on economic calculation (toleranc aprox. 2% of CO2 saving)



Batch Simulation (Meta tool)

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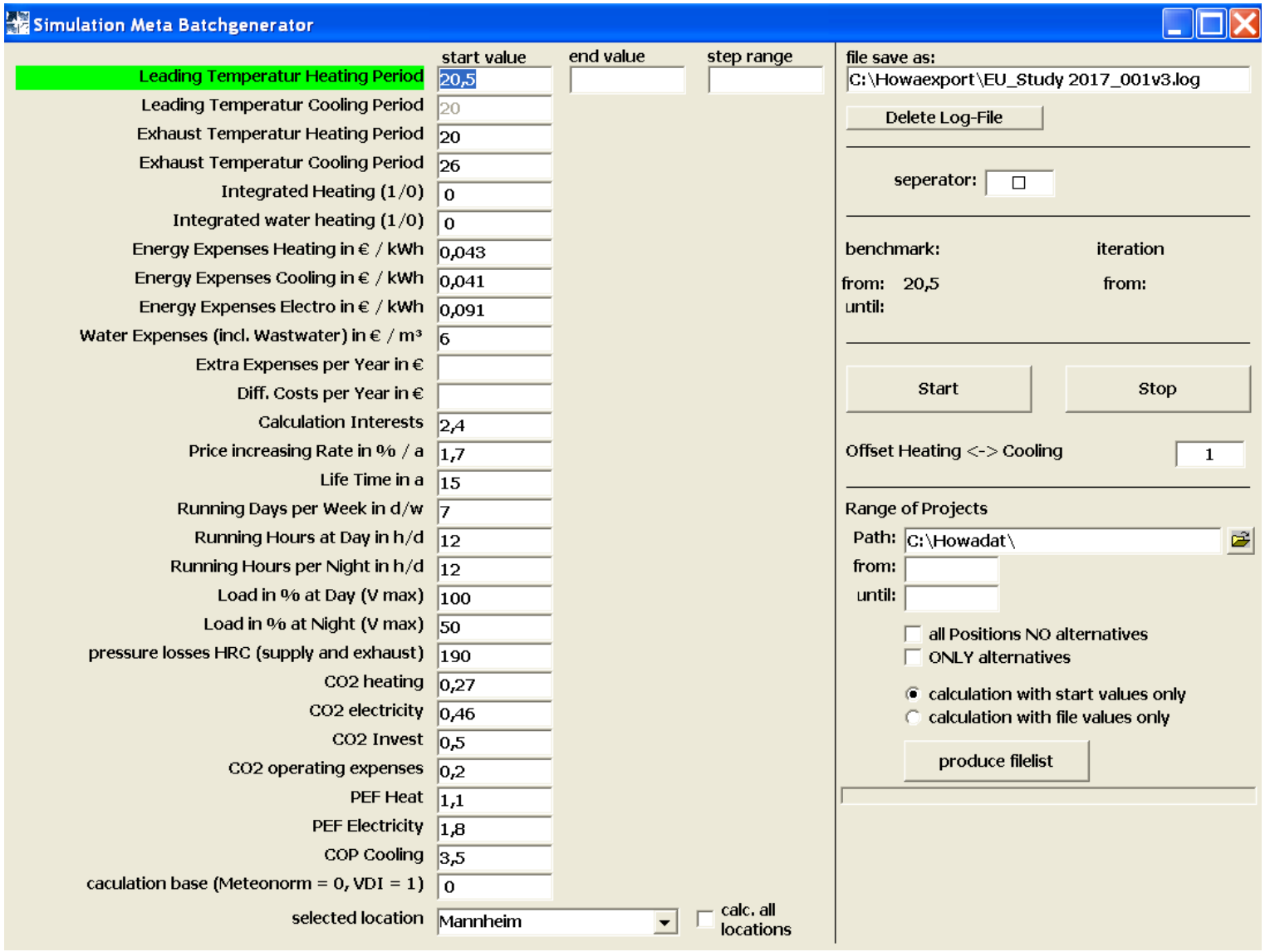
Umwelt-Campus Birkenfeld



Demand of Energy

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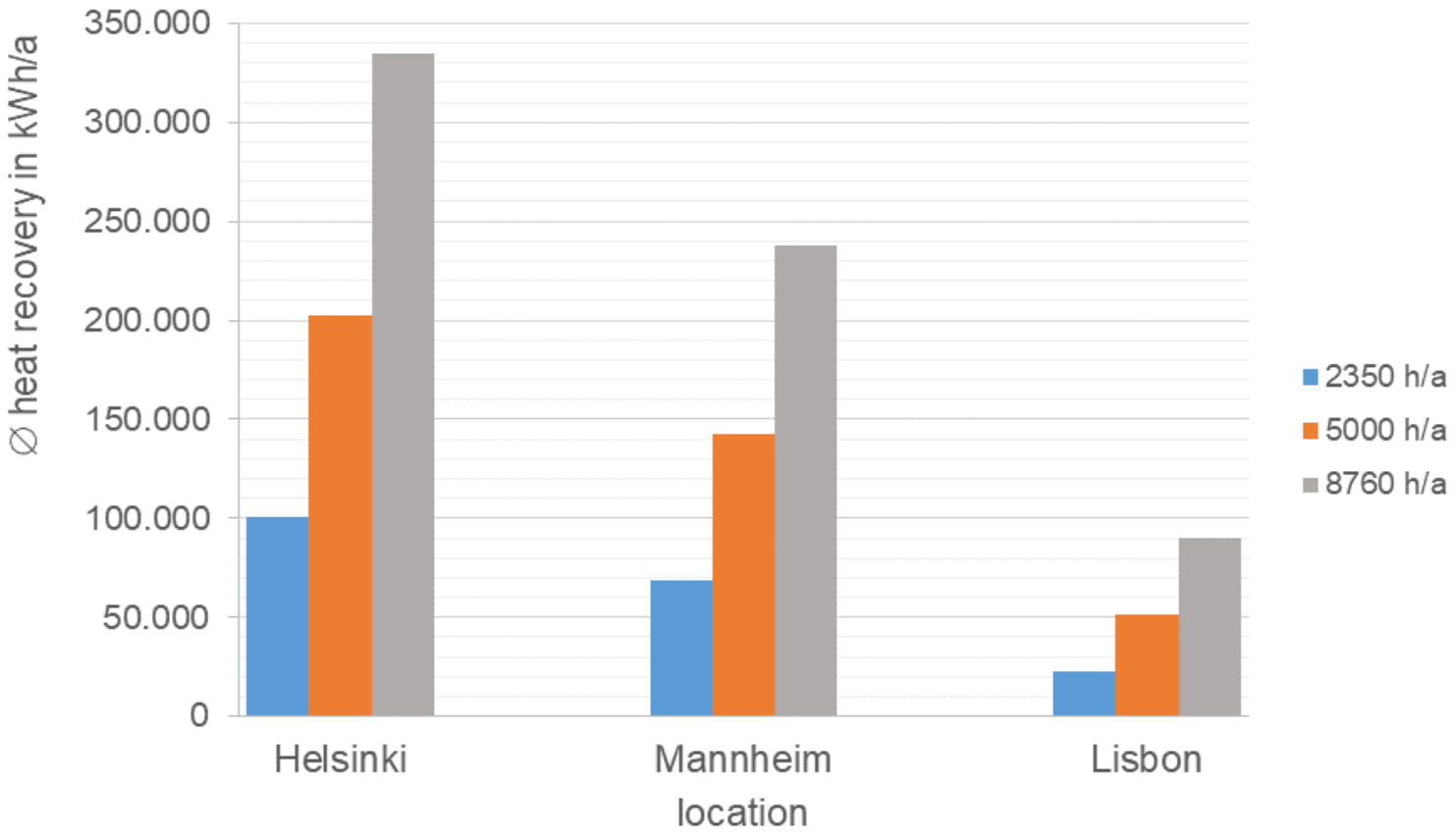
Umwelt-Campus Birkenfeld

		Day h h/a	night h h/a	total h/a	Heat kWh	colth kWh	heat HR kWh	colth HR kWh	North-South factor	operating time factor
North	Helsinki	2.346		2.346	145.840	2.495	100.467	204	4,35	1,00
3401										
Middle	Mannheim	2.346		2.346	99.520	8.903	68.943	1.196	2,99	1,00
3387										
South	Lisbon	2.346		2.346	34.799	21.128	23.090	2.888	1,00	1,00
2624	units									

		Day h h/a	night h h/a	total h/a	Heat kWh	colth kWh	heat HR kWh	colth HR kWh	North-South factor	operating time factor
North	Helsinki	3.754		5.005	278.187	4.160	202.227	328	3,94	2,01
3361										
Middle	Mannheim	3.754	1.251	5.005	193.915	14.963	142.320	2.039	2,77	2,06
3370										
South	Lisbon	3.754	1.251	5.005	72.647	37.607	51.312	5.418	1,00	2,22
3243	units									

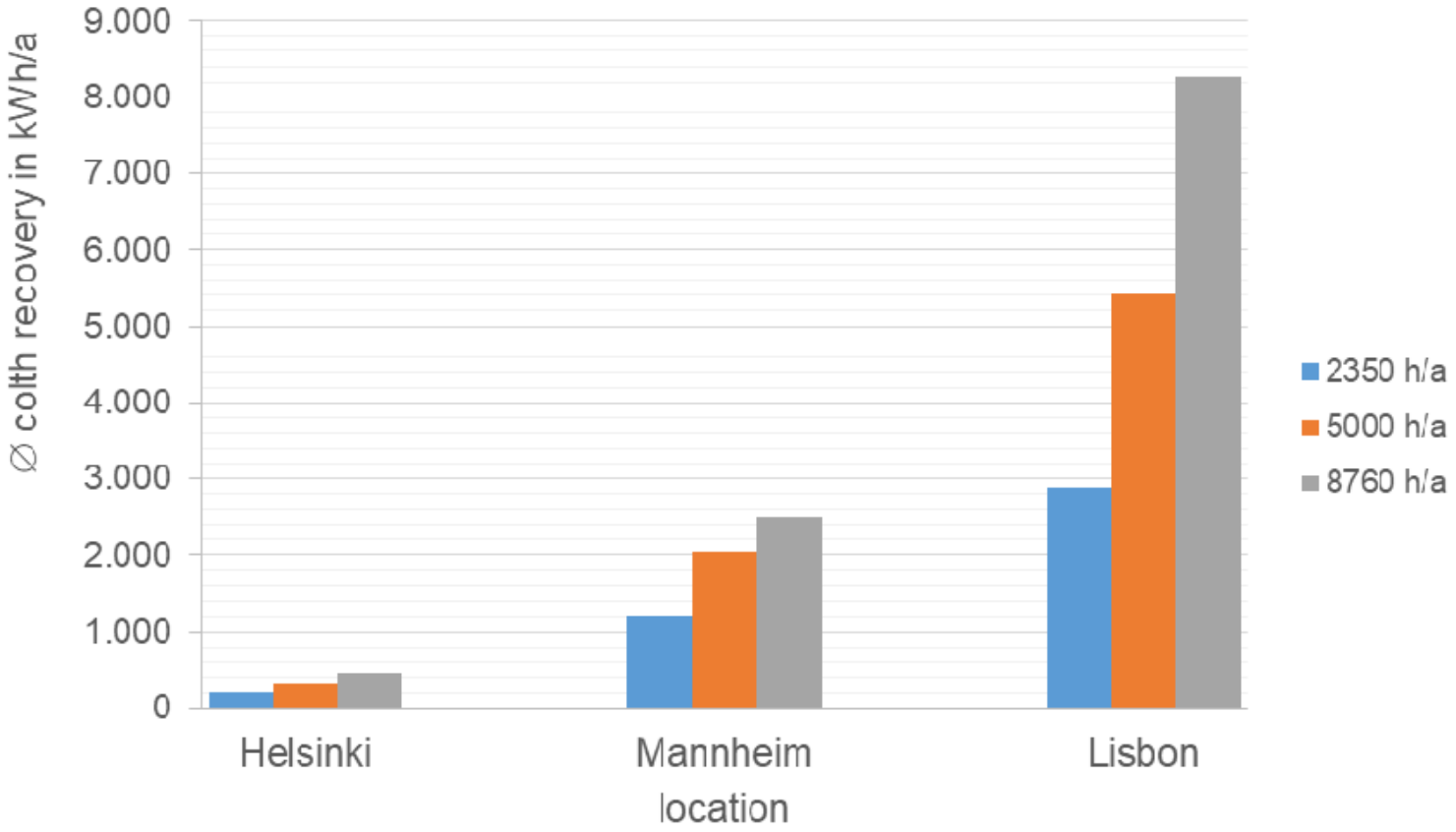
		Day h h/a	night h h/a	total h/a	Heat kWh	colth kWh	heat HR kWh	colth HR kWh	North-South factor	operating time factor
North	Helsinki	4.380	4.380	8.760	431.562	5.288	334.701	458	3,70	3,32
3302										
Middle	Mannheim	4.380	4.380	8.760	303.075	18.812	237.877	2.501	2,63	3,44
3302										
South	Lisbon	4.380	4.380	8.760	119.021	49.391	90.380	8.264	1,00	3,72
3320	units									

Heating



heatrecovery heating energies related to location and operating time

Cooling



heatrecovery cooling energies related to location and operating time

Results

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

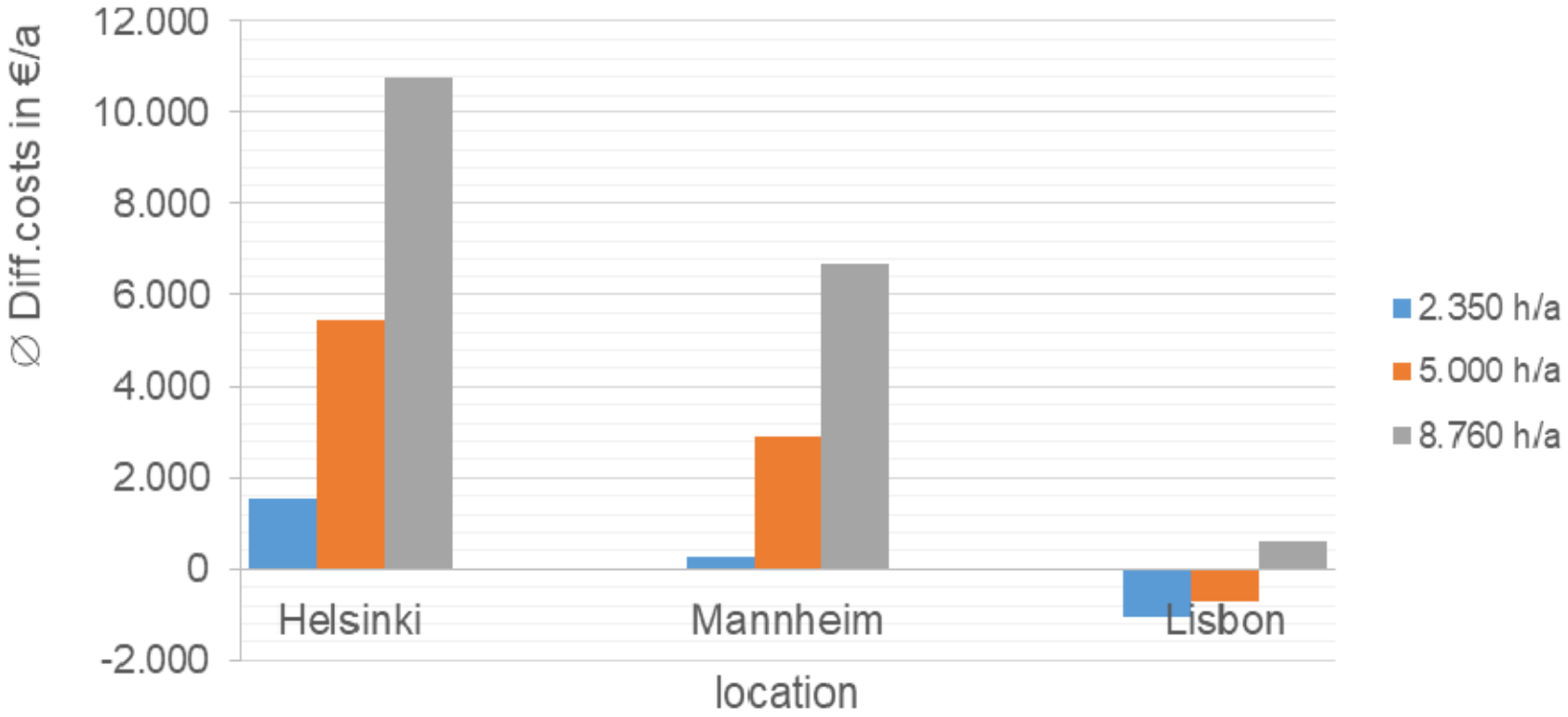
2.350 h/a		Diff. Costs €/a	1D Opt. €/a	HRE %	Delta 1D €/a	Delta 1D %	3D Opt. €/a	HRE %	Delta 3D €/a	Delta 3D	3D w m/s
North	Helsinki	1.558	2.138	59,3	580	37,2%	2.251	60,5	693	44,5%	1,22
			s =	8,65			s =	9,27			0,21
Middle	Mannheim	251	1.123	51,6	872	347,4%	1.204	53,0	953	379,7%	1,22
			s =	9,52			s =	10,35			0,21
South	Lisbon	-1.048	139	30,3	1.187	-113,3%	172	31,4	1.220	-116,4%	1,18
			s =	10,32			s =	9,37		s =	0,19

5.000 h/a		Diff. Costs €/a	1D Opt. €/a	HRE %	Delta 1D €/a	Delta 1D %	3D Opt. €/a	HRE %	Delta 3D €/a	Delta 3D	3D w m/s
North	Helsinki	5.458	5.705	68,7	247	4,5%	6.155	71,1	697	12,8%	1,09
			s =	6,48			s =	7,07			0,19
Middle	Mannheim	2.923	3.394	63,0	471	16,1%	3.741	65,7	818	28,0%	1,09
			s =	7,35			s =	8,19			0,19
South	Lisbon	-715	587	42,7	1.302	-182,1%	742	46,8	1.457	-203,8%	1,08
			s =	9,04			s =	10,55		s =	0,18

8.760 h/a		Diff. Costs €/a	1D Opt. €/a	HRE %	Delta 1D €/a	Delta 1D %	3D Opt. €/a	HRE %	Delta 3D €/a	Delta 3D	3D w m/s
North	Helsinki	10.802	10.989	74,4	187	1,7%	11.882	77,1	1.080	10,0%	1,03
			s =	5,05			s =	5,70			0,18
Middle	Mannheim	6.717	6.925	69,9	208	3,1%	7.641	73,1	924	13,8%	1,03
			s =	5,80			s =	6,55			0,18
South	Lisbon	568	1.564	53,0	996	175,4%	1.920	57,9	1.352	238,0%	1,02
			s =	8,23			s =	9,36		s =	0,18

Results

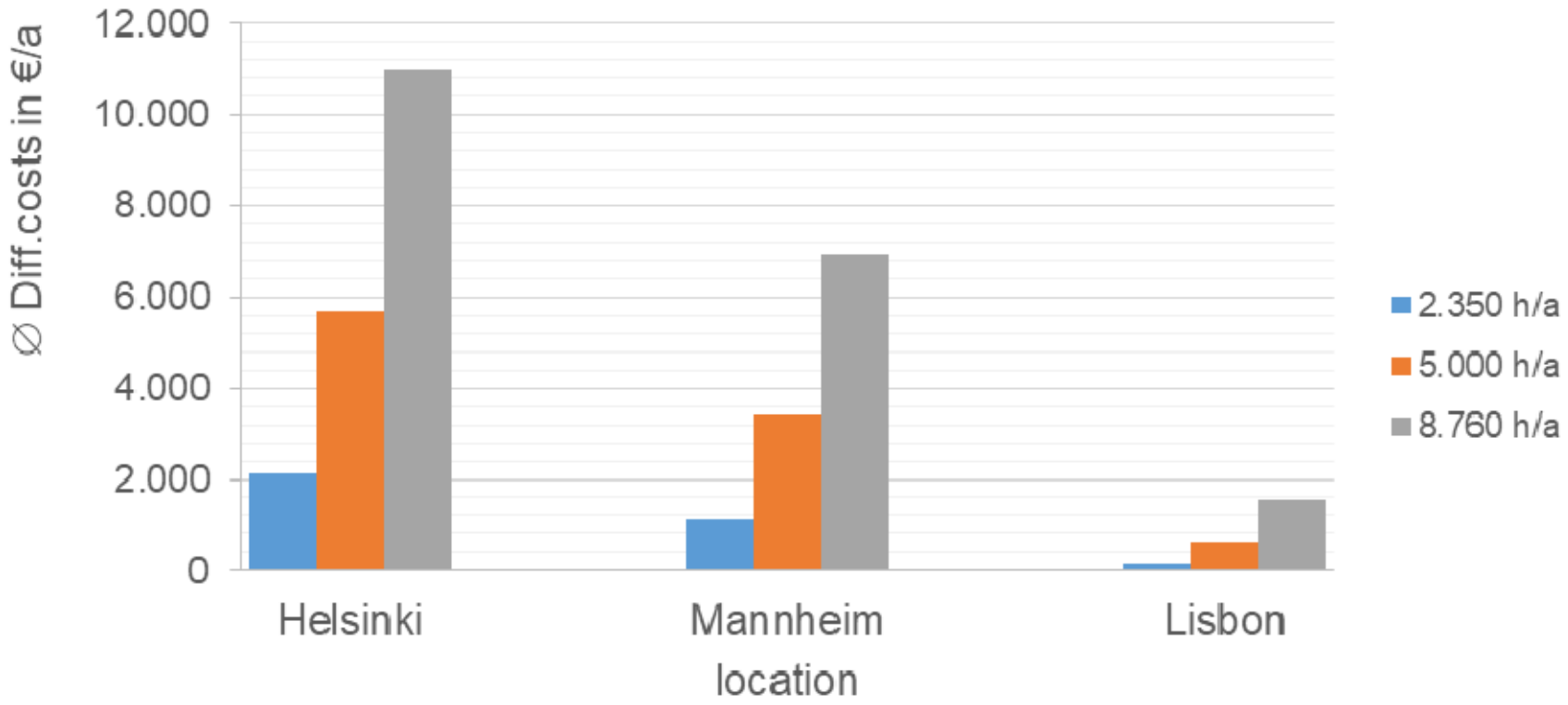
HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



yearly difference cost at selection conditions

Results

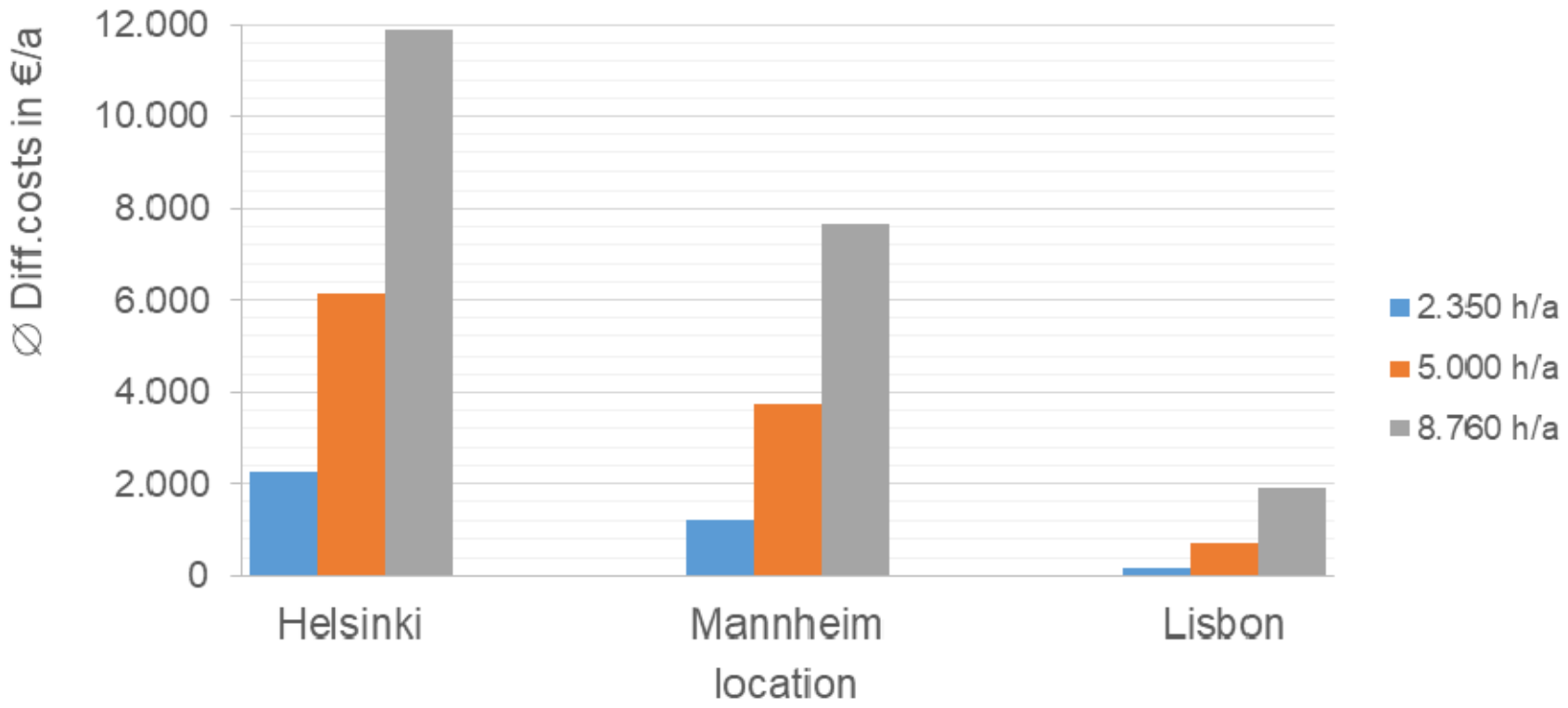
HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



yearly difference cost after 1D optimization

Results

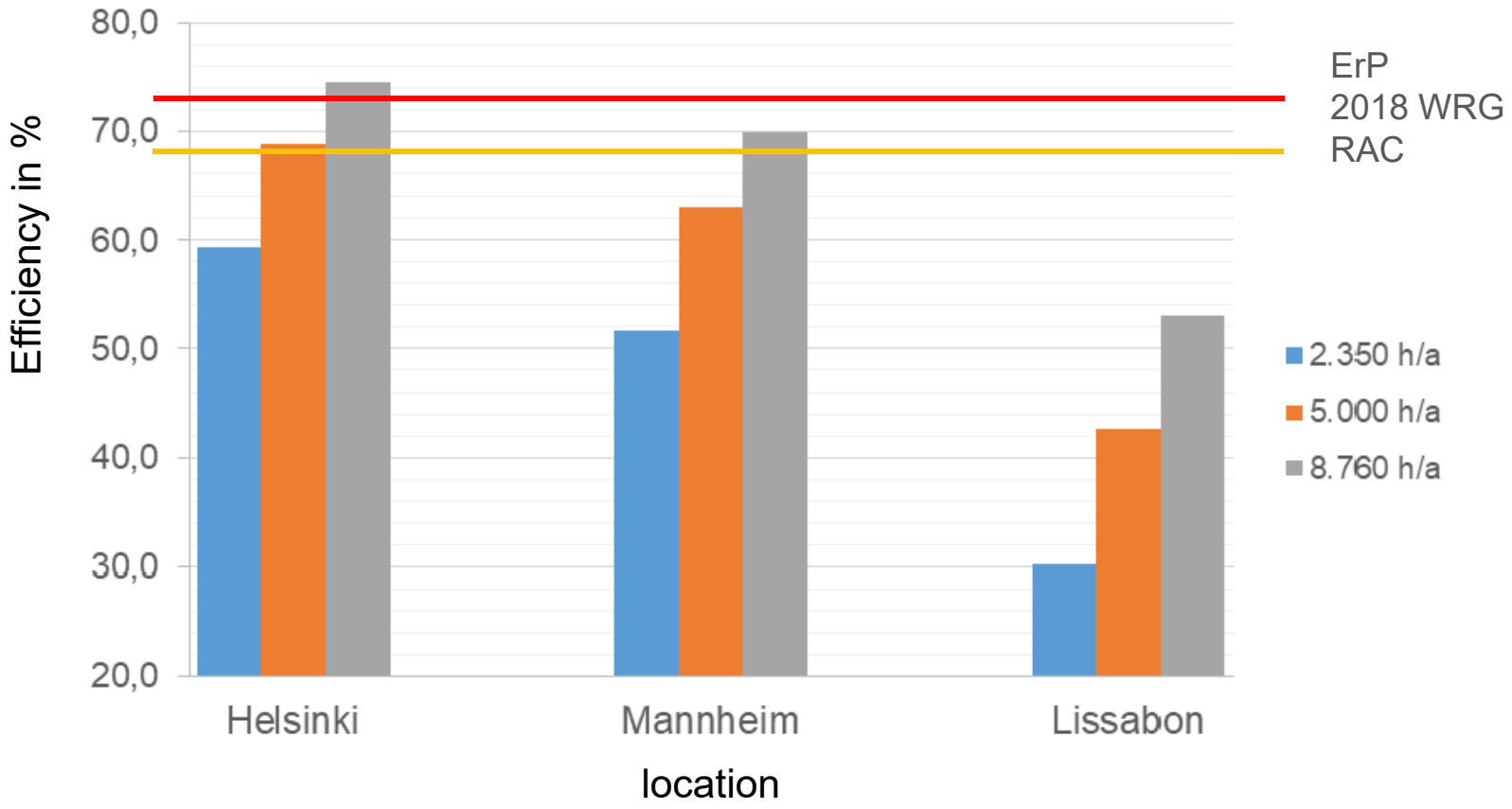
HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



yearly difference cost after 3D optimization

Results

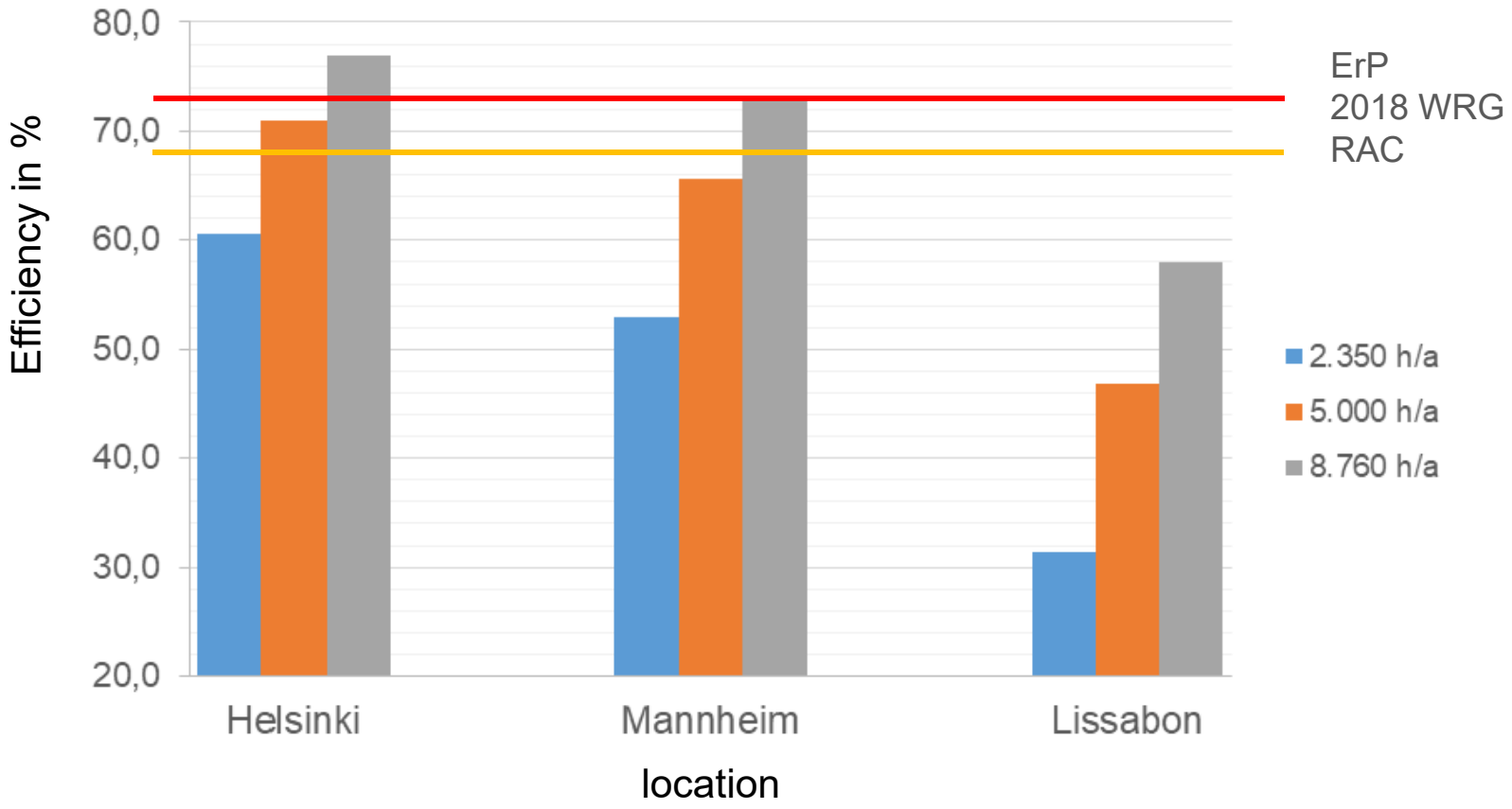
HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



temperatur efficiency after 1D optimization

Results

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



temperatur efficiency after 3D optimization

Reference conditions 2020

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

			NTU actual	NTU target	NTU Factor target / actual
North	Helsinki		2,84	5,36	1,98
		s =	0,97	0,64	0,50
Middle	Mannheim		2,84	5,37	1,98
		s =	0,97	0,64	0,51
South	Lisbon		2,86	5,47	2,00
		s =	0,87	0,50	0,49

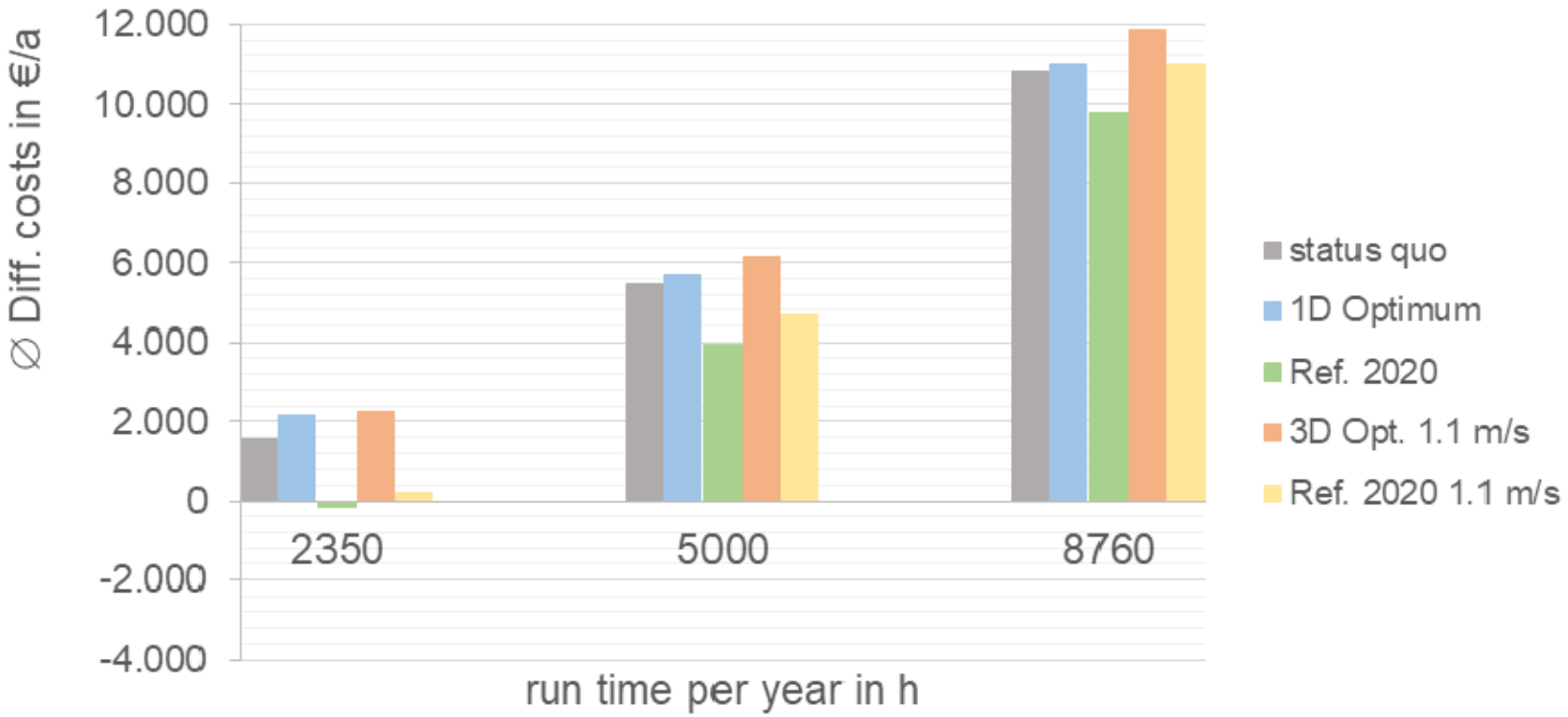
dimensionless heattransfer coefficient NTU

Reference conditions 2020

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

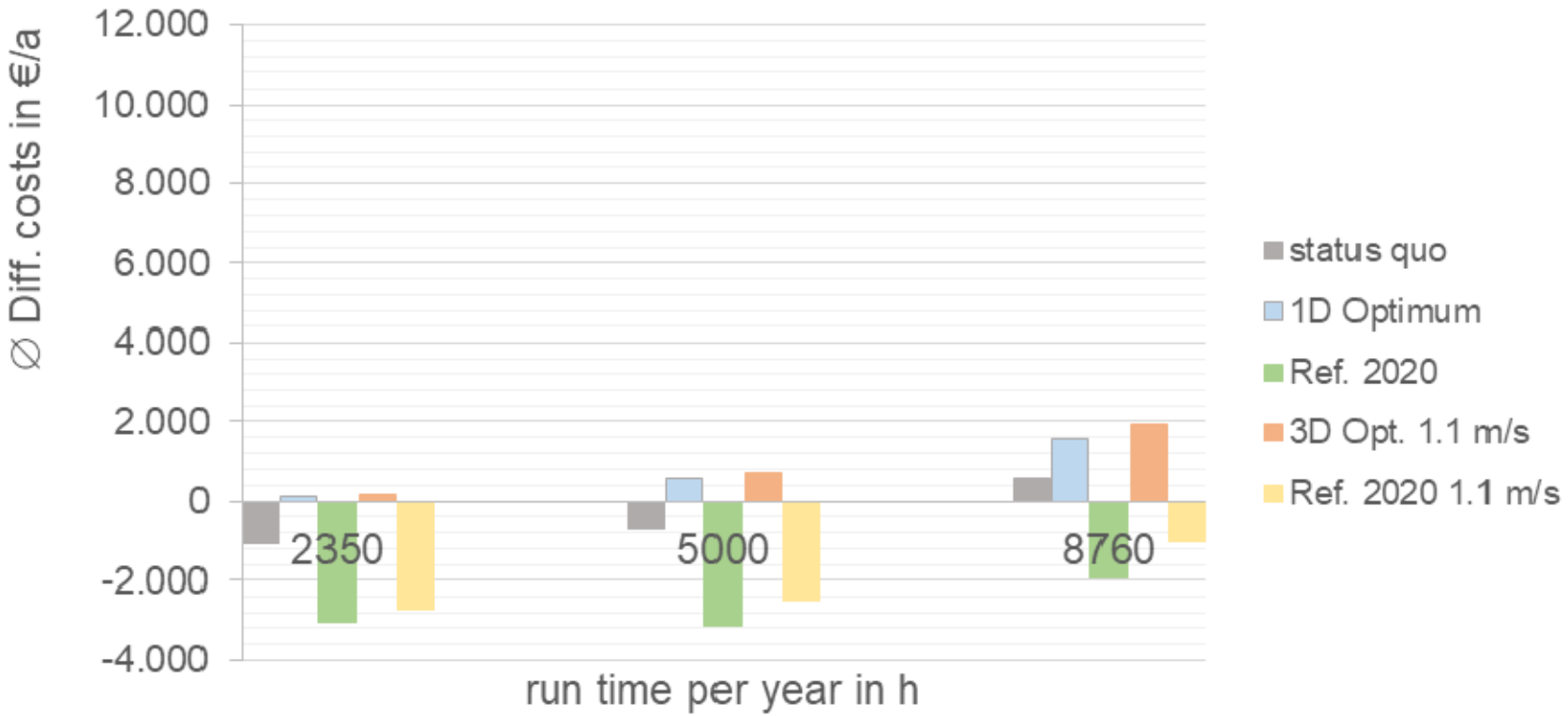
	run time h/a	Diff. costs actual €/a	Diff. costs 1 D Opt. €/a	Diff. costs Ref. 2020 €/a	Diff. costs 3D Opt. €/a	Diff. costs Ref. 2020 (1,1 m/s) €/a
Helsinki	2.350	1.558	2.138	-169	2.251	225
North	5.000	5.458	5.705	3.936	6.155	4.668
	8.760	10.802	10.989	9.804	11.882	10.980
Mannheim	2.350	251	1.123	-1.674	1.204	-1.524
Middle	5.000	2.923	3.394	1.007	3.741	1.673
	8.760	6.717	6.925	5.114	7.641	6.260
Lisbon	2.350	-1.048	139	-3.045	172	-2.722
South	5.000	-715	587	-3.149	742	-2.513
	8.760	568	1.564	-1.942	1.920	-1.000

Results



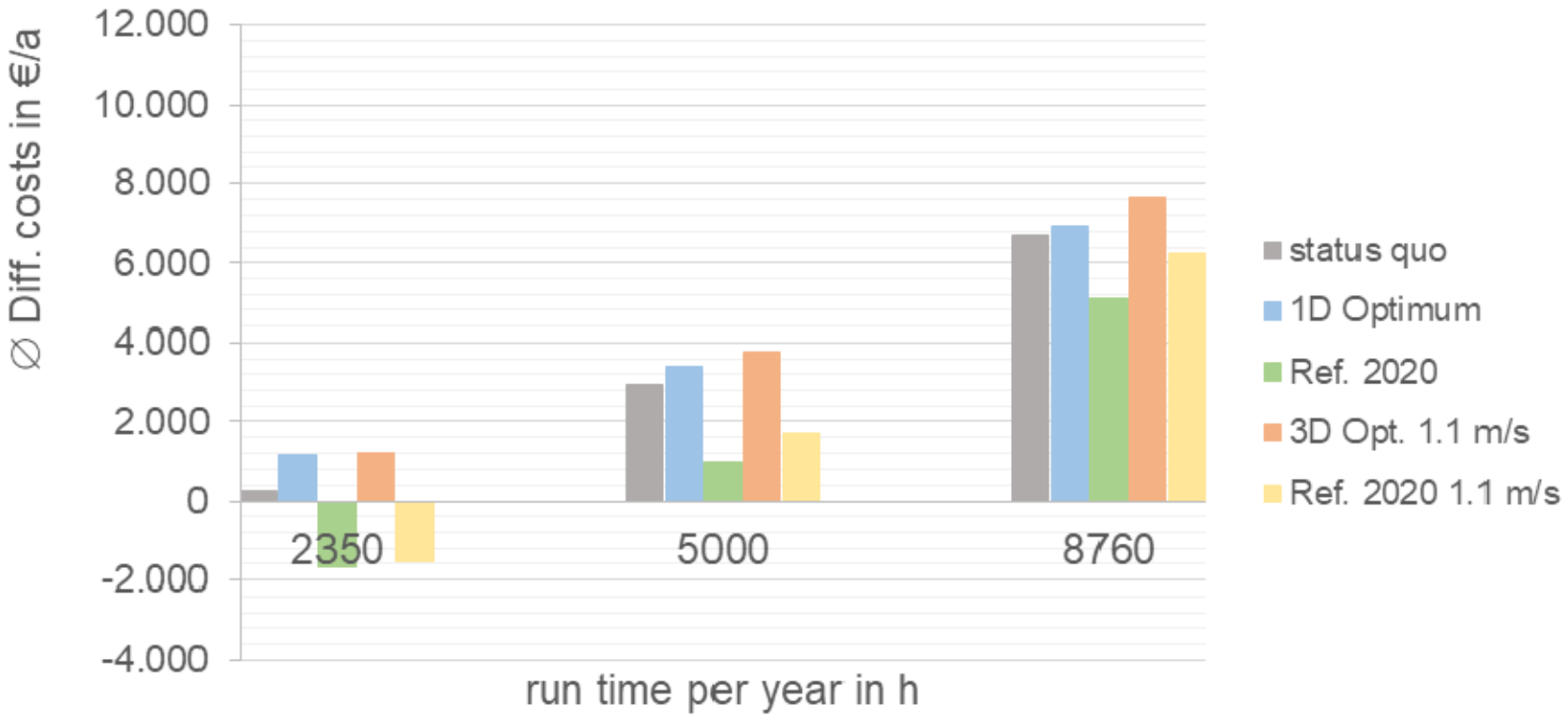
results for Helsinki

Results



results for Lisbon

Results



results for Mannheim

Consideration

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

		3D-Optimum	∅ Diff.-costs	ΔP		w
2.350 h/a		%	€/a	Pa		m/s
north	Helsinki	**61**	2.251	**58**		**1,22**
middle	Mannheim	**53**	1.204	**42**		**1,22**
south	Lisbon	**31**	172	**15**		**1,18**
5.000 h/a						
north	Helsinki	**71**	6.155	**72**		**1,09**
middle	Mannheim	**66**	3.741	**56**		**1,09**
south	Lissabon	**47**	742	**25**		**1,08**
8.760 h/a						
north	Helsinki	**77**	11.882	**87**		**1,03**
middle	Mannheim	**73**	7.641	**70**		**1,03**
south	Lissabon	**58**	1.920	**35**		**1,02**

optimum results based on study results

Consideration

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

		3D-Optimum	∅ Diff.-costs	ΔP		w
2.350 h/a		%	€/a	Pa		m/s
north	Helsinki	**71**	6.944	**61**		**1,01**
middle	Mannheim	**65**	4.097	**47**		**1,01**
south	Lisbon	**45**	773	**21**		**1,03**
5.000 h/a						
north	Helsinki	**79**	16.945	**91**		**1,00**
middle	Mannheim	**75**	10.762	**71**		**0,99**
south	Lissabon	**60**	2.725	**35**		**0,99**
8.760 h/a						
north	Helsinki	**83**	30.774	**119**		**1,01**
middle	Mannheim	**80**	20.616	**96**		**0,99**
south	Lissabon	**68**	6.005	**51**		**0,98**

alternative optimum results based on heat 0,08 and electricity 0,15 €/kWh

Consideration

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

		3D-Optimum	∅ Diff.-CO_2	ΔP		w
2.350 h/a		%	kg/a	Pa		m/s
north	Helsinki	**86**	26.007	**47**		**0,58**
middle	Mannheim	**83**	17.982	**38**		**0,60**
south	Lisbon	**76**	5.281	**21**		**0,56**
5.000 h/a						
north	Helsinki	**90**	60.814	**50**		**0,52**
middle	Mannheim	**88**	41.177	**41**		**0,52**
south	Lissabon	**81**	13.179	**23**		**0,51**
8.760 h/a						
north	Helsinki	**92**	105.521	**55**		**0,48**
middle	Mannheim	**90**	72.859	**46**		**0,49**
south	Lissabon	**84**	24.899	**27**		**0,50**

optimum results based on CO_2 emissions

Consideration

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

100 / 50 % load		3D Optimum	s	∅ Diff. - costs	ΔP average	s	w	s
2.350 h/a		%	%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**61**	9,3	2.251	**58**	15,2	**1,22**	0,21
middle	Mannheim	**53**	10,4	1.204	**42**	12,0	**1,22**	0,21
south	Lisbon	**31**	9,4	172	**15**	4,6	**1,18**	0,19
5.000 h/a								
north	Helsinki	**71**	7,1	6.155	**72**	17,0	**1,09**	0,19
middle	Mannheim	**66**	8,2	3.741	**56**	13,7	**1,09**	0,19
south	Lisbon	**47**	10,6	742	**25**	7,4	**1,08**	0,18
8.760 h/a								
north	Helsinki	**77**	5,7	11.882	**87**	19,7	**1,03**	0,18
middle	Mannheim	**73**	6,6	7.641	**70**	16,1	**1,03**	0,18
south	Lisbon	**58**	9,4	1.920	**35**	9,1	**1,02**	0,18

optimum results based on study results

Selected Operation

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

100 / 50 % load		3D Optimum	s	∅ Diff. - costs	ΔP average		s	w	s
2.350 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**61**		9,3	2.251	**58**	15,2	**1,22**	0,21
middle	Mannheim	**53**		10,4	1.204	**42**	12,0	**1,22**	0,21
south	Lisbon	**31**		9,4	172	**15**	4,6	**1,18**	0,19
5.000 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**71**		7,1	6.155	**72**	17,0	**1,09**	0,19
middle	Mannheim	**66**		8,2	3.741	**56**	13,7	**1,09**	0,19
south	Lisbon	**47**		10,6	742	**25**	7,4	**1,08**	0,18
8.760 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**77**		5,7	11.882	**87**	19,7	**1,03**	0,18
middle	Mannheim	**73**		6,6	7.641	**70**	16,1	**1,03**	0,18
south	Lisbon	**58**		9,4	1.920	**35**	9,1	**1,02**	0,18

2030 Climate change influence

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

IPCC 2030	A1B Scenario	3D		∅ Diff.	ΔP			
		Optimum		s - costs	average		s	w	s
2.350 h/a		%	%	€/a	Pa		Pa	m/s	m/s
north	Helsinki	**61**	9,0	2.264	**64**	16,6	**1,26**	0,22
		0,5%		0,6%	10,5%		3,3%	
middle	Mannheim	**50**	10,4	969	**42**	12,0	**1,26**	0,22
		-4,9%		-19,5%	-1,9%		3,3%	
south	Lisbon	**26**	10,5	126	**13**	5,2	**1,23**	0,19
		-15,9%		-26,7%	-13,0%		4,2%	
5.000 h/a		%	%	€/a	Pa		Pa	m/s	m/s
north	Helsinki	**71**	7,1	6.123	**80**	19,1	**1,13**	0,20
		0,0%		-0,5%	11,0%		3,7%	
middle	Mannheim	**64**	8,3	3.043	**56**	14,0	**1,13**	0,20
		-3,2%		-18,7%	0,4%		3,7%	
south	Lisbon	**44**	10,9	620	**25**	7,7	**1,12**	0,19
		-5,6%		-16,4%	-0,4%		3,7%	
8.760 h/a		%	%	€/a	Pa		Pa	m/s	m/s
north	Helsinki	**77**	6,1	11.708	**97**	22,4	**1,07**	0,19
		-0,3%		-1,5%	11,3%		3,9%	
middle	Mannheim	**71**	7,0	6.310	**71**	16,8	**1,07**	0,19
		-2,7%		-17,4%	1,4%		3,9%	
south	Lisbon	**56**	9,5	1.644	**36**	9,6	**1,06**	0,18
		-3,3%		-14,4%	2,3%		3,9%	

Selected Operation

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

100 / 50 % load		3D Optimum	s	∅ Diff. - costs	ΔP average		s	w	s
2.350 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**61**		9,3	2.251	**58**	15,2	**1,22**	0,21
middle	Mannheim	**53**		10,4	1.204	**42**	12,0	**1,22**	0,21
south	Lisbon	**31**		9,4	172	**15**	4,6	**1,18**	0,19
5.000 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**71**		7,1	6.155	**72**	17,0	**1,09**	0,19
middle	Mannheim	**66**		8,2	3.741	**56**	13,7	**1,09**	0,19
south	Lisbon	**47**		10,6	742	**25**	7,4	**1,08**	0,18
8.760 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**77**		5,7	11.882	**87**	19,7	**1,03**	0,18
middle	Mannheim	**73**		6,6	7.641	**70**	16,1	**1,03**	0,18
south	Lisbon	**58**		9,4	1.920	**35**	9,1	**1,02**	0,18

Partload Operation

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

70 / 40 % load		3D		∅ Diff.	ΔP			
		Optimum	s	- costs	average		s	w	s
2.350 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**59**		9,6	1.722	**85**	23,8	**1,50**	0,26
		-2,5%			-23,5%	47,2%		23,0%	
middle	Mannheim	**51**		10,7	934	**62**	18,3	**1,50**	0,26
		-3,2%			-22,4%	47,0%		23,0%	
south	Lisbon	**30**		9,4	129	**22**	6,9	**1,44**	0,22
		-5,7%			-25,0%	43,5%		22,0%	
5.000 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**70**		7,4	4.931	**107**	26,0	**1,33**	0,23
		-1,5%			-19,9%	49,2%		22,0%	
middle	Mannheim	**65**		8,4	3.010	**83**	20,9	**1,33**	0,24
		-1,8%			-19,5%	48,6%		22,0%	
south	Lisbon	**45**		10,6	596	**37**	11,1	**1,32**	0,23
		-3,2%			-19,7%	47,0%		22,2%	
8.760 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**76**		6,0	9.758	**128**	29,8	**1,25**	0,22
		-1,2%			-17,9%	47,8%		21,4%	
middle	Mannheim	**72**		6,9	6.245	**103**	24,4	**1,25**	0,22
		-1,4%			-18,3%	47,2%		21,4%	
south	Lisbon	**57**		9,6	1.557	**51**	13,7	**1,24**	0,22
		-2,2%			-18,9%	46,2%		21,6%	

Delta in Invest

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

		Heat production	colth production	total
noth	Helsinki	10.252 €	1.461 €	11.714 €
middle	Mannheim	9.975 €	9.904 €	19.879 €
south	Lisbon	6.291 €	15.231 €	21.521 €

Difference in Invest (HRS 21.350 €)

Selected Operation

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

100 / 50 % load		3D Optimum	s	∅ Diff. - costs	ΔP average		s	w	s
2.350 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**61**		9,3	2.251	**58**	15,2	**1,22**	0,21
middle	Mannheim	**53**		10,4	1.204	**42**	12,0	**1,22**	0,21
south	Lisbon	**31**		9,4	172	**15**	4,6	**1,18**	0,19
5.000 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**71**		7,1	6.155	**72**	17,0	**1,09**	0,19
middle	Mannheim	**66**		8,2	3.741	**56**	13,7	**1,09**	0,19
south	Lisbon	**47**		10,6	742	**25**	7,4	**1,08**	0,18
8.760 h/a		%		%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**77**		5,7	11.882	**87**	19,7	**1,03**	0,18
middle	Mannheim	**73**		6,6	7.641	**70**	16,1	**1,03**	0,18
south	Lisbon	**58**		9,4	1.920	**35**	9,1	**1,02**	0,18

ΔInvest heat- and colthproduction

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

100 / 50 % load		3D		∅ Diff.	ΔP			
		Optimum	s	- costs	average	s	w	s
2.350 h/a		%	%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**67**	9,1	3.309	**61**	15,2	**1,10**	0,21
		10,2%		47,0%	4,5%		-9,8%	
middle	Mannheim	**66**	9,9	2.955	**50**	30,8	**1,01**	0,21
		25,1%		145,4%	18,0%		-17,2%	
south	Lisbon	**58**	11,8	1.527	**32**	33,7	**0,96**	0,19
		85,4%		787,8%	107,8%		-18,6%	
5.000 h/a		%	%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**74**	7,1	7.493	**72**	17,0	**1,01**	0,18
		4,5%		21,7%	-0,4%		-7,3%	
middle	Mannheim	**73**	8,0	5.860	**58**	14,8	**0,95**	0,18
		11,0%		56,6%	3,2%		-12,8%	
south	Lisbon	**64**	10,5	2.532	**35**	30,3	**0,90**	0,17
		36,3%		241,2%	40,6%		-16,7%	
8.760 h/a		%	%	€/a	Pa	Pa	m/s	m/s
north	Helsinki	**79**	5,9	13.600	**85**	19,8	**0,97**	0,17
		2,6%		14,5%	-2,1%		-5,8%	
middle	Mannheim	**78**	6,7	10.147	**69**	17,1	**0,92**	0,17
		6,0%		32,8%	-1,1%		-10,7%	
south	Lisbon	**69**	9,1	3.990	**41**	30,4	**0,88**	0,16
		18,7%		107,8%	17,4%		-13,7%	

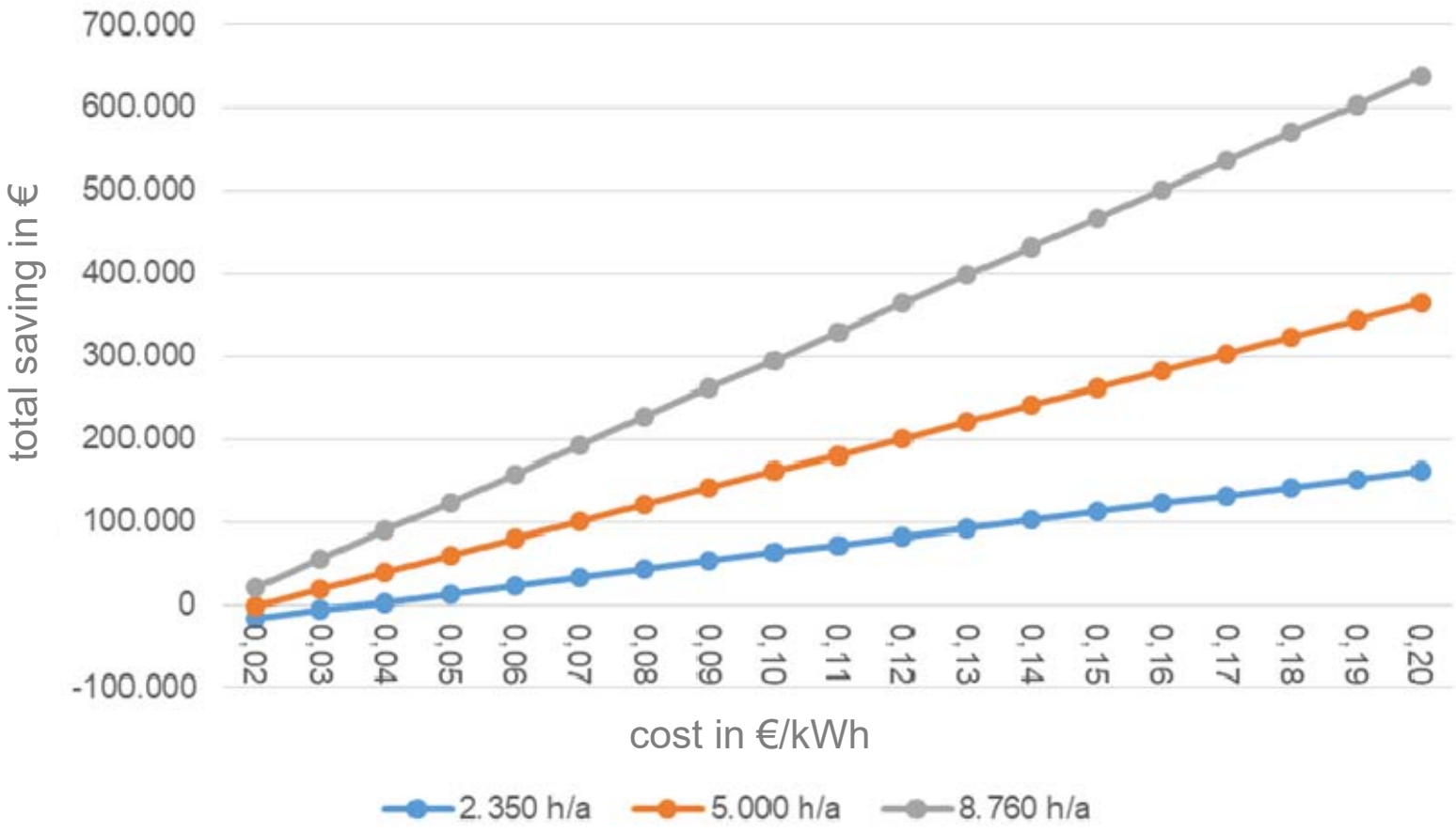
South validation (Roma)

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld

		3D-Optimum	∅ Diff.-costs	ΔP		w
2.350 h/a		%	€/a	Pa		m/s
middle	Mannheim	**53**	10,4	1.204		**42**
south 1	Lisbon	**31**	9,4	172		**26**
south 2	Roma	**40**	11,1	384		**15**
5.000 h/a						
middle	Mannheim	**66**	8,2	3.741		**56**
south 1	Lisbon	**47**	10,6	742		**25**
south 2	Roma	**55**	9,5	1.457		**39**
8.760 h/a						
middle	Mannheim	**73**	6,6	7.641		**70**
south 1	Lisbon	**58**	9,4	1.920		**35**
south 2	Roma	**65**	7,8	3.247		**51**

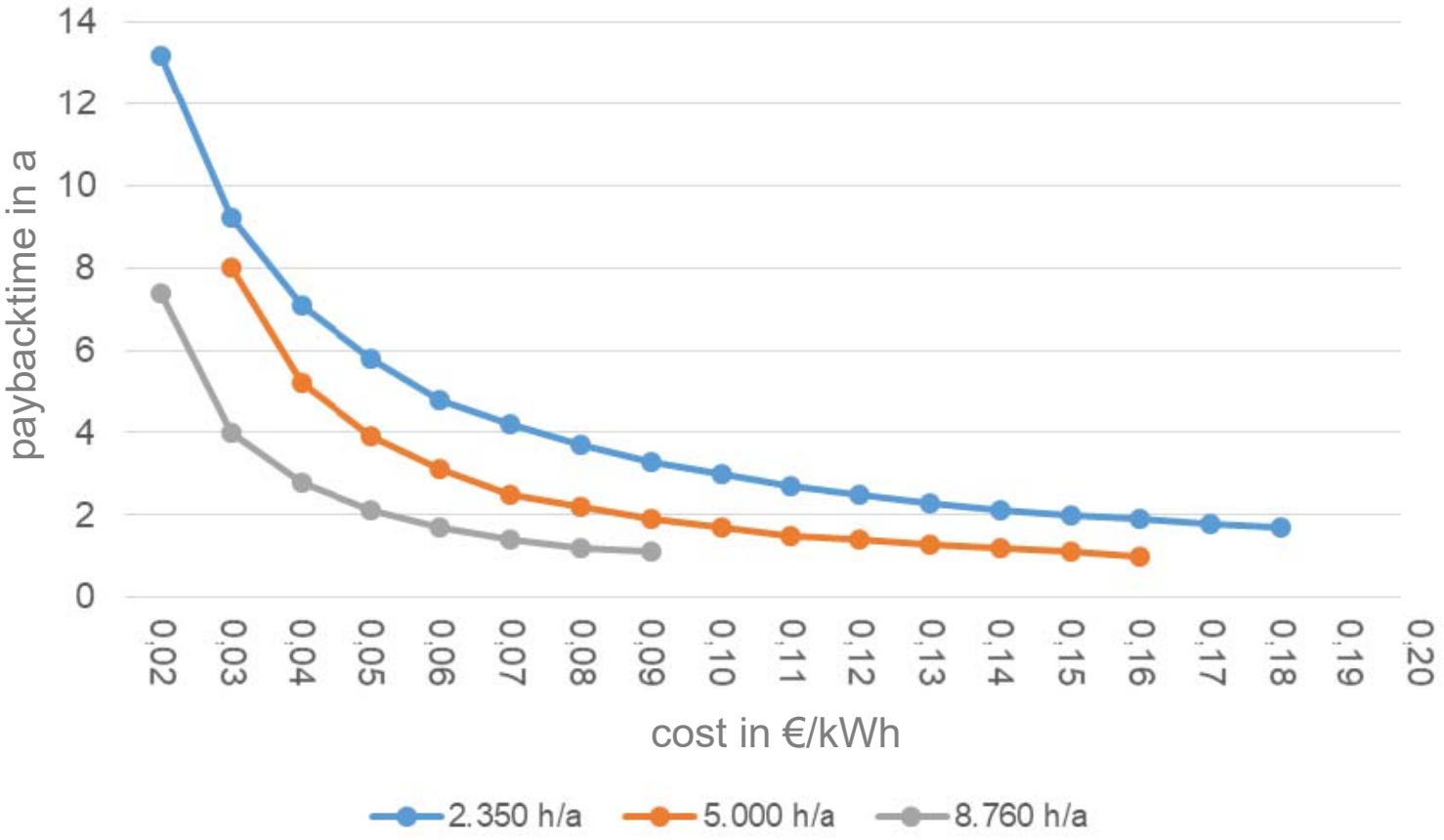
More cooling oriented location (roma)

Influence factors



price for heating

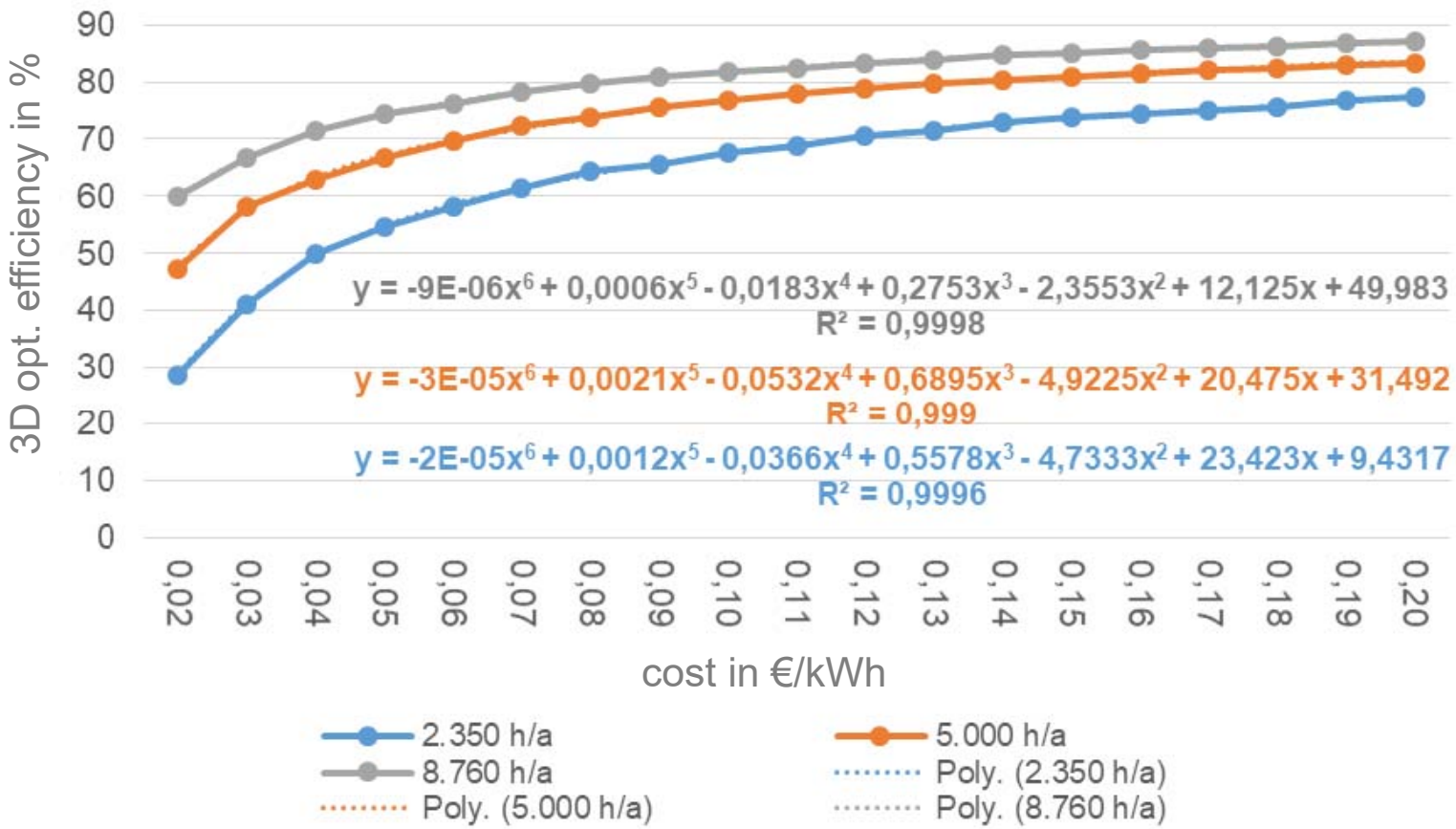
Influence factors



price for heating

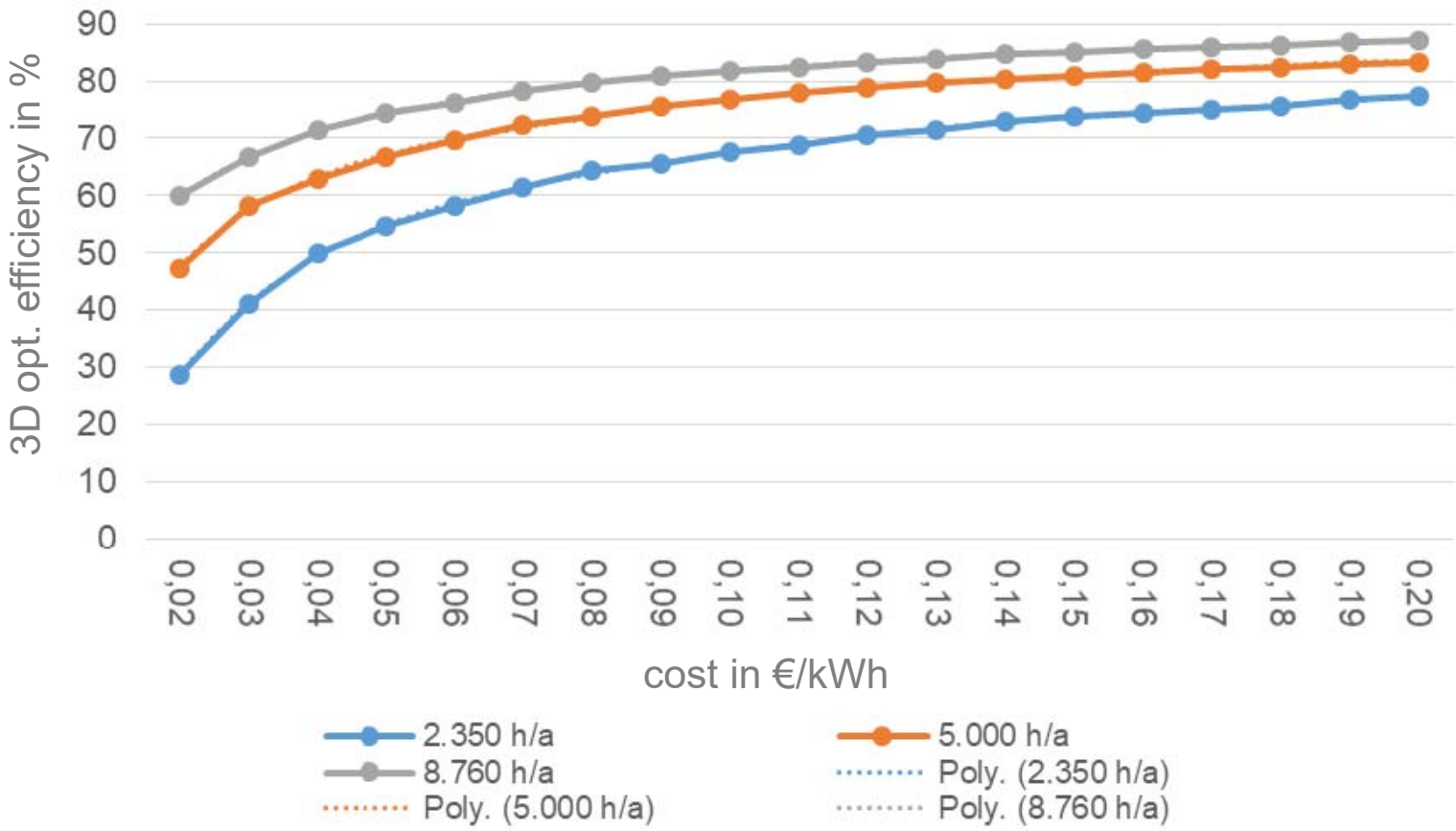
Influence factors

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



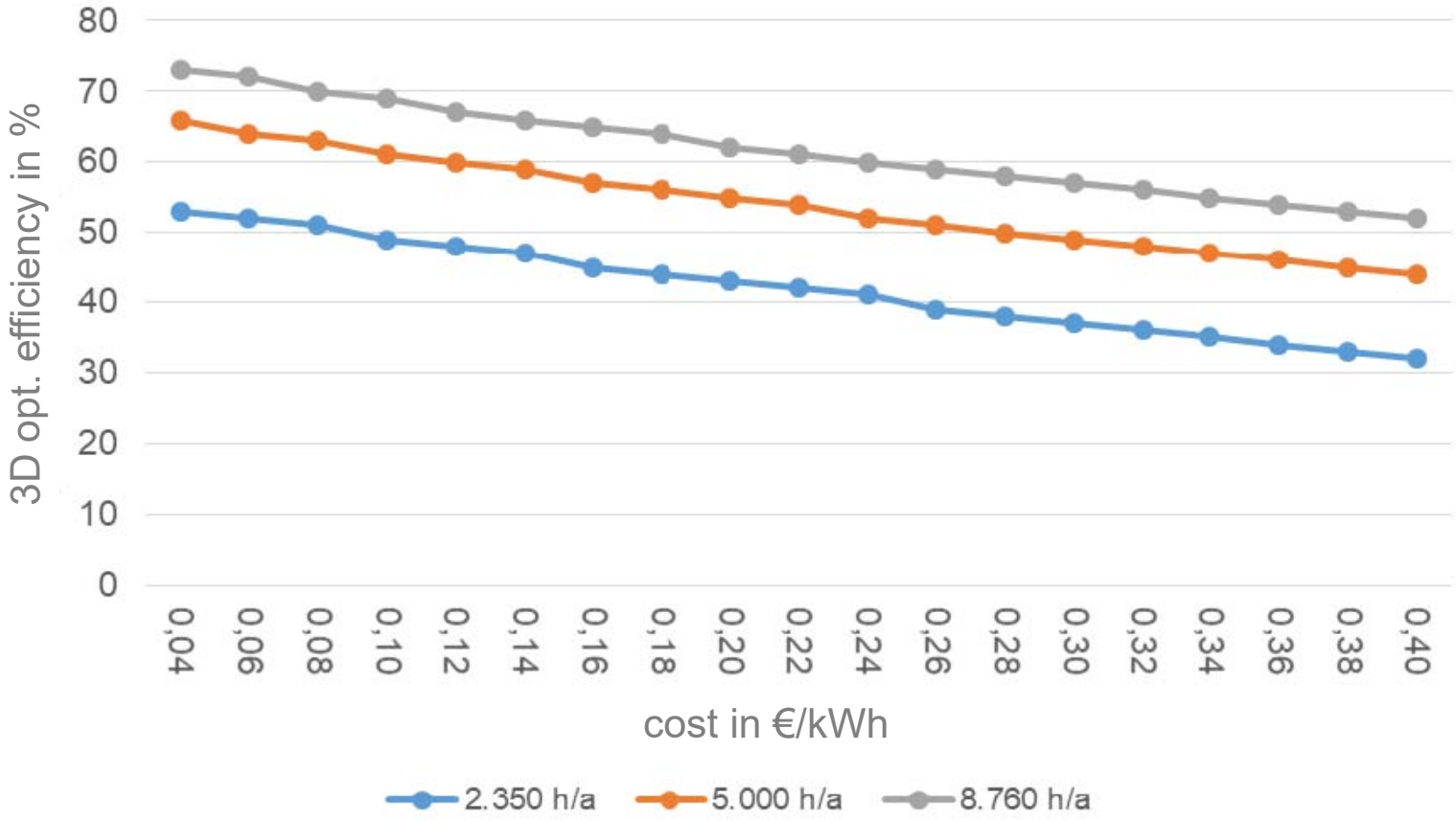
price for heating

Influence factors



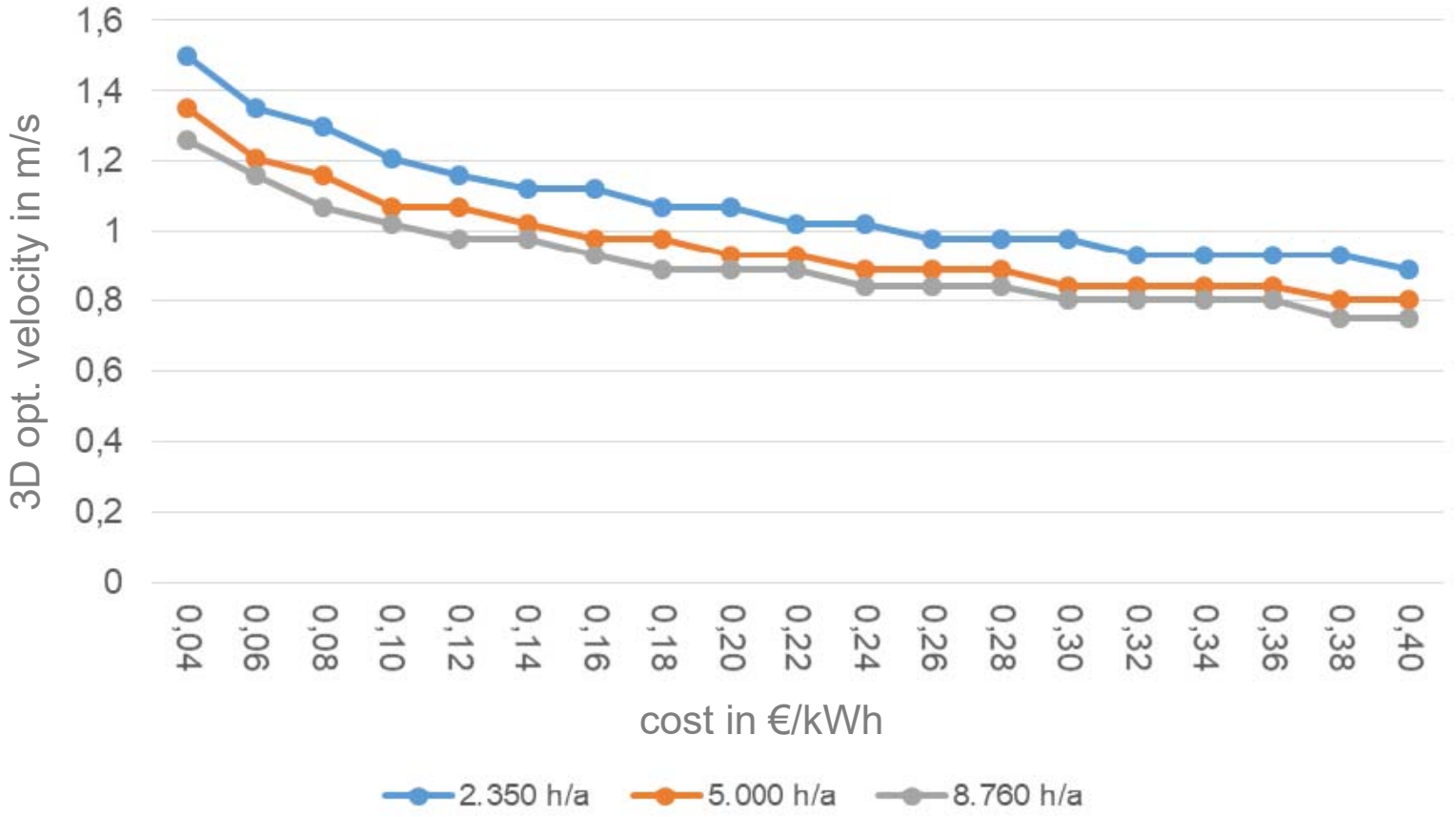
price for heating

Influence factors



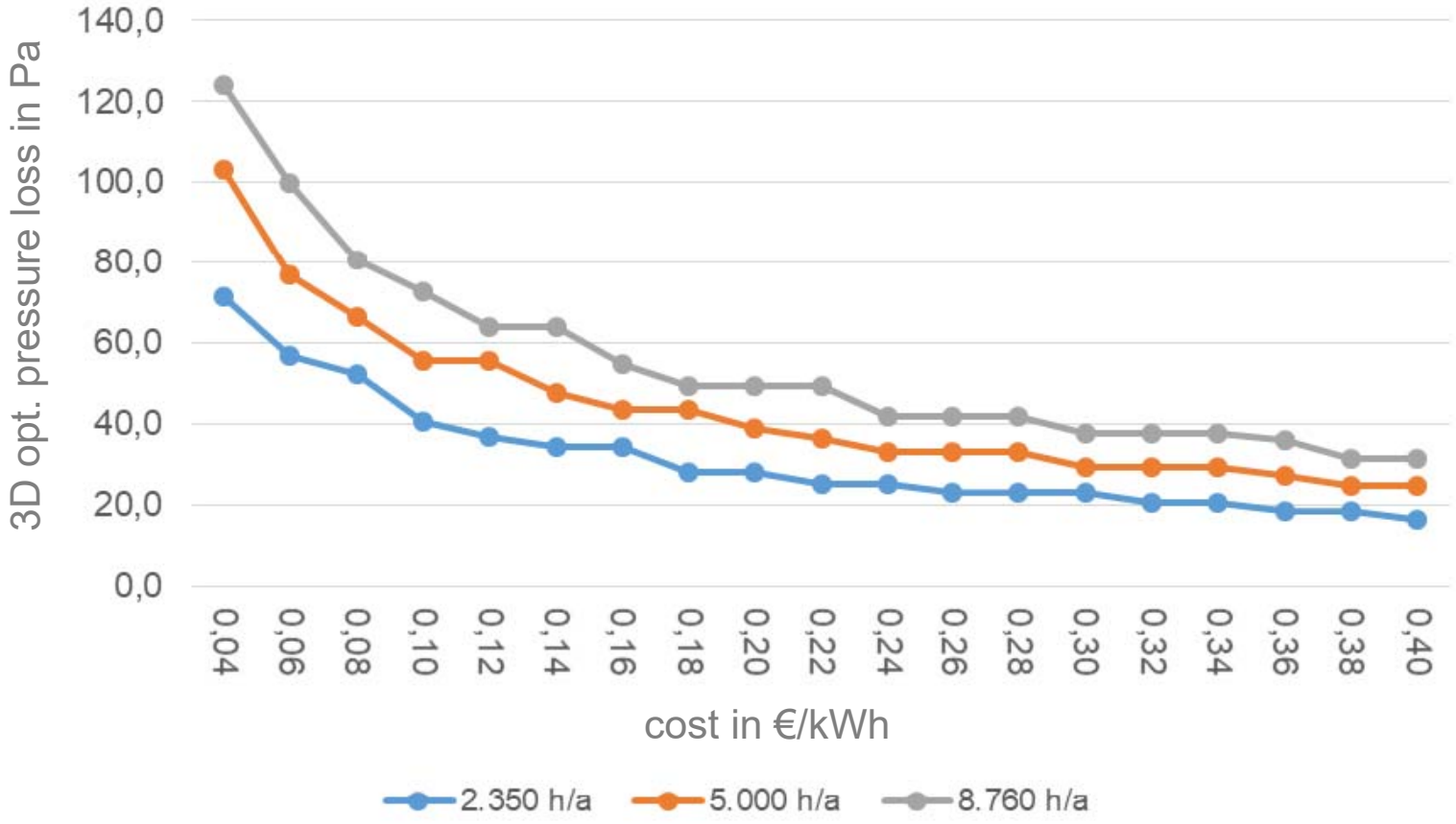
price for electricity

Influence factors



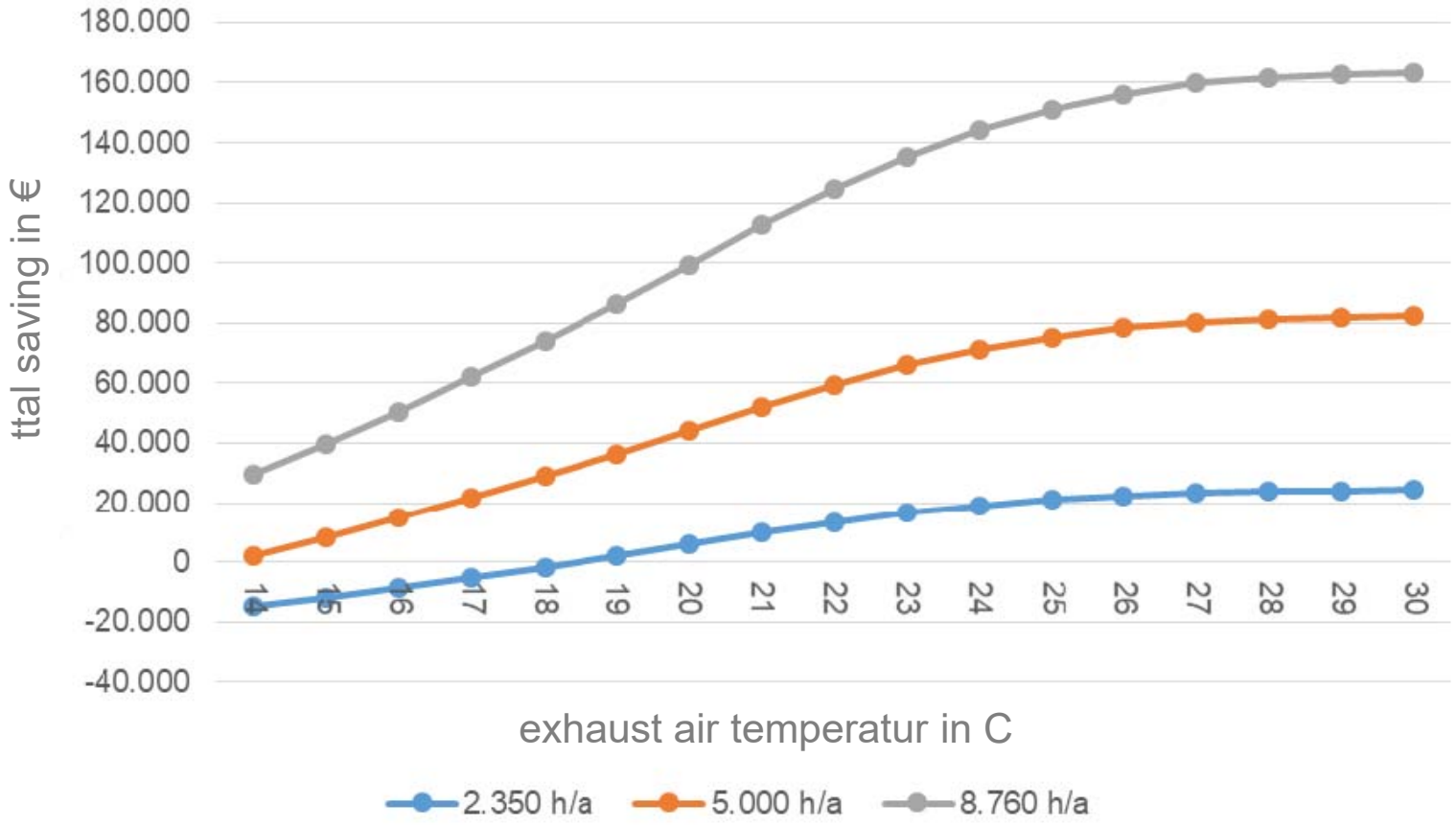
price for electricity

Influence factors



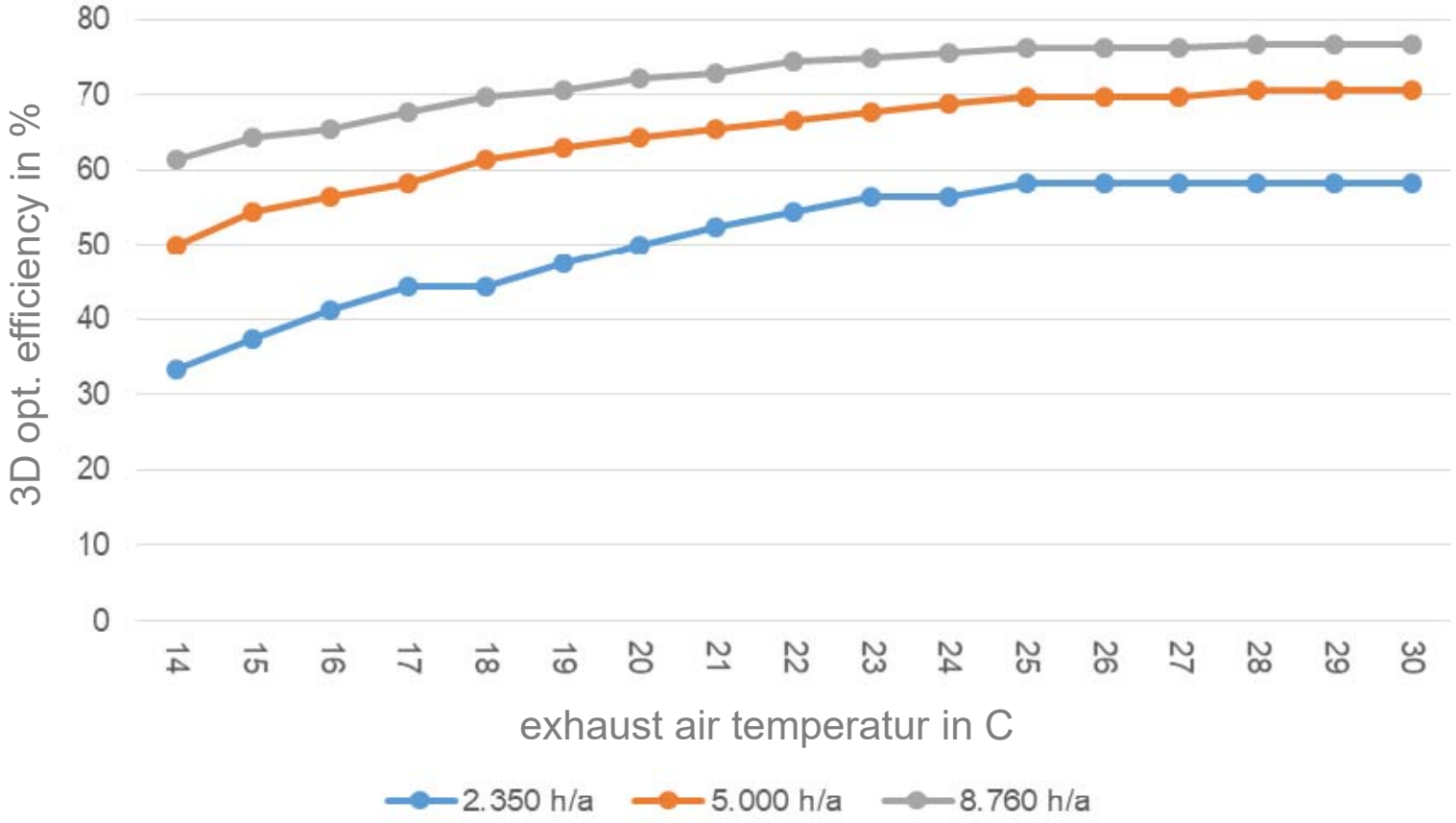
price for electricity

Influence factors



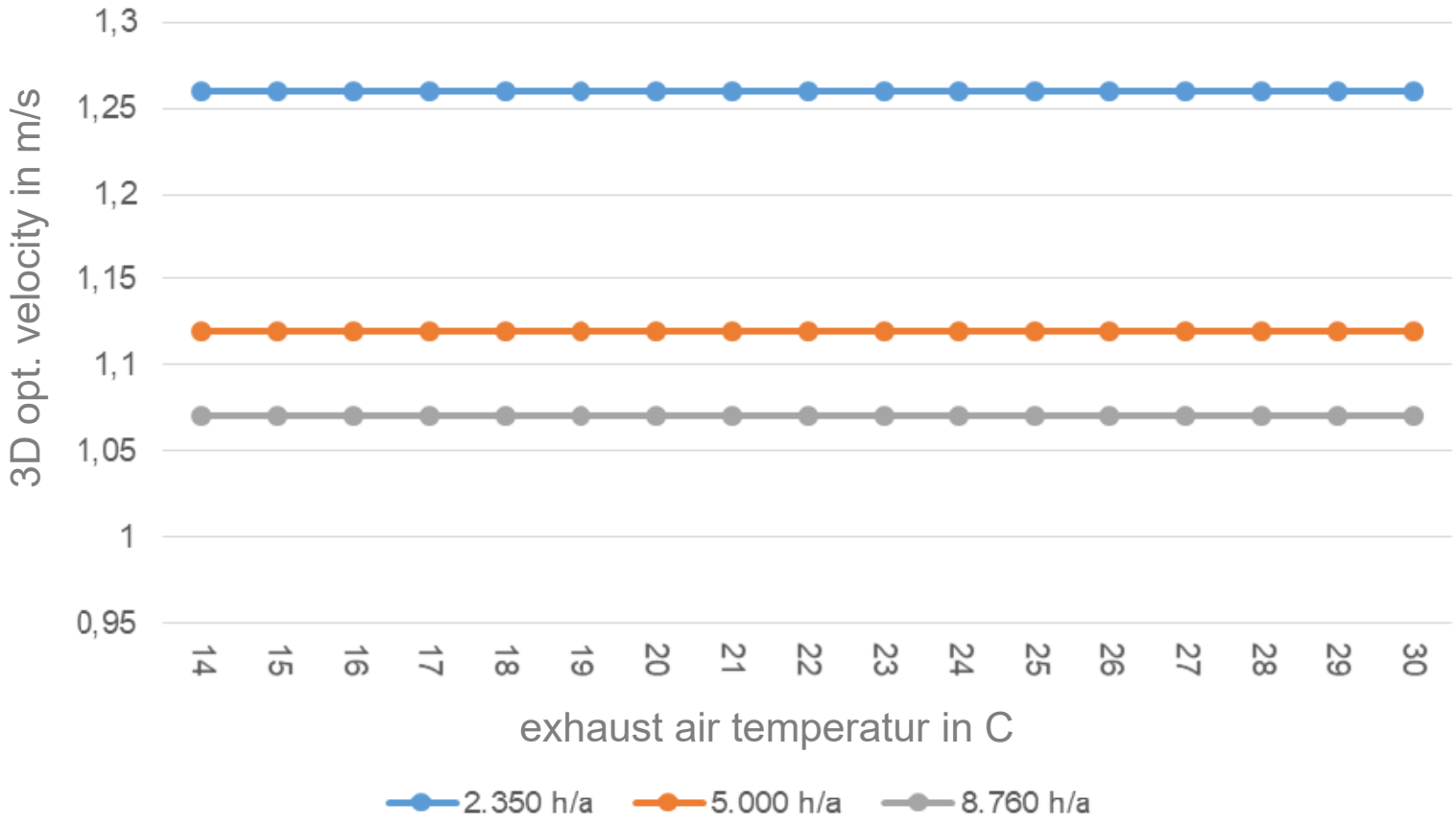
exhaust air temperature

Influence factors



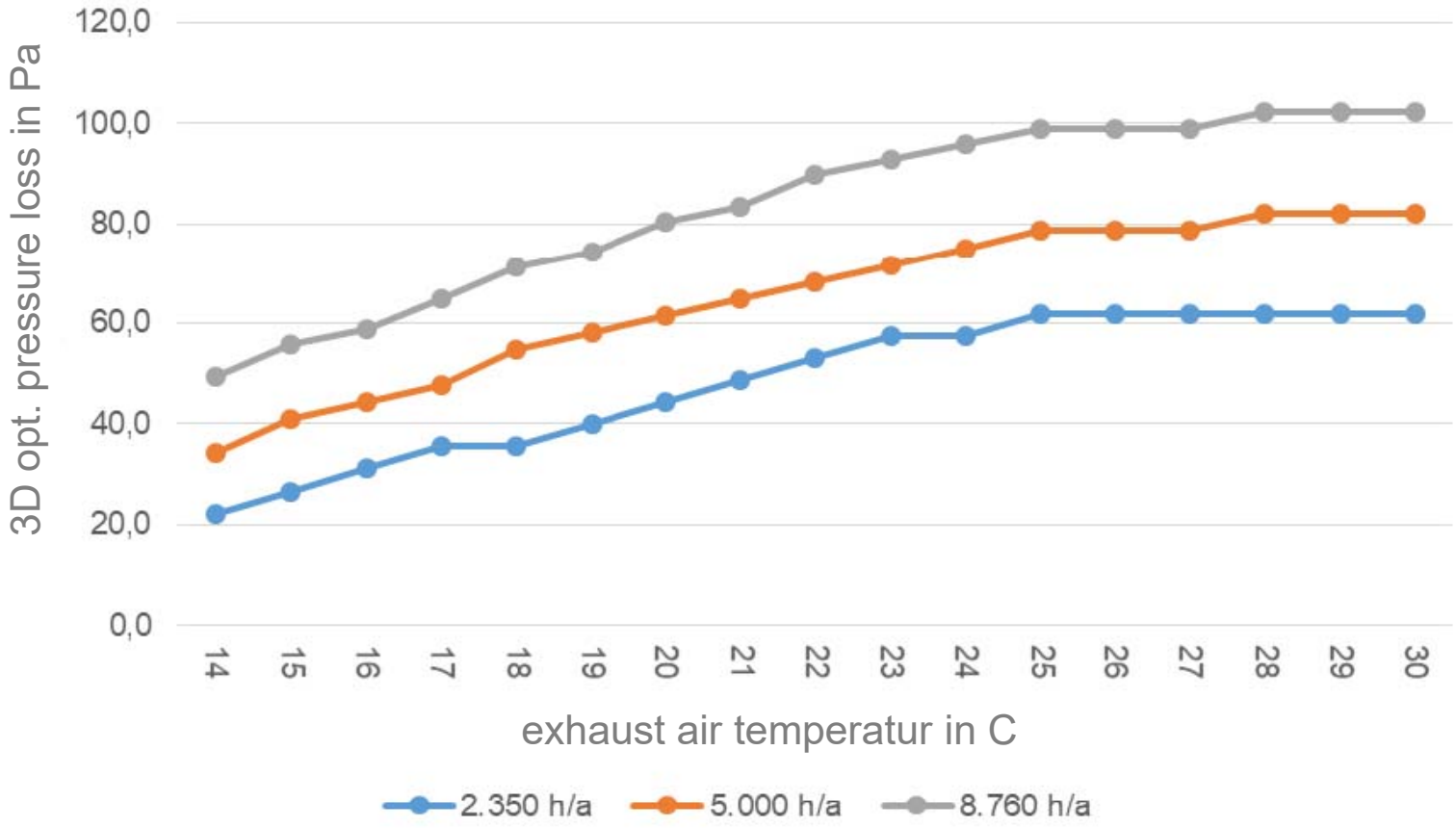
exhaust air temperature

Influence factors



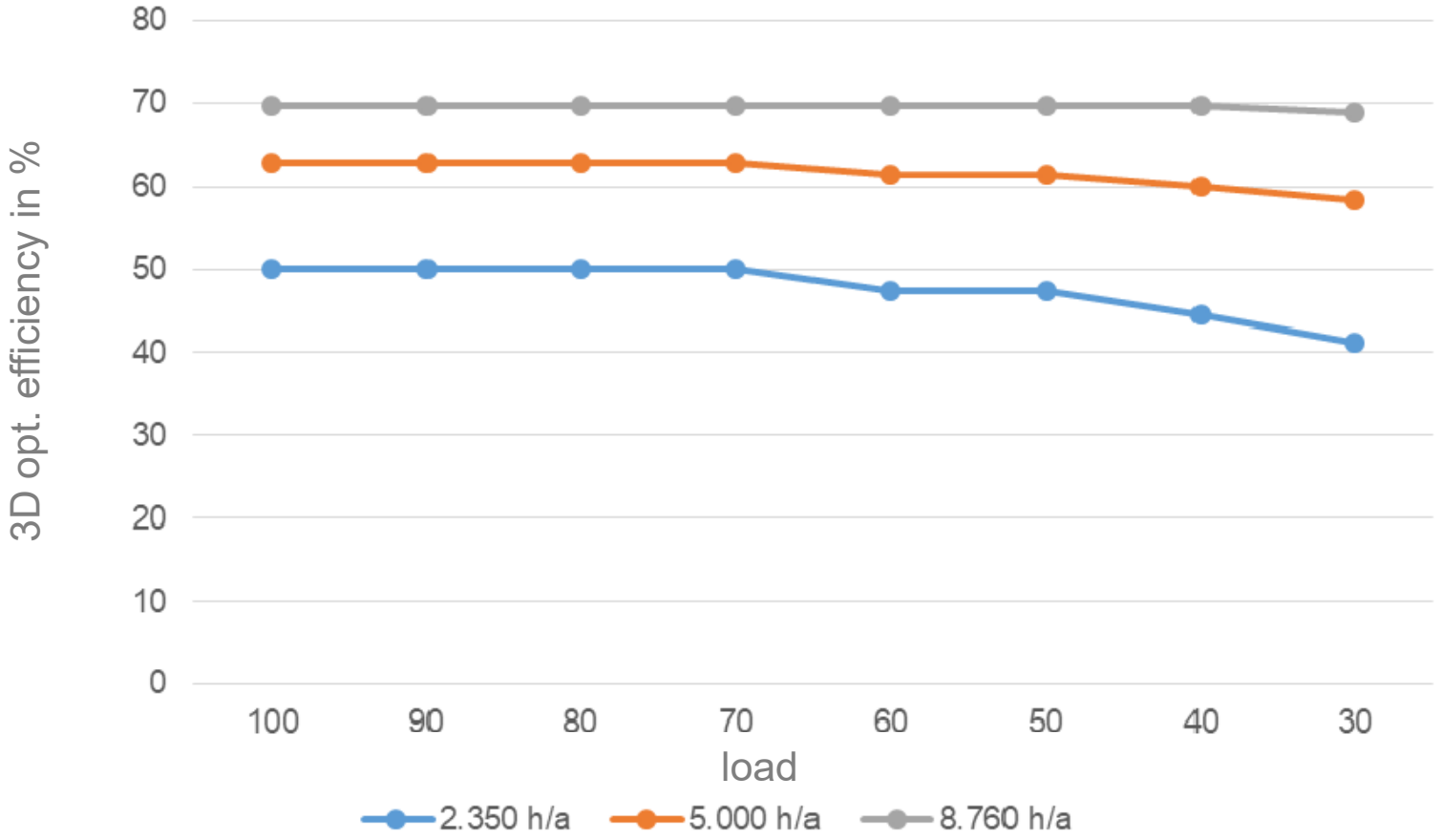
exhaust air temperature

Influence factors



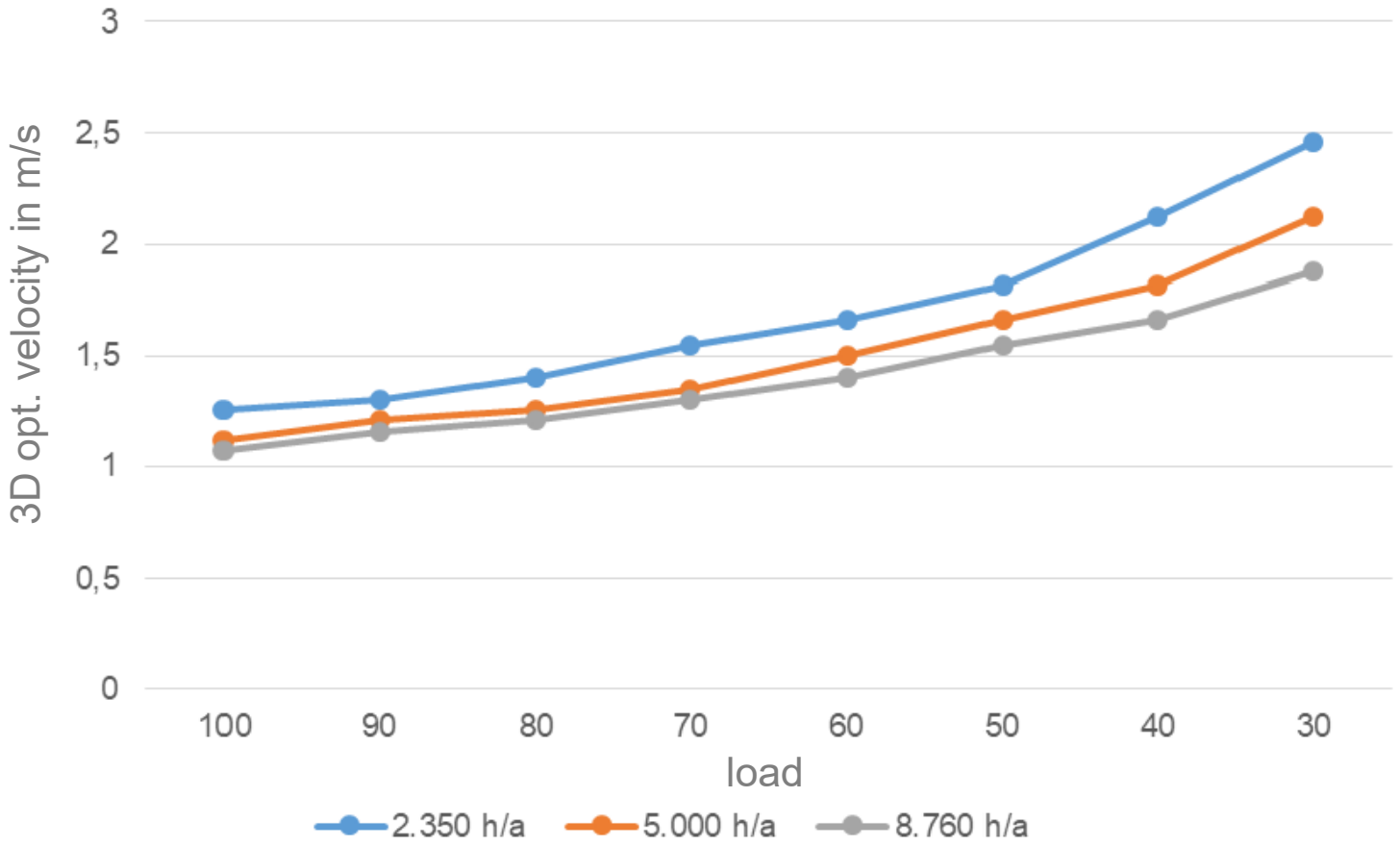
exhaust air temperature

Influence factors



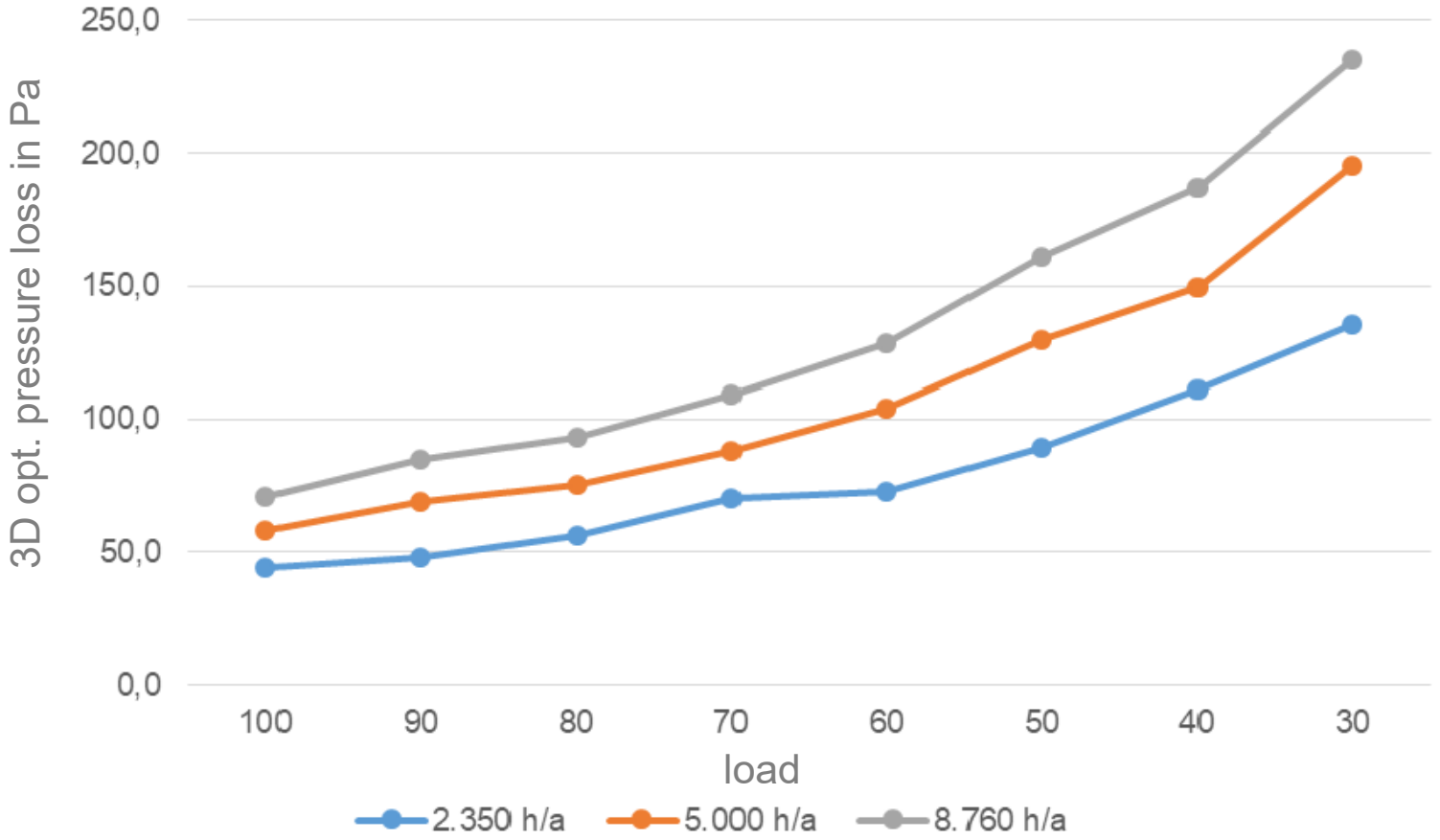
partload operation

Influence factors



partload operation

Influence factors



partload operation

Meteo influence

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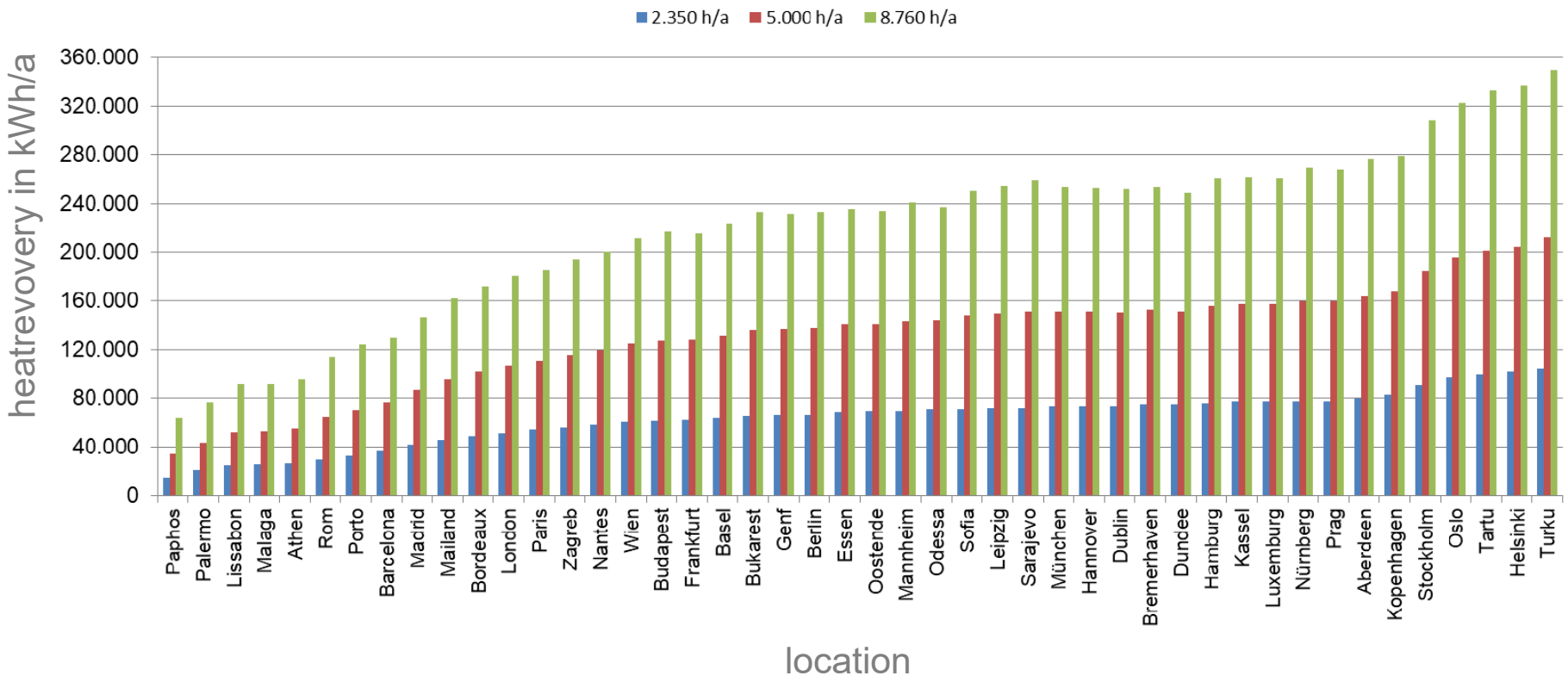
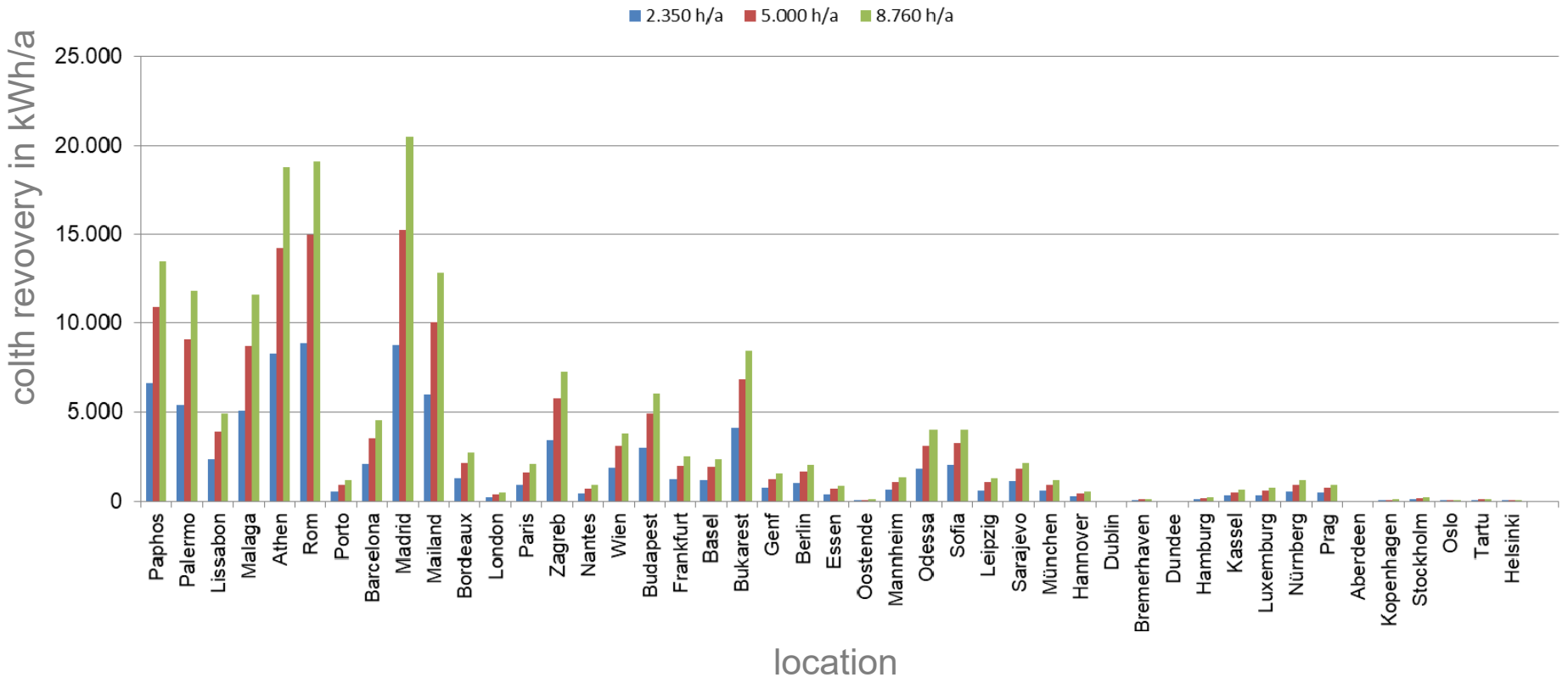


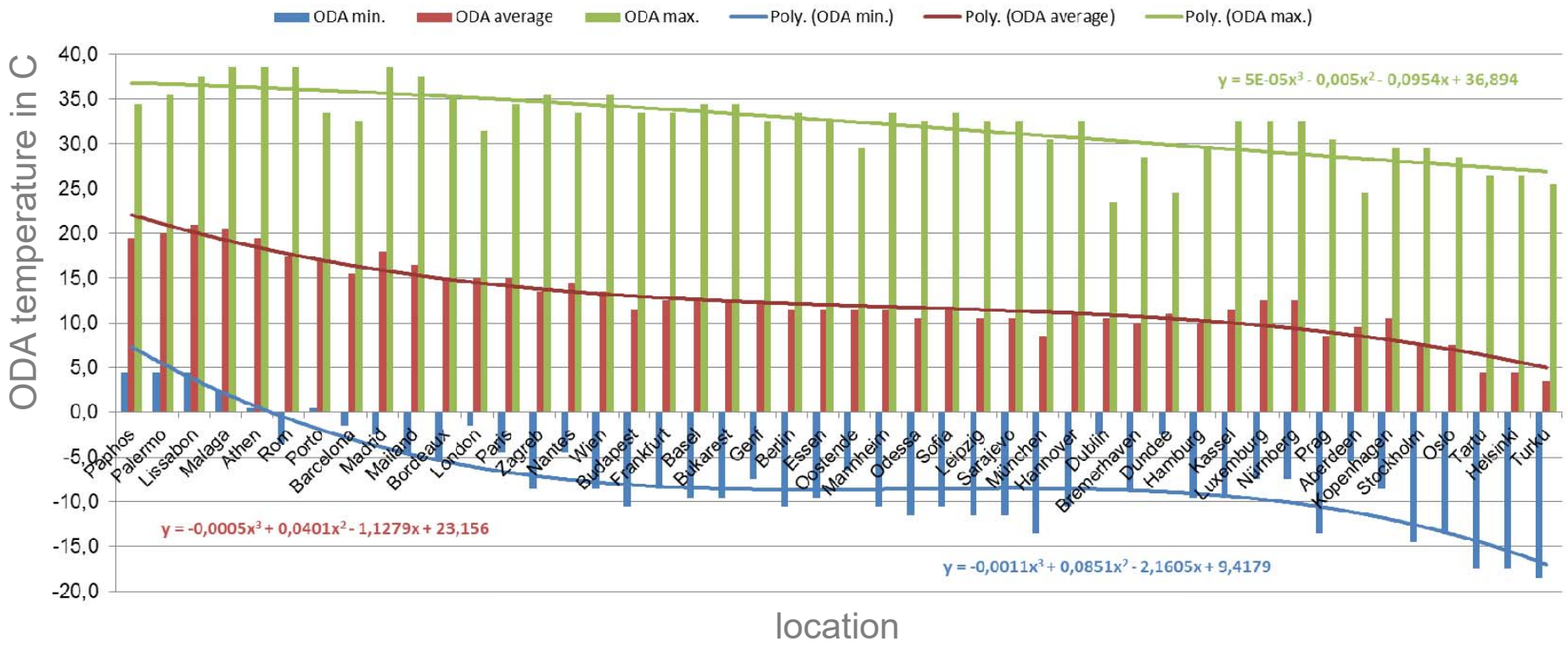
heatrecovery

Meteo influence



sensible colth recovery

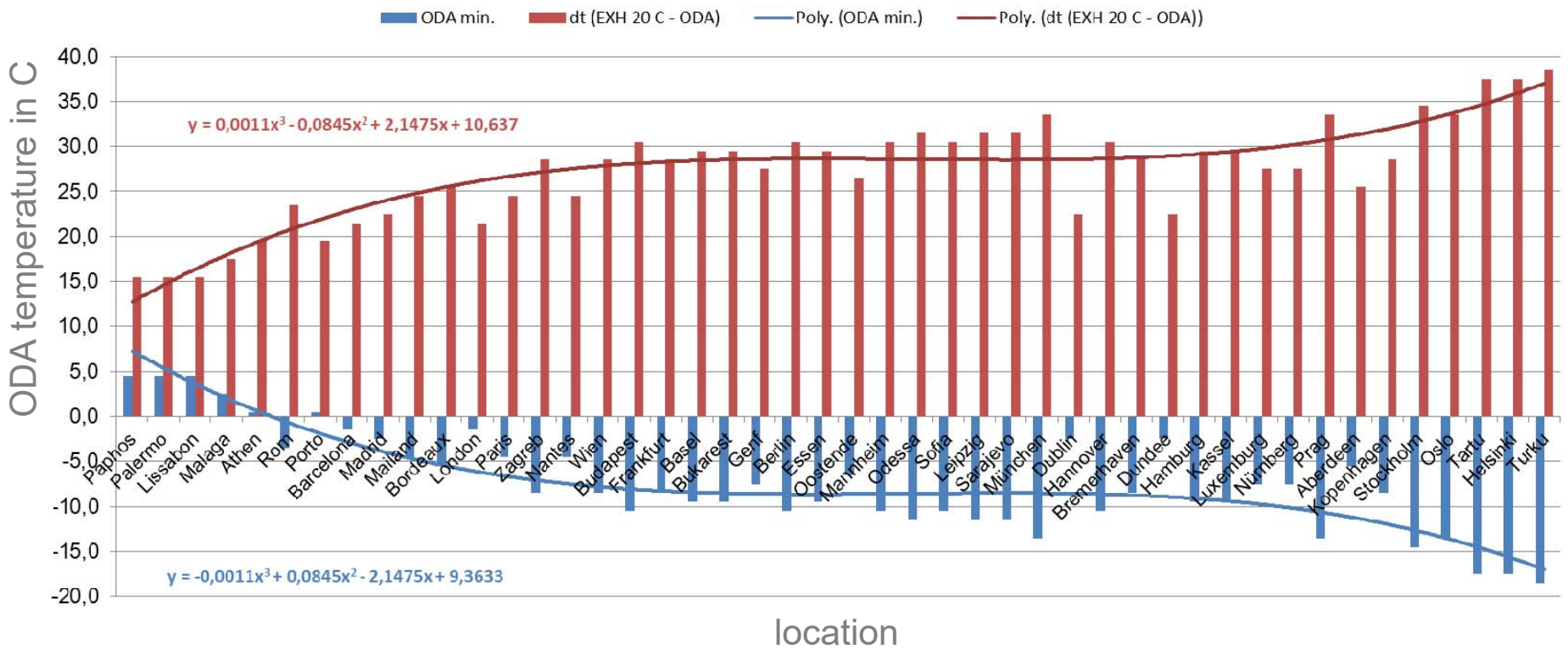
Meteo influence



ODA temperatures in C

Meteo influence

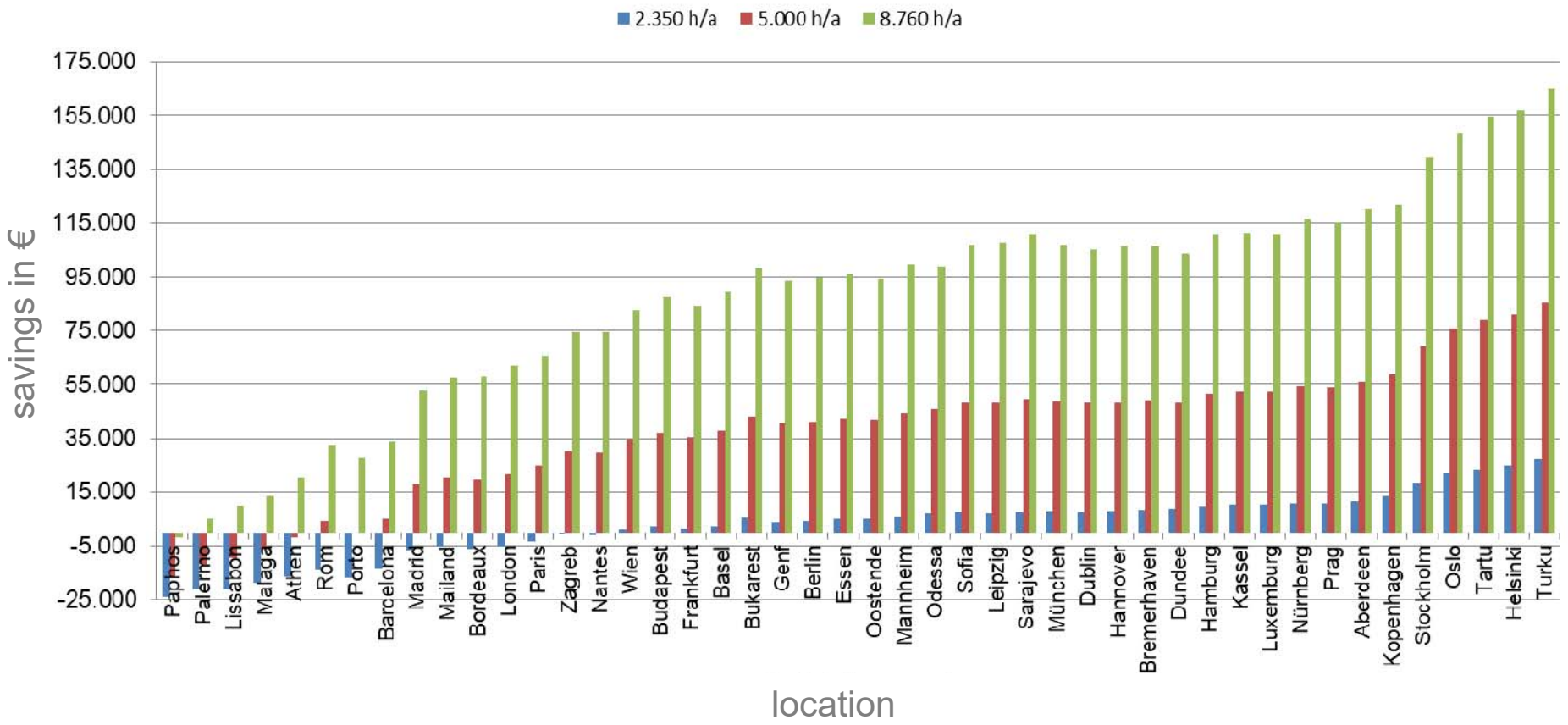
HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



ODA temperatures in C

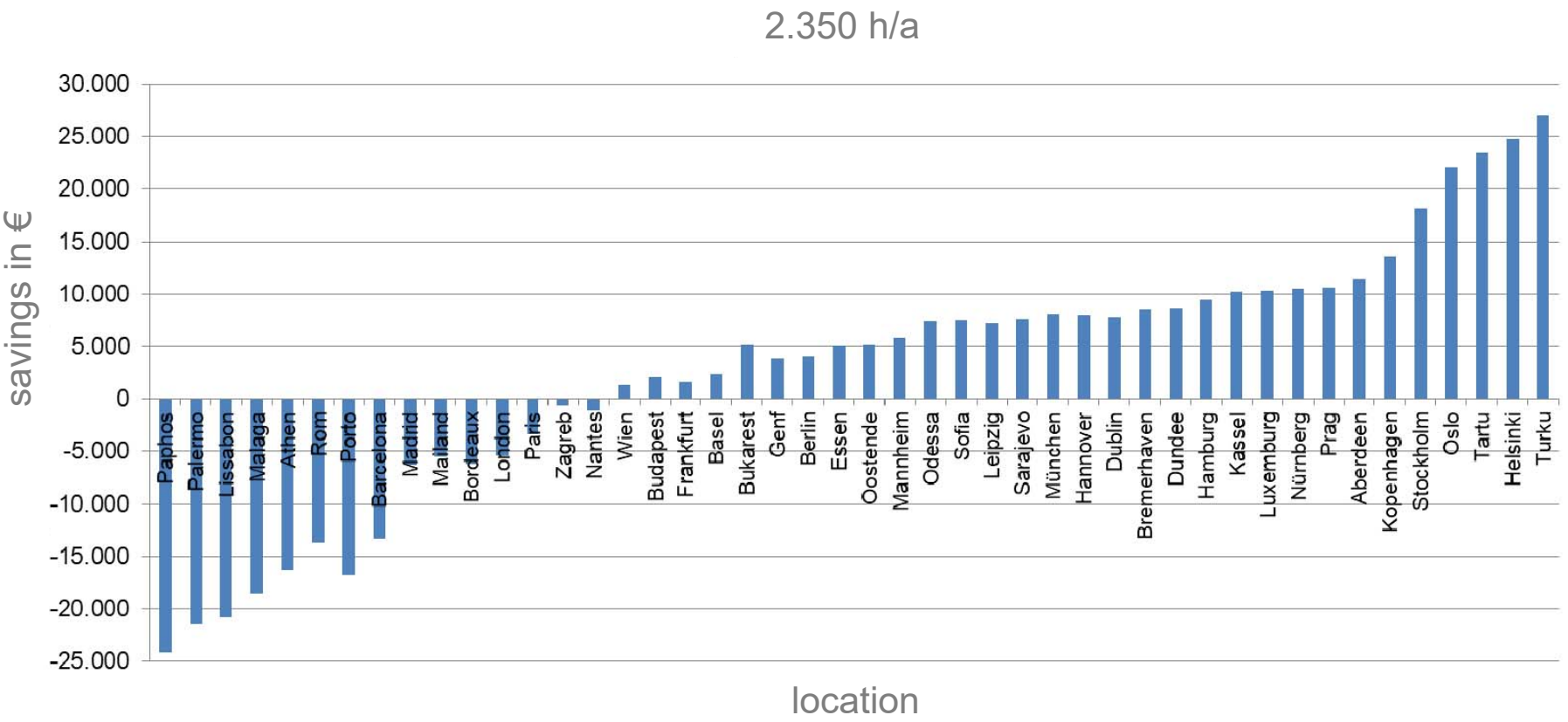
Meteo influence

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



capital value of savings

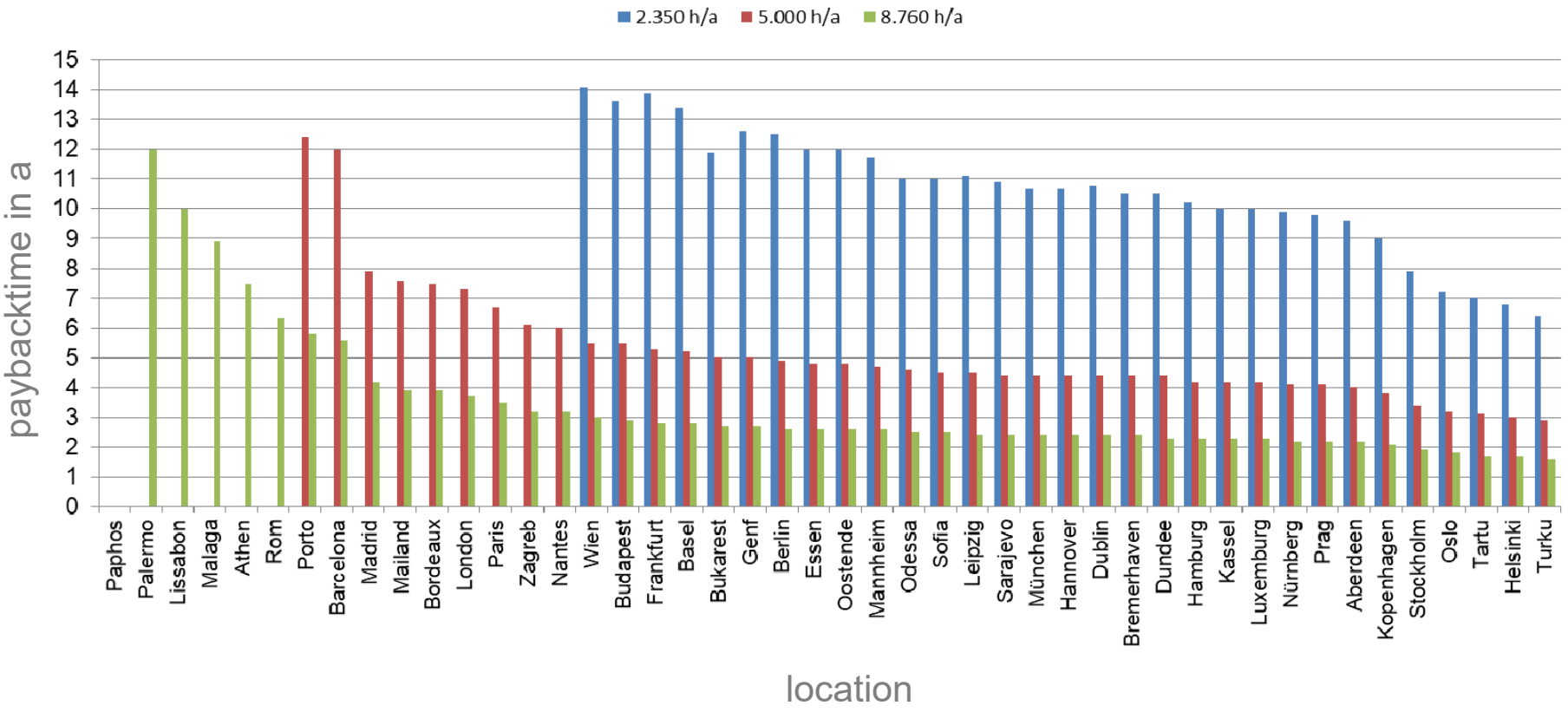
Meteo influence



capital value of savings

Meteo influence

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



payback time

Meteo influence

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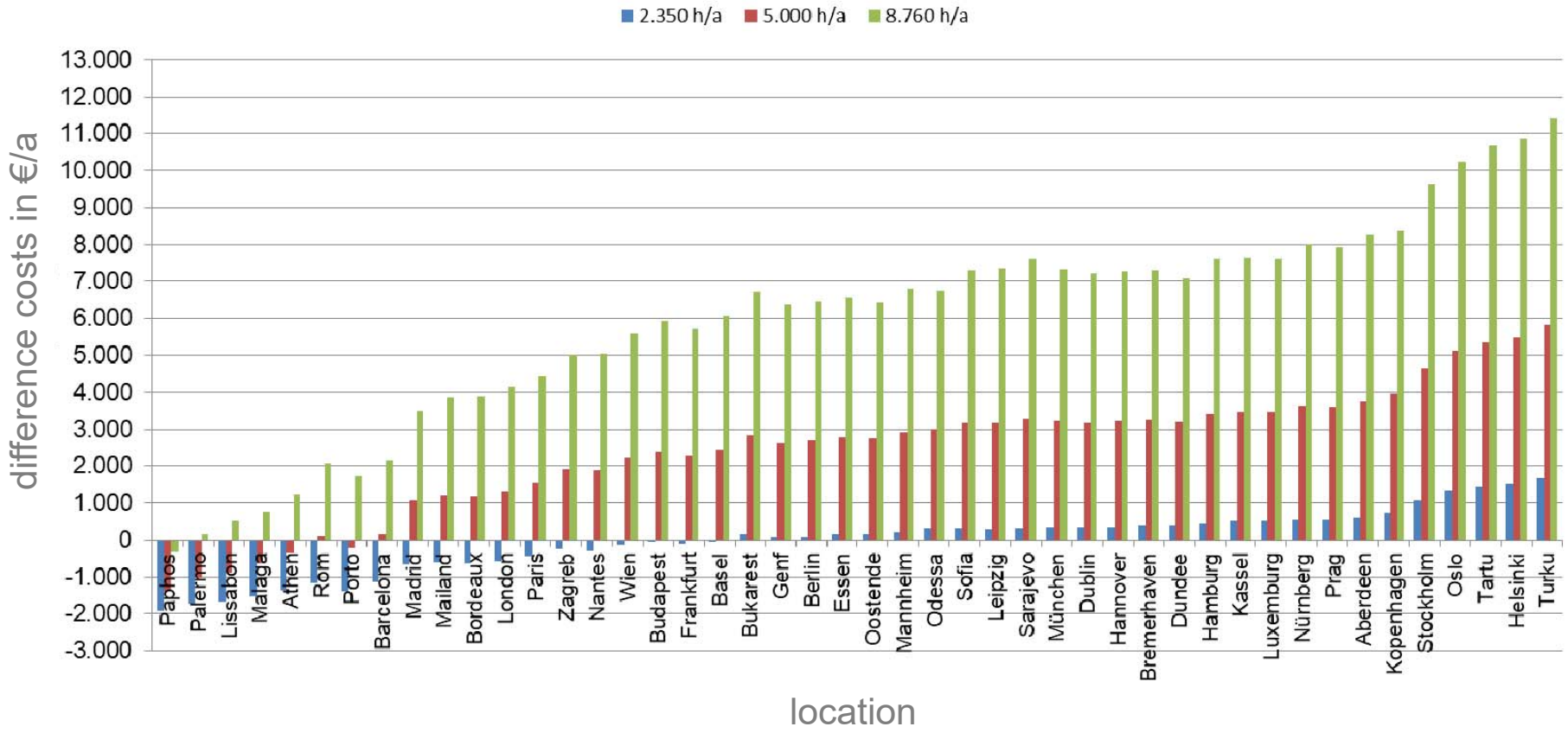
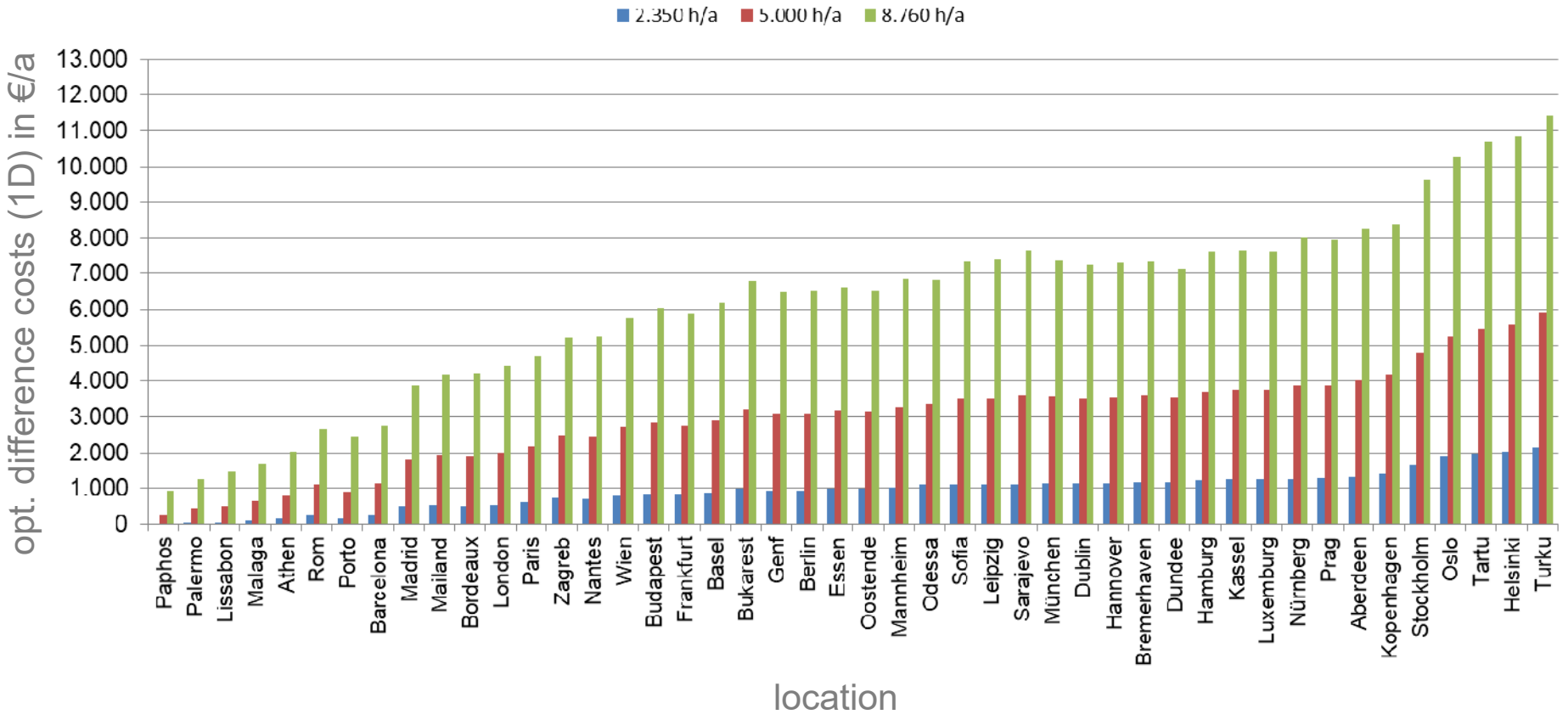
Umwelt-Campus Birkenfeld



difference costs per year

Meteo influence

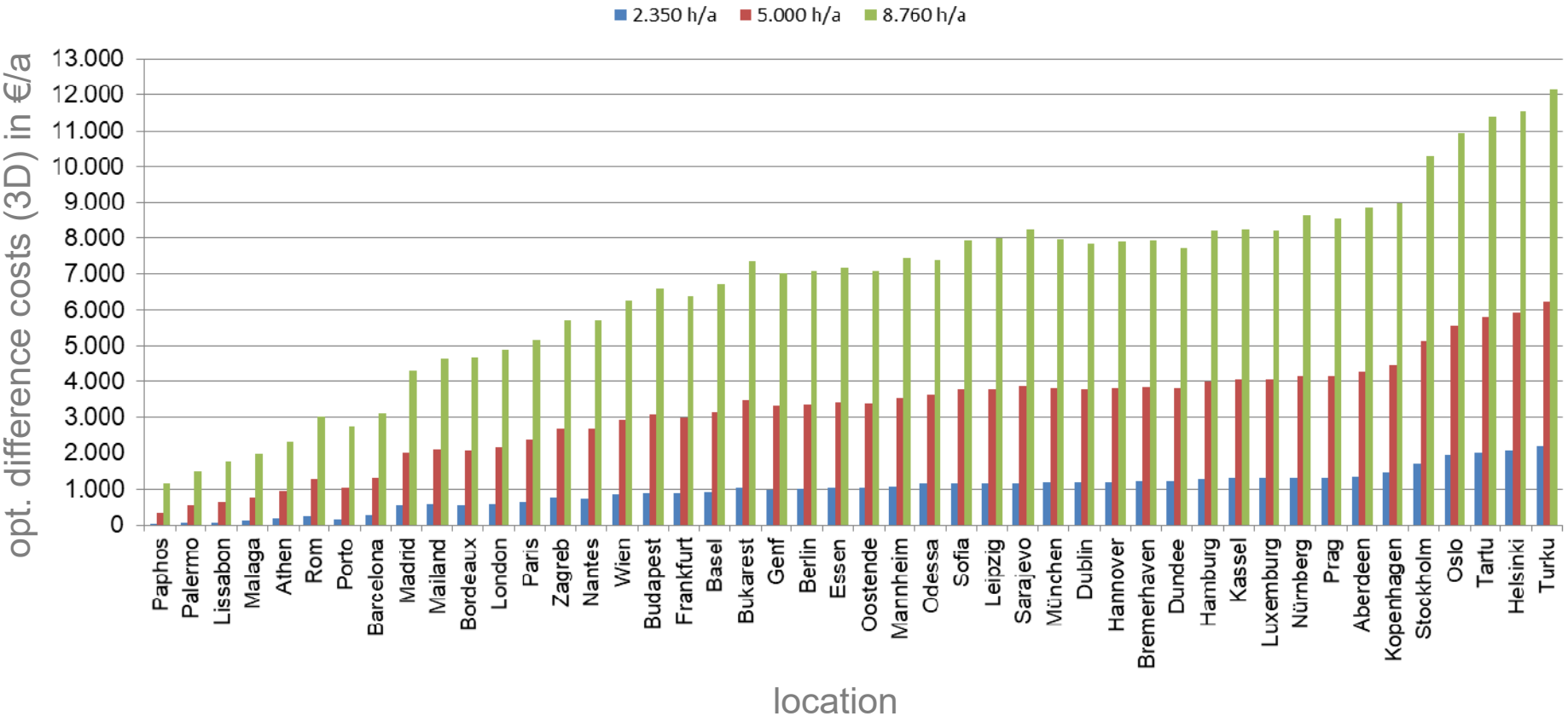
HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



difference costs per year 1D optimized

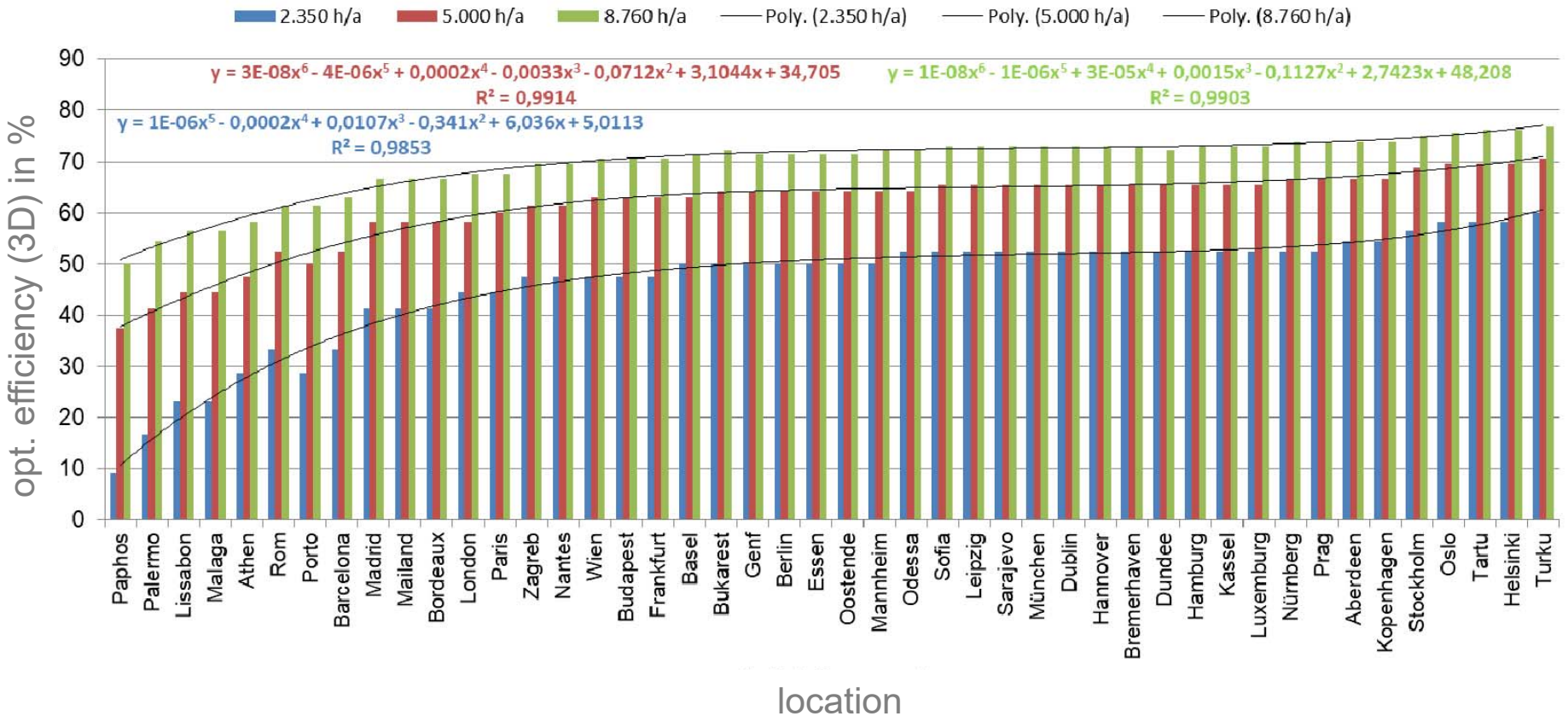
Meteo influence

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



difference costs per year 3D optimized

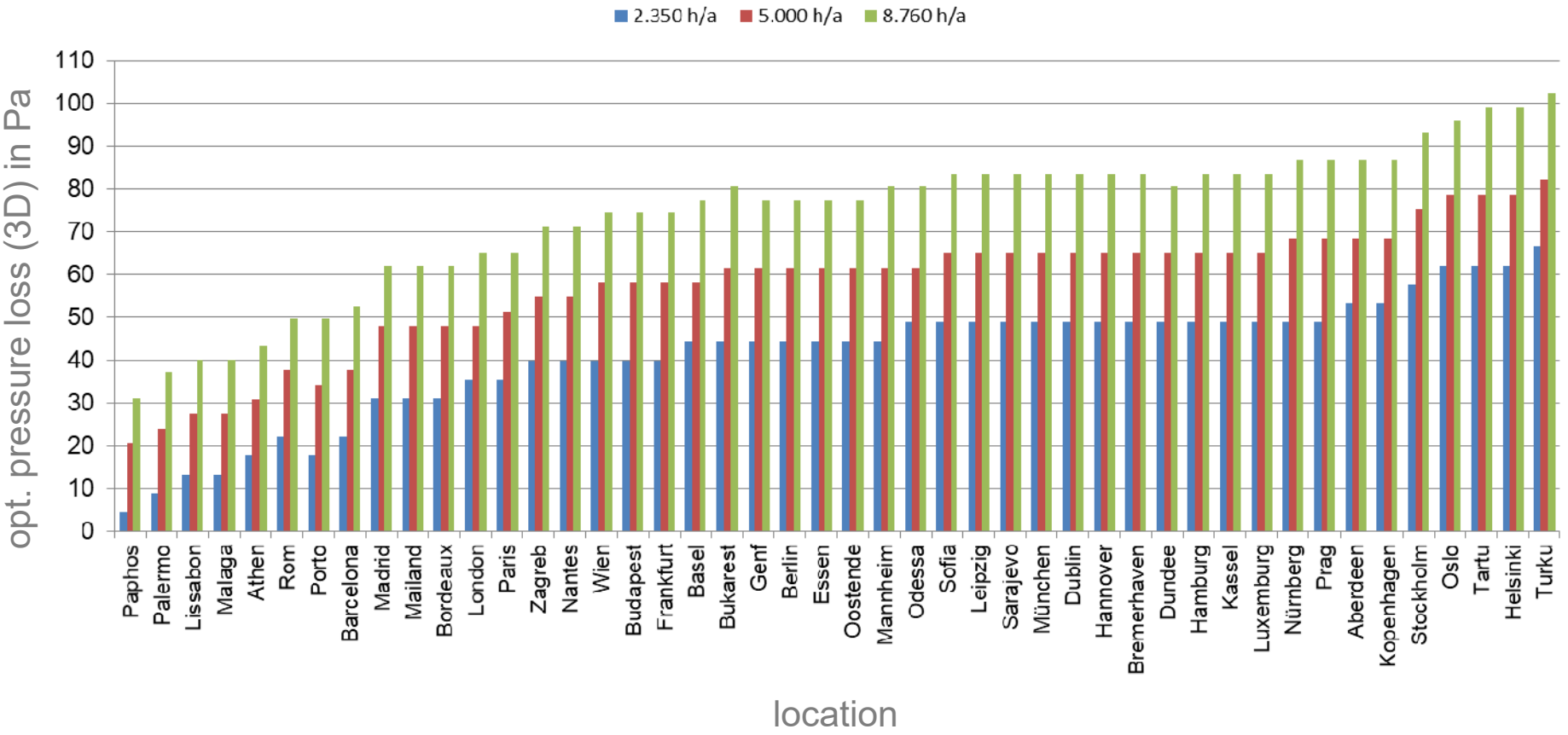
Meteo influence



efficiency 3D optimized

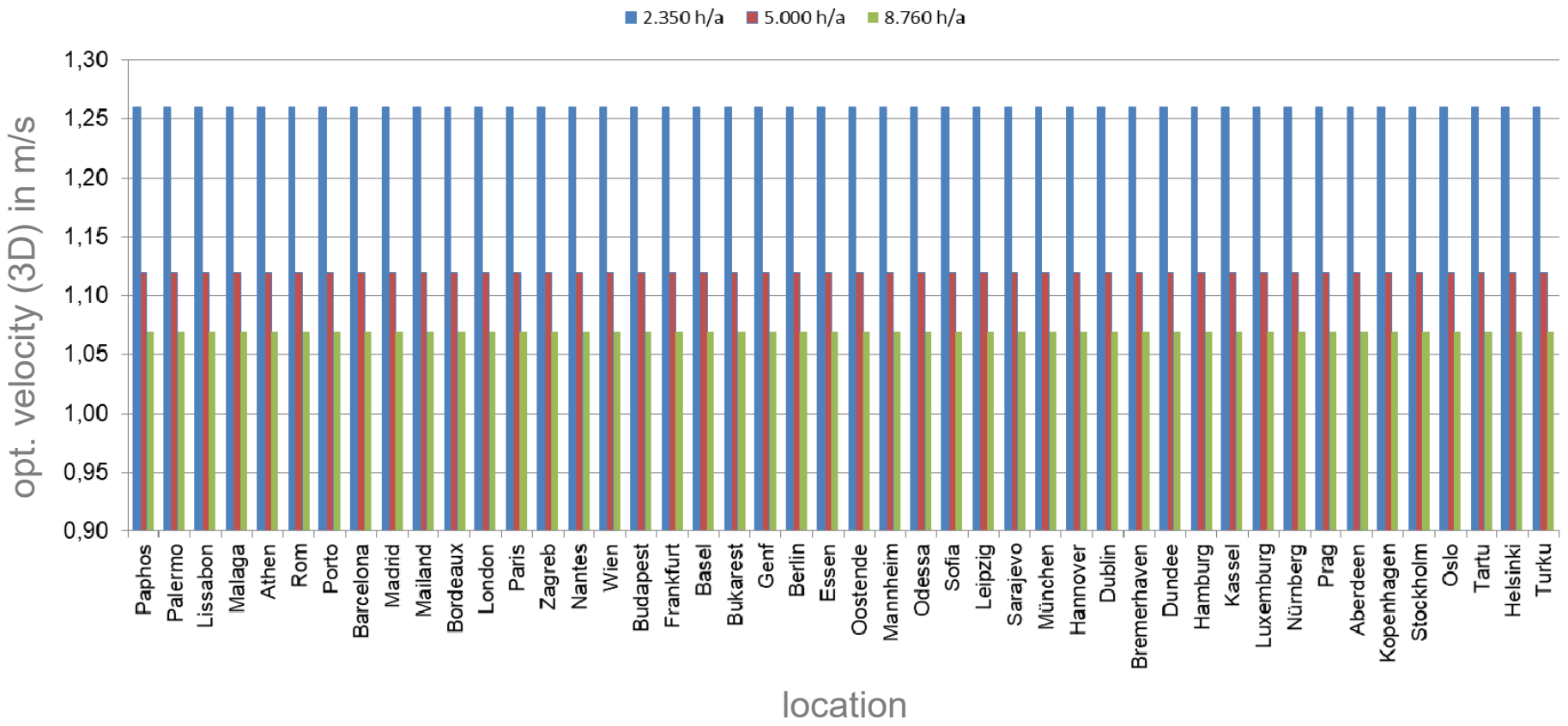
Meteo influence

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



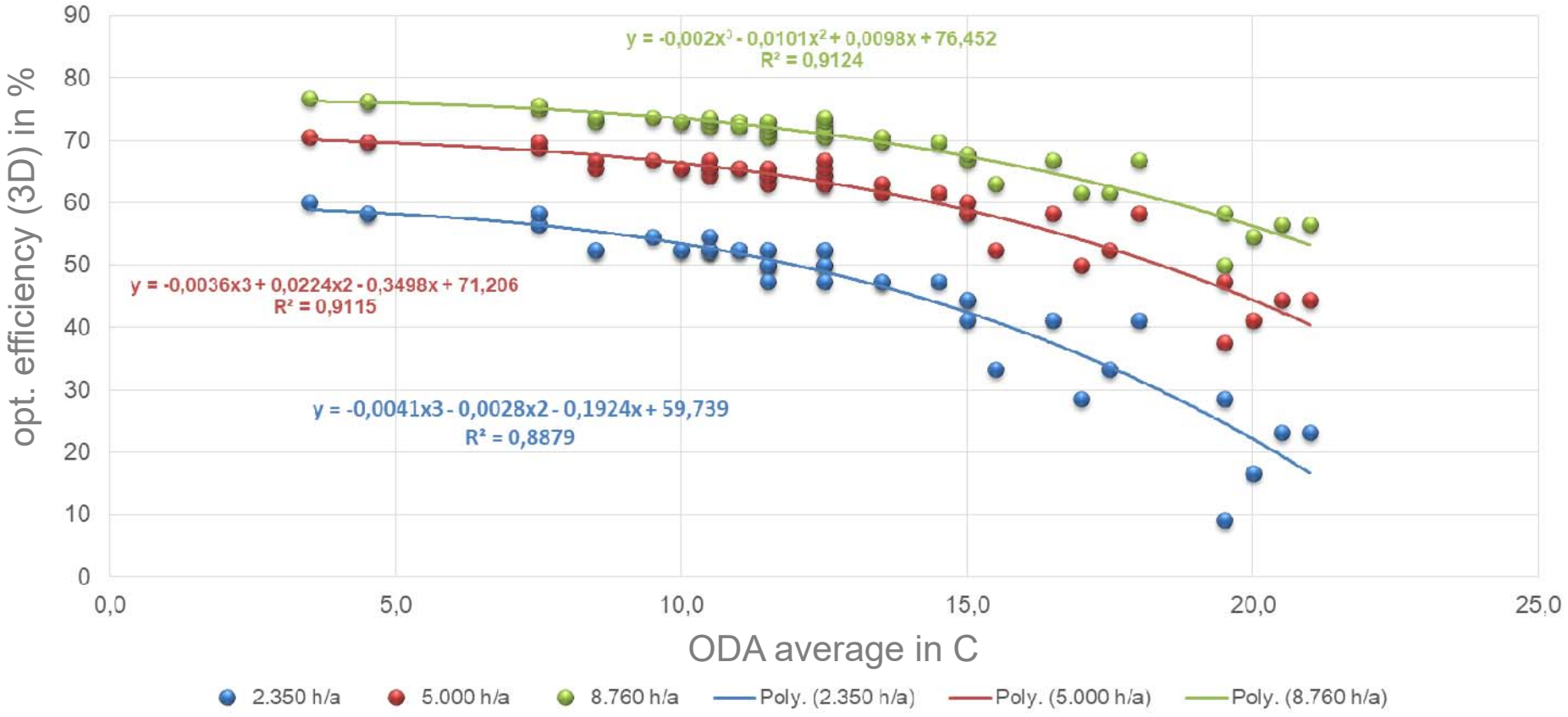
Pressure losses 3D optimized

Meteo influence



velocity 3D optimized

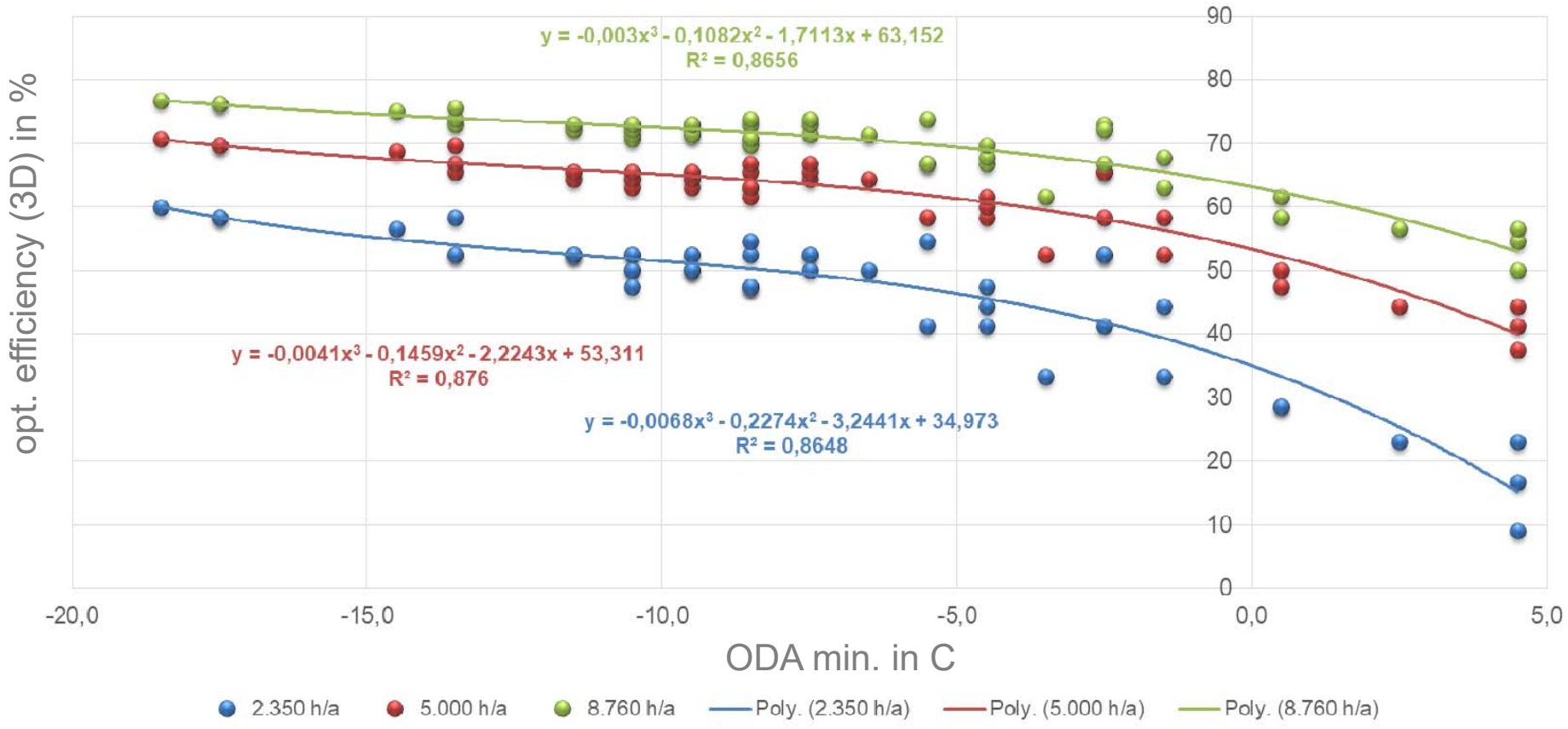
Meteo influence



efficiency 3D optimized

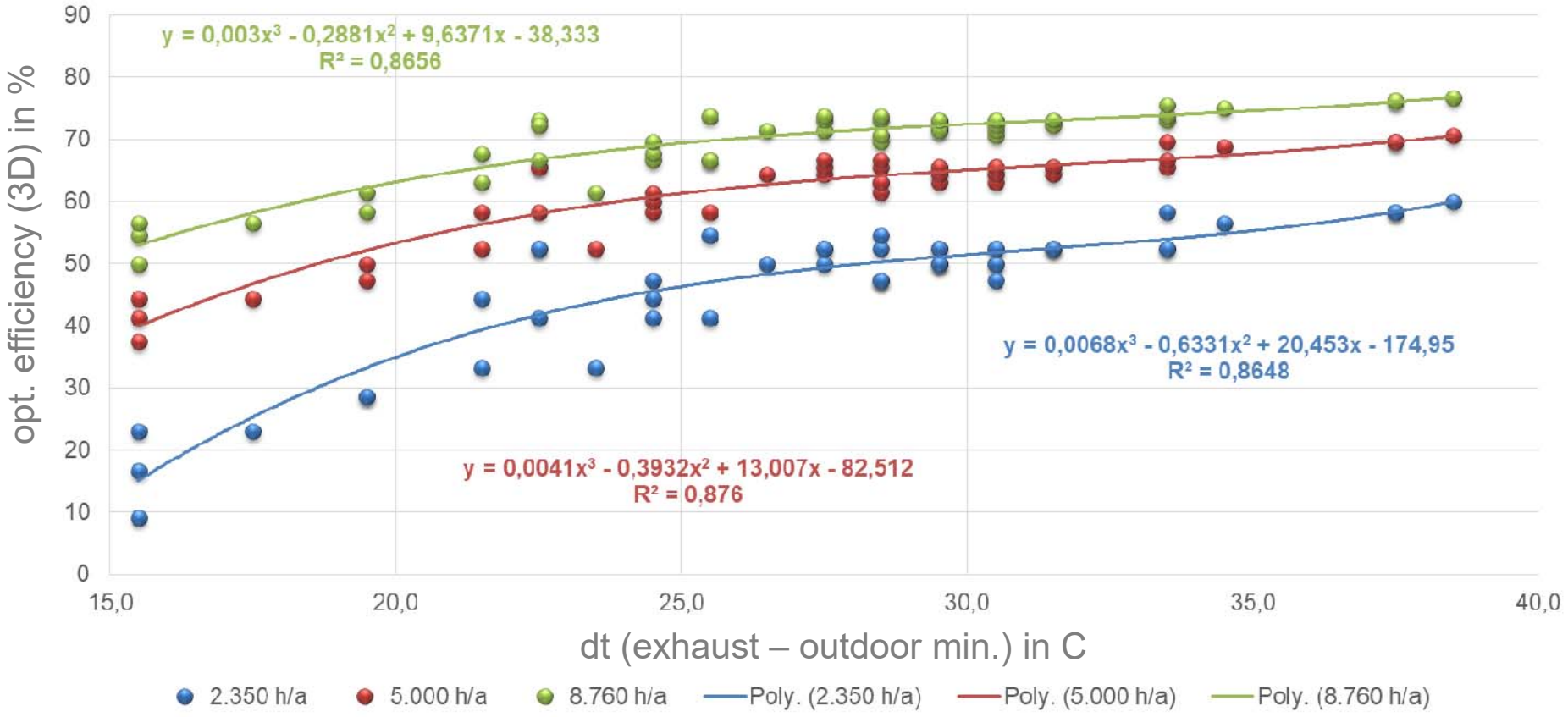
Meteo influence

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



efficiency 3D optimized

Meteo influence



efficiency 3D optimized

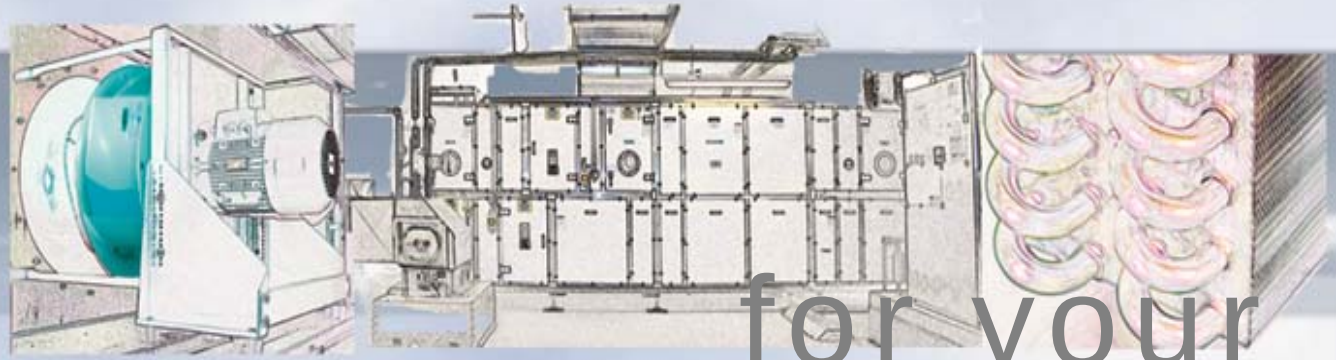
Needs

- Efficiency is directly linked to **running time**
- Efficiency is directly linked to **climate conditions**
- Efficiency is directly linked to **exhaust air temp.** and **target values**
- Efficiency is directly linked to **energy prices** (heating and electricity)

- Influency on **pressure losses** and **velocity** by **part load** operation
- Influency on **efficiency** by **boundary contions**
  (Influency on Invest for colth- and heatproduction)

- **low velocity** and **low pressure losses**

Thank you



for your

Attention

Heatrecovery in Europe

Economic and environmental study 2019

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Umwelt macht Karriere.