INNOVATIVE METHOD FOR PERFORMANCE INSPECTIONS OFTEN SAVE 20-30% THROUGH OPTIMISATION OF AIR-CONDITIONING AND REFRIGERATION.

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ABSTRACT

Air-conditioning, refrigeration and heat pump equipment is using 15 to 20% of the electrical energy globally. Many times these systems do not operate in an effective way. The paper present a method for and experience from performance testing in field and how documentation of performance can be used to optimize systems. Experience from many thousand performance inspections done in the field in Europe shows that savings of 20-30% is common and a survey done on 164 analyses shows that in newer systems 10% can be saved in average at minimal cost if actual performance is documented. Experience exists from all types of systems and the method has become accepted by hundreds of leading companies in most European countries. The European Union has introduced compulsory "Performance Inspections" on all Air Conditioning systems above 12 kW cooling capacity

1. INTRODUCTION

To establish the current status of a refrigeration or air-conditioning system is a prerequisite to optimisation, to minimize risk of failures as well as to take proper decisions for investments to improve or replace existing equipment. Few decision makers will decide on investment in energy optimisations or replacements if no base line can be established for economical calculations such as pay-off time or Life cycle cost.

The problem in relation to the RAC industry is that for two hundred years – since the invention of mechanical cooling in fact – we have not been able to accurately measure the performance of working cooling systems in the field. It has only been possibly in fully equipped climate-controlled laboratory, with a team of highly qualified engineers supported by data loggers and computers.

This kind of resource has been available to a few larger manufacturers. In any case, this approach does not lend itself to testing in the field by practitioners, in real world conditions - where the performance of the plant really matters.

In the low carbon age, it is now critical to deliver high performance, high efficiency cooling. But without being able to cost effectively measure the performance of a plant in operation, engineers and end users are left in the dark.

But it is possible to cost effectively establish performance of the complete system as well as all its main components. The industry must learn how and end user must realise that they can request documentation of performance and measures.

Figure 1, Field kit for non-invasive technology that does not require installation of flow meters to establish the performance and capacity.

2. THE INTERNAL METHOD FOR PERFORMANCE ANALYSIS, FIELD MEASUREMENT METHOD FOR REFRIGERATION AND AIR-CONDITIONING SYSTEMS.

The new performance analyser based on the "Internal Method" is a ground-breaking technology that has the potential to revolutionise the industry's approach to evaluating system performance.

For the first time, it enables engineers in the field to determine how well operating plant is performing, its actual COP, and other vital performance parameters without hours of tedious calculations of a highly skilled engineer.

It accurately determines a working system's:

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

This vital data is presented in clear charts, enabling the engineer or end user to gain an immediate picture of the actual performance of the system.

2.1 Innovative approach – how it works

Importantly, it is a non-invasive technology, and does not require significant disruption of the refrigeration circuit. This minimize the possibility of leaks of harmful refrigerant to atmosphere. Instead, it uses ten easy to apply sensors that are quickly attached at strategic points around the system. This is 7 temperatures, 2 pressures and active power as shown in (Figure 2).

An engineer can hook up the equipment in 20 minutes. Then the data starts flooding in. From the information gathered the key operating parameters that pinpoint the system's actual performance can be determined independent of any supplier data.

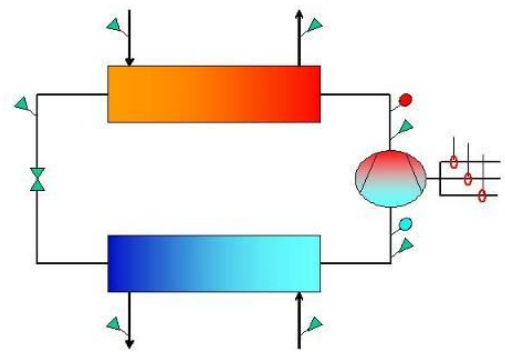

Figure 2, Sensors required and their location to establish performance of a standard refrigeration system.

At the heart of the performance analyser is the energy balance over the compressor (Figure 3) and a series of algorithms, based on the thermodynamic properties and operating characteristics of the refrigerant in use.

The heat losses are low relative the total input power limiting the impact of variation. So equation (1) will give a good accuracy of mass flow of refrigerant.

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

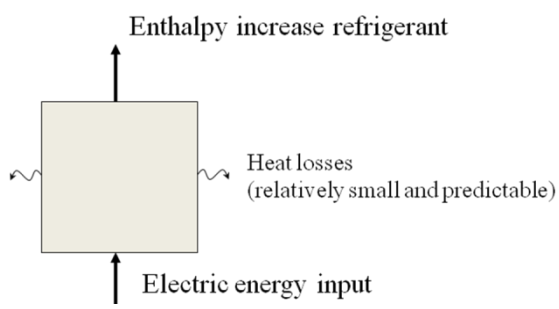

Figure 3, The energy balance with consideration of heat losses over the compressor allows calculation of mass flow.

From the above described energy balance and these enthalpies (Figure 4) all data required can be derived including COP, Capacities, and the compressors total isentropic efficiency.

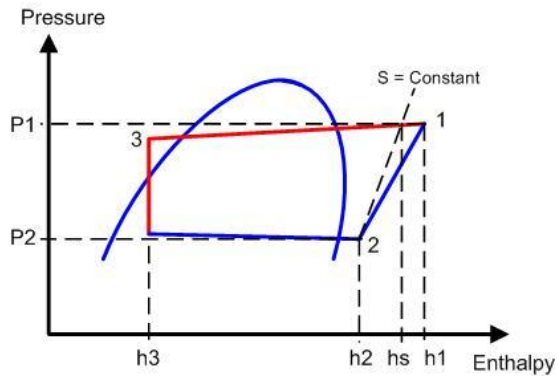

Figure 4, Pressure – enthalpy graph of "standard" refrigeration process.

Cooling Capacity = Mass flow * (h2 – h3) (2)

Heating Capacity = Mass flow * (h1 – h3) (3)

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

All commercial refrigerants and blends can be evaluated. The theoretical background to the method and how the need of costly and difficult flow measures can be eliminated has been presented at IIR and IEA conferences (Berglöf, 2004) and Fahlen (2005).

The collected data is recorded and instantaneously subjected to extensive calculations, without any need for the technician to interfere, from which the true performance of the plant is determined.

2.2 Well proven method

The method and technology was first developed in Sweden 22 years ago. With the latest technology for data collection, the flexibility has increased while the cost has decreased. The Nordic standardisation cooperation Nordtest included the method in their heat pump field testing standards, NT VVS 115/116, (1997). With the latest development of hard- and software, the method is now becoming accepted in the industry. More than 30 manufacturers and 300 contractors in 10 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 use the Internal Method to document the performance of their products and optimise the systems are Carrier, Trane, Johnson Control, Bitzer and DuPont.

Templates for different system configurations, such as those with external oil cooling, economisers and two-stage cascade systems, have been created, enabling the method to be used with all mainstream systems in use today – and specialty system of the future.

2.3 Practical benefits

All data required for a full evaluation of system as soon as sensors are connected most of the time without requirement to stop the system. Armed with the information provided, engineers can quickly 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
- fan underperformance

The system identifies irregularities in compressor performance that could result in future impairment of performance – or even plant breakdown, enabling pre-emptive maintenance.
Armed with this vital information, engineers can address the issues identified, optimising system performance. The result is huge potential savings in power consumption and carbon emissions over a plant's lifetime.

Without an effective method and an efficient tool, these problems normally go unrealised, with the plant continuing to perform inefficiently – or eventually breaking down with potentially catastrophic consequences for refrigerant loss and stock damage.

Whenever required a modem can be connected to the data collection unit and information in real time transferred to the Internet server where calculations are done and made available to any expert in the world who is given access through user name and password for validation and advice on best actions to take.

2.4 Advantages for the user in the field

The necessary sensors can be connected in 20 minutes, with immediate results and there are no size limitations. The method is used from 200 W to 20 MW of cooling capacity in all types of applications.

It can be easily portable (Figure 5) contained in a flight case size case. Alternatively the data collection can be permanent with wireless or broadband communication to an internet server. The server can send text and e-mail messages when efficiency is changing or indications on emerging problems long before things go wrong.

The new method drastically decreases the cost for performance inspections as no installation of flow meters are required. Paybacks of measurements are often very short as adjustments/optimisations are often done already during initial measurements as they become obvious when the whole process is visualised.

Figure 5, On-line performance test of an air-cooled chiller at site.

2.5 Global access to on-line expertise through Internet.

As all relevant parameters are logged and analysed and available on the Internet in-house support staff, manufacturers and suppliers as well as independent experts can be consulted and see reel life operation of the system including performance of all components in the system to give on site personal guidance on what can be done to trouble shoot and optimise systems. This makes it possible to in an extremely cost effective way access the best experts in the world.

2.6 Significant energy savings achieved in large survey

Refrigeration and air conditioning plant was already in 2002 estimated to use between 15 to 20 per cent of the electrical energy in Europe according to IIR (2002). This share is increasing as the requirement for comfort increases as well as the use of heat pumps to decrease energy consumption.

There is enormous potential to save energy by optimising existing refrigeration and air conditioning systems and the pressure on the industry to take action is increasing.

In a master thesis at the Royal Institute of Technology in Stockholm, John (2006), a survey based on 164 performance inspections on air conditioning, refrigeration and heat-pump systems showed that only 13 per cent of the systems operated within the specified performance criteria. That means that some 87 per cent did not perform to specification. The graph below (Figure 6) show the deviation of the performance in the 164 plants. The average “over-consumption” of electrical energy was approximately 10% in some cases over 30%.

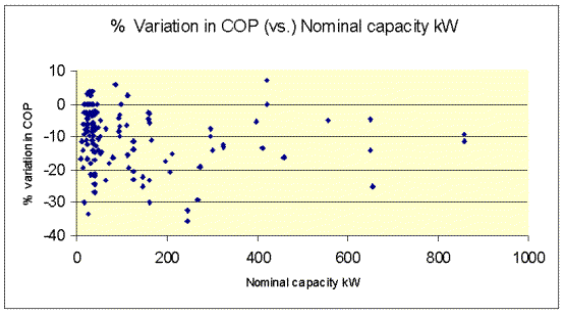

Figure 6, Variation of COP in 164 analysed systems (John 2006).

The problems identified, with examples of possible causes, were:

- **Incorrect sub-cool - refrigerant charge** caused by leaks or over-/ undercharging.
- **Incorrect superheat - operation of expansion device**. This can be caused by improper adjustment, malfunction or an incorrectly selected device.
- **Incorrect air or liquid flow over condenser / evaporator** due to incorrect design, wrong selection of fans / pumps and/or blocked filters resulting in higher system energy consumption.
- **Poorly adjusted controls.** For example, low pressure cut-out or condenser pressure controls causing significant waste of energy.
- **Poor efficiency of compressor** due to wear or damage to compressor**.**

If the identified savings was extrapolated to the total European market, the potential savings would be dramatic. The **power saved would correspond to the equivalent of all the electricity produced by wind power in Europe** or the total electrical consumption of Denmark or Portugal.

2.7 Leading supermarket, hotel and industrial operators as well as chiller suppliers now implement "Performance Analysing" to test and document performance.

Tesco the second biggest supermarket chain in the world and several other has invested in the technology to check on the performance and efficiency of its new CO2 refrigeration systems. The retailer is using the PC or Internet based system to monitor the performance of a new generation of environmentally friendlier cooling technologies under development, to help evaluate which operates most efficiently before adopting new systems.

"Up to now, the only way to find this information was through complex and invasive monitoring. It was extremely expensive and time-consuming", stated Andy Campbell, head of Tesco's Environmental Refrigeration Research and Development Programme. "With the new system, you just hook up the machine and it automatically calculates a full set of data on actual plant performance. This information is a gold mine for engineers, as you can use it to diagnose problems, check on performance, and as a tool for optimising the operation of plant."

Leading chiller manufacturer such as Carrier systematically use ClimaCheck to validate performance of new chillers as well as old where there is a discussion on the cost effectiveness of retrofit/upgrade or replacement.

2.8 The Internal Method is independently validated

The method and accuracy of the Internal Method results has been independently described in detail and validated in reports by SP, Swedish National Testing and Research Institute and by Professor Per Fahlén at Chalmers University in Gothenburg, Sweden i.e. *Fahlén, P.* and Johansson, K, (1989).
The method is also used alongside traditional, laboratory-based flow measurements by an increasing number of leading manufacturers, as well as by research teams at Universities and in Training Centres for technicians.

As mandatory performance inspections are becoming a requirement in Europe (by the Energy Performance in Building Directive) the method offers a cost-effective recording system behaviour and performance.

Data can be recorded for immediate evaluation/action on site or made visible in real time to competent analysts by using a modem/broadband connection.

2.9 Resolves disputes decrease warranty

There are many examples of significant energy optimisation being achieved and cases where years of conflicts between owner and contractor have been solved in just a few hours by documenting the actual equipment operation with the Internal method. As not only the performance but also each component's individual characteristics are documented problems can be identified and rectified without complicated discussions on who is responsible.

As the data will give logs with detailed documentation of the dynamics of a system in real life operation many problems that otherwise would risk to cause problems and failures can be pinpointed directly during commissioning or as soon as any indications occur rather that the common practice of a lot of quick fix measures to remove the symptoms e.g. alarms or low capacity often without correcting the under lying problem. The software can provide tabulated real-time logs and charts, which are easy to interpret.

The data can be presented on site with a notebook PC or via Internet to any PC or even a smart phone (Figure 7) to immediately warn for deviations in performance that might otherwise rumble on for years and resolve problems before they result in costly failures.

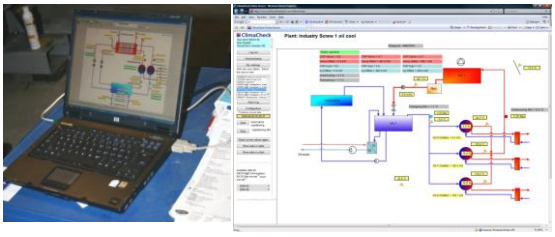

Figure 7, Performance Analyses on site or via web supervision can resolve disputes on plant

3. CASE: CHILLER INSTALLATION.

The following shows a print-out of a graph followed by a table from a plant performance analysis. It gives a read-out of key system parameters and operating characteristics, at start-up, part- and full-load. Below (Figure 8 and Figure 9) show a graph and table from a R134a Chiller with poor compressor efficiency at part load that improves significantly at full load.

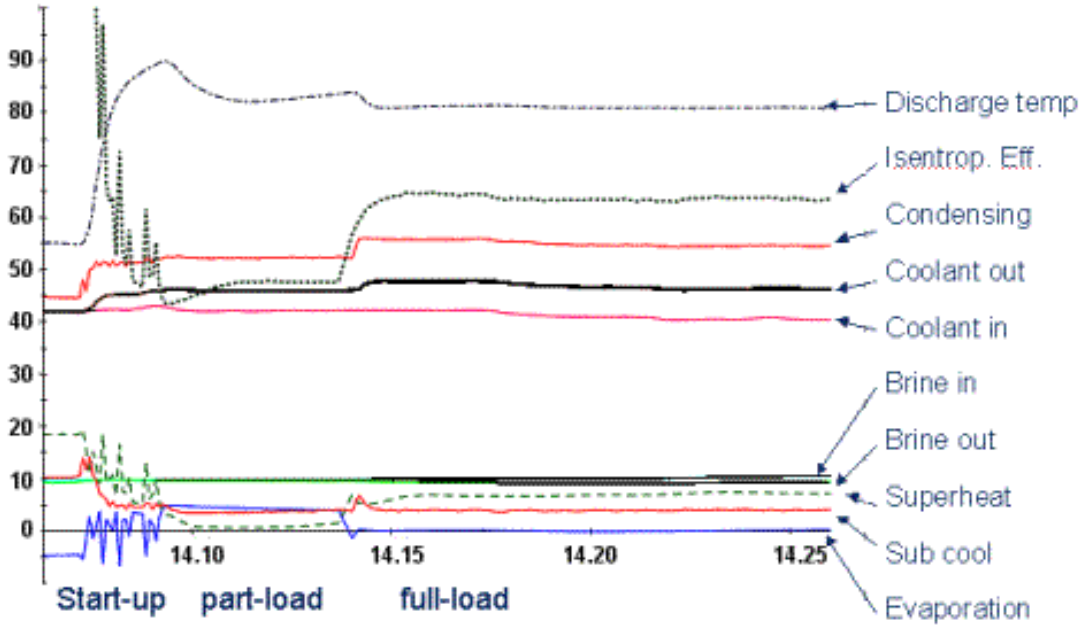

Figure 8, Visualisation in graph of Start-up – part load with poor efficiency – full load operation

16																				
17	Mean		10.1	9.2	1.92	0.0	6.9	6.9	0.0	46.9	13.88	55.0	4.0	81.1	63.4	75.8	2.37	180.1	3.30	250.6
18	Max		10.2	9.3	1.93	0.2	6.9	7.0	0.0	47.5	14.06	55.4	4.1	81.4	63.6	76.3	2.39	180.7	3.32	251.3
19	Min		10.1	9.2	1.91	-0.1	6.8	6.7	0.0	46.6	13.79	54.7	3.8	81.0	63.1	75.6	2.35	179.4	3.28	249.8
20																	0			
21	Date	Time	SecC Evap in (°C)	SecC Evap out (°C)	Ref Low press. (Bar(g))	Ref Evap Midpoint (°C)	Ref Comp in (°C)	Super heat (K)	SecW Cond in (°C)	SecW Cond out (°C)	Ref High press. (Bar(g))	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)	COP Heat	Cap. Heat (kW)
54	2006-01-11	14:15:40	10.2	9.4	1.93	0.2	7.0	6.9	0.0	47.8	14.17	55.7	4.0	81.2	64.5	76.1	2.38	180.8	3.31	251.6
55	2006-01-11	14:15:20	10.2	9.4	1.93	0.1	6.8	6.6	0.0	47.7	14.24	55.9	4.1	81.1	64.7	76.1	2.37	180.4	3.30	251.2
56	2006-01-11	14:15:10	10.1	9.4	1.93	0.1	6.6	6.5	0.0	47.8	14.14	55.7	3.9	81.0	64.1	75.9	2.36	178.8	3.29	249.4
57	2006-01-11	14:15:00	10.1	9.4	1.92	0.1	6.2	6.1	0.0	47.8	14.24	55.9	4.1	81.0	64.1	76.1	2.35	178.5	3.28	249.3
58	2006-01-11	14:14:50	10.1	9.4	1.92	0.1	5.9	5.8	0.0	47.9	14.19	55.8	3.9	81.0	63.5	75.9	2.32	176.3	3.25	246.9
59	2006-01-11	14:14:40	10.1	9.5	1.92	0.1	5.5	5.5	0.0	47.8	14.27	56.0	4.2	81.0	63.2	76.1	2.31	175.6	3.24	246.4
60	2006-01-11	14:14:30	10.0	9.5	1.93	0.2	5.4	5.2	0.0	47.7	14.27	56.0	4.4	81.4	62.4	76.5	2.29	175.1	3.22	246.2
61	2006-01-11	14:14:20	10.0	9.6	1.94	0.3	5.5	5.3	0.0	47.3	14.30	56.1	5.2	82.2	61.3	76.3	2.27	173.5	3.20	244.5
62	2006-01-11	14:14:10	10.0	9.6	1.96	0.5	5.8	5.4	0.0	46.3	14.25	55.9	6.9	83.6	59.4	77.2	2.27	174.9	3.20	246.7
	Latest data at top					-1.2	5.8	7.1	0.0	46.1	12.93	52.3	3.9	84.0	56.8	50.7	2.21	112.0	3.14	159.2
	Full Load above line					4.0	5.6	1.6	0.0	46.0	13.02	52.5	4.2	83.6	47.9	55.8	2.14	119.3	3.07	171.2
	Part load below line					4.0	5.5	1.5	0.0	46.0	12.96	52.4	4.0	83.5	47.6	55.6	2.13	118.7	3.06	170.4
						4.1	5.4	1.3	0.0	46.0	13.00	52.5	4.0	83.2	47.8	55.6	2.14	118.8	3.07	170.5
						4.1	5.3	1.1	0.0	46.1	12.95	52.3	3.9	83.0	47.6	53.8	2.13	114.8	3.06	164.9
						4.1	5.3	1.1	0.0	46.1	13.00	52.5	3.9	83.0	47.8	56.3	2.14	120.4	3.07	172.8
						4.2	5.2	1.0	0.0	46.0	12.98	52.4	3.9	82.9	47.6	55.6	2.14	118.8	3.07	170.5
						4.2	5.2	0.9	0.0	46.1	13.01	52.5	4.0	82.8	47.7	54.9	2.14	117.6	3.07	168.6
						4.2	5.2	0.9	0.0	46.0	12.98	52.4	3.9	82.7	47.7	56.2	2.14	120.4	3.07	172.7
72	2006-01-11	14:12:10	9.9	9.6	2.40	4.3	5.2	0.9	0.0	46.0	12.99	52.4	3.9	82.5	47.7	55.8	2.15	119.9	3.08	171.8

Figure 9, Visualisation of improved efficiency and performance in table when going from part to full load.

The R134a Chiller log in Figure 9 shows, automatically "high-lighted" in red, poor compressor efficiency and critically low super heat at part load that improves significantly at full load (and a closer view of data also show additional opportunities for optimisation). Several, before unexplained, compressors failures could now be explained by liquid carry over at part-load conditions. The energy consumption could be significantly reduced as well as the reliability improved when the obvious disadvantage with the operation strategy was documented. In this plant with large water volumes and eight compressors there was no need to run each compressor in part load. The part load solenoids could easily be disconnected.

4. CASE: REFRIGERATION PLANT

A measurement was initiated due to poor capacity on a commercial refrigeration chiller with plate heat exchangers for medium temperature application. The measurements showed an evaporation 6-8 K lower than design (-12°C), in spite of that a significant over-sizing had been used to give a good margin. There was also to improve efficiency a large suction gas heat exchanger. The measurements documented good functionality of the expansion valve, correct flows but still the dT between outgoing brine and evaporation was unacceptable. As there were no external factors, the distribution of the evaporator was considered a likely cause of the problem. By removing the insulation this could clearly be visualised when frost was forming on the evaporator surface (see **Fel! Hittar inte referenskälla.**). After a long period of discussions between the end-user, contractor, chiller manufacturer and heat exchangers manufacturer the work could be focused on solving the distribution problem in the evaporator. At the same time a unrelated problem with high motor currents could be explained as well as a problem with poor control of condenser fans.

The increase of energy consumption caused by the documented problems was more than 30%.

Figure 10, Side view of an evaporator "undressed" after documentation of poor performance. Picture show uneven distribution - at the right side of the evaporator a large sector is used for superheat to compensate for liquid carry over in the left side of the evaporator this mal-distribution resulted in a significant decrease of capacity and energy efficiency as well as operational problems

5. CONCLUSIONS

The requirement for Energy Performance in EU and on other markets can potentially improve the energy efficiency significantly - if well implemented - as many systems are not operating as the owners believe they are. A stronger focus and requirements for improved energy efficiency in refrigeration, and air-conditioning applications require improved methods to establish and document performance of system in the field. It has been documented that there is a significant deviation between design performance and achieved performance in the field. The Internal Method is based on easy to perform measurements of pressures and temperature of the refrigerant and the thermo-physical data of the refrigerant. It is not required for the system to be specially prepared, as all sensors can be connected in 20 minutes (although permanent sensors can be cost effective). The method allows the COP and capacity to be determined with good accuracy as well as identifying the performance and behaviour of each component in the system. This can all be done without flow meters or any manufacturer data. The Internal Method is suitable for commissioning, inspections and troubleshooting as it establish all characteristics in an independent and un-biased way.

Performance inspections and energy optimisation will become an important business for many consultants and contractors in the future. In most plants there are savings possible when actual performance is documented. Often significant savings as well as improved reliability can be achieved with low cost measures. The challenge is that owners, consultants and service providers are so "optimistic" of the status of refrigeration plants efficiency. 20 years of well documented experience exist and the method is now becoming internationally recognised.

6. REFERENCES

1. *Asercom 2003*, Definition of Total Heat Rejection Rate for Compressors, http://www.asercom.org/files/Heat_Reject_270503.pdf
2. *Berglöf, K*. 2004. Methods and Potential for Performance Validation of Air Conditioning, Refrigeration and Heat Pump Systems. IOR 2004.
3. *Berglöf, K*. 2005. Methods and Potential for on-site Performance Validation of Air Conditioning, 8th International Energy Agency Heat Pump Conference, Las Vegas.
4. *CEN* (Draft standard) prEN 15240, Ventilation for buildings - Energy performance of buildings - Guidelines for inspection of air-conditioning systems.
5. *EU 2002*, EU Directive 2002/91 on Energy Performance in Buildings,
6. *Fahlén, P*, 1994. "Performance tests of air source heat pumps under frosting conditions - Quality of Results". (SP Swedish National Testing and Research Institute. SP Report 1994:01, 338 pages.) Boras, Sweden.
7. *Fahlén, P*, 1996. "Field testing of refrigeration and heat pump equipment - Performance data inferred from measurements in the refrigerant system". (SP Swedish National Testing and Research Institute.) SPAR 1996:23, 41 pages. Boras, Sweden.
8. *Fahlén, P*. 2001. "Methods for field testing of refrigeration equipment and heat pumps - A pre-study" (in Swedish). (Elforsk report 01:26, 77 pages.) Stockholm, Sweden.
9. *Fahlén, P*. and Johansson, K, 1989. "Capacity measurement on heat pumps - A simplified measuring method" (in Swedish). (Swedish Council for Building Research. R4:1989, 80 pages.) Stockholm, Sweden.
10. *Fahlen, P*. 2004, Methods for commisioning and performance checking heat pumps and refrigeration equipment, IIR Compressor Conference in Papiernicka, Slovakia 2004.
11. *Fahlén, P*, 2005. "Performance audits of heat pumps-procedures and uncertainties". IEA Conference, Las Vegas.
12. *IIR 2002*, International Institute of Refrigeration, Refrigeration Report (2002).
13. *John Arul Mike Prakash*, Energy Optimisation Potential through Improved Onsite Analysing Methods in Refrigeration, 2006, Department of Energy Technology Royal Institute of Technology (KTH), Stockholm, Sweden.
14. *Naumburg, P-H. 1987,* Experience of Performance tests on medium size hermetic compressors, Scan Ref 4/87.
15. *NT VVS 115, 1997*. "Refrigeration and heat pump equipment: General conditions of field testing and presentation of performance". (Nordtest.) Esbo, Finland.
16. *NT VVS 116, 1997*. "Refrigeration and heat pump equipment: Check-ups and performance data inferred from measurements under field conditions in the refrigerant system". (Nordtest.) Esbo, Finland.