The ClimaCheck method To Measure – Analyze and optimize refrigeration processes.”

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1 The ClimaCheck method for performance analyzing of refrigeration and air conditioning systems.

The ClimaCheck method for performance analyses, also called the “Internal Method”, was first developed and patented in 1986 triggered by the need for measuring and validation of performance in the heat pump sector.
ClimaCheck enables engineers in the field to determine how well a plant is performing, its actual COP, capacity, and other vital performance parameters without hours of tedious calculations. The performance can be documented in an un-biased way without input from the manufacturer of the system or components. The method is based on fundamental thermodynamic properties and the laws of energy.

ClimaCheck accurately determines a working system’s (accuracy is based on RISE analytics and tests of error propagation):

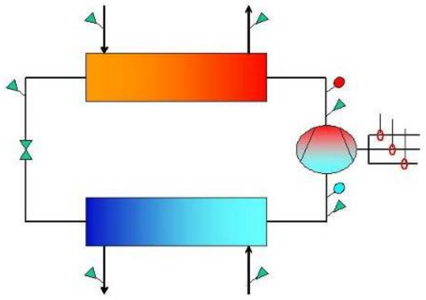
- Coefficient of Performance (± 5%)
- Cooling and heating capacity (± 7%)
- Power input (± 2 %)
- Compressor isentropic efficiency

This vital data can be presented dynamically in charts and tables, enabling the engineer and/or end user to gain an immediate picture of the actual performance of the system.

1.1 The innovative approach – how it works

Below the method is explained for a basic refrigeration system but with additional sensors it can be applied to virtually all vapor compression processes. For a basic system ten easy to apply sensors are attached at strategic points around the system. This is 7 temperatures, 2 pressures and active power as shown in Figure 1.

Required measuring points for a basic system as shown is:



- Temperature and pressure at entrance of compressor.
- Temperature and pressure at compressor exit.
- Liquid refrigerant before expansion device.
- Active electrical power.

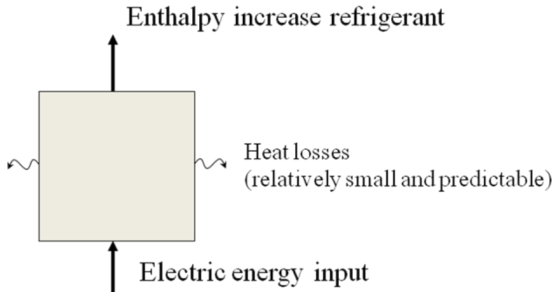
For reference of operating condition and heat exchanger evaluation the temperature of air/liquid entering and exiting condenser and heat exchanger are measured. IN total 10 measurements that are easy to apply to almost all systems in the field.

Figure 1, Sensors required and their location to establish performance of a standard refrigeration system.

At the heart of the performance analyzer is the energy balance over the compressor and a series of algorithms, based on thermodynamic properties and operating characteristics of the refrigerant in use.

The heat losses are low relative to the total input power limiting the impact of variation as documented by (Asercom, 2003) and (Naumburg, 1987). So, equation (1) will give a good accuracy of mass flow of refrigerant.

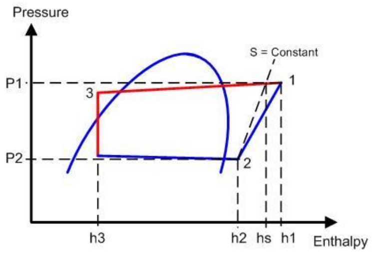
The losses varied in documentation and tests between three and ten percent in hermetic and semi-hermetic compressors without external cooling representing the vast majority of compressors on the market. For open drive and compressors with cooling the same methodology can be used by adding a model of the amount of energy not introduced in the refrigerant flow. When the net energy to the refrigerant flow calculated as the measured electrical power – heat losses are known the mass flow is also known through equation (1).



$$\text{Mass flow} = \frac{\text{(electrical input-heat losses)}}{\text{Enthalpy difference}} \quad (1)$$

From the above described energy balance and these enthalpies all data required can be derived including COP, Capacities, and the compressors total isentropic efficiency. Method described in more detail by i.e. (Berglof, 2004), (Berglof, 2005), and (Fahlén, 2004).

Figure 2, The energy balance with consideration of heat losses over the compressor allows calculation of mass flow



$$\text{Cooling Capacity} = \text{Mass flow} * (h2 - h3) \quad (2)$$

$$\text{Heating Capacity} = \text{Mass flow} * (h1 - h3) \quad (3)$$

$$\text{Isentropic Efficiency} = \frac{(hs - h2) * (1 - \text{rel. heat loss})}{(h1 - h2)} \quad (4)$$

Figure 3, Pressure – enthalpy graph of "standard" refrigeration process.

Example above show a basic system but the method can be applied to more complex systems - if the compressor shown in the picture above is a rack with i.e. 5 compressors this does not require additional sensors but to remotely evaluate the individual compressor it can be beneficial to add individual temperature sensors. If a desuperheater is installed for heat recovery, one additional temp sensor will identify how much “desuperheated energy” that is recovered.

Even complex transcritical two or three stage CO2 can be analyzed with the same method using some extra sensors as the example of a CO2 booster in Figure 1Figure 4.

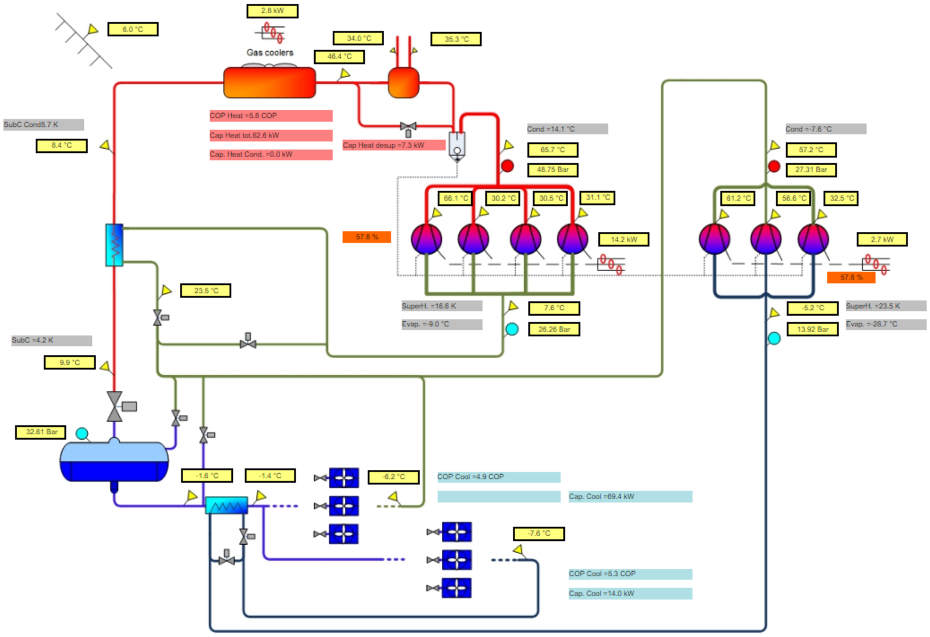


Figure 4, Sensors used in a CO2 booster system monitored in Seattle, Washington for a BPA project.

1.2 System Efficiency Index – SEI a benchmarking parameter for evaluation and optimization.

A major challenge in discussions on efficiency is the complexity of expressing and visualizing performance. EER/COP/Cooling efficiency are factors that vary with conditions and thus are challenging to use on dynamic systems. A performance indicator that are independent of ambient conditions that can be used for benchmarking is of great interest.

System Efficiency Index **SEI** was introduced for field measurements by ClimaCheck in 2014 and presented at IIR conference in Milano 2015 (Berglof, 2015). Increasing field experience prove SEI to be a powerful tool for the expert to benchmark systems and pinpoint weak point in systems. It also provides an opportunity to show owners and operators how their system performs and allow them to identify when performance deteriorate without thermodynamic competence.

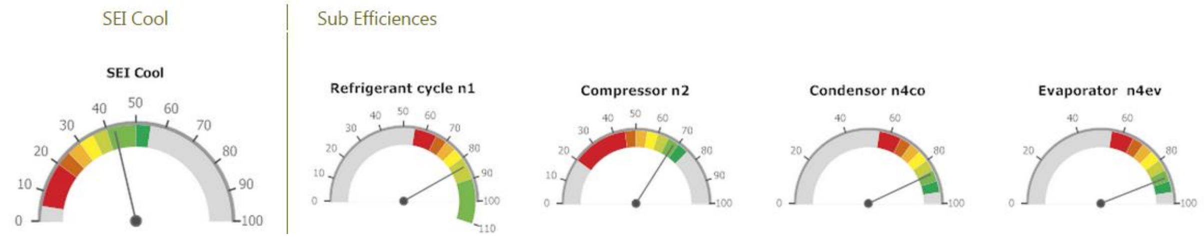


Figure 5, Visualization of SEI1 and sub efficiencies for a good system.

The key performance indicator **SEI,** is the efficiency for a refrigeration, air-conditioning or heat pump system compared to a 100 % efficient system (loss free) at the operating condition it is measured. In a project lead by The Research Institute of Sweden (RISE), financed by the Swedish Energy Agency, SEI has been evaluated as a tool to analyses field measurements. Industrial Partners in the project included Institute of Refrigeration in UK and companies from Sweden, UK, Germany and Spain. A report from the project is available to download from Internet (Lane Anna-Lena, 2014) . SEI is defined as measured COP divided by the Carnot efficiency of a process operating between the reference temperature on the cold and the reference temperature on the warm side.

$$SEI_{c,i} = \frac{COP_{c,i}}{\dfrac{T_{ref,c,i}}{T_{ref,h,i} - T_{ref,c,i}}}$$

1.2.1 Sub Efficiencies

The possibility to identify and benchmark weak points contributes to making the SEI concept a powerful tool for fault detection and communication.

The most interesting sub efficiencies as shown in Figure 5 are for most applications:

- ✓ Cycle efficiency
- ✓ Compressor efficiency
- ✓ Condenser efficiency
- ✓ Evaporator efficiency

As the sub efficiencies and SEI has a low dependence on the operating condition it proves to be a very practical analyzing and benchmarking parameter.

1.3 Energy signatures as a tool for validation of optimization

Performance can be measured and analyzed but require an expert to evaluate and identify optimization opportunities. Most equipment owners are mainly interested in costs and reliability and need information converted to kWh, USD and CO2 emissions to become interested. In refrigeration and air conditioning systems with dynamic loads and changing ambient conditions the energy consumption will change by the hour. Energy signatures is a key to create cost effective methods to predict, validate and benchmark performance.

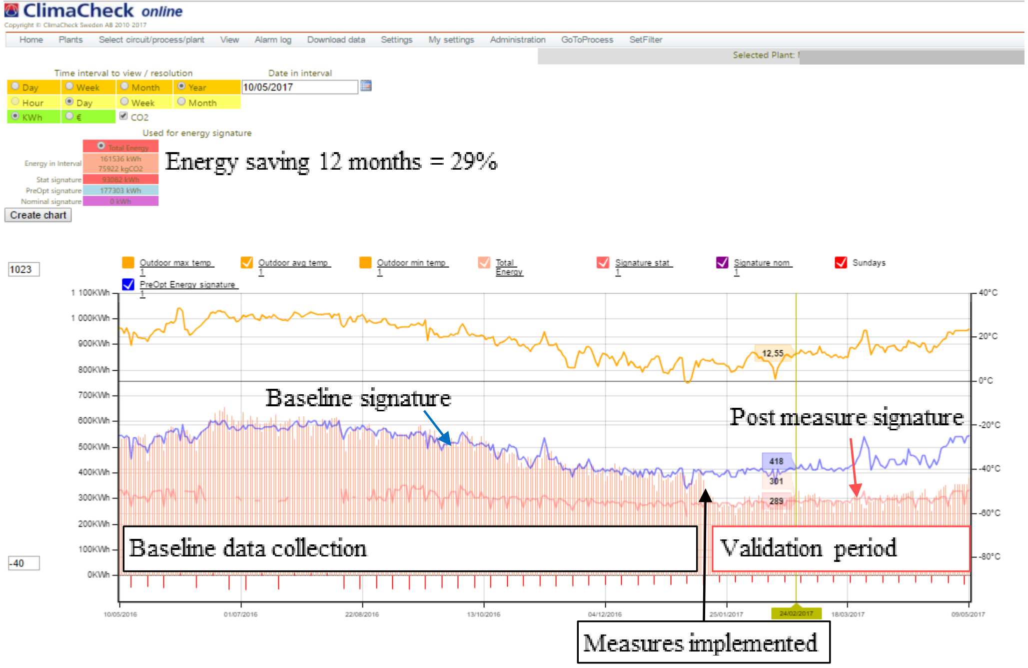
An energy signature in its most simple form establish kWh per hour at each occurring temperature for a site. Figure 6 show signatures for a supermarket in Sweden and one in Greece.

Figure 6, Typical energy signature Greece and Sweden show how two different supermarkets can be compared even if they are in different climate zones. If the supermarkets are normalized on size or feet of display case or other key factors different technologies can be benchmarked versus each other.

It shows how kWh/h consumption depends on ambient temperature but can still be compared for overlapping temperatures and normalized to desired indicator of size. Energy signatures are a necessary component to predict energy consumption in a plant and can be generated by measurements. In real life, it becomes slightly more challenging as load pattern in a supermarket or commercial property also varies with if store/office is open or closed. To create high and low load profiles are for many types of plants not a challenge.

With climate data for a location the energy signatures will facilitate the possibility to get annual consumption as well as predict energy/Euro/CO2 savings from a predicted measure.

As the energy signature allows that measurements done over periods with quite different ambient condition it becomes a necessary tool to validate impact of measures. There are way too many case studies done to show the savings of measures than compare different time periods without taking energy signature into account. Two weeks with the same average will not generate the same energy consumption if the temperature amplitude is higher one of the weeks Figure 7. below show energy optimization in a supermarket through low cost optimization measures based on measure – analyses – optimize – validate. Pink bars represent kWh/24 hours. Achieved savings are difference between actual consumption after measures and blue baseline energy signature.



Time interval to view / resolution: ○ Day ○ Week ○ Month ● Year

○ Hour ● Day ○ Week ○ Month

● KWh ○ € ☑ CO2

Date in interval: 10/05/2017

Used for energy signature: ● Total Energy

Energy in Interval: 161536 kWh, 75922 kgCO2

Stat signature: 93082 kWh

PreOpt signature: 177303 kWh

Nominal signature: 0 kWh

1023

-40

Energy saving 12 months = 29%

Baseline signature

Post measure signature

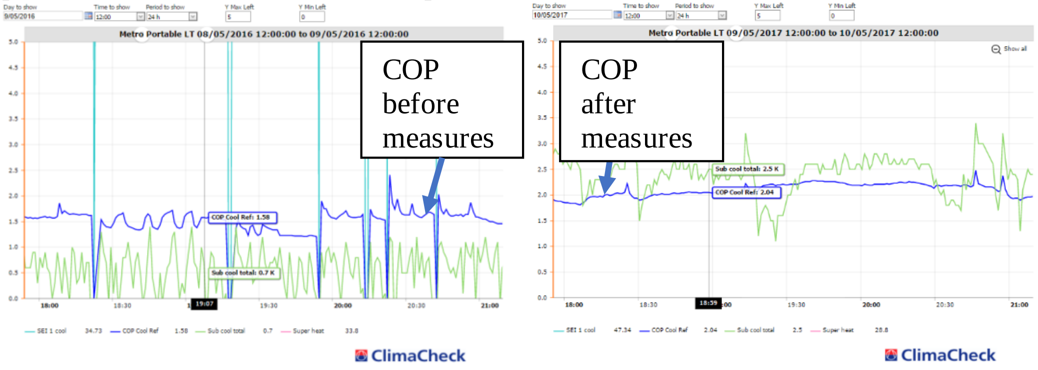
Baseline data collection

Validation period

Measures implemented

Figure 7, Energy saving visualized with energy signatures – this adjust energy consumption to ambient consumption

Figure 8 below shows the improvement of COP of a LT rack from replacement of compressor with poor performance and lower condenser pressure.



Day to show: 9/05/2016; Time to show: 12:00; Period to show: 24 h; Y Max Left: 5; Y Min Left: 0

Day to show: 10/05/2017; Time to show: 12:00; Period to show: 24 h; Y Max Left: 5; Y Min Left: 0

COP before measures

COP after measures

Figure 8, COP before and after measures

1.4 Well proven method

The method and technology were first developed in Sweden 1986 and validated by RISE (then SP) the national Swedish testing institute (Fahlén, 1989). More than 50 manufacturers and 400 contractors in 20 countries have introduced the "Internal Method" as a tool to improve their development, production and aftermarket activities. Examples of world leading companies in the industry that has validated and use the Internal Method to document the performance of their products and optimize the systems are Carrier, Trane, Johnson Control, Daikin, Copeland (Emerson), Bitzer, Gea, Danfoss Heat pumps, Chemour (DuPont) and many more.

1.5 Practical benefits

All the data required for a full evaluation of a system is available as soon as sensors are connected which for a basic system will take 20-30 minutes – often without requirement to stop the system. With the information provided, engineers can identify plant performance problems, including among many others:

- refrigerant shortage or over-charge
- incorrect superheat setting
- compressor damage or wear
- fouling of heat exchangers
- oil logging in the condenser/evaporator
- fan/pumps underperformance, flow problems on secondary medias (air/water/brine)
- control problems

The system identifies irregularities in compressor, component performance that could result in future impairment of performance – or even plant breakdown, enabling pre-emptive maintenance and energy optimization.

Armed with this vital information, engineers can address the issues identified, optimizing system performance. The result has a huge potential for savings in power consumption and carbon emissions over a plant's lifetime. Without an effective method and an efficient tool, these problems normally go unrealized, with the plant continuing to perform inefficiently – or eventually breaking down with potentially catastrophic consequences for refrigerant loss and stock damage.

2 ClimaCheck today

ClimaCheck has supplied the global refrigeration and air conditioning industry with more than 1200 performance analyzing and monitoring systems since 2004. ClimaCheck is used by more than 50 manufacturers for development and production test rigs as well as pilot tests.

ClimaCheck is used by more than 30 test institutes and universities for validation and research projects in the field. ClimaCheck offer portable inspection tools and turn key monitoring system but also integration in BMS/BAS systems and sever to server communication for third party systems that want to present real time performance data.

More information please contact: seanm@eeswest.com

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