European Study on heat recovery in non-residential buildings

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Abstract: The HR (heat recovery) is generally assessed very positively from a business and economic point of view. In order to demonstrate this development, a first study will evaluate around 5,000 design data elements. First, the designs are evaluated with the question of how the key efficiency characteristics of the HR have changed throughout the course of the years 2014 to 2017. Afterwards, all relevant design files are subjected to an economic efficiency calculation under defined conditions, in order to determine the potential for a multidimensional optimization. Furthermore, the impact of the EU 1253/2014 benchmarks from 2020 onwards will also be examined. In order to demonstrate this development in europe, a second study will evaluate around 3,300 design data elements. First, the designs are evaluated with the question of how the key efficiency characteristics of the HR have changed throughout the course of the years 2015 to 2018. Primary, all relevant design files are subjected to an economic efficiency calculation under defined conditions, in order to determine the potential for a multidimensional optimization. Then, the impact of the EU 1253/2014 benchmarks from 2020 onwards will also be examined. The influence of the climate is thereby also taken into account by examining three European sites (North-South view). At the same time, the influence of the run time of the systems will be calculated. Ultimately, the analyses will provide recommendations for the future design of the Ecodesign regulation.

1. The development of heat recovery in Germany as a base

Figure 1 shows the development of the average temperature transfer rate (temperature efficiency) (Φ) of heat recovery in nonresidential buildings within the years 2006 to 2013 for Germany.

The average temperature transfer rate rose from $\Phi = 60 \%$ in 2006 to $\Phi = 69.5 \%$ in 2012. In 2013, a stagnation for that figure will become evident for the first time, when the value dropped to $\Phi = 69.1 \%$. In the following years from 2014 to 2017, however, the HR developed positively again (see Figure 2).
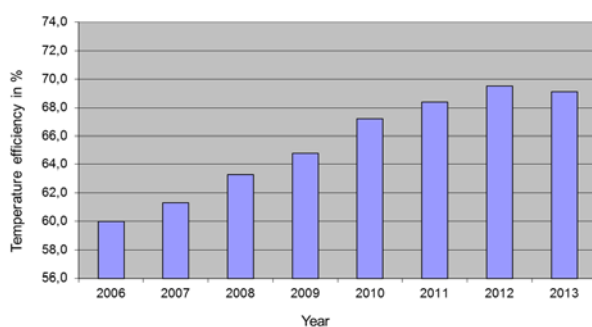

Fig. 1. Development of the temperature transfer rate of HR systems[1].

The degree of temperature transfer has risen continuously from $\Phi = 69.1 \%$ in 2013 to $\Phi = 73.3 \%$ in 2017. The EU 1253/2014 Ecodesign regulation has certainly contributed to this continuous increase in transmission degrees, which has prescribed mandatory minimum transmission rates of currently $\Phi = 68 \%$ (circle compound systems) and $\Phi = 73 \%$ (all other HR systems) since January 1, 2016. Figure 3 shows that both $\Phi = 63 \%$ (circle compound systems) and $\Phi = 67 \%$ (other HR systems) have limits that will be required by the Ecodesign regulation as of 2016. The presentation of the limit values has been observable since 2016, and was not yet discernible before the introduction of the Ecodesign regulation. However, even today there are still values below the requirements of EU 1253/2014, as central HR systems without fans (e. g. central HR systems) and systems with process air character are not covered by the regulation. Though, the standard deviation of the temperature transfer coefficients is at s = 5.5 % points.
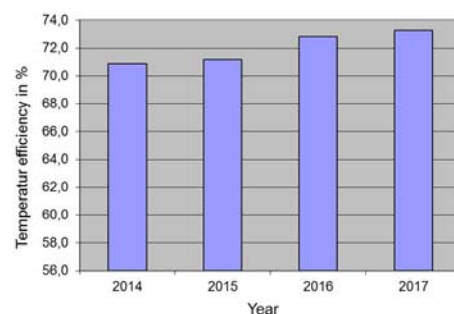

Fig. 2. Development of the temperature transfer rate of HR systems[2].

In addition to the benefits of heat recovery, the electrical costs for the operation of the HR system must also be considered. This effort is mainly caused by the pressure drop of the HR systems, which results in a higher fan power requirement.

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The development of the average differential pressure (Δp) of HR systems is shown in Figure 4. The average differential pressures have increased in the years 2006 to 2011 in proportion to the development of the temperature transfer coefficient. In 2012 and 2013 in particular, the average pressures losses have then decreased significantly despite high temperature transfer rates.
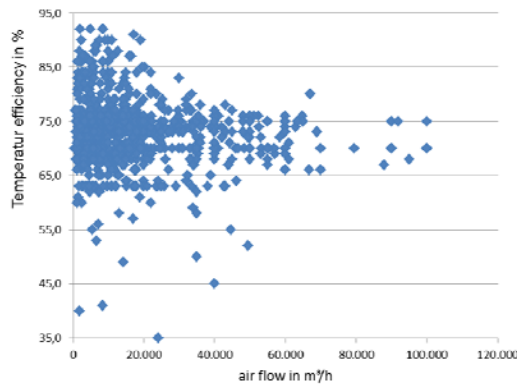

Fig. 3. Temperature transfer rates of HR systems in 2016.

In the last four years (see Figure 5), the pressure losses of HR systems have gradually decreased from Δp = 181 Pa in 2014 to Δp = 167 Pa in 2017, although the transmission degrees and thus the equipment required for heat recovery have increased.

However, Figure 6 also shows that the pressure losses are spread out considerably around the average values. The standard deviation is at s = 56.5 Pa.

When the countercurrent relationships of heat transfer are applied, the dimensionless heat exchanger ratio also increases from NTU = 2.43 in 2014 to NTU = 2.74 in 2017. This increased the amount of heat recovery required by 12.8 % during this period. At the same time, though, the pressure losses dropped by 9%.
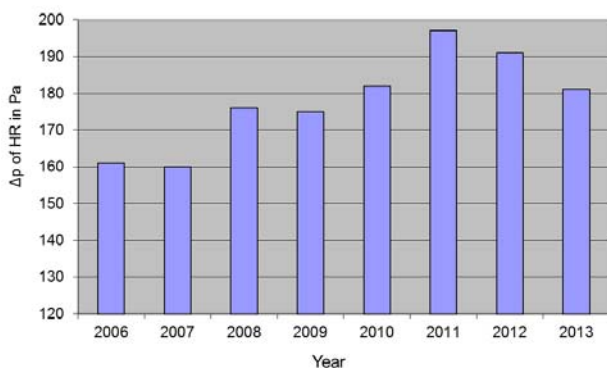

Fig. 4. Development of mean differential pressures of HR systems[3].

This is due to the fact that the flow velocities have continuously decreased during the observation period. Thus, the average flow velocity of the analysed devices in the clear device crosssection was still w = 1.66 m/s in

2013. Over the years, this has gradually fallen to w = 1.55 m/s in 2017 (see Figure 7).

The effective air velocity relative to the clear crosssection in the HR is naturally higher due to the frame components of the heat exchangers. In 2013 the velocity was at w HR = 2.32 m/s, and fell to w HR = 2.15 m/s by 2017 (see Figure 7).

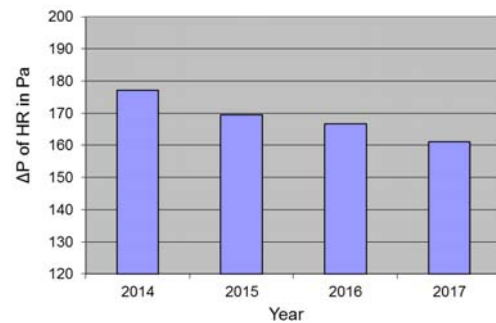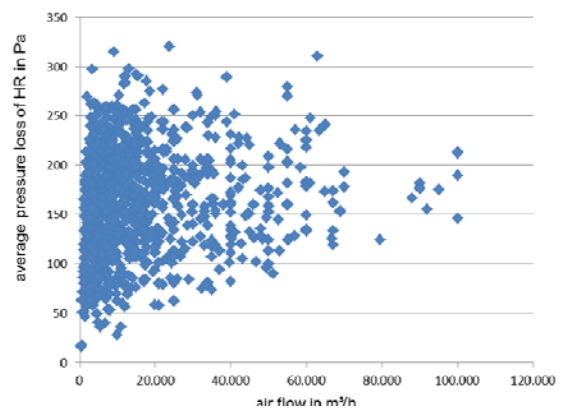**Fig. 5.** Development of mean differential pressures of HR systems[4].

Fig. 6. Development of differential pressures of HR systems in 2016[5].
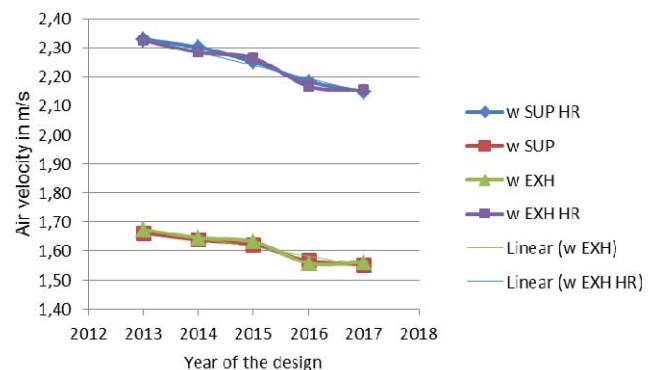

Fig. 7. Development of flow velocities in the HVAC and in the HR (in relation to the ribbed surface).

Looking at the individual designs, the following situation begins to emerge for the last 5 years (see Figure 8).

The share of HR systems with a transmission degree of at least Φ = 63% has risen continuously from a = 73.1% in 2013 to a = 94.6% in 2017. In 2016, the share

was already a = 94.1%. This shows a stagnation in the further development of average transmission degrees. HR systems with a transmission degree of at least Φ = 67% have risen continuously from a = 67.3% in 2013 to a = 91.9% in 2017. And HR systems with a transmission degree of at least Φ = 70% have also grown continuously from a = 57.3% in 2013 to a = 76.3% in 2017.
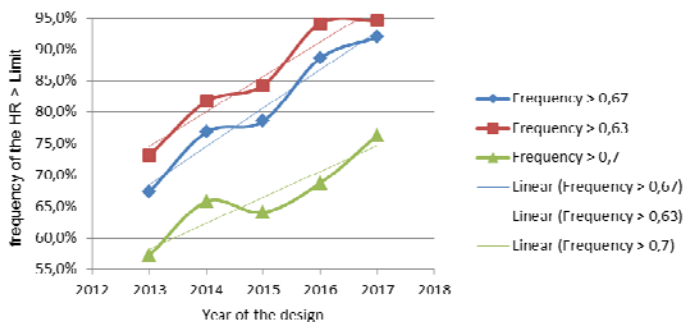

Fig. 4. Development of the share of highly efficient HR systems.

1.2 Outlook for EU1253/2014 based on germany

If the EU1253/2014 benchmarks to be used from 2020 for a revision of the Ecodesign regulation are already being utilized today, the following values must be observed. Circle compound systems (CC systems) should then achieve minimum transmission rates of Φ = 80%. All other heat recovery systems must reach at least Φ = 85%. If all designs of the last three years are converted using the dimensionless heat exchanger index NTU, the following values result (see Table 1).

Table 1. Change in heat output performance in relation to pressure losses.

Year	Δ ΔP	ΔP [Pa]	Δ Q Ref.
2017	182.3%	293.9	113.3%
2016	188.8%	314.6	114.6%
2015	212.4%	360.0	117.6%

The recovered power will increase by 13.3 % compared to 2017, while the pressure losses will increase by 182 % due to the enormous necessary equipment effort, if the flow speeds are assumed to be constant.

It becomes evident that even in previous years the heat output only increased by about 15 %, while the equipment effort and thus the pressure loss increased by a factor of 2 due to physical reasons.

It should be noted that heat recovery in Germany has developed positively, and has also established itself very successfully. It also becomes clear that the Ecodesign regulation 1253/2014 has led to a much more positive development in heat recovery than would have been possible without the Regulation. In 2013 in particular, there was a stagnation of the HR, which could no longer be observed as of 2014.

However, it should be noted that the transmission degrees scatter around the average value with a standard deviation of s = 5.5% points.

It also becomes evident that the increase in the efficiency of the HR was "compensated" by a reduction in the flow speeds in the HR.

This even made it possible to reduce the pressure loss of the HR despite increasing transmission degrees.

Nevertherless, if the reference values of the EU 1253/2014 are actually converted into applicable law as of 2020, the recovered heat output will increase by around 15%, but the equipment costs will increase by a factor of approx. 2.

The question arises as to whether this development provides economic advantages, because the HR is not only an economic measure, but also an economic one that explicitly affects each user in each individual case.

2. Development of heat recovery in Europe

Heat recovery systems have been used for years to reduce the required primary thermal energy demand in HVAC units and systems non residential buildings.

Despite this positive development, the question arises more and more frequently as to whether these provisions of the Ecodesign regulation EU 1253/2014 actually represent an optimum of the HR system in the microeconomic or national macroeconomic sense.

In order to answer this question, a total of approx. 3,300 air handling unit (AHU) designs from 2015 up to 2018 were evaluated according to economic aspects. These are actual designs that were carried out with TÜV-certified design software on the basis of specific tenders in a broad range of projects. Each device is therefore based on a real project with actual performance requirements that are in line with the market and therefore representative for the market of AHU´s used in non residential buildings.

Each HVAC unit with HR was subjected to a quasidynamic economic efficiency calculation using a batch generator (software bot). Two usage cases were thereby investigated. On the one hand, a design with initial values, i. e. predefined basic conditions that are to apply equally to all designs, and on the other hand, a design with file values, i. e. the data that was already selected in the concrete design for the respective project during the original design.

Three locations were selected to take into account the general conditions (starting values) in Europe. In addition to Mannheim as a central European location, Lisbon was selected as the southern location and Helsinki as the northern location.

The annual differential costs were determined as the basis for the economic valuation. These result from the monetary recovery of heat in the winter, and the recovery of cold in summer. The expenses resulting from the electrical energy requirement, maintenance costs, debt service, etc. were deducted from this amount.

While in Lisbon heat is recovered on average W = 23,890 kWh/a for a run time of around L = 2,350 h/a, in Helsinki this is W = 100,467 kWh/a for the same run time (see Figure 9).
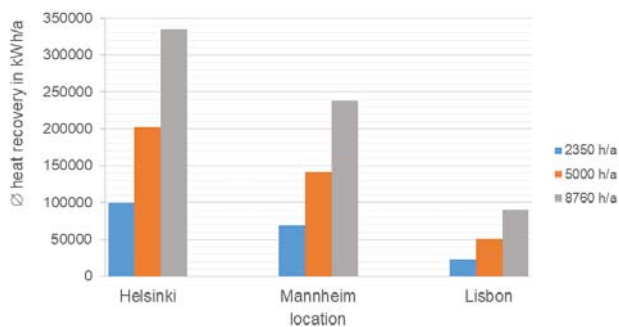

Fig. 9. Average heat recovery of the plants in kWh/a.

By contrast, the recovery of sensitive cold is very low (see Figure 10) and even in Lisbon there is a maximum of 9.1 % cold recovery compared to heat energy (see Figure 9). In Helsinki, the share of cold recovery is irrelevant, as it only accounts for 0.2 % of the heat energy.

If the monetary effect was calculated with a average price of 0.043 €/kWh for heat (based on European gas prices[7] for the last 10 years multiplied with distribution losses[8]), an electricity price of 0.091 €/kWh (EU 28 average last 10 years)[9], and a price of 0.041 €/kWh for cooling energy (calculated with COP=3 based on electricity). An imputed interest rate of 2.4 %/a (average EU last 10 years)[10] was applied. The rate of price increase was 1.7 %/a[11]. The useful life of the HR was selected with 15 years. The utilisation of the HR unit during daytime hours is assumed to be 100% of the target air volume, and at night hours 50%. The investment costs of the HR systems in the study are averaged at I = € 21,350.
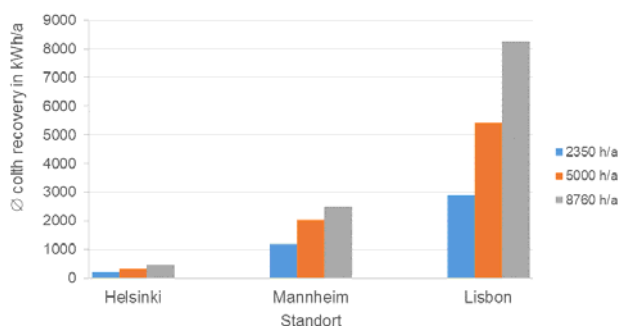

Fig. 10. Average cold recovery of the plants in kWh/a.

In a 9-hour operation (around L = 2,350 h/a), the plants examined in Lisbon would generate an average loss of K = -1,048 €/a at an efficiency of 73.2 %. Overall, 98.0% of all investments in Southern Europe

would be uneconomical (negative differential costs per year), while a profit of K = 1,558 €/a would be generated in Northern Europe for the same term. In Helsinki, therefore, only 10.9% of specific installations would generate projectspecific losses.

In the 24-hour operation, an average profit of K = 568 €/a would even be generated in Lisbon. However, even with this run time, 22.1 % of the examined plants would still generate a loss. In Helsinki, though, it would be possible to generate a profit of K = 10,802 €/a with the same investments (see also Figure 11). Under these conditions, 0,1% of the plants examined would be uneconomical at this location.
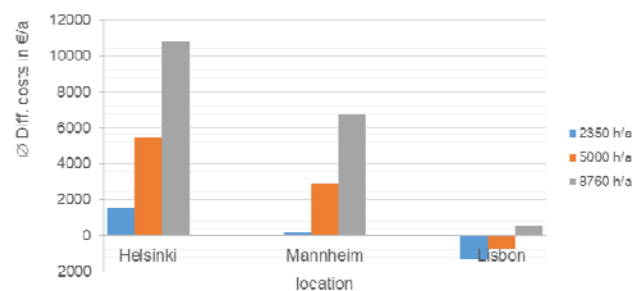

Fig. 11. Annual differential costs under design conditions.

If all plants were economically optimized at a constant design speed, a higher profit would be generated, which could avoid a loss on average for all plants.

However, the systems with average transmission degrees from Φ = 31.4 % in Lisbon to Φ = 60.5 % in Helsinki would then have to be produced, i. e. with significantly lower transmission rates than the actual, resulting average and undifferentiated Φ = 73.2 % of the systems investigated in this field study. In Mannheim, the optimum transmission degree under these conditions would be Φ = 53.0 %.

With a run time of L = 5,000 h/a, transmission degrees of Φ = 46.8 % in Lisbon and Φ = 71.1 % in Helsinki would be required. Mannheim then requires a transmission degree of Φ = 65.7 % at unchanged flow velocity.
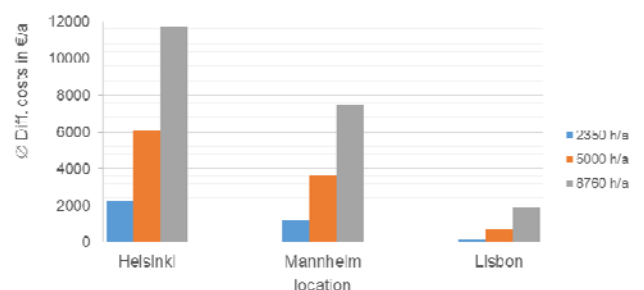

Fig. 12. Annual differential costs after 3D optimization.

Even during the 24-hour operation (L = 8,760 h/a), transmission degrees of Φ = 57.9 % (Lisbon) and Φ = 77.1 % (Helsinki), as well as Φ = 73.1 % (Mannheim) would make sense. A 10% higher profit could be generated in Helsinki, while a 238% higher profit could be achieved in Lisbon.

If a multidimensional optimization is carried out at a flow velocity of about w = 1.1 m/s, significantly higher gains could be achieved (see Figure 12). For a 9-hour operation in Mannheim, for example, the annual differential costs could be increased to € 953/a (+ 379.7 %) with an average of K = € 1,204/a.

A significant increase in yields would also be possible in 24-hour operation, which could be +10.0 % in Helsinki (K = 10,802 €/a to K = 11,882 €/a) and +238.0 % in Lisbon (K = 568 €/a to K = 1,920 €/a).

However, even in this case, the optimal transmission degree is not identical in the different locations. While in Lisbon max. Φ = 57.9 % makes sense, in Helsinki this is Φ = 77.1 %. In Mannheim, the maximum transmission degree under these conditions is Φ = 73.1 %. In the 9-hour operation, the maximum meaningful transmission degrees are reduced to a maximum of Φ = 60.5 % in Helsinki, Φ = 53.0 % in Mannheim and Φ = 31.4 % in Lisbon. Though, all transmission degrees can only be used sensibly if the flow velocity for design is around w = 1.1 m/s in order to minimize pressure losses.

2.1. Reference points

If the EU1253/2014 reference values, which are to enter into force from 2020 as part of the revision of the Ecodesign regulation are applied today, the result will be as follows (see Table 2 and Table 3).

On average, the HR would have to be twice as large in its transmission units as it has been in recent years.

In Helsinki, a 9-hour operation could no longer generate a profit of K = 1,558 €/a compared to the situation in recent years, with a loss of K = -169 €/a (see Table 3).

Table 2. Necessary change of the heat exchanger index Number of transfer units (NTU) under reference conditions.

		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

In Lisbon, instead of the loss of K = -1,048 €/a already incurred today, a significantly higher loss of K = -3,045 €/a would be the result. And in Mannheim a loss of K = -1,674 €/a would result instead of an average profit of K = 251 €/a. Even with a 24-hour operation (L = 8,760 h/a), the plants examined in Lisbon would cause an average loss of K = -1,942 €/a.

Table 3. Monetary results of the economic efficiency calculation under reference conditions.

	run time	Diff. costs K actual	Diff. costs K Opt.	Diff. costs K Ref. 2020	Diff. costs K 3D Opt.	Diff. costs K Ref. 2020 (1,
	h/a	€/a	€/a	€/a	€/a	€/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

Even under the current conditions, an average profit of K = 568 €/a would still be possible in Lisbon. By comparison, the same investments in Helsinki would generate an average profit of K = 10,802 €/a (in Mannheim K = 6,717 €/a).

Figure 13 and Figure 14 also show the annual savings for the Helsinki and Lisbon locations with different run times. Even at an optimal flow velocity of about w = 1,1 m/s, the reference values of the EU1253/2014 would cause lower yields. Although the average transmission degrees would be between Φ = 83 % and Φ = 84 % in this case, all profits would be lower than in the multidimensionally calculated optimum. Figure 15 shows the corresponding result for Mannheim.
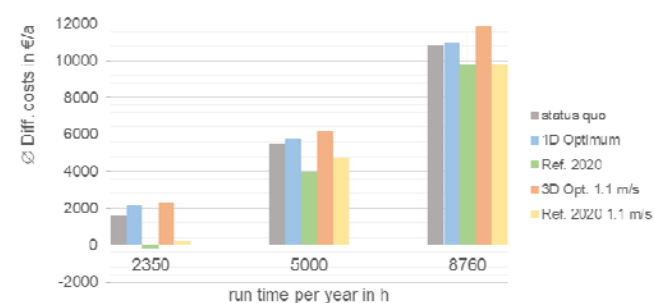

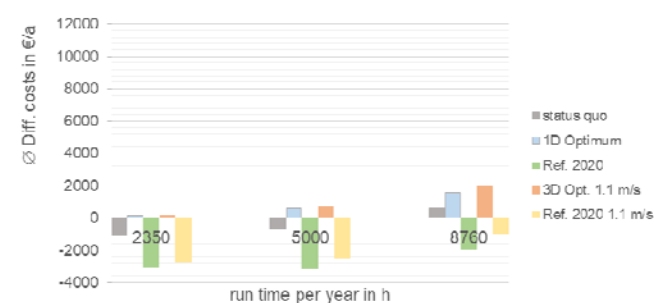**Fig. 13.** Annual differential costs under various conditions for Helsinki.

Fig. 14. Annual differential costs for Lisbon under different conditions.

Even in Helsinki, 24-hour operation would reduce the yields from K = 11,882 €/a to K = 10,980 €/a, i. e. by -7.6%. In Lisbon, on the other hand, a 9-hour operation (L = 2,350 h/a) would turn the remaining small profit of K = 172 €/a into a significant loss of K = -2,722 €/a.
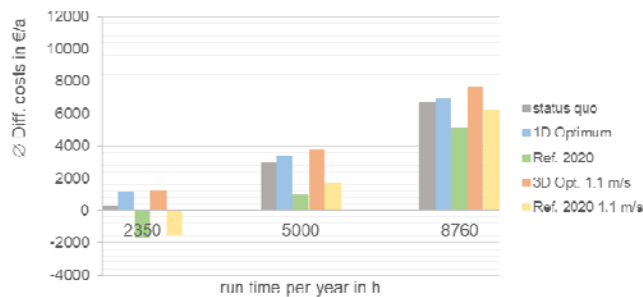

Fig. 15. Annual differential costs for Mannheim under various conditions.

2.3. Evaluation

It should be noted that the HR has successfully established itself in Europe. However, if the EU 1253/2014 reference values are actually converted into applicable law as of 2020, the recovered heat output will increase by around 15%, but the amount of equipment required will increase by a factor of around 2.

This development is not economic, as the average yields of the HR will fall across Europe. This has been clearly demonstrated by the field study at the individual case level at around 3,300 plants examined.

Profits will fall significantly in all cases. In the quintessence of the findings, the application of the reference values in Europe from 2020 will not make any investment in Europe more economical than it is today.

Table 4. Possible transmission degrees of the HR and their average annual differential costs.

		3D-Optimum	∅ Diff. Costs	dP average
2.350 h/a		%	€/a	Pa
North	Helsinki	61	2.251	58
Mid	Mannheim	53	1.204	42
South	Lisbon	31	172	15
		3D-Optimum	∅ Diff. Costs	dP average
5.000 h/a		%	€/a	Pa
North	Helsinki	71	6.155	72
Mid	Mannheim	66	3.741	56
South	Lisbon	47	742	25
		3D-Optimum	∅ Diff. Costs	dP average
8.760 h/a		%	€/a	Pa
North	Helsinki	77	11.882	87
Mid	Mannheim	73	7.641	70
South	Lisbon	58	1.920	35

It is to be hoped that the European Commission will also recognise and correct this design error in the regulation. It makes sense that the revision of the regulation must at least take into account both the location of installation of the HR and its run time.

If the results of the field study are reduced to the transmission degree, the following values could be useful for minimum transmission rates and maximum pressure losses at the HR (see Table 4).

The air velocity in the device should then be about w = 1.1 m/s. Lower air speeds are hardly sensible any more, as the systems should also to operate at partial load. At an air velocity of w = 1.1 m/s a partial load operation up to about w = 0.4 m/s would be possible.

List of abbreviations

a Frequency [%]

AHU Air handling unit

CC Circle compound system

EXH Exhaust air

ΔP Differential pressure loss [Pa]

Δ ΔP Change of the pressure drop [./.]

HR Heat recovery

I Investments [€]

K annual differential costs [€/a]

L Runtime [h/a]

NTU Number of Transfer units [./.]

Φ Temperature transfer coefficient or heat recovery efficiency [%]

s Standard deviation

SUP Supply air

w Flow velocity at the narrowest cross section in [m/s]

W Thermal energy [kWh/a]

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