Unit – 3 Notes

21EE0304T

EEP

Energy saving opportunities

Unit 3

A number of different measures can be adopted to save energy (see **Fig. K15**).

- **Reduce energy use**
  LED
  These measures try to achieve the same results by consuming less (e.g. installing highly energy-efficient lights which provide the same quality of light but consume less energy) or reduce energy consumption by taking care to use no more energy than is strictly necessary (e.g. another method would be to have fewer lights in a room which is too brightly lit).
- **Save energy** Cost per unit
  These measures reduce costs per unit rather than reducing the total amount of energy used. For example, day-time activities could be performed at night to in order to take advantage of cheaper rates. : Similarly, work could be scheduled to avoid peak hours and demand response programmes.
- **Energy reliability**
  They not only contribute to operational effectiveness by avoiding production downtime, but also avoid the energy losses associated with frequent restarts and the additional work associated with batches of spoiled products.

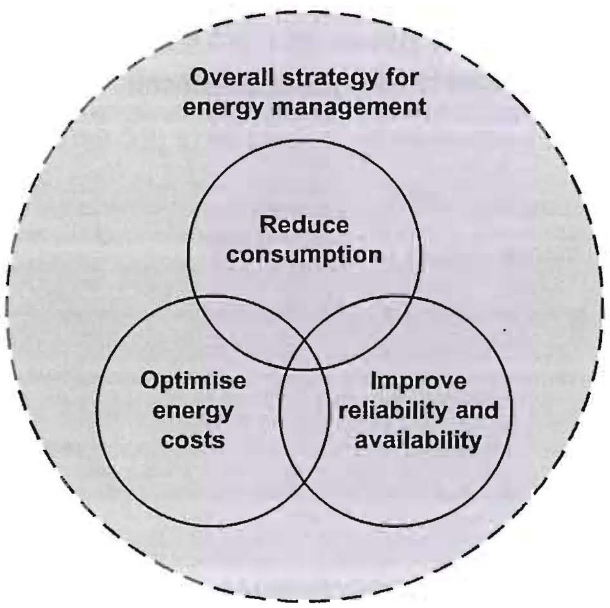


Fig. K15 – An overall strategy for energy management

Everyone immediately thinks of equipment for transforming energy (motors, lighting/heating devices) when considering areas where savings can be made. Less obvious, perhaps, are the potential savings offered by the various control devices and programmes associated with this type of equipment.

Energy saving opportunities - Motors

> Motors represent 80% of electrical energy consumption in the industry segment

Motorised systems are one of the potential areas where energy savings can be made.

Many solutions exist to improve the energy efficiency of these motorized systems, as described below. You can also refer to the white paper "Energy efficiency of machines: the choice of motorization"

Choice/replacement of the motor

Best efficiency IE3 (for < 375 kW

Those wishing to improve passive energy efficiency often consider replacing motors as a starting point, especially if the existing motors are old and require rewinding.

This trend is reinforced by the determination of major countries to stop low-efficiency motor sales in the near future. Based on the IEC60034-30 Standard's definition of three efficiency classes (IE1, IE2,IE3), many countries have defined a plan to gradually force IE1 and IE2 motor sales to meet IE3 requirements.

In the EU, for example, motors of less than 375 kW have to be IE3-compliant by January 2015 (EC 640/2009).

There are two reasons for replacing an old motor:

- To benefit from the advantages offered by new high-performance motors (see **Fig. K16**)

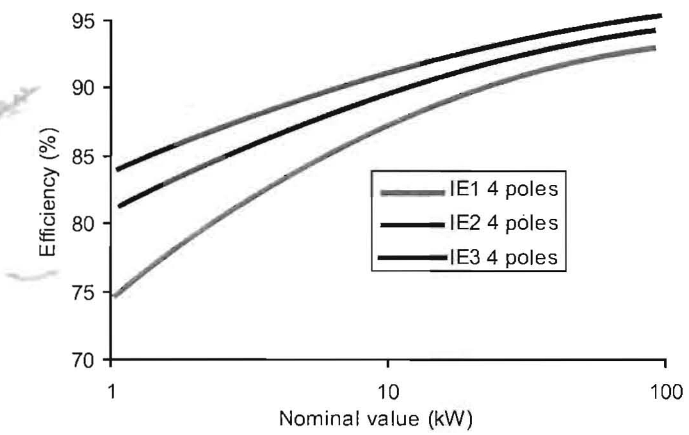


Fig. K16 – Definition of energy efficiency classes for LV motors, according to Standard IEC60034-30

Depending on their rated power, high-performance motors can improve operational efficiency by up to 10% compared to standard motors. By comparison, motors which have undergone rewinding see their efficiency reduced by 3% to 4% compared to the original motor.

- To avoid oversizing

In the past, designers tended to install oversized motors in order to provide an adequate safety margin and eliminate the risk of failure, even in conditions which were highly unlikely to occur. Studies show that at least one-third of motors are clearly oversized and operate at below 50% of their nominal load.

However:

- Oversized motors are more expensive.
- Oversized motors are sometimes less efficient than correctly sized motors: motors are at their most effective working point when operating between 30% and 100% of rated load and are built to sustain short periods at 120% of their rated load.

Efficiency declines rapidly when loads are below 30%.

- The power factor drops drastically when the motor does not work at full load, which can lead to charges being levied for reactive power.

Knowing that energy costs account for over 97% of the lifecycle costs of a motor, investing in a more expensive but more efficient motor can quickly be very profitable.

However, before deciding whether to replace a motor, it is essential:

- to take the motor's remaining life cycle into consideration.
- to remember that the expense of replacing a motor even if it is clearly oversized, may not be justified if its load is very small or if it is only used infrequently (e.g. less than 800 hours per year see **Fig. K17**).
- to ensure that the new motor's critical performance characteristics (such as speed)are equivalent to those of the existing motor.

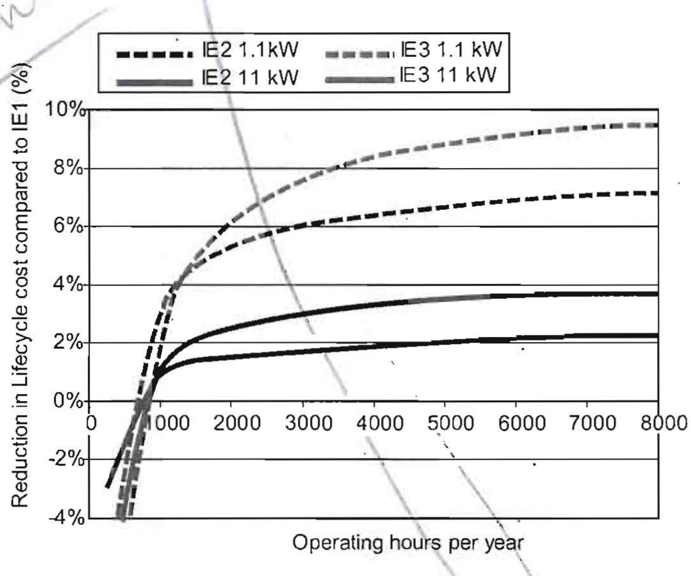


Fig. K17 – Life cycle cost reduction for IE2 and IE3 motors compared to IE1 motors, depending on the number of operating hours per year

Operation of the motor

Savings can be made by:

- Replacing an oversized old motor with an appropriate high-efficiency motor
- Operating the motor cleverly

> Choosing an appropriate motor starter/controller

Other approaches are also possible to improve the energy efficiency of motors:

- Improving active energy efficiency by simply stopping motors when they no longer need to be running. This method may require improvements to be made in terms of automation, training or monitoring, and operator incentives may have to be offered. If an operator is not accountable for energy consumption, he/she may well forget to stop a motor at times when it is not required.
- Monitoring and correcting all the components in drive chains, starting with those on the larger motors, which may affect the overall efficiency. This may involve, for example, aligning shafts or couplings as required. An angular offset of 0.6 mm in a coupling can result in a power loss of as much as 8%.

Control of the motor

> The method for starting/controlling a motor should always be based on a system-level analysis, considering several factors such as variable speed requirements, overall efficiency and cost, mechanical constraints, reliability, etc.

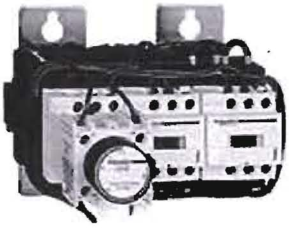
To ensure the best overall energy efficiency, the motor's control system must be chosen carefully, depending on the motor's application:

- For a constant speed application, motor starters provide cheap, low-energyconsumption solutions. Three kinds of starters can be used, depending on the system's constraints:
  - Direct on line starter (contactor)
  - Star Delta starter: to limit the inrush current, provided that the load allows a starting torque of 1/3 of nominal torque
  - Soft starter: when Star Delta starter is not suitable to perform a limited inrush current function and if soft braking is needed.

Example of constant speed applications: ventilation, water storage pumps, waste water treatment stirring units, conveyors, etc.

Fig. K18 – Motor starter examples (Schneider Electric)

Direct on line contactor
(TeSys Deca)



Star delta starter
(TeSys Deca)

Soft starter
(Altivar soft starter ATS480)

- When the application requires varying the speed, a Variable Speed Drive (VSD) provides a very efficient active solution as it adapts the speed of the motor to limit energy consumption.
  It competes favourably with conventional mechanical solutions (valves, dampers and throttles, etc.), used especially in pumps and fans, where their operating principle causes energy to be lost by blocking ducts while motors are operating at full speed.
  VSDs also offer improved control as well as reduced noise, transient effects and vibration. Further advantages can be obtained by using these VSDs in conjunction with control devices tailored to meet individual requirements.
  As VSDs are costly devices which generate additional energy losses and can be a source of electrical disturbances, their usage should be limited to applications that intrinsically require variable speed or fine control functions.
  Example of variable speed applications: hoisting, positioning in machine tools, closed-loop control, centrifugal pumping or ventilation (without throttle) or booster pumps, etc.

Fig. K19 – Variable Speed Drives of various power ratings (Altivar range, Schneider Electric)

Altivar 12
(≤ 4 kW)

Altivar 212
(HVAC, ≤ 75 kW)

Altivar Process ATV900
(≤ 2600 kW)

- To handle loads that change depending on application requirements, starters, VSDs, or a combination of both with an appropriate control strategy (see cascading pumps example **Fig. K20**) should be considered, in order to provide the most efficient and profitable overall solution.

Example of applications: HVAC for buildings, goods transport, water supply systems, etc.

The method for starting/controlling a motor should always be based on a system level analysis, considering several factors such as variable speed requirements, overall efficiency and cost, mechanical constraints, reliability, etc.

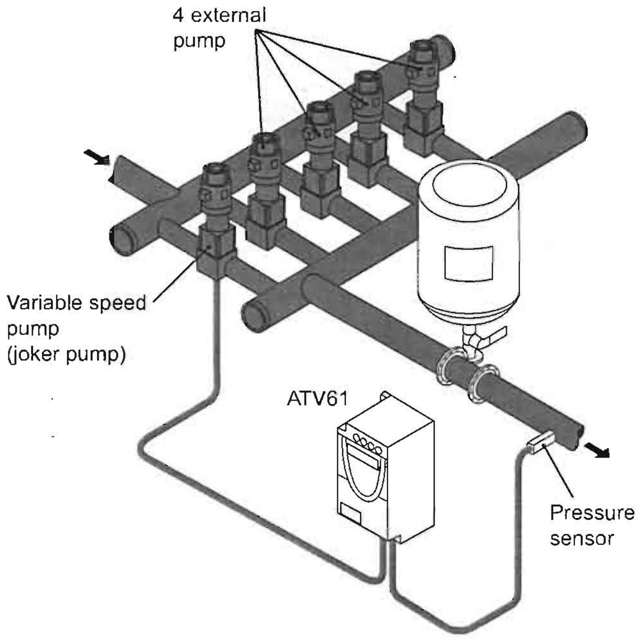


Fig. K20 – Example of cascading pumps, which skillfully combine starters and a variable speed drive to offer a flexible but not too expensive solution

→ used for variable loads like HVAC, water supply

Energy saving opportunities - Lighting

Lighting can account for over 35% of energy consumption in buildings, depending on the types of activities carried out in them. Lighting control is one of the easiest ways to make substantial energy savings for a relatively small investment and is one of the most common energy saving measures.

Lighting systems for commercial buildings are governed by standards, regulations and building codes. Lighting not only needs to be functional, but must also meet occupational health and safety requirements and be fit for purpose.

In many cases office lighting is excessive and there is considerable scope for making passive energy savings. These can be achieved by replacing inefficient luminaires, by replacing obsolete lights with high-performance/low-consumption alternatives and by installing electronic ballasts. These kinds of approach are especially appropriate in areas where lighting is required constantly or for long periods and savings cannot be achieved by simply switching lights off. The time taken to recoup investments varies from case to case, but many projects require a period of around two years.

Ex. ballasts = Converts AC voltage to a high freq o/p to start & regulate gas discharge in lamps — ensuring efficient lighting

Lights and electronic ballasts or LED technology

More efficient lights may be a possibility, depending on the needs, type and age of the lighting system. For example, new fluorescent lights are available, although ballasts also need to be replaced when lights are changed.

New electronic ballast are also available, offering significant energy savings compared to the earlier electromagnetic ballasts. For example, T8 lights with electronic ballasts use between 32% and 40% less electricity than T12 lights fitted with electromagnetic ballasts.

However, electronic ballasts do have a number of points of attention compared with magnetic ballasts:

- Their operating frequency (between 20 and 60 kHz) can introduce high frequency conducted and radiated disturbances, which can interfere with power line communication devices for example. Adequate filters must be incorporated.
- The supply current of standard devices is highly distorted, so that typical disturbances linked to harmonics are present, such as neutral current overload. Low harmonic emission devices are now available, which keep harmonic distortion to less than 20 percent of fundamental current, or even 5% for more sensitive facilities (hospitals, sensitive manufacturing environments ...).

The LED technology, introduced only a few years ago, offers significant prospects for progress, especially for smart control. LED are considered as the sustainable alternative solution to achieve energy savings objectives in the lighting sector.

This is the first lighting technology suitable for all fields (residential, service sector buildings, infrastructure ...) providing great energy efficiency and smart management capability.

Other types of lighting may be more appropriate, depending on the conditions involved. An assessment of lighting needs will focus on evaluating the activities performed and the required levels of illumination and colour rendering. Many existing lighting systems were designed to provide more light than required. Designing a new system to closely fit lighting needs makes it easier to calculate and ultimately achieve savings.

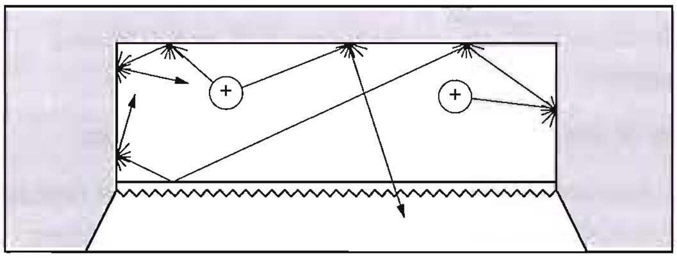
Apart from the issue of savings, and without forgetting the importance of complying with the relevant standards and regulations, there are other advantages associated with retrofitting lighting systems. These include lower maintenance costs, the chance to make adjustments based on needs (office areas, "walk-through" areas etc.), greater visual comfort (by eradicating the frequency beat and flickering typically associated with migraine and eye strain) and improved colour rendering.

Reflectors

A less common passive energy efficiency measure, but one which is worth considering in tandem with the use of lights fitted with ballasts, is to replace the reflectors diverting light to areas where it is needed. Advances in materials and design have resulted in better quality reflectors which can be fitted to existing lights. These reflectors intensify useful light, so that fewer lights may be required in some cases. Energy can be saved without having to compromise on lighting quality.

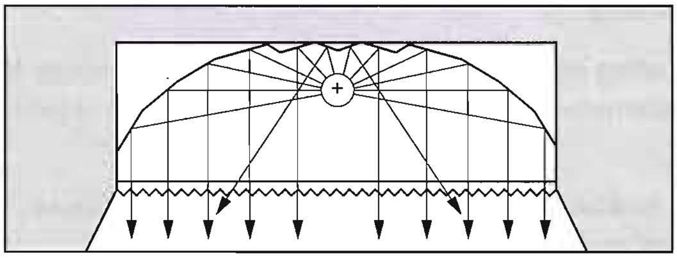
New, high-performance reflectors offer a spectral efficiency of over 90% (see **Fig. K21**). This means:

- Two lights can be replaced by a single light, with potential savings of 50% or more in terms of the energy costs associated with lighting.
- Existing luminaires can be retrofitted by installing mirror-type reflectors without having to adjust the distance between them. This has the advantage of simplifying the retrofitting process and reducing the work involved, with minimal changes made to the existing ceiling design.



Above: Around 70% of a fluorescent tube's light is directed sideways and upwards.

Below: The new silver surfaces are designed to reflect the maximum amount of light downwards.



parabolic reflector

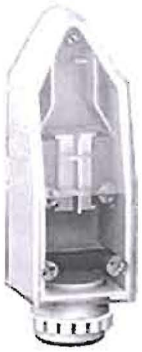
Fig. K21 – Illustration of the general operating principle for high-performance reflectors

Lighting control

The passive energy saving measures described above leave further scope for making savings. The aim of lighting control programmes is to give users the required levels of convenience and flexibility, whilst supporting active energy savings and cost reduction by switching lights off as soon as they are no longer needed. There are a number of technologies available with various degrees of sophistication, although the time taken to recoup investments is generally short at six to twelve months. A multitude of different devices are currently available too (see **Fig. K22**).

In 6-12 months, your expense will be come back

Fig. K22 – A selection of lighting control devices: timers, light sensors, movement sensors



- Timers to turn off lights after a certain period has passed. These are best used in areas where the typical time spent or period of activity is clearly defined (such as corridors).
- Occupancy/movement sensors to turn off lights when no movement has been detected for a certain period. These are particularly well suited to areas where the time spent or period of activity cannot be accurately predicted (storerooms, stairwells, etc.).
- Photoelectric cells/daylight harvesting sensors to control lights near windows. When sufficient daylight is available, lights are turned off or switched to night-light mode.
- Programmable clocks to switch lights on and off at predetermined times (shop fronts, office lights at nights and weekends)
- Dimmable lights to provide a low level of illumination (night light) at off-peak periods (e.g. a car park requiring full illumination until midnight, but where lower levels will suffice between midnight and dawn)
- Voltage regulators, ballasts or special electronic devices to optimise energy consumption for lights (fluorescent tubes, high-pressure sodium lights, etc.)
- Wireless remote control devices for simple and economical retrofitting of existing applications

These various technologies may be combined and can also be used to create a specific effect or atmosphere. For example, programmable lighting panels in meeting areas (for board meetings, presentations, conferences, etc.) have a number of different light settings which can be changed at the flick of a switch.

Centralised lighting management

Some of the lighting control systems currently available, such as those based on the KNX protocol, have the additional advantage of supporting integration into building management systems (see **Fig. K23**).

They offer greater flexibility of management and centralised monitoring, and provide more scope for energy savings by enabling lighting controls to be integrated into other systems (e.g. air conditioning). Certain systems enable energy savings of 30%, although efficiency levels will depend on the application involved and this must be chosen with some care.

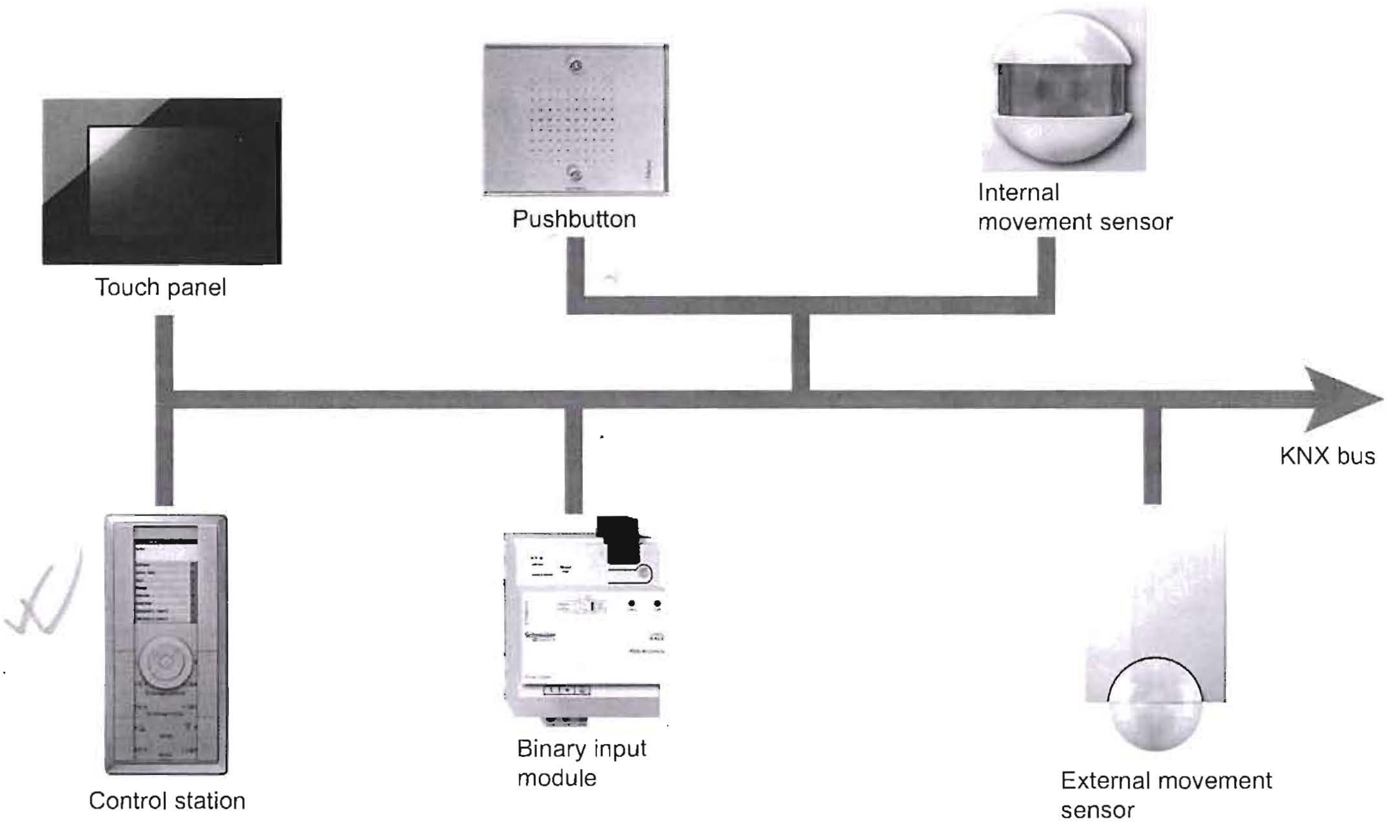


Fig. K23 – An example of links established using Schneider Electric's KNX system

If this type of system is to produce results, the design and implementation stage must begin with an audit of energy consumption and a study of the lighting system with a view to devising the best lighting solution and identifying potential reductions in terms of both costs and energy consumption. As far as this kind of technology is concerned, Schneider Electric also has solutions for offices as well as exterior lighting, car parking facilities, parks and landscaped gardens.

Energy saving opportunities - Power factor correction and harmonic filtering

- If the energy distribution company imposes penalties for reactive power consumption, improving power factor correction is a typically passive energy saving measure. It takes immediate effect after implementation and does not require any changes to procedures or staff behaviour. The investment involved can be recouped in less than a year.
  See **Power Factor Correction** for further details.

  Many types of equipment (variable speed drives, electronic ballasts, etc.) and computers generate harmonics within their line supply. The effects produced can sometimes be significant heat and vibration potentially reducing the efficiency and service life of such equipment as capacitor banks used for power factor correction. Harmonic filtering is another typical passive energy saving measure to consider.

See **Power harmonics management** for further details.

Energy saving opportunities - Load management

As part of their drive towards synchronizing the consumption and production of electrical energy over the long term, energy distribution companies tailor their rates to encourage consumers to reduce their requirements during peak periods.

A number of different strategies are possible, depending on consumption levels and operating requirements: restricting demand (see **Fig. K24**), avoiding peak periods, load scheduling or even generating additional energy on site.

This is also known as "demand response".

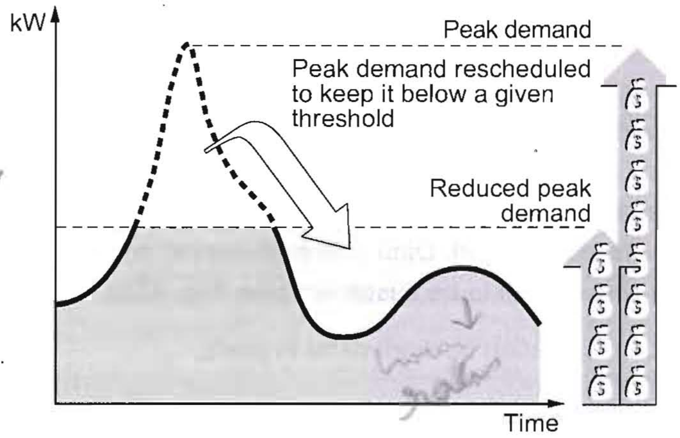


Fig. K24 – An example of a load-management strategy

Demand restriction

Energy distribution companies can use this solution in supply contracts containing optional or emergency (involving compulsory limits) restrictive clauses whose application is determined by the consumer (based on special rates). This management policy is typically used during the hottest or coldest months of the year when companies and private customers have very high requirements for ventilation, air conditioning and heating, and when electricity consumption exceeds normal demand considerably. Reducing consumption in this way can prove problematic in residential and service sector environments, as they may considerably inconvenience building occupants. Customers from industry may show more of an interest in this type of scheme and could benefit from contracts reducing unit costs by up to 30% if they have a high number of non-essential loads.

Peak demand avoidance

This method involves moving consumption peaks in line with the different rates available. The idea is to reduce bills, even if overall consumption remains the same

Load scheduling

This management strategy is an option for companies able to benefit from lower rates by scheduling consumption for all their processes where time of day is neither important nor critical.

Additional energy generation on site

The use of generating sets to supply energy improves operational flexibility by providing the energy needed to continue normal operations during periods of peak or restricted demand. An automated control system can be configured to manage this energy production in line with needs and the rates applicable at any given time. When energy supplied from outside becomes more expensive than energy generated internally, the control system automatically switches between the two.

Energy saving opportunities - Communication and information systems

Information systems Raw data converted to useful infn. for egy-efficiency

No Energy Efficiency is possible without communication.

But whether it relates to measurements, operating statuses or rate bases, raw data can only be useful when converted into usable information and distributed on a need-to-know basis to all those involved in energy efficiency with a view to improving the expertise of all participants in the energy management process. Data must also be explained, as people can only develop the management and intervention skills integral to any effective energy saving policy if they fully understand the issues involved. Data distribution must produce actions, and these actions will have to continue if energy efficiency is to be sustained (see **Fig. K25**).

However, this cycle of operations requires an effective communication network to be in place.

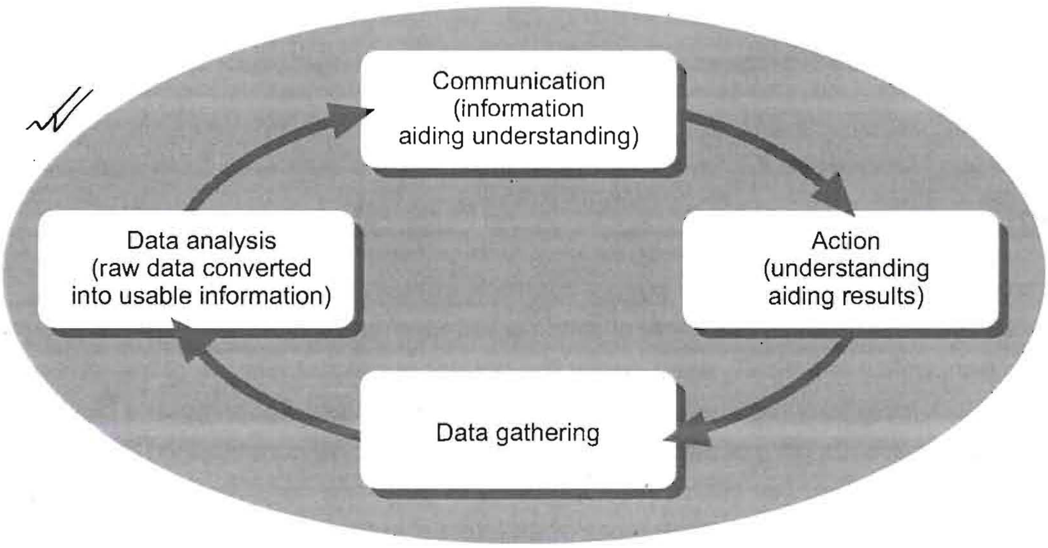


Fig. K25 – Operating cycle for data essential to energy efficiency

The information system can then be used on a daily basis by the operators at the various locations where electricity is consumed (for industrial processes, lighting, air conditioning, and so on) to achieve the energy efficiency objectives specified by company management. It can also ensure these same locations make a positive contribution to company operations (in terms of product volumes, conditions for supermarket shoppers, temperatures in cold rooms, etc.).

Monitoring systems

- For quick audits which can be performed on an ongoing basis.
  Encouraging familiarity with data and distributing it can help keep everything up to date, but electrical networks develop rapidly and are permanently raising questions about their ability to cope with such new developments.
  With this in mind, a system for monitoring the transfer and consumption of energy is able to provide all the information needed to carry out a full audit of the site. As well as electricity, this audit would cover water, air, gas and steam.
  Measurements, comparative analyses and standardised energy consumption data can be used to determine the efficiency of processes and industrial installations.
- For rapid, informed decision making
  Suitable action plans can be implemented. These include control and automation systems for lighting and buildings, variable speed drives, process automation, etc.
  Recording information on effective equipment use makes it possible to determine accurately the available capacity on the network or a transformer and to establish how and when maintenance work should be performed (ensuring measures are taken neither too soon nor too late).

Communication networks

Information and monitoring systems are synonymous with both intranet and Internet communication networks, with exchanges taking place within computer architectures designed on a user-specific basis.

Intranet

For the most part, data exchange in the industrial sector uses Web technologies permanently installed on the company's communications network, typically an intranet network for the sole use of the operator.

Concerning data exchange between components connected via a physical transmission link, the Modbus protocol is very widely used. Connection is possible with metering and protection devices in electrical networks. Initially created by Schneider Electric, it is very popular also in the building sector and considered as a standard protocol.

For carrying large amount of data between electrical distribution systems, the latest technology which is now introduced is Ethernet. It is strongly promoted for simplicity and performance. It is the most adapted media for either local display or distant servers.

In practice, electrical data is recorded on industrial Web servers installed in panel boards. The popular TCP/IP standard protocol is used for transmitting this data in order to reduce the ongoing maintenance costs associated with any computer network. This principle is well adapted to communicate data associated with promoting energy efficiency. No additional software is needed – a PC with an Internet browser is all that is required. As such, all energy efficiency data is recorded and can be communicated in the usual manner via intranet networks, GSM/GPRS, wifi, etc...

For simplicity and consistency, measurement devices and communication interfaces are advantageously embedded in the distribution panel boards. See Smart Panels.

Internet

Remote monitoring and control ~~improve data availability~~ and accessibility, whilst offering greater flexibility in terms of servicing. **Fig. K26** shows a diagram of this type of installation. Connection to a ~~server~~ and a standard Web browser makes it much easier to use data and export it to Microsoft Excel™ spreadsheets for the purpose of tracing power curves in real time.

Now, Ethernet technology allows easy connection of panel boards to the Internet, with compatibility with the rapidly developing Smart Grid facilities.

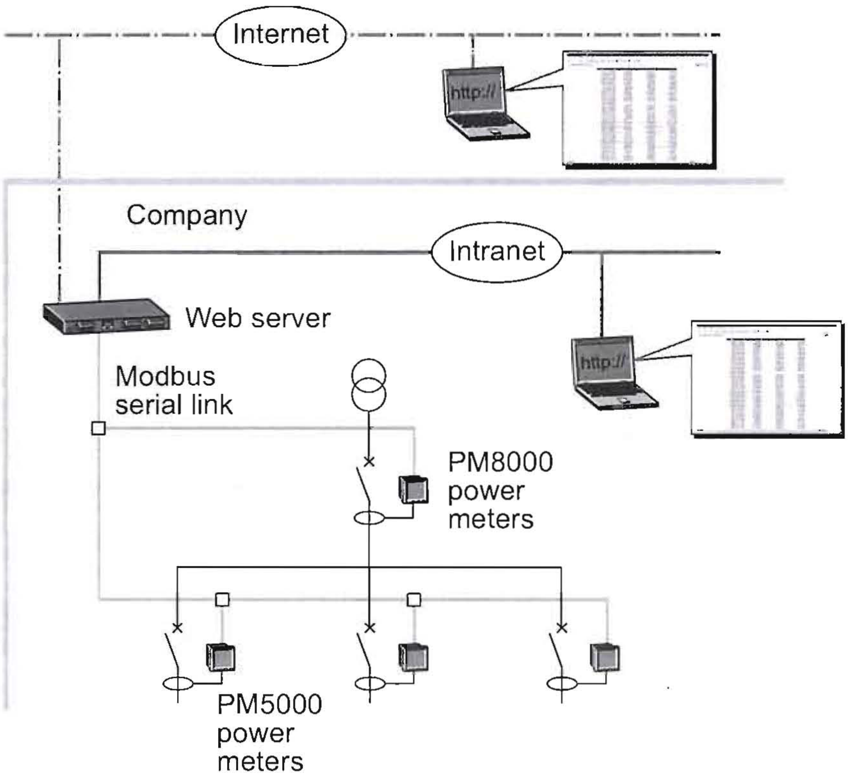


Fig. K26 – Example of an intranet information network protected by a server (EGX300 – Schneider Electric) and monitored from the Internet network

Architectures

Historically and for many years, monitoring and control systems were centralised and based on SCADA automation systems (Supervisory Control And Data Acquisition).

These days, a distinction is made between three architecture levels (see **Fig. K27**).

Level 1 architecture

Thanks to the new capabilities associated with Web technology, recent times have witnessed the development of a new concept for intelligent equipment. This equipment can be used at a basic level within the range of monitoring systems, offering access to information on electricity throughout the site. Internet access can also be arranged for all services outside the site.

Level 2 architecture

This system has been specifically designed for electricians and adapted to meet the demands of electrical networks.

This architecture is based on a centralised monitoring system designed to satisfy all the monitoring requirements for the electrical network. As might be expected, installation and maintenance work requires less expertise than for Level 3, since all the electrical distribution devices are already contained in a specialised library. In addition, acquisition costs can be kept to a minimum, as there are few requirements in terms of system integration.

Level 3 architecture

Investment in this type of system is usually restricted to top-of-the-range facilities consuming large amounts of energy or using equipment which is highly sensitive to variations in energy quality and has high demands in terms of electricity availability.

To ensure these high demands for availability are met, the system often requires responsibility to be taken for installation components as soon as the first fault occurs. This should be done in a transparent manner (any impact should be clear).

In view of the substantial front-end costs, the expertise required to implement the system correctly and the update costs generated as the network develops, potential investors may be deterred and they may require highly detailed prior analyses to be conducted.

Level 2 and Level 3 can be used side by side at certain sites.

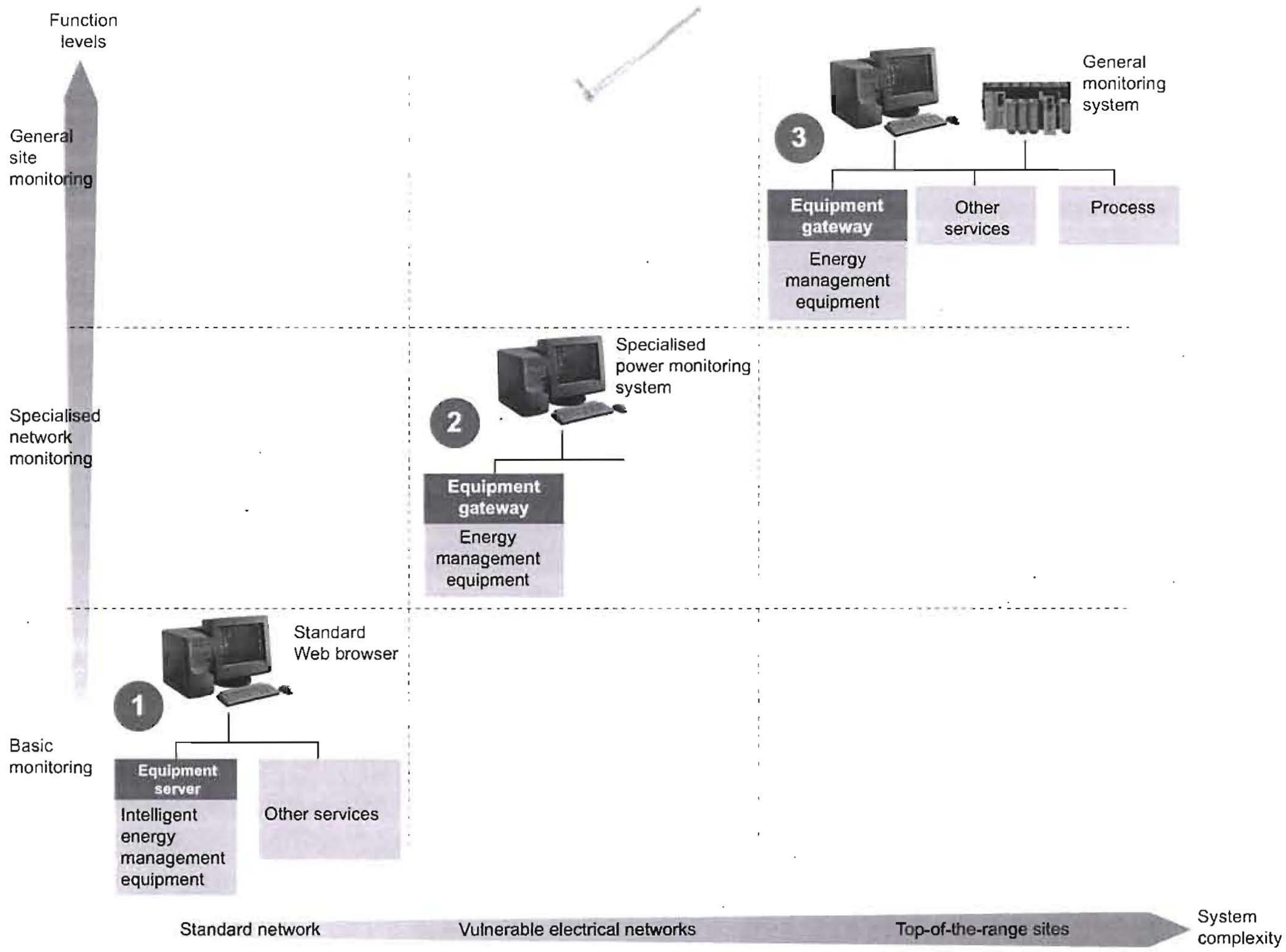


Fig. K27 – Layout of a monitoring system

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tips for energy saving in motor

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Here are some tips for saving energy with motors:

- Run at full capacity: Motors are most efficient when they are running at or close to full load.
- Run for shorter periods: Optimize systems so that motors run at full capacity for shorter periods instead of running continuously at a partial load.
- Use a variable speed drive: Run motors at a slower speed for longer to save energy. For example, a motor running at 80% speed uses only 50% of the power required to run at full speed.
- Use an efficient motor: Consider replacing an old electric motor with a high-efficiency motor.
- Regularly inspect: Check for signs of wear ~~and~~ tear, such as overheating, corrosion, or physical damage.
- Monitor vibration: Excessive vibration can cause the motor to fail more quickly.
- Keep clean: Keep motors clean from dirt and debris.
- Lubricate: Lubricate motors according to the manufacturer's specifications.
- Shade from the sun: Shade motors from the sun.
- Locate in a well-ventilated area: Locate motors in well-ventilated areas.
- Maintain a record: Maintain a record for each motor.

Electric Motors: How to Save Money and Energy?
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Tips to Save Energy with Variable Speed Drives
1. Run motors slower for longer. One of the most straightforward ways to save energy with variable speed drives is to run motors a...
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Generative AI is experimental.

Here are a few tips about improving efficiency and saving money on your electric motors.

1. Regular Inspection: Low resistance is the main reason for motor failure. ...
2. Correct Size: ...
3. Invest in Efficient Motors: ...
4. Protect against Contamination: ...
5. Understand the Energy Use: ...
6. Variable or Fixed Speed: ...
7. Reduce Wear and Tear: ...
8. Vibration:

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10 Tips to Save Energy and Money with Electric Motors

What are 10 ways to save energy?

Our top 10 energy saving tips

- Switch off lights and electrical appliances when not using them. ...
- Switch to energy-saving LED light globes. ...
- Shut doors and close curtains. ...
- Save energy in how you wash and dry clothes. ...
- Understand and improve your home's energy use. ...
- Save energy in the kitchen. ...
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Top 10 energy saving tips

How can you improve the efficiency of a motor?

Other than using enhanced magnetic materials, other factors like improving the geometry of the stator and rotor and employing improved motor cooling systems can reduce losses due to heat and, in turn, increase the overall motor efficiency. 29 May 2024

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10 Tips to Save Energy and Money with Electric Motors

With over 30 years of experience in motor control, Fairford Electronics is uniquely positioned to provide honest, unbiased and reliable information.

January 5, 2017

Industry is flooded with advice on how to save energy with electric motors. Most of these items of advice only tackle one issue, or in even worse cases only provide a single and biased viewpoint. With over 30 years of experience in motor control, Fairford Electronics is uniquely positioned to provide honest, unbiased and reliable information. Here are 10 tips from them on saving energy and money.

1. Measure

The phrase, 'If you can't measure it, you can't manage' remains a true statement for electric motors. To make the biggest impact, you must have a clear understanding of which motors and processes are consuming the most energy in your plant. This will allow you to target your efforts, and gain the quickest Return on Investment.

2. Understand Energy Use

El egy → Rotation + Heat egy

Electric motors are energy conversion devices, they convert electrical energy into rotational energy and some heat. It is important to understand the difference between motor speed (rotational speed) and motor load [opposing force (torque)]. The energy consumption of a motor is related to both speed and load. A slow motor with a full load will consume more energy than a fast motor with no load.

3. Fixed Speed v Variable Speed

Consider which applications are already variable speed, those that must remain fixed speed and those where the speed could be reduced. Be careful though, reducing speed on some applications will not reduce energy consumption. For example, halving the speed of a conveyor system will just mean the conveyor will take twice as long to move the same amount of material.

4. Turn it Off

It sounds simple, but the most effective way to save energy is to switch the motor off when it's not needed. Often the reason for not doing this is the perceived risk of additional wear and tear at motor start up. This is especially true for motors started Direct On Line or with Star Delta starters.

5. Efficient System Design

There is a little point in installing the latest high efficiency motors and equipment, if the entire system is fundamentally inefficient.

Study how the system works and identify when and where the motor is doing work unnecessarily.

6. Slow Down

In the simplest terms, at the same load, a slow motor does less work than a fast motor. So you can only save energy in applications where you need less work done.
Variable Speed Drives save energy by allowing the motor to do less work. They are very effective in reducing speed and saving energy in applications where the main opposing force is drag, so this is especially true in HVAC, fan and centrifugal pump applications. Due to the physics of drag, a small reduction in motor speed will result in a larger reduction in the work done and the energy consumed.

7. Use Energy Saving Motor Controls

All motors, even IE3/NEMA Premium Efficiency Motors are most efficient at near full load, as motor load fall below 50%, efficiency begins to reduce. This effect exists because the motor will always use a certain amount of energy to create the magnetic fields needed to rotate the motor irrespective of load.
In applications where the motor load is variable or the motor runs at light loads for long periods, Intelligent Energy Saving Motor Controllers should be used.

8. Size Motors Correctly

At full load all motors, even old motors, are surprisingly efficient. But as the load reduces, motor efficiency quickly falls away – even on the latest high efficiency motors. Therefore, a high efficiency motor is only truly efficient when it is being used near full load conditions.

It is a good engineering practice to slightly oversize a motor for a particular application, this will extend motor life and provide some extra capacity – when it is required, and if a motor is oversized, larger than required, the motor should be re-examined.

9. Use High Efficiency Motors

The latest IE3/NEMA Premium Efficiency motors are more efficient, but the efficiency gains are marginal. Only in few cases where the motor is very old and running 24/7, it will make financial sense to replace a perfectly functioning motor with a new motor.

However, upgrading the motor as it reaches the end of its service life, or when the motor fails, should be considered as best practice. Motor rewinds should only be considered when the motor cannot be replaced due to specific technical reasons or lack of availability of suitable replacements.

10. Reduce Wear & Tear

After energy costs, down time is the next single biggest cost to any plant operator.

causes wear & tear

A large amount of wear occurs when an electric motor is started; the high initial currents and forces put great strain on the mechanical and electrical systems. To reduce the damaging effects, Soft Starters should be used in all fixed speed applications, and this then will extend motor life.

tips for energy saving in motor

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Here are some tips to save energy in a motor:

- **Maintenance**: Regularly maintain the motor to keep it running efficiently. This includes:
  - Inspecting for wear and tear, such as misaligned shafts or worn bearings
  - Cleaning to remove dust and debris
  - Lubricating moving parts and bearings to reduce friction and wear
- **Motor sizing**: Replace larger motors that are only partially loaded with smaller motors that are fully loaded.
- **Motor use**: Optimize the system or process so that the motor runs at full capacity for shorter periods of time.
- **Power factor**: Correct the power factor to improve the efficiency of electrical power use. A high power factor indicates efficient use, while a low power factor indicates poor use.

Efficient use for high power factor

- **Motor location**: Keep motors in well-ventilated areas and shade them from the sun.
- **Motor controls**: Use energy-saving motor controls.
- **Motor efficiency**: Use an energy-efficient motor that produces the same shaft output power as a standard-efficiency motor, but uses less input power.

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Compressed Air Systems: An Introduction

Air Compressed into high pressure, provide Kinetic Egy; kept in tank; released to clean cracks/crevices or for automation line; boosts productivity — mostly used in automotive/Car industry, pharmaceutical industry, food beverage industry, manufacturing industry — speeds up stream line of production belt

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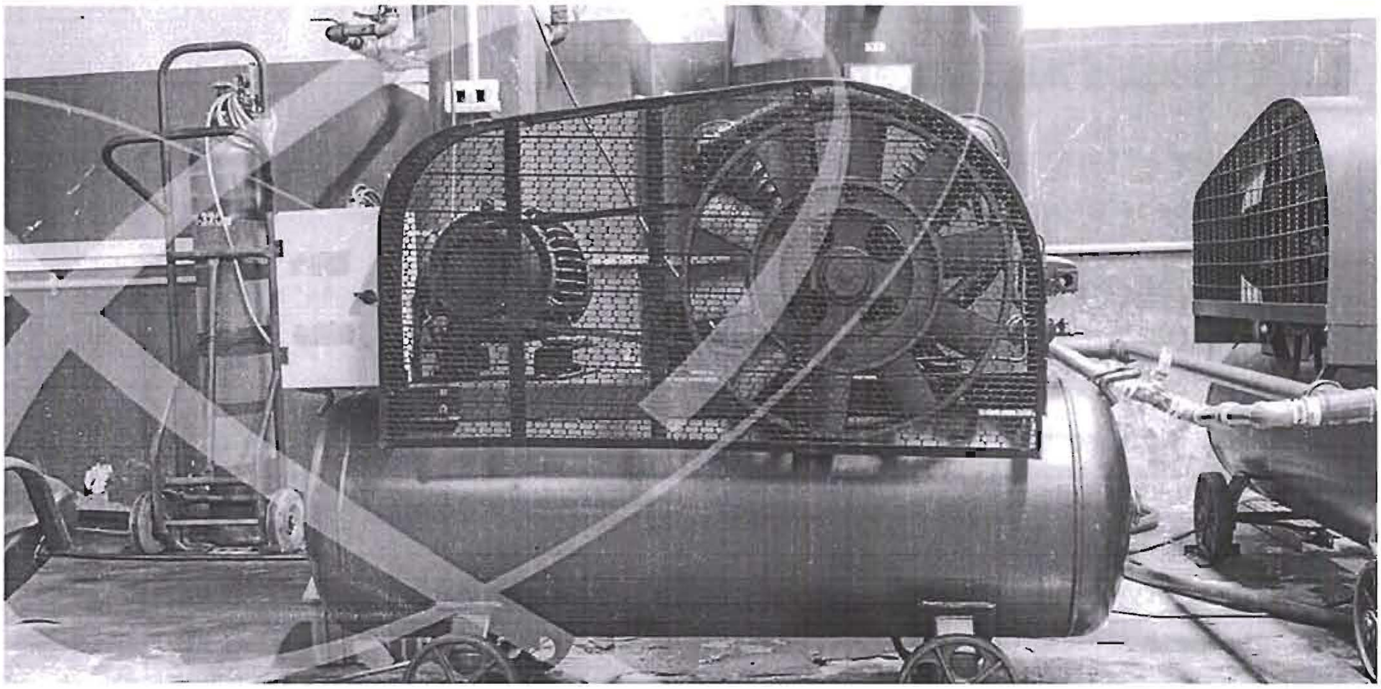
Posted on: September 20, 2023



Compressed air is so common in industrial applications that many people consider it a utility in the same way they view water and natural gas. Compressed air systems are valuable resources for powering a facility's machinery and tools and performing other essential tasks.

If you need to add the power of air to your operation, a compressed air system will provide the capability and utility you need to drive pneumatic tools and other resources. In this introduction to compressed air systems, we'll explore the basics of these reliable solutions.

What Is a Compressed Air System?

An air compressor system is a network of equipment that captures and distributes pressurized air to operate machinery and devices such as automated valves, slide gates and diverters. This

3.1 Introduction

- Air compressors account for significant amount of electricity used in Indian industries. Compressed air is an essential but costly utility and its use must be made wisely. Compressed air is generated from compressors which are largely driven by electricity. If efficiency is calculated, only 10% useful energy reaches the end point through compressed air. Thus there is a vast scope for energy saving through proper understanding of the functions of this utility and avoiding its wastage.
- The applications of compressed air are plenty. A few of them can be listed as:
  - operation of solenoid valves plunger
  - operation of pneumatic cylinders
  - instrumentation
  - pneumatic tool
- In the olden days, vast areas of instrumentation including modulating actuators, etc. were operated using compressed air especially 3-15 PSI standards. But slowly, these are being replaced by electronic and electrical drives mainly because of their accuracy, repeatability, maintainability and cost.
- However, there are certain hazardous areas, like the petroleum industry, the mining industry, etc. where even small electrical sparks are not permissible. In such areas it is compulsory to use pneumatic devices.

3.2 Category of Compressors

→ forces air into confined space, by reducing volume using mechanical device

- Compressors are broadly classified as:
  - Positive Displacement Compressors
  - Dynamic (Centrifugal) Compressors

→ Speeds up air to high velocity → creates energy which builds up air pressure

- The flow and pressure requirements of a given request determine the suitability of a particular type of compressor. These are further classified as:

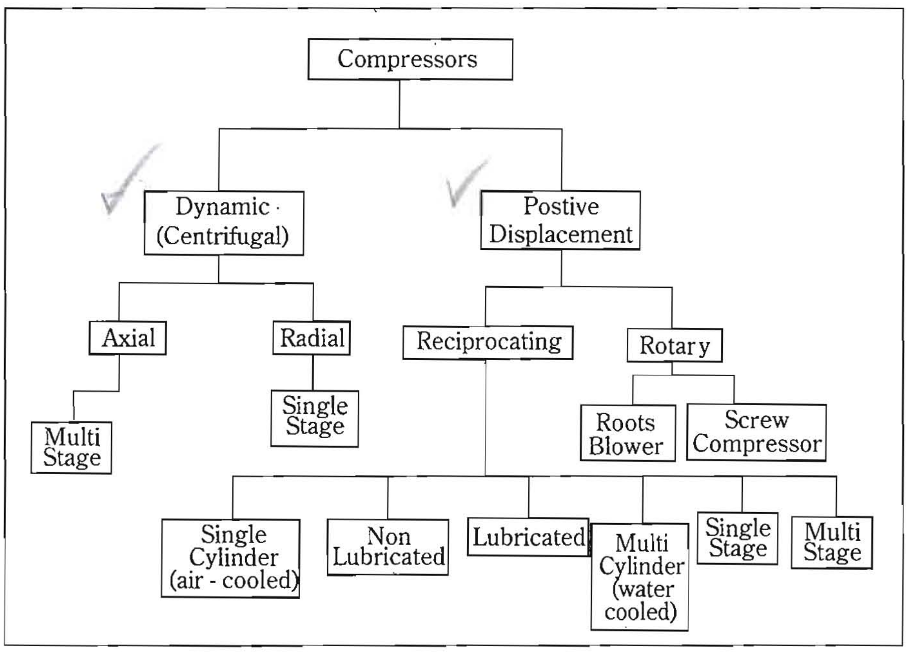


Fig. 3.1 Types of compressors

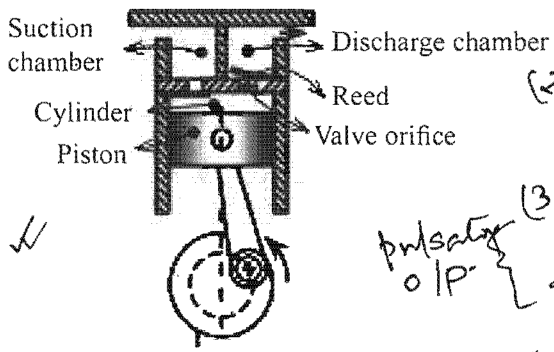
Positive displacement compressors

The compressors which increase the pressure of the gas by reducing the volume are called positive displacement compressors. These compressors are further classified into:

- reciprocating compressors
- rotary compressors

Reciprocating compressors

Reciprocating compressors are the most widely used compressors. They operate on the cylinder and piston principle. Their flow output remains constant over a wide range of discharge pressures. The capacity is directly proportional to the speed of the prime mover. The output however, is pulsating since in one cycle, air is allowed to enter and in the other it is compressed and discharged. To make this output smooth, a receiver is invariably used. Reciprocating compressors come in variety of types; such as: lubricated and non lubricated, single or multiple cylinder, water or air cooled, single or multi stage reciprocating compressors.

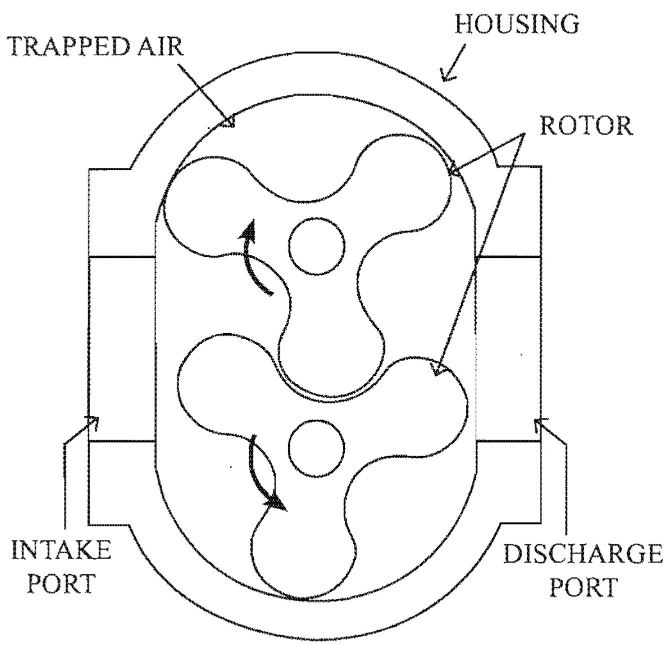


(1) Const. flow out put — with discharge pressure
(2) Capacity ∝ speed of prime mover
(3) one cycle : air is sucked in
pulsating o/p { II " : air is compressed & discharged
(4) Types: lubricated / Non lubri. Single / multiple large cylinder
(5) Need heavy foundation to check imbalance thrust & vibration

Fig. 3.2 A Typical reciprocating compressor

Rotary compressors

Rotary compressors unlike reciprocating compressors give a uniform flow. They are directly coupled to the prime mover and need less starting torque. Their outputs are higher compared to reciprocating compressors. Mechanically, reciprocating compressors give an imbalance, a thrust and vibrations, hence need heavy foundation. On the other hand, rotary compressors need a simple foundation. These compressors can give a discharge pressure upto 10 bar.



- Uniform flow o/p
- Coupled to prime mover
- Need less starting torque
- Hr o/p pressure (discharge pressure upto 10 bar)
- Need simple foundation.

Fig. 3.3 A typical rotary compressor

throttle =

Dynamic compressors

Dynamic compressors increase the air velocity, which is then converted to increased pressure at the outlet. They are basically centrifugal compressors and are further divided into:

- radial type
- axial flow types

·Increase air velocity
·Centrifugal compressor (Hr. o/p pressure)

Dynamic compressors operate on similar principles as centrifugal pumps. But one fundamental principle is to be understood. Pumps deal with liquid which is an incompressible fluid. Hence if you throttle output, the discharge is reduced. For air, if you throttle output, the pressure goes up because it gets compressed. This is how a centrifugal compressor operates. Hence these are typically suitable for outputs above 12000 CFM.

Compressors should be selected on the basis of individual requirements but as a general guideline, the given table may be used.

Type of Compressor	Capacity (m3/h)		Pressure (bar)	
	From	To	From	To
Roots blower compressor single stage	100	30,000	0.1	1
Reciprocating				
- Single / Two stage	100	12,000	0.8	12
- Multi stage	100	1,200	12	700
Screw				
- Single stage	100	2,400	0.8	13
- Two stage	100	2,400	0.8	24
Centrifugal	600	30,000	0.1	450

Table 3.1 Compressor selection chart

3.3 Efficiency of a Compressor

Compressor capacity:

→ or actual flow rate

Capacity of a compressor is the full rated volume of flow of gas compressed and delivered at conditions of total temperature, total pressure, and composition existing at the compressor inlet. It sometimes means actual flow rate, rather than rated volume of flow. This is also termed as Free Air Delivery (FAD) i.e. air at atmospheric conditions at any specific location. Because the altitude, barometer, and temperature may vary at different localities and at different times, it follows that this term does not mean air under identical or standard conditions.

Compressor efficiency :

Several different measures of compressor efficiency are commonly used: volumetric efficiency, adiabatic efficiency, isothermal efficiency and mechanical efficiency.

- Before going on to the formulae, one must understand that air behaves as per the gas equation:

$PV = mRT$ ✓

Where;
P = Pressure
V = Volume
m = Specific Mass
R = Constant
T = Absolute Temperature

⇒ Thermo steel bottle

Also, there are many thermodynamic processes like the isothermal, the adiabatic, the polytrophic, etc.

- ✓ Adiabatic and isothermal efficiencies are computed as the isothermal or adiabatic power divided by the actual power consumption. The figure obtained indicates the overall efficiency of compressor and drive motor.

- As air is compressed, its temperature at the outlet tends to increase. If this temperature is accounted, the calculations become complex and hence for simplicity, efficiency is calculated assuming the temperature remains constant. This efficiency is called Isothermal Efficiency.
- Isothermal power is calculated using the following:

Isothermal power (kW) = P_1 x Q_1 x $\log_e r/36.7$

Where,
P_1 = Absolute intake pressure kg/ cm^2
Q_1 = Free air delivered m^3/hr. → FAD = vol. of air flow / time
r = Pressure ratio P_2/P_1 P_2 =

- Since Actual Power can be measured on the electrical side, the Isothermal Efficiency is calculated as:

Isothermal Efficiency= Actual measured input power/Isothermal Power (Input power → Electrical input power)
Normally,manufacturers give the isothermal efficiency.

- Volumetric Efficiency:

Volumetric efficiency = Free air delivered (m^3/min)/Compressor displacement FAD = air flow (vol.) / minute

Compressor Displacement = $\frac{\pi}{4} \times D^2 \times L \times S \times \chi \times n$
Where,
D = Cylinder bore (metre)
L = Cylinder stroke (metre)
S = Compressor speed in rpm
χ = 1 for single acting and 2 for double acting cylinders
n = No. of cylinders

- For practical purposes, the most effective guide in comparing compressor efficiencies is the specific power consumption i.e. kW per volume flow rate , for different compressors.

3.4 Compressed Air System Components

- Apart from the compressor proper, there are certain system components in the compressed air system which also should be understood properly. The most important of these are as follows:
- Intake air filters: chalk, dust, pollen, mold, fibrous material

They prevent dust from entering the compressor and are normally specified in terms of microns (indicating the size below which dust cannot be prevented). Example, a 5-micron filter can prevent dust particles above 5 microns size where as cannot stop dust particles lower than 5 microns. Hence before choosing a filter, it is worthwhile to assess the dust conditions in the surroundings.

- Interstage coolers:

During compression the temperature of air increases, especially when multistage compressors are used, each stage needs ~~cooling~~. Hence coolers are required and they are mostly water-cooled. They need specific attention as per the manufacturer's recommendations.

- After Coolers: These are used to remove moisture. , cools system lubricants
- Air Dryers: Removes condensation from compressed air

These are used to remove the rest of the moisture which may be left at various locations in the pipelines.

- Moisture Drain Traps:

These are used at the end of piping sections to remove moisture in compressed air. Various types of moisture drain traps are available like manual drain cocks, timer based / automatic drain valves etc.

- Receivers:

Air receivers are provided to be storage and smoothening vital air output - reducing pressure variations from the compressor.

- Each of the components mentioned above, needs to be well-maintained for an overall good performance of the system. See Fig.3.4 for a typical compressed air system components and network.

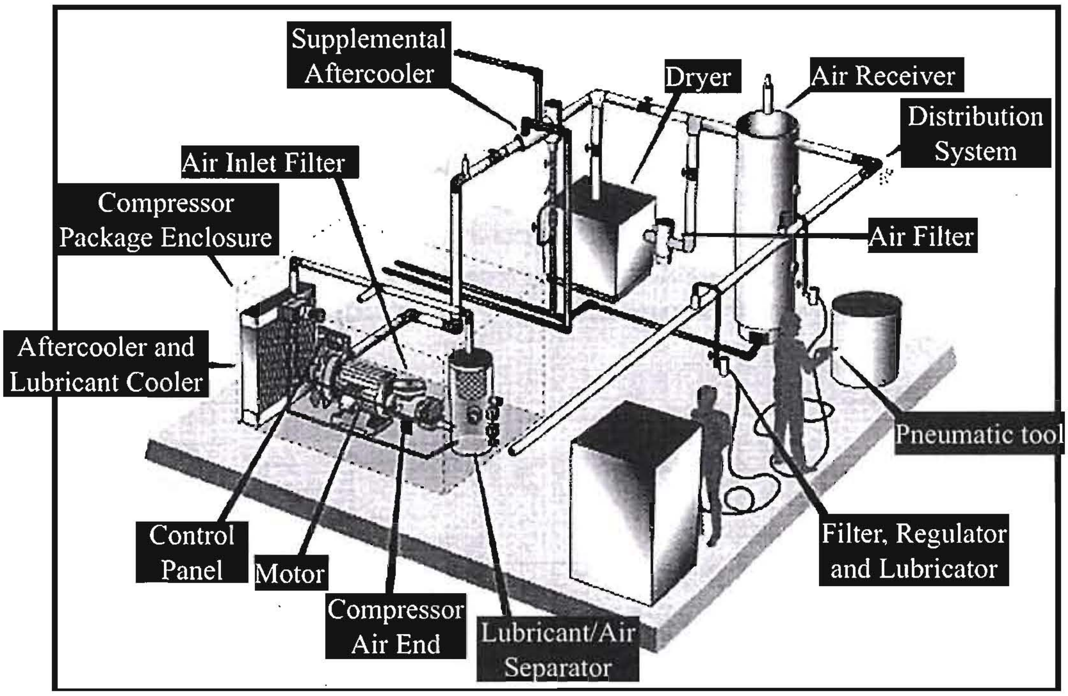


Fig. 3.4 A typical compressed air system components and network

3.5 Efficient Operation of Compressor

- There are a number of issues to be must be considered right at the stage of project planning and also during operation. This will ensure the efficient operation of the compressor. One important issue is the centralised compressor house or distribution system.
- A typical case (example, a cement plant) would explain the situation. In a cement plant, compressed air is required at various places. Apart from this, there is a vehicle workshop at the mines for vehicle maintenance. There is no point in running a compressed air pipeline from a centralised compressor house to the mines workshop. It is worth to provide an independent compressor for the mine vehicle maintenance workshop. Thus, locating a compressor at the proper location is most important since compressors once located cannot be shifted very easily.
- Cool Air Intake: Statistics show that every 40C rise in intake air results in additional 1% power consumption. Hence cool ambient temperature must be provided as intake air. There should be no heat source like a Kiln, Furnace, etc. near the compressor house.
- Dust free air intake is most essential for a compressor. The dust accumulated in the filter should be removed regularly and eventually, the filters must be replaced. There are manometers or pressure switches which will warn about the differential pressure across the filters so that their performance can be watched.
- Dry Air is equally important. Moisture in the air can get converted into water during compressor operations and damage compressor parts.
- The compressor must be operated within the altitude recommended by the manufacturer else its performance will be affected.
- The cooling water circuit should be properly maintained. As explained above, compression results in a rise in temperature and many compressors require intercoolers. The intercoolers are water cooled. They need to be maintained well. Especially the quality and quantity of water should be as per the manufacturer's recommendations.
- Optimum pressure settings should be set for load and unload operations.

Air Compressor Converts power to KE

Loaded Compressor => Compressing air & pumping into the system & pumping it into system upto a point which is "set".
load.

Unloaded Compressor => After set point, compressor still ~~runs~~ unloaded but not compressing any air

3.6 Capacity Assessment of A Compressor

- Unlike electricity, compressed air is not a continuous flowing energy. Example, in a plant if there is no operation of any pneumatic device for one hour the compressed air supplied will only cater to leakages. If there are no leakages during this time, then the compressor will run without compressing air. This operation is called unload.
- During unload operations, the prime mover is running the compressor, but it does not compress air. Thus, it meets only no load losses. The measurement of timings of load and unload operations and power consumption readings will give an idea about the efficiency of operation.
- The ideal method of compressor capacity assessment is through a nozzle test wherein a calibrated nozzle is used as a load, to vent out the generated compressed air. Flow is assessed, based on the air temperature, stabilization pressure, and orifice constant.
- Actual Free air discharge (Q)

$$✓ \quad Q = \frac{P_2 - P_1}{P_0} \times \frac{V}{T} \text{ Nm}^3\text{/Minute}$$

→ at Isothermal Cond. Compressed air temp T_2 = ambient air temp T_1

Else $FAD = Q \times \frac{273 + T_1}{273 + T_2}$ for $T_1 \neq T_2$

Where,
P_2 = Final pressure after filling (kg/cm2 a)
P_1 = Initial pressure (kg/cm2a) after bleeding
P_0 = Atmospheric Pressure (kg/cm2 a)
V = Storage volume in m3 which includes receiver, after cooler, and delivery piping
T = Time take to build up pressure to P2 in minutes

- The above equation is relevant where the compressed air temperature is same as the ambient air temperature, i.e., perfect isothermal compression. In case the compressed air temperature at discharge, say t2°C is higher than ambient air temperature say t1°C (as is usual case), the compressor free air delivery test (FAD) is to be corrected by a factor (273 + t1) / (273 + t2).

Leakage test

If the compressor has prolonged load operations, one can come to the conclusion that there are a lot of leakages. This means apart from the pneumatic devices, there are certain places where air is continuously being drained. The best way is to attend to the leakage and find out the reduction in load time.

- The Specific Power Consumption of a Compressor can be calculated in the following method:
  - If a compressor of capacity Qm3 FAD per minute is being operated with the following consumption, the specific energy consumption can be worked out.

Load Cycle P1kW for t1 minutes and Unload P2kW for t2 minutes, then specific energy consumption =
Air Delivered = Q x t_1 minutes

$$\textbf{Energy Consumed} = \frac{(P_1 \times t_1) + (P_2 \times t_2)}{60 \text{ kWh}}$$

Hence,

$$\textbf{Specific Energy Consumption} = \frac{(P_1 \times t_1) + (P_2 \times t_2)}{60 \times Q \times t_1} \textbf{ kWh/m}^3 \textbf{ of FAD} = \frac{\text{Energy Consumed}}{Q \times t_1}$$

- Note the sub-sequent time taken for 'load' and 'unload' cycles of the compressors. For accuracy, take ON & OFF times for 8 – 10 cycles continuously. Then calculate total 'ON' Time (T) and Total 'OFF' time (t).
- The system leakage is calculated as:

% leakage = T × 100 / (T + t)
(Or)
System leakage (m³/minute) = Q × T / (T + t)

T = ON time
t = OFF time

Where,
Q = Actual free air being supplied during trial, in cubic meters per minute (cmm)
T = Time on load in minutes
t = Time on unload in minutes

4.1 Introduction

- The Heating, Ventilation, and Air Conditioning (HVAC) and refrigeration system transfer heat energy from one atmosphere to the other. One of them is a closed environment, while the other is the open atmosphere of the Earth.
- HVAC includes the bi-directional flow of heat, in the sense that when earth's atmospheric temperature is too low, then the requirements of a closed atmosphere are to be maintained. Heat is injected into the closed atmosphere.
- Refrigeration on the other hand, has a unidirectional flow of heat. It always extracts heat from the closed atmosphere with the help of a low boiling point refrigerant and dispels it into the open atmosphere of the earth.

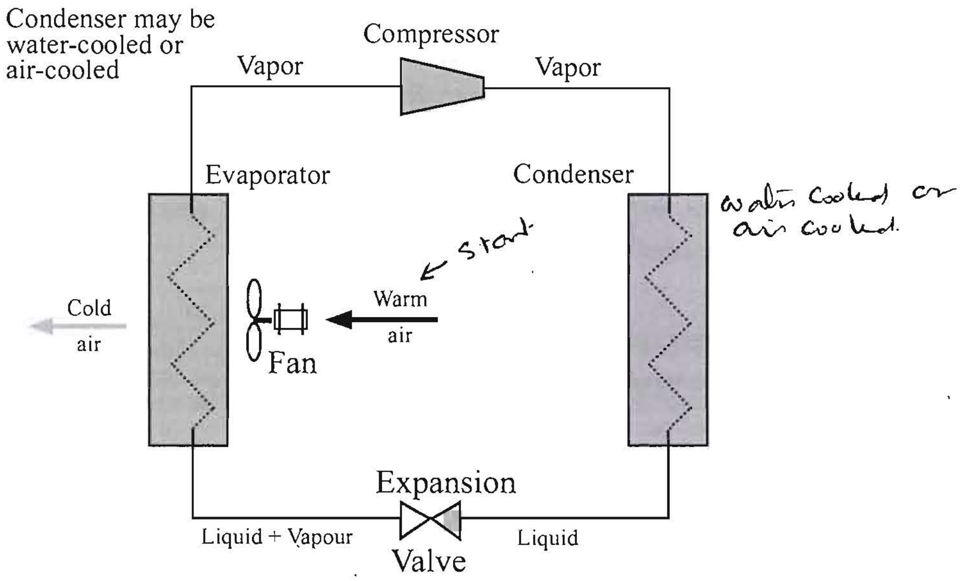


Fig. 4.1 Schematic representation of refrigeration system

- According to thermodynamic laws, heat cannot flow from a cold object to a hot object unless external work is done. The external work is done by the equipment used in HVAC/Refrigeration using electricity as the energy source.
- There are several heat transfer loops in the refrigeration system as described below. In Fig. 4.2, thermal energy moves from the left to the right as it is extracted from the space and expelled to the outdoors through five loops of heat transfer:

Easy

Indoor air loop

- In the leftmost loop, indoor air is driven by the supply air fan through a cooling coil, where it transfers its heat to chilled water. The cool air then cools the building space.

Chilled water loop

- Driven by the chilled water pump, water returns from the cooling coil to the chillers' evaporator to be re-cooled.

Refrigerant loop

- Using a phase-change refrigerant, the chillers' compressor pumps heat from the chilled water to the condenser water.

Condenser water loop

- Water absorbs heat from the chillers' condenser, and the condenser water pump sends it to the cooling tower.

Cooling tower loop

- The cooling tower fan drives air across an open flow of the hot condenser water, transferring the heat to the outdoors.

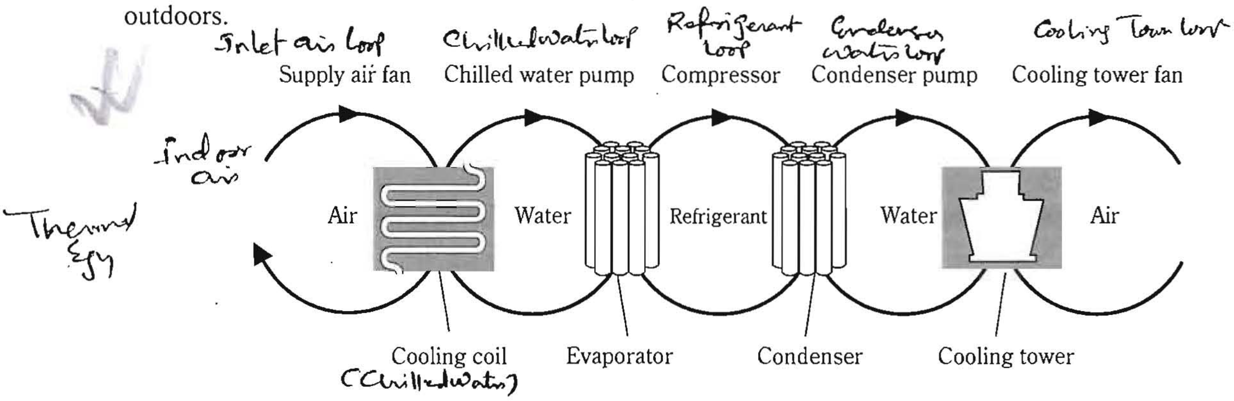


Fig. 4.2 Heat transfer loops in refrigeration system

4.1.1 Air-Conditioning System

Depending on applications, there are several options / combinations, which are available for use as given below:

- Air Conditioning (for comfort / machine)
- Split air conditioners
- Fan coil units in a larger system
- Air handling units in a larger system

4.1.2 Refrigeration Systems (for processes)

- Small capacity modular units of direct expansion type similar to domestic refrigerators, small capacity refrigeration units.
- Centralised chilled water plants with chilled water as a secondary coolant for temperature range over 50°C typically. They can also be used for ice bank formation.
- Brine plants, which use brines as lower temperature, secondary coolant, for typically sub zero temperature applications, which come as modular unit capacities as well as large centralised plant capacities.
- The plant capacities upto 50 TR are usually considered as small capacity, 50 – 250 TR as medium capacity and over 250 TR as large capacity units. Small 50 TR Medium 50 – 250 TR Large > 250 TR
- A large industry may have a bank of such units, often with common chilled water pumps, condenser water pumps, cooling towers, as an off site utility. TR = Rate at which heat is extracted = 3024 K Cal / hr.

The same industry may also have two or three levels of refrigeration & air conditioning such as:

- Comfort air conditioning (200 – 250°C)
- Chilled water system (80 – 100°C)
- Brine system (sub-zero applications)
- Two principle types of refrigeration plants found in industrial use are: Vapour Compression Refrigeration (VCR) and Vapour Absorption Refrigeration (VAR). VCR uses mechanical energy as the driving force for refrigeration, while VAR uses thermal energy as the driving force for refrigeration.

4.1.3 Capacity Measurement

The capacity of household refrigerators is measured in litres of volume of the enclosed chamber which is cooled. The capacity of the air conditioning system is measured in terms of TR. The term 1 TR means the rate at which heat is extracted. 1 ton signifies that amount of heat required to melt one ton of ice in 24 hours. This can be derived as given below.

1 Ton = 907 Kg. Please note Ton means 1 metric ton (MT).

BTU = British Thermal unit
latent-heat

The latent heat of Ice = 80 kCal/kg.
Hence the rate of extraction of heat equivalent to 1 TR will be:
(907 x 80)/24 = 3024 kCal/hr = (3024/0.252) BTU per hour = 12000 BTU/hr
In terms of kW, it will be 3.5169988 kW.
Since this is an ideal conversion assuming no losses, the operating efficiency criterion of any HVAC/Refrigeration system will be judged from kW/TR.

$1 TR = \frac{1 \text{ Ton} \times \text{Latent-heat}}{24 \text{ hr.}}$
= 3024 kCal / hr.

4.2 Types of Refrigeration System

The two principle types of refrigeration plants found in industry include:

- Vapour Compression Refrigeration (VCR) and
- Vapour Absorption Refrigeration (VAR)

VCR uses mechanical energy as the driving force for refrigeration, while VAR uses thermal energy as the driving force for refrigeration.

4.2.1 Vapour Compression Refrigeration

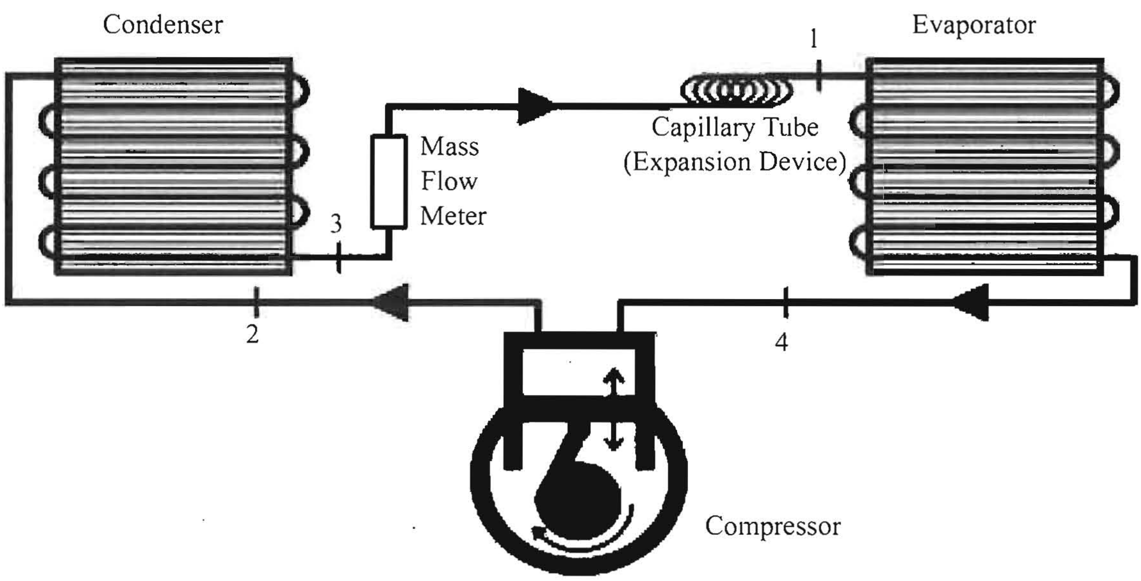
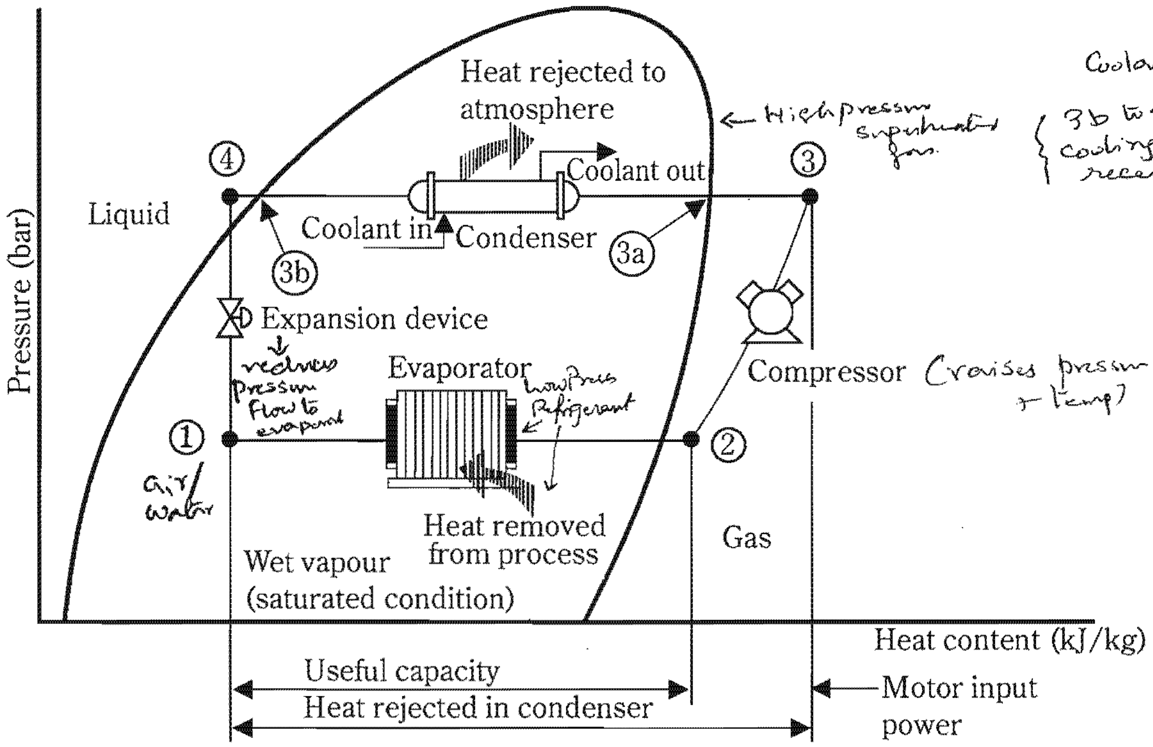


Fig. 4.3 Schematic representation of the vapour compression refrigeration cycle

- Heat flows naturally from a hotter to colder body. In refrigeration system, the opposite must occur i.e. heat flows from a colder to hotter body. This is achieved by using a substance called a refrigerant, which absorbs heat and hence boils or evaporates at a low pressure to form a gas. This gas is then compressed to a higher pressure, such that it transfers the heat it has gained to ambient air or water and turns back (condenses) into a liquid. In this way, heat is absorbed or removed from a low temperature source and transferred to a higher temperature source.
- The refrigeration cycle can be broken down into the following stages (see Figure 4.4):
  - 1–2 - Low pressure liquid refrigerant in the evaporator absorbs heat from its surroundings, usually air, water or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.
  - 2–3 - the superheated vapour enters the compressor where its pressure is raised. There will also be a big increase in temperature because a proportion of the energy input into the compression process is transferred to the refrigerant.
  - 3–4 - the high pressure superheated gas passes from the compressor into the condenser. The initial part of the cooling process (3–3a) desuperheats the gas before it is then turned back into liquid (3a–3b). The cooling

for this process is usually achieved by using air or water. A further reduction in temperature happens in the pipe work and liquid receiver (3b–4) so that the refrigerant liquid is sub-cooled as it enters the expansion device.

- 4–1 - The high-pressure sub-cooled liquid passes through the expansion device, which both reduces its pressure and controls the flow into the evaporator.
- It can be seen that the condenser has to be capable of rejecting the combined heat inputs of the evaporator and the compressor; i.e. (1–2) + (2–3) has to be the same as (3–4). There is no heat loss or gain through the expansion device.



Coolant: air/water
3b to 4 further cooling by liquid receiver

Fig. 4.4 Schematic diagram of a basic vapour compression refrigeration system

→ CFC → damaging ozone layer (100 yrs life time)
HCFC → 2-10% damage (2-25 yrs life time)
HFC → Zero ozone depletion

4.2.2 Alternative Refrigerants for Vapour Compression Systems

- The use of CFCs is now beginning to be phased out due to their damaging impact on the protective ozone layer present in the troposphere around the earth.
- The Montreal Protocol of 1987 and the subsequent Copenhagen agreement of 1992 mandated a reduction in the production of ozone depleting Chlorinated Fluorocarbon (CFC) refrigerants in a phased manner, with an eventual stop to all production by the year 1996.
- In response, the refrigeration industry has developed two alternative refrigerants;
  - based on Hydrochloro Fluorocarbon (HCFC)
  - another based on Hydro Fluorocarbon (HFC)
- The HCFCs have a 2–10% ozone depleting potential as compared to CFCs and also have an atmospheric lifetime between 2–25 years as compared to 100 or more years for CFCs (Brandt, 1992). However, even HCFCs are mandated to be phased out by 2005, and only the chlorine free (zero ozone depletion) HFCs would be acceptable.
- Until now, only one HFC based refrigerant, HFC 134a, has been developed. HCFCs are comparatively simpler to produce and the three refrigerants 22, 123, and 124 have been developed. The use of HFCs and HCFCs results in slightly lower efficiencies as compared to CFCs, but this may change with increasing efforts being made to replace CFCs.

4.2.3 Absorption Refrigeration

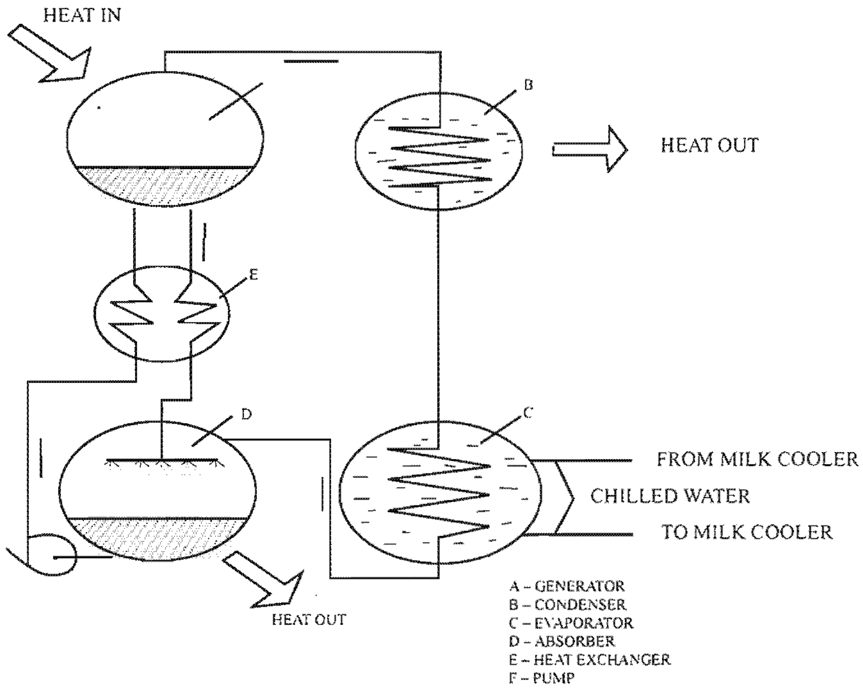


Fig. 4.5 Schematic diagram absorption refrigeration system

The absorption chiller is a machine which produces chilled water by using heat such as steam, hot water, gas, oil etc. Chilled water is produced by the principle that a liquid (refrigerant), which evaporates at low temperature, absorbs heat from the surroundings when it evaporates. Pure water is used as refrigerant and lithium bromide solution is used as the absorbent

Heat for the vapour absorption refrigeration system can be provided by waste heat extracted from process, diesel generator sets, etc. Absorption systems require electricity only to run pumps. Depending on the temperature required and the power cost, it may even be economical to generate heat/steam to operate the absorption system.
A description of the absorption refrigeration concept is given in Table 4.1

Refrigerant	Evaporating Press (kPa)	Condensing Press (kPa)	Pressure Ratio	Vapour Enthalpy (kJ/kg)	COP**Carnot
R 11	20.4	125.5	6.15	155.4	5.03
R 12	182.7	744.6	4.08	116.3	4.70
R 22	295.8	1192.1	4.03	162.8	4.66
R 502	349.6	1308.6	3.74	106.2	4.37
R 717	236.5	1166.5	4.93	103.4	4.78

Table 4.3 Performance of commonly used refrigerants*

* At -15°C Evaporator Temperature, and 30°C Condenser Temperature

COP = Coefficient of Performance $= \dfrac{Temp._{Evap}}{Temp._{cond} - Temp._{Evap}}$

The choice of the refrigerant and the required cooling temperature and load determine the choice of the compressor, as well as the design of the condenser, evaporator, and other auxiliaries. Additional factors, such as ease of maintenance, physical space requirements and the availability of utilities for auxiliaries (water, power, etc.) also influence component selection.

4.4 Types of Compressor and Their Applications

For industrial use, open type systems (compressor and motor as separate units) are normally used, though hermetic systems (motor and compressor in a sealed unit) also find service in some low capacity applications. Hermetic systems are used in refrigerators, air conditioners and other low capacity applications. Industrial applications largely employ reciprocating, centrifugal and more recently, screw compressors, and scroll compressors. Water-cooled systems are more efficient than air-cooled alternatives because the temperatures produced by refrigerant condensation are lower with water than with air.

4.4.1 Centrifugal Compressors

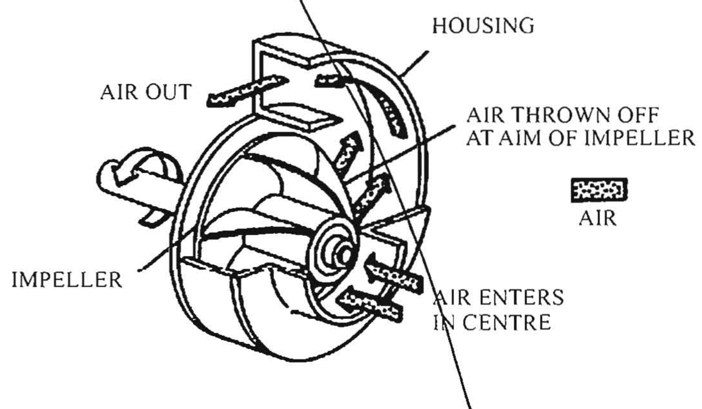


Fig. 4.7 Centrifugal compressor

- Centrifugal compressors are the most efficient types (see Figure 4.7), when they operate near full load. Their efficiency advantage is the greatest in large sizes and they offer considerable economy of scale, so they dominate the market for large chillers. They are able to use a wide range of refrigerants efficiently, so they will probably continue to be the dominant types in large sizes.
- Centrifugal compressors have a single major moving part -an impeller that compresses the refrigerant gas by the centrifugal force. The gas is given kinetic energy as it flows through the impeller. This kinetic energy is not useful in itself, so it must be converted to pressure energy. This is done by allowing the gas to slow down smoothly in a stationary diffuser surrounding the impeller.

compression, compound/cascade operation, direct cooling/secondary coolants) and equipment (type of refrigerant, compressor, evaporator, condenser, etc.) can be undertaken.

4.6 Performance Assessment of Refrigeration Plants

The cooling effect produced is quantified as tons of refrigeration (TR).
1 TR of refrigeration = 3024 kCal/hr heat rejected.
The refrigeration TR is assessed as

$$TR = \frac{Q \times Cp \times (T_i T_o)}{3024}$$ = Chiller tonnage

Specific Heat = Quantity of heat required to raise the temp. of one gram of a substance by 1° Celsius (Unit - Calories or joules per gm / °C)

Where,

Q = mass flow rate of coolant in kg/hr
C_p = coolant specific heat in kCal/kg^{0}C
T_i = inlet temperature of coolant to evaporator (chiller) in ^{0}C
T_0 = outlet temperature of coolant from evaporator (chiller) in ^{0}C
The above TR is also called as chiller tonnage

- Specific power consumption kW/TR is a useful indicator of the performance of a refrigeration system. By measuring the refrigeration duty performed in TR and the kiloWatt inputs, kW/TR is used as a reference energy performance indicator. = Specific power consumption
- In a centralised chilled water system, apart from the compressor unit, power is also consumed by the chilled water (secondary) coolant pump as well as condenser water (for heat rejection to cooling tower) pump and cooling tower fan in the cooling tower. Effectively, the overall energy consumption would be towards:
  - Compressor kW
  - Chilled water pump kW (Secondary coolant)
  - Condenser water pump kW (for heat rejection to cooling tower)
  - Cooling tower fan kW, for induced / forced draft towers

Total input kW

- The specific power consumption for certain TR output would therefore have to include:
  - Compressor kW/TR
  - Chilled water pump kW/TR
  - Condenser water pump kW/TR
  - Cooling tower fan kW/TR

The overall kW/TR is the sum of the above.

The theoretical Coefficient of Performance (Carnot),
COPCarnot -a standard measure of refrigeration efficiency of an ideal refrigeration system- depends on two key system temperatures namely;

- the evaporator temperature Te
- the condenser temperature Tc

With COP being given as:

$$COPCarnot = \frac{Te}{(T_c - T_e)}$$

This expression also indicates that a higher COPCarnot is achieved with higher evaporator temperature and lower condenser temperature. But COPCarnot is only a ratio of temperatures, and hence does not take into account the type of compressor. Hence the COP normally used in the industry is given by

$$COP = \frac{\text{Cooling effect (kW)}}{\text{Power input to compressor (kW)}}$$

Enthalpy – measurement of egy. in a thermodynamic system = System heat (internal egy.) + Volume x Pressure

where, the cooling effect is the difference in enthalpy across the evaporator and expressed as kW. The effect of evaporating and condensing temperatures are given in Figure 4.11 and Figure 4.12 below:

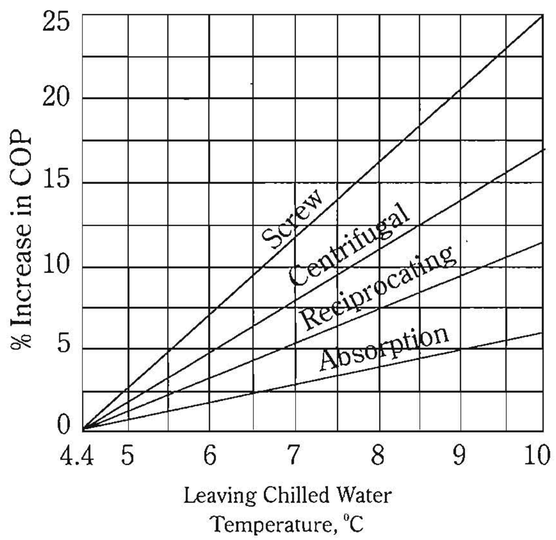


Fig. 4.11 Effect of evaporator temperature on chiller COP

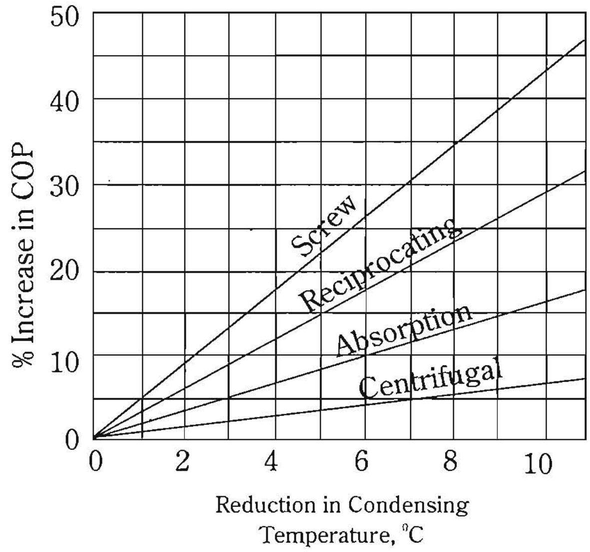


Fig. 4.12 Effect of condensing temperature on chiller COP

- In field performance assessment, accurate instruments for inlet and outlet chilled water temperature and condenser water temperature measurement are required, preferably with a least count of 0.1 C. Flow measurements of chilled water can be made by an ultrasonic flow meter directly or inferred from pump duty parameters. An adequacy check of chilled water is needed often and most units are designed for a typical 0.68 m^3/hr per TR (3gpm/TR) chilled water flow. Condenser water flow measurements can also be made by a non-contact flow meter directly or inferred from pump duty parameters. An adequacy check of condenser water is also often needed, and most units are designed for a typical 0.91 m3/hr per TR (4 gpm/TR) condenser water flow.
- In case of air conditioning units, the airflow at the Fan Coil Units (FCU) or the Air Handling Units (AHU) can be measured with an anemometer. Dry bulb and wet bulb temperatures are measured at the inlet and outlet of the AHU or the FCU and the refrigeration load in TR is assessed as:

$$TR = \frac{Q \times \rho \times (h_{in} - h_{out})}{3024}$$