BEST PRACTICE GUIDE

FOR

IMPROVING ENERGY EFFICIENCY

OF

FOOD MANUFACTURING PLANTS

IN SINGAPORE

March 2016

For:
Energy Efficiency and Conservation Department
National Environment Agency
Singapore

By:

LJ Energy Pte Ltd

Block 194 Pandan Loop
#06-09 Pantech Business Hub
Singapore 128383

TABLE OF CONTENTS

1.0 INTRODUCTION

The National Environment Agency (NEA) of Singapore, commissioned LJ Energy Pte Ltd to conduct an exercise to benchmark the energy efficiency of the food manufacturing plants in Singapore.

As part of the study, this Best Practice Guide has been prepared. The purpose of the Best Practice Guide is to serve as a reference document to help plant owners and operators identify and implement measures to optimise energy efficiency of their systems and equipment.

1.1 ENERGY USE IN FOOD MANUFACTURING SECTOR

Food manufacturing plants are high energy users and energy cost accounts for a significant portion of their operating cost. Therefore, improving energy efficiency has great potential to reduce the operating cost and thereby improve the profitability of food manufacturing plants in Singapore.

Most plants use both thermal and electrical energy. Thermal energy produced using natural gas, diesel and town gas is used in boilers to generate steam and hot water and also in some process applications such as roasting. Electrical energy is used mainly by cooling (chilled water) systems, refrigeration systems, compressed air systems, motors in production equipment and lighting systems. Figure 1.1 below shows the energy consumption profile of food manufacturing plants in Singapore.

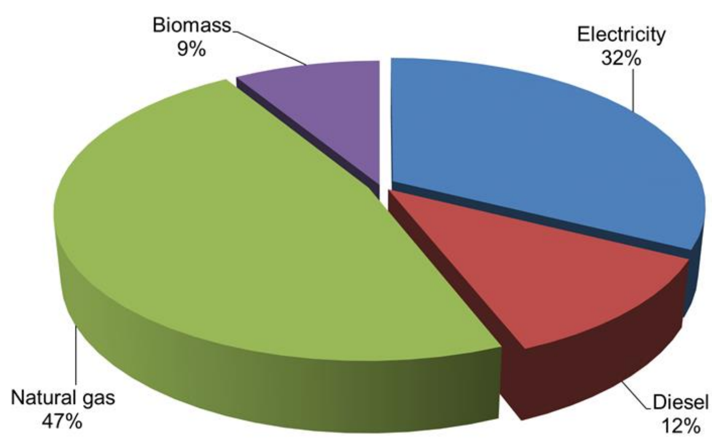


Figure 1.1 Energy consumption profile of food manufacturing plants in Singapore

1.2 OBJECTIVES OF THIS BEST PRACTICE GUIDE

The guide includes best practices to improve the energy efficiency of systems and equipment found in food manufacturing plants in Singapore. Special emphasis is given to the best practices identified during the benchmarking study, as well as those established in other industries but applicable to the food manufacturing sector.

The guide includes best practices that owners or operators are recommended to adopt during various stages of their food manufacturing plants:

Retrofits – Energy saving measures that adopt best available technologies in food manufacturing sector and other industrial sectors in Singapore.

Operations and Maintenance (O&M) – Good O&M practices for optimal and energy efficient operation of systems and equipment.

Design – Energy efficiency considerations to be integrated into the design of new energy consuming systems.

2.0 BOILER SYSTEMS

In food manufacturing plants, boilers are used for heating water or producing steam by combusting fuels (solid, liquid or gaseous). The generated steam is used for cooking or other heating applications. Boilers are either hot water boilers or steam boilers and can be classified as either water tube or fire tube boilers. In fire tube boilers, combustion gas flows through the tubes surrounded by water in one or more shell passes. In water tube boilers, water flows through the tubes surrounded by the combustion gas. In both types of boilers, heat is transferred from the combustion gases to the water. To increase the surface area available for heat transfer as well as for increased resident time, the tubes in boilers are arranged to have a number of passes.

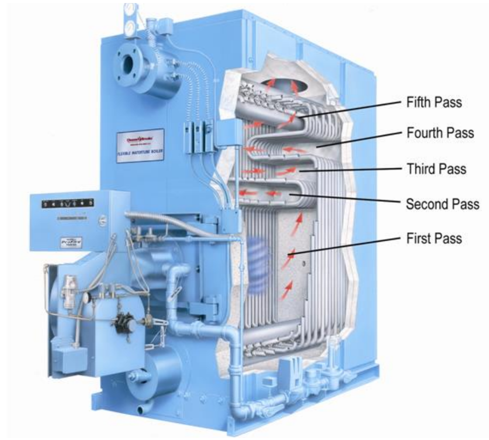


Figure 2.1 Water tube boiler

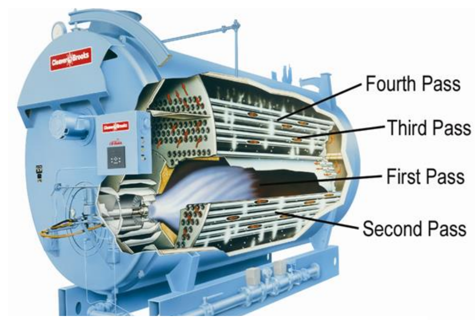


Figure 2.2 Fire tube boiler

In food manufacturing plants, a large percentage of the energy (fuel) is consumed by the boiler plants. As such, significant energy savings can be achieved by optimising boiler systems.

2.1 RETROFITS

The inefficiency in boiler systems is mainly due to the various losses taking place during operation. The main losses in a boiler systems are:

1. Heat loss due to dry flue gas resulting from incorrect air-fuel ratio.
2. Heat loss due to moisture in fuel and combustion air resulting from poor fuel quality and/or incorrect air-fuel ratio.
3. Heat loss due to moisture from the combustion of hydrogen component in fuels.
4. Heat loss due to radiation and unaccounted losses resulting from poor loading and/orpoor insulation of heat carrying parts of a boiler system.
5. Heat loss due to unburnt carbon in fly ash and bottom ash.

Therefore, minimising these losses through appropriate measures will result in improved boiler system efficiency.

Improving Combustion Efficiency

- The bulk of the losses in most boilers is due to the heat carried away by the flue gas through the chimney.
- If too much excess air is provided for combustion, the increased quantity of exhaust gas will lead to extra flue gas losses.
- Similarly, insufficient air for combustion results in wastage of fuel due to incomplete combustion and soot build up resulting in poor boiler efficiency.
- Boiler combustion efficiency, which indicates the ability of the combustion process to burn the fuel completely can be determined using a combustion analyser.
- The drop in combustion efficiency due to excess air is dependent on the type of boiler and amount of excess air.
- Generally, % of excess air requirement depends on the fuel but is usually about 10% (2% oxygen) as shown in Figure 2.3.
- For boilers operating at high excess air-levels, the air-fuel ratio of the combustion burner needs to be tuned. This can be achieved using an oxygen trim system, which can continuously monitor the oxygen level in the flue gas and adjust the air-fuel ratio automatically to maximize combustion efficiency.
- If the amount of excess air is due to the excessive draft created by the stack, a draft control damper could be installed to automatically control the draft by opening or closing the damper.
- If the excess air is caused through the use of old-type burners, they could be replaced with low excess air burners.

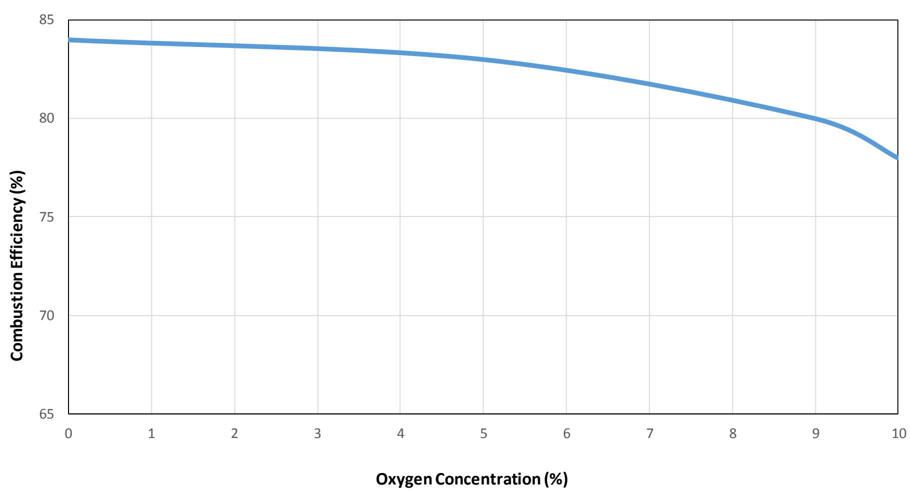
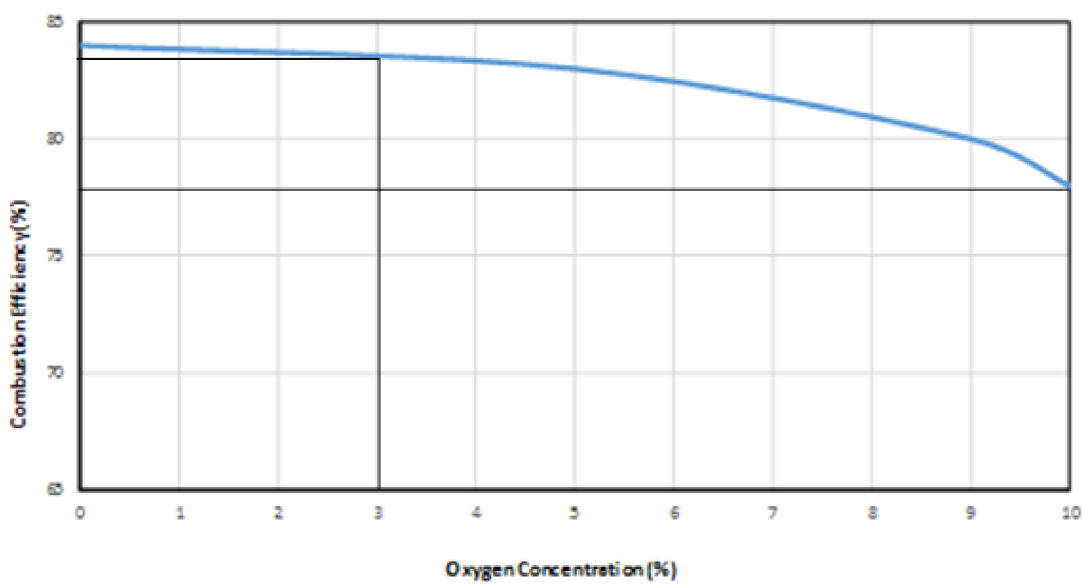


Figure 2.3 Variation in combustion efficiency at different O_2

Illustrative example on combustion efficiency improvement

Flue gas contains 10% oxygen. The improvement in efficiency achievable if the oxygen level in the flue gas can be reduced to 3% is estimated using Figure 2.3 as follows:

From the chart, if O_2 concentration in the flue gas is reduced from 10% to 3%, the combustion efficiency will improve from 78% to 83.5% (a 5.5% improvement).



Optimizing Steam Pressure

- Boilers have a maximum pressure rating, based on their construction, as well as a minimum value to prevent water carryover.
- Usually, the actual operating pressure is set based on the requirements of end users while ensuring it is within the specified maximum and minimum pressures by the boiler manufacturer.
- Since boiler efficiency depends on operating pressure, if the operating pressure is set much higher than required, energy savings can be achieved by reducing it to match the actual requirements.
- When the boiler pressure is reduced, more latent heat is available for heating applications (the higher the pressure, the lower the latent heat as shown in Figure 2.4 below), as a result of which, less steam is required for a particular heating load.
- Lower boiler pressure also results in less fuel energy being consumed to raise the heat content of feedwater to the saturation point.
- In addition, to improving boiler efficiency, reducing steam pressure helps to reduce steam leaks, distribution losses through reduced surface

temperature, as well as reduction of flash steam from vents of condensate recovery systems.

- If the steam pressure requirement varies at different time of the day, a standalone controller should be installed to change the pressure set-point of the boiler. In the controller, pressure at different time of the day could be programmed by the user. The standalone controller should be interlocked with the burner system such that the firing rate will be adjusted based on the pre-set pressure.

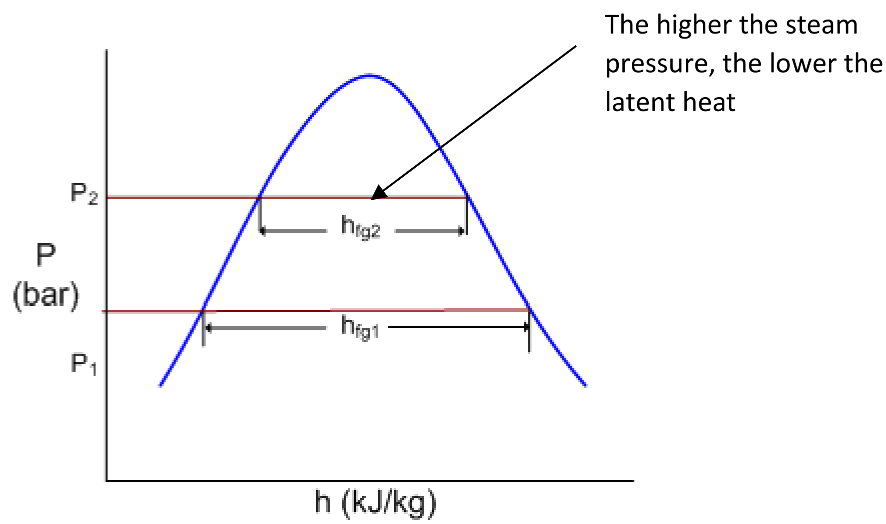


Figure 2.4 Pressure (P) - enthalpy (h) diagram showing the latent heat of steam

Type of Fuel

- Many modern boilers come with fuel switching capability, which can be operated on different fuels like natural gas or fuel oil.
- Generally, the combustion efficiency of gaseous fuels like natural gas is better than that of liquid fuels. In addition, use of natural gas produces less carbon emissions compared to other liquid fuels such as diesel. Therefore, where natural gas is available, it should be used as the fuel for the boiler.
- In some industrial plants, by-products from the process which can be in gaseous, liquid or solid form can be considered for use as the input fuel for boilers.
- Since fuel cost makes up the bulk of the cost of operating a boiler system, switching between fuels based on combustion efficiency and tariff can help to reduce energy cost.

Optimising Operation of Auxiliary Equipment

- In a boiler system, auxiliary equipment such as feedwater pumps, draft fans, hot water circulating pumps and condensate pumps also consume a significant amount of energy.
- Therefore, optimization of the operation of these auxiliary equipment will result in significant energy savings.
- If additional equipment are operated for extra reliability or to match certain boiler load conditions, some of these equipment can be switched off either manually or automatically, based on a set operating conditions.
- In large boiler systems, if multiple boilers are served by constant speed pumps (Figure 2.5(a)) operating purely based on water level in the boilers, the pumps can be installed with VSDs (Figure 2.5(b)) to modulate the flow based on a pre-set pressure in the feedwater header pipe.

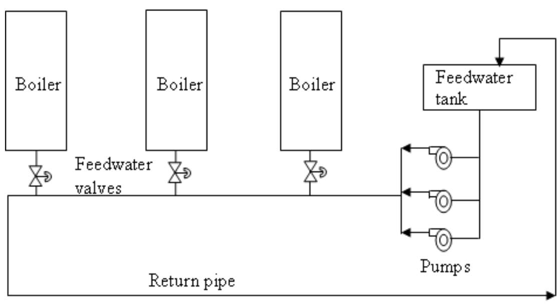


Figure 2.5(a) Conventional design for feedwater pumps

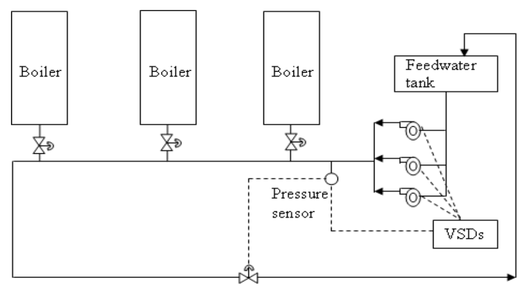


Figure 2.5(b) Optimised design for feedwater pumps

- Boiler fans are used to create the draft necessary for combustion and to carry the flue gases through the boiler.
- These fans normally operate at constant speed with the air flow controlled using a damper to match the boiler load. As a result, fan power consumption remains constant even when the boilers are operated at part load.
- If variable speed fans are used for this application, based on the affinity law [fan power $\propto$ (air flow rate)^3], there will be a significant reduction in fan energy consumption durng the part load operation of the boiler.

Illustrative example on optimization of auxiliary equipment:

The operating load and associated fan power consumption of a boiler with damper and VSD controls are tabulated below. The estimated total savings (using affinity law) is 296.8 kWh/day.

Table 2.1 Operating load and fan power consumption

Boiler loading *A*	*Operating hours a day* *B*	*Fan motor power with damper (kW)* *C*	*Fan motor power with VSD (kW)* $D = A^3 x 22$	*Power saving (kW)* *E=C-D*	*Energy savings (kWh/day)* *F=B x E*
100%	*2*	*22*	*22*	*0*	*0*
80%	*4*	*21*	*11*	*10*	*40*
60%	*10*	*19*	*5*	*14*	*140*
40%	*8*	*16*	*1.4*	*14.6*	*116.8*
				Total	*296.8*

Minimising Standby Losses

- Standby losses occur when a boiler is not firing and the hot surfaces inside the boiler lose heat to colder air circulating inside it.
- This loss is mainly due to natural convection and purging.
- Natural convection loss is due to the heating of the air in contact with the hot boiler surface making it lighter causing it to move up the stack and circulating cold air through the boiler.
- Purging losses occurs when the boiler combustion space is purged by the fan before firing the burners to ensure that there is only air inside the boiler.
- The standby losses due to natural convection can be avoided by installing dampers to prevent the circulation of air when the boiler is not being fired.
- Losses due to purging can be reduced by minimizing the on-off cycle of the burner system.

Minimising Conduction and Radiation Losses

- Boilers, auxiliary equipment and distribution piping systems are much hotter than the surrounding areas. Therefore, they lose heat at a faster rate through conduction, convection and radiation. The amount of heat loss depends on the surface temperature, which in turn depends on the insulation.

- Therefore, to minimise heat losses, the surface temperature should be maintained such that the difference (ΔT) between the surface and ambient temperatures is as low as possible.
- A surface temperature of about 40°C is adequate as the ΔT at this temperature will be about 5 to 10 °C. A surface temperature below 40°C is not economically feasible.

Boiler Loading and Controls

- In installations where multiple boilers of different capacities are available, automatic controls should be used to monitor the steam demand. A boiler should be selected based on the highest loading during operation.
- Where the total operating boiler capacity is much more than the demand, switching-off one of the boilers can be considered.

Heat Recovery from Flue Gas

- A significant amount of heat energy is lost through flue gas as all the heat produced by the burner cannot be transferred to the water in the boiler.
- Therefore, recovering part of the heat from flue gas can help to improve boiler efficiency.
- The heat from the flue gas can be recovered by using a heat exchanger called economizer installed after the boiler as shown in Figure 2.6.

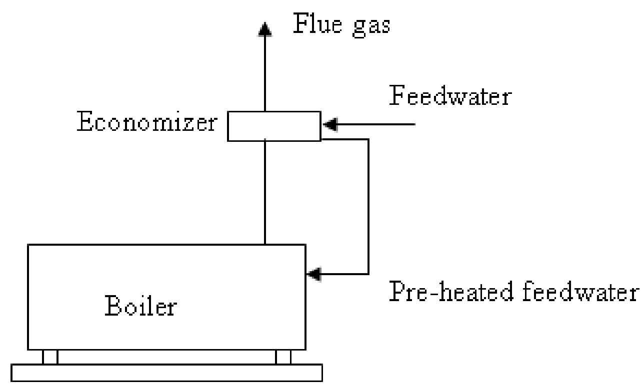


Figure 2.6 Arrangement of a typical economizer for heat recovery

- The recovered heat can be used for preheating of boiler feedwater, combustion air or for other applications.
- The amount of heat recovered is directly proportional to the ΔT (temperature difference) of the boiler flue gas and the fluid to be heated using the recovered heat.
- During the heat recovery process, to prevent acid formation and possible corrosion resulting from it, the flue gas should not be cooled below the

recommended temperature (recommended temperature depends on the fuel types).

- The acid formation depends on the acid dewpoint which in turn depends on the sulfur content of the fuel. Typical values of acid dew point for commonly used fuels are given in Table 2.2.
- The heat recovery from flue gas will be economically feasible only for a flue gas ΔT of at least 25 to 30°C.
- While implementing this heat recovery measure, it is important to check the existing fan and pump capacities. The introduction of the economizer will cause additional pressure drop that requires higher fan and pump capacities.

Table 2.2 Acid dew point for common fuel types

Fuel	Acid dewpoint temperature (°C)	Allowable exit stack temperature (°C)
Natural gas	66	120
Light Oil	82	135
Low sulfur oil	93	150
High sulfur oil	110	160

Illustrative example on heat recovery from flue gas:

A 4000 kg/hr (4 Ton/hr) boiler using approximately 167 L/hr of low sulfur oil operates with a flue gas temperature of 190°C. The energy savings possible if an economizer is installed to preheat feedwater at 90°C is estimated as follows:

For low sulfur oil, the ΔT possible for the flue gas is 40°C (190 °C – 150 °C)
The amount of fuel used
= 167 l/hr
= 150 kg/hr (taking the density to be 900 kg/m³)

Taking air to fuel ratio of 15:1, the amount of combustion air
= 15 x 150
= 2250 kg/hr

Total mass of flue gas
= (2250 + 150)
= 2400 kg/hr
= 0.67 kg/s

Heat recovered = $m \times C_p \times \Delta T$
= 0.67 x 1.1 x 40 = 29 kW (kJ/s)
= 104.4 MJ/hr
(taking specific heat capacity of flue gas, C_p*, to be 1.1 kJ/kg.K)*

If the heat content of the fuel is 40 MJ/kg, the reduction in fuel usage
= 104.4 / 40
= 2.6 kg/hr (2.9 L/hr)

Automatic Blowdown Control and Heat Recovery

- Blowdown is part of the water treatment process to remove solids and sludge from the boiler.
- Blowdown involves discharge of water at steam temperature, which has to be replaced with an equal amount of cold water.
- Often, blowdown is carried out periodically by discharging some water from the boiler.
- If an automatic blowdown system is installed, a continuous controlled discharge can be achieved to maintain a pre-determined TDS (total dissolved solids) or conductivity level. Such a system is normally able to maintain a higher TDS level resulting in lower water and heat losses from blowdown.
- Heat contained in the blowdown water can be recovered by installing heat recovery systems as shown in Figure 2.7.
- In addition, a flash steam recovery vessel can be installed to recover the flash steam generated by the blowdown.

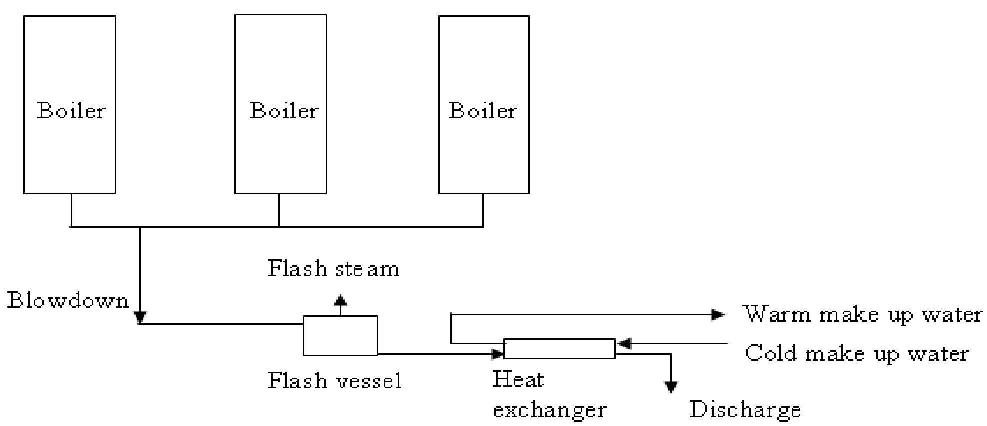


Figure 2.7 Arrangement of a typical economizer for heat recovery

Boiler Operating Configuration

- The efficiency of boilers varies based on load conditions and depends on how well the burner system can match load variations.
- Burner systems in boilers can either be single stage, two-stage or modulating type.
- Single-stage burners have only one output setting and vary burner output through on and off cycle leading to high standby losses.

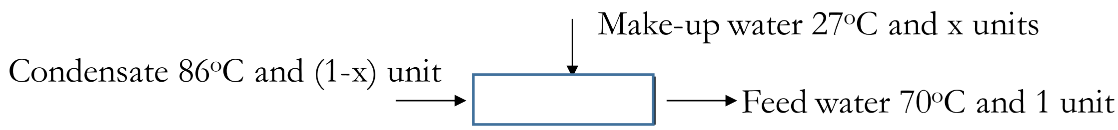
- In a modulating type burner, the heat output is modulated between a set of maximum and minimum settings to match the load requirements (minimum output as low as 25% of the maximum output).
- In order to minimize the heat input for a given steam load, a sequencing programme can be used to optimise the boiler operating configuration based on the prevailing load.

Condensate Recovery

- In most steam systems, after using the latent heat content of the steam, the resulting condensate still contains significant amount of heat. Therefore, recovering and reusing the condensate as feedwater will result in significant fuel energy savings.
- In addition to fuel energy savings, the condensate recovery and reuse helps to reduce water consumption (water cost), water treatment cost and blowdown.
- In some applications involving direct use of steam, the condensate recovery is not possible because of possible contamination. In such situations, the heat content of the condensate can be recovered using a heat exchanger.
- The amount of condensate recovered can be quantified by knowing feedwater, condensate and makeup water temperatures as illustrated in the example below.

Illustrative example on condensate recovery:

Feed water is provided to a boiler at 70°C from the feedwater tank. The temperature of condensate water returning to the tank is 86°C, while the temperature of makeup water is 27°C. The amount of condensate water recovered can be estimated as follows:



Performing a heat balance yields, $27x + (1-x)86 = 70$

$x = 0.27$ *= 27% of makeup water*

Therefore, 73% of condensate recovered.

Steam Traps

- Steam traps are used in steam systems to remove condensate and non-condensable gases.
- There are different types of steam traps like thermostatic, mechanical or thermodynamic used in boiler systems.
- The operation of steam traps is important because if they fail to operate correctly, significant amount of energy loss will result due to the inadvertent passing of steam through them.
- Therefore, the defective steam traps need to be identified by installing sight glasses (for visual inspection of leaks) or using ultrasonic leak detectors.
- Further, steam traps should be periodically inspected to ensure that they are in good working condition.
- In addition, the correct types of steam trap should be selected for each application.

Minimising Steam Leakage

- Steam leakage in a boiler system occurs from pipes, flanges, valves, connections, defective steam traps and process equipment.
- The steam leakage can be substantial in some steam distribution systems.
- Therefore, identifying steam leaks and eliminating or minimizing such leaks are important and will result in significant energy savings.

Minimising Feedwater Tank Heat Losses

- In boiler systems, feedwater tank provides a reservoir of recovered condensate and fresh makeup water for the boilers.
- The feedwater tank also gives a good indication of the system's health. For example, excessive feedwater temperature may indicate that some steam traps may be passing live steam, while a high makeup water flow may indicate that some condensate is not being returned to the tank.
- Feedwater is normally hot due to the recovered condensate and recovery of heat from other sources.
- Therefore, it is important to minimize heat losses from the tank through proper insulation as well as covering up the top of the tank.

Maintaining Heat Transfer Surfaces in Boilers

- Fouling and scaling in boilers are mainly due to inadequate water treatment. Similarly, soot buildup results from incomplete combustion.

- Fouling and scaling, as well as soot make the heat transfer ineffective resulting in increased thermal resistance that causes the boiler to operate inefficiently.
- Elevated flue gas temperature in a boiler is an indication of increased thermal resistance to heat transfer.
- Typically, 1 to 1.5 mm soot buildup on the fire side can increase fuel consumption by about 3 to 8 percent. Similarly, for the water side, scale buildup of 1 to 1.5 mm can result in an extra fuel consumption of about 4 to 9 percent.
- To avoid soot buildup, the fire-side heat transfer surface should be cleaned periodically, while on the water side, scaling and fouling should be removed.
- For boilers using gas and light oil, it is generally sufficient to clean fire-side heat transfer surfaces once a year.
- For boilers using heavy oil, the stack flue gas temperature is a good indication on whether cleaning is required.
- In addition, the TDS level should be maintained at the value recommended by the boiler manufacturer.

Isolating Off-line Boilers

- In some situations, one boiler is used to meet the load requirement while others are kept on standby mode.
- To prevent heat loss taking place from the standby boilers, dampers can be installed to automatically isolate them when they are not in operation.

Use of Decentralized Boiler System

- In bigger boiler installations, steam is usually generated centrally and distributed to various end users through very large piping network resulting in significant amount of distribution heat losses.
- The distribution heat losses can be minimized through the use of decentralized package boilers near the end users.
- Some package boilers can be operated at lower steam pressures resulting in further energy savings.

Boiler Replacement

- If a boiler is operated at low loading (below 40% of its capacity), radiation and convection losses from the boiler can form a significant percentage of the heat output resulting in poor boiler efficiency.
- In such situations, it may be financially justifiable to replace the boiler with or add a new small capacity boiler.

- Depending on load requirements, heat pumps can also be considered either to replace the boiler or to reduce the existing boiler load.

2.2 OPERATIONS AND MAINTENANCE MEASURES

- Identify and repair steam, water and fuel leaks on a regular basis.
- Check the surface temperature of the boiler, steam pipes and heating devices to ensure adequacy of insulation.
- Check for proper functioning of gauges, controls and instruments and repair them where necessary.
- Ensure that the operating pressure does not exceed requirements.
- Monitor the make-up water usage to ensure that the condensate recovery system is functioning effectively.
- Regularly check the combustion air-to-fuel ratio and adjust where necessary.
- Check TDS level of boiler water to ensure TDS level is maintained at the recommended value.
- Trend boiler parameters such as amount of fuel used, steam generated, steam pressure and temperature continuously to evaluate the boiler performance, e.g. thermal and combustion efficiencies.
- Review the efficiencies determined from the recorded parameters and schedule preventive maintenance accordingly.

2.3 DESIGN CONSIDERATIONS

- Size and select boiler capacity and operating pressure to match load requirements.
- Design piping system to minimize pressure losses and ensure adequate trapping points for condensate removal.
- Provide adequate insulation for boilers, piping and equipment utilizing steam.
- Select steam traps (type and sizing) to match requirements.
- Incorporate a condensate recovery system to maximise condensate recovery.
- Install automatic blowdown system with heat recovery system.
- Install blowdown and flash steam recovery system to recover heat and flash steam.
- Install oxygen trim system to monitor and adjust the combustion air-to-fuel ratio.
- Install economiser to recover heat from flue gas.
- Monitor condensate recovery rate by installing flow meter to verify whether there is any reduction in the amount of condensate recovered.
- Other parameters like thermal conductivity and total dissolved solid (TDS) level should also be monitored.

3.0 CHILLED WATER SYSTEMS

In food manufacturing plants, chilled water systems are used for providing process and space cooling. The key components of a chilled water system are chillers, chilled water pumps, condenser water pumps and cooling towers as shown in Figure 3.1.

A chilled fluid, which is normally water or a glycol solution (in low temperature systems), is cooled by a chiller and distributed to various loads using chilled water pumps. Once the chilled fluid absorbs heat from the load, it is then circulated back to the chiller.

The heat absorbed by the chiller is rejected to the environment through the condenser which can be water-cooled or air-cooled. In water-cooled chilled water systems, water from cooling towers is pumped to the condenser to remove heat using condenser water pumps.

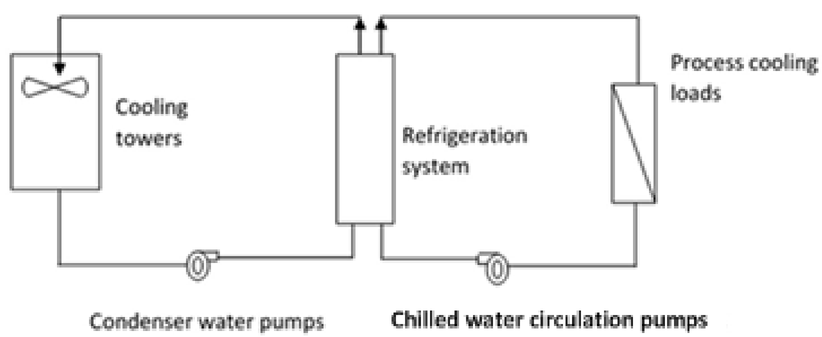


Figure 3.1 Schematic diagram of a typical water-cooled chilled water system

3.1 CHILLERS

Most chillers operate based on the vapour compression cycle, which consists of four mechanical components through which the refrigerant is circulated in a closed loop as shown in Figure 3.2.

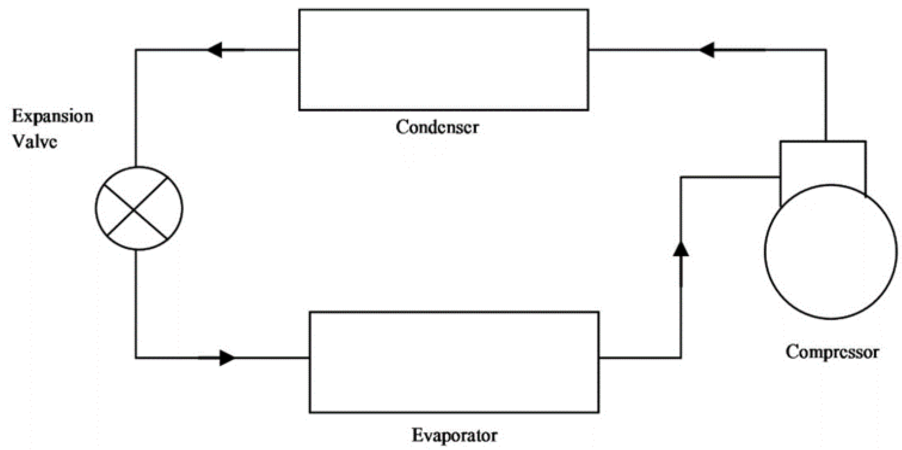


Figure 3.2 Vapour compression cycle

The refrigerant enters the compressor as low pressure vapour and is compressed to high pressure vapour. The high pressure vapour then flows to the condenser which is a heat exchanger where heat is rejected from the refrigerant and the refrigerant condenses from high pressure vapour to high pressure liquid. Next, the high pressure liquid refrigerant flows through the expansion valve to the evaporator and becomes low pressure liquid refrigerant. In the evaporator, the liquid refrigerant evaporates at low temperature by absorbing heat from the surroundings. This is the cooling effect of the refrigeration system. The refrigerant then becomes low pressure vapour and enters the compressor and the cycle is repeated.

The ideal (without any losses) vapour compression cycle can be represented on a pressure – enthalpy (p-h) diagram as shown in Figure 3.3.

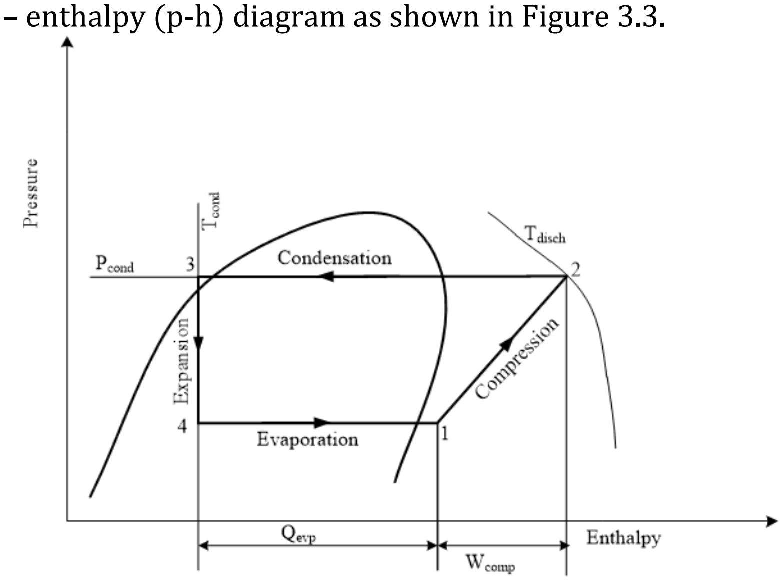


Figure 3.3 Pressure-enthalpy diagram for an ideal vapour compression cycle

Water-cooled chilled water systems are superior in performance in comparison to their air-cooled counterparts.

Chillers are classified according to the type of compressor used for compressing the refrigerant. The main types of compressors used are reciprocating, scroll, screw and centrifugal.

RETROFITS

The energy consumption in a chiller is mainly by the compressor motor and is dependent on the mass of refrigerant to be compressed, the compressor lift (difference between the evaporator and compressor pressures) and design characteristics of the chilled water system.

Therefore, savings in energy consumption of the chiller can be achieved by:

1. reducing the compressor load (mass of refrigerant that needs to be compressed),
2. reducing the compressor lift, and
3. optimising the operation based on compressor characteristics.

Increasing Supply Temperature

- The evaporator pressure can be maximised by operating the system to produce chilled fluid at the highest temperature acceptable for the heat removal process. To achieve this objective, it would also be necessary to ensure that circulation piping system is adequately insulated to prevent unnecessary heat gain by the chilled fluid.
- The efficiency of chillers generally improves by about 3% for every 1^{o}C increase in the set-point of the chilled fluid supply temperature. The improvement in efficiency (reduction in kW/RT) at different operating temperatures for a typical chiller is shown in Figure 3.4.
- In manufacturing processes that require the chilled fluid to be at vastly different temperatures, instead of operating one system at a particular temperature to suit the lowest value required, two or more systems can be operated at different temperatures as illustrated in Figure 3.5.

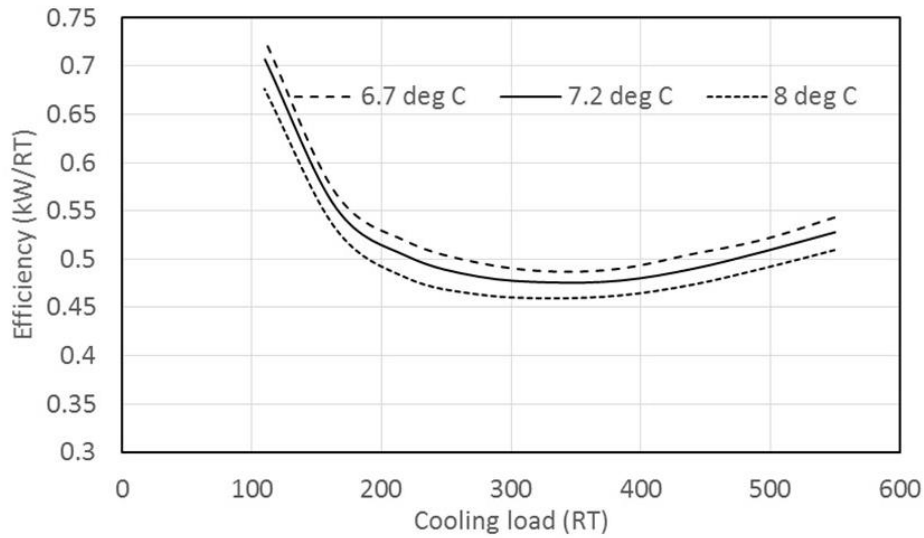


Figure 3.4 Chiller efficiency vs operating temperature for a 550 RT capacity chiller

Illustrative example on chilled water reset (increased supply temperature):

A cooling load of 500 RT is met by chilled water supplied at 5°C with a chilled water system operating efficiency of 0.66 kW/RT. If the cooling load can be satisfied with chilled water at 7°C, the resulting energy savings can be estimated as follows:

Present chiller efficiency = 0.66 kW/RT

Increase in chilled water supply temperature by 2°C will result in an improvement in chiller efficiency by about 6%.

Therefore, the expected chiller efficiency	*= 0.66 x (1 – 0.06)*
	= 0.62 kW/RT
Chiller power savings	*= 500 x (0.66 – 0.62)*
	= 20 kW
Annual operating hours	*= 8,760 hrs.*
Annual energy savings	*= 20 x 8,760*
	= 175,200 kWh

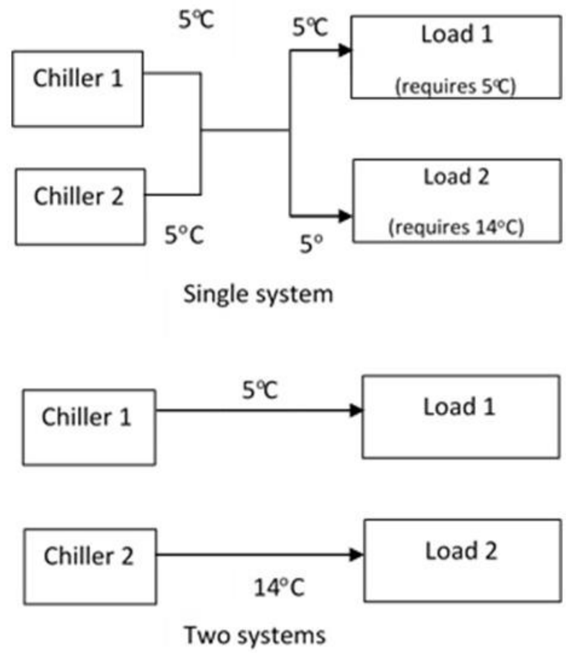


Figure 3.5 Single vs multiple cooling systems

Reducing Condenser Water Temperature

- Another way of reducing compressor lift in a chiller is by lowering the condenser pressure. This can be achieved by supplying condenser water at the lowest possible temperature.
- A decrease in condenser pressure will reduce the compressor lift and result in chiller efficiency improvement. The savings achievable is similar to that for the case of increasing the supply temperature of the chilled fluid.
- The most common condenser cooling fluid is water which is circulated through a cooling tower system to reject heat to the atmosphere. Since cooling towers remove heat mainly by evaporative cooling, the lowest achievable water temperature is the wet-bulb temperature of air. In order for the water to be cooled to the wet-bulb temperature, the cooling tower needs to be very large. Therefore, for economic reasons, cooling tower systems are designed to provide water at about 2 °C higher than the wet-bulb temperature.
- Therefore, to ensure the lowest possible temperature of condenser water, the respective cooling towers should be sized based on actual operating conditions such as the flow rate of water and conditions of ambient air.
- The flow rate of condenser water also affects the condenser pressure. Since the condenser water removes heat from the condenser by sensible

cooling (cooling without phase change), the quantity of heat removed is dependent on the flow rate and the temperature difference of the condenser water leaving and entering the condenser.

- For a chiller operating at constant heat rejection rate and condenser water suppy temperature, when the mass flow rate reduces, the temperature of the water at the exit of the condenser increases (constant specific heat capacity of water). When the temperature of the condenser water at the discharge of the condenser increases, the condenser temperature and pressure increase thereby leading to higher compressor lift.
- For example, if a particular condenser is designed to operate with cooling water entering at 25^{o}C and leaving the condenser at 30^{o}C (ΔT of 5^{o}C), if the flow rate is reduced to half the design value, the ΔT will become 10^{o}C and the temperature of condenser water leaving the condenser will increase to 35^{o}C.

Condition of Condenser

- Another factor that affects the condenser pressure (and therefore the compressor lift) is the heat transfer rate from the refrigerant in the condenser water.
- The heat transfer rate for a particular condenser is dependent on its design. However, the heat transfer rate can be reduced during operation due to scaling and fouling of the condensers. This results in increased resistance to heat flow.
- Therefore, condenser using water from cooling towers which are prone to scaling and fouling should be well maintained.
- Since it is not practical to manually clean condensers on a regular basis, automatic condenser tube cleaning systems should be used. The two main types of condenser cleaning systems are brush type and ball type.

Figure 3.6 shows a typical system using sponge balls for cleaning tubes. These sponge balls have a slightly larger diameter than the inside bore of the condenser tubes. The balls are circulated through the tubes at regular intervals. As the balls travel through the tubes, scale and fouling deposits are removed. After passing through the tubes, the balls are collected by a strainer. Thereafter, the balls are returned to the cleaning section for automatic cleaning and are injected back again after a pre-set time.

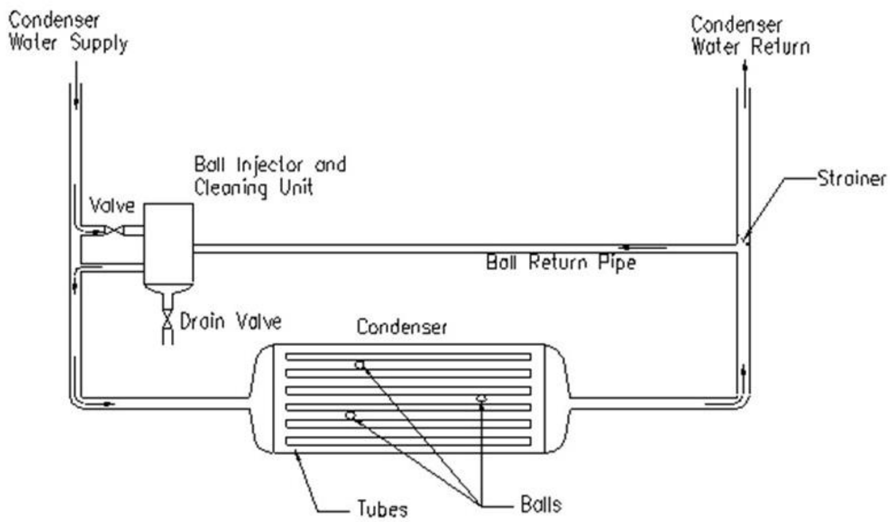


Figure 3.6 Arrangement of a typical ball type condenser cleaning system

Use of Water-Cooled Chillers

Figure 3.7 Water-cooled chiller

- Water-cooled chillers operate at a lower condensing pressure than air-cooled chillers. The lower condensing pressure is due to the rejection of heat to condenser water which is first cooled to a temperature a few degrees Celsius above the wet-bulb temperature of the ambient air (by the cooling towers).
- In air-cooled chillers, heat is directly rejected to the ambient air and the heat transfer is dependent on the dry-bulb temperature of the air. Further, the heat transfer in the water-cooled shell and tube heat exchangers is more effective than in finned type air-cooled condensers.
- The lower condensing pressure leads to a lower pressure differential between the evaporator and condenser which results in lower power consumption by the compressor. Therefore, water-cooled chillers are far more efficient than air-cooled chillers.
- Although water-cooled chillers are more efficient, they need cooling towers, condenser water pumps and a constant supply of water (to make-up for water evaporation at the cooling tower).

Illustrative example on water-cooled chiller:

A cooling load of 500 RT is met by an air-cooled chiller having an operating efficiency of 1.2 kW/RT. If it is replaced with a water-cooled chiller, the resulting energy savings can be estimated as follows:

Air-cooled chiller efficiency = 1.2 kW/RT

Water-cooled chiller efficiency = 0.52 kW/RT

Expected efficiency of the cooling tower fan and condenser water pump
= 0.08 kW/RT

Estimated improvement in chilled water system efficiency
= 1.2 – (0.52 + 0.08)
= 0.6 kW/RT

Chilled water system power savings	*= 500 x 0.6* *= 300 kW*
Annual operating hours	*= 8,760 hrs.*
Annual energy savings	*= 300 x 8,760* *= 2,628,000 kWh*

(there will be additional cost for water usage)

Use of Alternative Cooling Systems

- If a particular process does not require rapid cooling or a low temperature cooling medium, water from a cooling tower or a natural heat sink such as water from the sea can be used for heat removal, instead of chilled water or low temperature liquid that requires more energy intensive refrigeration systems to produce.

Illustrative example on alternative cooling system:

A cooling load of 300 RT is supplied by a chilled water system having an operating efficiency of 0.8 kW/RT. If this cooling can be provided by a cooling tower system, the resulting energy savings can be estimated as follows:

Chilled water system efficiency = 0.8 kW/RT

Expected efficiency of the cooling tower fan and condenser water pump
= 0.08 kW/RT

Estimated improvement in system efficiency	*= 0.8 – 0.08* *= 0.72kW/RT*
Chilled water system power savings	*= 300 x 0.72* *= 216 kW*
Annual operating hours	*= 8,760 hrs.*
Annual energy savings	*= 216 x 8,760* *= 1,892,160 kWh*

Improving Insulation

- The utility building where the chillers are installed is often several hundred metres away from the areas that require cooling. Therefore, the chilled fluid has to be transported over long distances and significant heat gain can result due to poor or inadequate insulation of the distribution piping.
- Similarly, unnecessary heat gain can also take place if the vessels or heat exchangers are not adequately insulated.
- Care should be taken not to only insulate the main body of the equipment, but also the fittings such as valves and flanges.

Isolating Loads

- A particular cooling system often serves numerous heat exchangers serving various processes. Generally, these processes are operated in batches and require cooling only at specific times.
- However, in most cases, the cooling fluid is allowed to flow through the heat exchanger even when heat removal is not necessary. This can lead to higher cooling load for the chillers due to heat gain from piping and heat exchangers.
- Therefore, isolation valves, ideally inter-locked with the respective heat exchangers, should be used to isolate the flow of the cooling fluid when heat removal is not required by a particular equipment.

Chiller Part-Load Characteristics

- The operating efficiency of chillers also depends on compressor characteristics and controls resulting in better efficiency when operating under particular load conditions.
- Therefore, for optimum energy efficiency, the most suitable chiller for a particular operation should be selected based on the cooling load profile.

Figure 3.7 shows how the operating efficiency of three different 300 RT capacity chillers vary with loading. The chiller operating with a constant speed centrifugal compressor has a good operating efficiency (low kW/RT) when the loading is above 80%. The chiller using a variable speed compressors have a lower kW/RT at loads below about 80% loading. Further, the operating efficiency of the chiller with multiple variable speed centrifugal compressors is best when loading is lower than about 50%.

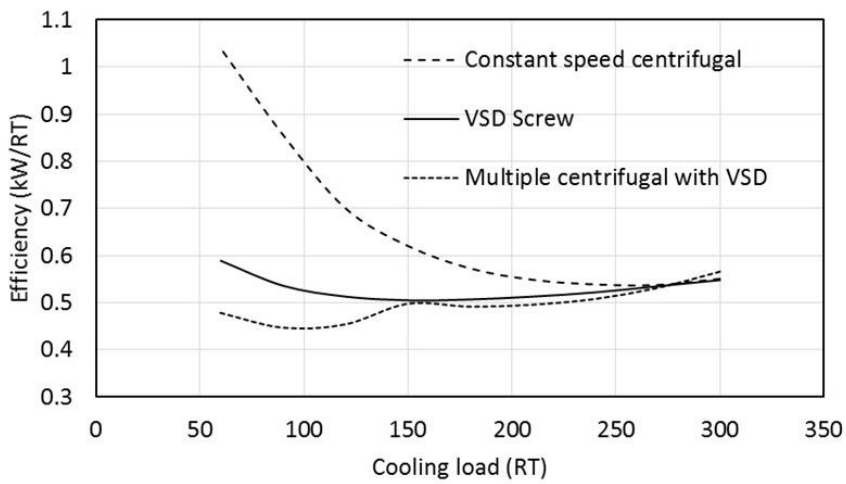


Figure 3.8 Part—load operating efficiency for three different 300 RT capacity chillers

Illustrative example on chiller part-load :

The building load profile and the efficiency data for the existing and new chiller are given below. The annual energy savings resulting from replacement of the existing chiller with the new chiller can be quantified as shown below in the table:

Table 3.1 Building cooling load profile and exsting chiller efficiency

Time	Building cooling load (RT)	Existing Chiller efficiency (kW/RT)
8 am - 10 am	400	0.62
10 – 12 noon	375	0.63
12 – 2 pm	450	0.61
2 – 6pm	400	0.62

Table 3.2 New chiller part-load efficiency

Chiller load (RT)	Chiller efficiency (kW/RT)
500	0.56
450	0.565
400	0.57
350	0.58
300	0.6

Table 3.3 Energy saving calculation

Operating hours (h) A	Building cooling load (RT) B	Existing Chiller efficiency (kW/RT) C	Proposed Chiller efficiency (kW/RT) D	Energy savings (kWh)/day B x (C – D) x A
6	400	0.62	0.57	120
6	375	0.63	0.575	123.75
6	450	0.61	0.565	121.5
6	400	0.62	0.57	240
Total daily energy savings				605.25 kWh
Total annual energy savings (365 days operation)				**220,916 kWh**

Sizing of Chillers

- In many plants, multiple chillers of relatively low cooling capacity are operated simultaneously to provide the cooling requirements of various systems.
- This results in lower loading of the chillers which results in poor efficiency.
- Also, low capacity chillers have relatively lower rated efficiency.
- Therefore, such multiple chillers can be replaced with a centralized system with higher capacity chillers that have higher rated efficiency. The centralized chilled water system can be operated at higher efficiency due to better loading (due to load diversity).

- In addition, the chillers should be sequenced to ensure that the most optimum set of chillers are operated to meet a particular cooling load.

Illustrative example on chiller sizing:

Three 50 RT and one 150 RT capacity chillers are operated to meet a cooling load of 300 RT. If one chiller of 300 RT capacity is used instead of multiple chillers of low capapcity, the resulting annual energy savings can be quantified as follows:

Present operating efficiency of 50 RT chillers = 0.8 kW/RT
Present operating efficiency of 150 RT chiller = 0.65 kW/RT
Operating efficiency of 300 RT chiller = 0.55 kW/RT
Cooling load = 300 RT
Chiller power savings = [(50 x 3 x 0.8) + (150 x 0.65) - (300 x 0.55)] = 52.5 kW
Annual operating hours = 8,760 hrs.
Annual energy savings = 52.5 x 8,760 = 459,900 kWh

Chiller Replacement

- If chillers are old and have relatively poor rated efficiency, they can be replaced with high efficiency chillers with efficiency of as high as 0.49 kW/RT, which are currently available in the market.
- Chillers with VSD compressors can be considered for applications with high variable loads.

Thermal Storage

- Thermal storage is a method of storing thermal energy in a reservoir for later use, and is particularly useful in plants with high intermittent cooling requirements.
- In applications with high variable cooling demand, thermal storage can help to achieve a stable chiller load as well as maintain the chilled water supply temperature.
- It can also result in the reduction of peak electrical demand and electricity cost.

Illustrative example on thermal storage:

A 600 RT chiller is used to provide an off-peak cooling of 100RT from 6 pm to 2 am (8 hours) with a chiller efficiency of 1.75 kW/RT. If this off-peak cooling could be provided using chilled water storage, the chilled water can be produced using the day chillers operating at 0.65 kW/RT. The resulting energy savings and storage requirement can be calculated as follows:

Daily saving = (1.75 – 0.65) kW/RT x 100 RT x 8 h = 880 kWh
Storage required = 100 RT x 8 hours = 800 RT-h

3.2 PUMPS

Pumps are used to circulate the cooling fluid which is usually chilled water or a solution of glycol between the chillers and the loads where heat needs to be removed. In addition, pumps are used to circulate water between the condenser of the chillers and cooling towers in water-cooled chilled water systems.

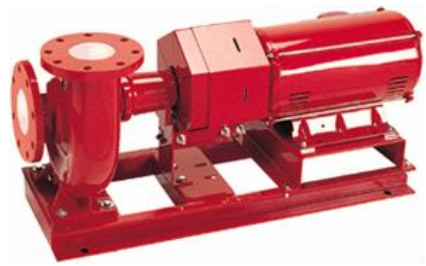


Figure 3.9 Typical pump

RETROFITS

Energy consumed by the pump's motor is dependent on the volume flow rate of the liquid being pumped and the pump pressure head (affinity law: Power $\propto$ flow^3).

Therefore, savings in pump energy consumption can be achieved by:

1. reducing the volume flow rate of liquid being pumped,
2. having correct pressure head of the pump,
3. having high efficiency pumps, and
4. having high efficiency motors.

Reducing Flow Rate – Pump Sizing

- Pumps are sized to provide the design flow rate while overcoming both the frictional and dynamic losses in the system.
- During the design stage, the pumps are sized using reference data.
- To combat the uncertainties involved in pump sizing during the design stage, a higher safety factor is sometimes used which results in over sizing of the pump.
- Excessive flow rate could be identified through on-site measurement and reduced by taking appropriate measures.
- Power consumption of the pump can be reduced by trimming the impeller, installing a VSD or replacing the pump with one of a smaller capacity. The resulting power savings can be estimated using the affinity law (Power $\propto$ Impeller diameter^3).

Illustrative example:

A chilled water pump is designed to pump 12 L/s of water when operating at 1450 rpm. It was observed that under actual operating conditions, the water *flow rate is 17 L/s and the pump motor consumes 17 kW. The reduction in pump power consumption if the pump speed is reduced to provide the design water flow rate of 12 L/s, can be estimated as follows:*

Current pump speed = 1450 rpm

Using the affinity law for pump speed, the new pump speed
= 1450 x (12/17)
= 1023 rpm

Using the affinity law for pump power, new power consumption due to the reduction of speed
$= 17 \times (1023/1450)^3$
= 6 kW

Reduction in power consumption= 17 – 6
= 11 kW

Reducing Flow Rate – Avoiding Bypass

- Where constant speed pumps are used, a constant flow is maintained in the system regardless of the load.
- In such systems, the additional flow available in the system during part-load is bypassed. This bypass flow constitutes a wastage in pumping energy.
- Hence, by using a variable speed drive system, the bypass and wastage of energy can be avoided.
- In some cases, the flow is constantly bypassed due to oversizing of the pump. In such cases, the pump can be downsized and the bypass can be eliminated.

Reducing Flow Rate – High ΔT

- ΔT refers to the temperature difference between supply and return temperatures of the cooling medium.
- Cooling load is directly proportional to the product of flow rate and ΔT.
- Therefore, a higher ΔT will result in reduced flow rate to meet the same cooling load.
- The reduced flow rate will result in lower pumping energy.

Illustrative example on high ΔT :

The ΔT for a cooling load of 1,000 kW is 5°C. If the ΔT is increased to 7°C, the resulting savings can be estimated as follows:

Flow rate required for chilled water ΔT *of* 5^oC (*Using* $Q = m \times C_p \times \Delta T$, $C_p = 4.2$ *kJ/kg.K*) $= 1{,}000/(4.2 \times 5)$
$= 47.6$ *L/s* $= 0.0476\ m^3/s$
Flow rate required for chilled water ΔT *of* 7^oC $= 1{,}000/(4.2 \times 7)$
$= 34$ *L/s* $= 0.034\ m^3/s$

Assuming a system pressure drop, ΔP*, of 2 bar (200 kPa), the pump and motor overall efficiency,* η*, of 72%, the pump power is calculated as follows:*

Pump power for chilled water ΔT *of* 5^oC $= (\Delta P \times V)/\eta$
$= (200 \times 0.0476)/0.72$
$= 13.2$ *kW*
Pump power for chilled water ΔT *of* 7^oC $= (200 \times 0.034)/0.72$
$= 9.4$ *kW*
Annual operating hours = *8,760*
Annual energy savings for the pump $= (13.2 – 9.4) \times 8{,}760$
= *33,288 kWh*

Reducing Pressure Losses – Avoidance of Throttling

- Oversizing of the pumps during the design stages are common practice due to the use of high safety factors.
- When the oversized pumps are put into operation, they are either operated at flow rates higher than required or with a throttling a valve to maintain the required flow rate. Both practices are energy inefficient.
- Instead, the required flow rate can be achieved by reducing the capacity of the pump without throttling, e.g. trimming impeller, installing a smaller capacity pump or using VSD.

Illustrative example:

A pump is designed to deliver 70 L/s of water to a chiller. However, actual measurement shows that the pump delivers 85 L/s by consuming 30 kW of electrical power. The power savings that can be achieved through a reduction of the flow by using a VSD is estimated as follows:

Using affinity law, $Power \propto (Speed)^3 \propto (flow)^3$
Measured power = 30 kW,
measured flow = 85 L/s
Design flow = 70 L/s

Therefore, estimated new pump power $= 30 \times (70/85)^3 = 16.8$ *kW*
Annual operating hours = *8,760*
Annual energy savings for the pump $= (30 – 16.8) \times 8{,}760$

= 115,632 kWh

Variable Flow Systems

- In variable flow systems, 2-way modulating valves are fitted to regulate the flow rates to the loads. Reduced flow rate in proportion to a reduced cooling load is achieved by closing the modulating valves. However, if the pumps are operating at constant speed, the overall power consumption of the pump remains almost the same and no significant energy savings is achieved.
- If the flow reduction could be achieved by adjusting the pump's speed using a VSD, the pump's power consumption can be reduced substantially.
- Based on the affinity law (Power $\propto$ Speed^3), a 20% reduction in flow rate will result in pump power savings of about 50%.

High Efficiency Pumps

- Pump's power consumption depends on flow rate, pump head and efficiency of the pump and motor.
- Therefore, for the same flow rate, pump head and motor efficiency, the motor's power consumption can be reduced by using a pump with higher efficiency.

Illustrative example on high efficiency pumps:

An 18.7 kW motor running a pump of 58% efficiency operating 12 hours a day and 365 days a year. The savings that will result if the pump is replaced with a 70% efficiency pump can be calculated as follows (assume motor is loaded to full capacity).

Electrical power savings	*= 18.7 x [(1/0.58) –(1/0.7)]*
	= 5.5 kW
Operating hours	*= 12 x 365 hrs.*
	= 4,380 hrs.
Annual electrical energy savings	*= 5.5 x 4,380*
	= 24,090 kWh/year

3.3 COOLING TOWERS

Cooling towers are used to reject heat from water-cooled chillers. They reject heat to the atmosphere through sensible and latent heat transfer.

Figure 3.10 Cooling tower

Cooling towers reject heat mainly by evaporative cooling. When water is sprayed in cooling towers, some of the water evaporates absorbing heat from the surrounding water, thereby cooling it. The amount of latent heat transferred depends on the moisture content of the air; the more dry the air is (lower wet-bulb temperature), the more latent heat will be transferred. In addition, sensible cooling also takes place between the warmer water and colder air. The amount of sensible cooling depends on the dry-bulb temperature of air. Therefore, the amount of heat rejected from cooling towers depends on both dry-bulb and wet-bulb temperatures of the outdoor air.

RETROFITS

Cooling Tower Sizing

- In a chilled water system, sizing of cooling towers is important to ensure that chiller efficiency is optimised.
- Undersized cooling towers will result in higher condenser water temperature, which causes the chiller to operate inefficiently.
- Similarly, if the condenser water temperature from the cooling towers can be lowered, chiller efficiency can be improved.
- For the same cooling load, if the cooling tower surface area is increased (oversized cooling tower), the air flow can be reduced.
- An oversized cooling tower will result in lower fan power consumption and higher capital cost of the cooling towers.
- Therefore, most of the time, cooling tower sizing is a trade-off between the initial capital cost and the running cost of the chillers and cooling towers.

Capacity Control

- In most central chilled water systems, operation of cooling towers is interlocked with the system.
- While system load varies with time, cooling towers continue operating at a constant capacity. From an energy saving point of view, it is recommended that the cooling tower capacity be varied in response to the changes in system load.
- Cooling tower capacity can be modulated by varying the air flow rate through fan staging or with the help of variable speed drives (VSDs).
- Fan staging involves switching on/off cooling tower fans in response to changes in heat rejection load, whereas VSDs modulate cooling tower capacity by varying the fan speed to match the system load requirement.
- It is also a good practice not to keep any cooling towers on standby mode. Instead, running all the available cooling towers on part load conditions to get the required total capacity.
- As per the affinity law, power consumption is proportional to the cube of the fan speed. Theoretically, a 20% reduction in load can lead to 50% reduction in fan power ($0.8^3 = 0.51$).

Illustrative example on capacity control:

Under normal operating conditions, a central chilled water system operates two out of the three cooling towers (CT) at full capacity while the third cooling tower is kept on standby mode. Each cooling tower fan motor operating at full load capacity consumes 24 kW. If all the three cooling towers are run at two-third capacity to achieve the effect of two cooling towers running at full capacity, resulting annual energy savings can be estimated as follows:

Full load cooling tower power for one CT	*= 24 kW*
Total power for two CTs	*= 2 x 24*
	= 48 kW
Power for one CT at two-third capacity	*= 24 x $(2/3)^3$*
	= 7.1 kW
Total power for three CTs	*= 3 x 7.1 = 21.3 kW*
Annual operating hours	*= 8,000 hrs.*
Annual energy savings for the facility	*= (48 – 21.3) x 8000*
	= 213,600 kWh

Installation Location

- The performance of cooling tower depends on air flow through them. Therefore, the cooling towers should be installed in such a way that air can flow freely into them.
- While installing cooling towers, a minimum distance between air intakes as well as obstructions as stipulated in the manufacturer's installation guide should be maintained. If installing cooling towers next to obstructions is unavoidable, the obstructions should be designed to facilitate air-circulation around the cooling towers, e.g. using louvre instead of solid panels.
- The ability of a cooling tower to provide its design cooling capacity depends on the operation of the water spray system, the in-fill and the fan.
- Therefore, regular maintenance should ensure that the water spray system is able to properly spread the water flow, the in-fill is in good condition and the fan is able to operate at the required speed.

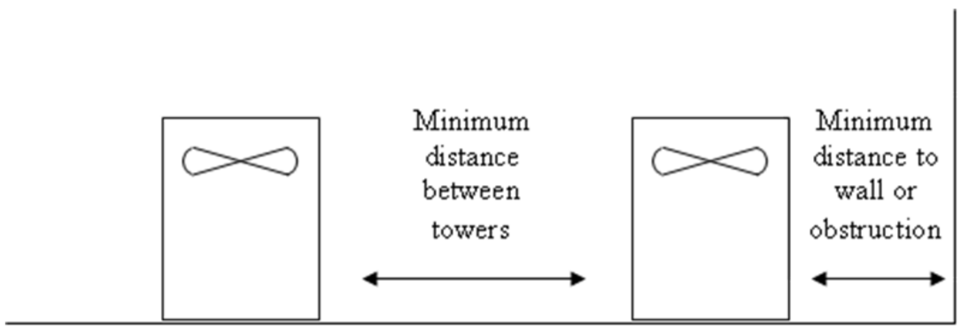


Figure 3.11 Cooling tower installation parameters

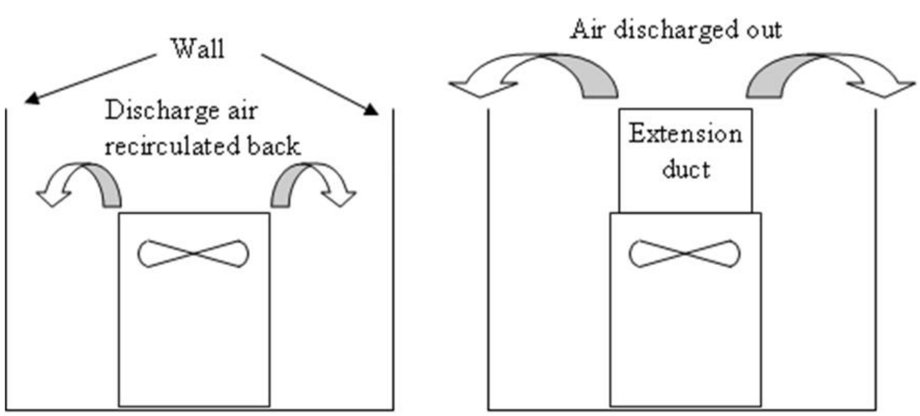


Figure 3.12 (a) improper installation (b) recommended installation

3.4 OPERATIONS AND MAINTENANCE MEASURES

- Monitor the chilled water supply temperature to ensure that it is not lower than the set-point. Calibrate or replace the temperature sensors where necessary.
- Check the approach temperature for the chiller evaporator and condenser and clean the tubes when necessary.
- Monitor the condenser water supply temperature to ensure the proper functioning of cooling towers.
- Clean the strainers regularly.
- Check the belt tension of cooling tower fans every three months.
- Clean in-fill of cooling towers and replace sections of damaged in-fill.
- Check and maintain chilled water pipe insulation to minimise heat gain.
- Allow adequate space around condenser area of the air-cooled chiller for proper heat rejection.
- Trend chilled water system's parameters such as energy consumption and amount of cooling produced continuously to evaluate its system performance (COP or kW/RT).

3.5 DESIGN CONSIDERATIONS

- When existing chilled water systems reach the end of their useful life and need replacement, the cooling load profile established through measurement can be used to design the new system. When designing cooling systems for new installations, the cooling load profile can be established through a simulation exercise and used to optimize the design (prevent oversizing or undersizing of equipment).
- Water-cooled chillers are much more energy efficient than air-cooled chillers, and should be used where possible.
- Separate chilled water systems operating at different temperatures can be considered for applications where cooling fluid of different temperatures are required.
- Where the cooling load is expected to vary significantly during daily operations, VSD chillers or different capacity chillers can improve system efficiency.
- Use a chiller monitoring system to operate the most efficient equipment combination in relation to the cooling load can help to optimize system efficiency.
- Incorporate valves with automatic controls to shut-off flow to equipment when not in operation can result in lower cooling demand and lower pumping power.
- Minimised pumping power by selecting chillers with lower evaporator and condenser pressure drop.

- During design of piping systems, using fittings with lower pressure drop, correct pipe sizing, avoiding right-angle piping and sudden enlargement or contractions and reducing pipe length can lead to lower pumping power.
- Consider energy efficiency (or life cycle cost) rather than lowest capital cost when selecting equipment such as chillers, pumps and cooling towers.
- Use variable flow pumping and fan systems where possible to modulate the flow rate in response to load variations.
- Auto tube cleaning systems for chiller condensers can help to maintain chiller efficiency by preventing scaling and fouling.
- When a particular application requires relatively high dehumidification, a dedicated standalone dehumidification system can be considered rather than operating the entire cooling system at a low operating temperature.
- Where a continuous stream of waste heat is available, absorption chillers rather than electric chillers, can be used for producing cooling.

4.0 REFRIGERATION SYSTEMS

Refrigeration systems are very common in the food manufacturing industry. As in the case of air conditioning system, refrigeration systems also produce cooling, but at a much lower temperature. Both air conditioning and refrigeration systems, which work on the vapour compression refrigeration principles, comprise a compressor, evaporator, condenser and an expansion device.

In industrial refrigeration systems, multiple compressors arranged in parallel are used to serve evaporators which may be operating at different temperatures. While evaporating temperatures can be as high as 15°C, the range can extend down to -40° or lower where separate low pressure and high pressure compressors are used (two stage compression).

Air-cooled, water-cooled and evaporative condensers are used for heat rejection. Similarly, different types of evaporators such as direct expansion, flooded type and liquid overfeed systems are used depending on load requirements. The most commonly used refrigerant is ammonia while Freon refrigerants are also used in some applications.

Figure 3.13 Screw type refrigeration

4.1 RETROFITS

Increase Compressor Suction Pressure

- Increasing suction pressure reduces the compressor pressure lift, which will save significant amount of compressor power consumption (3 to 5% improvement per ^{o}C).
- The suction pressure value for the compressor is set based on the required evaporator temperature. Therefore, the suction pressure should be set at the maximum possible value.
- For most designs, the saturation temperature of the refrigerant at a given suction pressure should not be greater than 10^{o}C below the refrigerated space temperature.

Illustrative example on increase of compressor suction pressure:

The set point of a cold room served by a refrigeration system is -36^{o}C when the lowest cold room temperature requirement is -20^{o}C. The average measured refrigeration load and system efficiency is about 200 RT and 2 kW/RT *respectively. The energy saving by resetting the cold room temperature to -33°C can be estimated as follows:*

Current suction set point temperature	*= - 36°C*
Current average cold room refrigeration system efficiency	*= 2 kW/RT*
Average refrigeration load	*= 200 RT*
Proposed suction set point temperature	*= - 33°C*
Estimated improvement due to increased suction set-point	*= 9% (3x3%)*
Estimated system efficiency after set point change	*= 2 kW/RT x 91 %*
	= 1.82 kW/RT
Power savings due to the temperature reset	*= (2.0 – 1.82) x 200*
	= 36 kW
Annual operating hours	*= 8,760*
Annual energy savings	*= 36 x 8,760*
	= 315,360 kWh

Reducing Condensing Pressure

- Similar to increasing suction temperature, reducing condenser pressure also reduces compressor pressure lift resulting in lower compressor power.
- A reduction in 1°C results in a power saving of 3 to 5%.
- Therefore, water-cooled systems, which can reduce the condensing temperature by about 5°C, should be used instead of air-cooled condensers.
- For water-cooled systems, evaporative condensers are able to achieve lower condensing temperatures compared to systems using cooling towers and water-cooled condensers.
- If the capacity of evaporative condenser is not sufficient (high condensing pressure), additional (standby) evaporative condensers can be operated in parallel to reduce the condensing pressure.

Illustrative example:

The measured condensing temperature of an ammonia refrigeration system is 38°C. The average measured refrigeration load and system efficiency is about 200 RT and 2 kW/RT respectively. The energy savings by improving the condensing temperature to 35°C can be estimated as follows:

Current condensing temperature	*= 38°C*
Current average refrigeration system efficiency	*= 2 kW/RT*
Average refrigeration load	*= 200 RT*
Proposed condensing temperature	*= 35°C*
Estimated improvement due to the decrease in condensing temperature	*= 9%*
Estimated system efficiency at lower condensing temperature	*=2 kW/RT x 0.91*

	= 1.82 kW/RT
Power savings due to the temperature reset	*= (2.0 – 1.82) x 200*
	= 36 kW
Annual operating hours	*= 8,760*
Annual energy savings	*= 36 x 8,760*
	= 315,360 kWh

Note: The additional power required for operating extra fans is not considered in the above example.

Repair / Replace Defective Controls

- Defective control systems may result in the operation of more compressors than required, leading to low loading and inefficient operation.
- Therefore, all controllers and sensors need to be checked and calibrated regularly.

New Systems

- When older refrigeration compressors reach the end of their useful life, they should be replaced with more efficient compressors using ammonia as refrigerant.

VSD for Compressors

- In variable load applications, VSD compressors can be used to vary the capacity rather than using sliding valves or other means of capacity control.

Alternative Systems

- Sometimes, industrial refrigeration systems are used for systems that do not require very low temperatures, e.g. 0-5°C. In such cases, alternative systems such as chilled water or glycol chillers can be used.

Vary Speed of Evaporator Fans

- It is a common practice to run the evaporator fans at full speed even after the refrigerated space has reached the set temperature.
- In such situations, the speed of the evaporator fan can be reduced by using a VSD.

Minimising Load

- Significant amount of energy savings can be achieved through various measures to reduce the refrigeration load.
- Once the refrigerated space reaches the set-temperature, the main contributors of cooling load for the refrigeration system are the lights, heat emitted by occupants and heat infiltrated into the refrigerated space.
- Therefore, lights should be switched-off when not required and inefficient lamps should be replaced with more efficient ones.
- Doors should be kept closed or automatic doors should be installed to minimise infiltration of air.
- Where possible, the products to be cooled to a low temperature using a refrigeration system can be pre-cooled with a relatively more efficient medium like cooling tower water or chilled water.

4.2 OPERATIONS AND MAINTENANCE MEASURES

- Consistently higher than design saturated discharge temperatures indicate probable fouling of condenser or poor cooling tower performance.
- Inspect the condenser piping and clean any scale or sludge from the condenser tubes.
- For air-cooled condensers, regularly check and clean the condenser coil.
- Consistently lower than design saturated suction temperatures should be investigated as they may indicate probable fouling of heat exchangers or low refrigerant charge.
- Check sensors and controllers to ensure that they are in working order.
- Check and repair damaged insulation to minimize heat gain.
- Check coils for excessive frost formation and change defrosting cycle where applicable.
- Ensure that all doors and openings of refrigerated spaces are sealed.
- For water-cooled systems, trend refrigeration system's parameters such as energy consumption and amount of cooling continuously to evaluate its system performance (COP or kW/RT).

4.3 DESIGN CONSIDERATIONS

- Ensure that the design temperature is really required through investigation and challenging user specifications. If possible, an attempt should be made to increase the temperature.
- Increase coil surface areas throughout the system to allow the compressor to operate at higher suction temperature.

- Use flooded evaporators which are more efficient, more robust and less sensitive to load variations than DX evaporators.
- Use evaporative condensers instead of air-cooled or water-cooled condensers.
- Use multiple compressors that can be loaded / unloaded in response to varying loads.
- Use VSD compressors for variable load applications.
- For low temperature applications or systems requiring vastly different operating temperatures, use two-stage compressors (low pressure and high pressure compressors) with intermediate economisers.
- If a small user is driving the central circulation temperature to be less than what the major users require, consider an individual system for that user.
- Where possible, use plate heat exchangers on evaporators and condensers to minimise temperature difference between refrigerant and process fluids.
- Use ammonia as the refrigerant where possible.
- Use good insulation material for refrigerated spaces.
- Ensure that there is an intermediate temperature zone between the access doorways of low temperature (-10^{o}C or below) rooms and ambient.
- Ensure that doors have automatic door closing and that alarms are present when doors are left open for extended periods.
- Where possible, cooling or pull-down of product temperature should be carried out in special chambers and not in general storage areas.
- Drives or heat-generating equipment should be kept out of the space being refrigerated.
- Air coolers should be selected to ensure fin-spacing is kept sufficiently wide enough to prevent excessive defrosting.
- Ensure compressor configuration allows for efficient operation from 10% to 100% of expected system load.
- Consider having multiple compressors matching specific loads, i.e. have a large compressor to run when a freezer is cooling products, and a smaller compressor for storage mode or weekend running.

5.0 PROCESS COOLING SYSTEMS

Cooling towers and pumps are used in the food manufacturing plants to circulate water for process cooling applications. Such systems typically operate 24 hours a day to remove heat from various processes and reject it to the ambient. A schematic diagram of the process cooling system is shown in Figure 5.1. Both sensible and latent heat transfer take place in cooling towers with latent heat predominating heat transfer. The cooling water supply temperature is designed based on the process heat rejection requirement. For economical reasons, the cooling water supply temperature of a cooling tower is about 2 ^{o}C above the prevailing wet bulb temperature.

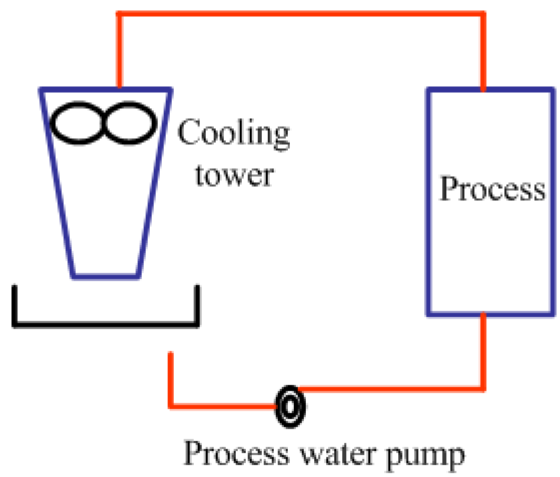


Figure 5.1 A typical process cooling system

5.1 RETROFITS

Cooling Tower Sizing

- Cooling towers should be selected based on heat rejection load requirements.
- For the same cooling load, if the cooling tower surface area is increased (oversized cooling tower and hence higher capital cost), the air flow can be reduced (lower fan power).
- Therefore, most of the time, cooling tower sizing is a trade-off between the initial capital cost and the running cost of the cooling towers.

Cooling Tower Capacity Control

- Cooling tower capacity can be controlled based on the heat rejection load.
- Cooling tower capacity can be modulated by varying the air flow rate through fan staging or with the help of variable speed drives (VSDs).
- Fan staging involves switching on/off cooling tower fans in response to changes in heat rejection load whereas, VSDs modulate cooling tower capacity by varying the fan speed to match the system load requirements.
- It is also a good practice to operate standby cooling towers so that the average fan speed of each cooling tower can be reduced while the total cooling tower capacity remain unchanged.
- From the affinity law, power consumption is proportional to the cube of the fan speed. Theoretically, a 20% reduction in air flow rate can lead to 50% reduction in fan power ($0.8^3 = 0.51$).

Reduced Cooling Water Supply Temperature

- If the cooling water supply temperature is lower than that required for process cooling, the water temperature can be raised by operating less cooling tower fans or reducing the speed of the operating fans.

Cooling Tower Installation

- The performance of cooling tower depends on air flow through them. Therefore, the cooling towers should be installed in such a way that air can flow freely into them.
- While installing cooling towers, the minimum distance between air intakes as well as distance from obstructions should be maintained as stipulated in the manufacturer's installation guide. If installing cooling towers next to obstructions is unavoidable, the obstructions should be designed to facilitate air-circulation around the cooling towers, e.g. using louvre instead of solid panels.
- The ability of a cooling tower to provide its design cooling capacity depends on the operation of the water spray system, condition of the in-fill and speed of the fan.
- Therefore, regular maintenance should ensure that the water spray system is able to properly spread the water flow, the in-fill is in good condition and the fan is able to operate at the required speed.

Reducing Cooling Water Flow Rate

- Pumps are sized to take care of the design flow rate while overcoming both the frictional and dynamic losses in the system.

- During the design stage, the pumps are sized with the help of charts and tables based on certain assumptions.
- To combat the uncertainties involved in the pump sizing during the design stage, a higher safety factor is also used resulting in more than required flow rate at the time of actual operation of the system.
- Low ΔT (temperature difference between return and supply temperature) is an indication of over sized pumps.
- In some cases, when the pump is oversized for the application, a pressure loss is artificially created by adding a throttling valve.
- In such situations, the pump impeller can be trimmed, the throttling valve can be removed, VSD can be installed to reduce pump speed or the entire pump can be replaced with a new pump sized to match the load requirements.
- For variable load applications, VSDs can be used to modulate the flow rate with changes in load.

Consolidation of Cooiling Towers

- Where multiple cooling towers are used to serve various loads, these systems can be consolidated into one combined system to achieve better efficiency since the heat rejection capacity can be better controlled to match varying load.
- If the loads are not continuous, isolation valves should be installed to automatically prevent cooling water being circulated through them. Pressure sensors and VSDs can be used to regulate the pump capacity accordingly.

High Efficiency Pumps

- Pump power consumption depends on flow rate, pump head and efficiency of pump and motor.
- Therefore, for the same flow rate, pump head and motor efficiency, the pump motor power consumption can be reduced by using a pump with a higher efficiency.

5.2 OPERATIONS AND MAINTENANCE MEASURES

- Check and clean heat transfer surfaces to maintain a low approach temperature.
- Clean the strainers regularly.
- For belt driven fans, check belt tension to ensure cooling tower fans operate at the design speed.
- Clean in-fill of cooling towers and replace damaged in-fill.

- Trend process cooling system's parameters such as energy consumption and amount of cooling continuously to evaluate its system performance (COP or kW/RT).

5.3 DESIGN CONSIDERATIONS

- Design system based on the highest possible cooling medium temperature that can satisfy the requirements.
- Select heat exchangers to have low approach temperature (temperature difference between entering cooling water and leaving process fluid) and minimum pressure drop.
- Where possible, use plate heat exchangers instead of shell and tube heat exchangers.
- Use auto tube cleaning systems for shell and tube heat exchangers.
- Incorporate valves with automatic controls to shut-off flow to equipment when not in operation.
- During design of piping systems, using fittings with lower pressure drop, correct pipe sizing, avoiding right-angle piping and sudden enlargement or contractions and reducing pipe length to lower pump power.
- Select pumps to have high efficiency at operating point.
- Use variable flow pumping systems to modulate the flow rate in response to load variations.
- Select cooling towers to have low approach temperature (temperature difference between cooling tower supply and wet bulb temperature).
- Install VSDs and controls to modulate the speed of cooling tower fans.

6.0 COMPRESSED AIR SYSTEMS

Compressed air is a form of stored energy that is used to operate machinery, equipment or processes. Compressed air is used in many food manufacturing plants and accounts for about 7% of the total electrical energy consumption. Due to the heat losses associated with generating compressed air, it is a very energy-intensive process.

Figure 6.1 Air Compressors

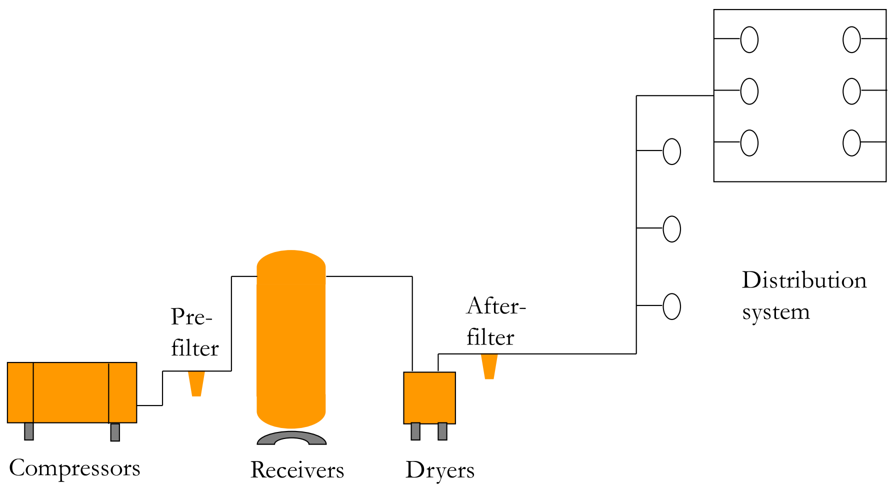


Figure 6.2 A typical compressed air system

The main components of a compressed air system comprises air compressors, dryers, filters, air receivers and distribution system as shown Figure 6.2. Common types of air compressors used in the industry are screw, reciprocating and centrifugal. To remove the moisture in the compressed air, dryers are often used. The commonly used dryers are refrigerated dryers, heatless desiccant dryers and externally heated desiccant dryers. Air compressors can be with oil-injected or oil-free.

6.1 RETROFITS

The inefficiency of air compressors is due to the intrinsic thermodynamic losses while compressing large volumes of air causing about 80% of the power input to be converted to heat. Therefore, the system efficiency improvement through the improvement of the single-stage compression process itself is difficult. However, from a system point of view, the efficiency could be improved through various system level optimization techniques like reducing compressed air demand, correct sizing of compressors, selecting energy efficient dryers and reducing leakages.

Reducing Compressed Air Demand

Identify and rectify leaks

- Leaks in compressed air distribution networks is an undesirable but regular phenomenon .
- Typically, the loads served by compressed air system are intermittent in nature, however leaks are constant and quite significant.
- Leakage levels at facilities can typically be 10-20% of the total usage.
- The monetary cost of leaks can be quite significant. Therefore, a leak detection programme should be adopted as part of the maintenance regime.
- The total amount of leakage can be quantified during a plant shutdown (no compressed air usage) and observing the load / unload operation of the compressors.
- In addition to the monetary costs, leaks can cause significant pressure drop resulting in excessive compressor load / unload cycling.
- Attempts are often made to combat pressure drop in systems with, excessive leakage by increasing the system discharge pressure.
- However, this makes the problem worse by increasing the leakage rate and creating more leaks.

Illustrative example on compressed air leak estimation:

A leakage test was conducted for a compressed air system, the load time (T) and unload time (t) of the compressor are 15 s and 45 s respectively. The compressor leakage rate can be estimated as follows:

Air compressor leakage rate (%) $= [T/(T+t)] \times 100$
$= [15/(15+45)] \times 100$
$= 25\%$

Use of alternative sources where possible

- Minimising compressed air demand can be the most effective means of mitigating the high power consumption of a compressed air system.
- The process requirements served by compressed air can often be better served through some other form of local operation.
- For example, for the cooling or drying of products, instead of using compressed air, alternative sources such as fans can be considered.

- Use blowers/fans instead of compressed air for blowing requirements.

Turn the compressed air system off

- If compressed air is not required in some areas of a plant for long periods, isolation valves (manual or automatic) should be installed on the line to minimise possible losses.
- In addition, distribution lines which are no longer in use should be isolated.
- Standard operating procedures should be formulated to ensure that compressed air flow to loads is isolated during non-operational periods.

Reduced Compressed Air Pressure

- In some applications, compressed air is produced at higher pressure and distributed to the end user through pressure reducing valves. This results in wastage of energy as the end user only requires compressed air at a lower pressure.
- In such instances, the pressure reducing valves should be removed and the compressor outlet pressure should be reduced.
- Reduction of 1 bar pressure could typically save about 6% of power for an air compressor.
- If only a few loads require a much higher pressure than the remaining loads, a standalone compressor or a booster compressor can be installed to serve the high pressure loads.

Illustrative example:

If the discharge pressure of an air compressor consuming 150 kW of power was reduced from 7.5 bar to 6.5 bar, the resulting annual energy savings can be estimated as follows.

Current power consumption of the compressor	*= 150 kW*
Reduction in compressed air pressure	*= 7.5 – 6.5 = 1 bar*
Power savings due to the pressure reduction	*= 150 x 6% = 9 kW*
Annual operating hours	*= 8,400*
Annual energy savings	*= 9 x 8,400*
	= 75,600 kWh

More Efficient Compressors

- If the air compressors are operating inefficiently, they could be replaced with better efficiency compressors.
- In situations where a multiple number of small compressors are in operation to serve load requirements, they can be replaced with a single more efficient compressor.
- It is vital to select a compressor to match load requirement so that unload operation where the compressor operates without producing any useful output can be avoided (about 20 to 30% of compressor power consumption is for the compressor unload operation).
- VSDs compressors can be considered for installations that have high load variations.
- Where there are no process limitations, oil-injected instead of oil-free compressors should be used as they are more energy efficient.

Compressed Air Recovery

- In applications like bottle blowing which require high pressure compressed air (up to about 40 bars), an air recovery system (ARS) could be installed to recover high pressure exhaust air and then supply it to low pressure end users.

Reduced Compressed Air Inlet Temperature

- Compressor energy consumption is also dependent on the inlet air temperature. At a higher inlet temperature, more air is required to be taken in for compression to produce the same output.
- It is common to find compressors sharing a common plant room where the ambient temperature is high (e.g. boiler rooms) or installed in a poorly-ventilated room.
- To minimize energy consumption, compressors should be located in a well ventilated area or in an area with mechanical ventilation.
- A 4°C reduction in the inlet air temperature will reduce compressor power by about 1%.

Location of Air Receivers

- Storage or air receivers should be placed at strategic points closer to the load in a system to accommodate transient load conditions.
- Air receivers can help to smoothen compressor loading by storing air during periods of low demand.
- Overall system pressure can also be reduced since receivers installed near intermittent loads can be filled gradually during low demand

periods. This helps to avoid sudden high flow rate from the compressor plant room to the load, which results in unnecessary pressure losses.

Appropriate Air Treatment Technique

- Based on the end user requirement, appropriate air treatment for the removal of moisture should be selected.
- For applications that do not require dry air, compressed air can be directly provided without any dryers.
- If there are a combination of loads, i.e. some require dry air but others do not, the compressed air distribution system should be separated into two systems and dry air provided to only loads that require it.
- The two main types of dryers are refrigerant and dessicant type. Since refrigerant type of dryers consume much less energy to operate than desiccant dryers, they should be used where possible.
- Where low dew-points (below $2^{o}C$) are required, externally heated desiccant dryers should be used instead of desiccant dryers that use compressed air for regeneration (purge air).
- Dew point sensors should be used in place of timers to minimize regeneration time and energy usage.

6.2 OPERATIONS AND MAINTENANCE MEASURES

- Check for air leaks and rectify them.
- Clean or replace filters regularly to minimize pressure losses.
- Check and adjust air regulators to supply the minimum required pressure.
- Check and adjust system pressure to the minimum required value.
- Check and ensure that condensate drain valves are in good working order.
- Check and adjust dew-point settings for dryers.
- Clean or replace cooling system filters and heat exchangers regularly.
- Install airflow meters for the main loads to measure and track the quantity of compressed air used.
- Trend compressed air system's parameters such as energy consumption, compressed air flow rate, pressure and temperature continuously to evaluate its system performance (kWh/Nm^3).

6.3 DESIGN CONSIDERATIONS

- Minimise compressed air demand by:
  - using vacuum pump systems to create vacuum as opposed to compressed air with venturi orifices
  - using blowers for cooling, agitating, aspirating, mixing, cleaning etc.
  - using electric actuators or hydraulics
  - using electrical tools instead of pneumatic ones.
- Select oil-injected compressors. If some loads require oil-free air, then have a separate oil-free system only for those loads
- Design piping system to minimise losses. A ring circuit design can be adopted so that air can flow in two paths to the load.
- Minimise use of flexible pipes which result in high leakage rates.
- Adequately size air receivers to minimise fluctuations in pressure and to achieve a lower system operating pressure.
- Install receivers near high and intermittent users of compressed air.
- Install pressure regulators to reduce pressure in sections of the distribution system to achieve user requirements.
- Install an independent compressor or booster compressor for high pressure loads.
- Install the compressors in a well ventilated space.
- Select the optimum type of compressor (reciprocating, screw or centrifugal) based on capacity and operating pressure (for more information refer to the compressor manufacturers' web portal).
- Select compressor capacity based on expected load and avoid over-sizing.
- Select VSD compressors for variable load applications.
- Use a sequencing controller for multiple compressor installations.
- Avoid additional drying where possible and select refrigerated dryers or externally-heated desiccant dryers depending on the dew-point requirement.
- Install dew-point controllers to ensure optimum operation of dryers.
- Incorporate heat recovery systems where waste heat can be recovered to heat air or water.

7.0 OVENS AND HEATERS

In the food manufacturing plants, ovens and heaters are used for baking as well as process applications. These ovens and heaters consume natural gas, electricity or steam.

Figure 6.3 Heater and Oven

7.1 RETROFITS

- Insulate the oven or heater walls and doors adequately to minimize heat losses.
- Reduce or eliminate openings on walls and doors to minimize heat losses and to prevent hot air from leaking out of ovens.
- Use pressure controls where feasible to minimize air leaks out of the equipment.
- Maintain correct air-fuel ratio through the use of automatic controls where combustion burners are used.
- Recover heat from exhaust or flue gases where possible and use it in applications like pre-heating of products or combustion air.

7.2 OPERATIONS AND MAINTENANCE MEASURES

- Clean heat transfer surfaces frequently to maintain high heat transfer efficiency in heat exchangers and other systems that use electrical heating elements, coils and radiant tubes.
- Adopt good operating practices, such as operating equipment at close to full load capacity.
- Plan production cycle in order to continuously operate ovens and heating equipment and avoid long gaps between cycles.

7.3 DESIGN CONSIDERATIONS

- Select equipment based on expected demand so that they can be operated continuously at close to maximum capacity.
- Ensure adequate insulation on exterior surfaces to minimize losses.
- Select equipment based on operating efficiency rather than capital cost.
- Minimize the use of internal components such as load supports, fixtures, trays and baskets that need to be heated during each cycle.
- Incorporate heat recovery systems where possible to recover waste heat from the exhaust.

8.0 PRODUCTION SYSTEMS AND MOTOR

In food manufacturing plants, equipment such as mills, rollers, grinders, pulverisers, refiners and packing machines are used in various production processes. The main energy consumers in these equipments are motors and majority of motors used have IE1 and IE2 efficiency rating. Motor loading of some motors are found to be below 40% resulting in inefficient operation of the motors.

Figure 8.1 Production

8.1 RETROFITS

- Use automatic controls for shutting-off equipment when they are not in operation.
- Install isolation devices within easy reach of operators to shut-off utilities such as compressed air, cooling fluid and heating.
- Replace low efficiency motors with IE3 or IE4 motors.
- Ensure that motors are running above 40% loading and replace them with smaller capacity motors where possible.
- For equipment with variable load duty cycles, use Variable Speed Drives (VSDs).
- Where applicable, minimise distance between processing and packing lines to minimise heat losses or heat gain.

8.2 OPERATIONS AND MAINTENANCE MEASURES

- Carry out preventive maintenance on regular intervals, in particular the moving and sliding parts of the equipment.
- Adopt good operating practices, such as operating equipment at close to full load capacity.
- Operate continuously and avoid long gaps between cycles.

8.3 DESIGN CONSIDERATIONS

- Select equipment based on expected demand so that they can be operated continuously at close to maximum capacity.
- Select equipment based on operating efficiency rather than capital cost.
- Select IE3 or IE4 motors.

9.0 LIGHTING SYSTEMS

Figure 9.1 Fluorescent Light

Lighting is essential to ensure the comfort, productivity and safety of occupants in buildings and manufacturing environment like food manufacturing plants. Lighting systems need to be designed in an energy efficient manner to provide the required illuminance level while using the minimum amount of energy.

9.1 RETROFITS

Figure 9.2 Highbay Light

Energy savings from lighting systems can be achieved through the following measures:

1. Reduce lighting levels
2. Use high efficiency lamps
3. Implement lighting controls
4. Adopt daylighting

The following sections describe typical energy saving measures for lighting systems.

Reducing Lighting Levels

- The lighting level for a particular space depends on the tasks to be performed in the space and other visual requirements.
- Generally, higher lighting levels lead to higher lighting energy consumption. Therefore, lighting levels should be minimised and maintained within the recommended value range.
- For existing installations where it is not cost effective to redesign the lighting systems, other means such as delamping, use of task lighting, and replacement of lamps can be considered to reduce energy consumption.

Use of Energy Efficient Lamps

- The amount of light emitted by a lamp per unit of electrical power consumed is the luminous efficacy of a lamp.
- The higher the efficacy, the better the efficiency of the lamp.
- Since different types of lamps have different efficacies, lamps with low efficacy can be replaced with those having higher efficacy.
- LEDs can be used in place of T8 fluorescent lamps, halogen and incandescent lamps.
- For highbay and outdoor applications, LED lamps can be used.

Illustrative example on energy efficient lamps:

If 100 nos. of 75 W incandescent lamps are replaced with 15 W LED lamps and if they operate 24 hours a day, seven days a week, achievable energy savings can be estimated as follows:

Annual operating hours	*= 8,760*
Annual energy savings	*= (75 - 15) x 100 x 8,760/1,000*
	= 52,560 kWh

Use of High Efficiency Electronic Ballast

- Ballasts are used to start and operate fluorescent and High Intensity Discharge (HID) lamps.
- Ballasts provide the voltage necessary to strike the arc in discharge lamps and to regulate current drawn by the lamp to maintain light output.
- The two main types of ballasts are magnetic and electronic.
- Electronic ballasts are superior to magnetic ballasts because they are typically 30% more energy efficient.
- Therefore, use of electronic ballasts in place of magnetic ballasts will save significant amount of energy.

Use of Better Reflectors

- Most standard reflectors used in luminaires of fluorescent lamps have a reflectivity of about 85% which is low in comparison to reflectors made of special materials capable of providing reflectivity of more than 90%.
- Therefore, replacing standard reflectors result in increased useable light, and can enable the removal of some lamps.

Lighting Controls

- Energy consumed by lighting can also be reduced by better matching operations with demand through lighting controls.
- Various systems such as timers, occupancy sensors and light sensors can be used to control lighting operations.
- Typical application of occupancy sensors can be storage areas, toilets, mechanical rooms and car parks which are not continuously occupied.
- Similarly, light sensors can be used to control perimeter and outdoor lighting.

Daylighting

- Day light falls on the exterior surfaces of most buildings even on cloudy days. This natural light can be captured through daylighting techniques to illuminate interior spaces of buildings and help reduce the energy consumption of artificial lighting.
- Some common daylighting features that can be used in manufacturing plants are skylights, windows and light tubes.

Illustrative example on daylighting:

Currently, 300 nos. of 210 W highbay lamps are used for 24 hours a day, seven days a week. The energy savings achievable through the installation of skylights as can be estimated as follows:

Annual operating hours before the installation of the skylight = 8,760 h
Annual operating hours after the installation of skylights = 5,256 h
(Assuming 60% reduction in the operating hours due to the switching off the bay lights)
Annual energy savings = 300 x 210 x (8,760 – 5,256)/1,000
= 220,752 kWh

9.2 OPERATIONS AND MAINTENANCE MEASURES

- Luminaires should be regularly cleaned as accumulation of dirt, and discolouring of reflectors can reduce illuminance levels.
- When lamps age, the lumen output can drop. Hence, lamps should be replaced when the illuminance level drops below the recommended value.
- Where sky lights are used, they should be cleaned to ensure maximum use of available day light.
- Check and ensure that sensors and controls are in working order.

9.3 DESIGN CONSIDERATIONS

- As artificial lighting accounts for a significant portion of electrical energy usage, daylighting techniques can be incorporated to maximize use of available natural light.
- Some common daylighting features that are used in manufacturing facilities are skylights, windows and light tubes.
- For single storey facilities, sky lights and windows can be used to provide sufficient illuminance levels during day time.

- For perimeter areas, maximum use of daylighting can be achieved through use of windows and glazing.
- For new installations, the design of artificial lighting should take into consideration factors such as lamp efficacy, lamp spacing, lamp height and performance of reflectors.
- Lighting circuits should be designed to enable switching off lighting in areas which are not continuously occupied and where there is daylight penetration.

10.0 COMBINED HEAT AND POWER SYSTEMS

In food manufacturing industry, large amounts of heat and electrical power are required. Usually, electricity is provided from the grid while heat is supplied by the boilers. Considering the thermal efficiency of electricity generation in power plants and the efficiency of boilers used for producing heat, the maximum overall efficiency achievable is about 65%.

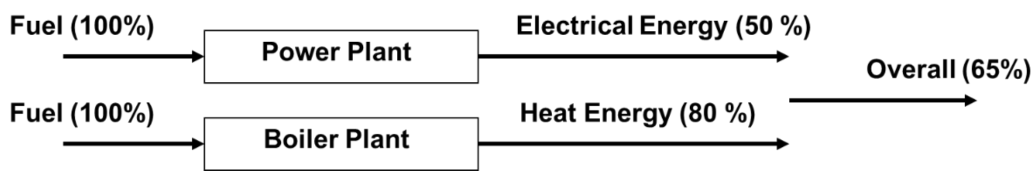


Figure 10.1 Individual generation of electricity and heat

Combined Heat and Power (CHP) refers to simultaneous generation of electricity and useful heating from one source of energy. More than 80% of the energy in the primary fuel can be utilized by CHP systems.

The main types of CHP systems use microturbines, internal combustion engines, gas turbines and steam turbines. Figure 10.2 shows the typical arrangement of an internal combustion engine-based CHP system which consists of an electrical power generator coupled to an internal combustion engine and a waste heat recovery boiler for generating steam and a heat exchanger for producing hot water.

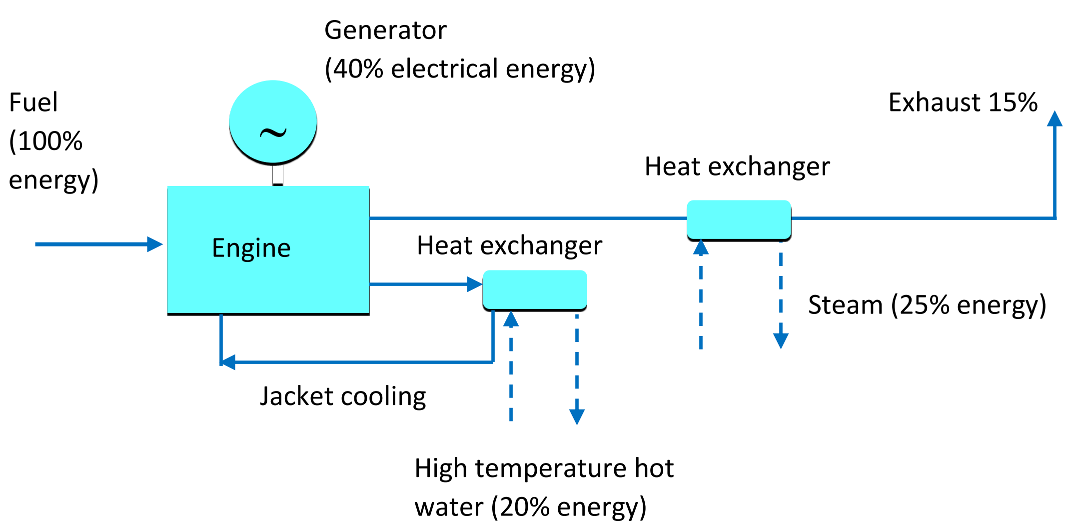


Figure 10.2 A typical internal combustion engine CHP system

Some of the fundamental requirements for a CHP system to be feasible are:

- Continuous operation (24 x 7)
- Availability of fuel (e.g. natural gas)
- Demand for both power and heat

Only some food manufacturing plants are able to satisfy the above minimum requirements. For such plants, it is recommended to conduct detailed studies to analyse the viability of using a CHP system. Factors to be considered include power demand, heating demand, infrastructure requirements, compliance to local regulations, investment cost, current and future fuel and electricity prices.

11.0 ENERGY MANAGEMENT SYSTEM

ISO 50001 – Energy Management Systems provides a framework for implementing an energy management system for continuous energy performance improvements. The standard provides guidance on how to integrate energy efficiency into management practices, to fine-tune production processes and improve the energy efficiency of industrial systems. It emphasizes regular energy audits and the use of relevant measured energy data to calculate and report energy performance. The standard obliges managers to develop technical and management measures to reduce energy and costs, and improve environmental performance.

A typical Energy Management System (EnMS) model is shown in Figure 11.1. It is based on ISO 50001 - Energy Management System and follows the Plan-Do-Check-Act (PDCA) framework.

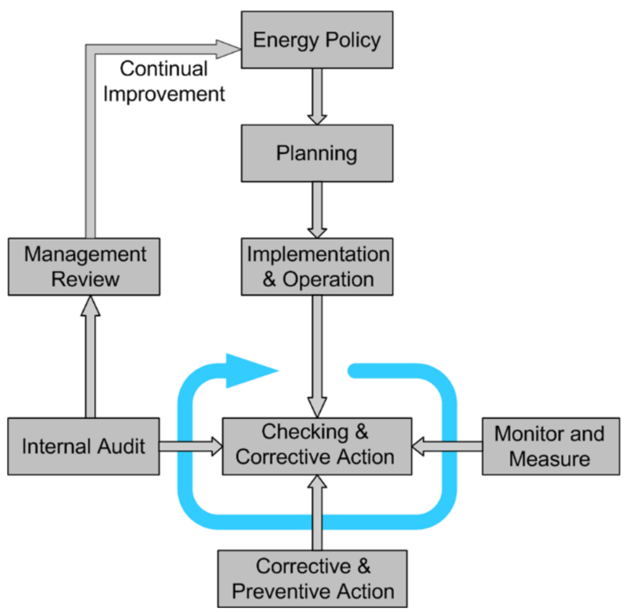


Figure 11.1 Typical energy management system model

The initial step of "Plan" is to establish objectives and goals for improvement in energy performance and a company policy to achieve them. The "Do" involves implementing the established plan while the "Check" process involves monitoring the actual performance against policies, objectives and key performance indicators and reporting the results. The final step, "Act" is to take the necessary actions to continually improve energy performance of the organization.

Recommendations for an effective EnMS:

- Have an explicit energy policy in place and disseminate it to all staff.
- Establish clear targets and goals.
- Appoint an Energy Management Team with representation from all stakeholders.
- Appoint a dedicated energy manager.
- Identify main energy consuming systems.
- Establish and track energy performance indicators (EnPIs) of main energy consuming systems.
- Assess the EnPIs regularly and take corrective action where required.
- Identify and invest in energy efficiency improvement opportunities.
- Conduct regular training to raise awareness on good energy management practices.

REFERENCES

1. ARI Standard 550/590- 2003, Water Chilling Packages Using the Vapour Compression Cycle, Air-Conditioning and Refrigeration Institute, 2003.
2. ASHRAE Handbook Fundamentals, ASHRAE, 2009.
3. Combined Heat and Power Design Guide, ASHRAE, 2015.
4. Energy Efficient Building Systems, Dr Lal Jayamaha, McGraw-Hill, 2006.
5. Energy Efficient Industrial Systems, Dr Lal Jayamaha, McGraw-Hill, 2016.
6. HVAC and Refrigeration Preventive Maintenance, Eric Kleinert, McGraw-Hill, 2015.
7. Industrial Refrigeration Handbook, Wilbert Stocker, McGraw-Hill, 1998.
8. ISO 50001 Energy Management Systems - Requirements with Guidance for Use.
9. Sustainable Thermal Storage Systems; Planning, Design and Operation, Lucas B.Hyman, McGra