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OPPORTUNITIES FOR ENERGY CONSERVATION IN RAC (REFRIGERATION AND AIRCONDITIONING)

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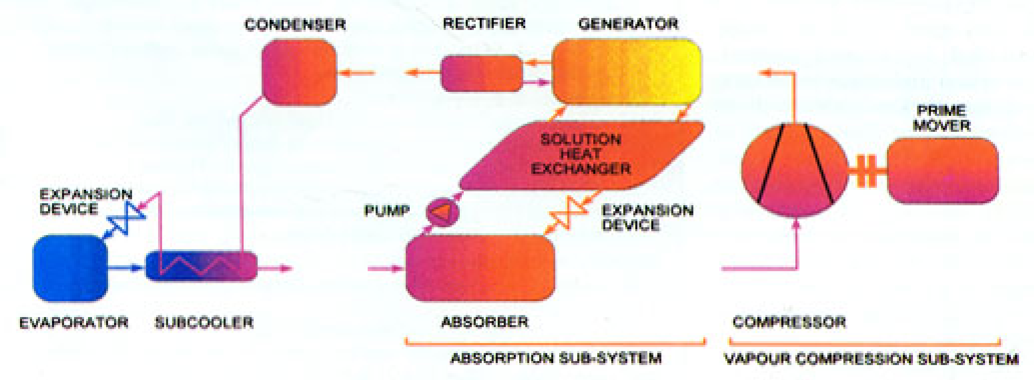
Increasing energy costs, inadequate electricity generation and distribution infrastructure and increasing demand for refrigeration and air-conditioning (RAC) are the problems faced by the users of refrigeration and air-conditioning systems. Effects of these problems can be reduced, by the HVACR community by implementing energy conservation measures in RAC. This article gives an overview of various opportunities for energy conversation RAC. It also discusses, in brief, the repercussions of various options on initial and operating costs.

ENERGY CONSERVATION

There is tremendous scope for energy conservation in refrigeration and air conditioning. Energy can be conserved at various levels. The RAC system can be divided into two major sub-systems, refrigeration equipment and delivery equipment. The first consisting of the components required to produce the consisting of the components required to produce the cooling effect and the latter to deliver this cooling effect to various sites in different modes. This article will review the opportunities for energy conservation relevant to the first sub-system the refrigeration equipment, and its comments. Various options to optimize the coefficient of performance (CPO), defined as the ratio of useful effect to the energy input, and ways to co-generate cold and hot utilities or cool utility and electricity or cold and hot utility along with electricity will be looked into.



A review of the opportunities for energy conservation will help in specifying the most suitable system. The choice of operating cycle, system and its components play an important role in reducing energy consumption. Variation in primary energy consumption, energy cost, total operating cost, initial or retrofitting cost and life cycle cost are the issues to be taken into account while identifying the best system.

VARIOUS REFRIGERATION CYCLES

A good variety of refrigeration cycles have been used to produce the cooling effect. Some of the commonly used systems for terrestrial applications are:

1. *Vapour Compression Cycle*: Some -Stage Two-Stage, Cascade
2. *Absorption Cycles*: Single and Two-Stage, LiBr / H_2O Single-stage and GAX (Generator, Absorber, Exchanger) NH_3/H_2O
3. *Steam Jet Ejection Cycles*: Single and multistage

Energy input to the vapour compression system is in the form of shaft work, which is usually provided by electric motors. Absorption and steam jet ejection systems are heat driven, these systems can be direct gas, oil or steam fired. Low grade heat, recovered from various sources can also be used o fire the absorption systems. Steam jet ejection water chillers offer very low COP in the range of 0.1 to 0.3 and are not good from energy conservation point of view. The factors influencing the choice of refrigeration cycle and rough guidelines for selection:

1. *Temperature Lift* which is the difference between the condensing temperature and the evaporator temperature, for lifts below 55 deg C a single stage cycle is appropriate; for higher lifts a two-stage compressor with flash inter-cooling will offer higher COP by reducing throttling loss and compressor work.

2. *Availability of Waste Heat* - if waste heat is available, absorption cycles will work out to be more economical; if heat is available above 85 deg C, single-stage LiBr/H_2O or NH_3/H_2O cycles with COP in the range of 0.5 to 0.6 for water chilling duty can save 75 to 85% electricity compared to vapour compression cycles; if heat is available above 175 deg C, two-stage LiBr/H_2O or NH_3/H_2O GAX cycles with COP in the range of 1.1 to 1.25 can save 90% electricity.
3. *Relative Pricing of Electricity and Fuel* - if electricity rate is above 3.75 Rs./kWh and the fuel cost is less than 7.5 Rs./kg then direct fired absorption refrigeration systems, with COP of 1.1, will cost less to operate.

System components and their selection

Having identified a suitable cycle for the refrigeration sub-system it is important to select the various components of the system in orders to maximize the benefits offered by he system **Table 1** lists the choice of main components of refrigeration and air-conditioning system along with the various choices available for each component.

Selection of the type of component used in a system is influenced by various factors like system capacity, maintainability, initial cost, energy conserving potential and availability in the local market. Let us briefly review the suitability of various components and their influence on the energy consumption of the system.

Table 1:Choice of Components for Refrigeration and Air-Conditioning System

Components common to vapour compression and absorption sub-system.

- Evaporator: air-cooling coil or DX coil, shell-and-tube liquid chillers, plate heat exchangers and special configurations for specific processes.
- Condenser: air-cooled, water-cooled and evaporatively-cooled
- Sub-cooler: tune-in-tube, shell-and-tube and plate heat exchanger
- Expansion device: capillary tube, short tube, orifice, thermal expansion valve, level control valve, electronic expansion valve and hand expansion valve.

Vapour compression sub-system

- Compressor: scroll, reciprocating, screw, rotary and centrifugal
- Prime mover: motor, engine, steam turbine and gas turbine
- Control: on-off, unloading of cylinders, slide valve control in screw comp and variable speed drives

Absorption sub-system

- Generator: steam fired, direct fired and waste heat fired
- Absorber: air-cooled water-cooled and evaporatively-cooled
- Pump: diaphragm, reciprocating, centrifugal and screw
- Solution heat exchanger: tube-in-tube, shell-and-tube and plate

- Rectifiers: adiabatic packed column and non-adiabatic shell-and-tube
- Control: on-off and variable speed drive

Delivery sub-system

- Air-handling unit: ducting, insulation, dehumidifier VAV, humidifier, fans and blowers
- Hydronic unit: piping, insulation and pumps
- Cooling tower: water pump and fan speed-control or on-off-control
- Storage: chilled water, glycol eutectic solution and ice.

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Evaporator:

Reducing the approach temperatures in the evaporator increases in pressure at the inlet of the compressor, which leads to increase in COP Where ever possible usually in small capacity and unitary systems, use of direct expansion (DX) air cooling coils can reduce energy consumption because of elimination of an intermediate heat exchanger and hence the temperature droop across it. Larger systems typically use shell-and-tube liquid chillers. Use of high performance heat transfer tubing, to enhance boiling as well as water/brine side heat transfer coefficients helps in reduce the size and cost of he system. They also lead to higher COP. Plate heat exchangers (PHE) offer similar advantages for middle capacity range However, cost of PHE is higher than other types.

Condenser:

Condensing temperature for an evaporatively-cooled condenser can be 5 and 15 deg.C lower than those for water-cooled and air-cooled condensers respectively. This leads to reduced compressor power. Evaporatively cooled condenser reduces the airflow, water pumping and chemical treatment requirements. Thus, they can lead to significant energy and operating cost savings. Their initial cost can be the lowest if properly designed and integrated with the refrigeration system. Water-cooled condensers should be preferred over air-cooled condensers are of various types. Their typical capacity range and features are listed below:

1. *Shell-and-tube:* 3 to 35,000kW, enhanced tubing n increase heat transfer coefficients, water side accessible for mechanical cleaning
2. *Shell-and-coil:* 2 to 50kw, tubes are neither replaceable nor mechanically cleanable
3. *Tube-in-tube:* 1 to 180kw, suitable for heating water in heat pump application
4. *Brazed plate:* 1.5 to 350kw, compact design, low refrigerant charge, only chemical cleaning possible, not recommended where water quality is poor.

Sub-cooler:

Sub-cooler is a component where the cold refrigerant vapour coming out of the evaporator exchanges heat with the liquid refrigerant coming out of the condenser. Sub-cooling increases the cooling capacity per unit refrigerant flow. In vapour compression systems, sub-cooling leads to increased compression work and hence, optimum level of sub-cooling needs to be provide. Excessive sub-cooling, beyond the optimum level leads to decrease in COP, In vapour compression systems, the optimum level of sub-cooling depends on the refrigerant, the lift and the compressor isentropic efficiency In absorption refrigeration systems sub-cooling has to be maximized. This is because there is no penalty in the specific volume of he vapour due to superheating. Small systems can use tube-in-tube heat exchangers, while large systems can employ plate or shell-and-tube heat exchangers. Sub-coolers can lead to 5 per cent to 10 per cent increase in COP.

Expansion Device:

Expansion device plays an important role in regulating the capacity of a refrigeration system. Smaller systems, typically less than 0.5 TR, use simple low cost devices like capillary tube, short tube and orifice. These devices work well at design condition, but, may allow excess or deficit flow at off design conditions. Also cycling losses are high because all the condense refrigerant migrates to the evaporator from the condenser during the off-cycle When the compressor comes on again this refrigerant will not fully vaporize in the evaporator, but will get carried over to the compressor shell. Thermal expansion, electronic expansion and level control vale regulate he refrigerant flows as per the control strategies that they are designed for. They do not contribute to cycling losses. Some large systems with steady heat loads and heat source and sink temperatures may use hand expansion valves.

Table 2: Various issues Relevant to Energy Conservation and influence of Different Energy Conservation Alternatives

Use of Energy
• Reduction in compression work-- reduced electricity consumption
• Reduction in primary energy usage--reduced fuel consumption at source
• Improved part load efficiency-- variable speed drives or on-off control of multi-module system

Energy Costs
• Reduction in compression work --higher heat exchanger
• Switching over to heat operated systems --higher initial investment
• Switching over to waste heat fired systems --higher initial investment

Initial investment

- Reduction in compression work --higher heat exchanger
- Switching over to heat operated systems --higher initial investment
- Switching over to waste heat fired systems --higher initial investment
- Solution heat exchanger: tube-in-tube, shell-and-tube and plate
- Improved part load efficiency --higher cost due to additional controls and duplication of some system components.

Compressor:

Compressors used in vapour compression systems can be classified based on type of design. Open semi-hermetic or bolted hermetic and welded-shell hermetic. They can also be classified under rotary (up to 40 KW), scroll (up to 50 KW), reciprocating (up to 150 KW), screw (70 to 4600 KW) and centrifugal types. In the open design the shaft extends through a seal in the crankcase for an external drive. Since the motor is external, the heat generated in the motor can be rejected directly to the ambient and hence does not contribute to increased compressor work. However, open systems may not be acceptable in most small applications due to maintenance issues. Scroll compressors are efficient choice for small systems. Oil or liquid injected screw compressors can offer significant reduction in work requirement.

Table 3: Opportunities for Energy Conservation Saving Primary Energy

Reduction in compression work

- Use of waster-cooled condensers and absorbers instead of air-cooled
- Use of evaporatively-cooled condensers and absorbers instead of water-cooled
- Reduction in LMTD -Using high performance heat exchangers and surface area
- Using non-azeotropic refrigerant mixture instead of pure refrigerants--better matching of temperature glides in the fluid streams being cooled and heated with that of the glides in the evaporator and the condenser
- Use of proper liquid refrigerant sub-cooler-based on the refrigerant and the operating conditions sub-cooling should be optimized not maximized

Switching over to heat operated systems

- Waste heat fired systems - reduced primary energy consumption by as much as 90%
- Use of proper solution sub-cooler - sub-cooling should be maximized based on economic consideration.

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Primary Drive:

Although the shaft power can be supplied by electric motor, engine (15 to 3500 kW), steam turbine or gas turbine, the most common prime mover is the electric motor. The convenience and low maintenance requirements of an electric motor make it a common choice. Direct engine coupled systems are available now which offer fuel based COP of as high as 1.8. The energy costs for these systems will be much lower than electric motor driven system. These systems offer the added advantage that they do not depend on the electric supply.

Controls:

Choice of controls and the schemes used play a significant role in conserving energy. Small systems (up to 15 KW) are fitted with on-off control which cost the minimum. Capacity of larger systems are costlier, but energy cost being almost zero they will always be a better choice from energy cost point of view.

Absorber:

Just like the condenser, it is preferable to use a evaporatively cooled absorber because this will improve the COP of the absorption refrigeration system. Evaporatively cooled absorption systems will not only reduce energy consumption, but will be more compact and its initial cost will be less. Water cooled system is the second-best option. Air cooled systems should be opted only when availability of water is a major problem. $LiBr/H_2O$ systems are mostly water cooled. Some small air cooled systems are available. NH_3/H_2O systems are available in all configurations.

Solution Pump:

Pump is the heart of the absorption refrigeration system. They can be of diaphragm, reciprocating, centrifugal and screw type. $LiBr/H_2O$ systems use seal-less centrifugal pumps. Diaphragm pumps are used for small systems up to 35 KW. Screw pumps, although costly, offer better control because they are positive displacement pumps and do not get vapour logged.

Solution Heat Exchanger:

Solution heat exchanger (SHE) design has a direct influence on the COP of absorption system. SHEs are of tube-in-tube for small capacities, shell-and-tube and plate type for larger units.

Rectifier:

Rectifiers are required in NH_3/H_2O systems. Optimal rectification for a particular application is recommended in order to maximize COP. Over rectification will increase the generator load and hence increase fuel consumption., Adiabatic packed column are commonly used. Non-adiabatic columns can offer better COP by internally recycling some of the heat of rectification.

Controls:

Capacity control in the case of absorption refrigeration systems should be effected by variable speed drives for the pumps. During part load operation, with reduced solution flow rate, the SHE duty reduces and so its effectiveness increases. Reduced circulation losses in the SHE lead to increased COP On the other hand on-off control can lead to increased cycling losses and increased energy consumption per unit cooling effect produced.

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ISSUES RELEVANT TO ENERGY CONSERVATION

Various issues relevant to energy conservation in RAC systems are:

1. Reducing primary energy or energy consumption
2. Reducing energy cost
3. Reducing initial investment

There is a difference between energy consumption and primary energy consumption. It is important to understand the difference between them. Energy consumption accounts for the electricity, fuel, and/or steam consumed at the point of use of the RAC equipment. Primary energy consumption accounts for the calorific value of fuel used at the source of generation of electricity, heat an/or steam which is used to operate the RAC equipment. Primary energy consumed also accounts for the efficiency of generation and transmission of electricity, heat and/or steam. Thus, one could cone across cases where primary energy consumption of a system, say system A, is less than that of another system, say System B But the energy consumption of he System A is larger then that for System B. The concept of primary energy consumption is useful when systems operating solely on electricity, like the vapour compression systems, are to be compared with those consuming both electricity and heat or fuel, like absorption refrigeration systems. Since, it calculates the amount of fuel consumed at source, it is also helpful in calculating he amount o carbon dioxide (CO_2) released into the atmosphere. Release of $CO_2$is used to estimate the total global warming potential of the system and is increasingly being used by the environmentalists. In some developed countries there are talks of imposing a CO_2tax, and the primary energy concept will gain more importance in the coming years.

Most of the users of RAC equipment are more concerned about the energy cost rather than the energy consumption or the primary energy consumption. It is important to realize that higher energy efficiency and primary energy efficiency may not mean lower energy costs. Relative price of electricity and various fuels used to operate the systems can shift the preference of the user to a lesser energy efficient system which offers lower energy costs, Comparison between electric vapour compression systems with direct fired absorption refrigeration systems is a classic example where the primary energy consumed by the electric vapour compression systems is less than that by direct fired absorption refrigeration systems. But, with high electricity costs the vapour compression systems cost more than the direct fired absorption refrigeration systems.

Along with the energy costs, the user is also concerned about the initial investment and the maintenance costs for the RAC system. In other words the life cycle costs of various RAC systems should be used for comparison. However, the system selection also gets influenced by cash flow situation of he user.

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Table 4: Opportunities for energy conservation reducing Life Cycle Cost

Reduction in Energy Cost
• Reduction in compressor power consumption
• Use of oil fired engine driven VC systems instead of electric motor driven
• Use of direct oil fired or steam fired absorption systems instead of EVC systems
• Use of waste heat fired systems

Reduction in initial investment
• Use of integrated waste heat fired systems with built-in heat recovery units.

OPPORTUNITIES FOR ENERGY CONSERVATION

In addition to optimizing the COP of RAC systems, it is possible to recover waste heat and utilize it for RAC. Cogeneration of electricity and refrigeration can lead to maximum savings. Exhaust gases and radiator hot water from diesel gensets (DG) can be used for operating absorption refrigeration systems.

A 1000KW DG would reject about 960KW in the form of hot exhaust gases and about 700KW in the form of radiator heat. Out of the 960KW exhaust heat only about 640KW is usually recoverable. This high temperature heat can operate a 200 TR two-stage LiBr/H_2O absorption chiller. The radiator heat can be used to operate an additional 100 TR single-stage LiBr/H_2O absorption chiller. Thus 300 TR of cooling can be obtained by tapping into the waste heat streams from a 1000KW DG. This will not only address the ozone depletion problem, but also, the global warming issue. The economics of such a system are also very attractive.

CONCLUSIONS

There are several opportunities for reducing energy consumption in refrigeration and air-conditioning systems. Appropriate selection of system components can lead to major energy savings. Modular systems or systems with good part load efficiency should be used to reduce energy consumption.

Heat operate refrigeration systems can be used to lower energy cost. Waste heat operated refrigeration systems can be used to reduce life cycle cost.

Table 5: Waste heat fired absorption chiller

Application -- Waste heat sources
• Ice making: boilers, diesel gensets, thermopacs, etc.
• Water chilling: boilers, diesel gensets, thermopacs, etc.
• Process fluid chilling: boilers, diesel gensets, thermopacs, etc
• Cold storage and blast freezing: boilers, diesel gensets, thermopacs, etc
• Cogeneration of electricity and refrigeration: diesel gensets, gas turbines, etc.
• Pre-cooling air at DG engine or GT compressor inlet: diesel gensets, gas turbines.

Impact energy usage
• Waste heat absorption instead of electric vapour compression system: 75 to 85% saving in electricity
• Waste heat absorption instead of fuel fired absorption system: up to 90% saving in primary energy

Economic and other advantages
• Low cost: lower initial cot compared to electric vapour compression systems with standby diesel gensets to supply electricity for the electric vapour compression systems
• Low payback periods: usually in the range of 1 to 1.5 years
• Capacity modulation: 25 to 100% of rated capacity
• Environment friendly technology: waste heat fired system can reduce global warming
• Environment friendly refrigerants: H_2O and NH_3 are natural refrigerants and do not lead to ozone depletion
• Cooling down cogeneration of electricity and refrigeration can pad to maximum sub-zero temperatures:NH^3system can provide cooling at to -30 deg.C.