BENEFITS OF ESTABLISHING SYSTEM EFFICIENCY INDEX DURING FIELD MEASUREMENTS ON AIR CONDITIONING AND HEAT PUMP SYSTEMS

Anna-Lena, Lane, M.Sc., SP Technical Research Institute of Sweden, Brinellgatan 4, 504 62 (Borås, Sweden);
Jessica, Benson, M.Sc.,Lic.Eng., SP Technical Research Institute of Sweden, Brinellgatan 4, 504 62 (Borås, Sweden);
Klas, Berglöf, M.Sc. Managing Director, ClimaCheck Sweden AB, Box 46, 131 06 (Nacka, Sweden)

Abstract:

The need for energy optimization of heat pump and air conditioning systems is large. This paper describes the concept of System Efficiency Index (SEI) and presents the benefits of using it instead of COP for performance optimization of installed systems. The use of SEI enables a comparison between the values from dimensioning of a plant and an actual operation in a plant. The SEI can indicate when the system performance is not optimal even though the COP value is high. The results from the two systems analyzed in this paper, show both the stable SEI expected for a well performing system, and a SEI that indicates a less efficient component.

Key Words: System Efficiency Index SEI, heat pumps, air conditioning, key performance indicator, COP, field measurements

1 INTRODUCTION

At present there is a lack of a concept which can be used to evaluate designs and compare design data with efficiency for installed systems measured in field. Traditionally COP (Coefficient of Performance) has been used but it has weakness as a comparator as it is strongly dependent on operating conditions that vary between different designs and from design conditions to measured conditions. Also, knowledge of how measured data should be interpreted and transformed into useful information for technicians and decision makers is poor or in many cases nonexistent.

The performance indicator discussed in this paper is based on the concept of Systems Efficiency Index (SEI), which has been used in work by IOR (Institute of Refrigeration) and the German Engineering Federation VDMA (VDMA Specification No. 24247). SEI is the ratio between the measured COP and the COP for an ideal process, operating between the same temperature levels.

2 KEY PERFORMANCE INDICATORS

2.1 COP

Coefficient of performance, COP, is used to a large extent today when the performance of heat pumps and air-conditioning equipment are evaluated. It is given by the ratio of useful energy output for heating, P_H or cooling, P_C over energy input, P_{em} for the process.

The definition of heating and cooling performance respectively:

— [-] (1)

— [-] (2)

The theoretically maximum reachable efficiency of the heat pump is that of a reversible process, the performance of this process is often referred to as the Carnot COP. In a reversible process all work added to the process contributes to the temperature difference between the cold and the hot side in the cycle. The reference temperature for the cold side is T_2 and for the hot side T_1. The calculation of COP Carnot, for heating and cooling, can therefore be simplified to:

$$COP_{H,Carnot} = \frac{T_1}{T_1 - T_2} \quad [-] \quad (3)$$

$$COP_{C,Carnot} = \frac{T_2}{T_1 - T_2} \quad [-] \quad (4)$$

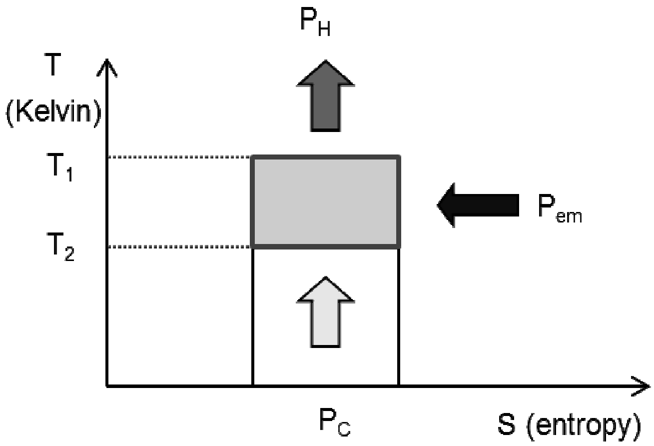

Figure 1 Principal temperature levels T1 and T2.

2.2 System Efficiency Index

Independent, both the British Institute of Refrigeration (IOR) and the German Engineering Federation (VDMA) has developed a methodology to establish energy efficiency at the dimensioning process considering the desired operating conditions for the plant (Madiment 2007), (VDMA Specification No. 24247 Part 2). The system efficiency index (SEI) presented here is a further development of their methodology. The SEI value can also be reached as a product of sub-efficiencies for a system, which allows identification of optimization potential in different parts of the process (Römer 2011).

SEI is based on the COP-value and the COP of an ideal, reversible Carnot process. It is created by defining the COP of a 100 % efficient refrigeration process between the desired temperature levels and comparing the actual COP with this value. The ideal or Carnot COP provides the ultimate reference, consistent with the laws of thermodynamics, for a process of transferring heat energy to a higher temperature level. The design or measured COP is then divided by the ideal COP and this ratio results in an efficiency that changes much less than COP with changes in temperatures and flow rates.
The SEI for heating mode and cooling mode is calculated in equation 4 and 5 respectively.

$$SEI_H = \frac{COP_H}{\frac{T_1}{T_1 - T_2}} \quad (4)$$

$$SEI_C = \frac{COP_C}{\frac{T_2}{T_1 - T_2}} \quad (5)$$

2.3 COP and SEI

The COP-value is useful for cost calculations, when comparing heat pump and air conditioning systems with other solutions. It is a measure of the actual energy performance at the specific operating conditions. Long term measurements are necessary to find out about the performance of a plant when using COP or SPF (Seasonal Performance Factor). Depending on the temperature levels for the condenser and evaporator the COP values for a refrigeration process is represented by the slope in figure 2, meanwhile the SEI values are stable during the same operating conditions.

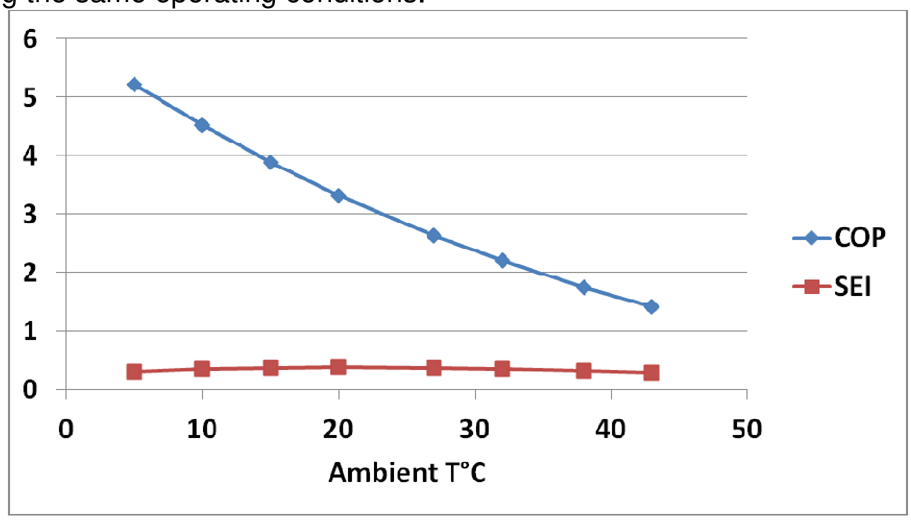

Figure 2. Values of COPc and SEIc for a condensing unit based on manufacturer's data, using R404A, with fixed evaporation at -10 °C, and 20 °C suction gas temperature.

The result in terms of COP from a short field measurement, for example during a day can be far from the design COP and does not relate to what is possible to achieve with the system under present conditions. Therefor it is difficult to evaluate if a low COP is being caused by a poor system design or if the operating point is disadvantageous. Also it is not intuitively understood from the COP value how far from optimal operation the machine is working under certain conditions.

The SEI however will show how well the system works compared to what is theoretically possible under the present conditions. The SEI values are more stable with varying temperatures within the suitable operating range as shown in figure 2. This allows SEI at different operating conditions to be compared and one measurement point can provide information about the system efficiency. A measure of the system efficiency can also be achieved by comparing the SEI from one system with values from other systems operating under similar conditions. Also, the SEI from an installation can be compared with theoretical design efficiency.

SEI values from different operating conditions will vary slightly based on the components sensitivity to the operating conditions and an optimum can be found showing the most favourable operating point for the system, with minimum of losses.

3 CATEGORISATION AND SYSTEM BOUNDARIES

The definition of the system boundaries influences the SEI value due to which auxiliary drives included and which temperatures that should be used as the references T1 and T2. Therefore the SEI should be calculated according to different system boundaries. This will reflect the impact of the different devices on the performance of the system. The system boundaries presented here are based on the work in SEPEMO-Build project (Zlottl and Nordman 2012).

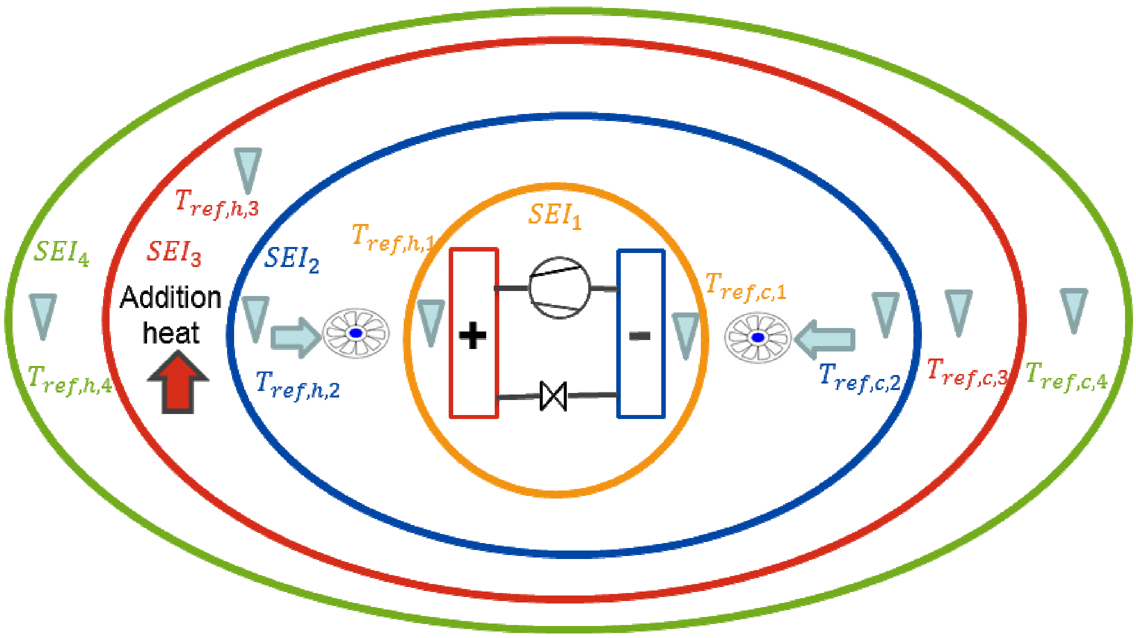

Figure 3: Direct system with system boundaries and reference temperatures

The SEI has been divided into four main system boundaries according to how much of the system that is included in the measurement. In the figures (3) and (4) the system boundaries for the direct and indirect system are illustrated.
The SEI 1 is the closest SEI and includes only the refrigerant process and the compressor power. The reference temperatures refer to delivered temperatures from the condenser and to the evaporator. The widest SEI, SEI4 refers to system boundaries going from the heat sink to the heat delivery. For an out-door heat pump, air to air, the system boundary for the cold side will be the out-door air near the heat pump and the reference temperature will be the evaporator air inlet temperature. Figure (3) shows system boundaries for this type of direct system. The system boundary on the warm side will be the indoor air and the reference temperature will be the indoor temperature.
Between SEI1 and SEI4 there is SEI2, which includes energy for transportation of energy from the machine to the system. The SEI3 includes energy for extra heating, and is applicable for heat pumps. Of course, there are many kinds of system,. Therefore the categorization is important to be able to compare different plants with each other by using the same system boundaries. Later on some examples from practical measurement will bring more clarity to this matter.

Heat pumps and air conditioning equipment have been examined. There are two main categories, direct expansion systems and indirect systems. The rest of the categories are mixtures of these. The application and type of cooling on each sides, for example exhaust air or outdoor air, also affect the categorization.

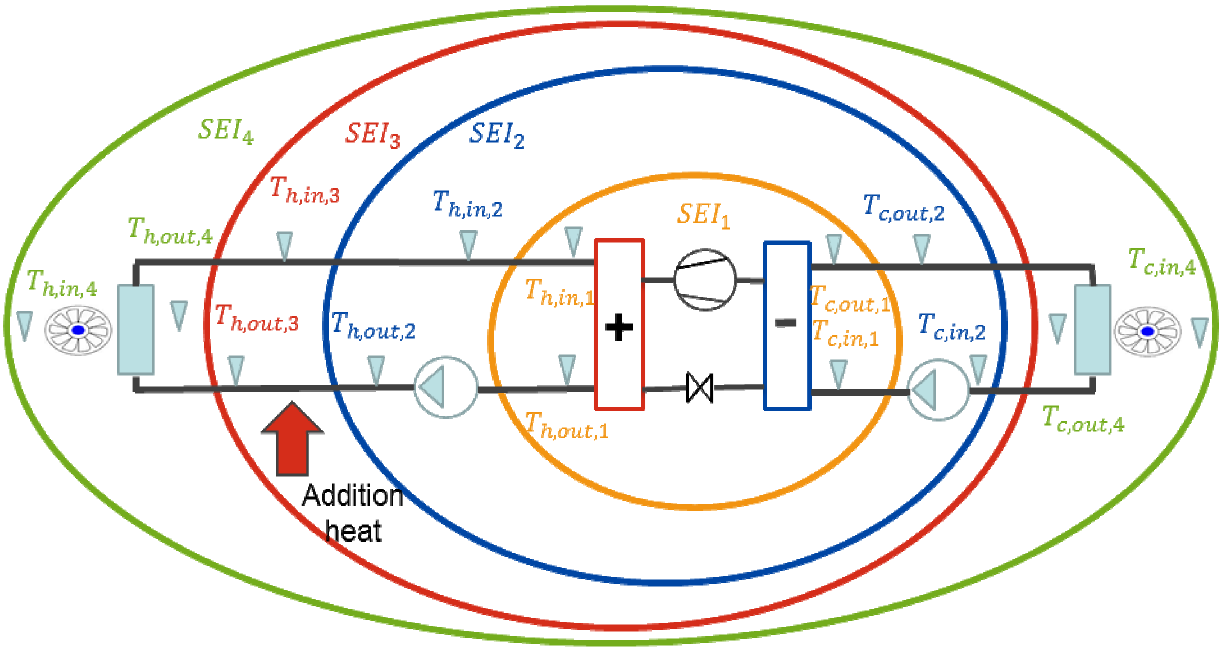

Figure 4: In-direct system with system boundaries and temperatures

Practical measurements have shown that a good reference temperature for an indirect system is the mean value of the in- and outgoing temperature at the system boundary. For example the reference temperature on the hot side for SEI2 used is:

$$T_{ref,h,2} = (T_{h,in,2} + T_{h,out,2})/2 \quad (6)$$

4 ANALYSIS OF DATA

In this chapter, evaluations of measurements from two systems are presented. The first is a ground source heat pump for which COP and SEI heating is calculated. The second system is an air conditioning system for which COP and SEI cooling is calculated.

4.1 Measurement method

The used and delivered energy have to be measured to calculate the COP that is used to calculate the SEI. This can be done with two major methods. The external method, where the energy delivered to the systems on the cold and warm side is measured with flow meters and temperature sensors and the energy is calculated from these parameters. This is easiest done when there is a liquid system on the secondary side. The energy delivered to the compressor and other components, depending on selected system boundary, is measured by electric meters.
The other method, (used in this project), is the internal method (Fahlén 2004). In this method the electrical energy to compressor and other components are measured with electric meters. The energy delivered on the cold and warm side is calculated from temperature and pressure measurements in the refrigerant circuit. In Figure (5), the measurement points are presented for the internal method.
To be able to calculate the SEI, in both methods, the reference temperatures also have to be measured with temperature sensors in the correct positions according to system boundaries.

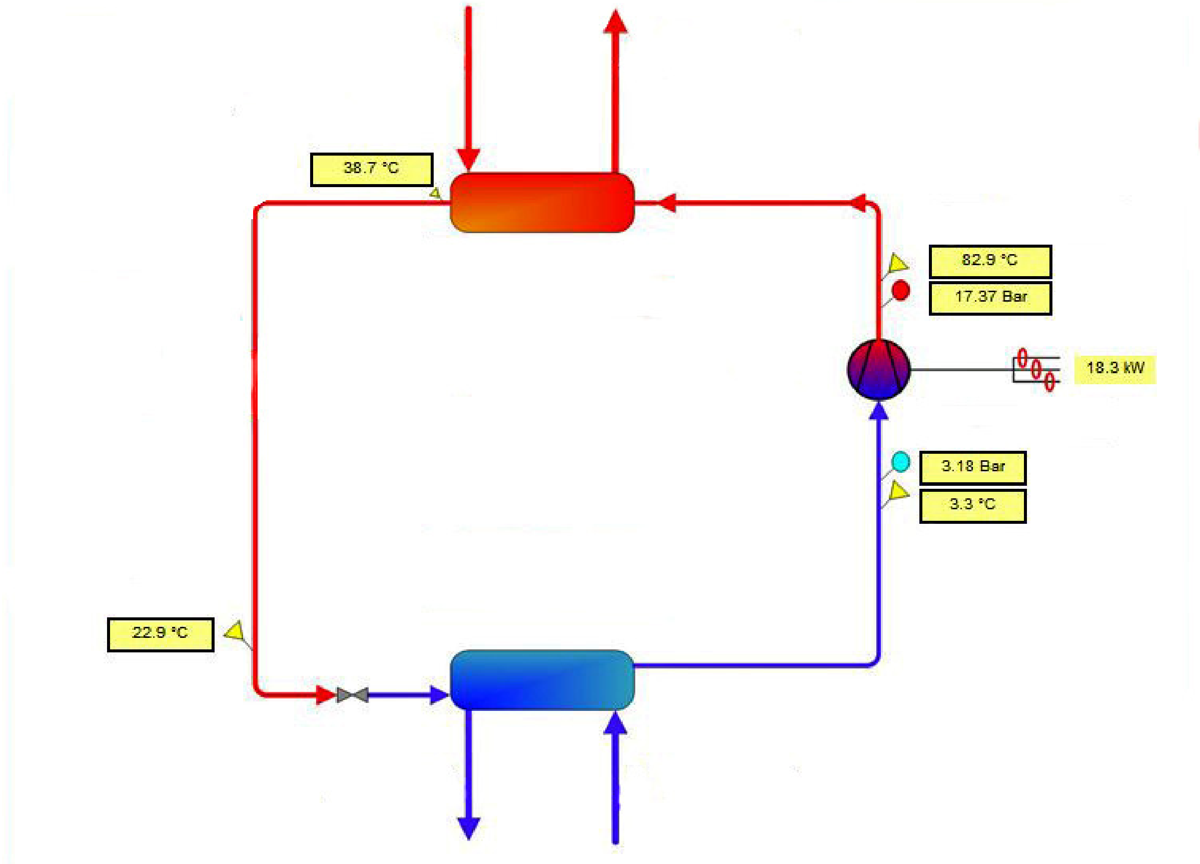

Figure 5: Measurement points for the internal method (COP) and reference temperatures for SEI.

4.2 Heat pump

The analysis has been done on measured data from a ground source heat pump that is used for space heating. The heat transportation is liquid based on both sides of the heat pump (ethanol on cold side and water on warm). The bore hole is also used for free cooling during the summer period, and during a part of the summer when the bore hole is too warm, the heat pump is used for cooling through heat exchangers on secondary sides (not reverse cycle).
The SEI1 heating has been calculated for the process during several cycles. The reference temperature on the cold side is the average temperature of the incoming and out-going secondary refrigerant. On the warm side the reference temperature also is the average temperature of the incoming and out-going secondary fluid. The SEI and COP shown in figure 7 are based on cycles during the heating period. The figure shows that the SEI1 heating is on a stable level during the heating mode.

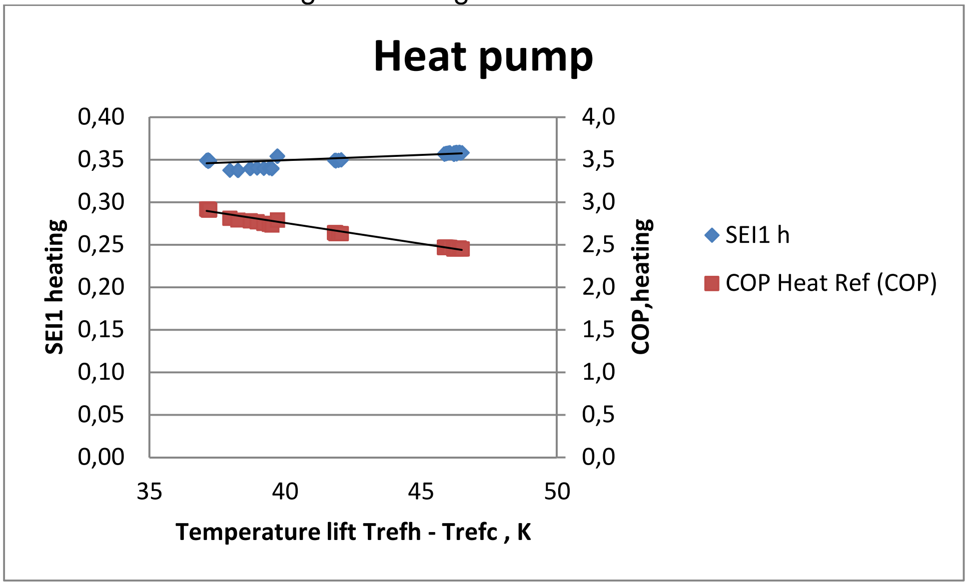

Figure 7: SEI1 heating and COP heating for a ground source heat pump

During space heating operation, the temperature on the cold side varies around 0 °C in an interval from -2 °C to 5 °C. The reference temperature on the warm side during heating period varies between 37 °C and 45 °C. All reference temperatures are the mean value of the in-coming and out-going secondary fluid temperatures. See equation (6) as an example.

4.3 Air conditioning

Measurements on a system for air conditioning have been used for analysis of SEI1. The system consists of two units with two circuits in each. The presented results are from measurements in one circuit in one of the units, the SEI1 is shown in table 1 and figure 8. However, measurements for the other circuit and units have been evaluated too.

The SEI should by the definition be constant if the unit works properly in all cases. Here, the SEI is lower when the temperature lift is low, even though the COP shows high values. A deeper analysis of the measured data gives the explanation. In the table 1 some of the measured values are presented. When looking at the values during low temperature lifts, they will show a high outgoing temperature on the cold side. The superheat is also found high. A conclusion is that the expansion valve in the unit does not work well at higher evaporating temperatures.

The difference between the condensing temperature and the $T_{ref\ h}$ has been calculated and added to the difference between the $T_{ref,c}$ and the evaporating temperature. This parameter says something about the heat exchangers. When the difference is high the SEI is low. Further ongoing work will show how SEI can be divided in sub-efficiencies highlighting the contribution of different components.

Table 1: Measurement points for one circuit in an AC unit. Point 1 to 4 is half load and point 5 to 11 full load

	Tc,in Deg C	Tc,out Deg C	Superheat Deg C	Tref,c Deg C	Tref,h Deg C	Temp diff in heatexchanger Deg C	Temp. lift, Deg C	COP	SEI
1	14.6	11.5	7.7	13.1	29.1	19.3	16.1	4.15	23.3
2	10.2	7.5	6.5	8.9	28.9	17.9	20.1	3.79	26.9
3	8.6	5.9	6.2	7.3	27.7	17.4	20.4	3.77	27.4
4	9.3	6.6	5.8	8.0	29.4	17.3	21.5	3.67	28.0
5	11.9	6.8	5.2	9.4	32.2	16.7	22.9	3.62	29.3
6	11.1	6.3	5.9	8.7	32.9	17.0	24.2	3.50	30.1
7	11.2	6.5	6.3	8.9	33.4	16.7	24.6	3.43	29.8
8	11.0	6.3	6.2	8.7	33.3	16.7	24.6	3.43	30.0
9	10.9	6.3	6.2	8.6	33.3	16.6	24.7	3.43	30.1
10	10.7	6.0	5.9	8.4	33.3	16.4	25.0	3.40	30.1
11	10.7	6.0	5.8	8.4	33.6	16.4	25.3	3.38	30.4

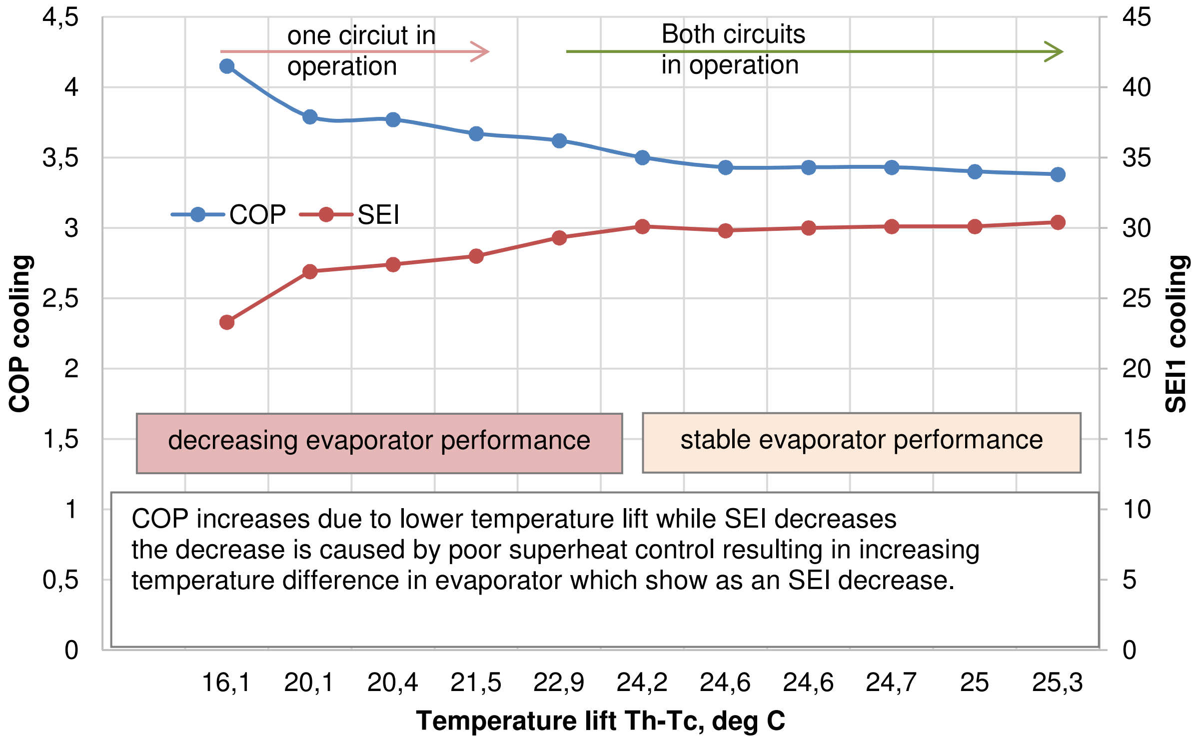

Figure 8: SEI1 and COP for an air conditioning unit, values from table 1

5 DISCUSSION

The use of SEI is a new way to analyse the system performance of a refrigeration process. As shown in the two analysed systems, the COP increases at lower temperature lift, but the

SEI shows that the process actually loses in performance. The COP should be even better. There is work on-going to define sub efficiencies for SEI that will help localise where greatest losses in the process can be found. By using sub efficiencies a poor component can be singled out and this is valuable information for system development and energy optimization. In systems where it is feasible, the component could even be replaced. Due to the variation of operating conditions for refrigeration, air conditioning and heat pump systems where they rarely or “never” operate at design or rating conditions in the field the measuring and validation has been challenging. It is often considered to cause more discussions than improvements to the site and thus rarely done.
The focus on COP rating conditions where the above measurement no.1 with a COP at first site could seem to be a good operation with a COP of 4.15 at first sight seems good whereas measurement no.11 with a COP of only 3.38 seems poor. In fact the performance of the latter is significantly better due to better utilisation of evaporator with better optimised expansion valve at this condition.

The SEI and sub efficiencies allow evaluation of a system at conditions other than the design point and comparison of systems even if conditions are not identical.

In this paper two systems were analysed, one heat pump, showing SEI1 for heating and one air conditioner showing SEI1 for cooling. These two figures cannot be compared since the operation is different; i.e. heating and cooling.

Further analysis and evaluation of measurements are needed and in progress to provide input for a scale that can show if a system is good or poor when a measurement is done. The desire is to develop guide lines for different system categories and to define the range of SEI and the sub efficiencies from state of the art to where system or component is in need of replacement.

6 REFERENCES

Fahlén P, 2004. Methods for commissioning and performance checking of heat pumps and refrigeration equipment. IIR conference compressors 2004, Papiernicka, Slovakia, 2004-09-29--10-01. (International Institute of Refrigeration.)

Römer S, et al. 2011. Universal energy efficiency evaluation method of refrigeration systems. IIR ICR conference 2011, Prague, Czech Republic, 2011-08-21--08-26.

VDMA Specification No. 24247 “Energy efficiency of refrigeration systems”

VDMA Specification No. 24247 Part 2: “Requirements for system design and components”

Zlottl A, Nordman R, 2012 D4.2. /D 2.4. Concept for evaluation of SPF Version 2.2 A defined methodology for calculation of the seasonal performance factor and a definition which devices of the system have to be included in this calculation. Heat pumps with hydronic heating systems, in, Available online http://www.SEPEMO.eu/deliverables/wp4/ 2012.

Maidment, G G et al, 2007 Development of the System Efficiency Index (SEI) for Refrigeration and Air Conditioning Systems, IOR 2007 Annual Conference