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WELCOME *Energy in Buildings and Industry* and the Energy Institute are delighted to have teamed up to bring you this Continuing Professional Development initiative aimed at energy managers.

This is the fourth module in the third series and focuses on the latest thinking in refrigeration. It is accompanied by a set of multiple-choice questions. To qualify for a CPD certificate readers must submit at least eight of the ten sets of questions from this series of modules to *EiBI* for the Energy Institute to mark. ***Anyone achieving at least eight out of ten correct answers on eight separate articles qualifies for an Energy Institute CPD certificate***. This can be obtained, on successful completion of the course, for a fee of £15 (for members) or £25 (for non-members).

The articles, written by a qualified member of the Energy Institute, will appeal to those new to energy management and those with more experience. The following topics will appear in the next six issues of EiBI: recent legislation; integrated renewables; fuel cells; the building envelope; water management; and lighting.

If you miss any of the modules in the series (the first two were on BEMS and small-scale CHP) and let us know (mark.thrower@btinternet.com) and we will send the missing modules to you by e-mail in 'pdf' format.

The previous 20 modules from the first two series are also available free of charge. Please contact me by e-mail if you would like to receive these.

MARK THROWER, MANAGING EDITOR

CURRENT THINKING ON...

ENERGY EFFICIENCY IN REFRIGERATION SYSTEMS

By Carl Peat, Clouds Environmental Consultancy Ltd

Refrigeration and air conditioning costs are reported to amount for around 11 per cent of the UK total energy produced1. This is estimated to cost users around £350m per year. Furthermore, the majority of refrigeration systems are powered by electricity and so the environmental impact of producing this amount of cooling is both inefficient and damaging to the environment.

This article examines the energy issues surrounding refrigeration systems, and their design and operation. It specifically deals with electric-powered vapour compression systems, although many of the principles are also applicable to other types of system.

System Design

Designing an efficient system can lead to significant savings. As with most electric, motor-operated machinery, the running costs over a lifetime can be far greater than the initial purchasing costs. It is estimated that a refrigeration system will cost more than six times to run than it will to purchase. Clearly, the life cycle costs of running such plant should be considered when designing a system. By considering energy efficiency at the design stage it is not unreasonable to recognise lower running costs of between 20-50 per cent to provide the same amount of cooling.

There are other benefits to consider by designing an energy-efficient system such as:

- IMPROVED RELIABILITY;
- LOWER MAINTENANCE COSTS;
- LONGER LIFETIME.

The key areas in designing an energy efficient refrigeration system are summarised here and discussed in more detail within this article

- SYSTEM CHARACTERISTICS;
- COMPRESSOR CHOICE;
- REFRIGERANT CHOICE;
- CONTROLS;
- EVAPORATORS AND CONDENSERS

System characteristics

When designing a refrigeration system the scope for accommodating energy efficiency is at its most economical point. There are several guiding factors that determine the scope for a refrigeration system at this stage. Product, or process, temperature requirements are usually the main driving factor. One of the key design issues is to ensure that refrigeration systems are sized as closely to anticipated loads as possible. Oversizing plant not only costs more to purchase, it can add significantly to the running costs. It is also important to consider the following items when designing any refrigeration system:

ENSURE THAT CAPACITY VARIATION IS UNDERSTOOD AND ACCOMMODATED

Capacity control should be fully understood when designing systems. Configuring multiple compressors with a sound knowledge of low load conditions can not only reduce running costs but could reduce initial capital costs. For example for a given application it may be best to provide one fixed capacity machine to cope with the steady demand, and a smaller machine equipped with capacity control to cope with peak loads. Typically, capacity control of fixed-speed machines is met with unloading valves. This type of unloading is least efficient and wherever possible systems should be designed to allow for multiple compressors to be switched instead. Variable speed screw and scroll type compressors are becoming more economically available and

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consideration should be given to these if at all possible.

MINIMISE TEMPERATURE LIFT
This is arguably the key area where energy savings can be recognised. The temperature lift is the difference between the evaporating and condensing temperatures. Every 1°C reduction in temperature lift gives a 2-4 per cent reduction in energy use and increase in cooling capacity. Temperature lift can be reduced by designing systems with higher evaporating temperatures and lower condensing temperatures.

SUPERHEAT
This is the increase in temperature of the refrigerant gas above the evaporating temperatures. Superheat is always evident in refrigeration systems (to ensure that refrigerant vapour/liquid mix boils off before returning to the compressor) and it is this temperature that is measured by an expansion valve phial. Superheat external to the evaporator (i.e. in suction lines) is not normally useful and decreases the gas density and mass flow rate, thereby decreasing efficiency. Therefore superheat should be kept to a minimum. Electronic expansion valves can operate with much lower superheat settings without risking liquid return to the compressor.

SUB COOLING
Sub cooling of the liquid refrigerant by using oversized condensers or by mechanical means can increase refrigeration capacity whilst normally not incurring any power increase. Sub cooling can also be used to minimise "flash gas" at the expansion device. Care must be taken to ensure that liquid lines of sub cooled refrigeration circuits are insulated. Liquid pressure amplification can be used in conjunction with sub-cooling to deliver savings of around 25 per cent.

SEPARATE LOW AND INTERMEDIATE EVAPORATOR REQUIREMENTS
Ensure that cooling temperatures are matched to the system. Provide dedicated cooling systems to those areas that require lower temperatures as much as possible. For systems that require very low temperatures (those that require evaporating temperatures below -50°C) cascade or compound systems may prove the most energy efficient.

MINIMISE COOLING LOADS
Ensure that refrigerated areas are well insulated and that air ingress is kept to a minimum. Wherever possible remove the need for occupants to work in refrigerated areas. Ensure that extraneous heat loads are minimised by choosing low wattage lighting, removing unnecessary equipment etc. Provide intermediate "free cooling" if possible when cooling hot products. This can be achieved through the use of recycled mains or river water, or simply by using ambient air to minimise the cooling load on electrical plant. Run fans and pumps only when required.

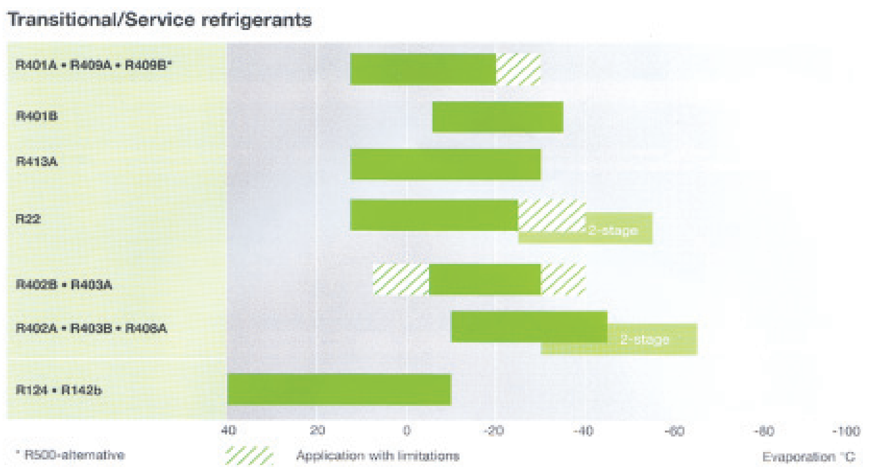

Figure 1 - Application Ranges for HCFCs and Service Blends

CONSIDER DEFROST METHOD
The evaporating temperature normally dictates the defrost method. Whenever evaporating below 0°C frost will accumulate on the evaporator and a periodic defrost is necessary. Avoiding defrost periods is the best method of reducing the energy impact of cycles. Wherever possible defrost on demand may offer significant energy saving over timed sequential control wherever forced defrost is required. There are two options normally available to carry out defrosts:

1) off cycle – the liquid line solenoid switches off along with the compressor and the cold room/cabinet air gradually clears ice from the evaporator. Certain evaporators (usually with wider fin spacing) are usually required for this type of defrost, and is normally not suitable for storage areas below 3°C.

forced – with electric heater elements or a warm liquid (warm gas or glycol). Electric defrost usually uses more energy as the heat is not internal to the evaporator coil and so does not use the surface area of the tubes to dissipate it. This means defrost sequences tend to last longer. Warm gas defrosts normally require head pressures to be kept artificially high and can incur additional installation and capital costs.

COMPRESSOR CHOICE
Selection of compressors cannot normally be undertaken alone and decisions have to be made on refrigerant choice when deciding what type of compressor is most suitable for the application. Recent developments in compressor technology have meant that compressors are available that offer up to 25 per cent lower running costs. These savings are achieved through the use of advanced valve plate technology and motor cooling. A good source of reference for these types of compressors is the Equipment Technology list www.eca.gov.uk

There are several types available for consideration depending upon application. It is important to design any system with knowledge of the manufacturers' coefficient of performance (CoP) to examine which compressor choice will be most suitable at full and part load.

REFRIGERANT
Selecting the most efficient and environmentally benign refrigerant is a complex area and one which could warrant a paper by itself. It is perhaps useful to carry out a Total Equivalent Warming Impact assessment (TEWI) when considering a refrigerant. Often system constraints dictate only a few refrigerants. However, there are many blends available that require specialist appraisal. Recent developments have seen CO2 being used once again as a refrigerant, but specialist knowledge is needed for designing such systems. The two figures indicate current commonplace refrigerants and detail transitional HCFC2 types along with HFC3 and blends along with their relative operating ranges. The charts are kindly reproduced from the Bitzer Refrigerant report. Halogen-free refrigerants are not discussed although their potential is expansive.

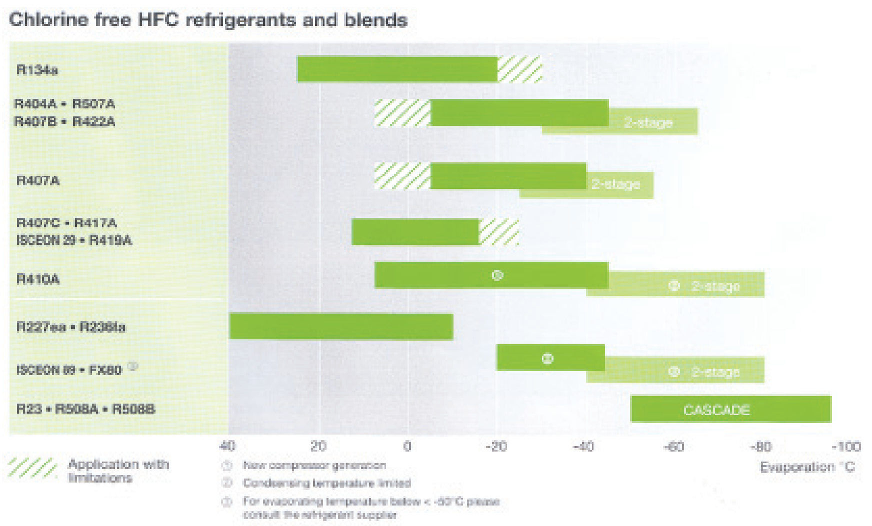

Figure 2 - Application Ranges for HFC Refrigerants

CONTROLS
Modern thinking dictates that most refrigeration systems be controlled electronically. This type of control normally allows for tighter control of equipment and for complex control strategies to be incorporated into an efficient design. Modern sensors are quick to react to temperature and pressure changes and so control of equipment can be quicker and more effective.

FAN SPEED CONTROL
Varying the speed of fans to match demand can provide significant savings. This type of technology is commonplace on higher specification air conditioning equipment. Two-speed fans to operate in cooler ambient temperatures are available as are variable speed machines. Consideration should be given to floating head pressure control when selecting this technology as fan speed control may not be fully exploited.

FLOATING HEAD PRESSURE AND ELECTRONIC EXPANSION DEVICES
Until fairly recently condensing head pressures have been kept artificially high by cycling off condenser fans. This has been for two main reasons:

- to ensure that a good "head" of liquid was available at the expansion device; and
- to provide high pressure warm gas available for defrost

However, recent designs have dismissed warm gas defrost in favour of electric to enable condensing head pressures to be "floated" down in low ambient temperatures. This effectively minimises the work requirements of the compressor and so energy savings in the region of 25 per cent are realised. Care must be taken to ensure that condensing temperatures are not lowered to such an extent that flash gas and erratic control exists at the expansion device. However, if a thermostatic expansion valve is the only constraint the rule-of thumb is that the minimum economic condensing temperatures for plants producing cooling at 5°C or below should not be above 25°C. Electronic expansion devices reduce the risk of flash gas and allow lower condensing pressure to be maintained. Care must be taken to assess the energy effect of running condenser fans against potential savings from reducing condensing pressure.

EVAPORATORS/CONDENSER
Perhaps the key design criteria when selecting condensers and evaporators is the design temperature difference between the refrigerant and the medium to be cooled. A simple energy equation perhaps demonstrates this best

$$Q = A \times U \times td$$

Where
Q = Capacity of heat exchanger (kW)
U = U value of surfaces/fluids (kW/m2 K)
A = Surface area of heat exchanger (M2)
td = Temperature difference (i.e. space temp – evaporator temperature) (K)

It is clear from the above that selecting a smaller heat exchanger means that a lower evaporating or higher condensing temperature is required. While this would reduce the capital costs it would increase the temperature lift as previously discussed. The simplest way therefore is to select larger heat exchangers wherever possible. Care must be taken to ensure that condensers are not designed too large to over condense refrigerant.

The type of condenser or evaporator is largely dependant upon the application and constraints. Air-cooled condensers are commonly considered inefficient when compared to water-cooled or evaporative. Compact plate heat exchangers offer significant efficiencies cost effectively. Whenever specifying air-cooled equipment ensure that high efficiency motors are specified. Savings between 3-5 per cent are achievable.

System installation, Operation and maintenance

INSTALLATION
Condensers should be sited out of direct sunlight and not facing south. Also ensure that the rejected warm air cannot recirculate. Recirculation has the effect of minimising the effective heat rejection capacity of the condenser by reducing the available temperature difference (td), and subsequently raises head pressures. Plant rooms must have adequate ventilation. When sizing ventilation louvres for plant rooms containing condensing units allow a minimum of 1.5 times the condenser air on face area. Ensure that evaporators are sited to maximise cooling and efficient air throw. Additionally, ensure that all plant can be accessed easily to carry out regular maintenance.

• OPTIMISATION
Regular monitoring of refrigerant plant and proactive optimisation can lead to further significant savings for installed refrigeration systems. Recent work carried out by Sainsbury's supermarkets4 demonstrates that regular monitoring of energy consumption and adjustment of set points can yield significant savings. In all of the stores where monitoring and optimisation has been carried out savings of on average 12 per cent have been recognised. Consideration for permanent logging for larger systems can provide the additional benefit of highlighting component failure or the adverse effect of a user/maintainer incorrectly adjusting a set point. This ensures that time and effort spent in the optimisation process is not wasted.

• MAINTENANCE
Evaporators and condenser coils should be cleaned regularly air allowed to freely flow through them. Check defrost sequences are minimised while still effective; check that ice is not restricting air flows through evaporators. Ensure that condensate can

freely drain from evaporators. Ensure that motors and pulleys are all in good order and lubricated. Carry out regular refrigerant leak checks (soon to be mandatory for certain size plant, see later). Refrigerant leakage has a dramatic impact upon the efficiency of refrigeration systems. It is commonly accepted that a partially charged system can reduce the efficiency by around 11 per cent.

Ensure operating pressures and temperatures are as per design information and check the operation of controls and safety devices. Check door strips and curtains along with insulation. Replace any valve caps or service access caps. Ensure refrigerated products do not restrict air flows. Ensure no unnecessary heat loads have been introduced to cooled areas such as electrical plant and machinery.

Legislative Considerations 5

• F GAS

Article 3 of the F-gas Regulation states that a specified list of stationary applications containing 3kg or more of fluorinated greenhouse gases shall be inspected for leakage by certified personnel. These regulations are thought to be introduced within the next year. One possible impact of the regulations may inevitably cause designers to switch from VRF type air conditioning systems to traditional fan coil chilled water systems due to the difficulties in carrying out leak checking on hidden pipework. This will inevitably lead to an increase in life cycle costs.

• PRESSURE EQUIPMENT REGULATIONS 1999 (SI 1999/2001) (PER) (PED)

The PER 1999 entered into force on 29th November 1999. From 30th May 2002 all pressure equipment with a maximum allowable pressure above 0.5 bar and placed on the market in the UK must comply with these regulations. Under the regulations, equipment and assemblies must be safe, meet essential safety requirements, satisfy appropriate conformity assessment procedures and carry CE markings. Pressure equipment that does not meet these requirements after 30th May 2002 cannot be legally supplied in the UK or the EU and non compliance could result in prosecution.

• PRESSURE SYSTEMS SAFETY REGULATIONS 2000

These regulations cover the 'in-use' requirements of pressure systems and for systems of over 25kW installed compressor power call for a regular periodic inspection by a competent person in accordance with a written scheme of examination.

BS EN 378:2000 PARTS 1, 2, 3 & 4

BS EN378:2000 does not satisfy all the essential safety requirements of the Directive 97/23/EC (PED) but designing plant in accordance with BS EN378:2000 and with reference to IoR Safety Code for Ammonia will assist manufacturers, installers and contractors in complying with the PER. The new European Standard has been in effect from December 2000 and any equivalent national standards have been withdrawn.

About the Author

Carl Peat is a consultant with Clouds Environmental Consultancy Ltd based in Portsmouth. Carl is a registered consultant with the Carbon Trust and an approved assessor with the Energy Efficiency Accreditation Scheme.

References

1 Source GPG364 - Service and maintenance a technicians guide
2 Hydrochlorofluorocarbons
3 Hydrofluorocarbons
4 Courtesy of Mr N Rivers Sainsbury's supermarkets.
5 Courtesy of Institute of Refrigeration

Further Reading

• Institute of Refrigeration - Management of Energy in Supermarket Refrigeration Systems (N Rivers);
• Bitzer Refrigerant Report- www.bitzer.co.uk;
GPG279 Running Refrigeration Plant Efficiently - A Cost Saving Guide for Owners;
• GPG280 Energy Efficient Refrigeration Technology - The Fundamentals;
• GPG283 Designing Energy Efficient Refrigeration Plant;
• GPCS302 Improving Refrigeration Performance Using Electronic Expansion Valves.

SERIES 3: MODULE 04 TEST QUESTIONS

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

1. What is the temperature difference between the condensing temperature and the evaporator temperature commonly known as?
☐ superheat ☐ sub-cooling
☐ temperature lift ☐ saturation temperature

2. When comparing compressor performance what key information should be obtained from the manufacturer
☐ coefficient of performance at low load
☐ coefficient of performance at full and part load
☐ volumetric flow rate
☐ maintenance requirements

3. When selecting evaporators or condensers which of the below factors economically reduce system running costs?
☐ increased surface area
☐ increased temperature difference
☐ materials of construction
☐ fan speed

4. What type of defrost is most economical for chillers operating above 3°C?
☐ warm gas ☐ off cycle
☐ defrost on demand ☐ electric defrost

5. What is the average cost of leakage to UK refrigeration users in terms of energy spend?
☐ 11 per cent ☐ 30 per cent
☐ 5 per cent ☐ 15 per cent

6. Savings of up to 25 per cent are achievable by floating condensing pressures. How this best achieved?
☐ head pressure control ☐ floating head pressure control
☐ fan speed control ☐ defrost control

7. When setting condensing units which of the following statements is true?
☐ ensure that cool clean air is drawn onto the condenser
☐ recirculate warm air from the condenser discharge
☐ install in a south facing orientation
☐ install inside a refrigerated area

8. F Gas regulations are most likely to be applied to what size systems?
☐ all size systems ☐ less than 2kg refrigerant charge
☐ 1 kg and above ☐ 3kg and above

9. PER 1999 requires that all systems must carry what?
☐ CE marking ☐ leak detection
☐ electronic control ☐ maintenance schedules

10. What type of assessment is recommended when considering refrigerant choice?
☐ coefficient of performance check
☐ pressure enthalpy charts
☐ total equivalent warming impact
☐ Pressure Equipment Regulations

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Completed answers should be mailed to:

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