ENERGY EFFICIENCY BENCHMARKING STUDY OF FOOD MANUFACTURING PLANTS IN SINGAPORE
Acknowledgements

LJ Energy Pte Ltd would like to thank the ten food manufacturing companies for participating in this study and for all the assistance provided during the site data collection process. We also gratefully acknowledge the guidance, support and leadership provided by the Energy Efficiency and Conservation Department of the National Environment Agency (NEA).

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EXECUTIVE SUMMARY

Project Information

LJ Energy Pte Ltd was appointed by the National Environment Agency (NEA) Singapore to conduct an Energy Efficiency Benchmarking Study of Food Manufacturing Plants in Singapore.

Ten food manufacturing plants located in various parts of Singapore participated in the benchmarking study.

The study involved developing an assessment framework to evaluate the energy efficiency of major systems and equipment installed in food manufacturing plants and thereafter conducting level 3 audits for each individual plant. The audits included on-site measurement of each major system and equipment to obtain the data and other information required for execution of the assessment framework.

On conclusion of the level 3 audits, each plant received a customised report. It included the energy consumption profile for the major systems, recommendations for energy efficiency improvement, associated savings, implementation cost for each recommendation, comparison of the energy performance of major systems with established benchmarks and assessment of maintenance practices and maturity level of energy management system.

Main Findings

Natural gas, electricity, diesel and biomass were the main energy sources of the ten food manufacturing plants. Natural gas accounted for 47% while electricity, diesel and biomass accounted for 32%, 12% and 9% of the total energy consumption of the ten plants respectively.

Fuels such as natural gas, diesel and biomass were used by boilers and process heating systems such as roaster. Electricity was mainly used by production equipment motors, chilled water systems, refrigeration systems, compressed air systems and lighting systems.

The energy consumption profile of the ten plants is as follows:

- Boilers (59%)
- Production equipment motors (15.5%)
- Process heating systems (8.5%)
- Chilled water systems (3.8%)
- Refrigeration systems (2.7%)
- Compressed air systems (2.3%)
- Lighting (1.7%)

Majority of the boilers were steam boilers, which operated at pressures ranging from 7 to 16 bar. Most boilers (63%) use natural gas as the fuel, while diesel (25%) and town gas (12%) were used by the remaining boilers. The operating thermal efficiency of steam boilers varied from 75 to 83%. The efficiencies of most steam boilers were within the benchmark range of 79 to 81% except for boilers that operated at relatively low loading of about 40%.

The operating COPs (coefficient of performance) of chillers varied from 2.61 to 5.27, which were all poorer than the benchmark value of 6.9. This was mainly due to the age and low cooling capacity of the chillers, low operating supply temperature and the use of air-cooled chillers. Old and low cooling capacity (<300 RT) chillers usually have lower efficiencies.

Similarly, the chilled water system efficiency (COP) was also found to be much lower than the benchmark value due to inefficient chillers, pumps and cooling towers.

The COPs of refrigeration systems, except for those that were air-cooled or operating at part-load condition, ranged from 1.2 to 4.0 and were close to the benchmark values for the respective operating temperatures.

Compressed air systems provided air at 5.5 to 7.5 bar for applications such as pneumatic controls and actuators while air at 39 bar was supplied for bottle blowing. Air compressors were mainly the oil-injected type. Some oil-free compressors were used to avoid product contamination. The specific power consumption of most oil-injected air compressors were within the recommended band of benchmark values.

More than 90% of motors used for production equipment were rated at the IE1 and IE2 efficiency level. Some motors were found to be operating at low loading.

Lighting illuminance levels were generally higher than the recommended values. Similarly, the associated lighting power density values were also higher than the recommended values.

**Improvement Measures**

Many energy saving opportunities have been identified. If implemented, these opportunities will yield an annual energy savings of 103.1 TJ or 8.2% of total annual energy consumption. Of the total annual energy savings, 16.4
million kWh (or 59 TJ) of electricity and 44 TJ of fuel savings per year were identified.

Based on the electricity tariffs and fuel charges incurred by the ten plants, the potential savings work out to be about $3.5 million of energy cost savings a year, with an average payback period of 2.9 years.

A summary of the main energy saving opportunities identified are listed below:

**Boiler systems**
- Reduce amount of excess air supplied to the boiler
- Recover heat from flue gas
- Reduce boiler operating pressure
- Recover condensate
- Adopt automatic blowdown system for boilers
- Reduce heat losses from boilers and heating equipment
- Improve boiler loading
- Use heat pumps and solar heaters for hot water applications

**Chilled water systems**
- Increase supply temperature for chillers
- Replace air-cooled chillers with water-cooled chillers
- Replace chillers with new equipment sized to match the load
- Replace inefficient pumps and reduce capacity of pumps
- Use variable speed drives (VSD) for cooling tower fans and pumps

**Refrigeration systems**
- Increase suction pressure and reduce condensing pressure for refrigeration systems
- Replace defective refrigeration system controls
- Use VSD compressors
- Replace inefficient refrigeration systems
- Minimise refrigeration load
- Use variable speed evaporator fans

**Compressed air systems**
- Rectify compressed air leaks
- Reduce compressed air usage
- Replace air compressors
- Recover compressed air from high pressure bottle blowing process

**Production systems**
- Replace IE1 and IE2 motors with IE3 or IE4 motors
- Replace motors operating at low loading with smaller motors
Lighting systems

- Replace inefficient lamps
- Reduce illuminance levels

Measures have also been identified to improve the energy management and maintenance practices in the ten plants. In addition, the following recommendations were provided:

- Facilitate interaction among energy managers to share best practices within the food manufacturing sector;
- Prioritise energy management and improve motivation of staff involved in energy management through rewards and recognition;
- Develop ability of energy management team to convince top management to invest in energy efficient technologies;
- Consider newer technologies and more efficient designs when replacing old equipment; and
- Invest resources to identify energy saving opportunities from process equipment and systems, which account for a significant portion of the plant's total energy usage.
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1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

LJ Energy Pte Ltd was appointed by National Environment Agency (NEA) Singapore to conduct an Energy Efficiency Benchmarking Study of Food Manufacturing Plants in Singapore.

Ten food manufacturing plants are located in various parts of Singapore participated in the benchmarking study.

The study involved developing an assessment framework to evaluate the energy efficiency of major systems and equipment installed in food manufacturing plants and thereafter conducting level 3 audits for each individual plant. The audits included on-site measurement of each major system and equipment to obtain the data and other information required for execution of the assessment framework.

On conclusion of the level 3 audits, each respective plant received a customised report. The reports included the energy consumption profile for the main systems, areas identified for improvement of energy efficiency, associated savings, implementation cost for each recommendation, comparison of the energy performance of key equipment and systems with established benchmarks and assessment of maintenance practices and maturity level of energy management system.

This final report is an aggregation of the main findings and benchmarking results for all the ten plants. This report also includes a summary of effective measures to improve energy efficiency in the participating plants, including identifying major systems and equipment that have a greater scope for energy efficiency improvement and an assessment of the quantum of financial investment required to implement the recommendations.

1.2 OVERVIEW OF FOOD MANUFACTURING INDUSTRY

Singapore’s food and beverage manufacturing industry has made great strides since the country’s independence 50 years ago when food manufacturers were predominantly domestic-oriented and comprised a majority of small and medium enterprises (SMEs) as well as family-run businesses.

Over time, with investment and R&D, these businesses modernised to increase productivity and produce higher end food products. Now, the food manufacturing sector is a major contributor to the Singapore economy with
more than 840 establishments accounting for a value-add of more than $2.8 billion which is a 0.7% of the GDP (ref. Economic Development Board and Spring Singapore).

Food manufacturing plants are energy-intensive plants and a significant portion of their operating cost is due to energy use. Therefore, improving energy efficiency has great potential to reduce the operating cost and thereby improve the profitability of food manufacturing plants in Singapore.

To enhance business competitiveness, some food manufacturing plants are undergoing restructuring. Cost savings achieved through energy efficiency measures would play a key role in enhancing the competitiveness of the industry in Singapore.

1.3 OBJECTIVES

The main objectives of the Study were to:

a) develop an energy consumption profile of the food manufacturing industry by studying the major systems and equipment of each participating plant

b) identify suitable metrics to assess and benchmark the energy efficiency of major systems and equipment;

c) assess and benchmark the energy efficiency of major systems and equipment of participating plants; and

d) identify effective measures to improve the energy efficiency of major systems and equipment, taking into account factors such as improvement potential of energy efficiency measures identified and implementation feasibility and cost.

1.4 INFORMATION ON THE PARTICIPATING PLANTS

To ensure that the findings of the study provide an accurate representation of food manufacturing plants in Singapore, the participating plants were selected based on their overall energy consumption and type of energy consuming equipment and systems installed in their facilities.

Out of the ten plants selected, nine plants have a minimum energy consumption of 30 TJ per year while the remaining plant has a minimum energy consumption of 15 TJ per year.

The ten participating plants are involved in manufacturing of either finished food products or ingredients used in other food manufacturing
processes. The final food products manufactured by these plants can be further categorised as beverage, dairy, noodle, cooked food and frozen food.

1.5 DESIGNATION OF PLANTS

To protect the confidentiality of the data, each participating plant has been assigned an identification number and are denoted as plant-1 to plant-10 in this report.

The assigned number for each plant is used throughout the report such that a particular plant denoted as plant-1 is referred to as plant-1 in all charts and analysis in the report. The assigning of plant numbers is random and does not infer a ranking of the performance of the plants.

The ten participating food manufacturing plants do not have the same energy consuming systems. Therefore, the charts only show comparison of same systems or equipment against the benchmarks. For plants which have more than one of the same system or equipment and are vastly different such that the findings cannot be combined, they have been separately designated (e.g. plant-7(a) and plant-7(b)) in the analysis.
2.0 ASSESSMENT FRAMEWORK

An Assessment Framework ("AF") was developed to evaluate the energy efficiency of major systems and equipment of the plants. The main objectives of the AF are to:

a) identify major energy consuming systems and equipment that account for at least 80% of the total primary energy consumption of each participating plant;

b) identify suitable Energy Performance Indicators ("EnPIs") for assessing the energy efficiency of the major energy consuming systems and equipment;

c) develop suitable methodologies for measuring the identified EnPIs for the various equipment and systems; and

d) benchmark the performance of the equipment and systems using the measured EnPIs with industry established values or standards.

2.1 METHODOLOGY

The methodology used to develop the energy performance assessment framework for the food manufacturing plants is illustrated in Figure 2.1

![Assessment framework](image)

**Figure 2.1. Assessment framework**

2.2 EVALUATION METRICS

Evaluation metrics were developed to assess the energy performance of systems and equipment that accounted for at least 80% of the total energy consumption of each participating plant.

The evaluation metrics developed included:

- Identification of EnPIs
- Methodology for computing EnPIs
The detailed Assessment Framework used for the study is published as a separate document.
3.0 SUMMARY OF FINDINGS

3.1 TYPES OF ENERGY USED

Food manufacturing plants use energy in the form of electricity, natural gas, diesel and biomass. Natural gas, diesel and biomass are used by boilers which produce steam for process requirements. Natural gas is also used by some process heating systems. Electricity is used mainly by systems such as production machine motors, chillers, pumps, cooling towers, compressed air systems and refrigeration systems.

3.2 BREAKDOWN OF ENERGY USAGE

The total annual energy consumption of the ten participating plants was about 350 million kWh (1,260 TJ/year). Figures 3.1 and 3.2 show the breakdown of different types of energy usage by the plants.

![Figure 3.1 Percentage breakdown of different types of energy usage]
Figure 3.2 Breakdown of overall energy usage by the plants

A breakdown of total energy usage by different systems is shown in Figure 3.3. Boiler system was the single largest user of energy accounting for approximately 60% of the total plant energy consumption.

Figure 3.3 Breakdown of total energy usage by system

Breakdown of electricity usage by the different end-users is shown in Figure 3.4. Production equipment was the single largest user of electrical energy accounting for about 48% of the total plant electrical energy consumption while chillers, refrigeration systems and compressed air systems consumed about 12%, 8% and 7% respectively.
3.3 BOILER SYSTEMS

Boiler system is one of the main energy consumers in food manufacturing plants and accounted for about 60% of the total energy consumed in the ten plants that participated in the study.

Steam and hot water boilers were used for heating and process applications like drying. All the boilers evaluated in the study were fire-tube boilers, except for one which was a water-tube boiler.

Natural gas and diesel were the main types of input energy source for the boilers except for three individual boilers which operated using town gas, biomass and electricity respectively.

The operating pressure of the boilers were set between 7 and 16 bars (gauge pressure) and temperatures between 170 and 240°C in the individual plants, as shown in Figure 3.5. The boiler operating pressure and the respective saturation temperature of steam were found to be much more than the highest value required for process applications in some plants.
Operating thermal efficiency, which is a measure of how much energy in the input fuel is converted to useful energy in the generated steam, varied from 75 to 83% (excluding electrical boiler) as shown in Figure 3.6. The thermal efficiencies of boilers operating at low loading (39 to 40%) were 6 to 8% lower than the best operating efficiency. The efficiency of the electric boiler was lower than expected as the demand for steam was intermittent and the boiler was in hot stand-by mode 24 hours a day.
Concentration of $O_2$ (oxygen) in the flue gas varied from 5 to 11.6%. These values were relatively high compared to the recommended value of 2%, which translates to an excess air level of 10% for efficient combustion. Figure 3.7 shows the $O_2$ concentration and temperature of flue gas for the different plants. Generally, the flue gas temperatures of those boilers operating with more excess air were low.

Figure 3.7 Flue gas temperature and oxygen concentration

Figure 3.8 Net combustion efficiency
Only three plants (plants 1, 3 and 4) used economizers to recover heat from the exhaust flue gas. The net combustion efficiency is a measure of how much excess air is required by the burner for complete combustion (i.e. highest efficiency at no excess O₂). The combustion efficiencies of the steam boilers varied from 83 to 92% as shown in Figure 3.8. As expected, the hot water boiler operated at a better combustion efficiency of 95%.

Only one plant (plant 1) used an automatic blowdown system to maintain the boiler TDS (total dissolved solids) while all the other plants relied on periodic manual blowdowns.

The amounts of condensate recovered ranged from 23% to 88% as shown in Figure 3.9. The low condensate recovery rate of 23% was because the particular plant used steam for both food preparation as well as heating chemicals. The condensate from the latter process was discarded to prevent contamination of the food items being manufactured. Although the amount of condensate recovered for plant 1 was relatively low, some of the condensate was actually used as hot water for process applications. The condensate recovery was low for plant 10 since a significant portion of the steam was used in the food manufacturing process.

![Figure 3.9 Amount of condensate recovered](image)
3.4 CHILLED WATER SYSTEMS

Chilled water systems, which accounted for close to 4% of the total energy consumption and 12% of the electricity consumption, were used in most plants. Chilled water systems operated 24 hours a day and were used mainly for process cooling. They were generally more than 10 years old.

In some plants, chilled water systems were also used for space cooling. In other plants, package units and split air conditioning systems were used for space cooling. All the chilled water systems used chilled water except for two systems that used glycol for low temperature operation. The chilled water and glycol supply temperatures ranged from 3.6 to 16°C as shown in Figure 3.10.

![Figure 3.10 Cooling medium supply temperature](image)

The average operating cooling loads for the chilled water systems ranged from 95 to 500 RT as shown in Figure 3.11.
Figure 3.11 Average cooling load

Condenser water supply temperatures for the water-cooled chillers varied from 27.5 to 30°C. The operating COPs (coefficient of performance) of the chillers ranged from 2.61 to 5.27 (0.67 to 1.3 kW/RT). Air-cooled chillers have the lowest COPs (2.61 to 3.17). Water-cooled chillers in systems with an average cooling load of about 500 RT operated at the highest COP of 4.73 and 5.27.

Figure 3.12 Operating COP of chillers

Pumps were used to circulate the cooling fluid, which was chilled water or glycol, from the chillers to the various cooling loads. Most pumps were
oversized for their applications, resulting in higher than design flow and low ΔT (difference in return and supply temperatures). As shown in Figure 3.13, the minimum ΔT was about 2 to 3.5°C while the maximum ΔT for most plants was about 4 to 5°C. The ΔT was relatively higher for plant 8 since the chillers were used for process cooling applications.

![Figure 3.13 ΔT of cooling fluid](image)

*Figure 3.13 ΔT of cooling fluid*

![Figure 3.14 Efficiency and specific power consumption for chilled water pumps](image)

*Figure 3.14 Efficiency and specific power consumption for chilled water pumps*
All chilled water pumps operated at constant speed while some pumping systems have throttling valves to reduce flow. The pump efficiencies (mechanical output of pump/electrical input to motor) varied from 30 to 64%, as shown in Figure 3.14.

Pumps were used to circulate water from the condenser of water-cooled chillers to the cooling towers. Most pumps were oversized for the application resulting in higher-than-design flow rates and low \( \Delta T \) (difference in return and supply temperatures) as shown in Figure 3.15. The minimum \( \Delta T \) was about 1 to 4°C while the maximum \( \Delta T \) was about 2 to 8°C.

![Figure 3.15 ΔT for condenser water](image)

All condenser water pumps operated at constant speed while some pumping systems have throttling valves to reduce flow. The pump efficiencies (mechanical output of pump/electrical input to motor) varied from 33 to 70% as shown in Figure 3.16.
Figure 3.16 Efficiency and specific power consumption for condenser water pumps

A mix of cross-flow and counter-flow cooling towers were used for water-cooled chillers. In all except one plant, the chilled water systems used dedicated cooling towers that were not used for process cooling applications. The supply temperatures of water from the cooling towers ranged from 27.5 to 30°C and were generally within design values.

Figure 3.17 Cooling tower water supply temperature
All cooling tower fans, except one, operated at constant speed. As shown in Figure 3.18, the specific power consumption values of cooling tower fans \((\text{kW}_c/\text{kW}_e)\) varied from 29 to 117. The high specific power consumption of 117 was for the plant using variable speed fans while the very low value of 29 was due to low \(\Delta T\) (difference between return and supply temperatures) of 2.1°C.

![Figure 3.18 Specific power consumption for cooling towers](image)

The efficiencies (COP) of the chilled water systems, which are derived from the efficiencies of their respective chillers, cooling medium pumps, condenser water pumps and cooling towers, are shown in Figure 3.19.

The COPs of air-cooled chilled water systems varied from 1.3 to 2.9 \(\text{kW}_c/\text{kW}_e\). COPs of low capacity chilled water systems (20 to 30 RT) varied from 1.3 to 2.0 \(\text{kW}_c/\text{kW}_e\), while the COPs varied from 2.9 to 4.0 \(\text{kW}_c/\text{kW}_e\) for relatively higher capacity chilled water systems (above 120 RT).
3.5 REFRIGERATION SYSTEMS

Refrigeration systems were used for low temperature cooling applications and cold rooms in five of the ten plants that participated in the study. They accounted for 2.7% of the overall energy consumption of the ten plants and 8.2% of the overall electricity consumption. All plants, except plant 5 and plant 10, used ammonia as the refrigerant. Plant 5 and plant 10 used R507 and R404a respectively. The operating cooling load of the refrigeration systems ranged from 36 to 150 RT.

Most refrigeration systems have water-cooled evaporative condensers or water-cooled condensers with cooling towers. The evaporators used were flooded type, liquid overfeed and direct expansion. The operating temperatures ranged from -30 to -10°C. The COPs of the refrigeration systems varied from 1.2 to 4.0. A summary of the energy performance of the refrigeration systems is shown in Figure 3.20.

![Figure 3.19 COPs for chilled water systems](image-url)
3.6 COMPRESSED AIR SYSTEMS

Compressed air is used in most plants for the operation and control of pneumatic equipment, machines and processes. They accounted for 2.3% and 7.2% of the overall energy usage and electricity usage of the ten plants respectively. A combination of fixed speed and variable speed drive (VSD) compressors were used. While most compressors were oil-injected type, a few systems used oil-free type to prevent contamination of the manufacturing processes. All plants used refrigerated dryers except for one which did not use a dryer.

The compressed air systems’ operating pressures ranged from 5.5 to 7.5 bar, except for one system that operated at 39 bar for bottle blowing as shown in Figure 3.21.
The specific power consumption values (kWh/Nm³) of compressed air systems are shown in Figure 3.22. These values ranged between 0.07 and 0.1 kWh/Nm³, except for the oil-free type and high pressure system that operated at much higher values.
The compressed air leakage rate estimated for each of the plant during plant shutdown, where there were no manufacturing activities, ranged from 6% to 44%.

![Figure 3.23 Compressed air leakage rate](image)

### 3.7 PROCESS COOLING SYSTEMS

Process cooling towers and associated pumps were used to remove heat from manufacturing processes. The systems were operated for 24 hours a day and accounted for 0.7% and 2.3% of the overall energy usage and electricity usage of the ten plants respectively.

The system consists of cooling towers and circulation pumps. All the pumps and cooling tower fans were operated at constant speed irrespective of the actual heat load of the processes.

The circulating pumps’ specific power consumption \((kW_e/kW_c)\) values ranged from 0.02 to 0.031 while the pump efficiencies (mechanical output of pump/electrical input to motor) varied from 45 to 60% as shown in Figure 3.24.
The specific heat rejection rates of the cooling towers (kWh/kWe) varied from 20 to 270 while the cooling water supply temperatures were between 26.8 and 37°C as shown in Figure 3.25.

Figure 3.24 Pump specific power consumption and efficiency

Figure 3.25 Cooling tower heat rejection rate and supply temperature
3.8 PRODUCTION SYSTEMS AND MOTORS

Motor-driven equipment such as mills, rollers, grinders, pulverizers and refiners were used in various production processes. They accounted for 15.5% and 48% of the overall energy consumption and electricity consumption respectively.

Motors of different capacities were used to operate the equipment. The efficiency ratings of majority of the motors (more than 90%) were IE1 and IE2. Measured power consumption showed that loading of some motors were below 40%.

Motors of smaller capacities between 0.25 and 1.5 kW were used for packaging and filling machines for bottling and packing of different products. The average energy consumption of the packaging systems was only 0.2% of the overall energy consumption of the plants and 0.7% of the electricity consumption of the plants.

3.9 LIGHTING

Artificial lighting was provided for production areas, warehouses (storage areas), offices and common areas. Although a combination of the T8 fluorescent lamps, PLC downlight, LED, mercury vapor, sodium vapor and halogen lamps was used, the majority of lamps used was T8-type fluorescent lamps.

Lighting systems accounted for 1.7% of the overall energy consumption and 5.4% of the electrical consumption.

Lighting illuminance levels (lux) and lighting power density (W/m²) for production areas, warehouse storage areas and offices are shown in Figures 3.26 to 3.28.
Figure 3.26 Illuminance levels and power density – production areas

Figure 3.27 Illuminance levels and power density – warehouse areas
Illuminance levels for production areas ranged from 100 to 650 lux and the corresponding power densities ranged from 4 to 22 W/m². Similarly, the illuminance levels for warehouse storage areas and offices ranged from 50 to 350 lux and 295 to 884 lux respectively. The corresponding lighting power densities ranged from 2 to 13 W/m² in the warehouse and 4 to 22 W/m² in the office areas.
4.0 BENCHMARKING RESULTS

The performance of the various systems was evaluated using the EnPIs (energy performance indicators) and benchmark values listed in the Assessment Framework. Assessment of the performance of the energy consuming systems in the ten plants against the benchmark values is described in this section of the report.

4.1 BOILER SYSTEMS

4.1.1 BENCHMARKS

The EnPIs selected for assessing the performance of boiler systems are:

(a) Boiler thermal efficiency; and
(b) Condensate recovery factor.

Boiler thermal efficiency

The boiler thermal efficiency is defined as:

\[
\text{Boiler thermal efficiency} = \frac{\text{Heat output to steam, kW}}{\text{Heat input of fuel, kW}}
\]

Heat output to steam = heat content of steam (kW) – heat content of feedwater (kW)

Heat input of fuel = mass flow rate of fuel (kg/s) x calorific value of fuel (kJ/kg)

Benchmark value of boiler thermal efficiency: \( \geq 79\% \)

Condensate recovery factor

Condensate recovery factor is defined as the fraction of the condensate recovered from the generated steam and returned back to the boiler. The condensate recovery factor is expressed as:

\[
\text{Condensate recovery factor} = \frac{\text{Amount of Condensate recovered, } m^3/\text{day}}{\text{Feed water flowrate, } m^3/\text{day}}
\]

Benchmark value of condensate recovery factor: Since this value is process dependent, there is no established benchmark value. However, based on the findings of the study, for general heating applications, the recommended industry benchmark is \( \geq 80\% \).
4.1.2 OBSERVATIONS

As shown in Figure 4.1, thermal efficiencies of the boilers were generally close to the minimum benchmark value of 79%. The few boilers operating below the recommended minimum value were operating at low loading of 39 to 40%. It was also evident from the data that, higher boiler loading resulted in higher thermal efficiency, and boilers operating at above 60% loading have a 6 to 8% superior thermal efficiency.

Figure 4.1 Thermal efficiency of boilers
Figure 4.2 Condensate recovery factor of boiler systems

The amount of condensate recovered is shown in Figure 4.2. The amount of condensate recovered for the three plants which used steam purely for heating applications was above the industry benchmark value of 80%.

The main reason why the condensate recovery rate was lower than the target value for the majority of plants was because part of the steam was used in manufacturing processes. In addition, the low condensate recovery rate of 23% for plant 3 was because this particular plant used steam for both food preparation as well as heating chemicals. The condensate from the latter process was discarded to prevent contamination of manufactured food items. Although the amount of condensate recovered for plant 1 was relatively low, the condensate was actually used as hot water for process applications thereby, not incurring additional energy losses. The condensate recovery was low for plant 10 since a significant portion of the steam was used in the manufacturing process.

4.1.3 RECOMMENDATIONS

Based on the findings of the study, the following are the recommendations to improve the performance of boiler systems to achieve the various benchmark values.

- The operating pressures of the boilers ranged from 7 to 16 bar (Figure 4.3). It was observed that the operating pressure could be reduced by 1 to 2 bar for some plants since the maximum pressure and temperature of steam required were much lower than the current operating values.
Reducing steam pressure will result in better operating efficiency, lower energy usage to raise the enthalpy of feedwater to the operating pressure and will also help to lower the overall steam demand due to higher latent heat content.

![Steam Pressure Chart]

**Figure 4.3 Boiler operating pressure**

- Various fuels were used for the boilers. The most commonly used fuels were natural gas (where available) and diesel. One boiler used biomass which was a by-product of the manufacturing process while another used an electric boiler.
- Based on the types of fuel used, percentage concentration of O$_2$ in the flue gas represented the percentage of excess air provided for combustion. As shown in Figure 4.4, the concentration of O$_2$ in flue gas varied from 5 to 11.6%, which was relatively higher than the ideal value of 2% (10% excess air).
- Higher-than-required excess air resulted in part of the heat being unnecessarily carried away by the flue gas resulting in lower boiler thermal efficiency.
The flue gas temperatures are also shown in Figure 4.4 and varied from 171 to 243°C, except for plant 5 that used a hot water boiler.

As can be seen from Figure 4.4, when the amount of excess air increased, the flue gas temperature dropped.

Only three plants (plants 1, 3 and 4) have economisers to recover heat from flue gas as indicated in Table 4.1.

Since the flue gas temperature was much higher than the acid dew-point (temperature required to prevent acid formation), economisers can be installed to recover waste heat from the flue gas to pre-heat feed-water.

Most plants (except plant 1) did not have automatic blowdown control systems to maintain the TDS level. Installing such a system would help to maintain a higher TDS level of 2500 ppm. This would result in lower water usage and lower heat losses.

When an automatic blowdown system is installed, a flash steam recovery vessel and a heat recovery system can be incorporated to pre-heat make-up water using the waste heat in the blowdown.

Combustion efficiency of a boiler represents the ability of the burner to burn the fuel completely using a specific air to fuel ratio. With increase in excess air, boiler efficiency decreases as part of the heat energy is lost through the extra air in the flue gas. The combustion efficiencies of the boilers are shown in Figure 4.5. They varied from 83 to 91% (except for the hot water boiler which has a 95% efficiency). The combustion efficiencies of all the boilers were better than the 79%
benchmark. Figure 4.5 also indicates that the boilers operating with high excess air have lower combustion efficiency.

<table>
<thead>
<tr>
<th>Plant</th>
<th>Auto blowdown system</th>
<th>Economiser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Plant 2</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Plant 3</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Plant 4</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Plant 5</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Plant 6</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Plant 7</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Plant 8</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Plant 9</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 4.1 Information on boiler systems

![Figure 4.5 Combustion efficiencies of boilers]

**4.2 CHILLED WATER SYSTEMS**

**4.2.1 BENCHMARKS**

Chilled water systems consist of chillers, pumps and cooling towers (for water-cooled chillers). The EnPIs selected for assessing the performance of chiller systems are:

**Chiller efficiency**

Chiller efficiency, which is the coefficient of performance (COP), is defined as:
**Efficiency or COP**

\[
\text{Efficiency or COP} = \frac{\text{Cooling produced, } kW_c}{\text{Electric power consumption of chiller, } kW_e}
\]

*Cooling produced* = mass flow rate of cooling medium (kg/s) x specific heat capacity of water (kJ/kg.K) x temperature difference of cooling medium entering and leaving chiller.

Benchmark value of chiller efficiency: \( \text{COP} \geq 6.9 \) (0.51) for water-cooled systems \( \geq 300 \) RT (industry benchmark based on findings of the study).

Benchmark based on SS530 (water-cooled chillers):
- \(<150\) RT \( \quad \text{COP} = 5.771 \) (0.609 kW/RT)
- \( \geq 150\) RT and \( <300\) RT \( \quad \text{COP} = 5.771 \) (0.608 kW/RT)

**Pump specific power consumption**

Specific power consumption of chilled water / glycol circulation pumps and condenser water pumps is defined as:

\[
\text{Specific power consumption} = \frac{\text{Power consumed by pump, } kW_e}{\text{Cooling produced by chiller, } kW_c}
\]

Benchmark value of pump specific power consumption: 0.0085 kW\(_e\)/kW\(_c\) (industry benchmark) or 0.03 kW\(_e\)/RT for applications with normal pressure drop.

**Pump system efficiency**

Pump system efficiency (combined for pump and motor) for chilled water / glycol pumps and condenser water pumps is defined as:

\[
\text{Pump system efficiency(%)} = \frac{\text{Pump flow rate, } m^3/s \times \text{pump head, } N/m^2}{1000 \times \text{Pump motor power, } kW_e}
\]

Benchmark value of pump system efficiency: 72% (pump 80% x motor 90%).

**Cooling tower specific heat rejection rate**

Cooling tower specific heat rejection rate is defined as:

\[
\text{Specific heat rejection rate} = \frac{\text{Cooling produced by chillers, } kW_c}{\text{Power consumed by cooling tower fans, } kW_e}
\]

Benchmark value of cooling tower specific heat rejection rate: \( \geq 117 \) kW\(_c\)/kW\(_e\) (industry benchmark).
Chiller system efficiency

Chilled water system efficiency, which is the system coefficient of performance (COP), is defined as:

\[ \text{System Efficiency or COP} = \frac{\text{Cooling produced, } kW_c}{\text{Electric power consumption of system, } kW_e} \]

*Cooling produced = sum of cooling produced by all chillers in operation*

*Electrical power consumption of system = power consumed by chillers, pumps and cooling towers*

Benchmark value of chilled water system efficiency: \( \text{COP} \geq 5.85 \) or 0.6 \( kW_c/RT \) for water-cooled chillers (industry benchmark).

4.2.2 OBSERVATIONS

Chillers

The operating COPs of the chillers are shown in Figure 4.6. The COPs of all the chillers were less than the industry benchmark value of 6.9 which is based on water-cooled chillers of capacity 300 RT or more.

![Figure 4.6 Efficiency (COPs) of chillers](image)

The COPs were between 2.61 to 3.17 for the air-cooled chillers. The COP of the water-cooled chiller in plant 7 (designated as 7(b)) was also relatively poor due to the low cooling load (20 RT). The chillers operating at cooling load of 125 to 165 RT have COPs of about 4. The chillers operating at relatively higher load (300 to 550 RT) have better COPs of 4.73 to 5.27.
Some of the reasons for the low COPs are listed below.

a) Chillers used in three of the plants are air-cooled
b) All chillers except for some in plant 5 and plant 7 have rated capacities less than 300 RT
c) The supply temperature of the cooling liquid is less than 6.7°C for plant 1 and plant 7.
d) Age of the chillers are more than 10 years

**Chilled water and glycol pumps**

The estimated specific power consumption and efficiencies of the chilled water and glycol pumps are shown in Figures 4.7 and 4.8.

![Figure 4.7 Specific power consumption of chilled water / glycol pumps](image)

Specific power consumption of the chilled water and glycol pumps ranged from 0.02 to 0.07 kW_e/kW_c. The specific power consumption of pumps in plant 2 met the benchmark value while the specific power consumption of pumps in plant 5 and plant 10 were close to the benchmark value.

The high pump specific power consumption was due to the following reasons:

- Pump capacity was generally more than required as indicated by low ΔT (Figure 3.14), which for most systems were between 2 to 4.5°C (can be increased to be higher than 5°C)
- All pumps operated at constant speed, irrespective of the demand
- High pressure losses due to throttling and piping system design
- Low efficiency of pumps and motors as indicated in Figure 4.8.
As can be seen in Figure 4.8, the efficiencies of the chilled water and glycol pumps were less than the benchmark value for all the plants.

Pumps in plants 2, 5 and 8 have better efficiencies which were between 55 and 64%. This resulted in better specific power consumption (Figure 4.7). The low pump efficiencies seen in other plants were probably due to the original design and selection of the pumps.

**Condenser water pumps**

The estimated specific power consumption and efficiencies of the condenser water pumps are shown in Figures 4.9 and 4.10.

Specific power consumption of the condenser water pumps ranged from 0.02 to 0.03 kWₑ/kWₑ for all plants except plant 6, which has a high specific power consumption of 0.12. This was due to the flow rate being much higher than required (ΔT only 2.1°C) and the relatively low pump efficiency of 33% (Figure 4.10).

Although the pump efficiencies were less than the benchmark value of 72% for all the plants, the efficiencies were generally better than those of the chilled water and glycol pumps.
In Figure 4.11, which shows both the specific power consumption and efficiencies of the condenser water pumps, higher pump efficiencies for plants 1, 2 and 3 resulted in lower specific power consumption.
As shown in Figure 4.12, only the cooling tower in plant 1 was able to achieve the minimum target specific power consumption of 117 kW_c/kW_e. This was because, only this cooling tower has VSDs (variable speed drives) installed to vary the fan speed in response to changes in the heat rejection load. Data indicated that the cooling towers installed in plants 2, 5, 6 and 7 would be able to achieve the target value of 117 kW_c/kW_e if VSDs were installed to modulate the fan speed. The specific power consumption for the tower in plant 6 was extremely low since the heat rejection load was only about 30%.
**Chilled water system performance**

The COPs of the chilled water systems, which include the chillers, pumps and cooling towers (for water-cooled chillers), are shown in Figure 4.13. The COP values ranged from as low as 1.3 to 4.0 and were all much lower than the industry benchmark value of 5.85 kW\(_c\)/kW\(_e\), which was for water-cooled chillers operating at 7\(^\circ\)C and minimum chiller capacity of 300 RT.

The main reasons for the low system COP are:

a) Some chillers are air-cooled

b) Most chillers are old (over 10 years old) and have low rated efficiency

c) Use of multiple low-capacity chillers (only plants 5 and 7 have chillers with capacity of 300 RT or more)

d) Low supply temperature of cooling fluid for plants 1 and 7 due to the need for low relative humidity in some areas served by the systems

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**Figure 4.13 Efficiency of Chilled water systems**

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**4.2.3 RECOMMENDATIONS**

Based on the findings of the study, following are the recommendations to improve the performance of the chilled water systems so that they can achieve the various benchmark values.

- Replace air-cooled with water-cooled chilled water systems (subject to availability of space and water)
- Replace old chillers which have reached the end of their useful life with more efficient new chillers sized to match the cooling load
- Consolidate multiple chilled water systems into a single system as it can operate at better efficiency due to improved loading from demand aggregation
- Increase the supply temperature of chilled water where possible
- Install standalone dehumidification / cooling systems for areas that require low relative humidity so the chilled water system can be operated at a higher temperature
- Convert glycol cooling systems into chilled water systems for better heat transfer characteristics.
- Replace oversized pumps with pumps sized to match load requirements
- Select pumps and motors to have best efficiency at the expected operating point
- Increase the ΔT for both the cooling fluid as well as condenser water to minimise pumping power
- Install VSDs with suitable controls where applicable to vary pump speed in response to load variations
- Remove throttling valves and improve piping design to reduce pressure losses
- Install VSDs with suitable controls for cooling tower fans to modulate speed in response to changes in the load

4.3 REFRIGERATION SYSTEMS

4.3.1 BENCHMARKS

The EnPI selected for assessing the performance of refrigeration systems is the coefficient of performance (COP) which is a measure of the system efficiency.

COP is defined as:

\[
COP = \frac{\text{Cooling produced refrigeration system, } kW_c}{\text{Electric power consumption of refrigeration system, } kW_e}
\]

Electric power consumption of refrigeration system = power consumed by compressor + power consumed by heat rejection system pumps and fans (where applicable)

Benchmark value of COP based on screw compressors using evaporative condensers (industry benchmark):
Evaporator / Condenser temperature, °C | Efficiency (COP), kW_e/kW_e
---|---
-35/+35 | 1.8
-20/+35 | 2.9
-5/+35  | 4.3

### 4.3.2 OBSERVATIONS

The operating COPs of the refrigeration systems are shown in Figure 4.14. Most of the refrigeration systems used evaporative condensers or water-cooled condensers except for plant 10 which used an air-cooled condenser. The COPs of the refrigeration systems used in plants 2 and 4 were close to the benchmark values (based on the operating temperatures). The low COP for plant 4 was due to the operation of more compressors caused by a malfunctioned control system while the low COP for plant 5 was due to the use of multiple low-capacity reciprocating compressors.

![Figure 4.14 Efficiency of the refrigeration systems](image)

### 4.3.3 RECOMMENDATIONS

Based on the findings of the study, the recommendations to improve the performance of the refrigeration systems to achieve the benchmark values are as follows:
- Since the refrigeration system’s compressor power consumption depends on the pressure lift (pressure difference between the evaporator and condenser), the primary aim is to reduce it
• Evaporator temperature should be set based on maximum allowable temperature of the process cooling or cold room requirement
• The compressor suction pressure should be set so that the saturation temperature is not higher than 10°C below the temperature of the refrigerated space or process.
• Air-cooled condensers should be replaced with evaporative condensers to lower the condensing pressure
• If the condensing pressure is high when using evaporative condensers, check the heat rejection capacity of the condenser and install additional capacity or if available, operate spare condensers in parallel with the one normally in operation
• Check sensors and controls to ensure that only the minimum number of compressors required to satisfy the load is in operation
• Use variable speed compressors where possible
• For systems that need not operate below 0°C, chilled water or glycol systems should be used.
• Reduce the refrigeration load by minimizing heat gain into the refrigerated space by means such as sealing openings, improving insulation, minimizing lighting usage within the refrigerated space and using energy efficient lighting such as LEDs.

4.4 COMPRESSED AIR SYSTEMS

4.4.1 BENCHMARKS

The EnPIs selected for assessing the performance of compressed air systems are:

(a) Specific power consumption
(b) Leakage rate

Specific power consumption

Compressed air system specific power consumption is defined as:

$$\text{Specific power consumption} = \frac{\text{Average energy consumption of compressed air system, kWh}}{\text{Average free air delivery, Nm}^3}$$

Benchmark value of specific power consumption: (ref. German Energy Agency - dena)
<table>
<thead>
<tr>
<th>Pressure ratio*</th>
<th>Specific power consumption, kWh/Nm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.05 – 0.073</td>
</tr>
<tr>
<td>5</td>
<td>0.058 – 0.083</td>
</tr>
<tr>
<td>6</td>
<td>0.067 – 0.097</td>
</tr>
<tr>
<td>7</td>
<td>0.073 – 1.07</td>
</tr>
<tr>
<td>8</td>
<td>0.08 – 0.117</td>
</tr>
<tr>
<td>9</td>
<td>0.087 – 0.127</td>
</tr>
<tr>
<td>10</td>
<td>0.092 – 0.135</td>
</tr>
<tr>
<td>20</td>
<td>0.113 – 0.192</td>
</tr>
</tbody>
</table>

*Pressure Ratio PR = Ratio of outlet to inlet pressure of compressor

**Leakage rate**

Compressed air leakage rate was determined by switching off equipment which normally used compressed air (during plant shut-down) and recording the load and unload times of the compressor.

The leakage rate is defined as:

\[
\text{Leakage rate} = \frac{(\text{Free air delivery rate}, m^3/\text{minute}) \times (\text{Average load time, minutes})}{(\text{Average load time, minutes} + \text{Average unload time, minutes})}
\]

Benchmark value of compressed air leakage rate: <2%

**4.4.2 OBSERVATIONS**

The specific power consumption and operating pressure of the compressed air systems are shown in Figure 4.15. The specific power consumption values for oil-injected compressors operating at pressure of 5.5 to 7.5 bar ranged from 0.07 to 0.1 kWh/Nm³. The specific power consumption values of the oil-free systems were higher and ranged from 0.13 to 0.14 kWh/Nm³ while the high pressure (39 bar) compressor has a specific power consumption of 0.21 kWh/Nm³.
Figures 4.15 Specific power consumption of compressed air systems

Specific power consumption values of compressed air systems increased with increase in pressure ratio (ratio of inlet to discharge pressures). Figure 4.16 shows the values of specific power consumption and pressure ratio for the various plants plotted in relation to the lower and upper bands of the benchmark values.

As can be seen from Figure 4.16, the operating specific power consumption values of all the oil injected compressors were within the benchmark values except for one plant. The reason for the high specific power consumption for this plant was due to the use of multiple low-capacity reciprocating compressors.
Figures 4.16 Specific power consumption comparison with benchmark values

Compressed air leakage rates of the different plants are shown in Figure 4.17. The leakage rates varied from 6% to as high as 44% and were generally much higher than the target value of <2%.

4.4.3 RECOMMENDATIONS

Based on the findings of the study, the following are the recommendations to improve the performance of compressed air systems.

- Set the lowest operating pressure required to meet user requirements
• Use oil-injected compressors instead of oil-free compressor where possible as the latter is more energy efficient
• Avoid unload operation of compressors by better matching capacity to load
• Use VSD compressors to accommodate varying loads
• Rectify any leaks that may be present in the distribution pipes
• Provide adequate capacity of receiver tanks including secondary tanks closer to high intermittent users
• Use dryers only where required and select dryer type and dew point settings based on actual requirements

4.5 PROCESS COOLING SYSTEMS

4.5.1 BENCHMARKS

The EnPIs selected for assessing the performance of cooling tower systems are:

(a) Specific heat rejection rate of cooling towers
(b) Specific power consumption of pumps
(c) Efficiency of pumps

Specific heat rejection rate

Cooling tower specific heat rejection rate is defined as:

\[
\text{Specific heat rejection rate} = \frac{\text{Heat rejection rate, } kW_h}{\text{Electric power consumption of cooling tower fans, } kW_e}
\]

Benchmark value of specific heat rejection rate: \( \geq 117 \text{ kW}_h/\text{kW}_e \)

Specific power consumption of pumps

The specific power consumption of cooling tower pumps is defined as:

\[
\text{Specific power consumption} = \frac{\text{Power consumed by cooling tower pumps, } kW_e}{\text{Heat rejection rate, } kW_h}
\]

Benchmark value of specific power consumption: \( \leq 0.0085 \text{ kW}_e/\text{kW}_h \).

Pump efficiency

Efficiency of cooling tower water pumps is defined as:

\[
\text{Pump system efficiency(\%)} = \frac{\text{Pump flow rate, m}^3/\text{s} \times \text{pump head, N/m}^2}{1000 \times \text{Pump motor power, kW}_e}
\]

Benchmark value of efficiency of cooling tower water pumps: 72\% (pump efficiency of 80\% and motor efficiency of 90\%)
4.5.2 OBSERVATIONS

Six plants used cooling tower systems for process cooling applications. Comparison of the performance of the process cooling tower systems with benchmark values are shown in Figures 4.23 and 4.26.

![Specific heat rejection rate of cooling towers](image)

**Figure 4.18** Specific heat rejection rate of cooling towers

As can be seen in Figure 4.18, only cooling towers in plants 1 and 3 were able to meet the minimum target heat rejection rate of 117 kW\(_h\)/kW\(_e\). The better specific heat rejection rate for plant 1 was because the cooling tower fans were installed with VSDs while for plant 3, the cooling towers were operating at high water supply temperature.

Specific power consumption values of the pumps ranged from 0.02 to 0.031 and were higher than the benchmark minimum value of 0.0085 (Figure 4.19). The overall pump and motor efficiency of the plants ranged from 45 to 60% (Figure 4.20).
The pump specific power consumption and efficiency values are shown in Figure 4.21. The chart clearly indicates the correlation between pump efficiency and pump specific power consumption (higher the efficiency, lower the specific power consumption), except for plant-3 which operated at a high supply temperature.
4.5.3 RECOMMENDATIONS

Based on the findings of the study, recommendations to improve the performance of cooling towers to achieve the benchmark values are as follows:

- Install VSDs for cooling tower fans and modulate speed based on heat rejection load
- Operate the cooling towers to supply cooling water at the highest temperature acceptable for the cooling applications
- Reduce pump flow rates where possible to increase the $\Delta T$
- Remove throttling or pressure losses in the system to reduce pump head
- Combine multiple systems where possible
- Install VSDs for pumps and vary the pump capacity for variable load systems
- Select the pumps and motors to achieve a minimum combined efficiency of 72%, when replacing pumps

4.6 LIGHTING

4.6.1 BENCHMARKS

The EnPIs selected for assessing the performance of lighting systems are:

(a) Lighting power density
(b) Illuminance level

**Lighting power density**

The lighting power density is defined as:

\[
\text{Lighting power density} = \frac{\text{Power of lamps including gear or ballast}, W_e}{\text{Floor area}, \text{m}^2}
\]

Benchmark values of lighting power density (SS530):
- 7 W/m\(^2\) for warehouses
- 10 W/m\(^2\) for storage areas
- 12 W/m\(^2\) for office areas
- 13 W/m\(^2\) for production areas

**Illuminance level**

Illuminance level or Lux level is the luminous flux incident on a surface of unit area.

Benchmark value of Illuminance level or Lux (SS531 Part-1):
- 100 to 200 lux for warehouses / storage areas
- 200 to 500 lux for production areas
- 300 to 500 lux for office areas

**4.6.2 OBSERVATIONS**

The illuminance levels and lighting power density for production areas, warehouse / storage areas and office areas are shown in Figures 4.22 to 4.27.
**Figure 4.23 Illuminance level for production areas**

**Figure 4.24 Illuminance level for office areas**

Benchmark (SS531 Part-1) 200 – 500

Benchmark (SS531 Part-1) 300 – 500
Figure 4.25 Lighting power density for warehouse / storage areas

Figure 4.26 Lighting power density for production areas
RECOMMENDATIONS

Based on the findings of the study, the following are the recommendations to improve the performance of lighting systems to achieve the benchmark values.

- Reduce the illuminance level in areas which have significantly higher levels by de-lamping
- Replace lamps which are mainly T8 fluorescent with LED lamps
- Redesign the lighting systems to minimize illuminance levels (where applicable)
- Use natural light where possible

4.7 PRODUCTION SYSTEMS AND MOTORS

Motor-driven equipment such as mills, rollers, grinders, pulverizers and refiners were used in various production processes. Motors of different capacities were used to operate different equipment. Different packaging machines were also used for bottling and packing of different finished products.

Since all ten participating plants have vastly different manufacturing processes, the equipment used were very different and its performance cannot be compared. In addition, only a few plants used packaging systems as plants manufacturing food ingredients, frozen food and cooked food did not utilise packing machines and insufficient data is available for a meaningful comparison.
5.0 SUMMARY OF ENERGY SAVING MEASURES

5.1 BOILER SYSTEMS

Improving combustion efficiency

A major loss in boiler systems is due to the hot gases discharged through the chimney. If there is a lot of excess air, the increased quantity of exhaust gas will lead to higher heat losses. Similarly, insufficient air for combustion results in wastage of fuel due to incomplete combustion and reduces the heat transfer efficiency due to soot buildup on heat transfer surfaces.

The amount of excess air required depends on the type of fuel and, in general, a minimum of about 10 to 15% excess air is required for complete combustion. This translates to about 2 to 3% excess oxygen.

The drop in combustion efficiency due to excess air is dependent on the type of boiler and the amount of excess air. Based on the chart (Figure 5.1), if the O\textsubscript{2} concentration is reduced from 5% to 3%, the resulting improvement in efficiency will be about 1% (83% to 84%).

![Figure 5.1 Combustion efficiency versus O\textsubscript{2} concentration (ref. Cleaver-Brooks Boiler Efficiency Guide)](image)

Therefore, for boilers operating at high-excess air levels, the combustion burner operation should be tuned to optimise the air to fuel ratio. This can normally be achieved by adjusting the mechanical linkages that control fuel and air flow to the burner to provide the correct air to fuel ratio at different operating loads for the boiler. Ideally, an oxygen (O\textsubscript{2}) trim system should be installed to continuously monitor the oxygen level in the flue gas and automatically adjust the air to fuel ratio to maximize combustion efficiency.

Heat recovery from flue gas

A significant amount of heat energy is lost through flue gases as all the heat produced by the burning fuel cannot be transferred to the water or steam in the boiler. As the temperature of the flue gas leaving a boiler typically
ranges from 150 to 250°C, about 10 to 20% of the heat energy is lost through it. Therefore, recovering part of the heat from flue gas can help to improve the efficiency of the boiler.

Heat can be recovered from the flue gas by passing it through a heat exchanger (commonly called an economiser) installed after the boiler as shown in Figure 5.2. The recovered heat can be used to preheat boiler feedwater, combustion air, or for other applications. The amount of heat recovered depends on the flue gas temperature and the temperature of the fluid to be heated.

![Figure 5.2 Arrangement of a typical economiser](image)

To prevent corrosion due to acid condensation, the temperature of the flue gas needs to be maintained well above the acid dew point. The acid dew point depends on the sulfur content of the fuel. Some typical values are given in Table 5.1 below.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Acid dew point temperature (°C)</th>
<th>Allowable exit stack temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>66</td>
<td>120</td>
</tr>
<tr>
<td>Light oil</td>
<td>82</td>
<td>135</td>
</tr>
<tr>
<td>Low sulfur oil</td>
<td>93</td>
<td>150</td>
</tr>
<tr>
<td>High sulfur oil</td>
<td>110</td>
<td>160</td>
</tr>
</tbody>
</table>

*Table 5.1 Acid dew point temperature for some common fuels*

The feasibility of installing a heat recovery system for flue gas depends on factors such as the flue gas temperature, allowable exit stack temperature, the inlet temperature of the fluid to be heated and the operating hours of the boiler. Generally, the allowable reduction in flue gas temperature should be at least 25°C for a heat recovery system to be economically viable.

**Reducing operating pressure**

Boilers have a maximum operating pressure rating based on their construction, and a minimum value to prevent carryover of water. The actual operating pressure is normally set based on the requirements of the
end-users, while ensuring it is within the specified maximum and minimum values.

Since boiler efficiency depends on the operating pressure, if the operating pressure is set 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 (lower the pressure, higher the latent heat), as a result of which, less steam is required for a particular heating load. In addition, the heat input required to raise feed-water to the saturation temperature also reduces with lowering of steam pressure. Hence, for the same heating load, the total heat input to the boiler will reduce.

Therefore, the required steam pressure and temperature should be reviewed and the boiler operating pressure set to the lowest possible value while ensuring that it is within the boiler operating specifications.

**Condensate recovery**

In most steam systems, steam is used mainly for heating by extracting its latent heat. The resulting condensate is at steam temperature and still contains a considerable amount of heat. Therefore, returning condensate to the boiler feed-water tank will result in significant fuel energy savings.

Since condensate is distilled water, it is ideal for use as boiler feed-water. Condensate recovery will help to reduce water consumption, water treatment cost, and frequency of boiler blowdown.

Usually, a low feed-water temperature or high make-up water flow indicates that less condensate is recovered. If the make-up water flow is metered, the difference between the amount of steam produced and make-up water flow will give an indication of the amount of condensate that is not recovered. This is especially relevant for applications which do not consume live steam (such as open sparge coils and direct steam injection systems).

For applications where condensate cannot be recovered due to possible contamination, heat can be recovered to pre-heat make-up or feed-water by means of a heat exchanger.

**Automatic blowdown control**

Boiler blowdown is part of the water treatment process and involves removal of sludge and solids from the boiler. Makeup water used for boilers contains various impurities. As water is converted to steam, the concentration of the impurities that remain in the boiler increases. If this concentration is allowed to increase, it will lead to accelerated corrosion, scaling and fouling of the heat transfer surfaces of the boiler. Therefore, it is
necessary to remove part of the water with high concentration of impurities from the boiler through boiler blowdown and replace it with fresh water.

Boiler blowdown is often performed manually, where a fixed quantity of water is drained periodically to maintain the water within acceptable TDS limits.

Blowdown involves replacing discharged boiler water at steam temperature with an equivalent amount of cold water. Energy loss resulting from blowdown can be minimised by installing automatic blowdown systems to reduce excessive blowdown as shown in Figure 5.3.

![Automatic blowdown control system](image)

**Figure 5.3 Automatic blowdown control system (courtesy of Spirax Sarco)**

Automatic blowdown control systems monitor the pH and conductivity of the boiler water and only perform blowdown to maintain an acceptable level water quality when required. Automatic blowdown systems are preferred as they can maintain the TDS level close to the maximum allowable value.

In addition, a heat exchanger can be added to recover heat from blowdown to pre-heat make-up water.

**Reducing losses from boilers and heating equipment**

The surface temperature of boilers, distribution piping, and heating equipment in steam systems is higher than the surrounding areas. Therefore, heat is lost through radiation and convection. The amount of heat lost depends on the surface temperature of the hot surface which in turn depends on the insulation (thickness, thermal conductivity and condition). To minimise heat loss, all hot surfaces should be covered with insulating materials. Furthermore, the insulation should be of adequate thickness and in good condition.
Based on experience of boilers operating at normal conditions, heat loss due to radiation and convection is about 0.5 to 1% for a boiler operating at full load. Since the radiation and convective losses remain the same irrespective of boiler loading, a 1% loss at full load can increase to 4% when the boiler is operating at 25% load.

**Improving boiler loading**

Generally, the thermal efficiency of boilers operating at full load (design capacity) is comparable. However, boilers operating at low load will be inefficient. If a boiler is operated at below 40% of its rated capacity, the losses can account for a significant percentage of the heat input from the fuel resulting in low boiler efficiency (about 5% lower). In such situations, it may be financially justifiable to replace the existing boiler or install a new boiler which is sized to match the required operating load conditions.

**Use of heat pumps and solar heaters**

For hot water systems, heat pumps can be used instead of hot water boilers. Heat pumps operate based on the vapour compression cycle and can operate at COP (coefficient of performance) of greater than 5.0, which means that 5 units of heat can be produced using 1 unit of electrical input. Since heat pumps also produce cooling at the evaporator, this “cold energy” produced can be further utilised to provide air conditioning which can further improve the COP to above 8.0.

Most heat pumps can produce a maximum water temperature of about 60°C. Some heat pumps are able to operate at even higher temperatures but have other constraints such as the need for a minimum loading.

Due to their superior energy efficiency, heat pumps should be considered for hot water applications. In addition, where space is available, solar hot water heaters can be used to pre-heat makeup water to reduce the heating load of the heat pumps.

**5.2 CHILLED WATER SYSTEMS**

**Increasing supply temperature**

In chillers, the compressor lift which is the pressure difference between the condenser and evaporator pressures can be reduced by increasing the evaporator pressure (by increasing the evaporator temperature).

Based on experience, efficiency of chillers improves by about 2 to 4% for every 1°C increase in the set-point of the cooling fluid supply temperature. Hence, the evaporator pressure can be maximised by operating the system to produce cooling fluid at the highest temperature acceptable for heat removal.
In manufacturing processes which require the cooling fluid to be at vastly different temperatures, instead of operating one chilled water system at a particular temperature to suit the lowest value required, two or more chilled water systems can be operated at different temperatures.

If only one particular load requires a low cooling fluid temperature, a separate standalone system can be used to serve only that load so that the main chilled water system can operate at a higher temperature.

Similarly, if a low operating temperature is set to increase dehumidification (low relative humidity), alternative dehumidification systems such as desiccant wheels and run-around coils can be used so that the main cooling system can operate at a higher temperature.

For low temperature system using brine / glycol solutions, once the operating temperature is increased, it may be possible to change the cooling fluid to chilled water which has better heat transfer characteristics.

### Use of water-cooled chillers

In chillers, heat is rejected in the condenser normally to either water or ambient air during condensing and chillers are categorised according to whether the condenser is water-cooled or air-cooled.

In air-cooled chillers, a single fan or a number of fans are used to blow ambient air through the condenser which is normally a finned heat exchanger. Water-cooled chillers have shell and tube heat exchangers where the heat is rejected to the condenser water. This warm condenser water is then pumped to cooling towers where heat is rejected to the environment. Heat transfer at the cooling towers takes place mainly by latent cooling where some of the warm condenser water evaporates absorbing the latent heat of evaporation from the condenser water, thereby cooling it.

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 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 better 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 and should be used where possible.
Sizing of chillers and chiller replacement

The operating efficiency of chillers depends on their loading and generally, the chiller efficiency is best when operating in the range 60% to 100% of the capacity (VSD chillers have different characteristics).

Therefore, chillers should be sized so that they can operate most efficiently at the cooling load. If the cooling load is highly variable, VSD chillers or multiple chillers can be considered to optimise the operating efficiency.

Old and inefficient chillers should be replaced. When selecting new chillers, the cooling demand profile and the part-load performance of the new chillers should be taken into consideration.

Replacing inefficient pumps

In situations where the pump efficiency is low due to the use of an inefficient pump or incorrect pump selection (pump is not operating at the selected duty point), the actual pump operating point (flow rate and pressure head) should be assessed and a new high efficiency pump selected for the required duty.

Reducing capacity of pumps

Pumps are sized to provide the design flow requirements while overcoming the various resistances in the system. Friction losses in piping, across valves and fittings are normally estimated using specification and research data. Due to the uncertainty of these estimated values and provision for possible changes during installation to suit site constraints, safety factors are added to the design. As a result, a pump can end up being over-sized for its intended application.

When the capacity of a pump is more than the required value, it will result in a higher than required liquid flow rate and greater energy consumption by the pump. Sometimes, when the flow rate is high, valves are used to throttle the flow to achieve the required flow rate. This too results in energy wastage.

Therefore, if a pump’s capacity is more than required, the capacity should be reduced to match the demand by reducing the pump speed, trimming the impeller or replacing the pump with a suitably sized pump.

Capacity control of cooling towers

Capacity of cooling towers is dependent on the air flow through them. Therefore, the operating capacity can be reduced by lowering the air flow rate which would result in lower fan energy consumption.
The best means of achieving this is by using variable speed drives (VSDs) to control cooling tower fan speed. The speed of the cooling tower fans in operation can be modulated to maintain a set temperature.

Theoretically the power consumed by fans is proportional to the cube of the fan speed. When the cooling load drops to 80%, the speed of cooling tower fans can also be reduced accordingly resulting in a drop in power consumption of about 50% \((0.8^3 = 0.51)\).

**Operating extra cooling towers**

Almost all installations have one or more stand-by cooling towers to allow servicing and repair of the operating cooling towers. In such cases, the stand-by cooling towers can be run in parallel with the cooling towers already operating so that all operating cooling tower fan speed can be reduced to provide the same amount of heat rejection. Theoretically, two cooling towers operating at 50% speed can provide the same heat rejection as one at 100% speed.

**5.3 REFRIGERATION SYSTEMS**

**Increasing compressor suction pressure**

The operating efficiency of a compressor in refrigeration systems improves when the suction pressure (and temperature) is increased. Based on experience, an increase in 1°C in suction temperature improves the compressor operating efficiency by about 3 to 4%. Therefore, refrigeration systems should be operated at the maximum possible operating temperature.

In applications where a refrigerated space is used for storing different products at different times, then ideally, the operating temperature should be changed every time the product being stored is changed. For instance, if a cold room used normally to store poultry at -2°C is used to store beef, then the temperature can be set at 1°C which will improve the compressor efficiency by about 10%.

In systems serving multiple applications with wide range of operating temperatures, having separate systems to serve low temperature and high temperature applications can improve compressor efficiency.

**Reducing condenser pressure**

Condensers used for refrigeration systems can be air-cooled or water-cooled with cooling towers and evaporative condensers. Air-cooled condensers consist of refrigerant coils with circulation fans and the
condensing pressure and therefore the temperature is dependent on the dry bulb temperature of air.

Water-cooled condenser consists of shell and tube condensers or plate heat exchangers where the refrigerant is condensed into liquid using water from cooling towers which can reach close to the wet-bulb temperature of ambient air. Evaporative condensers are also commonly used in industrial refrigeration systems. They are essentially a combination of a cooling tower and refrigerant condenser and can operate at a relatively lower condenser pressure.

The operating efficiency of compressors is dependent on the compressor lift which is the difference between the suction and discharge pressures, and can be improved by reducing the condensing pressure. The refrigerant condensing pressure is dependent on the condensing temperature of the cooling fluid. Hence, water-cooled condensers and evaporative condensers which reject heat at condensing temperatures close to the wet-bulb temperature of air result in lower condensing pressures compared to air-cooled condensers.

The efficiency gain when using water-cooled systems instead of air-cooled condensers is dependent on the dry bulb and wet-bulb temperature of ambient air. In general, improvement in compressor efficiency of 10 to 20% can be achieved by using water-cooled systems.

**Repair / replace controls**

In refrigeration systems, the compressor operation is controlled to maintain the required temperature in the refrigerated space. This is achieved by monitoring the suction pressure at the compressor and varying the compressor capacity by loading / unloading, speed variation or slide valve. In systems with multiple compressors, suction pressure is also used to control the number of compressors in operation.

If the suction pressure sensor or controller is defective, compressors would be loaded unnecessarily resulting in energy wastage. Therefore, the functionality of the sensor and controller should be regularly checked to ensure optimum system operation.

**Replacing inefficient systems**

Some old refrigeration systems operate inefficiently due to factors such as older technology, wear and tear, and capacity mismatch.

When systems are due for replacement, they should be replaced with new equipment sized to match the actual demand. Variable speed compressors should be used where the load is expected to vary significantly.
The type of compressors should also be selected to better match load characteristics keeping in mind that reciprocating compressors operate at lower loading while screw compressors operate at high loading.

**Using alternative systems**

Since refrigeration systems can be significant energy users, alternative cooling systems can be explored to provide full or partial cooling. For cooling applications from about 0 to 10°C, chillers with glycol or chilled water can be considered.

If the temperature of the product is high when reaching the refrigeration system, alternative cooling systems can be used to pre-cool the product before refrigeration. Such alternative cooling systems can be ambient cooling or using other less energy intensive cooling fluids such as cooling tower water or chilled water.

**Varying speed of evaporator fans**

Evaporators consist of coils where the liquid refrigerant evaporates by absorbing latent heat of vaporization and changes to vapour state, thereby providing cooling. In addition to the coil, evaporators have fans to circulate air between the coil and the cooled space.

Although the rated capacity of evaporator fans is relatively low compared to the compressor power, since they operate 24 hours a day, they can account for a significant amount of energy consumption. To reduce energy consumption during operation, variable frequency drives (VFDs) can be installed together with a suitable temperature sensor and controller to reduce the fan speed or completely switch them off when the desired space temperature is reached.

**Reducing load**

During storage of products in a cold room, the heat gain is dependent on many factors like the storage temperature, insulation of the storage space, air leakages between the cold space and external environment and heat added by lighting installed inside the storage space.

Once the product being stored reaches the storage temperature, the refrigeration system operates continuously only to remove heat gain from external and internal sources of heat. The main internal source of heat is lighting. Therefore, energy efficient lighting like LEDs which emit less heat should be used while the usage of lighting should be minimized by switching them off when not required. Occupancy sensors can be used to switch off most of the lighting leaving a few to be controlled manually.
Due to the large temperature gradient between the refrigerated space and the ambient, good insulation should be used to minimize heat gain through the exterior surfaces of the storage space and refrigerant pipes. In addition, air leakage between the cold space and the exterior should be minimized by replacing ineffective door seals regularly and only opening the doors when required. In applications where the doors need to be frequently opened, automatic doors or strip curtains should be installed.

5.4 COMPRESSED AIR SYSTEMS

Rectifying leaks

Since compressed air is produced, stored, distributed and used at a much higher pressure than the surrounding air, compressed air will leak through even the smallest openings resulting in energy wastage. In many compressed air systems, leaks account for about 5 to 20% of the total compressed air usage.

Common sources of leaks are pipe fittings, flexible tubes, couplings, pressure regulators, condensate traps and pipe joints.

Since compressed air systems are highly energy intensive, a regular leak detection program should be implemented and leaks rectified as soon as possible.

Using alternative sources

Often compressed air is used for applications that can be served by alternative systems which consume less energy to perform the same task. For example, high pressure blowers can be used for tank agitation, cleaning and product drying.

Replacing inefficient compressors

Where multiple small compressors are used, they can be replaced with a single large capacity compressor which can operate more efficiently. In addition, when replacing compressors, the capacity of the new compressors should be determined by measuring the actual load to minimize unloading of compressors.

If the compressed air demand is highly variable, a variable speed compressor can be considered. Since oil-free compressors are less efficient than oil-injected type, they should be used only for applications which may have potential for product contamination.

Compressed air recovery

Typically compressed air at 40 bar is used for bottle blowing applications. Since the same bottle blowing machines also require low pressure air for
operation of actuators and controls, part of the high pressure compressed air can be recovered as low pressure air after the bottle blowing process.

Such compressed air recovery systems are available for most types of bottle blowing machines and part of the used high pressure air can be recovered at various stages of the blowing process.

**Reduction in pressure ratio**

The system pressure, which is the pressure at which compressed air is supplied, depends on factors such as the pressure requirements of the end users, pressure losses in the system, storage capacity and variation in demand.

A higher discharge pressure results in a higher compressor power as the compressor has to work against a higher back pressure. The rule-of-thumb used in industry is a 7 to 8% increase in compressor power for every 1 bar increase in compressor discharge pressure.

Therefore, the system pressure should be set to the minimum value required to satisfy the various uses while minimizing pressure losses in the system.

**Dryers**

For applications where it is not necessary to provide dry compressed air, the system can be operated without a dryer. Where drying is necessary, refrigerated dryers should be used unless very low dew-points are required.

### 5.5 PRODUCTION EQUIPMENT

**Replace old motors with more efficient motors**

Most motors used for production equipment are rated to be IE1 or IE2. These motors can be replaced with more efficient IE3 motors and where feasible, with IE4 motors.

Changing from IE1 to IE2 motors improves efficiency by about 1 to 2%; IE1 to IE3 by about 2 to 4%.

**Replace under-loaded motors with lower capacity motors**

Motors used for production equipment are often oversized for the application and hence operate at low loading. The motor operating efficiency is related to the loading and the efficiency drops significantly from the rated value generally when the loading is below about 40% of the rated capacity.
Therefore, the loading of high capacity motors should be evaluated and where possible, replaced with lower capacity motors. When replacing these motors, IE3 or if feasible, IE4 motors should be considered.

If motor loading is artificially increased for fans and pumps by throttling dampers or valves, the possibility of eliminating the throttle should be considered when selecting a new motor.

**Improving surface insulation**

Production equipment such as ovens, heaters and roasters consume electricity, town gas or natural gas to heat products. Part of the heat input is lost to the surroundings by convection and radiation at the outer surface of the equipment. Since the amount of heat loss is dependent on the surface temperature, losses can be minimized by providing adequate insulation to reduce the surface temperature.

**Heat recovery**

In production equipment where waste heat is discharged to the environment, heat recovery systems should be considered to recover part of the waste heat which can be used for pre-heating the incoming stream of air or product. In applications where waste heat cannot be used for the same process due to the possibility of contamination, the waste heat can be used for other applications such as producing hot water or pre-heating boiler make-up water by means of a heat exchanger.

### 5.6 PROCESS COOLING SYSTEMS

**Cooling tower sizing and fan control**

Capacity of cooling towers is dependent on the air flow through them. Therefore, when the heat rejection load is lower than the design value (such as when only part of the plant is in operation), it is not necessary to run the cooling towers at full capacity. The cooling tower capacity can be reduced by reducing the air flow which would result in lower fan energy consumption.

One way of achieving this is by cooling tower fan cycling where some fans are switched On/Off to control the supply water temperature. However, this can result in a swing in water temperature and can cause premature wear and tear of the cooling tower fan motor drives.

A better way is to use variable frequency drives (VFDs) to control the cooling tower fan speed. The speed of the cooling tower fans in operation can be modulated to maintain a set supply temperature. The easiest control strategy is to maintain the water supply temperature at the design value.
Alternatively, the set-point can be adjusted to maintain a cooling tower approach temperature (difference between water supply and wet-bulb temperatures) so that the water supply temperature is always at a fixed number of degrees higher than the wet-bulb temperature.

Theoretically, the power consumed by fans is proportional to the cube of the fan speed. When the cooling load drops to 80%, the speed of cooling tower fans can also be reduced accordingly, resulting in a drop in power consumption of about 50% \( (0.8^3 = 0.51) \). Therefore, this control strategy can lead to significant savings from the cooling tower fans at part-load. Use of VFDs to control cooling tower capacity rather than fan staging also leads to reduction in wear tear of the drives due to lower fan speed and less drift losses (water losses) due to lower air velocity.

**Cooling water pump sizing and control**

Energy consumed by the pumps can be reduced by minimising losses in the piping system, selecting pumps to operate at the highest efficiency and reducing the circulating flow rate to meet the minimum required for the cooling process.

In most plants, cooling tower water cooling systems serve numerous heat exchangers serving various production processes. Batch production are used in most plants and cooling is only required at specific times during each production cycle. However, in most cases, the cooling water is allowed to flow through the heat exchangers even when cooling is not required. As a result, energy is wasted in the pumps.

In such situations, motorised valves should be installed to shut off the flow to the respective heat exchangers when cooling is not required. The circulating pumps may also be fitted with variable speed drives and a control system to maintain a minimum set pressure. In addition, temperature controls should be installed whereby the valves automatically adjust to attain the minimum flow rate for the desired rate of cooling.

**Cooling water supply temperature and range**

The amount of energy consumed by cooling towers is dependent on the supply water temperature. The lowest achievable water supply temperature is the wet-bulb temperature. To achieve that, a large surface area and air flow rate is required.

To minimize energy consumption, cooling towers should be designed and operated to provide cooling water at the maximum temperature acceptable by the process cooling system.
The "range" for cooling towers is the difference in temperatures between the return and supply streams of water. This range should be maximised where possible to reduce pumping energy consumption.

**5.7 LIGHTING**

**Replacing inefficient lamps**

The amount of light emitted by a lamp per unit of electrical power consumed is the luminous efficacy of a lamp (lumens/Watt). Higher luminous efficacy represents better energy efficiency of the lamp. Since different types of lamps have different efficacies, lamps with low efficacy can be replaced with those having higher efficacy.

Lighting for most office and manufacturing area can be provided by LED lamps. For high bay applications, LEDs and metal halides can be considered. LEDs and high pressure sodium lamps can be considered for outdoor lighting.

**Reducing illuminance levels**

The lighting level or lux level required depends on the type of space, tasks performed in the space and other visual requirements. General illuminance guidelines used for design of lighting systems for different applications are available in lighting reference books and codes of practice.

Generally, higher lighting levels lead to higher lighting energy consumption. Therefore, lighting levels should be minimised and maintained based on the recommended values and actual requirements.

For new installations, this can be achieved through good lighting design by optimising factors such as lamp wattage, number of lamps and lamp spacing. Similarly, for existing installations where it is not cost effective to redesign lighting systems, other means such as de-lamping, use of task lighting and replacement of inefficient lamps can be considered to reduce energy consumption.

**Lighting controls**

Energy consumed by lighting can also be reduced by minimising their usage by better matching operations demand through lighting controls. Various systems such as timers, occupancy sensors and light sensors can be used to control lighting operations.

Simple timers can be used to switch-on and off all or some lighting circuits at pre-determined times based on occupancy schedules. Provision for manual override can be incorporated into the controls so that occupants can extend the operating hours of lighting circuits based on individual
requirements. Lighting control systems can consist of simple timers which have 24-hour clocks to daily switch-on and off lighting at pre-set times to timers which can be used to program lighting schedules for a year or more where holidays and other special requirements can be programmed in advance.

Occupancy sensors can also be used to switch-on lighting when a space is occupied and switch-off the lighting after a preset time delay when the space is not occupied. Typical applications for occupancy sensors are in storage areas, toilets, car parks, meeting rooms, and common areas.

Exterior and interior areas of buildings which are exposed to natural light can have light sensors to switch-off or dim artificial lighting when sufficient natural light is available. The daylight controls can be open loop type where the sensor detects available daylight or closed loop type where the sensor detects available light at a work space.

5.8 OVERALL ENERGY SAVINGS

The total electrical energy savings identified for the ten food manufacturing plants is shown in Table 5.1. The total annual electrical energy savings was 16.4 million kWh (59 TJ) which worked out to be about 13% of the overall electrical energy consumption of the plants.

<table>
<thead>
<tr>
<th>Plant Designation</th>
<th>kWh/year</th>
<th>TJ/year</th>
<th>% of Total Electrical Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>1.3 million</td>
<td>4.7</td>
<td>10</td>
</tr>
<tr>
<td>Plant 2</td>
<td>1.8 million</td>
<td>6.5</td>
<td>19</td>
</tr>
<tr>
<td>Plant 3</td>
<td>1.0 million</td>
<td>3.6</td>
<td>20</td>
</tr>
<tr>
<td>Plant 4</td>
<td>2.2 million</td>
<td>7.9</td>
<td>19</td>
</tr>
<tr>
<td>Plant 5</td>
<td>1.8 million</td>
<td>6.5</td>
<td>14</td>
</tr>
<tr>
<td>Plant 6</td>
<td>0.8 million</td>
<td>2.9</td>
<td>11</td>
</tr>
<tr>
<td>Plant 7</td>
<td>3.5 million</td>
<td>12.6</td>
<td>11</td>
</tr>
<tr>
<td>Plant 8</td>
<td>1.0 million</td>
<td>3.6</td>
<td>21</td>
</tr>
<tr>
<td>Plant 9</td>
<td>1.2 million</td>
<td>4.3</td>
<td>23</td>
</tr>
<tr>
<td>Plant 10</td>
<td>1.9 million</td>
<td>6.8</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>16.4 million</td>
<td>59</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 5.1 Summary of electrical energy savings

The total annual fuel energy savings identified was 44 TJ which worked out to be about 5% of the overall fuel energy usage of the plant as shown in Table 5.2.
### Table 5.2 Summary of fuel energy savings

The electrical and fuel energy savings broken down into the various energy consuming systems are shown in Table 5.3 and Figure 5.4. The highest percentage of savings identified were for boiler systems which were the biggest energy user in food manufacturing plants followed by chillers, compressed air and cooling tower systems.

<table>
<thead>
<tr>
<th>Plant Designation</th>
<th>TJ/year</th>
<th>% of Total Fuel Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>2.8</td>
<td>1</td>
</tr>
<tr>
<td>Plant 2</td>
<td>6.1</td>
<td>14</td>
</tr>
<tr>
<td>Plant 3</td>
<td>5.1</td>
<td>5</td>
</tr>
<tr>
<td>Plant 4</td>
<td>5.9</td>
<td>6</td>
</tr>
<tr>
<td>Plant 5</td>
<td>3.2</td>
<td>60</td>
</tr>
<tr>
<td>Plant 6</td>
<td>9.8</td>
<td>16</td>
</tr>
<tr>
<td>Plant 7</td>
<td>7.2</td>
<td>5</td>
</tr>
<tr>
<td>Plant 8</td>
<td>3.9</td>
<td>12</td>
</tr>
<tr>
<td>Plant 9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plant 10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>44</strong></td>
<td><strong>5</strong></td>
</tr>
</tbody>
</table>

### Table 5.3 Summary of savings by system

<table>
<thead>
<tr>
<th>Cost Savings $/year</th>
<th>TJ/year</th>
<th>% of Total Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler systems</td>
<td>0.76</td>
<td>43.4</td>
</tr>
<tr>
<td>Chilled water systems</td>
<td>0.97</td>
<td>20.7</td>
</tr>
<tr>
<td>Refrigeration systems</td>
<td>0.29</td>
<td>5.6</td>
</tr>
<tr>
<td>Compressed air systems</td>
<td>0.6</td>
<td>14.7</td>
</tr>
<tr>
<td>Process cooling (cooling tower) systems</td>
<td>0.58</td>
<td>11.9</td>
</tr>
<tr>
<td>Production systems</td>
<td>0.2</td>
<td>4.6</td>
</tr>
<tr>
<td>Lighting systems</td>
<td>0.1</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3.5 million</strong></td>
<td><strong>103.1</strong></td>
</tr>
</tbody>
</table>
Figure 5.4 Summary of savings by system

The annual cost savings potential computed using the fuel and electrical energy savings (listed in Tables 5.1 and 5.2) is summarized in Table 5.4. The total cost savings worked out to be about $3.5 million a year. The estimated simple payback period for implementing the identified energy saving measures was 2.9 years.

<table>
<thead>
<tr>
<th>Plant Designation</th>
<th>$ million/year</th>
<th>Simple payback period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>0.35</td>
<td>1.8</td>
</tr>
<tr>
<td>Plant 2</td>
<td>0.42</td>
<td>2.0</td>
</tr>
<tr>
<td>Plant 3</td>
<td>0.30</td>
<td>3.5</td>
</tr>
<tr>
<td>Plant 4</td>
<td>0.32</td>
<td>3.5</td>
</tr>
<tr>
<td>Plant 5</td>
<td>0.52</td>
<td>2.7</td>
</tr>
<tr>
<td>Plant 6</td>
<td>0.15</td>
<td>5.4</td>
</tr>
<tr>
<td>Plant 7</td>
<td>0.63</td>
<td>2.8</td>
</tr>
<tr>
<td>Plant 8</td>
<td>0.22</td>
<td>4.2</td>
</tr>
<tr>
<td>Plant 9</td>
<td>0.22</td>
<td>1.6</td>
</tr>
<tr>
<td>Plant 10</td>
<td>0.36</td>
<td>3.1</td>
</tr>
<tr>
<td>Total</td>
<td>3.49</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Table 5.4 Energy cost savings
5.9 FEASIBILITY OF COMBINED HEAT AND POWER

In addition to the energy efficiency measures identified, it may be possible to incorporate combined heat and power generation systems for food manufacturing plants since they use both thermal and electrical power.

Combined Heat and Power (CHP) refers to the 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.

Figure 5.4 shows the difference in efficiency between the conventional method of individually generating electricity and heat (steam) separately with a combined system.

![Comparison of efficiency for conventional vs CHP](image)

**Figure 5.4** Comparison of efficiency for conventional vs CHP

Figure 5.5 illustrates the main components of a CHP system which consists of a conventional power generation system (engine, gas turbine or steam turbine) together with a waste heat recovery system for steam generation.

![Typical arrangement of a CHP system](image)

**Figure 5.5** Typical arrangement of a CHP system
Some of the basic requirements for a CHP system to be feasible are:

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

Using these basic requirements, it is feasible for four out of the ten participating plants to install a CHP system.

### 5.9.1 TYPE OF SYSTEM

The main types of CHP systems use micro-turbines, internal combustion engines, gas turbines and steam turbines.

Figure 5.6 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.

![Internal Combustion Engine CHP System Diagram](image)

**Figure 5.6** *Arrangement of an internal combustion engine CHP system*

As shown in Figure 5.6, approximately 40% of the input energy can be converted to electrical energy while 25% and 20% of the input energy can be converted to steam and hot water respectively.

### 5.9.2 POTENTIAL SAVINGS

Potential savings estimated based on the heat and power demand for the four eligible plants is summarized in Table 5.5.
<table>
<thead>
<tr>
<th>Plant *</th>
<th>Heat demand (kW)</th>
<th>Electrical Power demand (kW)</th>
<th>Energy cost savings ($/year)</th>
<th>Estimated system cost ($)</th>
<th>Simple payback period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant A</td>
<td>9500</td>
<td>1500</td>
<td>0.74 m</td>
<td>4.0 m</td>
<td>5.4</td>
</tr>
<tr>
<td>Plant B</td>
<td>1100</td>
<td>1000</td>
<td>0.42 m</td>
<td>2.5 m</td>
<td>6.0</td>
</tr>
<tr>
<td>Plant C</td>
<td>1200</td>
<td>1100</td>
<td>0.46 m</td>
<td>2.5 m</td>
<td>5.4</td>
</tr>
<tr>
<td>Plant D</td>
<td>560</td>
<td>700</td>
<td>0.19 m</td>
<td>1.5 m</td>
<td>7.9</td>
</tr>
</tbody>
</table>

Note: The four plants are numbered from A to D to maintain anonymity as the data in the table and their eligibility for CHP may lead to identification of the plant number used for benchmarking data.

Table 5.5  Savings potential for CHP systems

The electricity and natural gas tariffs vary from one plant to another and are dependent on the period of energy supply contract. Therefore, average tariff values of $0.10/kWh and $13.48/mmBTU were used for electricity and natural gas respectively, to compute the above cost saving values. A detailed CHP feasibility analysis should include a sensitivity analysis based on differing tariff rates.

5.9.3 RECOMMENDATIONS

Based on the preliminary data presented in Table 5.5 which indicates a simple payback period of approximately 5 to 8 years, it would be advisable to implement CHP systems only for suitable food manufacturing plants.

Therefore, it is recommended to conduct detailed studies for the shortlisted plants to further analyse the viability of installing CHP systems by considering other factors like infrastructure requirements, compliance to local regulations, investment cost and future energy and electricity prices.
6.0 ENERGY MANAGEMENT PRACTICES

Maturity level of existing Energy Management System (EnMS) of the participating plants is evaluated based on the following criteria:

1) Energy policy
2) Energy management team
3) Energy monitoring and accounting
4) Capabilities and training needs
5) Availability of funding

The EnMS for each plant was evaluated using the following metrics and was carried out by site observations and interviews with the relevant staff.

**Metrics for Evaluating the Energy Management System**

<table>
<thead>
<tr>
<th>Level</th>
<th>Energy policy</th>
<th>Energy management team</th>
<th>Energy monitoring and accounting</th>
<th>Capabilities and training needs</th>
<th>Availability of funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No explicit energy policy.</td>
<td>No formal delegation of responsibility for energy consumption.</td>
<td>No accounting / information for energy consumption.</td>
<td>Little knowledge / expertise in energy management.</td>
<td>No investment for improving energy efficiency, only no cost measures were implemented.</td>
</tr>
<tr>
<td>2</td>
<td>Unwritten set of guidelines.</td>
<td>Energy management is part-time responsibility of somebody with limited influence.</td>
<td>Facility engineer compiles energy consumption report based on invoice data for internal use within technical department.</td>
<td>Have at least one person with some knowledge of energy management or attended training in energy management.</td>
<td>Only low cost energy saving measures were implemented.</td>
</tr>
<tr>
<td>3</td>
<td>Energy policy set by department or energy manager but not adopted.</td>
<td>Energy manager appointed, reporting to ad-hoc committee, line management and authority not defined properly.</td>
<td>Energy consumption monitoring &amp; targeting based on main meter data. Energy unit has ad-hoc involvement in budget setting.</td>
<td>Have one Singapore Certified Energy Manager (SCEM).</td>
<td>Energy saving measures with only short term payback period were implemented.</td>
</tr>
<tr>
<td>4</td>
<td>Developed formal energy policy, but no commitment from top management.</td>
<td>Energy manager accountable to energy committee representing all users, chaired by a member from senior management.</td>
<td>Energy consumption of major energy users are monitored using sub-meters. Energy savings not reported to respective users.</td>
<td>Have more than one SCEM.</td>
<td>Energy saving projects were evaluated using the same payback criteria as with other investment.</td>
</tr>
</tbody>
</table>
6.1 FINDINGS

Results of the study are summarized in Figures 6.1 to 6.5.

Figure 6.1 Evaluation of Energy Policy
Figure 6.2 Evaluation of Energy Management Team

Figure 6.3 Evaluation of Energy Monitoring and Accounting
The main findings on the effectiveness of the respective energy management systems can be summarized as follows:

- EnMS implemented in the plants are not certified to any standard (eg. ISO 50001)
- Most plants do not have a clear energy policy and most stakeholders are not aware of energy management goals
Energy management is generally the responsibility of the energy manager and only one plant has a formal energy management team. Energy managers’ role in energy management is mainly part-time. In most plants, only the total energy consumption is tracked and there are no key Energy Accounting Centres (EACs). There are only a few permanent monitoring systems installed in the plants and as such, no regular tracking of EnPIs (energy performance indicators). With a maximum of only one SCEM per plant, the availability of trained personnel required for a sustainable energy management programme is considered to be inadequate. Since specific budget provisions are not available for energy management, funding is secured on a case-by-case basis for energy saving projects.

6.2 RECOMMENDATIONS FOR IMPROVEMENT

Based on the findings of the study, the following are the main general recommendations to improve the energy management systems in the plants:

- Put in place clear energy policy with targets
- Establish a formal energy management team with representative from all stakeholders
- Appoint a dedicated energy manager
- Identify main EACs
- Install monitoring systems for the EACs and energy sub-meters
- Set EnPIs for the EACs and regularly track performance
- Recognise and reward staff based on achieving targets
- Implement ISO 50001 compliant EnMS
7.0 OPERATIONS AND MAINTENANCE PRACTICES

The maintenance practices for the participating plants were evaluated based on observations and interviews with relevant personnel using the following metrics.

### Maintenance Practices Metrics

<table>
<thead>
<tr>
<th>Level</th>
<th>Filters and strainers</th>
<th>Steam leaks</th>
<th>Compressed air leaks</th>
<th>Condensers, boilers and heat exchangers</th>
<th>Motors and drives</th>
<th>Monitoring and control system</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No regular schedule for checking and maintenance</td>
<td>Significant amount of leaks observed and no formal programme to minimise leaks</td>
<td>Significant amount of leaks observed and no formal programme to minimise leaks</td>
<td>No regular schedule for checking and maintenance</td>
<td>No regular schedule for checking and maintenance</td>
<td>No regular schedule for checking and maintenance</td>
</tr>
<tr>
<td>2</td>
<td>Have a regular schedule but no evidence of compliance</td>
<td>No formal programme to minimise leaks but only few leaks observed</td>
<td>No formal programme to minimise leaks but only few leaks observed</td>
<td>Have a regular schedule but no evidence of compliance</td>
<td>Have a regular schedule but no evidence of compliance</td>
<td>Have a regular schedule but evidence of wrong or erroneous display readings</td>
</tr>
<tr>
<td>3</td>
<td>Have a regular schedule and evidence of compliance</td>
<td>Have a regular program to check for leaks but some leaks are observed</td>
<td>Have a regular program to check for leaks but some leaks are observed</td>
<td>Have a regular schedule and evidence of compliance</td>
<td>Have a regular schedule and evidence of compliance</td>
<td>Have a regular schedule and display of readings appear to be normal</td>
</tr>
<tr>
<td>4</td>
<td>Have a comprehensive maintenance programme with key performance indicators and regular tracking of performance</td>
<td>No leaks are observed</td>
<td>No leaks are observed</td>
<td>Regular monitoring of performance with set KPIs</td>
<td>Have a predictive maintenance programme (vibration monitoring etc.) in addition to regular preventive maintenance</td>
<td>Have a regular maintenance programme together with regular checking and calibration of sensors</td>
</tr>
</tbody>
</table>

### 7.1 FINDINGS

Results of the study are summarized in Figures 7.1 to 7.6.
Figure 7.1 Evaluation of Maintenance Relating to Filters & Strainers

Figure 7.2 Evaluation of Maintenance Relating to Steam Leaks
Figure 7.3 Evaluation of Maintenance Relating to Compressed Air Leaks

Figure 7.4 Evaluation of Maintenance Relating to Boilers & Heat Exchangers
The main findings on maintenance practices relating to energy management can be summarised as follows:

- Preventive maintenance strategies are commonly used and there is very little evidence on the use of predictive maintenance strategies
- Filters and strainers are regularly checked and cleaned to minimise pressure losses
• Steam leaks are generally rectified (no significant steam leaks were observed)
• Steam traps are regularly checked and defective ones are repaired or replaced
• Relatively high compressed air leakage in a number of plants indicates no regular leak rectification programmes are in place
• No regular fine-tuning boiler burners to adjust air to fuel ratio as indicated by high excess air in most plants
• There is no regular checking and calibration of sensors and instruments used for monitoring as many were observed to be inaccurate or not in operation

7.2 RECOMMENDATIONS FOR IMPROVEMENT

Based on the findings of the study, the following are the main recommendations to improve maintenance practices relating to energy management for the various plants:

• Regularly check and calibrate monitoring sensors and control systems so that the performance of key EACs and EnPIs can be closely monitored
• Supplement the current preventive maintenance programs with predictive maintenance strategies such as ultrasonic leak testing for compressed air and steam traps
• Regularly conduct compressed air leak tests to minimise energy wastage due to leaks
• Install permanent systems to monitor boiler flue gas composition and temperature so that the air to fuel ratio can be adjusted and the combustion efficiency optimised
8.0 OVERALL CONCLUSIONS

Following are the main findings and conclusions:

- Ten plants participated in the energy efficiency benchmarking study of food manufacturing plants
- The main energy consuming systems were identified and a suitable assessment framework was developed
- Comparison of the performance of individual systems with benchmark values indicate significant potential for improvement
- Many energy saving opportunities have been identified and savings have been quantified
- Total energy savings of 103.1TJ/year have been identified for the participating plants
- Measures have also been identified to improve energy management and maintenance practices in the plants

Recommended follow-up action:

- Facilitate interaction among energy managers to share best practices within the food manufacturing sector
- Prioritise energy management and improve motivation of staff involved in energy management through rewards and recognition
- Develop ability to convince top management and secure commitment and funding for energy management
- Consider current technology and more efficient designs when replacing old equipment
- Invest resources to identify energy savings from process equipment and systems which account for a significant portion of the energy usage