April 2015

Assessment Framework for Energy Efficiency Benchmarking Study of Food Manufacturing Plants

1. INTRODUCTION

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.

The benchmarking study is to cover ten food manufacturing plants ("Plants"), out of which, eight of the Plants should have a minimum energy consumption of 30 TJ per year while the remaining two Plants should have a minimum energy consumption of 15 TJ per year.

The main objectives of the Study are 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.

Therefore, to facilitate the Study, an Assessment Framework ("AF") was developed to assess 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.

The proposed approach for the study is illustrated in Figure 1.1

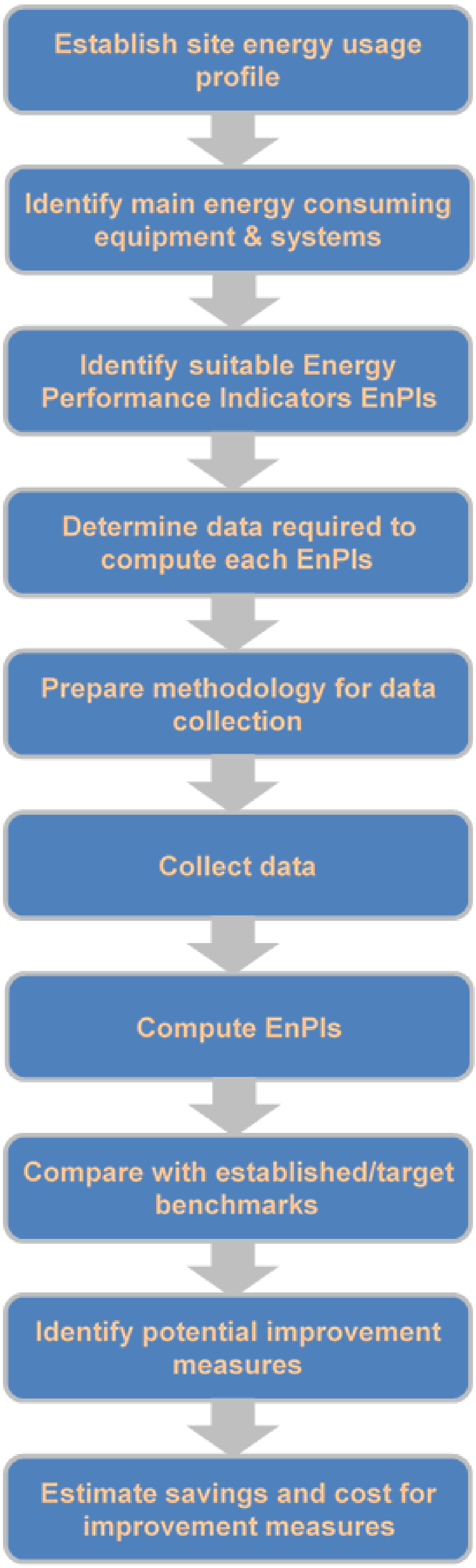


Figure 1.1. Proposed Approach

The subsequent sections of this document provide a detailed description of the AF to be used for the proposed study.

2. SITE ENERGY USAGE PROFILE

The first step in the AF is to establish the energy usage profile of each Plant. This will involve identifying the types of primary energy used and establishing the annual usage for each type of primary energy as well as the total energy usage from historic data as shown in Figures 2.1 to 2.4.

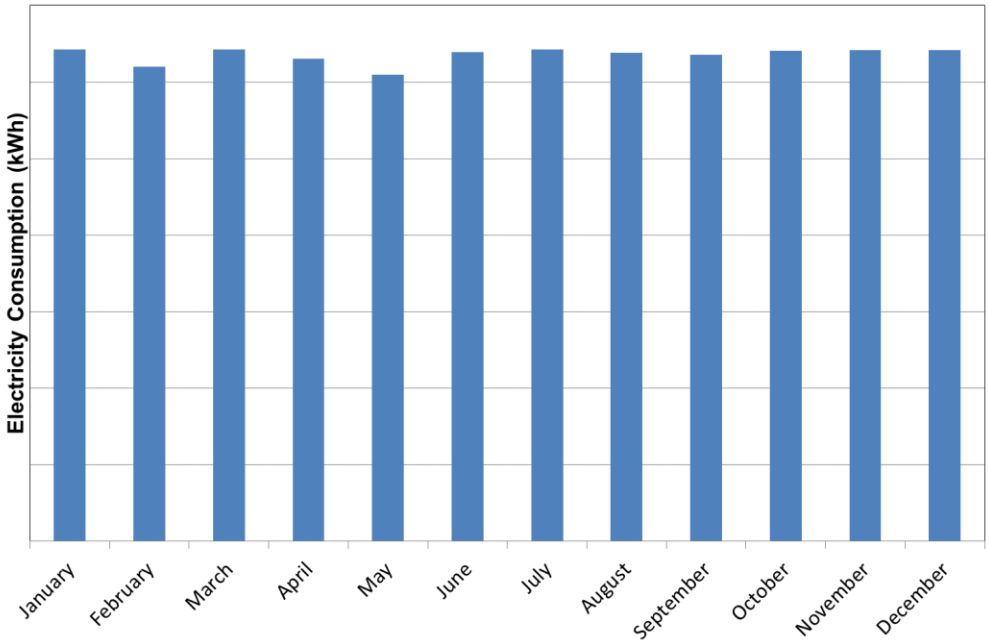


Figure 2.1. Monthly electrical energy usage

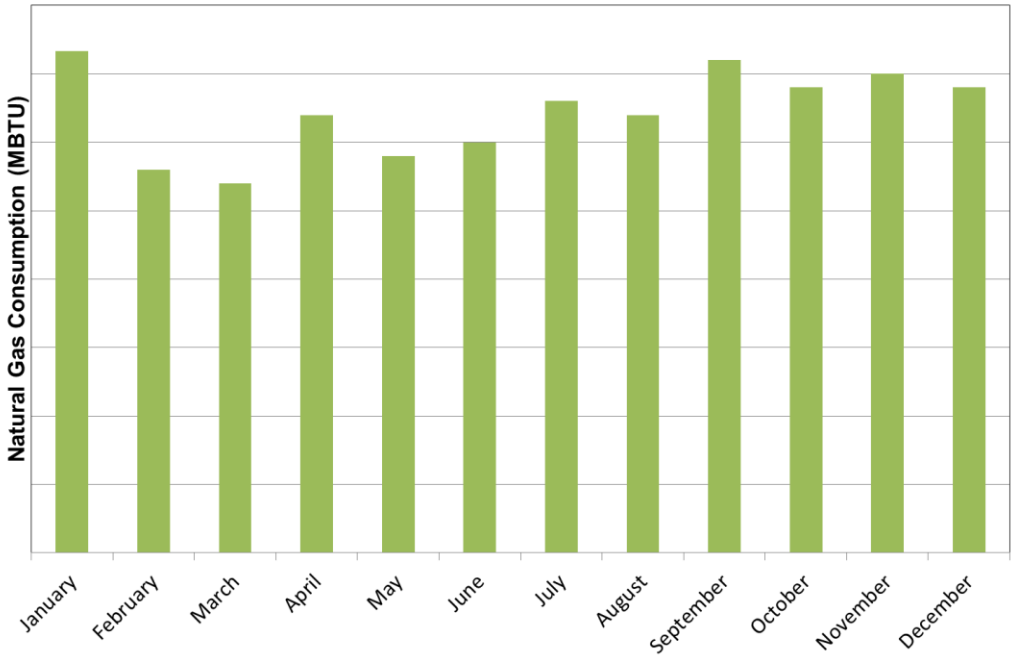


Figure 2.2. Monthly natural gas usage

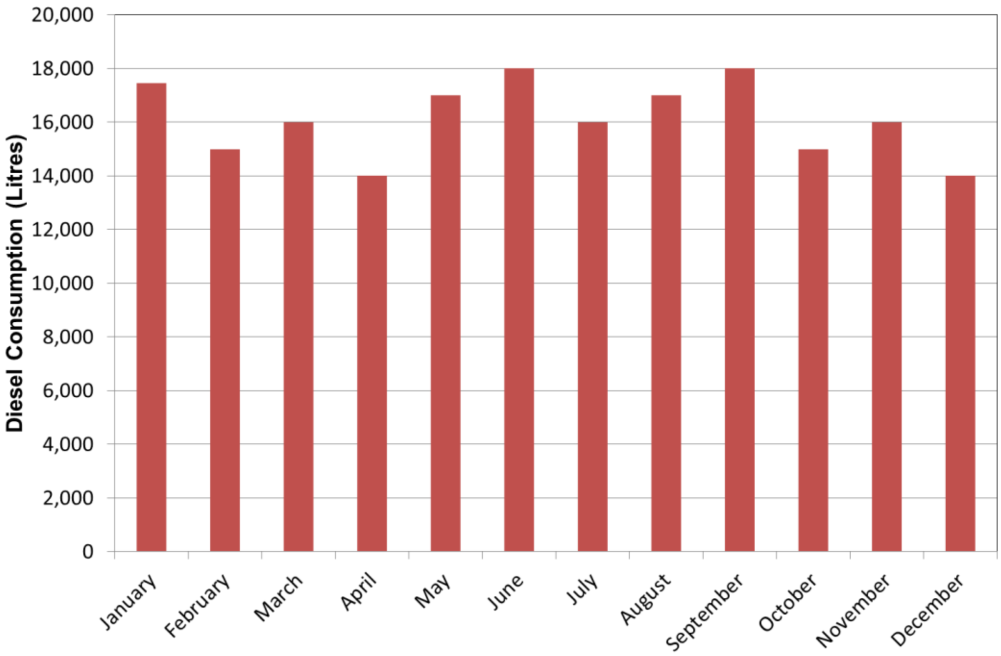


Figure 2.3. Monthly diesel usage

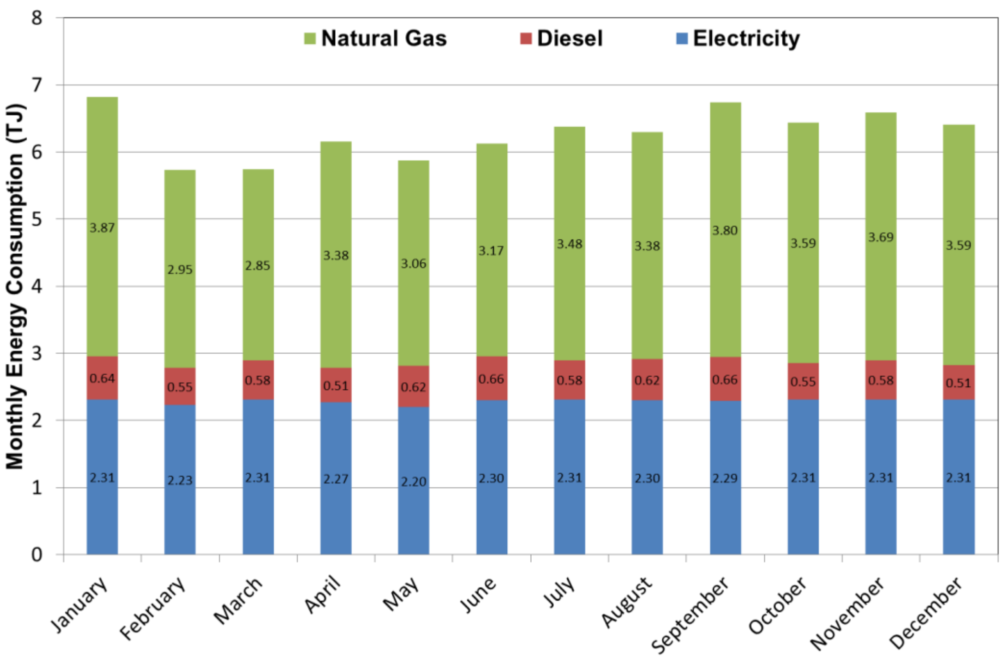


Figure 2.4. Total energy usage

Thereafter, an exercise will be performed to establish the usage of each type of primary energy and the total energy usage by the different equipment and systems. This is to establish that all equipment and systems which account for at least 80% of the total energy usage have been identified.

The initial estimation of the energy usage by each equipment and system will be performed by referring to one or more of the following information:

a) Sub-meter data (where available)

b) Previous measurements from audits, ECA submissions etc. (if available)

c) Equipment specifications and operating hours

Typical energy breakdown charts are illustrated in Figures 2.5 to 2.7

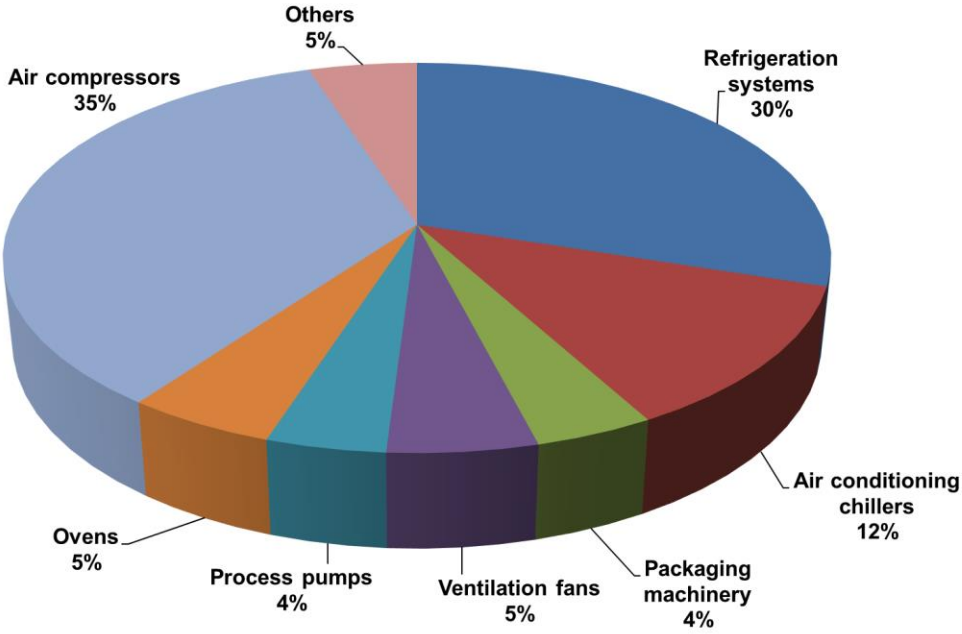


Figure 2.5. Breakdown of electrical energy usage

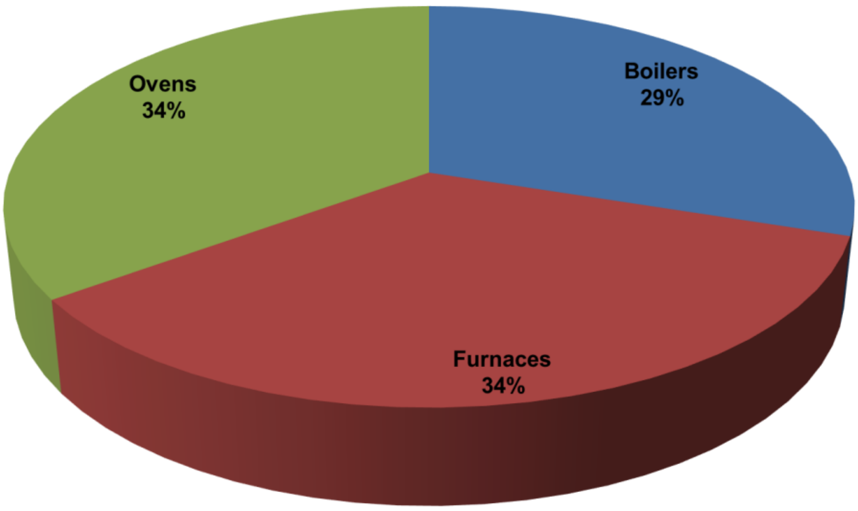


Figure 2.6. Breakdown of natural gas usage

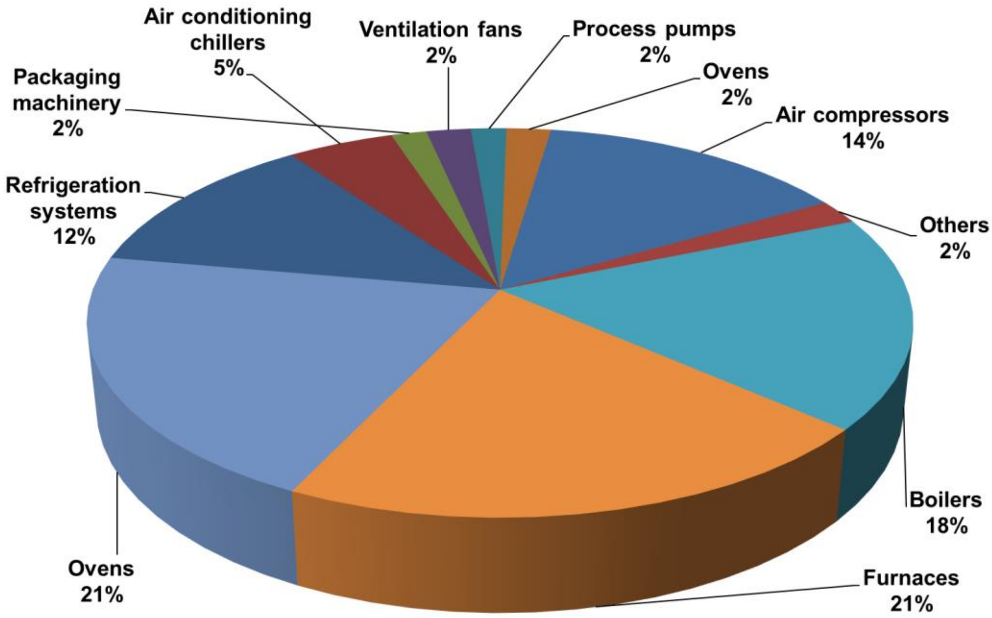


Figure 2.7 Breakdown of total energy usage

Once the equipment and systems that account for at least 80% of the total primary energy consumption of each participating Plant is identified, the energy efficiency and performance of each of the equipment and systems will be assessed using the framework described in the following section.

During the actual assessment of each Plant, the breakdown of total energy usage will be re-computed to check whether the equipment and systems identified account for at least 80% of the total usage of the Plant. Additional equipment and systems will be included in the assessment to make up any shortfall.

3. DEVELOPMENT OF ENERGY PERFORMANCE INDICATORS

Once the equipment and systems that account for at least 80% of the total primary energy consumption of each participating Plant is established, the energy efficiency and performance of each of the equipment and systems can be assessed by comparing their performance with industry established values or standards.

This section of the AF provides a list of suitable Energy Performance Indicators (EnPIs) for assessing the energy efficiency of different equipment and systems, together with the proposed methodology for measuring each of the proposed EnPIs.

3.1 CHILLED WATER SYSTEMS

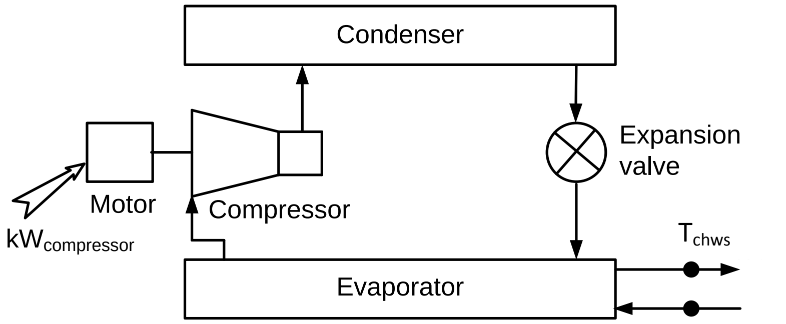
3.1.1 Chillers

EnPI-1: COP of Chiller

Formula: $COP_{chiller} = \dfrac{Q_{cooling}}{kW_{compressor}}$

Unit: kW_c/kW_e

Schematic diagram of chiller showing measurement locations:



Description of parameters:

$kW_{compressor}$ = Chiller compressor power consumption, kW
$Q_{cooling}$ = Cooling load of the chiller, kW
$Q_{cooling} = m_{chw} \times Cp \times (T_{chwr} - T_{chws})$, kW
m_{chw} = Mass flow rate of chilled water, kg/s
Cp = Specific heat capacity of water = 4.2 kJ/kg.K
T_{chwr} = Chilled water return temperature, ^oC
T_{chws} = Chilled water supply temperature, ^oC

Heat and mass balance analysis:

For water cooled systems, a heat balance will be conducted to ensure accuracy of the measurements. The overall measurement system should be capable of calculating a resultant efficiency within 5% of the true value.

The relationship between the chiller cooling load and heat rejection rate can be represented by the following equation:

$$Q_{condenser} = Q_{cooling} + kW_{compressor}$$

where,

$Q_{condenser}$ = Heat rejection rate of the chiller, kW

$Q_{condenser} = m_{cw} \times Cp \times (T_{cwr} - T_{cws})$, kW

m_{cw} = Mass flow rate of condenser water, kg/s

Cp = Specific heat capacity of water = 4.2 kJ/kg.K

T_{cwr} = Condenser water return temperature, ºC

T_{cws} = Condenser water supply temperature, ºC

Others:

The following parameters will also be used to evaluate the overall performance of chillers:

1. Chilled water supply temperature
2. Condenser water supply temperature
3. Average chiller loading

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
m_{chw}	Ultrasonic Flow meter	±2%	Trend log	1 minute interval for 7 days
T_{chwr}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days
T_{chws}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days
m_{cw}	Ultrasonic flow meter	±2%	Trend log	1 minute interval for 7 days
T_{cwr}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days
T_{cws}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days
$kW_{compressor}$	Power transducer	±1%	Trend log	1 minute interval for 7 days

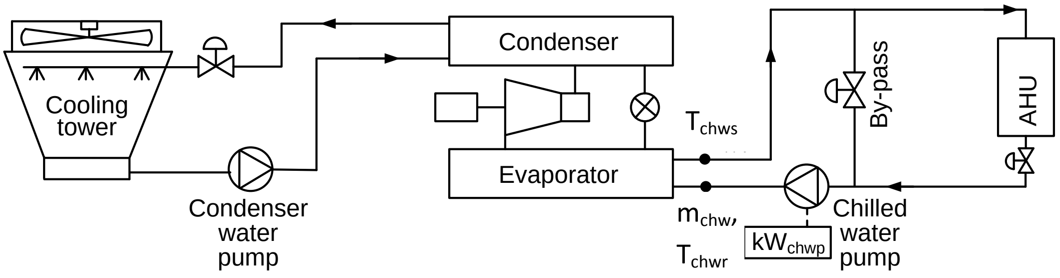
3.1.2 Chilled Water Pumps

EnPI-2: Specific Power Consumption of Chilled Water Pumps

Formula: $SPC_{chwp} = \dfrac{kW_{chwp}}{Q_{cooling}}$

Unit: kW_e/kW_c

Schematic diagram of sensor location:



Description of parameters:

kW_{chwp} = Power consumed by chilled water pump, kW
$Q_{cooling}$ = Cooling load of the chiller, kW
$Q_{cooling} = m_{chw} \times Cp \times (T_{chwr} - T_{chws})$, kW
m_{chw} = Mass flow rate of chilled water, kg/s
Cp = Specific heat capacity of water = 4.2 kJ/kg.K
T_{chwr} = Chilled water return temperature, ^{o}C
T_{chws} = Chilled water supply temperature, ^{o}C

Heat and mass balance analysis: Not required

Measured parameters:

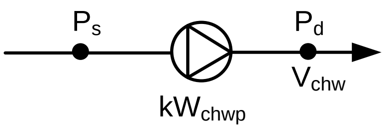
Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
m_{chw}	Ultrasonic flow meter	±2%	Trend log	1 minute interval for 7 days
T_{chwr}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days
T_{chws}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days
kW_{chwp}	Power meter	±1%	Trend log	1 minute interval for 7 days

EnPI-3: Efficiency of Chilled Water Pump System

Formula: $\eta_{chwp} = \frac{V_{chw} x\, \Delta P}{kW_{chwp} x\, 1000}$ x 100%

Unit: Percentage

Schematic diagram of sensor location:



Description of parameters:

kW_{chwp} = Power consumed by chilled water pump, kW
V_{chw} = Volume flow rate of chilled water, m^3/s
Δp = Pressure difference, Pa
= $(P_d - P_s)$, Pa
P_d = Pump discharge pressure, Pa
P_s = Pump suction pressure, Pa

Heat and mass balance analysis: Not required

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Remarks
V_{chw}	Ultrasonic flow meter	±2%	Spot measurement	Average value from chiller measurements
P_d	Pressure gauge	±0.5%	Spot measurement	-
P_s	Pressure gauge	±0.5%	Spot measurement	-
kW_{chwp}	Power meter	±1%	Spot measurement	-

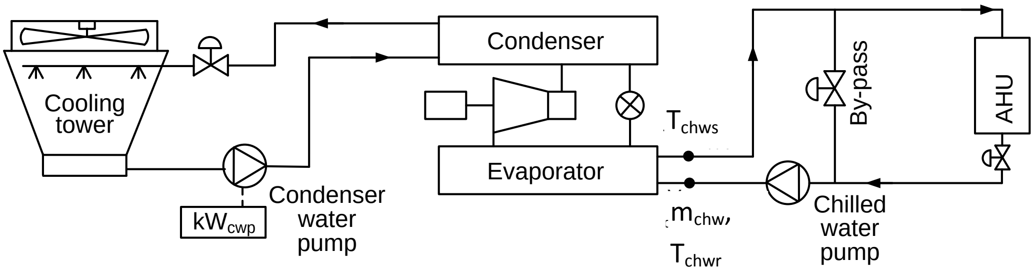
3.1.3 Condenser Water Pumps

EnPI-4: Specific Power Consumption of Condenser Water Pumps

Formula: $SPC_{cwp} = \frac{kW_{cwp}}{Q_{cooling}}$

Unit: kW_e/kW_c

Schematic diagram of chiller showing sensor location:



Description of parameters:

kW_{cwp} = Power consumed by condenser water pump, kW
$Q_{cooling}$ = Cooling load of the chiller, kW
$Q_{cooling} = m_{chw} \times Cp \times (T_{chwr} - T_{chws})$, kW
m_{chw} = Mass flow rate of chilled water, kg/s
Cp = Specific heat capacity of water = 4.2 kJ/kg.K
T_{chwr} = Chilled water return temperature, °C
T_{chws} = Chilled water supply temperature, °C

Heat and mass balance analysis: Not required

Measured parameters:

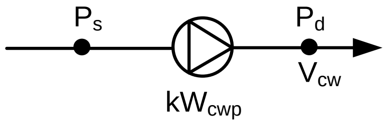
Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
m_{chw}	Ultrasonic flow meter	±2%	Trend log	1 minute interval for 7 days (From chiller)
T_{chwr}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days (From chiller)
T_{chws}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days (From chiller)
kW_{cwp}	Power meter	±1%	Spot measurement for constant speed or logging for variable speed	Spot measurement for constant speed or logging at 1 minute interval for 7 days for variable speed

EnPI-5: Efficiency of Condenser Water Pump System

Formula: $\eta_{chwp} = \frac{V_{cw} \, x \, \Delta P}{kW_{cwp} \, x \, 1000}$ x 100%

Unit: Percentage

Schematic diagram of sensor location:



Description of parameters:

kW_{cwp} = Power consumed by condenser water pump, kW
V_{cw} = Volume flow rate of condenser water, m^3/s
Δp = Pressure difference, Pa
= $(P_d - P_s)$, Pa
P_d = Pump discharge pressure, Pa
P_s = Pump suction pressure, Pa

Heat and mass balance analysis: Not required

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Remarks
V_{cw}	Ultrasonic flow meter	±2%	Spot measurement	Average value from chiller measurements
P_d	Pressure gauge	±0.5%	Spot measurement	-
P_s	Pressure gauge	±0.5%	Spot measurement	-
kW_{chwp}	Power meter	±1%	Spot measurement	-

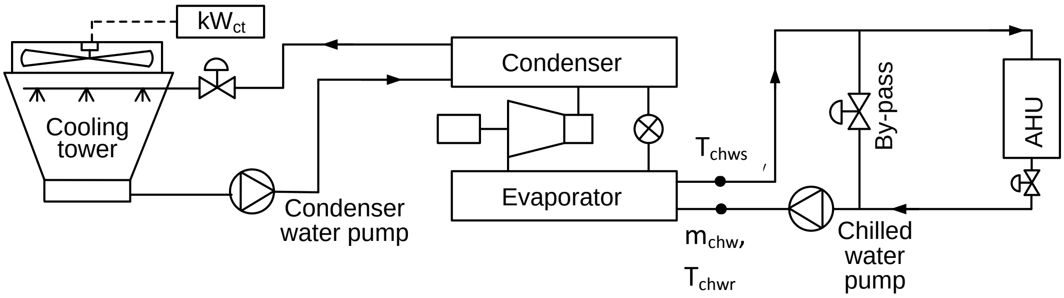
3.1.4 Cooling Towers

EnPI-6: COP of Cooling Towers

Formula: $COP_{ct} = \frac{Q_{cooling}}{kW_{ct}}$

Unit: kW_c/kW_e

Schematic diagram of chiller showing sensor location:



Description of parameters:

kW_{ct} = Power consumed by cooling tower fan, kW
$Q_{cooling}$ = Cooling load of the chiller, kW
$Q_{cooling}$ = m_{chw} x Cp x ($T_{chwr} - T_{chws}$), kW
m_{chw} = Mass flow rate of chilled water, kg/s
Cp = Specific heat capacity of water = 4.2 kJ/kg.K
T_{chwr} = Chilled water return temperature, ^oC
T_{chws} = Chilled water supply temperature, ^oC

Heat and mass balance analysis: Not required

Others:

1. Approach temperature (difference between condenser water supply temperature, T_{cws} and wet bulb temperature, T_{wb}) would be compared with the cooling tower design specification to assess the performance of the cooling tower system. Wet bulb temperature will be determined from the Psychrometric chart using measured dry bulb temperature and relative humidity of ambient air.

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
m_{chw}	Ultrasonic flow meter	±2%	Trend log	1 minute interval for 7 days (From chiller)
T_{chwr}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days (From chiller)
T_{chws}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days (From chiller)
T_{cws}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days (From chiller)
T_{wb}	Ambient temperature & RH sensor	±0.5°C and 3% RH	Trend log	1 minute interval for 2 days
kW_{cwp}	Power meter	±1%	Spot measurement for constant speed or logging for variable speed	Spot measurement for constant speed or logging at 1 minute interval for 7 days for variable speed

3.1.5 Chilled Water System

EnPI-7: COP of Chilled Water System

Formula: $COP_{chilled\ water\ system} = Q_{cooling}/kW_{compressor} + Q_{cooling}/kW_{chwp} + Q_{cooling}/kW_{cwp} + Q_{cooling}/kW_{ct}$

Unit: kW_c/kW_e

Others:

1. Cooling load histogram will be produced to determine if the chillers are sized properly.
2. Chilled water flow rate will be compared with system cooling load requirements to assess the pumping system performance.

Measured parameters:

Refer to sections 3.1.1 to 3.1.5

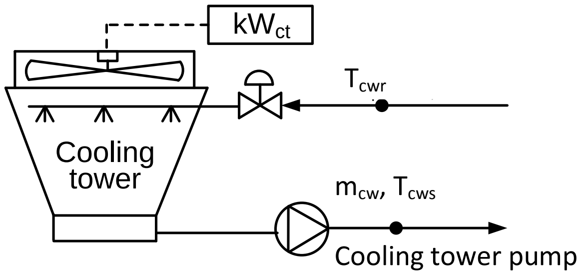
3.2 PROCESS COOLING (COOLING TOWER) SYSTEMS

EnPI-1: Specific Heat Rejection Rate by Cooling Tower

Formula: $COP_{ct} = \frac{Q_{heat}}{kW_{ct}}$

Unit: kW_c/kW_e

Schematic diagram of cooling tower showing sensor location:



Description of parameters:

kW_{ct} = Power consumed by fan of cooling tower, kW
Q_{heat} = Heat rejection rate, kW
$Q_{heat} = m_{cw} \times Cp \times (T_{cwr} - T_{cws})$
m_{cw} = Mass flow rate of cooling tower water, kg/s
Cp = Specific heat capacity of water = 4.2 kJ/kg.K
T_{cwr} = Cooling tower water return temperature, °C
T_{cws} = Cooling tower water supply temperature, °C

Heat and mass balance analysis: Not required

Measured parameters:

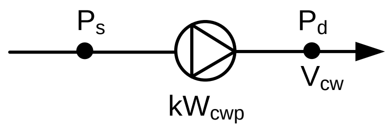
Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
m_{cw}	Ultrasonic flow meter	±2%	Trend log	Logging at 1 minute interval for 1 to 2 days
T_{cwr}	Thermistor	±0.04°C	Trend log	Logging at 1 minute interval for 1 to 2 days
T_{cws}	Thermistor	±0.04°C	Trend log	Logging at 1 minute interval for 1 to 2 days
T_{wb}	Ambient temperature & RH sensor	±0.5°C and 3% RH	Trend log	1 minute interval for 2 days
kW_{ct}	Power meter	±1%	Spot measurement for constant speed or logging for variable speed	Spot measurement for constant speed or logging at 1 minute interval for 1 to 2 days for variable speed

EnPI-2: Efficiency of Cooling Tower Water Pump System

Formula: $\eta_{chwp} = \frac{V_{cw} \, x \, \Delta P}{kW_{cwp} \, x \, 1000} \text{ x } 100\%$

Unit: Percentage

Schematic diagram of sensor location:



Description of parameters:

kW_{cwp} = Power consumed by cooling tower water pump, kW
V_{cw} = Volume flow rate of cooling tower water, m^3/s
Δp = Pressure difference, Pa
= $(P_d - P_s)$, Pa
P_d = Pump discharge pressure, Pa
P_s = Pump suction pressure, Pa

Heat and mass balance analysis: Not required

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Remarks
V_{cw}	Ultrasonic flow meter	±2%	Spot measurement	
P_d	Pressure gauge	±0.5%	Spot measurement	-
P_s	Pressure gauge	±0.5%	Spot measurement	-
kW_{cwp}	Power meter	±1%	Spot measurement	-

Others:

The following parameters will also be used to evaluate the overall performance of cooling tower systems:

1. Cooling tower water supply temperature (comparison with design values)
2. Temperature difference between cooling tower return and supply water streams
3. Approach temperature (difference between cooling tower water supply and wet bulb temperatures) will be compared with the cooling tower design specification to assess the performance of the cooling tower system. Wet bulb temperature will be determined from the Psychrometric chart using measured dry bulb temperature and relative humidity of ambient air.

3.3 REFRIGERATION SYSTEMS

EnPI-1: Specific Energy Consumption

Formula: $\frac{\text{Energy consumption of Refrigeration system, kWh/day}}{\text{Weight of material inside refrigerated space}}$ and

$$\frac{\text{Energy consumption of Refrigeration system, kWh/day}}{\text{Volume of refrigerated space}}$$

Unit:

Description of parameters:

- Volume of refrigeration space will be determined from specification / drawing

- Average weight of materials stored inside the refrigerated space will be determined from records
- Average daily energy consumption of refrigeration system compressor will be measured

Heat and Mass Balance Analysis: Not required

Measured Parameters:

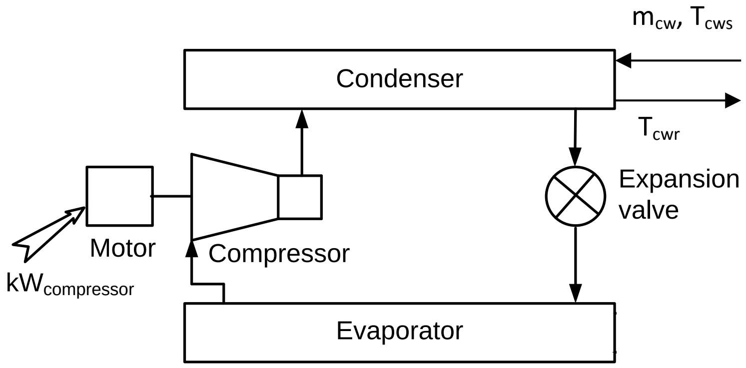
Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
Power consumption of refrigeration compressor	Power transducer	±1%	Trend log	1 minute interval for 7days

EnPI-2: COP of Refrigeration System
Case-1: Water cooled condenser

Formula: $COP_{rs} = \dfrac{Cooling\ \ produced\ by\ the\ refrigeration\ system, kW}{Power\ consumption\ of\ \ refrigeration\ compressor^{*}, kW}$

* Power consumption of cooling tower fans and pumps to be included for those with dedicated cooling systems

Unit: kW_c/kW_e



Formula to Compute Refrigeration Load:
Refrigeration load, kW = Heat rejection rate of cooling tower, kW - Input power to motor of compressor, kW

Description of parameters:

$kW_{compressor}$ = Refrigeration system compressor power, kW
$Q_{cooling}$ = Refrigeration load , kW
= $(Q_{heat} - kW_{compressor}\ x\ F)$
Q_{heat} = heat rejection rate of refrigeration system
= $m_{cw}\ x\ Cp\ x\ (T_{cwr} - T_{cws})$, kW
m_{cw} = Mass flow rate of condenser water, kg/s
Cp = Specific heat capacity of water = 4.2 kJ/kg.K
T_{cwr} = Condenser water return temperature, ^oC
T_{cws} = Condenser water supply temperature, ^oC

F = 1.0 for hermetically sealed systems
= motor efficiency /100 for open drive

Heat and Mass Balance Analysis: Not required

Measured Parameters:

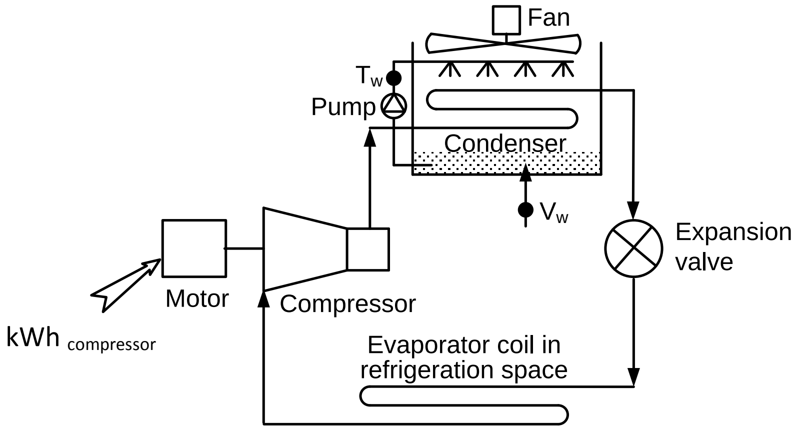
Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
m_{cw}	Ultrasonic flow meter	±2%	Trend log	1 minute interval for 7 days s
T_{cwr}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days
T_{cws}	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days
$kW_{compressor}$	Power transducer	±1%	Trend log	1 minute interval for 7 days
kW_{fan}	Power meter	±1%	Spot measurement	-
kW_{pump}	Power meter	±1%	Spot measurement	-

Case-2: Evaporative condenser

Formula: $COP_{rs} =$

$$\frac{\textit{Cooling produced by the refrigeration system, kWh/day}}{\textit{Energy consumption of refrigeration compressor, pump and fan, kWh/day}}$$

Unit: kWh_c/kWh_e



Description of parameters:

$$Refrigeration\ load = \left[\left(\frac{V_w \rho_w h_{fg@Tw}}{3600}\right) - (kWh_{compressor}) \mathbf{x}\, F\right],\ kWh/day$$

V_w = Volume of make-up water to evaporative condenser, m^3/day
ρ_w = Density of water at T_w, kg/m^3
$h_{fg@Tw}$ = Latent heat of vaporization of water at T_w, kJ/kg
T_w = Temperature of circulating water of evaporative condenser, °C
$kWh_{compressor}$ = Input energy to compressor motor, kWh/day

kWh_{pump} = pump energy consumption, kWh/day
kWh_{fan} = fan energy consumption, kWh/day
F = 1.0 for hermetically sealed systems
= motor efficiency /100, for open drive

Formula to Compute Refrigeration Load:
Refrigeration load, kW = Heat rejection rate of evaporative condenser, kW - Input power to motor of compressor, kW.

Heat and Mass Balance Analysis: Not required

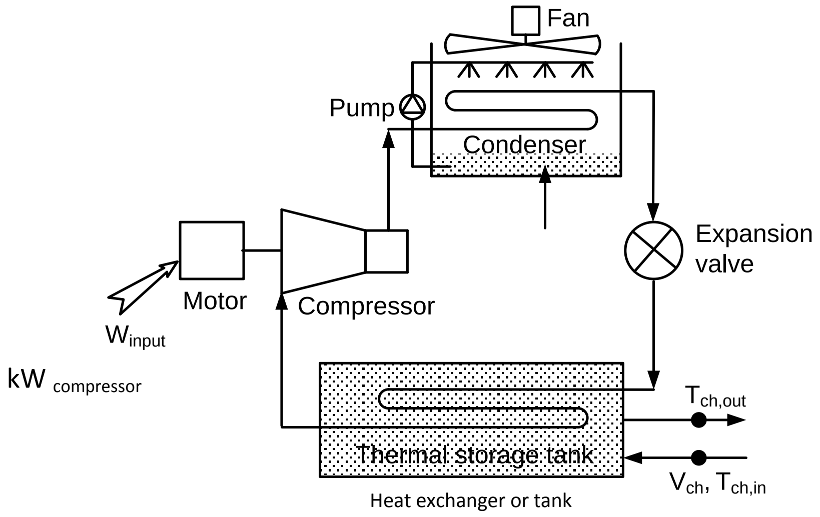
Measured Parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
V_w	Water meter	±2%	Daily readings	7 days
T_w	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days
kWh_{pump}	Power meter	±1%	Spot measurement of kW	-
kWh_{fan}	Power meter	±1%	Spot measurement of kW	-
$kWh_{compressor}$	Power transducer	±1%	Trend log	1 minute interval for 7 days

Case-3: Evaporator coil severing heat exchanger or thermal storage tank

Formula: $COP_{rs} = \dfrac{\text{Cooling produced by the refrigeration system, kW}}{\text{Power consumption of refrigeration compressor, pump and fan, kW}}$

Unit: kW_c/kW_e



Description of parameters:

$$kW_c = V_{ch}\rho_{ch}C_{p,ch}(T_{ch,out} - T_{ch,in}),\ kW$$

V_{ch} = Volume flow rate of chilled water, m^3/s
ρ_{ch} = Density of cooling water at $T_{ch,in}$, kg/m^3
$C_{p,ch}$ = Specific heat capacity of cooling water, kJ/kg K
$T_{ch,in}$ = Inlet temperature of cooling water, °C

$T_{ch,out}$ = Outlet temperature of cooling water, °C

Heat and Mass Balance Analysis: Not required

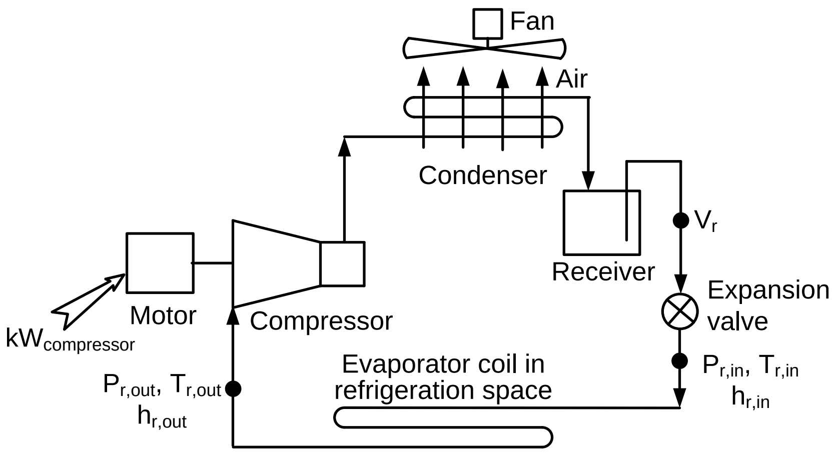
Measured Parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
V_{ch}	Ultrasonic flow meter	±2%	Trend log	1 minute interval for 7 days
$T_{ch,in}$	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days
$T_{ch,out}$	Thermistor	±0.04°C	Trend log	1 minute interval for 7 days
$kW_{compressor}$	Power transducer	±1%	Trend log	1 minute interval for 7 days
kW_{fan}	Power meter	±1%	Spot measurement	-
kW_{pump}	Power meter	±1%	Spot measurement	-

Case-4: Direct expansion type
Scenario-1: Refrigerant flow rate can be measured
Formula: COP_{rs} =

$$\frac{\textit{Cooling produced by the refrigeration system, kW}}{\textit{Power consumption of refrigeration compressor and fan, kW}}$$

Unit: kW_c/kW_e



Description of parameters:

$$\textit{Cooling produced by the refrigeration system} = m_r\left(h_{r,out} - h_{r,in}\right), \text{kW}$$

$$\textit{Mass flow rate of refrigerant } m_r = V_r \rho_r, \text{kg/s}$$

m_r = Mass flow rate of refrigerant, kg/s
V_r = Volume flow rate of liquid refrigerant, m^3/s
ρ_r = Density of liquid refrigerant, kg/m^3
$kW_{compressor}$ = Input power to motor of compressor, kW
kW_{fan} = Input power to fan, kW
$h_{r,in}$ = Enthalpy of refrigerant at $P_{r,in}$ and $T_{r,in}$, kJ/kg
$h_{r,out}$ = Enthalpy of refrigerant at $P_{r,out}$ and $T_{r,out}$, kJ/kg

$P_{r,in}$ = Pressure of refrigerant at inlet of evaporator, kPa
$T_{r,in}$ = Temperature of refrigerant at inlet of evaporator, °C
$P_{r,out}$ = Pressure of refrigerant at outlet of evaporator, kPa
$T_{r,out}$ = Temperature of refrigerant at outlet of evaporator, °C

If it is not possible to measure refrigerant temperature and pressure continuously and convert to enthalpy, it is proposed to take average readings for a number of sample periods of time (1-hour each).

Heat and Mass Balance Analysis: Not required

Measured Parameters:

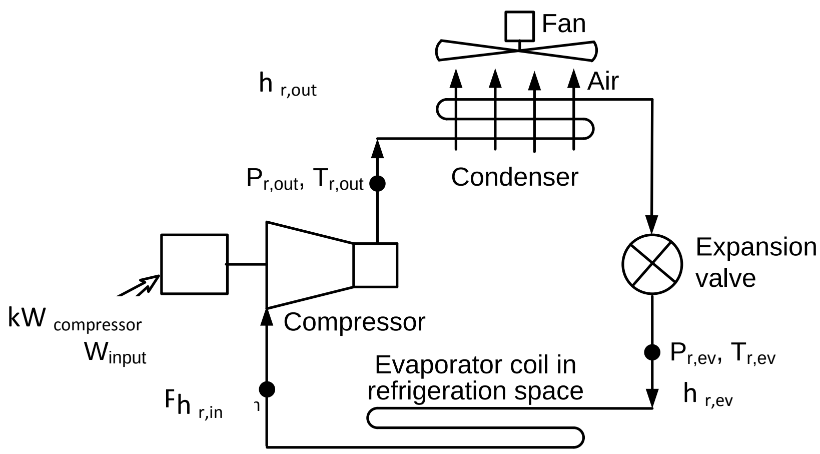
Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
V_r	Ultrasonic flowmeter	±2%	Trend log	1 minute interval for 3 days
$P_{r,in}$	Pressure gauge	Based on installed sensor	Spot measurement / Trend log (if permanent sensor is available)	Average for one hour
$P_{r,out}$	Pressure gauge	Based on installed sensor	Spot measurement / Trend log (if permanent sensor is available)	Average for one hour
$T_{r,in}$	Surface temperature sensor	±1°C	Trend log	Average for one hour
$T_{r,out}$	Surface temperature sensor	±1°C	Trend log	Average for one hour
$kW_{compressor}$	Power transducer	±1%	Trend log	1 minute interval for 3 days
kW_{fan}	Power meter	±1%	Spot measurement	-

Scenario-2: Refrigerant flow rate can be calculated

Formula:

$$COP_{rs} = \frac{Cooling\ produced\ by\ the\ refrigeration\ system, kW}{Power\ consumption\ of\ refrigeration\ compressor\ and\ fan, kW}$$

Unit: kW_c/kW_e



Description of parameters:

$$\textit{Mass flow rate of refrigerant } m_r = \frac{kW_{compressor}}{h_{r,out} - h_{r,in}}, \text{ kg/s}$$

$$\textit{Refrigeration load} = m_r\left(h_{r,in} - h_{r,ev}\right), \text{ kW}$$

$kW_{compressor}$ = Input power to motor of compressor, kW
m_r = Mass flow rate of refrigerant, kg/s
$h_{r,in}$ = Enthalpy of refrigerant at $P_{r,in}$ and $T_{r,in}$, kJ/kg
$h_{r,out}$ = Enthalpy of refrigerant at $P_{r,out}$ and $T_{r,out}$, kJ/kg
$h_{r,ev}$ = Enthalpy of refrigerant at $P_{r,ev}$ and $T_{r,ev}$, kJ/kg
$P_{r,in}$ = Pressure of refrigerant at inlet of compressor, kPa
$T_{r,in}$ = Temperature of refrigerant at inlet of compressor, ^{o}C
$P_{r,out}$ = Pressure of refrigerant at outlet of compressor, kPa
$T_{r,out}$ = Temperature of refrigerant at outlet of compressor, ^{o}C
$P_{r,ev}$ = Pressure of refrigerant at inlet of evaporator, kPa
$T_{r,ev}$ = Temperature of refrigerant at inlet of evaporator, ^{o}C

Since it will not be possible to measure refrigerant temperature and pressure continuously and convert to enthalpy, it is proposed to take average readings for a number of sample periods of time (1-hour each).

Accordingly, the calculation for refrigeration load will be as follows:

$$\textit{Mass of refrigerant } m_r = \frac{kWh_{compressor}}{3600(h_{r,out} - h_{r,in})}, \text{ kg/s}$$

$$\textit{Refrigeration load} = m_r\left(h_{r,in} - h_{r,ev}\right), \text{ kW}$$

Input power to motor of compressor = Rate of energy transfer to the refrigerant by compressor

Heat and Mass Balance Analysis: Not required

Measured Parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
$P_{r,in}$	Pressure gauge	Based on installed sensor	Spot measurement / Trend log (if permanent sensor is available)	Average for one hour
$P_{r,out}$	Pressure gauge	Based on installed sensor	Spot measurement / Trend log (if permanent sensor is available)	Average for one hour
$P_{r,ev}$	Pressure gauge	Based on installed sensor	Spot measurement / Trend log (if permanent sensor is available)	Average for one hour
$T_{r,in}$	Surface temperature sensor	±1°C	Trend log	Average for one hour
$T_{r,out}$	Surface temperature sensor	±1°C	Trend log	Average for one hour
$T_{r,ev}$	Surface temperature sensor	±1%	Trend log	Average for one hour

$kW_{compressor}$	Power transducer	±1%	Trend log	1 minute interval for 3 days
kW_{fan}	Power meter	±1%	Spot measurement	-

Scenario-3: Determination of refrigerant flow rate and calculation of COP are not practically possible (for cold rooms).

Formula:

$$\frac{Energy\ consumption\ of\ refrigeration\ compressor\ and\ fan, kWh/day}{Volume\ of\ refrigeration\ space, m^3}$$

Unit: $(kWh/day)/m^3$

Description of parameters:

$kW_{compressor}$ = Input power to motor of compressor, kW
kW_{fan} = Input power to fan, kW
V_{space} = Volume of refrigeration space, m^3

Volume of refrigeration space will be determined using drawings / specifications.

Heat and Mass Balance Analysis: Not required

Measured Parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
$kW_{compressor}$	Power transducer	±1%	Trend log	1 minute interval for 3 days
kW_{fan}	Power meter	±1%	Spot measurement	-

Measured power consumption of the compressor and fan of existing refrigeration system will be compared with simulated power consumption of energy efficient refrigeration system to support the same space. Following parameters of existing refrigeration system will be used to simulate the power consumption of the energy efficient refrigeration system:

1. Temperature of refrigerated space
2. Temperature of condenser
3. Type of compressor
4. Type of refrigerant
5. Volume of refrigerated space

Others:

The following parameters will also be used to evaluate the overall performance of refrigeration systems:

1. Operating temperature of refrigeration system / cold room
2. Approach temperature of water cooled condensers

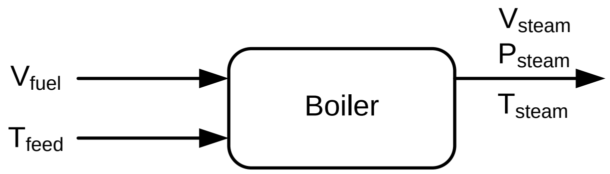
3.4 BOILER SYSTEMS

EnPI-1: Boiler Thermal Efficiency η_{boiler}

Formula:
Unit: %

Option 1 – Plant has steam flow meter

Schematic diagram of system showing sensor locations:



Description of Parameters:

Energy output to steam = V_{steam} x ρ_{steam} x h_{steam} – m_{feed} x h_{feed}
V_{steam} = Volume flow rate of steam, m^3/s
ρ_{steam} = Density of steam at boiler outlet temperature and pressure, kg/m^3
= Density of steam at T_{steam} and P_{steam}, kg/m^3
h_{steam} = Enthalpy of steam at the outlet of the boiler, kJ/kg
= Enthalpy of steam at T_{steam} and P_{steam}, kJ/kg
T_{steam} = Temperature of steam at boiler outlet, ^oC
P_{steam} = Pressure of steam at boiler outlet, bar
m_{feed} = mass flow rate of feed water = V_{steam} x ρ_{steam} *(kg/s)*
h_{feed} = Enthalpy of feed water at temperature T_{feed}
Energy input of fuel = V_{fuel} x ρ_{fuel} x *CV*
V_{fuel} = Fuel consumption rate, m^3/s
ρ_{fuel} = Density of fuel, kg/m^3
CV = Gross calorific value of fuel, kJ/kg

Heat and Mass Balance Analysis: Not required

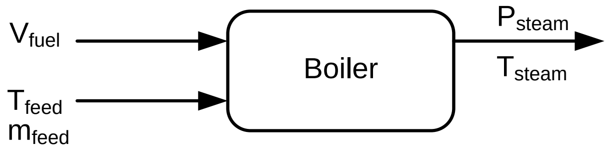
Others: Specification of fuel will be used to determine the gross calorific value of fuel.

Measured Parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
V_{steam}	Plant flow meter	Based on installed sensor	Trend log	1 minute interval for 3 days
T_{steam}	RTD	Based on installed sensor	Spot measurement / Trend log	1 minute interval for 3 days (Depending on installed system)
T_{feed}	Thermistor	±0.2°C	Trend log	1 minute interval for 3 days
P_{steam}	Pressure gauge	Based on installed sensor	Spot measurement / Trend log	1 minute interval for 3 days (Depending on installed system)
V_{fuel}	Plant flow meter or tank measurements	Based on installed sensor	Cumulative	Daily readings

Option 2 – Plant does not have steam flow meter

Schematic diagram of system showing sensor locations:



Description of Parameters:

$Energy\ output\ to\ steam = m_{steam}\ x\ h_{steam} - m_{feed}\ x\ h_{feed}$

m_{feed} = Mass flow rate of feed water to boiler, kg/s

T_{feed} = Feed water temperature, °C

h_{feed} = Enthalpy of feed water at T_{feed}, kJ/kg

m_{steam} = Mass flow rate of steam, kg/s = m_{feed} - m_{bd}

$Feed_{TDS}$ = TDS level of feed water

$Boiler_{TDS}$ = TDS level of boiler

h_{steam} = Enthalpy of steam at the outlet of boiler, kJ/kg

= Enthalpy of steam at T_{steam} and P_{steam}, kJ/kg

T_{steam} = Temperature of steam at boiler outlet, °C

P_{steam} = Pressure of steam at boiler outlet, bar

Energy input of fuel = $V_{fuel}\ x\ \rho_{fuel}\ x\ CV$

V_{fuel} = Fuel consumption rate, m^3/s

ρ_{fuel} = Density of fuel, kg/m^3

CV = Gross calorific value of fuel, kJ/kg

Heat and Mass Balance Analysis:

Based on mass balance of water as shown in the figure above:

Mass flow rate of water at the inlet of the boiler (kg/s) = mass flow rate of steam (kg/s) + blowdown rate (kg/s)

Others: Specification of fuel will be used to determine the gross calorific value of fuel.

Measured Parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
m_{feed}	Ultrasonic flow meter	±2%	Trend log	1 minute interval for 3 days
T_{feed}	Thermistor	±0.04°C	Trend log	1 minute interval for 3 days
T_{steam}	RTD	Based on installed sensor	Spot measurement/Trend log	1 minute interval for 3 days (Depending on installed system)
P_{steam}	Pressure gauge	Based on installed sensor	Spot measurement/Trend log	1 minute interval for 3 days (Depending on installed system)
V_{fuel}	Plant flow meter or tank measurements	Based on installed sensor	Cumulative	Daily readings
TDS	Measured by permanent sensor or periodic sampling as part of boiler O&M procedure	Based on current sensor / measurement methodology	Periodic sampling	-

EnPI-2: Condensate recovery factor

Formula: $= \dfrac{Amount\ of\ Condensate\ recoverd}{Feed\ water\ flow rate}$

Unit: %

Description of parameters:

$Amount\ of\ condensate\ recovered = V_{feed} - MU_{water}$

V_{feed} = Feed water flow rate, m^3/day

MU_{water} = Make-up water flow rate, m^3/day

Heat and Mass Balance Analysis:

Condensate recovery rate (kg/s) = Feed water flow rate (kg/s) – Make-up water flow rate (kg/s)

Measured Parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
V_{feed}	Ultrasonic flow meter	±2%	Trend log	1 minute interval for 3 days
MU_{water}	Plant water flow meter	±2%	Cumulative	Daily readings

Others:

The following parameters will also be used to evaluate the overall performance of boilers and steam systems:

1. Operating pressure
2. Combustion efficiency (where possible)
3. Steam leaks

3.5 OVENS AND FURNACES

EnPI-1: Energy Usage Efficiency

Formula: $\dfrac{Energy\ absorption\ rate\ by\ the\ products, kW}{Energy\ input\ rate\ to\ Furnace\ or\ Oven\ or\ Electirc\ Heater, kW}$

Unit: %

Description of parameters:

Energy input rate to fuel fired furnace or oven, $Q_{in} = V_{fuel} \times \rho_{fuel} \times CV$, kW

V_{fuel} = Fuel consumption rate, m^3/s

ρ_{fuel} = Density of fuel, kg/m^3

CV = Gross calorific value of fuel, kJ/kg

Energy input rate to electrical furnace or oven, Q_{in} = Input electrical power to the heater, kW

Energy absorption rate by the products, $Q_{out} = Q_{in} - Q_{conv} - Q_{rad} - Q_{ex}$

Convection heat loss from furnace skin $Q_{conv} = h_c A(T_{skin} - T_{air})/1000$, kW

Convective heat transfer coefficient $h_c = 10.45 - v + 10v^{0.5}$, $W/m^2 K$

v = Air flow velocity ranges from 2 to 20 m/s (natural)

A = Exposed surface area of furnace or oven, m^2
T_{skin} = Average temperature of furnace exposed surface, ^oC
T_{air} = Surrounding air temperature, ^oC

Radiation heat loss from furnace exposed surface

$$Q_{rad} = \sigma A \varepsilon[(T_{skin})^4 - (T_{air})^4]/1000, kW$$

σ = Stefan-Boltzmann constant, 5.67×10^{-8} $W/m^2 K^4$
ε = Emissivity of furnace surface
A = Exposed surface area of furnace or oven, m^2
T_{skin} = Average temperature of furnace exposed surface, K
T_{air} = Surrounding air temperature, K

Energy flow rate with flue gas $Q_{ex} = m_{flue} \times C_{p,flue} \times T_{flue}$
m_{flue} = *Total mass flow rate of flue gas, kg/s*
$C_{p,flue}$ = Specific heat of flue gas at T_{flue}, kJ/kg K
T_{flue} = Flue gas temperature, ^oC
(Note: Q_{ex} would be calculated for fuel fired furnace)

Determination of total mass flow rate of flue gas:

- Measure fuel consumption rate using existing fuel flow meter = $V_{fuel} \times \rho_{fuel}$, kg/s
- Calculate stoichiometric air fuel ratio and stoichiometric mass flow rate of air, kg/s
- Measure O_2 or CO_2 or CO concentration in exhaust flue gas using gas analyzer (if port available)
- Determine excess air flow rate based on measured O_2 or CO_2 or CO concentration, %
- Total mass flow rate of flue gas (m_{flue}), kg/s = Measured fuel consumption rate, kg/s + Stoichiometric air flow rate, kg/s x (1 + Excess air flow rate, fraction), kg/s

Heat and Mass Balance Analysis: Not required

Others: Specification of fuel will be used to determine the gross calorific value of fuel (where applicable).

Measured Parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
Electrical power	Power transducer	±1%	Trend log	1 minute interval for 3 days
T_{skin}	Infrared sensor	±1°C	Spot measurement	-
T_{air}	Temperature sensor	±0.5°C	Spot measurement	-
T_{flue}	RTD	Based on installed sensor	Spot measurement	-
V_{fuel}	Plant flow meter or tank measurements	Based on installed sensor	Cumulative	Daily readings

3.6 COMPRESSED AIR SYSTEMS

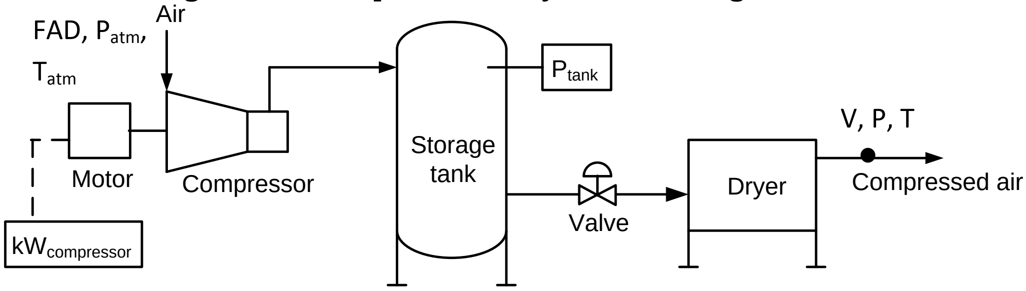
EnPI-1: Specific Energy Consumption of Compressor

Formula:

$$\frac{\text{Energy consumption of compressors, dryers \& cooling system, kWh/day}}{\text{Free air delivery rate at normal conditions, } Nm^3\text{/day}}$$

Unit: kWh/Nm^3

Schematic diagram of a compressed air system showing sensor location:



Description of parameters:

Free air delivery rate FAD = Average air intake rate into compressor, Nm^3/h

$FAD_{actual} = (P \times V \times T_{atm}) / (P_{atm} \times T)$

$FAD_{normal} = (P \times V \times T_{normal}) / (P_{atm} \times T)$

V = Volume flow rate at the measured point, m^3/s

P = Pressure at the measurement point, kPa

P_{atm} = Atmospheric pressure, kPa

T = Temperature at the measurement point, K

T_{atm} = Temperature of ambient air, K

T_{normal} = Temperature of air at normal condition, 273K

Heat and mass balance analysis: Not required

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
V	Ultrasonic flow meter	±2%	Trend log	1 minute interval for 3 days
P	Pressure transmitter	±0.5%	Trend log (where port available)	1 minute interval for 3 days
T	Surface temperature sensor	±0.5°C	Spot measurement/Trend log (if sensor is available)	-
T_{atm}	RTD	±0.5°C	Spot measurement	-
$kW_{compressor}$	Power transducer	±1%	Trend log	1 minute interval for 3 days

EnPI-2: Leakage Rate

Formula:

$$System\ Leakage = \frac{FAD\ x\ Average\ load\ time, minutes}{Average\ load\ time + Average\ unload\ time, minutes}$$

Unit: % and m^3/min

Description of parameters:

System leakage = $(Q\ x\ T) / (T + t)$, m^3/min

Q = Compressor FAD capacity, m^3/min

T = Average load time (minutes)

t = Average unload time (minutes)

Measurement steps:

- Switch-off equipment which use compressed air (plant shut-down)
- Operate the compressor and charge the system to the operating pressure
- Measure the time taken for “load” and “unload” cycles continuously for about 10 cycles

Heat and mass balance analysis: Not required

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement duration
T	Stop-watch		Spot measurement	10 cycles
t	Stop-watch		Spot measurement	10 cycles

EnPI-3: Compressor Loading Percentage

Formula: $$\frac{Average\ duration\ of\ loaded\ operation, minutes}{Average\ duration\ of\ loaded\ and\ unloaded\ operation, minutes}$$

Unit: %

Description of parameters:

Loading percentage = $T / (T + t)\ x\ 100$

T = Average load time (minutes)

t = Average unload time (minutes)

Measurement steps:

- Measure the time taken for “load” and “unload” cycles continuously for about 10 cycles

Heat and mass balance analysis: Not required

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
T	Stop-watch		Spot measurement	10 cycles
t	Stop-watch		Spot measurement	10 cycles

Others:

The following parameters would also be used to evaluate the overall performance of compressed air systems:

1. Operating pressure
2. Intake temperature
3. Operating dew-point
4. Dryer power

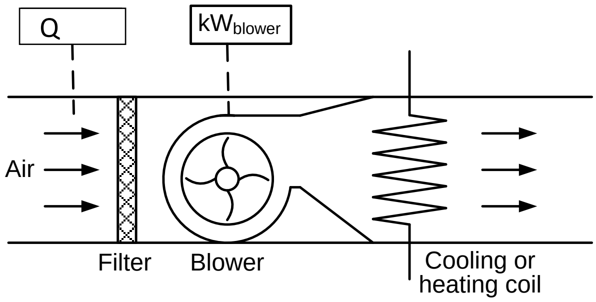
3.7 FAN SYSTEMS

EnPI-1: Specific Power Consumption of Fans

Formula: $\frac{\text{Power consumption of fan, kW}}{\text{Volume flow rate of fan, m}^3\text{/s}}$

Unit: kW/m³/s

Schematic diagram of typical fan system showing sensor location:



Description of parameters:

Q = Volume flow rate of air, m³/s

kW_{blower} = Fan / Blower power consumption, kW

Heat and mass balance analysis: Not required

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
Q	Hot wire anemometer	±0.015 m/s	Spot measurement	-
kW_{blower}	Fluke power meter	±1%	Spot measurement	-

Others:

The following parameters will also be used to evaluate the overall performance of ventilation systems:

1. Number of air changes
2. Type of filter / filter pressure drop
3. Code requirements

3.8 LIGHTING SYSTEMS

EnPI-1: Lighting Power Density

Formula: $$\frac{Power\ of\ lamps\ including\ gear\ or\ ballast, W}{Floor\ area, m^2}$$

Unit: W/m^2

Description of parameters:

- Count number and types of lamps
- Determine power of lamps, gear or ballast by measuring the power consumption of 2 nos. of sample lighting circuits and counting number of lamps connected to the corresponding circuits (where feasible).
- If different types of lamps or receptacle loads are connected with the lighting circuits, rated power of lamps, gear or ballast will be used.
- Determine floor area served

EnPI-2: Illuminance Level (Lux):

Unit: Lux

Description of parameters:

- Measure Lux level for each type of space usage
- Measure Lux level at few locations for each type of space usage to determine the range of illuminance level

3.9 PRODUCTION SYSTEMS

EnPI-1: Comparison of Specific Energy Consumption

Comparison of actual specific energy consumption to the rated specific energy consumption

Formula: $$\frac{Actual\ energy\ consumption\ of\ production\ process, kWh_{process} / actual\ output}{Rated\ energy\ consumption\ of\ production\ equipment\ , kWh / rated\ output}$$

Unit: None

Description of parameters:

- Energy consumption of selected production processes will be measured for a particular period
- Number of product units produced or weight of material processed (or any other suitable quantity of measure) during the same period will be recorded
- The rated energy consumption of the production equipment and its rated capacity will be obtained from the manufacturer specifications

Heat and mass balance analysis: Not required

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
$kWh_{process}$	Power transducer	±1%	Trend log	1 minute interval for 2 days
Actual output of system	-	-	Production records	2 days

3.10 PACKAGING SYSTEMS

EnPI-1: Specific Energy Consumption

Formula: $$\frac{Total\ energy\ consumption\ of\ packaging\ process, kWh}{Number\ of\ unit\ produced\ during\ the\ same\ period}$$

$$\frac{Total\ energy\ consumption\ of\ packaging\ process, kWh}{Volume\ or\ weight\ of\ products\ packaged\ during\ the\ same\ period}$$

Unit: kWh/unit

Description of parameters:

- Energy consumption of selected packaging system will be measured for a particular period
- Number of product units produced or weight of material processed (or any other suitable quantity of measure) during the same period will be recorded

Heat and mass balance analysis: Not required

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
$kW_{packaging}$	Power transducer	±1%	Trend log	1 minute interval for 2 days
Output of system	-	-	Production records	2 days

EnPI-2: Comparison of Specific Energy Consumption

Comparison of actual specific energy consumption to the rated specific energy consumption

Formula: $$\frac{Actual\ energy\ consumption\ of\ packaging\ process, kWh_{packing} / actual\ output}{Rated\ energy\ consumption\ of\ packaging\ equipment\ , kWh / rated\ output}$$

Unit: None

Description of parameters:

- Energy consumption of selected packaging system will be measured for a particular period

- Number of product units produced or weight of material processed (or any other suitable quantity of measure) during the same period will be recorded
- The rated energy consumption of the packaging system and its rated capacity will be obtained from the manufacturer specifications

Heat and mass balance analysis: Not required

Measured parameters:

Parameter	Sensor type	Accuracy	Measurement type	Measurement Duration
$kWh_{packing}$	Power transducer	±1%	Trend log	1 minute interval for 2 days
Actual output of system	-	-	Production records	2 days

3.11 OTHER SYSTEMS

As stated in Section-2, if the total energy consumption of the equipment and systems measured is less than 80% of the total energy usage of the plant, additional equipment and systems will be included in the assessment.

3.11 EVALUATION OF MATURITY LEVEL OF ENERGY MANAGEMENT SYSTEM

Maturity level of existing Energy Management System (EnMS) will be 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

An interview will be conducted with the relevant personnel in the plant to evaluate present status using the following metrics:

1) Energy policy

- ☐ Level-1: No explicit energy policy
- ☐ Level-2: Unwritten set of guidelines
- ☐ Level-3: Unadopted energy policy set by department or energy manager
- ☐ Level-4: Developed formal energy policy, but no commitment from top management
- ☐ Level-5: Energy policy, planning and regular review. Commitment of top management as part of environmental strategy

2) Energy Management team

- ☐ Level-1: No formal delegation of responsibility for energy consumption
- ☐ Level-2: Energy management is part-time responsibility of somebody with limited influence
- ☐ Level-3: Energy manager appointed, Reporting to ad-hoc committee, Line management and authority not defined properly
- ☐ Level-4: Chaired by member managing board, Energy manager accountable to energy committee representing all users
- ☐ Level-5: Energy Management System is fully integrated into management structure, Clear delegation of responsibility for energy consumption

3) Energy Monitoring and Accounting

- ☐ Level-1: No accounting / information for energy consumption
- ☐ Level-2: Facility engineer compiles energy consumption report based on invoice data for internal use within technical department

- Level-3: Energy consumption monitoring & targeting based on main meter data. Energy unit has ad-hoc involvement in budget setting
- Level-4: Energy consumption of major energy users are monitored using sub-meters. Energy savings not reported to respective users
- Level-5: Formal and informal communication by Energy manager & energy staff at all levels

4) **Capabilities and training needs**

- Level-1: Little knowledge / expertise in Energy Management
- Level-2: Have at least one person with some knowledge of Energy Management or attended training in Energy Management
- Level-3: Have one Certified Energy Manager
- Level-4: Have more than one Certified Energy Manager
- Level-5: Have more than one Certified Energy Manager and operations and Facility management staff regularly attend Energy Management related training

5) **Availability of funding**

- Level-1: No investment for improving energy efficiency. No cost energy saving measures taken
- Level-2: Only low cost energy saving measures taken
- Level-3: Energy saving measures with only short term payback period taken
- Level-4: Same payback criteria as for other investment
- Level-5: In favor of "Green" schemes with detailed investment appraisal of new energy efficient equipment and upgrading scopes

3.12 EVALUATION OF MAINTENANCE PRACTICES

The maintenance practices will be evaluated based on observations and interview of relevant personnel using the following metrics:

- **Filters & strainers**

  - Level-1: No regular schedule for checking and maintenance
  - Level-2: Have a regular schedule but no evidence of compliance
  - Level-3: Have a regular schedule and evidence of compliance
  - Level-4: Have a comprehensive maintenance program with key performance indicators and regular tracking of performance

- **Steam leaks**

  - Level-1: Significant amount of leaks observed and no formal program to minimise leaks
  - Level-2: No formal program to minimise leaks but only few leaks observed

- ☐ Level-3: Have a regular program to check for leaks but some leaks are observed
- ☐ Level-4: No leaks are observed

- **Compressed air leaks**

  - ☐ Level-1: Significant amount of leaks observed and no formal program to minimise leaks
  - ☐ Level-2: No formal program to minimise leaks but only few leaks observed
  - ☐ Level-3: Have a regular program to check for leaks but some leaks are observed
  - ☐ Level-4: No leaks are observed

- **Condensers, boilers and heat exchangers**

  - ☐ Level-1: No regular schedule for checking and maintenance
  - ☐ Level-2: Have a regular schedule but no evidence of compliance
  - ☐ Level-3: Have a regular schedule and evidence of compliance
  - ☐ Level-4: Regular monitoring of performance with set KPIs

- **Motors and drives**

  - ☐ Level-1: No regular schedule for checking and maintenance
  - ☐ Level-2: Have a regular schedule but no evidence of compliance
  - ☐ Level-3: Have a regular schedule and evidence of compliance
  - ☐ Level-4: Have a predictive maintenance program (vibration monitoring etc.) in addition to regular preventive maintenance

- **Monitoring and Control system**

  - ☐ Level-1: No regular schedule for checking and maintenance
  - ☐ Level-2: Have a regular schedule but evidence of wrong or erroneous display readings
  - ☐ Level-3: Have a regular schedule and display of readings appear to be normal
  - ☐ Level-4: Have a regular maintenance program together with regular checking and calibration of sensors

4.0 BENCHMARKING VALUES

Energy Performance Indicators (EnPIs) will be compared with benchmark or established values which are summarized in the table below.

Energy Performance Indicator	Unit	Benchmark Value
Chilled Water Systems		
EnPI-1: COP of chillers (water cooled, >300RT)	**kW_c/kW_e (kW_e/RT)**	6.9 (0.51)
EnPI-2: Specific power consumption of chilled water pumps	**kW_e/kW_c (kW_e/RT)**	0.0085 (0.03)
EnPI-3: Efficiency of chilled water pump system	**%**	72
EnPI-4: Specific power consumption of condenser water pumps	**kW_e/kW_c (kW_e/RT)**	0.0085 (0.03)
EnPI-5: Efficiency of condenser water pump system	**%**	72
EnPI-6: COP of cooling towers	**kW_c/kW_e (kW_e/RT)**	117 (0.03)
EnPI-7: COP of chilled water system	**kW_c/kW_e (kW_e/RT)**	5.85 (0.60)
Process Cooling (Cooling Tower) Systems		
EnPI-1: Specific heat rejection rate by cooling tower	**kW_c/kW_e**	117
EnPI-2: Efficiency of cooling tower water pump system	**%**	72
Refrigeration Systems		
EnPI-1: Specific energy consumption	**-**	Not available

<table>
<tr>
<td>EnPI-2: COP of refrigeration system</td>
<td>COP</td>
<td>
<table>
<tr><th>Evaporative Condenser Temp (˚C)</th><th>COP</th></tr>
<tr><td>-35 / +35</td><td>1.8</td></tr>
<tr><td>-20 / +35</td><td>2.9</td></tr>
<tr><td>-5 / +35</td><td>4.3</td></tr>
</table>
</td>
</tr>
<tr><td colspan="3">Boiler Systems</td></tr>
<tr>
<td>EnPI-1: Boiler thermal and combustion efficiency</td>
<td>%</td>
<td>
<table>
<tr><th rowspan="2">Boiler Type</th><th rowspan="2">Fuel Type</th><th colspan="2">Efficiency (%)</th></tr>
<tr><th>Combu -stion</th><th>Therm- al</th></tr>
<tr><td rowspan="2">Hot Water</td><td>Gas</td><td>82</td><td>80</td></tr>
<tr><td>Oil</td><td>84</td><td>82</td></tr>
<tr><td rowspan="2">Steam</td><td>Gas</td><td>79</td><td>79</td></tr>
<tr><td>Oil</td><td>81</td><td>81</td></tr>
</table>
</td>
</tr>
<tr>
<td>EnPI-2: Condensate recovery rate</td>
<td>%</td>
<td>80</td>
</tr>
<tr><td colspan="3">Oven and Furnaces</td></tr>
<tr>
<td>EnPI-1: Specific energy consumption</td>
<td>kWh/no. of units or</td>
<td>To use manufacturer specifications where available</td>
</tr>
<tr><td colspan="3">Compressed Air Systems</td></tr>
<tr>
<td>EnPI-1: Specific energy consumption</td>
<td>kWh/ Nm^3</td>
<td>
<table>
<tr><th>Pressure Ratio*</th><th>kWh/ Nm^3</th></tr>
<tr><td>4</td><td>0.050 – 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 – 0.107</td></tr>
<tr><td>8</td><td>0.080 – 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>0.133 – 0.192</td></tr>
</table>
*Pressure Ratio = Ratio of outlet to inlet pressure of compressor
(Source: German Energy Agency – dena)
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</table>

EnPI-2: Leakage rate	**% and m^3/min**	<2%
EnPI-3: Compressor loading percentage	**%**	Not available
Fan Systems		
EnPI-1: Specific power consumption of fans	**kW/CMH**	**SS 553:2009** 1.7 $kW/m^3/s$ (CAV) 2.4 $kW/m^3/s$ (VAV)
Lighting Systems		
EnPI-1: Lighting power density	**W/m^2**	**SS530:2014** 7 W/m^2 for warehouses 10 W/m^2 for storage areas 10 W/m^2 for mechanical & electrical rooms 12W/m^2 for office areas 13 W/m^2 for manufacturing (Assembly area)
EnPI-2: Illuminance level (Lux)	**Lux**	**SS531 Part 1: 2006 (2013)** 100 to 200 Lux for warehouses 200 to 500 Lux for work / manufacturing places 300 to 500 Lux for office areas 300 Lux for cutting, sorting and washing areas
Production Systems		
EnPI-1: Comparison of specific energy consumption	**-**	To use manufacturer specifications where available
Packaging Systems		
EnPI-1: Specific energy consumption	**kWh/unit**	To use manufacturer specifications where available For common packaging systems, to compare with best performing site
EnPI-2: Comparison of specific energy consumption	**-**	Not available