How do you make your Heat Pumps and Chillers Operate as you Planned?

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International Energy Agency IEA HPT Annex 52 (see also page 20-21) recently published "New Guideline to Instrumentation and data" to address the challenges experienced with verification of performance of Ground Source Heat Pumps. With increasing energy prices and a focus on climate change, this guide will be useful for those pushing optimization and reliability based on documentation of performance. One of the methods described for performance analyzing is the "Internal Method", based on thermodynamic analytics of the processes. This article describes experiences of field monitoring with this method and faults that can be identified and corrected.

Based on 40 years of experience in troubleshooting and optimization of heat pump/chiller installations, the question often comes up: "**How hard can it be to get things right?**" But the fact is that without the right information and clear responsibilities with monitoring performance, systems will not be efficient.

HVACR systems consume almost 20% of the global electricity. And it is often documented that 20-30% of the energy is wasted due to faults and lack of optimization. With experience from thousands of measurements, the conclusion is that virtually no systems are well optimized. Therefore, optimization of existing plants is a "low hanging fruit" when it comes to the reduction of carbon emissions.

The misconception that keeping the right temperature equals good performance "allows" many systems to run inefficiently.

Equipment owners hesitate to invest in performance analyzing when nobody knows there is a fault. Even a low investment is unattractive when ROI is uncertain without a baseline.

Problems are often recognized only when a system trips or the required temperatures are not maintained. The lack of focus on performance is a result of the structure of the property market and how HVACR systems are purchased. Property owners are seldom experts in heat pumps/chillers and purchase a building using consultants to specify the requirements they desire. The contracted builder, in turn, contracts a series of sub-contractors to supply all the necessary systems.

It has been extremely rare that the specification of Measuring and Verification (M&V) delivers the information required to ensure that systems operate as intended over varying conditions.

A HVACR system performance is affected by 5-6 subcontractors – all with their own specification to follow. Most specifications focus on peak load conditions which rarely or never occur. So, commissioning staff often run chillers/heat pumps in building with low load at whatever outdoor conditions that happen to be at the commissioning date.

If a system is operated to specified temperatures without tripping, it is assumed that the system operates as specified. It is becoming common to specify to check winter and summer conditions, but this is less fruitful than to continuously log information in a structured way. It is cost-effective to ensure that data is collected in a structured way on all sites. Essential is also to assign the responsibility to document total performance and verify subsystems versus specification at relevant conditions. This will minimize "reactive maintenance", which is costly for the equipment owner but profitable for a contractor.

Increasing pressure to improve efficiency and reliability

Rising energy prices, energy shortage and an increased focus on sustainability will force equipment owners to focus on efficiency. Maintaining a temperature will not be good enough. The industry needs to improve the specification of design as well as that M&V is a part of proper commissioning and maintenance.

International Energy Agency (IEA) HPT Annex 52 recently published "New Guideline for Instrumentation and Data" [1] that collect international experiences on what is recommended to make a cost-effective evaluation of performance. With a structured approach to data collection and analyses to evaluate each subsystem, commissioning and predictive maintenance can be implemented effectively. The required sensors are often standard today. It is not a question of adding many expensive sensors; it is a to follow "good practice" for what sensors are used and how they are mounted and verified. It is also important how data is collected and stored to turn data into information required to verify performance.

Digitalization is here to stay

Any building designed today will include a lot of sensors. A typical heat pump/chiller for commercial buildings will have pressure and temperature sensors, and it should be standard to sub-meter larger electrical loads.

Obviously, supply and return temperatures of chilled and cooling water and air temperatures are measured, but sampling should follow good practice. Some values are required every minute, whereas others make no sense to store more than hourly. To track energies, it is preferred to store hourly data together with outdoor conditions, whereas it is totally useless to have hourly averages on temperatures and pressures in a heat pump/chiller that can have started and stopped several times in that hour.

It all comes down to make information out of available data. Annex 52 Guidelines establish a good practice to make benchmarking possible.

What can go wrong?

It could be seen as if the heat pump/chiller is a simple product with four main components. However, when realized that every degree of increased temperature lift will cause a 2-5% increase in energy consumption, it should be obvious that it deserves more attention than an alarm when pressure or current goes out of the allowed envelope.

A common explanation I encounter in problematic installations is that the heat pump/chiller is too big. However, there is no site that does not have a load starting from 0 kW.

Nevertheless, it is effective, as site staff has minimal possibilities to question the statement and do not know how often it is used to point the finger at somebody else.

A control system should handle all loads from zero to full load, and the water volumes are often more than sufficient to give the inertia required to avoid short cycling with proper set-up. The hydronic systems have a significant internal volume in pipes and equipment and normally offer sufficient volumes even without extra accumulators. The all-too-common short cycling issues occurring are related to commissioning.

Besides the insufficient commissioning of the control system over the wide envelope, the system perspective is often missing when each sub-contractors take responsibility for their own delivery and nobody for the total. Obviously, distribution systems, heat source and heat sink must function well together with the heat pump/chiller. These temperatures, as well as ambient, should be logged with energy use for heat pump/chiller and preferably also for pumps and fans, see Figure 1 as an example.

When the distribution systems are balanced, the largest "electricity consumer" - the refrigeration process - remain unattended. In fact often 60% of the energy is neglected when the heat pump/chiller is assumed to work as rated. This leaves a huge, number of possible faults unattended and system efficiency and reliability reduced. This leaves a huge number of possible faults unattended and system efficiency and reliability reduced. It is necessary to ensure that the heat pump/

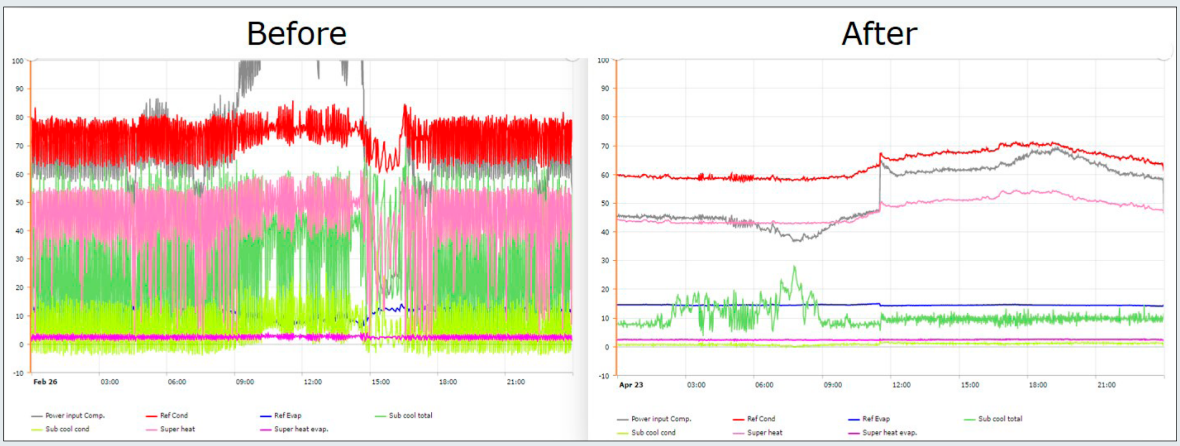

Figure 1. Erratic controls should be stabilized to avoid failures and waste of energy.

chiller itself is in good shape and have the best operation conditions possible, including:

A. Correct refrigerant charge
B. Correct superheat
C. No compressor problems
D. Evaporator efficiency
    a. Correct flow
    b. No air or fouling
    c. No oil issues
E. Condenser efficiency
    a. Correct flow
    b. No air or fouling
    c. No oil issues
    d. No none-condensables in refrigerant circuit.
F. No excess pressure drops in the refrigerant circuit.

Common practice for maintenance inspections do not verify performance, and it is virtually impossible to do that during a service inspection as the system is highly unlikely to operate stably at the time inspection is carried out.

How to find and fix the faults?

The "Internal method" described in IEA HPT Annex 52 makes it possible to measure the total System Efficiency Index (SEI) as well as all relevant KPIs in real-time (see Figure 2). Enabling alerts if any change of performance occurs as the thermodynamic evaluation establishes:

- System Efficiency Index
- Sub-efficiencies for:
    - Compressor
    - Condenser
    - Evaporator
- All key maintenance parameters
    - Refrigerant charge
    - Superheat
    - Subcool
    - Approaches
    - Flows

A dashboard, as in Figure 3, gives the same performance information in real-time as a test rig at a production facility, based on data from sensors that usually are standard today. If a sensor is missing in controls, it can be added at a marginal cost. The data is sent to cloud-based services, where it is analyzed. The information will be sent to the owner and available to experts that can take decision on corrective measurements.

The KPIs is compared with adjustable limits that should be but rarely are included in operating manuals.

The single most common issue is that controls are not properly set up to handle different operating conditions and loads. This result in all kinds of problems such as tripping on oil protection and failures.

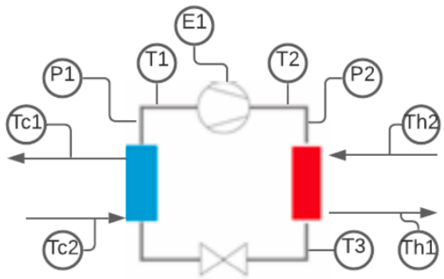

Figure 2-2. Measurement locations for the internal method of a heat pump as described in Lane et al (2014).

Table 2-2. Recommended measurement points for a basic ground-source heat pump using the internal method (see Figure 2-2).

Description	Fig. 2-2	Comments
Heat pump compressor electrical input	E1	Electric power of compressor
Source-side supply and return temperatures	Tc1, Tc2	May be paired for calibration of ∆T
Load side supply and return temperatures	Th1, Th2	May be paired for calibration of ∆T
Pressure and temperature of refrigerant	T1, P1	Before compressor
Pressure and temperature of refrigerant	T2, P2	After compressor
Liquid temperature of refrigerant	T3	After condenser and before expansion device

Figure 2. Sensors required for Internal method described in Annex 52.

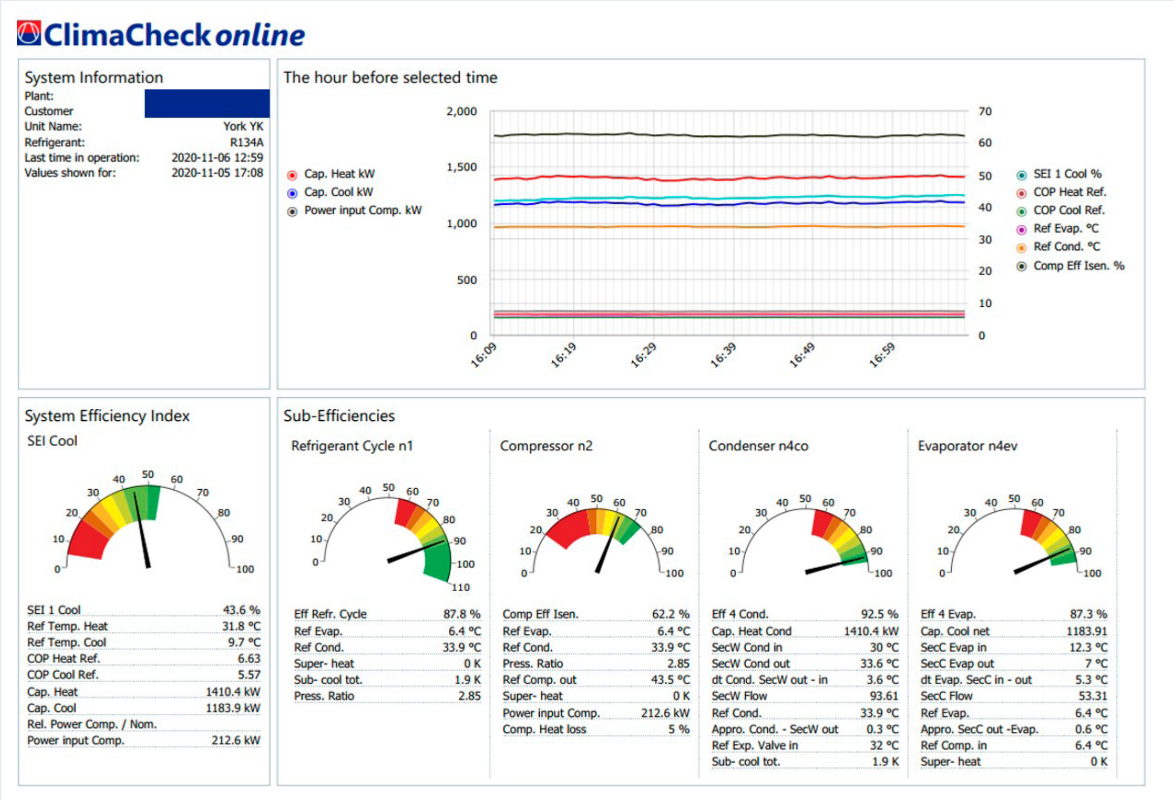

Figure 3. Dashboard with all KPIs required for maintenance and optimization.

One of the most obvious and easiest energy-saving measures is to use “floating set points” on both the cold and warm sides. Single set-points based on design conditions on the cold and warm side increases electricity consumption by 20-40%. There are few buildings that require the standard design of 7°C chilled water during mild temperatures (if ever). Even if the design would, e.g., a 7°C chilled water supply, it is common that there are safety margins to allow significantly higher set-points. For lower outdoor temperatures, a so-called floating set-point can be used to reduce operating cost by 3-5% for every degree. The lowest possible temperature lift that delivers the desired temperatures should always be established. The same with the “poor practice” of leaving air-cooled chillers and dry coolers on high set-points; this should have been history a long time ago, but we find that it is common that when systems have been optimized, somebody resets the system to his own “rule of thumb” without an understanding of the impact on running cost. Unless a site is commissioned as a complete system over different operating conditions, it will rarely work well.

When performance is analyzed in the cloud, the technician/ engineer receives a warning as soon as any performance deviation occurs, and before every site visit, a digital inspection can be done to ensure that any potential optimization measure is carried out during the site visit. Continuous performance monitoring also enables early detection of leaks, so-called “Indirect leak detection” in EU-vocabulary as changes in pressures and temperatures will indicate a decrease in refrigerant charge. As this “catch” all leaks, this is more reliable than gas detectors that are challenging to mount, so they catch all leaks. Obviously, the combination of leak detectors and “indirect leak detection” adds value for larger or critical plants.

Next step is predictive maintenance

The future is to implement guidelines such as IEA HPT Annex 52 and monitor systems 24/7 with state-of-the-art analytics to detect any deviation in performance. To pinpoint the cause instead of going to site on a schedule and handle failures when they happen. An introduction to the challenges in transiting from “Business as usual” in a conservative industry to predictive maintenance is available in the “Guide to Predictive Maintenance for HVACR systems” [2].

“To Measure is to know.”

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