METHODS AND POTENTIAL FOR ON-SITE PERFORMANCE VALIDATION OF AIR CONDITIONING, REFRIGERATION, AND HEAT PUMP SYSTEMS.

M. o Sc. Klas Berglöf, Managing Director, Berglöf Refrigeration Technology Ltd

Nysätravägen 24, S-131 33 Nacka, Sweden

tel. +46 (0)8 55 61 55 75

klas@berglof-kylteknologi.se

Websites: www.climacheck.com

ABSTRACT

This paper describes an innovative method using a "Refrigeration Performance Analyzer" based on on-line measurements and analyses of the refrigeration process. The method is cost-effective to establish the performance of virtually any refrigeration, heat-pump or air-conditioning system. The method gives performance as well as detailed information of all components characteristics, within 30 minutes from entering the plant room, without the need for fixed installation of measuring equipment.

The method uses easy to apply sensors to measure pressure, temperature and electrical power. Through thermodynamic calculations it is possibly to calculate the refrigeration cycle. Through the innovative approach of establishing the mass flow of refrigerant based on an energy balance of the compressor the cooling and heating capacity can be established with an accuracy that can normally not be achieved outside the laboratories at reasonable cost.

Currently the method is used by equipment manufacturer, service companies and consultants to get detailed information of capacities and optimization in a cost effective way both in development laboratories, production test facilities and in the field.

The method has been proven by theoretical analyses as well as parallel measurements with traditional methods. Due to its inherent insensitivity to measurement errors, it is cost effective for field measurements. Theory as well as experience shows an accuracy of 7% or better in measured cooling and heating capacity.

Keywords: ***refrigeration, air-conditioning, heat pump, performance analyzer, analyzer, analyzing, analyzing, field measurement, energy efficiency, trouble shooting, optimization, inspection.***

1 INTRODUCTION

The focus on Energy efficiency is increasing as a result of the Climate Change debate as well as increasing cost of electricity. Historically, there has not been a significant interest for the difference between design performance and actual performance after installation. If correct temperatures are achieved and the system is not braking down to often everybody is "happy". To actually verify performance in the field has been considered to difficult. Most research and development work is focused on trimming the performance at designed rating conditions whereas the experience show that many systems after installation work very far from their optimum often at very different conditions from the rating condition.

New requirements are changing the requirement on operation and service of refrigeration systems. Ozone depletion, global warming, increased energy prices and costs for downtime are changing the expectations on service providers. Is the refrigeration trade up to this challenge? Otherwise, the increased focus could result in more business for other sectors in the industry with fewer competencies to actually improve the COP of refrigeration and AC-systems.

All EU-members shall according to the EU Directive 2002/91 on Energy Performance in Buildings (EU 2002), before January 4, 2006, implement regulations on whom and how air-conditioning systems with a rated capacity over 12 kW should be performance tested. There are so far no description on what methods to use or what competencies that will be required by the person to perform the “inspection”. There are discussions to limit it to checking that “air-coils are not dirty” and/or theoretical analyses on W/m3 and kWh/m3. These are all very rough indications on a systems performance and optimization and can not be expected to change the energy consumption significantly. This paper presents a method for “Refrigeration Performance Analyzing” based on measurements in the refrigerant circuit (and for reference on the secondary sides). Through an energy balance over the compressor the process can be analyzed including COP, capacity and all relevant parameters for evaluation of performance and optimization. The method and its accuracy is validated by among others the SP Swedish National Testing and

Research Institute (Fahlén P., Johansson K. 1989) in theory and practice and has been used with good results in Sweden and other markets for almost 20 years. The increased focus on energy efficiency through the Kyoto Protocol, EU-Directives and spectacular power black-outs at AC-peak loads is expected to lead to an increased interest for ensuring optimized operation. New development of hard- and software has at the same increased the flexibility and decreased the price for data logging equipment. New standards for data exchange and communication also make integration in Building Management Systems cost effective. The method is presented together with experiences and examples from on-site performance testing. The key advantages with the described method compared to traditional flow based performance testing is the lower sensitivity for measurements errors e.g. higher accuracy in the field and the possibility to identify not only a difference in performance but also in detail pinpointing the cause for it cost effectively.

The streamlining of many end-user organisations with reduction of their in-house expertise has made evaluation of service contractor’s skills and quality of work more difficult. Consultants on the other hand seldom have the possibility to follow up on installations and in particular rarely get long term feedback from all relevant aspects including annual energy consumption, service cost and user satisfaction (such as experienced comfort of an AC system and influence of type of exposure on sales results and flexibility for renewing the “image” in a supermarket).

An increasing number of less competent end-users results in a trend to focus on hourly rates from the service sector rather than on quality. Contractors continuously complain over that lowest initial price always wins contracts for new plants in-spite of not always meeting all requirements in the specifications. The organisation in many projects with different divisions or companies responsible for initial cost and operating costs further decrease the possibility for a long term view on energy consumption. There has been some introduction of Life Cycle Cost (LCC) analyses in some purchasing processes but due to the problems with verification and follow up caused by the number of variables influencing an actual plant the success of introducing this concept seem to have been limited so far.

New requirements such as the European Directive for Energy Performance in Buildings will lead to a much stronger focus on preventive service and energy optimisation. The interpretation of annual performance inspections on all air-conditioning systems over 12 kW is still not defined but hopefully the refrigeration trade can together with the authorities make the requirements a tool to improve the quality of work. With an increased focus on energy efficiency, low leakage rates and minimized refrigerant charges the importance of effective methods for performance testing will increase.

The described method was developed after the heat pump “boom” in Sweden in the first half of the eighties a new perspective was introduced. Investment in heat pumps are done strictly to minimize the operating cost resulting in a different perspective than in commercial refrigeration and air-conditioning. That the comfort remained the same as before was a precondition and then the decreased cost was the sole reason for the investment and many customers were monitoring the cost continuously. This resulted in a demand for field measurement methods to prove that installed heat pumps fulfilled the energy specifications and cost savings in the contract.

This was and still is to a large extent different from the situation for air-conditioning and refrigeration systems where the complaints often occur only if the temperature becomes unacceptable or failure rates gets out of hand.

To use temporary (or in a few cases permanently) installed flow meters and temperature sensors proved a costly and difficult task, resulting in a high degree of uncertainty. When traditional flow/dT measurements indicated that a heat-pump did not meet the specification the answer to why was as remote as when the investigation started. The in this paper described “Refrigeration Performance Analyser” method based on measurements in the refrigeration circuit was developed and patented 1986. A major advantage is that the method will work without preinstalled sensors/meters. The method can be used as effectively on direct as on indirect refrigeration systems and regardless of the capacity. Also systems with parallel evaporators, sub coolers, heat recovery condensers and de-super heaters can be analyzed and COP and capacity established as well as the performance and status of the individual components. The method makes on-line presentation of all relevant parameters possible and document them in a way that makes it feasible for a third party (e.g. manufacturer or consultant) to evaluate the operation in detail.

There are currently close to 300 systems using the “Refrigeration Performance Analyser” method to shorten the time to develop new systems in manufacturers laboratories, shorten the time and improve the information from test after production and at commissioning, field inspections, trouble shooting and for scheduled maintenance.

2 THE “REFRIGERATION PERFORMANCE ANALYZER” METHOD

The “Refrigeration Performance Analyzer” method use well-known property calculations to establish the refrigeration process. This is not innovative by itself but the calculation of massflow, capacity and COP is based on an energy balance over the compressor see Fig. 1, which has proved to be a robust and cost effective way to achieve an accurate field method for evaluation of compressor based refrigeration systems with suction gas cooled hermetic and semi hermetic compressors.

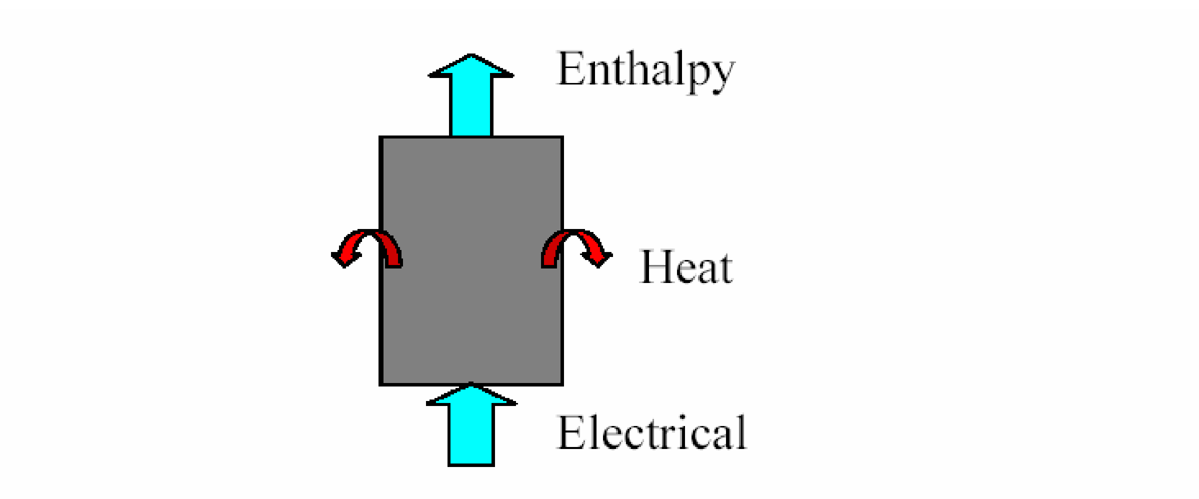

Fig. 1. Black box analyses of compressor to allow performance and capacity calculation.

These compressors are used in the overwhelming majority of all air conditioning, refrigeration and heat pump systems on the market today. The method also proved to be easily adopted for open compressors or air cooled compressors and more complex systems (with additional input required for the energy balance). Also for complex installations it is possible to use the method without that the person performing the measurements having the thermodynamic knowledge of the calculations. All calculations can be stored in “templates”. The advantage of the method is besides the relatively low sensitivity for errors in the measurements also that it gives information for a “total” evaluation of the components in the refrigeration system and presents detailed results of any changes introduced.

Literature studies and tests at the Royal Institute of Technology in Stockholm (Naumburg 1987) indicated that the only “unknown” parameter - the heat loss from the compressor – could be predicted (in most situations is between 3-10%) of the electrical input for semi-hermetic and hermetic compressors. It also became clear that using even a simple fixed assumption (7%) is acceptable for most applications as even a “large” change of heat rejection such as a 50% increase or decrease would result in an error of only 3-4% in the measurements. Experience show that the variations normally are lower. Variation in heat rejection from a large number of compressor manufacturers is documented by (Asercom 2003). The conclusion from this is that the compressor can be used as a for field condition accurate “flow meter” for a refrigerant circuit.

Mass flow = (electrical input-heat losses)/ Enthalpy difference between compressor inlet and outlet.

With this knowledge it is possible to calculate not only the refrigerant properties but also cooling and heating capacities by using two pressure transducers, three temperature sensors and an electrical power transducer.

The sensors used are mounted on the outside of the tubing. The sensors necessary to calculate the “standard” refrigeration process is shown in Fig. 2.

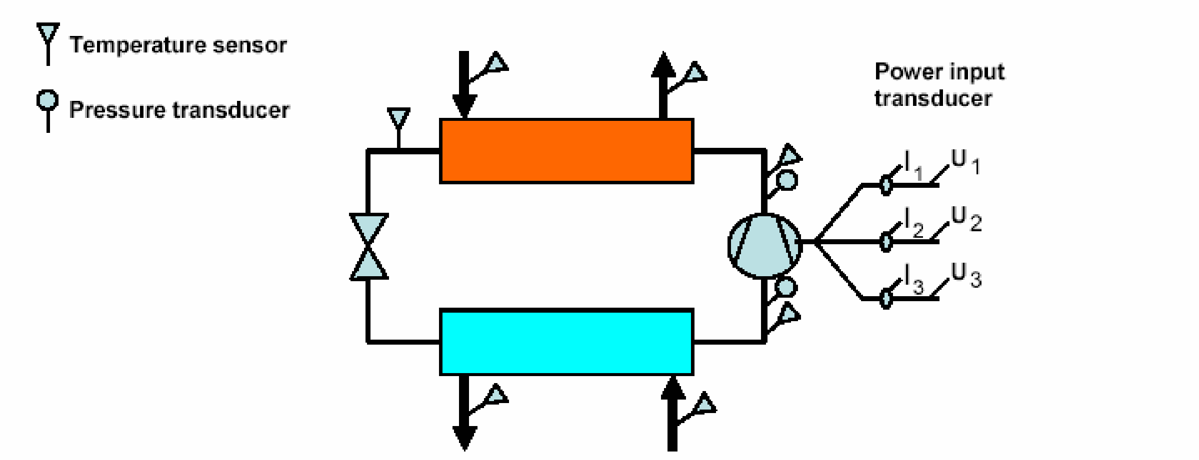

Fig. 2. Sensors required to evaluate the ”standard” refrigeration process (I and U are current and voltage measurements to measure Active Power input to compressor).

The process introduced in a pressure-enthalpy diagram from the measurements is shown in Fig. 3. The enthalpies are calculated with the physical data for the refrigerant in use.

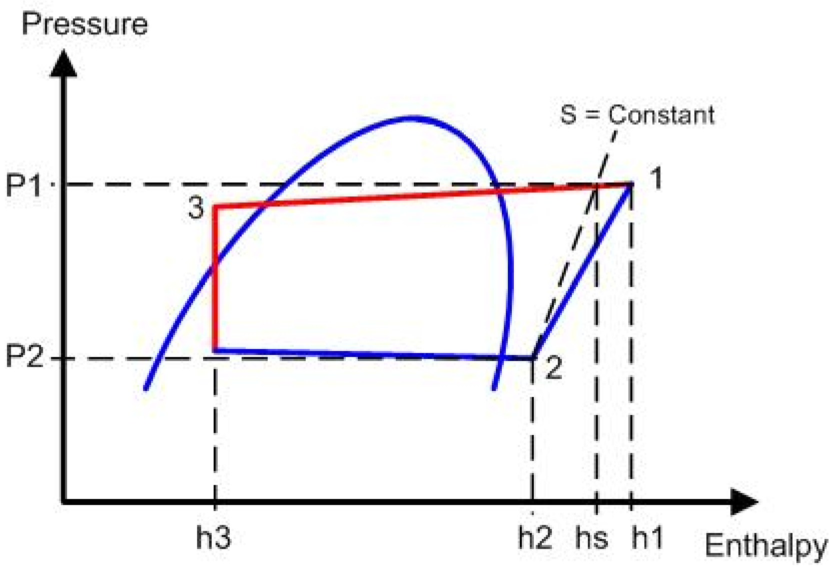

Fig. 3. Pressure – enthalpy graph of "standard" refrigeration process.

From the above described energy balance and these enthalpies all data required can be derived including COP, Capacities, and the compressors total isentropic efficiency.

COP heating = ((h1-h3) / (h1-h2)) * (1 – Heat losses / Electrical Input)

COP Cooling = ((h2-h3) / (h1-h2)) * (1 – Heat losses / Electrical Input)

Cooling Capacity = Mass flow * (h2 – h3)

Heating Capacity = Mass flow * (h1 – h3)

Isentropic Efficiency = ((hs – h2) / (h1 – h2))* (1 – Heat losses / Electrical Input)

The accuracy under field conditions has proven to be higher than what can normally be achieved at acceptable cost with flow meter and temperature sensors on the secondary systems. When air is the secondary media moisture and uneven temperature/flow distribution makes measurements in the field even more difficult. The method have a practical accuracy on capacity measurement better than 7% and can be applied in less than 30 minutes to most existing systems without even stopping the compressor. A theoretical evaluation and practical tests was done by (Fahlén P., Johansson K. 1989) and (Fahlen P. 2004). The test at the SP, SP Swedish National Testing and Research Institute, as well as many parallel test at manufacturers development and production test rigs show that the method is practical and to use with good reliability. The following limitations should be understood:

The simplified assumption for heat losses is valid for suction gas cooled compressors. For other compressors the factor should be modified based on comparative tests. For laboratory use the heat losses can be specified with operating and ambient as parameters but in most field applications a fixed loss gives an acceptable accuracy.

If the method is applied to open or air-/water cooled systems the accuracy will depend on how well motor efficiency or external cooling is known.

The refrigeration process needs to be "complete" to achieve full accuracy (e.g. super heat before compressor and subcool before expansion valve.

If the system is operating without sub cooling and/or super heat this will be identified by the measurements and should be corrected before a full accuracy can be achieved.

The refrigerant in the system need to be known. In case of unknown mixtures of refrigerants or blends with the wrong composition the method will often identify a problem but if not understood the results can be wrongly interpreted.

3 PRESENTED RESULTS FROM “REFRIGERATION PERFORMANCE ANALYSING”

Through the thermo dynamical calculations all relevant data in the refrigeration can be presented on-line allowing the engineer or technicians to take immediate action and see the result. Key results that are presented are:

- ✓ COP
- ✓ Capacity
- ✓ Power input
- ✓ Compressor isentropic efficiency
- ✓ Super-heat
- ✓ Subcool
- ✓ Evaporator performance, temperature difference, heat transfer coefficient, flow rate
- ✓ Condenser performance, temperature difference, heat transfer coefficient, flow rate

For complex systems further information can be included in the calculation templates and presented.

4 DOCUMENTATION OF PERFORMANCE RESULTS IN DECREASED ENERGY CONSUMPTION AND SERVICE COSTS.

Many refrigeration and air-conditioning systems consume more energy than calculated. This is not only caused by poor calculation methods and “commercial factors”. There is frequently a lack of optimisation of operation of the systems when systems are inspected. Experience from years of field inspections show a variety of explanations to that over 60% of the installations are found not to operate at the best possible COP in spite of that these inspections are announced to the contractor in advance and they consider the system ready for inspection. Many of these “problems” are not identified until an inspection with a full evaluation of the refrigeration process is performed. Common causes that have been identified are (not in order of occurrence).

- ✓ Overrating of units cooling capacity in manufacturing data.
- ✓ Underestimation of electrical input to compressors, pumps and fans.
- ✓ Overrating of heat exchangers by manufacturers (especially at low heat fluxes).
- ✓ Wrong input in calculations of compressor and components data.
- ✓ Wrong charge or adjustments of expansion valve.
- ✓ Defect components or poor maintenance such as blocked filter.
- ✓ Operation in unfavourable conditions due to set-points or control problems.
- ✓ Optimisation/balance of the system (such as capacity and flow rates).

A large percentage of the failures to systems are not caused by normal wear or material weaknesses. With improved commissioning and service procedures decreased maintenance and energy costs can be achieved. Proper service require a qualified service technician and proper equipment. The “problem” is not that the facts are unknown, difficult to understand or questioned but that the focus for contractors and service companies are seldom on actually optimising the systems but rather on with a minimum of hours finishing the job and few end users are competent to realise the importance of the optimisation. A key factor to increase the overview and understanding of the importance of careful optemisation is the presentation of the information. The documentation and presentation of information can be presented in tables (Fig. 4), graphs (Fig. 5) and flowcharts (Fig. 6) to make interpretation easy.

Time	SecC Evap in (C)	SecC Evap out (C)	Ref Evap Midpoint (C)	Super heat (K)	SecW Cond in (C)	SecW Cond out (C)	Ref Cond Mid point (C)	Sub cool total (K)	Ref Comp out (C)	Comp Isen. eff** (%)	Power input Comp. (kW)	COP Cool	Cap. Cool (kW)
14:12:05	-3.2	-5.4	-14.7	9.2	29.4	34.0	38.8	1.3	68.5	59.2	15.4	2.02	31.2
14:12:00	-3.2	-5.4	-14.9	9.5	29.5	34.5	39.0	1.6	68.4	59.5	15.5	2.04	31.6
14:11:55	-3.1	-5.4	-14.9	9.8	29.5	34.7	38.9	1.6	68.4	59.3	15.6	2.06	32.1
14:11:50	-3.1	-5.4	-15.1	10.0	29.4	34.8	38.8	1.7	68.5	58.9	15.6	2.06	32.2
14:11:45	-3.1	-5.3	-14.8	9.9	29.1	34.7	38.6	1.6	68.6	58.3	15.5	2.06	31.9
14:11:40	-3.0	-5.3	-14.9	10.0	28.9	34.7	38.2	1.3	68.6	57.8	15.4	2.05	31.5

Fig. 4. Table with selection of calculated data.

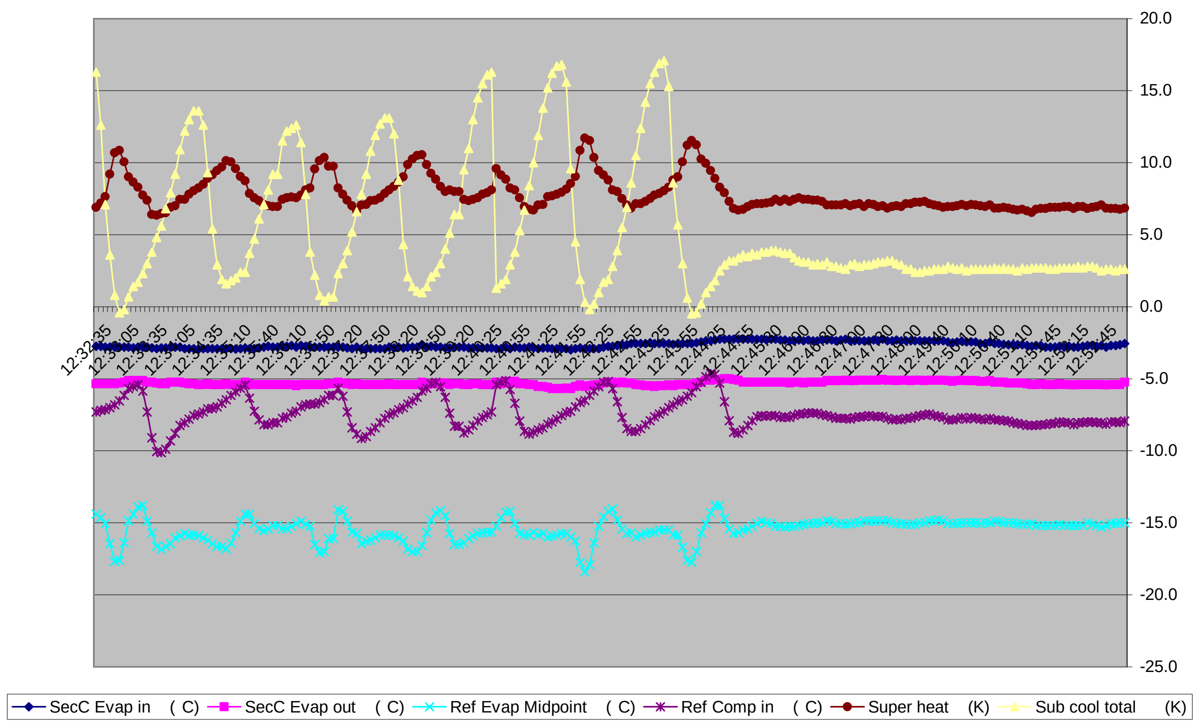

Fig. 5. Graph displaying unstable conditions that are stabilised during measurements.

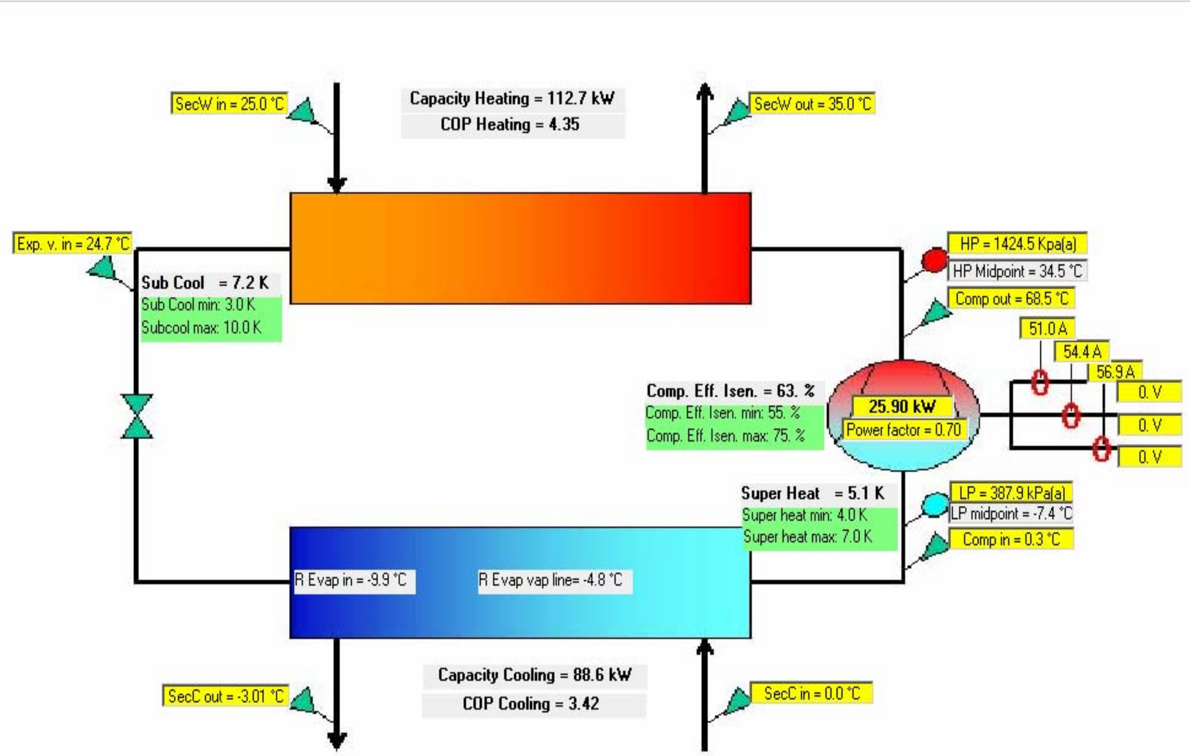

Fig. 6. Information presented in flow-chart for easy interpretation.

One experience is that conflicts between contractors and end-users can be solved quickly when the actual problem is quickly identified. Otherwise these are frequently allowed to continue for a long time and escalate to become serious before the focus becomes to actual measure and identify the problem. Often the end-user is dissatisfied and blames the contractor who explains the problem with other contractors, consultants or change of conditions. Were measurements, with the described method, has been performed the refrigeration units performance has been documented. With the documentation it is possible to judge if the refrigeration unit as such is the cause of the problem or not. In many cases also problems in "external" systems and/or operating conditions can be pinpointed and corrected. A survey of identified problems of 276 performed inspections is shown in Fig. 7.

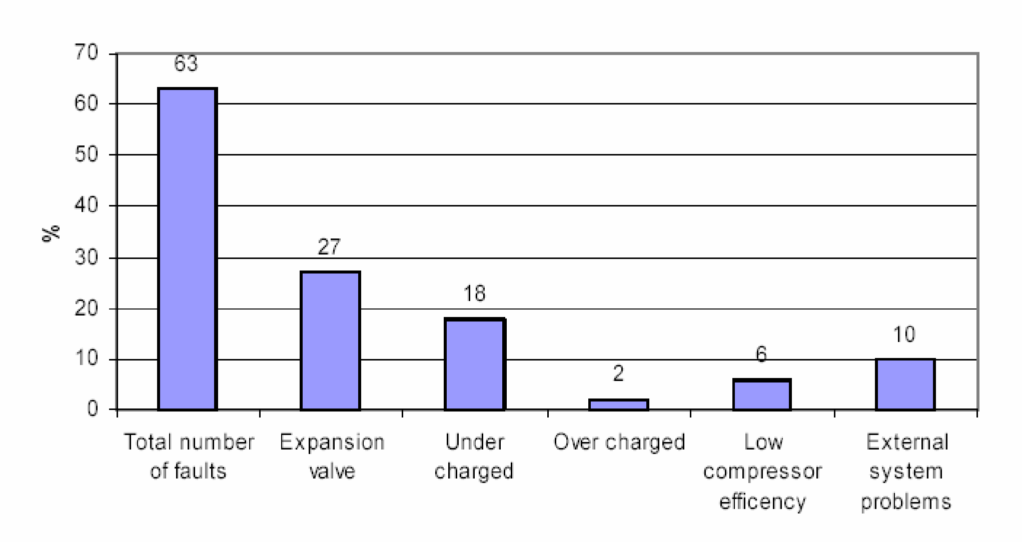

Fig. 7. Results of 276 performed inspections with Refrigeration Performance Analysers.

5 FIELD EXPERIENCE OF INSPECTIONS WITH "REFRIGERANT PERFORMANCE ANALYSERS"

In the following a brief summary of results documented at a number of recent inspections are presented. It is not claimed that these problems could not have been identified without this method just that it is a practical and cost-effective method that will document the full process and thus identify expected and unexpected problems or verify optimal operation.

5.1 Field Experience From "Refrigeration Performance Analyser" Used on an 11 kW Domestic Heat Pump.

The house owner experienced several cut outs of the heat pump during cold conditions. The indications were on high discharge temperatures. In spite of repeated contacts with the contractor and visits by service people the problem still occurred from time to time. The contractor claimed there was nothing wrong with the unit every time they checked and vaguely referred the problem to the "system". A "Refrigeration Performance Analyser" was used to trouble shoot the system and it could within 1 hour be clearly documented that the compressors isentropic efficiency was lower than normal for that type of compressor. This resulted in a higher discharge temperature that "only" caused an obvious problem at the edge of the operating envelope. Service staff checking the system did not identify the higher discharge temperature at the conditions when they checked the system. The heat pump manufacturer replaced the compressor and the problem has not reoccurred.

5.2 Field Experience with a "Refrigeration Performance Analyser" to Support Decision Process in Dairy Industry with 3.2 MW Cooling Capacity with Four Ammonia Screw Compressors.

The inspection was initiated after several incidents of unsatisfactory cool-down of the process in connection with high load conditions. A decision to expand compressor capacity with a fifth compressor at significant costs had been taken. To ensure the best way of integrating this in the existing system a consultant was contracted. To ensure that the status of the current system would not interfere with this decision the consultant convinced the industry to order a performance test with "Refrigeration Performance Analyser". The inspection was planned with one day installation of equipment with on-line analyses, data collection during one week after which equipment was dismounted (a data logger with 16 temperature sensors and 8 analogue inputs was sufficient for simultaneous evaluation of all four compressors, total COP and total capacity). The analyses clearly identified that the focus was not the compressor capacity as such but rather the heat transfer in the ice-banks that at high load conditions with all four existing compressors in operation the evaporation temperatures was reaching the level were compressors started to download in spite of high temperatures in the storage tanks. Additional capacity would only result in further decrease of evaporation further reducing the capacity of existing compressors making the installation of a new a poor investment. An increase of heat transfer surface/coefficient on the other hand would through the resulting higher evaporation be more than sufficient to achieve desired results and also allow more energy efficient operation year around. The decision based on the analyses has been to focus on increasing the heat transfer in the ice-banks, through increased refrigerant flow and a "Refrigeration Performance Analyser" module will be added to the BMS system to make continuous supervision of performance and optimisation possible.

5.3 Supermarket with Medium Temperature Chiller with Propylene Glycol and Low Temperature Chiller with CO_2 as Secondary.

For performance control after commissioning and comparison of different system solutions a test with "Refrigeration Performance Analyser" was ordered on the three medium temperature circuits on totally 230 kW and two low temperature circuits with total capacity 43 kW. Measurements on all five systems were performed during one day without any pre-installation of equipment. The analyses showed that all medium temperature systems were operating at evaporation 2-4 K below design conditions (with high superheat). One of the systems was clearly under charged and a flow regulator for one of the condenser behaved erratic.

With proper optimisation the energy consumption will be more than 10% lower than before.

5.4 Field Experience from Air-Conditioning Chillers with Economisers and Heat Recovery Condensers.

In a large office complex two chillers with four screw compressors each was installed. The chillers were equipped with economisers on all eight refrigerant circuits. On each chiller two of the circuits have heat recovery condenser installed. The system had been installed for two and a half year (two year warranty) with continuous problems, experienced as insufficient cooling capacity and problems with high pressure tripping explained as insufficient capacity of the dry coolers. The dry coolers had been equipped with water nozzles to increase the capacity without significant improvements. After the end of the warranty period without clear identification of the cause of all problems the importers service organisation was replaced with an independent service company. During the first annual inspection after the take over of maintenance the service provider noted unexpected noises from one of the compressors operating on heat recovery. Oil tests were taken but before the results were received the compressor motor protection cut out and inspection showed heavy mechanical wear that was irreparable. Inspections also showed that the corresponding compressor on the other chiller was damaged and had to be replaced. The insurance company recommended that a “Refrigeration Performance Analyser” should be used to identify the cause rather than just installing new compressors. The analyses showed that the systems were over charged for operation with no demand for heat-recovery resulting in extreme condensing temperatures. The service man from the importer had, by charging the systems with heat recovery condensers active without consideration to its effect and proper understanding of the unit’s internal refrigerant buffering system, filled the system with 20% more than nominal charge. The “over-charging” was documented in the service journal. After adjustment of the charge the system had enough capacity with two compressors out of operation during the unusually hot summer 2003. The cost for repairs are in the order of magnitude of 40 000 Euro and the annual increase of energy cost close to 10 000 Euro without taken the lost heat recovery into account.

6 TECHNOLOGY IS AVAILABLE THE CHALLENGE IS TO CHANGE THE PRACTICE, EDUCATE THE TRADE AND MAKE END-USERS AWARE OF THE POTENTIAL.

The development of cost effective measurement equipment and powerful microprocessors in combination with modern communication and data transfer possibilities allows many systems to be checked regularly or even continuously with the described method at significantly lower long term cost than the current services as the sensors to a large extent is already in place on many state of the art control and BMS systems (currently normally without advanced analyses of the data). For systems without factory installed sensors these can be mounted either temporarily (often in less than 30 minutes) or at acceptable costs permanently for somewhat larger systems. With the sensors in place the data can be transferred directly with cables to a lap-top PC with the software or through GSM/GPRS/Internet to a computer/web-service that can do the calculation of the performance in detail as data is received.

These services are becoming available but the challenge is les technical than to change the mentality on the market were all systems are considered to work at the optimum as long as there is no complaints or failures. Only a few end-users are requesting documented performance at commissioning and/or tracking their service and energy costs in ways allowing them to identify problems or quality of the service providers. Service providers are more and more becoming dependent on maintenance contracts with low prices and failures as an important revenue with higher margins (as long as it is after warranty). The separation of responsibility for initial cost and energy/maintenance together with reduced in-house competency at many end-users will be a challenge to the refrigeration trade when it comes to implement the Energy performance directive placing a responsibility on the “performance inspectors” to document performance and recommending improvements. But the directive should help many contractors and service providers to motivate investment in equipment and training of staff. With the described method the investment in hard and software is less than a compressor failure with a larger hermetic compressor.

7 CONCLUSIONS

Modern technology allows well known thermo physical theory to be integrated in field measurement systems to do on-site/on-line analyses of performance of refrigeration, air-conditioning and heat pump units. The advantage of basing the analyses directly on the refrigerant circuit is that all details of the system can be analyzed and that the difficult and costly measurements of air and liquid flows can be avoided. To base the calculation of refrigerant mass-flow, capacity and COP on an energy balance of the compressor have proven to be practical and achieve a total accuracy as good as or better than alternatives for field measurements.

The challenge is to introduce new ways of doing things in an often conservative trade under environmental as well as economical pressure. The "Refrigeration Performance Analyzer" method can be a cost effective solution used on site or by remote/internet connection and by using predefined templates for each type of systems a flexibility can be achieved without requiring the operator to be fully skilled in thermodynamic calculations.

REFERENCES

Asercom 2003, Definition of Total Heat Rejection Rate for Compressors, http://www.asercom.org/files/Heat_Reject_270503.pdf

EU 2002, EU Directive 2002/91 on Energy Performance in Buildings,

Fahlen P. 2004, Methods for commisioning and performance checking heat pumps and refrigeration equipment, IIR Compressor Conference in Papiernicka, Slovakia 2004.

Fahlén P., Johansson K. 1989, Effektmätning på Värmepumpar, Förenklad mätmetod, Byggforskningsrådet R4:1989.

Naumburg P-H, Experience of Performance tests on medium size hermetic compressors, Scan Ref 4/87.