Energy Efficiency Opportunities Assessment Guidelines for Registered Corporations

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National Environment Agency
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Abbreviations

BIC	Best-In-Class
CAPEX	Capital Expenditure
ECA	Energy Conservation Act
ECS	Energy Consuming System
EE	Energy Efficiency
EEO	Energy Efficiency Opportunities
EEOA	Energy Efficiency Opportunities Assessment
EMB	Energy and Mass Balance
ESCO	Energy Service Company
IES	Institution of Engineers, Singapore
NEA	National Environment Agency
RBA	Relevant Business Activities
RC	Registered Corporation
PFD	Process Flow Diagram
VO	Verification Office
VSD	Variable Speed Drive

1 Industrial Energy Efficiency Requirements for Registered Corporations (RCs)

1.1 Purpose

This guidebook serves as a reference for registered corporations (RCs) in the conduct of an energy efficiency opportunities assessment (EEOA) under the Energy Conservation Act (ECA) and provides some good practices to identify energy efficiency opportunities (EEOs).

1.2 Background

The industrial sector consumes the largest share of energy in Singapore. To improve energy efficiency (EE) in the industrial sector, the ECA was introduced in 2013 to require energy-intensive users[1] in the industrial sector to implement mandatory energy management practices. To enhance these practices, the ECA was amended in 2017 to introduce, among others, a new requirement for RCs to carry out periodic EEOAs on all relevant business activities (RBAs) under their operational control.

Note: An RBA is a business activity that is carried out at a single site and is attributable to one of the following: (a) manufacturing and manufacturing-related services, (b) supply of electricity, gas, steam, compressed air and chilled water for air-conditioning, and (c) water supply and sewage and waste management.

Majority of improvement projects implemented at ECA premises have thus far focused on utility systems, while improvements in process systems have been uncommon. As process systems often consume utilities (such as steam, chilled water and compressed air) that are generated by upstream utility systems, potential EE improvements in the former may lower demand for the latter. A holistic energy assessment of a business activity should thus cover interrelated energy consuming systems (ECSs), in order to reap higher EE gains.

1.3 EEOA Requirements for RCs

1.3.1 <u>Assessment Period</u>

The timeframe within which RCs shall conduct an EEOA and submit an EEOA report is defined as an Assessment Period. This is a period of six consecutive calendar years determined by NEA. All data obtained from the assessment of ECSs shall fall within this period.

[1] Energy-intensive users refer to those that consume 54TJ or more of energy annually in at least 2 out of the 3 preceding years.

1.3.2 Conduct of 1st EEOA

RCs are required to conduct separate EEOAs for each RBA (except large power-generating RBAs) under its operational control and submit the EEOA reports by the end of the respective Assessment Periods. Please refer to the table below for the Assessment Period to conduct the 1st EEOA for each RBA.

Date business activity becomes relevant	Start date of assessment period	End date of assessment period
On or before 2 Jun 2017	1 Jan 2016[2]	31 Dec 2021
After Jun 2017	Date that business activity becomes relevant	6 years from date that business activity becomes relevant

In the event that a RBA becomes non-relevant, the RC will only need to conduct EEOA for that business activity when it becomes relevant again and six years will be given to submit the EEOA report from the date that the business activity becomes relevant again. Please note that RCs will still be required to submit EEOA reports for its other RBAs that are still relevant.

1.3.3 Subsequent Conduct of EEOAs

In the last year of its current Assessment Period, each RBA will be classified into one of the following two categories based on its energy consumption:

(i) Tier 1 RBA – the RBA consumes ≥500 TJ for at least two out of three preceding calendar years

(ii) Tier 2 RBA – the RBA consumes ≥54 TJ but <500 TJ for at least two out of three preceding calendar years

For Tier 1 RBAs, subsequent Assessment Periods begin immediately after the end of the current Assessment Period.

For Tier 2 RBAs, NEA will conduct three-yearly reviews from the end of the current Assessment Period on the need for subsequent EEOAs to be conducted on the Tier 2 RBA. Should there be a need to conduct another EEOA, NEA will notify the RC of the Tier 2 RBA and a six-year Assessment Period will commence from the date of notice to conduct the EEOA.

Note: Tier 1 and Tier 2 RBAs differ only in the frequency of which they have to conduct subsequent EEOAs after the first (i.e. the rigour of the EEOAs between the two tiers is the same).

[2] RCs are allowed to submit reports of energy audits conducted no earlier than this date, provided the reports meet all of the EEOA requirements and are endorsed by a certified EEO Assessor.

2 Energy Efficiency Opportunities Assessment (EEOA) Process

The EEOA is a systematic means of identifying economically viable EEOs, which forms the basis for sustained EE improvement for the organisation. The key phases of the EEOA process are shown in the diagram below:

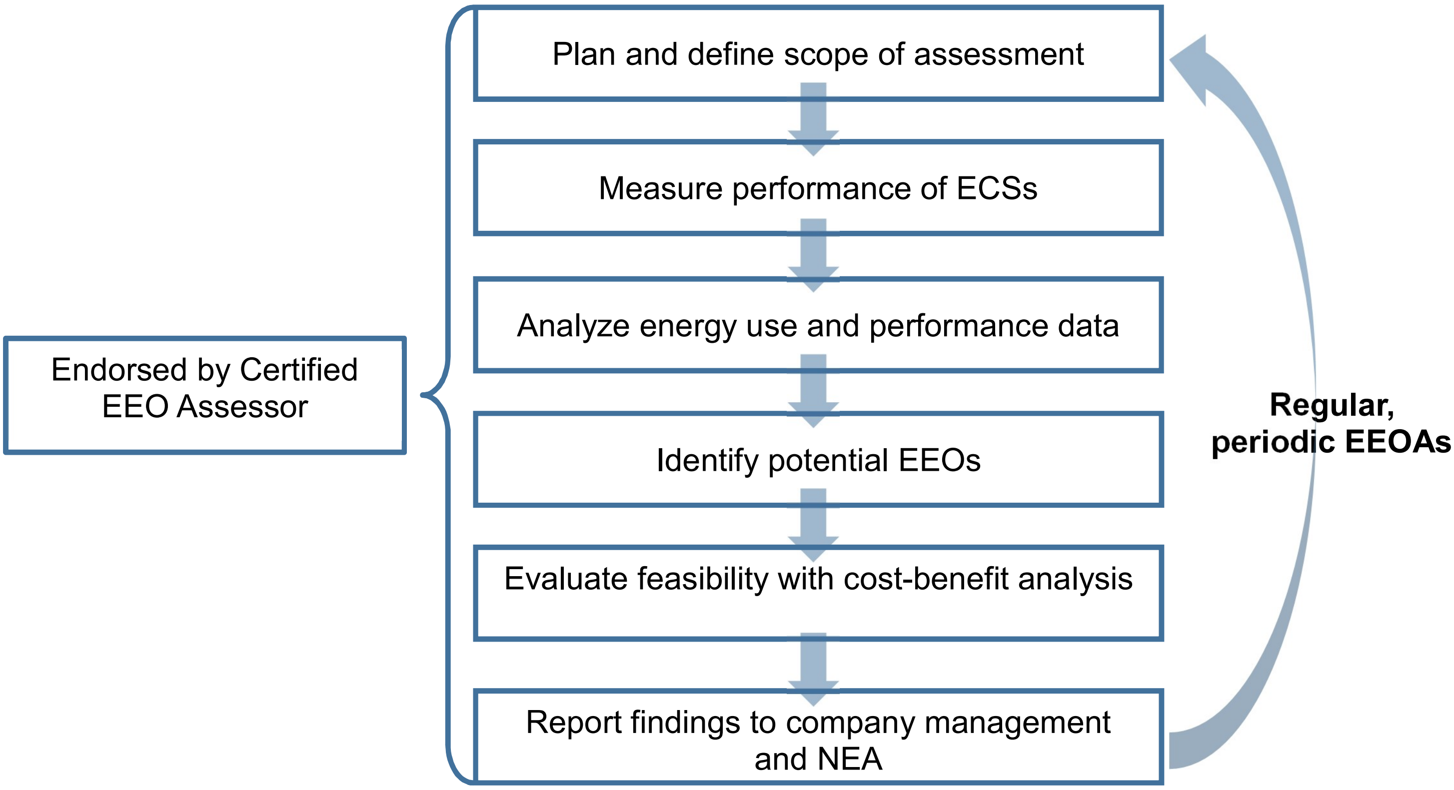


Figure 1: EEOA Process

2.1 Plan and Define Scope of Assessment

Having an EEOA plan is essential to ensure the assessment meets the company's goals and requirements under the ECA. The plan should outline the actions required, who is involved, when actions are undertaken, and the financial and technical resources that are needed. Some key elements to consider during the development of an EEOA plan are:

2.1.1 <u>Leadership</u>

Visible leadership and commitment from senior management provides clear direction and purpose to the assessment by ensuring:

- Suitable energy performance objectives are established
- EEOA objectives are aligned with business priorities and organisational values

Senior management should support, motivate and recognise the efforts of staff and other stakeholders involved in the identification and implementation of EEOs. Senior management should also ensure that adequate financial and human resources are made available to carry out the energy assessment and achieve the energy performance objectives.

2.1.2 EEOA Team

As with every project planning, the first step is to set up a team to plan for and conduct the EEOA. The EEOA team should comprise experts with a wide variety of skillsets and expertise that includes representatives from all areas that can affect energy performance. Together, they should be able to effectively conduct an EEOA, that is, collect and analyse energy and process data, identify and evaluate EEOs, give fresh perspectives and make the business case for identified EEOs. The EEOA team should include, but not be limited to:

- Senior management (at corporate and site level) and business development managers who can integrate energy management and best practices into business objectives, encourage cooperation within the company and assist with making a business case for identified EEOs;
- Production, process development and facility management staff (e.g. energy managers, engineers and technicians) who are familiar with the day-to-day equipment and operation issues and have in-depth technical knowledge and experience in process design and optimisation;
- Energy consultants and solutions providers (e.g. Energy Service Companies (ESCOs)) who possess good analytical skills, relevant technical knowledge, and are able to provide a fresh perspective towards identifying EEOs; and
- Equipment suppliers who are kept abreast of the technological advancement of the key equipment used in the facility and well versed in the operation and maintenance of the equipment.

With a dedicated team coming from diverse backgrounds and expertise, clear roles, responsibilities and accountabilities should be allocated to each member involved and this information should be documented in the EEOA report.

Within the EEOA team, the company shall appoint at least one certified EEO Assessor to endorse the EEOA report before submission to NEA. The EEO Assessor should be involved in conducting the EEOA with the team. Depending on the needs and scope of the EEOA, companies may choose to appoint certified in-house or independent assessors.

In-house assessors are company employees nominated by their senior management, and should only endorse EEOAs for their company. Independent EEO Assessors, on the other hand, are third-party entities, typically energy consultants or solutions providers, who can endorse EEOAs for different companies. Regardless of the assessor classification, EEO Assessors shall hold a valid EEO Assessor certificate issued by the Institution of Engineers, Singapore (IES) in order to be recognised as certified. Details of the EEO Assessor certification scheme and list of certified EEO Assessors can be found on the IES webpage.[3]

2.1.3 Scope of EEOA

The EEOA shall cover:

A. ECSs consuming fuel or energy commodities totalling at least 80% of the total energy consumption of the business activity; and

B. Other ECSs consuming energy output from systems identified in (A), either directly or indirectly.

Refer to Figure 2/Table 1 and Figure 3/ Table 2 below for examples on how to determine the scope of the EEOA.

2.1.4 Reference Period

In the identification of ECSs that make up at least 80% of the total energy consumption, RCs shall make use of the data acquired during a chosen reference period of 12 consecutive months within the six-year Assessment Period. For example, a Tier 1 RBA can select the reference period to be Jan – Dec 2022 during the Assessment Period of Jan 2022 – Dec 2027 to identify at least 80% of the business activity's total energy consumption.

Importantly, the RC must ensure that the operations of an RBA during the chosen reference period are representative of the typical day-to-day operations of the RBA operating at its intended capacity. In addition, the total energy consumption for the reference period has to be consolidated from fuel consumed and purchased energy commodities during that period.

2.1.5 Mapping of ECSs

It is essential to use an updated process flow diagram of the business activity, to map out the ECSs according to the production process. The process flow diagram could be used to create an energy flow diagram to indicate the energy requirements of the energy consuming systems that include processes and equipment.

The mapping of ECSs should be based on the process flow and production streams. This will provide a clearer picture of the production process of the business activity. Refer to the examples below on the mapping of ECSs within a styrene production plant and a semiconductor facility.

[3] IES webpage: http://eeoa.sg/

Example: Styrene Production Plant

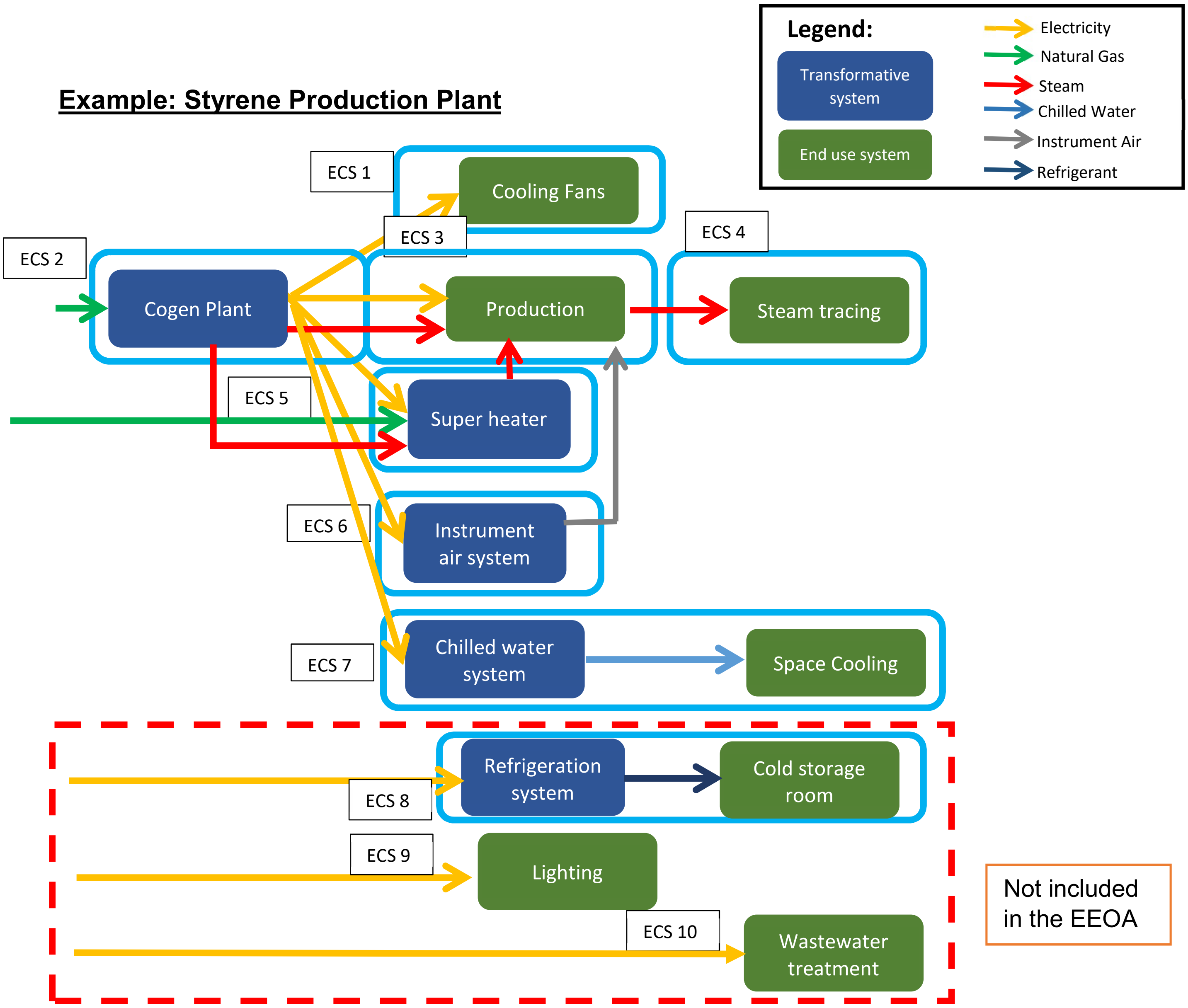


Figure 2: ECS Process Flow Diagram for Styrene Production Plant

In the EEOA report template for RCs, the RC will be required to fill up Table 1: Scope of EEOA as shown below. Table 1 will indicate the ECSs that will be included in the EEOA. The RC shall state if the ECS is transformative or end-use[4] in nature. In addition, for transformative ECSs only, the RC shall state the end use ECSs that are linked to these transformative ECSs. This is done to eliminate double counting of ECSs. It is also a requirement to report the ECSs that will not be covered under the EEOA, as shown in Tables 1 and 2 below.

Table 1: Scope of EEOA for Styrene Production Plant

<u>Reference period: Jan to Dec 2017</u>

Energy consuming system (ECS)	**Description of ECS**	**Type of fuel or energy commodity consumed**	**Type of ECS (Transformative/ End use)**	**(For transformative ECSs only) State end use ECSs linked to this ECS**	**Energy consumption (TJ/ year)[5]**	**Percentage of energy consumption vs total energy consumption**
ECS 1	*Cooling fans to cool down the system*	*Electricity*	*End use*		*Nil*	*Nil*
ECS 2	*Cogen plant to generate steam and electricity*	*Natural Gas*	*Transformative*	*ECS 1, ECS 3, ECS 4, ECS 5, ECS 6, ECS 7*	*251,960*	*79%*
ECS 3	*Catalytic dehydrogenation of ethyl-benzene*	*Electricity*	*End use*		*Nil*	*Nil*
		Steam	*End use*		*Nil*	*Nil*
		Instrumental air	*End use*		*Nil*	*Nil*
ECS 4	*Steam tracing to keep the transfer lines warm*	*Steam*	*End use*		*Nil*	*Nil*
ECS 5	*Heater to heat up 2 barg steam to 610 Deg C*	*Natural Gas*	*Transformative*	*ECS 3*	*3,538*	*1.1%*
		Electricity	*End use*		*Nil*	*Nil*

[4] Transformative ECSs convert fuel and energy commodities to be used in other ECSs. End-use ECSs consume the energy to generate products/outcomes and there is no further transfer of energy.
[5] If the end-use ECS is linked to a transformative ECS, fill nil. If the ECS is a transformative system that is linked to another ECS that is a transformative system, only account for the energy used by the first transformative ECS. The energy consumption of the subsequent ECS should be nil.

ECS 6	*Instrument air system to actuate the control valves*	*Electricity*	*Transformative*		*Nil*	*Nil*
ECS 7	*Chilled water system to use for space cooling*	*Electricity*	*End use*		*Nil*	*Nil*
Sum of energy consumed by ECSs that will be assessed in EEOA					***255,498***	***80.1%***
ECS 8	*Refrigeration system for cold storage room*	*Electricity*	*End use*		*25,496*	*8%*
ECS 9	*Lighting*	*Electricity*	*End use*		*15,758*	*5%*
ECS 10	*Wastewater treatment*	*Electricity*	*End use*		*22,062*	*6.9%*
Total site energy consumption					***318,814***	***100%***

Example: Semiconductor Facility

Quoted & altered from "Cost Savings and Energy Efficiency Improvements Using Best Practices in Semiconductor Fabs - Singapore EENP Conference 2011 - Andreas Neuber - Applied Materials" for example illustration.

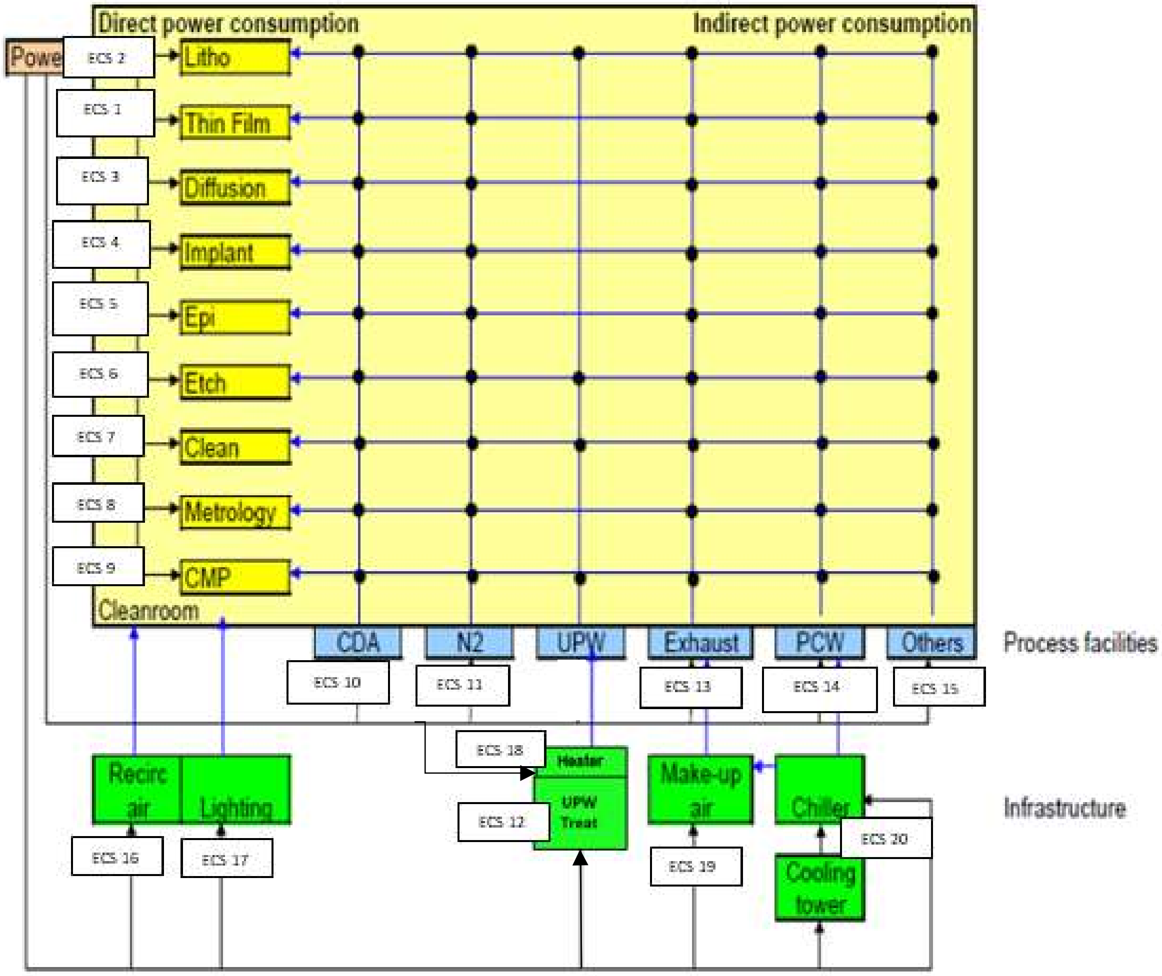


Figure 3: ECS Process Flow Diagram for Semiconductor Facility

Table 2: Scope of EEOA for Semiconductor Facility

<u>Reference period: Jan to Dec 2017</u>

Energy consuming system (ECS)	Description of ECS	Type of fuel or energy commodity consumed	Type of ECS (Transformative/ End use)	(For transformative ECSs only) State end use ECSs linked to this ECS	Energy consumption (TJ/ year)[6]	Percentage of energy consumption vs total energy consumption
ECS 1	*Thin Film: Chemical vapor deposition (CVD) process*	*Electricity*	*End use*		*97.4*	*13%*
ECS 2	*Photo-lithography process*	*Electricity*	*End use*		*89.9*	*12%*
		Hot ultra-pure water	*End use*		*Nil*	
ECS 3	*Dopant diffusion process*	*Electricity*	*End use*		*89.9*	*12%*
ECS 4	*Ion Implantation process*	*Electricity*	*End use*		*52.5*	*7%*
ECS 5	*Epitaxy process*	*Electricity*	*End use*		*60*	*8%*
ECS 6	*Wet etching process*	*Electricity*	*End use*		*75*	*10%*
		Hot ultra-pure water	*End use*		*Nil*	
ECS 7	*Wafer clean (scrubber) process*	*Electricity*	*End use*		*15*	*2%*
		Hot ultra-pure water	*End use*		*Nil*	
ECS 8	*Metrology Process*	*Electricity*	*End use*		*7.5*	*1%*
ECS 9	*Chemical-Mechanical-Polishing (CMP) Process*	*Electricity*	*End use*		*30*	*4%*
		Hot ultra-pure water	*End use*		*Nil*	
ECS 12	*Ultra-Pure Water (UPW) treatment system*	*Electricity*	*End use*		*7.5*	*1%*

[6] If the end-use ECS is linked to a transformative ECS, fill nil. If the ECS is a transformative system that is linked to another ECS that is a transformative system, only account for the energy used by the first transformative ECS. The energy consumption of the subsequent ECS should be nil.

Energy consuming system (ECS)	Description of ECS	Type of fuel or energy commodity consumed	Type of ECS (Transformative/ End use)	(For transformative ECSs only) State end use ECSs linked to this ECS	Energy consumption (TJ/ year)[6]	Percentage of energy consumption vs total energy consumption
ECS 16	*Air re circulation system (HVAC)*	*Electricity*	*End use*		*7.5*	*1%*
ECS 17	*Lighting system*	*Electricity*	*End use*		*7.5*	*1%*
ECS 18	*Heater system*	*Electricity*	*Transformative*	*ECS 2, 6, 7 and 9*	*60*	*8%*
Sum of energy consumed by ECSs that will be assessed in EEOA					***599.7***	***80%***
ECS 10	*Clean Dry Air for valve control / clean process*	*Electricity*	*Transformative*	*ECS 1,2,3,4,5,6,7,8 and 9*	*30*	*4%*
ECS 11	*N2 plant for purging / clean system*	*Electricity*	*Transformative*	*ECS 1,2,3,4,5,6,7,8 and 9*	*15*	*2%*
ECS 13	*Exhaust gas emission & treatment system*	*Electricity*	*Transformative*	*ECS 1,2,3,4,5,6,7,8 and 9*	*15*	*2%*
ECS 14	*Process Chilled water system*	*Electricity*	*Transformative*	*ECS 1,2,3,4,5,6,7,8 and 9*	*30*	*4%*
ECS 15	*Misc. Processes*	*Electricity*	*Transformative*	*ECS 1,2,3,4,5,6,7,8 and 9*	*7.5*	*1%*
ECS 19	*Makeup air Unit (MAU)*	*Electricity*	*Transformative*	*ECS 13*	*7.4*	*1%*
ECS 20	*Chiller system*	*Electricity*	*Transformative*	*ECS 14 and 19*	*45*	*6%*
Total site energy consumption					***749.6***	***100%***

2.1.6 Information and Data Collection

Information and data should be used to quantify and analyse energy use, identify and quantify energy saving opportunities, and track performance and outcomes (where actions are implemented).

Business contextual information that influences energy use and returns on EE investments should be identified and documented. Information below should be considered during the assessment:

a) Key business priorities and plans affecting investment timing and returns (such as relocation, expansion, site and equipment replacement, maintenance and shutdown schedules, or key contractual constraints); and
b) Other external factors affecting investment returns (such as market factors, rising energy prices or interest rates) if applicable.

The EEOA team should identify, document and implement in-depth data collection and analysis processes, including:

a) The collection of energy consumption and associated cost data for key processes, systems or activities from facilities owned by the company;
b) The collection and analysis of production or activity data (such as products, outputs, or square metres of floor space), to allow for the development of energy use performance indicators, at the appropriate level, with consideration of variations over time;
c) The collection and analysis of data for other process factors that impact on energy use (such as ambient temperature or production inputs) to determine the impact of these factors on energy use;
d) The collection and analysis of data for the energy and material flows associated with key processes, systems and activities, to systematically and rigorously quantify where energy is being used, transformed, wasted or lost;
e) The comparison of performance to actual or theoretical energy use benchmarks, at the relevant level (process, technology, activity or site) to identify potential inefficiencies and opportunities; and
f) The development and documentation of measures to assess the uncertainty and completeness of energy data and resolve any material data gaps.

Relevant data and information to be collected include, but is not limited to:

a) Type and description of the ECSs and their sub-systems and equipment that constitute at least 80% of the total energy consumption of the business activity;

b) Design, operation and maintenance documents related to the ECSs identified, including relevant:
   i. Material and energy flow diagrams (e.g. process flow, energy flow, Sankey diagrams);
   ii. As-built documents (e.g. drawings, equipment specification sheets, plot plan, process control system logic);

iii. Standard operating procedures; and
iv. Preventive maintenance records and practices.

c) Characteristics of the ECSs and its influence on energy consumption and performance, including:
   i. Interactions between equipment, sub-systems and ECSs;
   ii. Mode of operation (e.g. batch, semi-batch, continuous);
   iii. Seasonal or life-cycle dependency (e.g. relatively higher energy input during certain months of the year);
   iv. Relevant variables (e.g. flow, pressure, temperature) and requirements (e.g. regulatory, safety, product specification) that the company perceives to have influence over plant performance or operability.

d) Historical and current energy performance data that is representative of the business as usual operations of the ECSs and equipment, including:
   i. Energy consumption;
   ii. Quantity of intended input/ output (e.g. feedstock, cooling load quantity, amount of product);
   iii. Energy performance indicators (e.g. specific energy consumption, energy efficiency);
   iv. Relevant variables (e.g. pressure, flow, temperature);
   v. Relevant related measurements (e.g. power factor measurement, stack gas measurement); and

e) Monitoring equipment, configuration and analysis information (e.g. local gauges, distributed control systems, instrumentation types);

f) Future plans that may significantly affect energy performance (e.g. planned expansions, contractions, changes in production volumes, major alteration of the ECSs);

g) Energy audits or previous studies related to energy performance of the ECSs identified; and

h) Reference energy rate schedule(s) (or tariffs) and carbon emission factors to be used for financial and carbon abatement analysis.

2.2 Measurement of ECS Performance

2.2.1 Measurement Plan

For any on-site data measurement and collection, the EEOA team has to develop a measurement plan. The data measurement plan has to be continually revised based upon the EEOA team's findings during the energy audit. The main items that should be included in the measurement plan to ensure data quality are:

a) A list of relevant measurement points and their associated processes and measuring equipment;
b) Measurement duration and frequency of each measurement, that is, individual data points or continuous monitoring;
c) A suitable time period where the activities are representative;
d) Responsibilities for carrying out the measurements, including personnel working for, or on behalf of, the organisation; and
e) Calibration and traceability of measurement equipment.

The EEOA team should:

a) Evaluate the reliability of data provided and highlight defaults or abnormalities;
b) Use technically appropriate/sound calculation methods presented in a transparent way;
c) Document the methods used and any assumption made;
d) Subject the results of the analysis to appropriate quality and validity checks (e.g. using different formula and parameters to verify the same results); and
e) Consider any regulatory or other constraints of the potential EEOs.

The EEOA team should address sources of uncertainty of measured data. These specific sources of uncertainty could include but are not limited to the following:

a) Variability of operating conditions, including schedules, levels and products;
b) External factors including weather;
c) Effect of potential differences between the planned measurements and the actual measurements;
d) Inherent accuracy of the proposed measurement methods covering accuracy of collected data or analysis method.

2.2.2 Measurement Uncertainties

There are many possible sources of uncertainty in measurement, the main ones include:

a) Sampling – The sample may not be fully representative;
b) Readability – Personal bias in reading analogue instruments, instrument resolution or discrimination threshold, or errors in graduation of scale;
c) Instrument calibration – Uncertainty values assigned to measurement instruments, reference standards and reference materials;

d) Instrument drifting (e.g. changes in the characteristics or performance of a measuring instrument since the last calibration); and
e) Repeatability (e.g. variations in repeated measurements made under apparently identical conditions – such random effects may be caused by, for example, the variability in the performance of the measurement taker).

Measurement uncertainties should be a key consideration in selecting metering systems, together with maintenance/calibration requirements and how applicable metering is to a particular application. For a given accuracy requirement, the more cost-effective metering systems would be those requiring less maintenance and less frequent calibration. An operational team should be involved in metering decisions to ensure that the chosen solution is suitable to the specific operating conditions of the plant and integrated into operational procedures.

As with other measurements, metering accuracy should be stated in terms of precision and confidence level. Most manufacturers quote accuracy for their meters. The confidence level is likely to be 95% but this should be confirmed.

2.2.3 Engineering Calculations and Estimates

For ECSs, it is a requirement for the material and energy flows in and out of each ECS to be measured or derived using engineering calculations with measured data as inputs. Engineering estimates (e.g. rule of thumbs, use of industrial standards) of material and energy flow data for ECSs are not allowed.

For measurement of equipment or sub-systems within ECSs (i.e. sub-ECSs), it is very likely to encounter situations in which measurement is not plausible or extremely difficult. In such cases, the EEO team may consider the use of engineering estimates to estimate the material and energy flow data.

2.3 Analyse Energy Use and Performance Data

2.3.1 Energy-Mass Balance

EEOA necessitates the need to analyse the energy and material flows through the site, processes, systems and equipment. For many processes, the best way of looking at energy and material flows is through an energy-mass balance (EMB).

An energy balance is a mathematical statement of the conservation of energy, and a systematic accounting for energy flows and transformations in a system, including energy flows embodied in materials. Mass flows carry enthalpy, kinetic and potential energies.

A detailed EMB identifies the flow of materials and energy through a process, showing where energy is being used, wasted and lost. Rigorous EMB is used to identify opportunities to save energy by highlighting points in the system where energy use or materials usage are greater than estimated or required. Large imbalances in energy or material flows can indicate data deficiencies or anomalies in system performance, such as leaks. It is mandatory that an EMB covers at least 80% of the energy use at a site to enable coverage of all key energy using processes / activities.

A sample template of an EMB is provided in the EEOA RC template.

Companies are required to report at least the following parameters as part of the energy and mass balance for compressed/instrument air systems.

- Volumetric (STP) flowrate of air
- Power consumed by compressed/instrument air system

2.3.2 Analysis between ECSs

An EMB is required between ECSs. The energy and production input and output of each ECS shall be measured or derived from measured data. Continuous production and energy commodities data over a minimum period of two weeks where production volume is representative of the normal business operations shall be collected. Refer to the examples in Tables 3 and 4 on EMBs performed between ECSs in a styrene production plant and a semiconductor facility respectively.

Table 3: Mass and Energy Balance between ECSs for Styrene Production Plant

Energy Consuming System	ECS1					ECS2					ECS3					ECS4				
	Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products		
Energy Commodities and Stream	**Mass Flow**	**Energy Flow**	**Mass Flow**	**Energy Flow**	**Energy lost**	**Mass Flow**	**Energy Flow**	**Mass Flow**	**Energy Flow**	**Energy lost**	**Mass Flow**	**Energy Flow**	**Mass Flow**	**Energy Flow**	**Energy lost**	**Mass Flow**	**Energy Flow**	**Mass Flow**	**Energy Flow**	**Energy lost**
Units	**Kg/hr**	**MJ/hr**	**Kg/hr**	**MJ/hr**	**MJ/hr**	**Kg/hr**	**MJ/hr**	**Kg/hr**	**MJ/hr**	**MJ/hr**	**Kg/hr**	**MJ/hr**	**Kg/hr**	**MJ/hr**	**MJ/hr**	**Kg/hr**	**MJ/hr**	**Kg/hr**	**MJ/hr**	**MJ/hr**
Electricity		10690			2138				88927			359								
Moving air	44899	0.22	44899	8552																
Chilled water																				
NG						5249	251960			37053										
Super heated Steam @ 120 barg , 610 Deg								36572	125980		4351	15809								
Super heated Steam @ 2 barg , 610 Deg											25000	93153								
Super heated Steam @ 18 barg , 260 Deg											7221	20454			310					
Low pressure steam @ 3 bar													941	2575		941	2575			2221
Condensate @ 120 barg													4351	5170		4351	5170			3530
Condensate @ 18 barg													6876	6168		6876	6168			3575
Condensate @ 3 barg to condensate recovery																		12168	4587	
Cooling water											1272671	133452	1249935	233581	1913					
Instrument air																				
Ethyl-benzene											10000	2982								
Hydrogen													404	1997						
Benzene Toluene													388	352						
Styrene													9273	4395						
Residual Wastewater													24935	5219						

Energy Consuming System	ECS5					ECS6					ECS7				
	Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products		
Energy Commodities and Stream	**Mass Flow**	**Energy Flow**	**Mass Flow**	**Energy Flow**	**Energy lost**	**Vol Flow**	**Energy Flow**	**Vol Flow**	**Energy Flow**	**Energy lost**	**Mass Flow**	**Energy Flow**	**Mass Flow**	**Energy Flow**	**Energy lost**
Units	**Kg/hr**	**MJ/hr**	**Kg/hr**	**MJ/hr**	**MJ/hr**	**Nm^3/hr**	**MJ/hr**	**Nm^3/hr**	**MJ/hr**	**MJ/hr**	**Kg/hr**	**MJ/hr**	**Kg/hr**	**MJ/hr**	**MJ/hr**
Electricity		340					22748			11902		54790			16437
Moving air															
Chilled water											16016352	673968	16016352	472643	201325
NG	74	3538			354										
Super heated Steam @ 120 barg , 610 Deg	25000	90833			864										
Super heated Steam @ 2 barg , 610 Deg			25000	93153											
Super heated Steam @ 18 barg , 260 Deg															
Low pressure steam @ 3 bar															
Condensate @ 120 barg															
Condensate @ 18 barg															
Condensate @ 3 barg to condensate recovery															
Cooling water															
Instrument air						42126		42126							
Ethyl-benzene															
Hydrogen															
Benzene Toluene															
Styrene															
Residual Wastewater															

Derivation of figures from ECS 6 (Instrumental Air System)

In 1 hour, incoming energy flow: 22748 MJ/hr x 1hr = 6318.96 kWh (Predetermined number)

Flowrate of compressed air: 6318.96 / 0.15 (assumed compressed air system efficiency of 0.15 kWh/Nm^3) = 42126.4 Nm^3/hr

Derivation of figures from ECS 7(Chilled Water System)

Incoming energy flow:
For chilled water return temp of 10^{o}C (assumed to be measured in this example), (enthalpy of water at 10^{o}C = 42.08 kJ/kg)
Energy flow = 16016352 kg/hr x 42.08 kJ/kg / 1000 ≈ 673968 MJ/hr

Outgoing energy flow:
For chilled water supply temp of 7^{o}C (assumed to be measured in this example), (enthalpy of water at 7^{o}C = 29.51 kJ/kg)

Energy flow = 16016352 kg/hr x 29.51 kJ/kg / 1000 ≈ 472643 MJ/hr

Energy lost by chilled water, Qcooling = 673968 – 472643 = 201325 MJ/hr (subsequently lost to atmosphere at cooling tower)

For more examples, please refer to Appendix: Examples of measurement at energy consuming system level

Table 4: Mass and Energy Balance between ECSs for Semiconductor Facility

Energy Consuming System (ECS)	ECS 1					ECS 2					ECS 3					ECS 4					ECS 5					ECS 6					ECS 7				
	Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products		
Fuel/Energy Commodities and Stream	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss
Units	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr
Electricity		97.44					89.95					89.95					52.47					59.96					74.96					14.99			
UPW								33.04	3.47	0.38																		68.63	7.20	0.79			96.59	10.13	1.11
Hot UPW						33.04	11.07																			68.63	22.99				96.59	32.35			
Processed Wafer Area [cm2 Si/ yr]	4.22E+08		4.22E+08			4.22E+08		4.22E+08			4.22E+08		4.22E+08			4.22E+08		4.22E+08			4.22E+08		4.22E+08			4.22E+08		4.22E+08			4.22E+08		4.22E+08		
Re-circulated air volume (CMH)																																			
Illuminated Floor Area (m2)																																			

Energy Consuming System (ECS)	ECS 8					ECS 9					ECS 12					ECS 16					ECS 17					ECS 18				
	Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products			Incoming/ Consumed		Outgoing/ products		
Fuel/Energy Commodities and Stream	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss	Mass Flow	Energy Flow	Mass Flow	Energy Flow	Energy Loss
Units	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr	kt/yr	TJ/yr	kt/yr	TJ/yr	TJ/yr
Electricity		7.50					29.98					7.50					7.50					7.50					59.96			1.48
UPW								55.92	2.79	0.80	254.19	26.65	254.19	26.65												254.19	26.65			
Hot UPW						55.92	18.73																					254.19	85.14	
Processed Wafer Area [cm2 Si/ yr]	4.22E+08		4.22E+08			4.22E+08		4.22E+08																						
Re-circulated air volume (CMH)																5.71E+05		5.71E+05												
Illuminated Floor Area (m2)																					9.78E+03		9.78E+03							

2.3.3 Derived from Measured Data

There may be cases where it is difficult to measure the energy and production input and output of certain ECSs or sub-ECSs, for instance, due to high safety risk in installing meters. For such cases, one may choose to derive these parameters via EMB or equipment performance curves (e.g. pump curves) based on measurements of other suitable parameters. Below are some examples of how energy and production data may be derived from other sources of measured data.

a) Mass balance

With reference to the example in section 2.3.4, assume that it is difficult to measure the flow rate of stream S3110. To obtain the flow rate of S3110, it is possible to perform a sub-ECS 1 mass balance if the streams S311 (feed), S316 (superheated steam) and S3130 (recycle) are measured.

By mass conservation law, total output out of system = total input into system.

Flow rate of S3110 = Sum of flow rates of S311, S316 and S3130
= 10,000kg/h + 25,000kg/h + 10kg/h
= 35,010kg/h

b) Energy balance

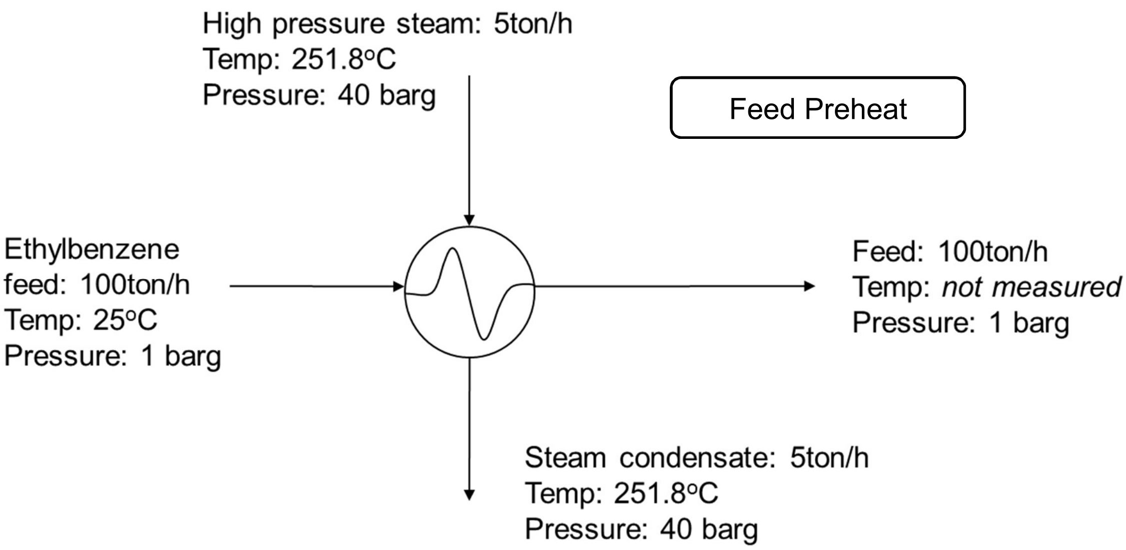


Figure 4: Mass and Heat Balance around a Feed Preheat System

Consider the preheat system shown above with no thermocouple installed at the feed output. Flow, temperature and pressure parameters for feed input, steam input and output are measured and shown above. Using an energy balance, the energy of the feed output stream can be determined.

From steam tables, at 251.8°C and 40 barg, the latent heat of steam is 1,705.71kJ/kg.

Assuming 100% heat transfer in the heat exchanger*, the heat transferred by the high-pressure steam to the feed = 5,000kg/h x 1,705.71kJ/kg = 8,529MJ/h.

At 25°C and 1 barg, specific enthalpy of ethylbenzene feed = 748.26kJ/kg.

By energy conservation law,

Energy of feed output = Energy of feed input + heat transferred by steam
= 100,000kg/h x 748.26kJ/kg + 8,529MJ/h
= 74,826MJ/h + 8,529MJ/h
= 83,355MJ/h

Note: In reality, there will be energy losses during heat transfer and these should be factored into the energy balance calculations. For the EEOA report, please state how such losses are estimated.

Energy balance for power may be performed in a separate power balance table. An illustration of a power balance, is shown below.

Power consumed by ECS 4[7] (relevant variables) = Total power consumption – Power consumed by ECS 1 (measured) – Power consumed by ECS 2 (measured) – Power consumed by ECS 3 (measured)

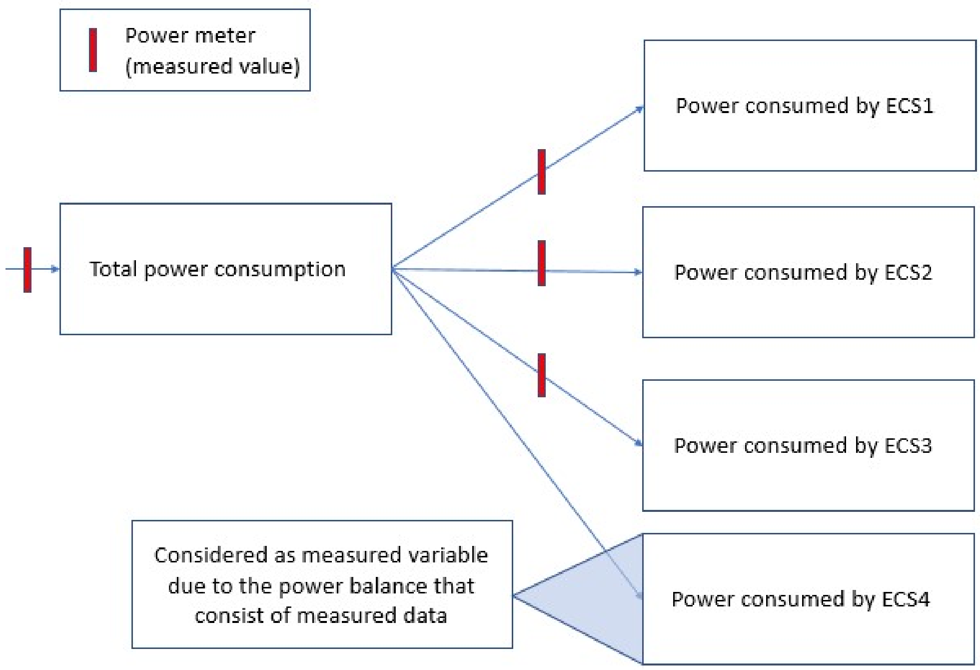


Figure 5: Power balance

[7] ECS 4 may be redefined as an ECS that comprises remaining systems with no power measurements or relevant variables.

c) <u>Pump performance curves</u>

In the case of pumps, one may choose to measure the flow rate of the fluid flowing through the pump, and refer to its pump characteristic curves (usually provided by the pump vendors) to determine the power and energy consumed by the pump.

Referring to the characteristic curves of a radial flow centrifugal pump shown on the right, for a measured water flow rate of 1,500m^3/h, the shaft pump power required is 60kW. Energy consumed by the pump can then be calculated.

Alternatively, if the pump power versus flow rate curve is not provided, the shaft pump power required can also be calculated based on the pressure head and efficiency curves. For a measured water flow rate of 1,500m^3/h, the pressure head that can be overcome is 10.5m and the pump efficiency is 72%.

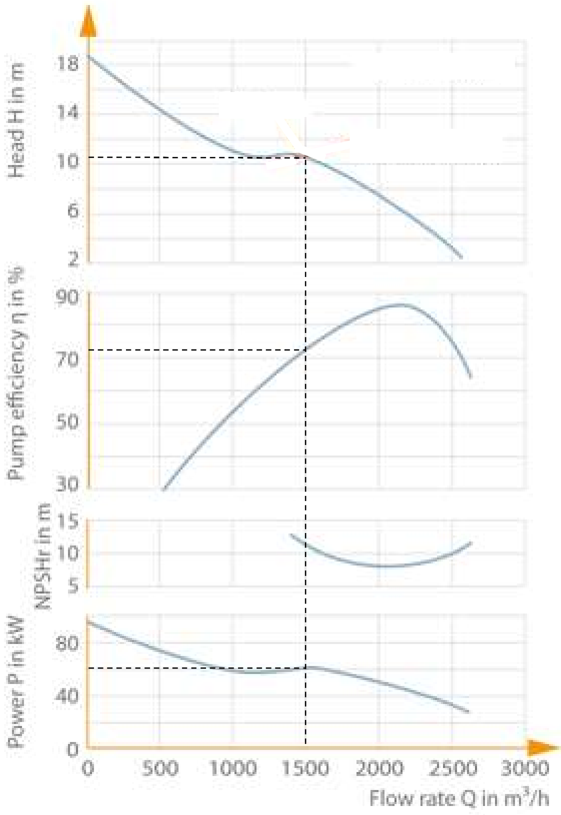


Figure 6: Pump Curve

Differential pressure = density of water x gravity x pressure head
= 1,000kg/m^3 x 9.81m/s^2 x 10.5m
= 103kPa

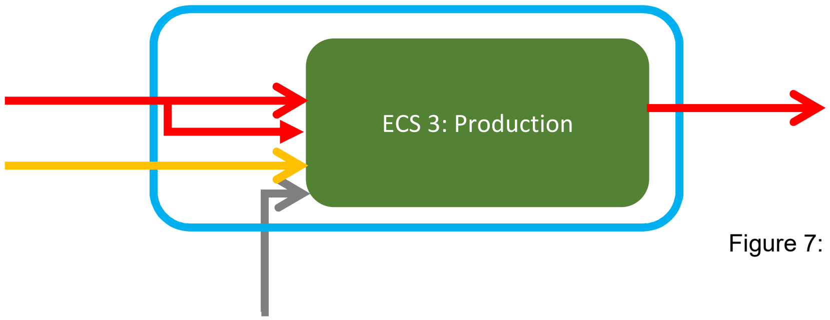
Theoretical pump power required = flow rate x differential pressure
= 1,500m^3/h x 103kPa
= 154,500kJ/h = 42.9kW

Shaft power required = theoretical pump power required / pump efficiency
= 42.9kW/0.72 ≈ 60kW

2.3.4 Analysis within ECSs

An EMB within the ECS will show the detailed breakdown of the energy consumers and identify the areas to focus on when attempting to identify EEOs. The energy and production input and output of sub-ECSs can be measured, derived from measured data or estimated. Refer to examples below for EMBs performed within ECSs in a styrene production plant and a semiconductor facility.

Example: Styrene Production Plant



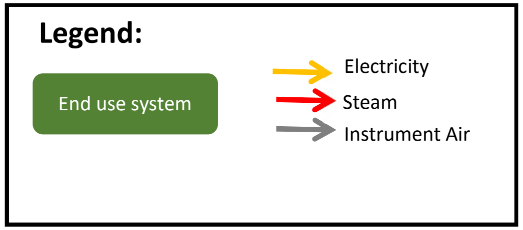
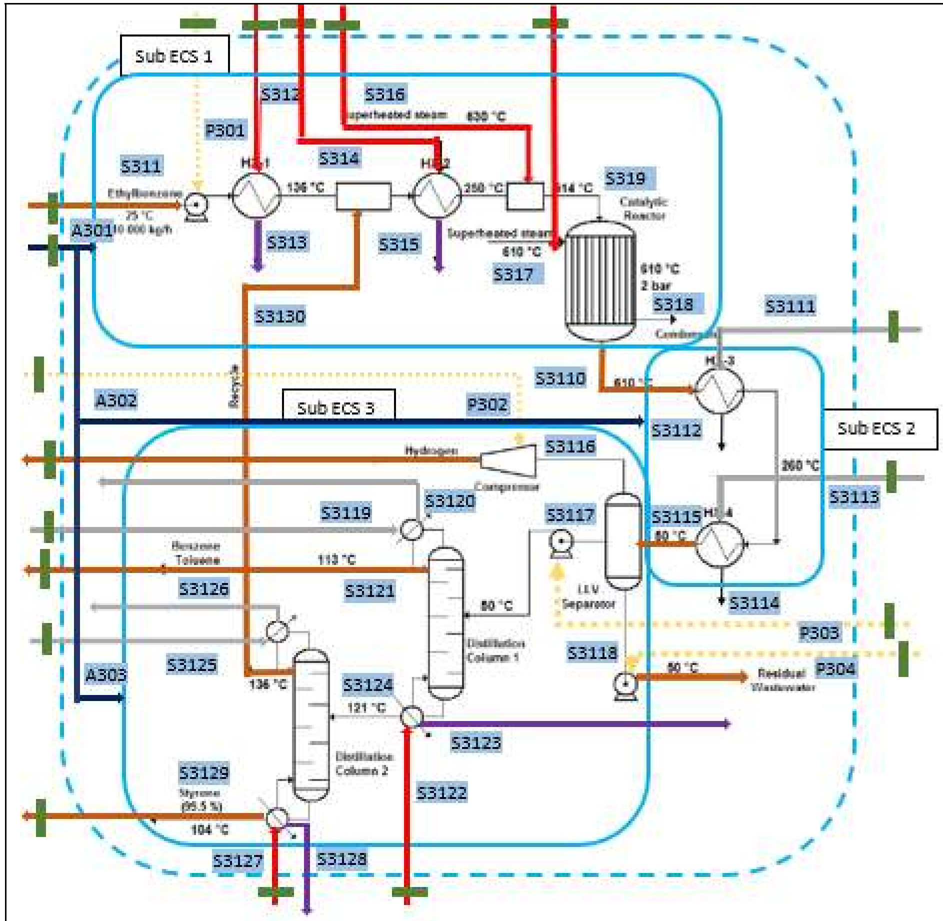


Figure 7: Energy Flow into and out of ECS 3 in a Styrene Production Plant

Energy Consuming System: Production unit

Description of System: Catalytic dehydrogenation of ethyl-benzene (ECS 3) contains three stages. 1. Ethyl-benzene pre-heating, mixing, vaporization and dehydrogenation, 2. Cooling, and 3. Separation/Purification
Base case/ Existing system details: ECS 3 is shown as an demonstration on how the template can be used.



- Green markers show the process streams and energy commodities that are measured in and out of the ECS.
- Steam is represented as red lines going into the heat exchangers, reactor and reboilers.
- Cooling water is represented as grey lines going into heat exchangers and condensers.
- Power is represented as dotted yellow lines going into the pumps and compressor.
- Instrument air is represented as dark blue lines going into sub ECSs.
- Condensate is represented by purple lines going out of heat exchangers and reboilers.

- The ECS is broken down into 3 sub-ECSs which consist of
  - Sub ECS 1 involves eethyl-benzene pre-heating, mixing, vaporization and dehydrogenation
  - Sub ECS 2 involves cooling
  - Sub ECS 3 involves separation/purification
- This is an example taken from the simulation of styrene production process via catalytic dehydrogenation of ethylbenzene using CHEMCAD process simulator (Amaury P erez Sanchez, 2017).

Table 5: Mass and Energy Balance for Sub-Energy Consuming Systems in ECS 3

Sub-Energy Consuming System (Sub-ECS)				Sub-ECS 1					Sub-ECS 2					Sub-ECS 3					Loss	
				Incoming/ Consumed		Outgoing/ products		Energy transfer	Incoming/ Consumed		Outgoing/ products		Energy transfer	Incoming/ Consumed		Outgoing/ products		Energy transfer		
Stream no.	Stream	Temp (°C)	Pressure (barg)	kg/h (Nm3/hr)	MJ/h	kg/h (Nm3/hr)	MJ/h	MJ/h	kg/h (Nm3/hr)	MJ/h	kg/h (Nm3/hr)	MJ/h	MJ/h	kg/h (Nm3/hr)	MJ/h	kg/h (Nm3/hr)	MJ/h	MJ/h	kg/h (Nm3/hr)	MJ/h
S311	Ethyl-benzene	25	1	10000	2982															
S312	Steam for HX1	260	18	2787	8171			5671												
S313	Condensate from HX1	260	18			2654	2381												133	119
S314	Steam for HX2	260	18	984	2887			2004												
S315	Condensate from HX2	260	18			935	839												49	44
S316	Super heated steam for dilution in the reactor	610	2	25000	93153															
S317	Super heated steam for heating reactor	610	120	4351	15809			10639												
S318	Condensate 120 barg	610	120			4351	5170													
S319	Feed mixture	514	2	35010	103812															
S3110	Reacted product	610	3.5			35010	107650		35010	107650										
S3130	Recycle / DC2 Top	136	1	10	2															
S3111	Cooling water into HX3	25	3						280245	29386			23468							
S3112	Cooling water from HX3	45	3								280245	52854								
S3113	Cooling water into HX4	25	3						926871	97192			73085							
S3114	Cooling water from HX4	45	3								904229	168381							22642	1896
S3115	Cooled reacted product	50	6								35010	11097		35010	11097					
S3116	Hydrogen	50	5													404	1997			
S3117	LLV Middle	50	5													9671	3881			
S3118	LLV Bottom / Wastewater	50	5													24935	5219			

Sub-Energy Consuming System (Sub-ECS)				Sub-ECS 1					Sub-ECS 2					Sub-ECS 3					Loss	
				Incoming/ Consumed		Outgoing/ products		Energy transfer	Incoming/ Consumed		Outgoing/ products		Energy transfer	Incoming/ Consumed		Outgoing/ products		Energy transfer		
Stream no.	**Stream**	**Temp (ºC)**	**Pressure (barg)**	**kg/h (Nm3/hr)**	**MJ/h**	**kg/h (Nm3/hr)**	**MJ/h**	**MJ/h**	**kg/h (Nm3/hr)**	**MJ/h**	**kg/h (Nm3/hr)**	**MJ/h**	**MJ/h**	**kg/h (Nm3/hr)**	**MJ/h**	**kg/h (Nm3/hr)**	**MJ/h**	**MJ/h**	**kg/h (Nm3/hr)**	**MJ/h**
S3119	Cooling water into condenser in DC1	25	3											60465	6340			5063		
S3120	Cooling water out condenser in DC1	45	3													60370	11376		95	17
S3121	DC1 Top / Benzene, Toluene	113	1.5													388	352			
S3122	Super heated steam for heating reboiler DC1	260	18											3305	9067			6446		
S3123	Condensate from reboiler DC1	260	18													3167	2841		138	262
S3124	DC1 Bottom	121	1.5													9283	4649			
S3125	Cooling water into condenser in DC2	25	3											5091	534			425		
S3126	Cooling water out of condenser in DC2	45	3													5091	959			
S3127	Super heated steam for heating reboiler DC2	260	18											145	329			173		
S3128	Condensate from reboiler DC2	260	18													120	107		25	48
S3129	DC2 Bottom / Styrene	104	1													9273	4395			
P301	Power for ethylbenzene pump				12															
P302	Power for compressor																313			
P303	Power for LLV middle pump																4			
P304	Power for wastewater pump																30			
A301	Instrument air for Sub ECS1			14042		14042														
A302	Instrument air for Sub ECS2								14042		14042									
A303	Instrument air for Sub ECS3													14042		14042				

Total specific energy consumption of existing system: Total energy consumption of the ECS consists of the superheated steam used to heat up the reactant, reactor and reboilers and power used for the pumps and compressor. These amount to 36,622J/h. Feed into the ECS is 10,000 kg/h. Total specific energy consumption of the ECS = 36,622/10,000 = 3.66 MJ/kg
Specific energy commodity consumption of existing system: <Provide a list below with respect to each fuel or energy commodity per feed or product of the system and state the timeframe that the data is collected.> Specific steam consumption of ECS = 3.62 MJ/kg (1 Oct 2019 to 15 Oct 2019) Specific power consumption of ECS = 0.036 MJ/kg (1 Oct 2019 to 15 Oct 2019)
Derivation of energy consumption from measured variables (if any): <Provide related correlation graphs or formulas from specific datasheets and show the derivation of the figures in Table 3 if applicable> Data was obtained from a research paper on the simulation of styrene production process via catalytic dehydrogenation of ethylbenzene using CHEMCAD process simulator written by Amaury Perez Sanchez, Eddy Javier Perez Sanchez, Rutdali Maria Segura Silva in 2017. Thus, there are no available trends or graphical presentations of measurements. However, it is expected that the RC will have available information to conduct such analysis.

Example: Semiconductor Facility

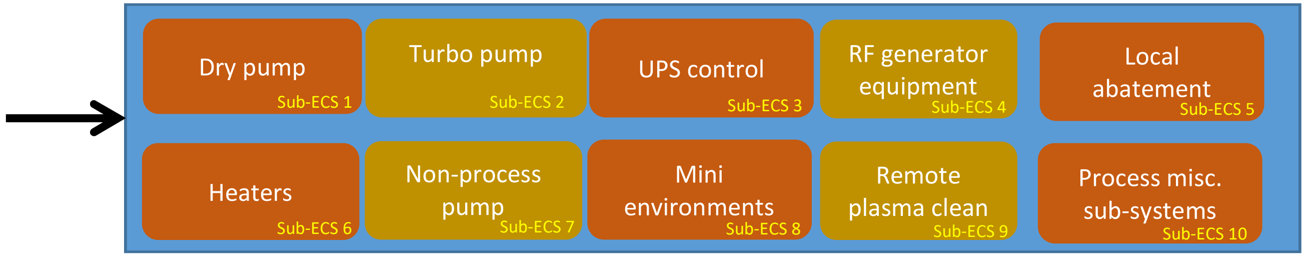


Figure 8: Energy Flow within ECS 1 in a Semiconductor Facility

Energy Consuming System: Thin film – Chemical vapour deposition – Dry pump

Description of System: ***Chemical vapour deposition (CVD) process*** **The process system energy consuming systems (sub-ECS) are as below:** **1) Dry pump** **2) Turbo pumps** **3) UPS control** **4) RF generator equipment** **5) Local abatement** **6) Heaters** **7) Non-process pump** **8) Mini environments** **9) Remote plasma clean** **10) Process misc. sub system**
Base case/ Existing system details: • The arrow shows the energy input, electricity into the ECS. Table 6: Mass and Energy Balance for Sub-Energy Consuming Systems in ECS 1

Sub-Energy Consuming System (Sub-ECS)	Sub-ECS 1	Sub-ECS 2	Sub-ECS 3	Sub-ECS 4	Sub-ECS 5	Sub-ECS 6	Sub-ECS 7	Sub-ECS 8	Sub-ECS 9	Sub-ECS 10
Fuel/Energy Commodities and Stream	**Energy Consumed**	**Energy Consumed**	**Energy Consumed**	**Energy Consumed**	**Energy Consumed**	**Energy Consumed**	**Energy Consumed**	**Energy Consumed**	**Energy Consumed**	**Energy Consumed**
Electricity [kWh]	1.09E+07	2.89E+06	3.23E+05	2.71E+06	2.03E+06	1.82E+06	1.21E+06	9.11E+05	2.94E+06	1.26E+06
Processed wafer area [cm2 Si]	4.22E+08									

Total specific energy consumption of existing system:

Total annual energy consumption of ECS 1 (consists of electricity consumption) = 2.71E+07 kWh = 97.4TJ

Total specific energy consumption of ECS 1 =(Total annual energy consumption)/ (Total wafer area processed in a year) = (2.71E+07)/(422,134,666.667)

= 0.064 kWh/cm2 Si

Specific energy commodity consumption of existing system:

<Provide a list below with respect to each fuel or energy commodity per feed or product of the system and state the timeframe that the data is collected.>

Specific power consumption of ECS 1 = 0.064 kWh/cm2 Si (1 Jan 2017 to 15 Jan 2017)

Derivation of energy consumption from measured variables (if any):

Data and schematics are derived from "Cost Savings and Energy Efficiency Improvements Using Best Practices in Semiconductor Fabs - Singapore EENP Conference 2011 Andreas Neube - Applied Materials"

***Note: Although the example is derived from the above-mentioned report, the derived data & quoted financial numbers are fictitious based on domain engineering scenarios for providing an RC example.*

<Provide related correlation graphs or formulas from specific datasheets and show the derivation of the figures in Table 4 if applicable>

2.4 Identify Potential EEOs

Once the data has been analysed, the next step would be to identify and evaluate all potential EEOs. The EEO identification process is informed by rigorous analysis and involves relevant personnel identified in the EEOA plan. This process is broad, open-minded and encourages innovation. The EEO identification process should result in a list of implementable and feasible ideas, which are then documented. EEOs may arise from a variety of situations, such as:

a) Technological advances;
b) Changes in operations;
c) Performance deterioration due to wear and tear or inadequate maintenance;
d) Data-enabled optimisations;
e) Developments in best practices, and others.

EEOs may be high investment, low investment or marginal-investment opportunities.

Types of EEOs	Characteristics	Examples
High investment	• Significant CAPEX • Large energy savings • System-level implementation • Less prevalent	• Retrofit of chilled water system • Installation of Co-generation system
Low investment	• Low CAPEX • Incremental energy savings • Common and prevalent	• Equipment modifications e.g. impeller trimming. • Installation of VSD for frequency control • Improve insulation
Marginal-investment	• No or minimal CAPEX • Incremental energy savings • Projects relating to adopting best operating practices or energy management improvements	• Set-point adjustments • Improved maintenance scheduling • Minimizing compressed air or steam leaks

For high/low investment EEOs, there is a need to consider the financial feasibility of the project and ensure that budgetary requirements are met. For such projects, companies may consider adopting various financing options or performance contracting models to improve cash flow and reduce technical risks. Companies can also apply for relevant funding support from the government. More details are available on NEA's website.

2.4.1 Benchmarking

Benchmarking is an approach that can be used to assess a facility's relative performance in comparison to selected reference points. A facility should set appropriate metrics depending on the scope of benchmarking, and apply a consistent basis for comparison, which may require adjustments based on operating conditions or production output.

Benchmarking can be applied on different levels, e.g. facility level, system level, etc. When applied on a system (ECS) level, a benchmarking exercise can help the EEOA team identify areas for improvement and quantify the degree of potential improvement that can be achieved with EE measures.

The following are different possible reference points that may be used in benchmarking and their applications:

a) Industry standards – Where available, the facility may benchmark against established industry standards or averages. Deviation from the industry averages may suggest that there are economically feasible EEOs.

b) Best-in-class (BIC) – Comparison against a best performer in the industry or facilities adopting certain BIC technologies may provide insight on the achievable potential and project ideas for the facility to consider and evaluate. Once EEOs have been identified, the performance gap between the identified EEO and BIC should be quantified, and the BIC technology case should be evaluated in terms of its feasibility as per section 2.5. Specific industrial benchmarks such as Solomon for refinery and petrochemicals could be used as a reference.

c) Historical performance – Where industry benchmarks are unavailable for certain processes or companies may deem that available benchmarks are not applicable for their operations, facilities may opt to benchmark against their past performance or against a "New & Clean"[8] condition, where actual performance may have degraded due to wear and tear, or changes in operating parameters may have impacted energy performance.

   Benchmarking against historical performance allows a facility to identify sources of performance deterioration and subsequent rectification actions to be taken or potential incremental improvements that may have minimal capital outlay, such as maintenance measures or re-commissioning.

d) Similar facilities and companies in the same industry – For new fabs/plants without historical performances/baselines, benchmarking can be conducted by cross referencing against similar/sister facilities in other countries or against companies in the same industry.

[8] "New and Clean" condition refers to the simulated performance (based on design or commissioning data) of the equipment at current operating conditions, where the state of the equipment is new and clean.

e) Best practices on work culture and operation procedures – Conduct studies on similar process, equipment and manufacturing environment to facilitate better understanding on the required scope and boundaries. With this exercise, the company will be able to identify viable operation procedures which can be adopted and optimised. The company can also take the opportunity to cultivate a work culture of problem-solving and energy efficiency.

2.4.2 Identification of EEOs based on Competency and Expertise

Facilities can consider adopting industry best practices or new technologies as EEOs. To assess applicability of best practices, new technologies or potential opportunities in specific processes, the EEOA team should exercise engineering judgement and expertise, and can consult competent and experienced plant personnel, equipment specialists, consultants or equipment vendors etc. to provide different ideas and perspectives to generate EEOs.

Assessments should also take into account the operating lifetime, condition, operation and level of maintenance of the existing systems when considering EEOs.

Some best practices include:

a) Use of pinch technology to determine potential for heat integration and energy savings across the entire plant;
b) Retrofitting of boiler systems to improve heat recovery and reduce energy loss, e.g. optimise boiler loading, install economizer, recover condensate, use steam traps to reduce steam leakage;
c) Use of light gauge overbend furnace elements to improve furnace efficiency and capability, and vacuum insulation to reduce the amount of heat lost from the furnace through radiation;
d) Recovery of unused waste heat to drive suitable processes;
e) Use of cold energy from vaporizing liquefied natural gas to reduce energy use for cooling operations, air separation etc.;
f) Right-sizing of chiller systems (including pumps and cooling towers) and implementation of variable flow systems (e.g. variable speed drives) to improve energy performance;
g) Use of clean dry air instead of nitrogen for process requirements – nitrogen can be produced on-site instead of purchasing liquid nitrogen to reduce energy footprint;
h) Replace low efficiency motors with IE3 or IE4 motors and use variable speed drives for equipment with variable load duty cycles;
i) Use of mist humidifiers for cleanroom utilities and humidification, which are less energy-intensive than electrode-type humidifiers.
j) Use energy efficient lighting such as LED lamps; and
k) Use of overall plant optimization tool to optimize utilities and machinery (e.g. automatic controls for shutting off equipment when not in use) and reduce unnecessary energy losses.

2.4.3 Evaluation of Design and Configuration Options to Address System Needs

Actual user or customer requirements/demands may differ from what the existing configuration is designed for and/or is operating at due to changes in operations over time (e.g. change in product or product specifications), or over-sizing during design due to use of wide margins.

Facilities may thus explore opportunities to right size or re-configure their operations to lower energy use while meeting the user/customer requirements and demands.

2.4.4 Data Analysis

Availability of meters and measurements allow facilities to collect useful data on their operations that may be used to identify EEOs. The EEOA team may utilise data to:

a) Identify relationships between energy performance and relevant variables through regression analysis, simulations or otherwise;
b) Identify trends and anomalies;
c) Determine optimum operating points; and
d) Perform system-level analysis such as pinch analysis.

Please note that for each EEO identified, the material and energy flow data shall be measured for a period of not less than 2 weeks. This data includes direct measurements and variables used to derive material and energy flow data.

2.4.5 Future Changes in Operation

EEOs should be identified and evaluated with future changes in operations taken into consideration. Future changes in operation include:

a) Future changes in production/generation capacity;
b) Projected expansions, contractions, or changes in production volume;
c) Projected/anticipated changes in, or replacement of, equipment or systems that have significant energy implications; and
d) Projected removal or the outsourcing of facilities, equipment or systems.

Facilities should inform the EEOA team of and document future changes in operations to their best knowledge.

2.5 Evaluate Feasibility of EEOs with Cost-Benefit Analysis

Ideas are filtered to identify a documented list of potential opportunities that can be analysed to a level sufficient for informed evaluation with a payback period.

A whole of business evaluation that considers benefits beyond just energy savings (such as benefits relating to reliability, production, or occupational health and safety) is undertaken to enable decision-makers to make informed business decisions about EEOs.

The evaluation process should be clearly documented, covering the details listed below, with ideas categorised as feasible or not for implementation; to give decision makers credible information on which to base investment decisions.

The EEOA team shall assess the technical and economic feasibility of implementing each EEO identified based on the following criteria:

a) Cost of investment;
b) Operations cost;
c) Annual energy savings[9];
d) Specific energy consumption;
e) Financial savings;
f) Returns on investment (minimally payback period);
g) Annual greenhouse emissions abatement;
h) Other criteria, economic or otherwise, where appropriate;
i) Other non-energy benefits (e.g. improvement in productivity or reliability); and
j) Potential interactions between various opportunities.

Reasons for the categorisation of all identified ideas (both feasible and not for implementation) shall be documented. Please refer below for examples of how identified EEOs are assessed.

Example: Styrene Production Facility

Energy Consuming System: Production unit			
Energy efficiency opportunities (EEO)	**Estimated energy savings (TJ/yr)**	**Estimated greenhouse gas abatement (tCO2e/ yr)**	**To be implemented? (Y/N)**
<Description of EEO> EEO 1: Install pressurized condensate recovery	43.42 TJ/yr	2,436 tCO2e /yr	Y
Energy savings for EEO is estimated to be 43.42 TJ/yr. Feed into the ECS is 87.6 kt/yr. Improvement in specific energy consumption from EEO = 43.42/87.6 = 0.496 TJ/kt = 0.496 MJ/kg **Total specific energy consumption after implementation**: 3.66 MJ/kg – 0.496 MJ/kg = 3.16 MJ/kg			

[9] Energy savings shall be quantified against measured baseline energy performance.

Rationale

Report the analysis for each EEO, which shall include:

- Description/discussion of each energy efficiency opportunity identified on how it can reduce energy consumption and improve energy performance relative to the base case and how it compares with best available technologies and benchmarks in energy efficiency.

  Steam is required for process reaction and heating. This steam is generated by the cogeneration plant. This includes the 18-barg steam that is used to preheat the feed going into heat exchanger 1. Any reduction in use of lower tier steam would reduce the steam generation requirement of the cogeneration plant in this example.
  Currently, the steam system steps down 120-barg steam to 18-barg steam using letdown valves, hence minimising this flow will reduce energy loss.
  Also, the example uses a vented condensate recovery system where condensate is recovered in an open-to-atmosphere tank. The condensate is subsequently used in the heat recovery steam generation section of the cogeneration plant. This results in the loss of flashed steam that could be recovered for process heating.
  The proposed EEO1 is to retrofit a pressurized condensate recovery system. In a pressurized condensate recovery system, recovered condensate is maintained at 18 barg, which will also reduce pumping requirements for boiler feed water. In addition, the recovered flash steam can be used for process heating.
  The current vented recovery system configuration is much simpler and requires lower initial investment than pressurized recovery systems. Sizing condensate transport lines is also much easier as piping can be sized similar to water piping once condensate and flash steam have been separated. Thus, EEO1 requires installation of flash vessels and changing pipe sizes to suit the new flow requirements.

- Provide description and additional benefits if there are any interactions and dependencies with other EEOs

  This will reduce the amount of flash steam vented to atmosphere and water can be recovered and reused. The absence of flash steam cloud will improve the plant's working environment.
- Estimated cost of investment

  Cost of investment is SGD 1,000,000 for the retrofitting of pressurised condensate system inclusive of pipe replacement and installation of flash vessels.

Breakdown of retrofit pressurised condensate system cost	Cost (SGD)
Pressurised condensate tank 18 barg	550,000
Flash drum	50,000
Retrofit existing condensate pipes that need to be replaced	400,000

- Estimated cost of operations

  There is no increase in operation cost. Energy cost will be accounted under energy savings.
- Estimated annual energy savings and annual greenhouse gas emissions compared to the system in the base case

  Estimated annual energy saving and greenhouse gas emissions is calculated based on the steam saved from 18 barg steam consumption. The steam savings will result in the reduction of duct firing in the cogeneration plant.

  <u>Calculation of the flash steam generated from 120 barg condensate</u>

  <u>Assume no loss of heat and by conservation of energy:</u>

$$m_{fs} = \frac{m_c(h_c - h_{fc})}{h_{fg}}$$

120 barg condensate load	m_c	kg/h	4,351
Specific enthalpy of condensate	h_c	kJ/kg	1,495
Specific enthalpy of saturated water	h_{fc}	kJ/kg	897
Latent heat of flash steam	h_{fg}	kJ/kg	1,900
Flash steam at 18 barg flowrate	m_{fs}	kg/h	1,370

- 120-barg condensate flowrate is obtained from the steam flowrate of Stream S318, which is measured with an orifice flowmeter. It is assumed that there is minimal loss of steam or condensate. (This is considered as a measured variable. At least 2 weeks data on the steam flowrate of Stream 318 should be submitted and clearly indicated in the appendix with timestamp.)
- Since 18 barg steam is generated by the cogeneration plant, the steam savings will reduce duct firing requirements.
- Annual reduction of 18 barg steam requirement from cogeneration plant = 1,370 kg/h * 24 hours/day * 365 days/yr = 12,001,200 kg/yr

Reduction of steam required from cogeneration plant	kg/h	1,370
Super high-pressure steam enthalpy @ 120 barg 610 deg C	kJ/kg	3,633
Enthalpy of water @ 3 barg 90 deg C	kJ/kg	377
Super high-pressure steam saving per year	kg/yr	12,001,200
	kJ/yr	39,075,907,200
	TJ/yr	39.08

- Annual reduction of 120 barg steam requirement from cogeneration plant = 12,001,200 kg.

Assuming duct firing is 90% efficiency Note : This example is based on a fictional styrene plant, it does not include a comprehensive utility set up. It is important to account the energy savings of the EEO with the site utility system in mind.		
Energy saved from reduced firing	TJ/yr	43.42
Natural gas savings (Using default net calorific values)	kt/yr	904.6
Greenhouse gas savings (Using default IPCC natural gas carbon factor)	tCO2e /yr	2,436

- Estimated financial savings

Assume the cost of natural gas is SGD 3.38 per mmBTU

Cost of natural gas saved due to implementation of EEO1 = 43.42TJ/yr * 9.478*10^2 mmBTU/TJ * SGD 3.38/mmBTU = SGD 139,098 per year

- Payback period or internal rate of return and other non-energy efficiency benefits (such as productivity or reliability) if any

Payback period of EEO1 = SGD 1,000,000 / (SGD 139,098/yr) = 7.19 years

- Proposed implementation timeline

Next plant turnaround in 2 years' time, 2021.

- Future changes in production generation capacity, if any

No change in production plans

- An explanation if EEO was not implemented or if no EEOs were identified.

Nil.

Methodology

Report methodology on how energy savings were calculated, how project cost was derived including type and source of data used, basis for calculations, estimates and assumptions, and its accuracy, etc. Base case for all EEOs presented above have to be measured or derived from measured variables.

Refer to above for methodology.

<table>
<tr><th colspan="3">Average cost of natural gas, SGD per mmBTU (Prices should reflect the company's utility cost for more accurate payback calculations)</th></tr>
<tr><td>Apr 2019</td><td>3.59</td><td rowspan="6">3.38</td></tr>
<tr><td>May 2019</td><td>3.6</td></tr>
<tr><td>Jun 2019</td><td>3.27</td></tr>
<tr><td>Jul 2019</td><td>3.21</td></tr>
<tr><td>Aug 2019</td><td>3.07</td></tr>
<tr><td>Sep 2019</td><td>3.56</td></tr>
</table>

Example: Semiconductor Facility

<table>
<tr><td colspan="4">Energy Consuming System : Thin Film</td></tr>
<tr><td>Energy efficiency opportunities (EEO)</td><td>Estimated energy savings (TJ/yr)</td><td>Estimated greenhouse gas abatement (tCO2e/ yr)</td><td>To be implemented? (Y/N)</td></tr>
<tr><td>EEO 1: Smart idle mode for dry pump

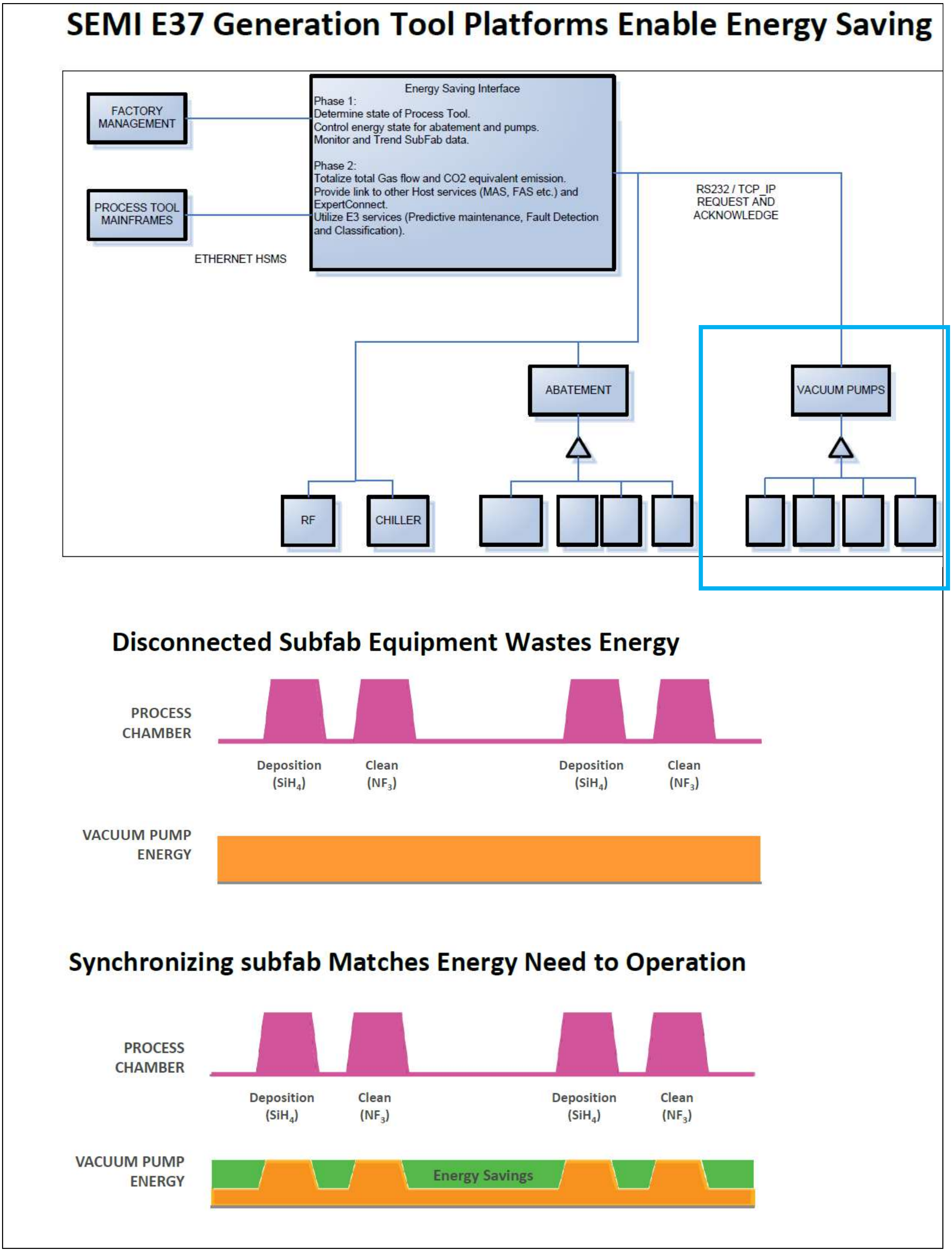
[sub-ECS 1]</td><td>8.4 TJ/yr</td><td>Greenhouse gas abatement (indirect) = 954.72 tCO2e/yr</td><td>Y</td></tr>
<tr><td colspan="4">(1) Base case energy consumption (without smart idle mode) = 2.71E+07 kWh/yr

(2) Energy consumption with EEO1 implemented (with smart idle mode) = 2.5E+07 kWh/yr

(3) Total wafer area processed in a year = 422134666.667 cm2 Si

Specific energy consumption after implementation: (2)/(3) = (2.5E+07)/(422134666.667)

= 0.059 kWh/cm2 Si</td></tr>
<tr><td colspan="4">Rationale
Report the analysis for each EEO, which shall include:
- Description/discussion of each energy efficiency opportunity identified on how it can reduce energy consumption and improve energy performance relative to the base case and how it compares with best available technologies and benchmarks in energy efficiency.
Disconnected and unsynchronized subfab equipments (such as dry vacuum pumps) are maintained at constant operation regardless of process chamber running conditions. With SEMI E37 generation tool platform functionality, energy savings can be achieved by adopting smart idle modes.</td></tr>
</table>


SEMI E37 Generation Tool Platforms Enable Energy Saving
FACTORY MANAGEMENT
PROCESS TOOL MAINFRAMES
ETHERNET HSMS
Energy Saving Interface
Phase 1:
Determine state of Process Tool.
Control energy state for abatement and pumps.
Monitor and Trend SubFab data.
Phase 2:
Totalize total Gas flow and CO2 equivalent emission.
Provide link to other Host services (MAS, FAS etc.) and ExpertConnect.
Utilize E3 services (Predictive maintenance, Fault Detection and Classification).
RS232 / TCP_IP REQUEST AND ACKNOWLEDGE
ABATEMENT
VACUUM PUMPS
RF
CHILLER
Disconnected Subfab Equipment Wastes Energy
PROCESS CHAMBER
Deposition (SiH_4)
Clean (NF_3)
Deposition (SiH_4)
Clean (NF_3)
VACUUM PUMP ENERGY
Synchronizing subfab Matches Energy Need to Operation
PROCESS CHAMBER
Deposition (SiH_4)
Clean (NF_3)
Deposition (SiH_4)
Clean (NF_3)
VACUUM PUMP ENERGY
Energy Savings

- Provide description and additional benefits if there are any interactions and dependencies with other EEOs

  Nil.
- Estimated cost of investment

  Cost of investment for software installation, data integration & consultation service = SGD 1,080,000

  Based on vendor quotation.

Breakdown of investment cost	Cost (SGD)
Software installation + health check bundle	850,000
Data integration	150,000
Consultation service	80,000

- Estimated cost of operations

  No cost of operation as this software installation will be maintained by the existing Fab Computer Integrated Manufacturing team together with the Facility team.
- Estimated annual energy savings and annual greenhouse gas emissions compared to the system in the base case

  Data is collected and saved in the database by software controller, which can be retrieved on demand to produce resource consumption and emission reports as needed.

  (1) Base case energy consumption (without smart idle mode) = 1.09E+07 kWh/yr

  (2) Energy consumption with EEO1 implemented (with smart idle mode) = 8.61E+06 kWh/yr

  (3) Annual energy savings ((1) – (2)) = 2.34E+06 kWh/yr = 8.4 TJ/yr

  Annual greenhouse gas abatement achieved = (2.34E+06 /1E6) * 408 = 954.72 tCO2e/yr, where 408 tCO2e/GWh is the greenhouse gas emission factor for electricity.
- Estimated financial savings

  Estimated cost savings per year = 2.34E+06 * 0.22 = SGD 514,800/yr

  (0.22 = electricity tariff in SGD/kWh)
- Payback period or internal rate of return and other non-energy efficiency benefits (such as productivity or reliability) if any

  Payback period = (SGD 1,080,000 / (SGD 514,800/yr)) = 2.1 years
- Proposed implementation timeline

  By end of Q3, 2022.
- Future changes in production generation capacity, if any

  No future changes expected.
- An explanation if EEO was not implemented or if no EEOs were identified.

  Nil.

Methodology

Report methodology on how energy savings were calculated, how project cost was derived including type and source of data used, basis for calculations, estimates and assumptions, and its accuracy, etc. Base case for all EEOs presented above have to be measured or derived from measured variables.

Refer to above for methodology.

Data utilized is collected and saved by software controller into database for the period of 1 Jan 2017 to 31 Dec 2017.

2.5.1 Implementation Strategy of Shortlisted EEOs

In addition to the evaluation criteria listed above, the EEOA team shall consider the following and generate an implementation strategy of all shortlisted EEOs:

a) Maintenance scheduling (e.g. turnaround/shutdown schedules); and
b) Potential interactions with other EEOs and future changes in operations.

The implementation strategy shall include:

a) Ranking/Priority of EEOs and the key decision factors;
b) Necessary follow-up studies/actions to be taken for each EEO; and
c) Recommended timeline for carrying out EEOs, including whether RCs will be pursuing grant support for these EEOs.

For each shortlisted EEO, the EEOA team should also recommend a measurement and verification plan that the RBA can adopt in order to validate their energy savings.

2.6 Report Findings to Company Management and NEA

Upon completion of EEO evaluation, the EEOA team should present the findings and recommendations to the company's management for further consideration. Management who is responsible for decisions on financial investment and the allocation of resources will need to evaluate these recommendations resulting from the EEOA and the proposed implementation strategy.

A final report detailing the process and results of the EEOA shall be submitted to NEA. The reporting requirements are detailed in the next section.

3 EEOA Reporting Requirements for RCs

3.1 Executive Summary

The report shall provide an executive summary on the key findings of the EEOA, including the following:

a) Summary and breakdown of total energy use within the chosen reference period;
b) Summary of energy, greenhouse gas, and financial savings from EEOs selected for implementation, including proposed timeframe and priority ranking for implementation; and
c) Summary of energy, greenhouse gas, and financial savings from EEOs not selected for implementation.

3.2 Overview of RC and EEOA Plan

The report shall provide general information on the RC, e.g. business objectives, type of business activities, plant capacity, type of products, plant layout etc.

The report shall also provide an overview of the EEOA plan including the methods and processes used to conduct the assessment, the criteria for ranking of EEOs, as well as the team members involved in conducting the EEOA.

The report shall also provide detailed block, process or energy flow diagrams, including EMBs, that show the transfer of energy commodities, feed and products between the ECSs assessed in the EEOA. Please refer to section 2.3.2 for examples on how to report such information. All measurement data used in deriving the mass and energy flows shall be submitted in an appendix for verification.

3.3 Details of Assessment

The report shall provide a detailed analysis of each ECS assessed in the EEOA, including the EEOs identified for each ECS.

- Please refer to section 2.3.4 for the requirements and detailed examples on how to report ECS analysis.
- Please refer to section 2.5 for the requirements for EEO analysis and examples on how to report EEO analysis.

3.4 Instrument Records

The report shall provide a list of monitoring instruments (including instrument specifications) used throughout the EEOA. All measurement data used for ECS and EEO analyses shall be submitted in an appendix in a clear manner for verification.

Table 7: Instrument Specifications for EEOA Measurements

Process flow/ step/ line to be measured	ECS/ Sub ECS	Parameters to be measured	Units	Type of monitoring instruments	Frequency of measurements	Duration of measurements	Indicative accuracy of instruments (%)
Feed water for Cogen	Cogen	Flowrate	kg/min	Orifice flowmeter	Reading per min	1 Oct 2019 to 15 Oct 2019	± 1.0%
Feed water for Cogen	Cogen	Temperature	°C	Thermistors	Reading per min	1 Oct 2019 to 15 Oct 2019	± 0.03°C
Feed water for Cogen	Cogen	Pressure	barg	Pressure transmitter	Reading per min	1 Oct 2019 to 15 Oct 2019	± 1.0%
CVD	Dry pump	Voltage	Voltage	Power Meter	Reading per second	1 Jan 2017 to 15 Jan 2017	+/- 0.5 %
		Current	mA	Power Meter			+/- 0.5 %

A template for the EEOA report for RCs can be found on NEA’s website: https://www.nea.gov.sg/our-services/climate-change-energy-efficiency/energy-efficiency/industrial-sector.

3.5 EEOA Report Submission

The report detailing the process, results and recommendations of the EEOA shall be, in order:

a) Signed by the certified EEO assessor who is principally responsible for conducting the assessment;
b) Endorsed by the Chief Executive of the RC; and
c) Submitted by a person authorised by the RC.

The first EEOA report must be submitted by 31st Dec 2021 using the relevant form provided in the electronic service provided at http://www.nea.gov.sg. Subsequent cycles of the EEOA report are to be submitted in accordance with the requirements laid out in section 1.3.3.

Any data used for the EEOA shall be kept for at least 10 years from date of submission of report to NEA.

Appendix: Examples of measurement at energy consuming system level

i. Chilled water system

Specific energy consumption (kW/RT)

$$=\frac{kW_{chill \quad water\ system}}{Q_{cooling}} = \frac{kW_{chill} \quad +k \quad cwp+kW_{chwp}+ \quad ct}{\rho V_{ch} Cp_{water}(T_{chwr}-T_{chws})/3.517}$$

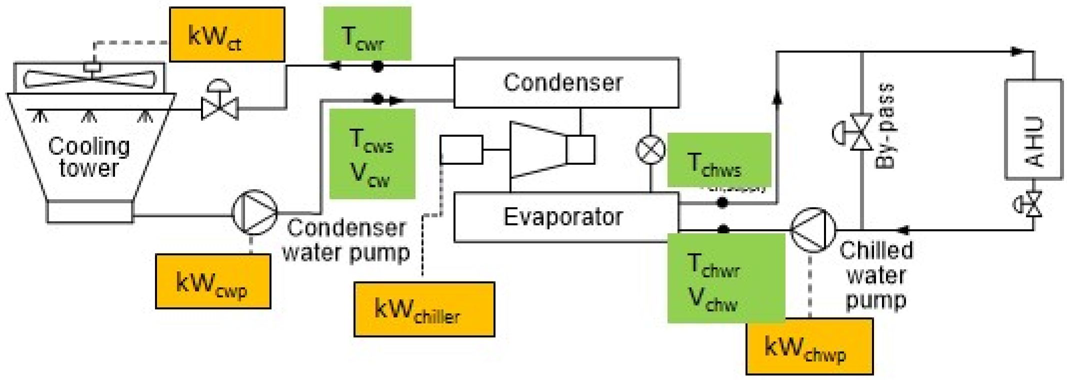


Figure 9: Schematic diagram of chilled water system showing measurement locations

Description of parameters:

$kW_{chilled\ water\ system}$= Power consumption of chiller plant, kW
$kW_{chiller}$= Power consumption of chiller, kW
kW_{chwp}= Power consumption of chilled water pump, kW
kW_{cwp}= Power consumption of condenser water pump, kW
kW_{ct}= Power consumption of cooling tower, kW

$Q_{cooling}$ = Cooling load of the system, RT
$Q_{cooling}$= ρ V_{chw} x Cp_{water} x ($T_{chwr} - T_{chws}$), kW
ρ=density of water= 1kg/L
V_{chw} = Volumetric flow rate of chilled water, L/s
Cp_{water} = Specific heat capacity of water = 4.19 kJ/kg K
T_{chws} = Chilled water supply temperature, ^oC
T_{chwr} = Chilled water return temperature, ^oC
V_{cw} = Volumetric flow rate of condender water, L/s
T_{cws} = Condenser water supply temperature, ^oC
T_{cwr} = Condenser water return temperature, ^oC
1 Rerigeration Tonne (RT) = 3.517 kW

Recommended:

Heat and mass balance analysis:

For chilled water system, a heat balance is recommended to be conducted to ensure Uncertainty of the measurements. The measurements can be considered as accurate, if at least 80% of the points fall within ±5% error, based on the formula below.

$$Heat\ Balance\ error\ (\%) = \frac{(Qcooling\ (kW) +\ kWchiller) - \ Qcondenser\ (kW)}{Qcondenser\ (kW)} \times 100$$

Where,

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

$Q_{condenser} = \rho\ V_{cw}$ x Cp_{water} x $(T_{cwr} - T_{cws})$, kW

Measured Parameters:

Parameter	Sensor type	Location	Uncertainty	Measurement type
$kW_{chiller}$	Power meter (including current transducer)	At power panel	±1%	Trend log
kW_{chwp}	Power meter (including current transducer)	At power panel	±1%	Trend log
kW_{cwp}	Power meter (including current transducer)	At power panel	±1%	Trend log
kW_{ct}	Power meter (including current transducer)	At power panel	±1%	Trend log
m_{chw}	Magnetic Flow Meter	At individual chiller outlet	±1%	Trend log
T_{chws}	10kΩ, four-wired Thermistor	At individual chiller outlet	±0.05°C	Trend log
T_{chwr}	10kΩ, four-wired Thermistor	At individual chiller inlet	±0.05°C	Trend log
T_{wb}	Ambient temperature & RH sensor		±0.5°C and 3% RH	Trend log
m_{cw}	Magnetic Flow Meter	At individual chiller outlet	±1%	Trend log
T_{cws}	10kΩ, four-wired Thermistor	At individual cooling tower	±0.05°C	Trend log
T_{cwr}	10kΩ, four-wired Thermistor	At individual cooling tower	±0.05°C	Trend log

a. <u>Cooling Tower Systems</u>

Specific Energy Consumption (kW/RT)= $\frac{kW_{ct}+k\quad_{cwp}}{Q_{heat}/3.517}=\frac{kW_{ct}+kW_{cwp}}{\rho V_{cw}Cp_{water}(T_{return}-T_{supply})/3.517}$

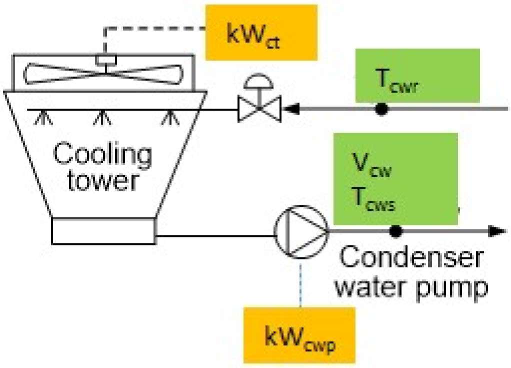


Figure 10: Schematic diagram of cooling water system showing sensor location

Description of parameters:

kW_{ct} = Power consumed by cooling tower fans, kW
kW_{cwp} = Power consumed by condenser water pumps, kW
Q_{heat} = Heat rejection rate, kW
ρ=density of water= 1kg/L
V_{cw} = Volumetric flow rate of condenser water, kg/s
Cp_{water} = Specific heat capacity of water = 4.19 kJ/kg K
T_{cwr} = Cooling tower water return temperature, °C
T_{cws} = Cooling tower water supply temperature, °C

Measured Parameters:

Parameter	Sensor type	Location	Uncertainity	Measurement type
m_{cw}	Ultrasonic flow meter/ Orifice Flowmeter	At individual chiller outlet	±2%	Trend log
T_{cwr}	10kΩ, four-wired Thermistor	At individual cooling tower	±0.05°C	Trend log
T_{cws}	10kΩ, four-wired Thermistor	At individual cooling tower	±0.05°C	Trend log
T_{wb}	Ambient temperature & RH sensor		±0.5°C and 3% RH	Trend log
kW_{ct}	Power meter (including current transducer)	At power panel	±1%	Trend log

ii. Seawater cooling system

Specific energy consumption (kWh/tonne) $=\frac{kWh_{swp}}{m_{sw}}$

Or

Efficiency $=\eta$ (%) $=\frac{V_{sw}\times\Delta P}{kW_{swp}\times 1000}$ x100%

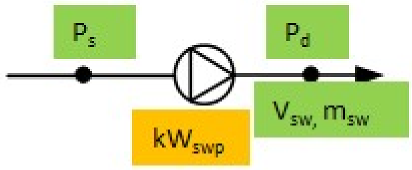


Figure 11:Schematic diagram of seawater system sensor location

Description of parameters:

kW_{swp}= Power consumed by seawater pump, kW
m_{sw} = Mass flow rate of seawater, tonnes/h
V_{sw} = Volumetric flow rate of seawater, m^3/s
Δp = Pressure difference, Pa = (P_d - P_s), Pa
P_d = Pump discharge pressure, Pa
P_s = Pump suction pressure, Pa

Measured Parameters:

Parameter	Sensor type	Uncertainity	Measurement type
m_{cw}	Ultrasonic flow meter/ Orifice Flowmeter	± 2%	Trend log
T_{cwr}	10kΩ, four-wired Thermistor	± 0.05ºC	Trend log
T_{cws}	10kΩ, four-wired Thermistor	± 0.05ºC	Trend log
T_{wb}	Ambient temperature & RH sensor	± 0.5ºC and 3% RH	Trend log
kW_{swp}	Power meter (including current transducer)	± 1%	Trend log
P_s	Pressure transmitter	± 0.5%	Trend log
P_d	Pressure transmitter	± 0.5%	Trend log

iii. Refrigeration and process cooling systems

a. Cold room: Specific energy consumption (kWh/tonne or KWh/m^3)

$$= \frac{Energy\ consumption\ of\ Refrigeration\ system,\ kWh/day}{Weight\ of\ material\ inside\ refrigerated\ space} \quad \text{(for cold room)}$$

$$= \frac{Energy\ consumption\ of\ Refrigeration\ system,\ kWh/day}{Volume\ of\ refrigerated\ space} \quad \text{(for cold room)}$$

Measured Parameters:

Parameter	Sensor type	Uncertainty	Measurement type
Power consumption of refrigeration compressor	Power meter (including current transducer)	± 1%	Trend log

b. Large refrigeration system (water cooled)

Specific energy consumption (kW/RT) = $\frac{kW_{cooling\ system}}{Q_{cooling}}$

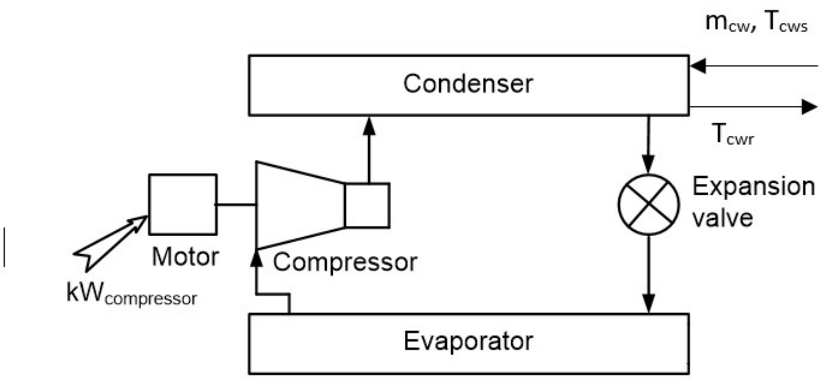


Figure 12:Schematic diagram of refrigeration system sensor location

Description of parameters:

$kW_{cooling\ system}$ = Power consumption of refrigeration system
= $kW_{compressor}$ + kW_{pump} + kW_{ct}

$kW_{compressor}$ = Refrigeration system compressor power, kW

$Q_{cooling}$ = Refrigeration load, kW = Heat rejection rate of cooling tower, kW - Input power to motor of compressor, kW = $(Q_{heat} - kW_{compressor} \times F)$

Q_{heat} = heat rejection rate of refrigeration system
= $m_{cw} \times Cp \times (T_{cwr} - T_{cws})$, kW

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

Cp = Specific heat capacity of water = 4.19 kJ/kg.K

T_{cwr} = Condenser water return temperature, ^{o}C

T_{cws} = Condenser water supply temperature, ^{o}C

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

Measured Parameters:

Parameter	Sensor type	Uncertainity	Measurement type
m_{cw}	Ultrasonic flow meter/ Orifice Flowmeter	± 2%	Trend log
T_{cwr}	10kΩ, four-wired Thermistor	± 0.05ºC	Trend log
T_{cws}	10kΩ, four-wired Thermistor	± 0.05ºC	Trend log
$kW_{compressor}$	Power meter (including current transducer)	± 1%	Trend log
kW_{ct}	Power meter (including current transducer)	± 1%	Trend log
kW_{pump}	Power meter (including current transducer)	± 1%	Trend log

iv. Boiler systems

Specific energy consumption (kJ/kJ)= $\frac{Energy\ input\ (fuel)}{Energy\ output\ (steam)}$

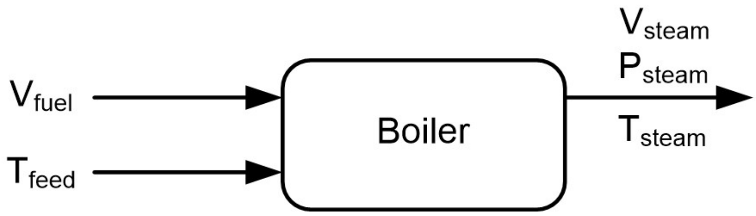


Figure 13: Schematic diagram of boiler system sensor location

Description of Parameters:

Energy output (steam) = $V_{steam} \times \rho_{steam} \times h_{steam} - m_{feed} \times h_{feed}$
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 = $V_{steam} \times \rho_{steam}$ *(kg/s)*
h_{feed} = Enthalpy of feed water at temperature T_{feed}

Energy input of fuel = $V_{fuel} \times \rho_{fuel} \times CV$
V_{fuel} = Fuel consumption rate, m^3/s
ρ_{fuel} = Density of fuel, kg/m^3
CV = Net calorific value of fuel, kJ/kg

Measured Parameters:

Parameter	Sensor type	Uncertainity	Measurement type
V_{steam}	Inline flow meter/ Orifice Flowmeter	Based on installed sensor	Trend log
T_{steam}	RTD or thermocouple	Based on installed sensor	Trend log
T_{feed}	10kΩ, four-wired Thermistor/ RTD/ thermocouple	± 0.2^{o}C/ ± 1-2^{o}C	Trend log
P_{steam}	Pressure transmitter	Based on installed sensor	Trend log
V_{fuel}	Fuel flow meter	Based on installed sensor	Trend log

v. Ovens and furnaces

Specific energy consumption (kW/kW or kJ/kJ) = $\frac{Electricity\ or\ Fuel\ input}{Energy\ gained\ by\ product}$

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 = Net 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, $5.67 \times 10^{-8}\ W/m^2\ K^4$
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)*

For Convection and Radiation heat loss, T_{skin} *is normally taken as spot measurement either with a infra red gun or thermal scan.*

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

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

Measured Parameters:

Parameter	Sensor type	Uncertainty	Measurement type
Electrical power	Power meter (including current transducer)	± 1%	Trend log
T_{flue}	RTD	Based on installed sensor	Trend log
V_{fuel}	Plant flow meter or tank measurements	Based on installed sensor	Cumulative

vi. Compressed air systems

Specific energy consumption (kWh/Nm³)=

$$\frac{Power\ consumption\ of\ compressors, dryers\ and\ cooling\ system, kW}{Compressed\ air\ production,\ \frac{Nm3}{h}}$$

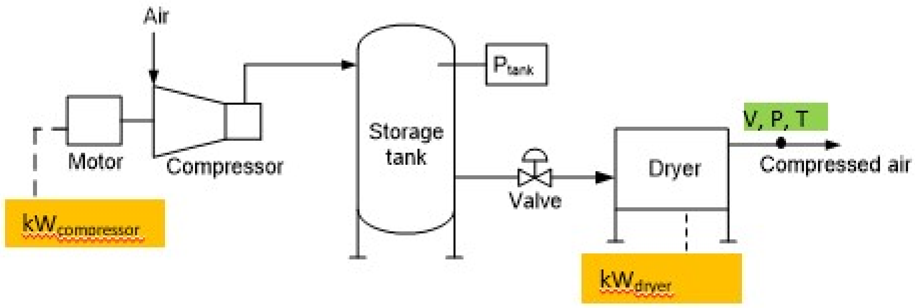


Figure 14: Schematic diagram of a compressed air system showing sensor location

Description of parameters:

Compressed air production (Nm^3/h) = (P x V x T_{normal}) / (P_{atm} x T)

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

P = Pressure at the measurement point, kPa

P_{atm} = Atmospheric pressure, kPa

T = Temperature at the measurement point, K

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

Measured parameters:

Parameter	Sensor type	Uncertainty	Measurement type
V	Thermal dispersion flow meter/ Ultrasonic flow meter/ pitot tube sensors/ Venturi meter	Based on installed sensor	Trend log
P	Pressure transmitter	± 0.5%	Trend log
T	Surface temperature sensor	± 0.5°C	Trend log
$kW_{compressor}$ kW_{dryer} $kW_{cooling}$	Power meter (including current transducer)	± 1%	Trend log

vii. Fan systems

Specific Power Consumption of Fan (kW/CMH) = $\frac{Power consumption\ of\ fan, kW}{Volume flowrate of\ fan, CMH}$

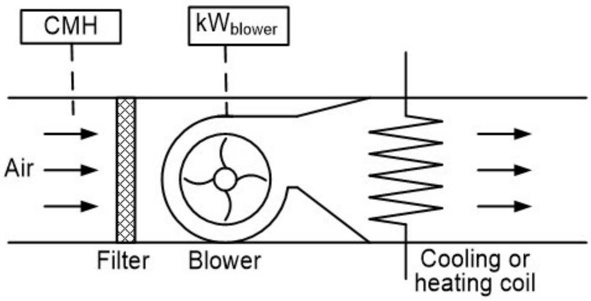


Figure 15:Schematic diagram of typical fan system showing sensor location

Description of parameters:

CMH = Volume flow rate of air, m^3/h
kW_{blower} = Fan / Blower power consumption, kW

Measured parameters:

Parameter	Sensor type	Uncertainty	Measurement type
CMH	Pitot tube/ Venturi meter	Based on installed sensor	Trend log
kW_{blower}	Power meter (including current transducer)	± 1%	Trend log

viii. Lighting systems

Lighting Power Density (kWh/m^2) = $\frac{Electricity\ consumption\ per\ year, kWh}{Floor\ area, m2}$

Measured parameters:

Parameter	Sensor type	Uncertainty	Measurement type
$kWh_{lighting}$	Power meter (including current transducer)	± 1%	Trend log