Energy Efficiency Opportunities Assessment and Energy Performance Measurement Guidelines for New Ventures

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National Environment Agency
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Abbreviations

AEC	Annual Energy Consumption
BCA	Building and Construction Authority
DC	Development Control
ECA	Energy Conservation Act
EE	Energy Efficiency
EEO	Energy Efficiency Opportunities
EEOA	Energy Efficiency Opportunities Assessment
EMB	Energy and Mass Balance
EPM	Energy Performance Measurement
FEED	Front-End Engineering Design
GHG	Greenhouse Gas
NEA	National Environment Agency
NV	New Ventures
P&ID	Piping & Instrumentation Diagram
PFD	Process Flow Diagram
QP	Qualified Person
TJ	Tera-Joules (10^{12} multiple)
VO	Verification Office
VSD	Variable Speed Drive

1 Industrial Energy Efficiency Requirements for New Ventures

1.1 Background

The industrial sector consumes the largest share of energy in Singapore. To improve energy efficiency (EE) in the industrial sector, the Energy Conservation Act (ECA) introduced in 2013 requires energy-intensive users[1] in the industrial sector to implement the following mandatory energy management practices:

a) appoint at least one certified energy manager;
b) monitor and report energy use and GHG emissions annually; and
c) develop an energy efficiency improvement plan and update the plan annually.

The ECA was amended in 2017 to introduce the following new requirements:

a) existing facilities are to implement structured energy management system, and carry out energy efficiency opportunities assessment (EEOA) periodically; and
b) new ventures are to carry out EEOA to review the facility design in order to identify economically feasible EE improvement opportunities, and install instruments to report the energy performance of key energy consuming systems[2] based on measured data in their annual energy use report.

New ventures refer to any new business activities or expansions of existing business activities that consume total energy equal to or exceed 54 TJ per calendar year .

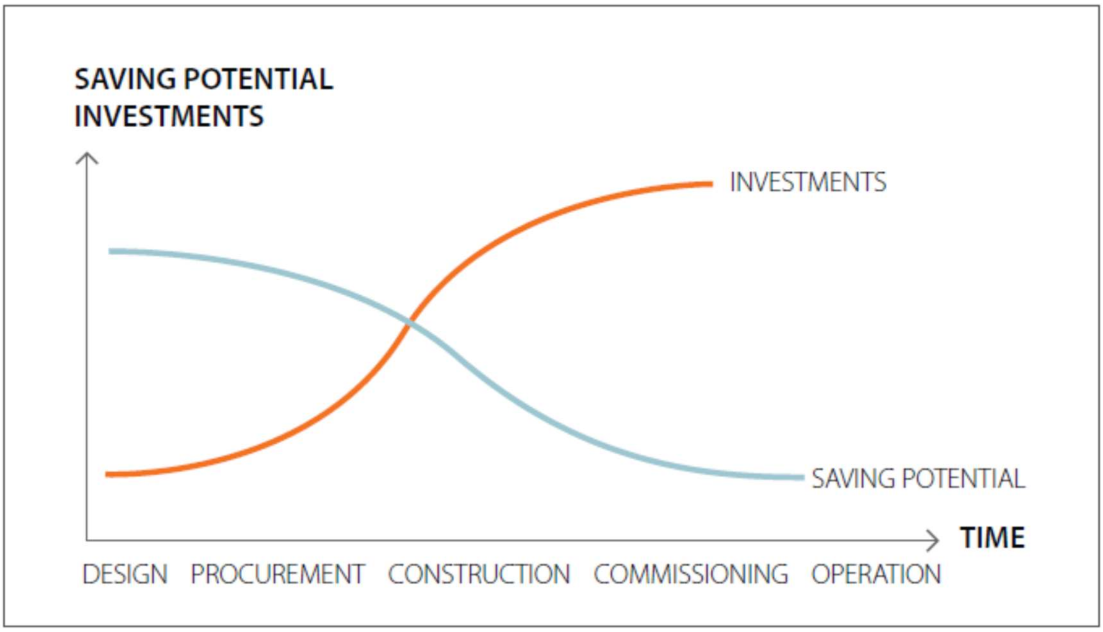
1.2 Rationale for EEOA Requirement for New Ventures

Many system design synergies are only available early in the design process before system choices are locked in. As the design process advances, it becomes costlier and more challenging to make changes to earlier decisions as it will entail redoing parts of the design, and changes also tend to be less effective in achieving EE improvement. It becomes far costlier and less effective to retrofit or improve a facility for EE after it has been built. It is therefore important to consider energy efficiency as early as possible in the design of a facility. Figure 1 illustrates how the energy saving potential of a facility decreases over a project lifecycle while the investment cost needed to realise the energy saving rises.

[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.

[2] Key energy consuming systems refer to those that account for at least 80% of a facility's total energy consumption

Figure 1: Savings potential and cost of investments for energy efficiency



Source: Sustainability Energy Authority of Ireland, Energy Efficient Design Methodology

Designing a facility to be energy and resource efficient can reduce:

a) Capital cost of the systems, due to right-sizing of capacity in upstream utility systems, e.g. smaller motors, refrigeration & air compressor systems can be reduced if downstream utility demand can be accurately assessed;
b) Operating costs, due to lower resource and energy use;
c) Maintenance costs for the systems. For example, reducing thermal loads and stress can lead to lower maintenance costs and improved uptime.

The EEOA requirement for new ventures is meant to ensure that companies identify opportunities for EE improvement and consider them early for incorporation into the facility design.

1.3 Eligibility of EEOA Requirement for New Ventures

The owner of a new venture who

- applies planning permission to URA on or after 1 October 2018;
- carries out business activity at a single site and attributable to one of the following industry sectors:

  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

- and has an estimated annual energy consumption (AEC) of 54 TJ or more based on 24 hours per day, 365 days of operations at 100% of designed production capacity

will need to carry out an EEOA and submit an EEOA report to the NEA. The detailed requirements of the EEOA process can be found in the next section.

AEC calculator from the website link below can be used to check if the estimated AEC is ≥ 54 TJ per year.

Energy Consumption Calculator:
https://www.nea.gov.sg/our-services/climate-change-energy-efficiency/energy-efficiency/industrial-sector

2 Energy Efficiency Opportunities Assessment (EEOA) Process

The design of an industrial facility commonly follows the following stages:

(1) *Concept Engineering* where a feasible process to be used within the facility is identified,
(2) *Front-End Engineering Design (FEED)* where the types of equipment and systems needed for the process are decided, and
(3) *Detailed Design* where the detailed size and capacity of these equipment and systems are developed.

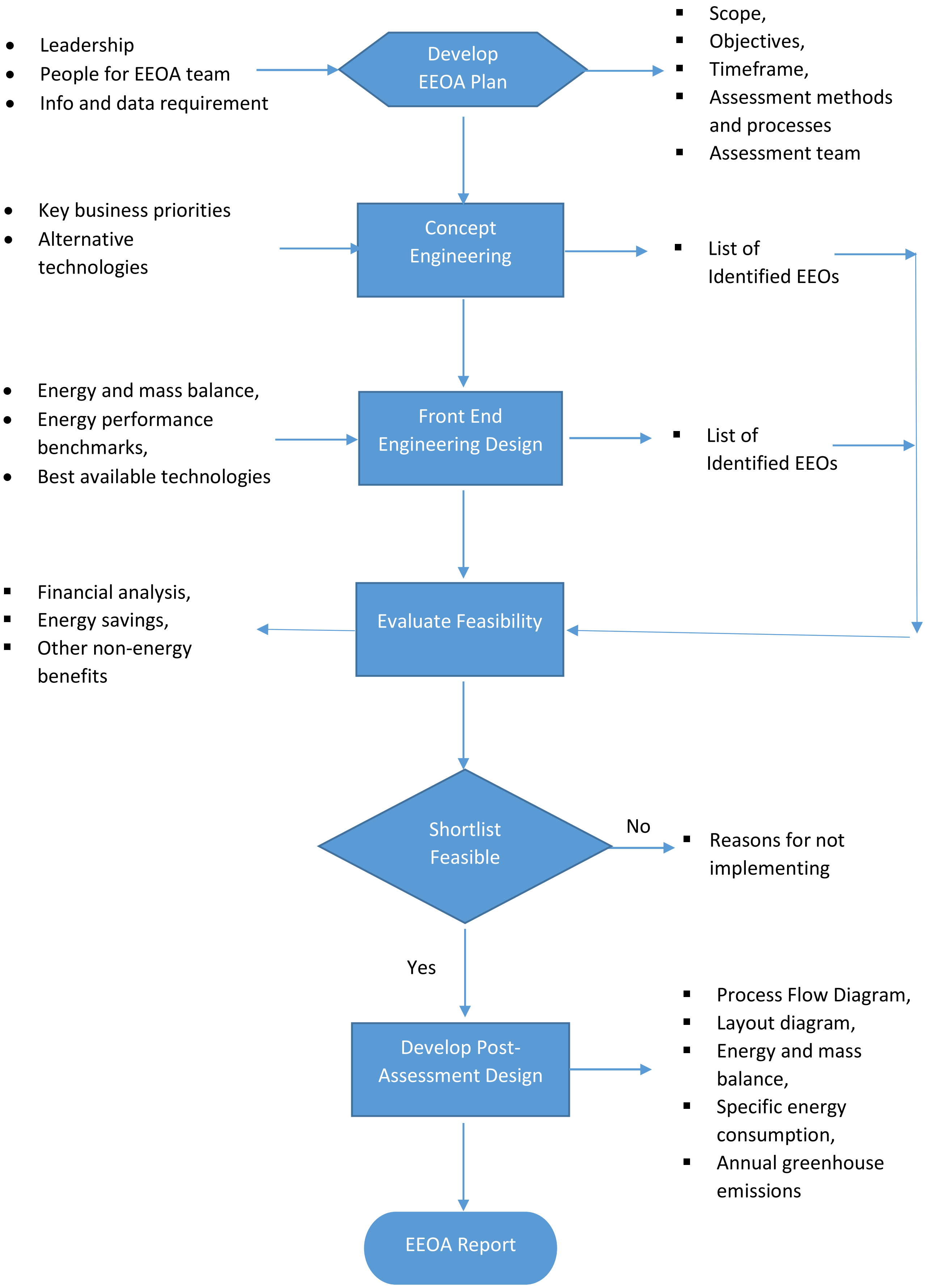
Owner of new ventures (NV), especially for complex projects, should start the EEOA process early and engage NEA's Verification Office (VO) early at concept design phase to discuss the details. This will help to minimise clarifications during the EEOA report review and ensure timely approval of the EEOA reports.

The key elements of the EEOA process are:

1. Develop EEOA plan
2. Identify EE Opportunities
3. Evaluate Feasibility
4. Shortlist Feasible EE Opportunities
5. Develop Design for Facility and each Energy Consuming System

A process flow chart of the EEOA process can be found below.

Figure 2: EEOA process flow



2.1 Develop EEOA plan

The first step of the EEOA process is to develop a plan to conduct the EEOA, which will detail the scope, objectives, and assessment methods of the EEOA. The plan should also document the team members involved in the assessment including their names, roles, job functions and experience level.

Some key elements to consider during the development of EEOA plan are:

<u>Leadership</u>

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

- Setting and communicating energy performance objectives
- Ensuring that assessment 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 energy efficiency opportunities. Adequate financial and human resources should be made available to achieve the energy assessment and energy performance objectives.

<u>Formation of EEOA team</u>

A multi-disciplinary team with technical competence working in collaboration will be required to conduct an meaningful EEOA for NV. The team lead should have the required competence to appreciate the different technical disciplines and steer the team towards achieving an effective EEOA. The team members should actively participate in the assessment and look into various aspects of the design to ensure it is energy efficient. They should effectively collect and analyse energy and process data based on design information, industry norm, best practices or exisiting sister plant, identify and evaluate energy efficiency opportunities, provide fresh perspectives and make the business case for the energy efficiency opportunities identified. Skilled and knowledgeable people with the following areas of expertise should be included. (List is not exhaustive)

(a) People from various levels of the site or business unit who have a direct or indirect influence on energy use and cost (such as site managers, operators, sub-contractors, tenants or people responsible for equipment procurement, maintenance, finance, marketing or production); and

(b) People from within the corporation who can integrate energy productivity into business objectives and assist with making a business case for identified opportunities (such as the chief financial officer, business case analysts, business or process improvement managers or people responsible for procurement, corporate and operations management, public relations, strategic planning or operational excellence); and

(c) People with energy, technology, process and facility design expertise (such as process, mechanical, electrical, and instrument engineers/ designers, suppliers of current and alternative equipment and technologies, systems modelling experts or engineers, operation and commissioning personnel); and

(d) People external to the new venture who can give alternative perspectives, question assumptions and practices, and encourage innovation (such as experienced operators from other sites, corporate expert groups, internal or external engineering experts, or academics).

Clear roles, responsibilities and accountabilities of each team member should be documented in the EEOA report and the team should be appreciated for its efforts.

Information and data collection

Data used in each design stage should be verified and representative of at least 80% of the calculated total energy consumption of the NV. This data and information should be used to quantify and analyse energy use, identify and quantify energy saving opportunities, and track performance and outcomes (where actions are implemented).

Energy data should be analysed from different perspectives to understand relationships between activity and consumption. This will be crucial for energy efficiency opportunities identification. Owner can also establish a stretch target of energy savings compared to industry norm or existing sister plants to encourage the EEOA team to look in depth for energy efficiency opportunities.

Business contextual information that influences energy use and returns on energy efficiency investments should be identified and documented. Information below should be included 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.

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 similar 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 uncertainity and completeness of energy data and resolve any material data gaps.

EEOA necessitates the need to analyse the energy and material flows through the NV 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 recommended that an EMB cover at least 80% of the energy use at a site to enable coverage of all key energy using processes / activities.

The EEOA report requires data reporting at different stages of design, eg. FEED base case. Thus, it is essential to ensure the data is available at each design stage and well understood.

2.2 Identify EE Opportunities

A comprehensive process is undertaken to identify all potential cost-effective energy efficiency opportunities. The process is informed by rigorous analysis and involves the relevant people identified in the EEOA plan. This process is broad, open-minded and encourages innovation. The process should result in a comprehensive list of ideas, which are then documented.

Identify energy efficiency opportunities during the Concept Engineering stage by considering:

a) Optimum methods or processes to produce outputs eg. alternative choices of solvent and catalyst for reaction, optimization of reaction or separation pressures and temperatures.
b) Alternative technology choices including best available technology

Identify energy efficiency opportunities, for energy-consuming systems that make up at least 80% of the total energy consumed, as calculated in the post-assessment design, considering:

a) Location and arrangement of equipment to allow opportunities such as heat transfer between processes or reduction of pressure drop.

b) Alternative technology choices including best available technologies, e.g. waste heat recovery and usage of VSD motors.

c) Best operating practices, e.g. pinch analysis for heat integration

2.3 Evaluate Feasibility

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 energy efficiency opportunities.

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

Assess the feasibility of implementing each energy efficiency opportunity identified based on the following criteria:

a) Cost of investment
b) Operations cost
c) Annual energy savings
d) Financial savings
e) Payback period or internal rate of return
f) Annual greenhouse emissions abatement
g) Other criteria, economic or otherwise, where appropriate
h) Other non-energy benefits (e.g. improvement in productivity or reliability)
i) Potential interactions between various opportunities

Document reasons for the categorisation of all identified ideas (both feasible and not for implementation).

2.4 Shortlist Feasible EE Opportunities

Management who is responsible for decisions on financial investment and the allocation of resources need to evaluate these recommendations resulting from the assessment and the necessary contextual information, such as:

(a) Total estimated energy use and energy cost relative to variable estimated operating costs and profit for the manager’s area of responsibility; or

(b) Estimated energy savings identified for each opportunity; or

(c) The impact that identified opportunities are estimated to have on productivity and overall energy costs; or

(d) The total quantifiable costs and benefits, including a payback period, for each opportunity; or

(e) The business recommendation for each opportunity; or

(f) Recommendations to improve data and evaluation accuracy (if necessary).

The presentation of this information will allow management to decide the business response to the assessment, including the opportunities that are to be implemented, investigated further (including improvements in data and evaluation accuracy), or not implemented.

2.5 Develop Design for Facility and each Energy Consuming System

Establish arrangements to implement the business response by setting timelines, resources and accountabilities covering all energy efficiency opportunities that the NV decides to implement.

Incorporate shortlisted energy efficiency opportunities into a post-assessment design, and calculating the energy and greenhouse savings from each of these opportunities incorporated.

Develop a post-assessment design with the following details:

a) Layout, energy and mass balance and process flow diagram of the NV
b) Estimated annual energy consumption, by type(s) of fuel or energy commodity
c) Estimated quantity of output(s)
d) Estimated specific energy consumption (energy consumed divided by output)
e) Estimated annual greenhouse emissions
f) For energy-consuming systems that make up at least 80% of the calculated total energy consumption of the NV:
    i. Type and description of system
    ii. Estimated annual energy consumption, by type(s) of fuel or energy commodity
    iii. Estimated quantity of output(s)
    iv. Estimated specific energy consumption
    v. Estimated annual greenhouse emissions

2.6 EEOA Reporting Requirements for New Ventures

2.8 Executive Summary

Provide brief description of the chosen EEOs and their energy, greenhouse and financial savings.

(a) Summary of total energy use and specific energy consumption;

(b) Summary of energy, greenhouse, and financial savings from EE opportunities incorporated into the post-assessment design;

(c) Summary of energy, greenhouse, and financial savings from EE opportunities not incorporated into the post-assessment design;

2.8 Overview of New Venture and EEOA Plan

Provide general information on NV, eg. business objectives, type of business activities, plant capacity, type of products, etc.

Provide overview of EEOA plan including its defined scope and boundaries, objective(s), timeframe, assessment methods, processes and team members.

2.8 Details of Assessment

Detail the process of identification and analysis of energy efficiency opportunities, during the Concept Engineering stage, and for energy-consuming systems that make up at least 80% of the calculated total energy consumption of the new venture in the post-assessment stage. The analysis for each opportunity shall include:

a) Justifications for chosen base cases in concept engineering and FEED stages
b) Description/ discussion of each energy efficiency opportunity identified on how it can reduce energy consumption relative to the base case and how it compares with best available technology and benchmarks in energy efficiency.
c) Considerations on any interactions or dependencies with other energy efficiency opportunities
d) An explanation why it was selected/ not selected
e) Cost of investment
f) Estimated cost of operations
g) Estimated annual energy savings and reduction in greenhouse emissions compared to the base case
h) Estimated financial savings

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

The EEOA must be conducted on the basis of 24 hours per day, 365 days of operations at 100% of designed production capacity.

2.8 Details of Post-Assessment Design

Provide the estimated energy use and specific energy consumption of the NV, including at the Concept Engineering and FEED stages.

Provide details of the post-assessment design as spelt out in Section 2.5.

A template for EEOA report can be found in the NEA website,

https://www.nea.gov.sg/our-services/climate-change-energy-efficiency/energy-efficiency/industrial-sector.

2.7 EEOA Report Submission

2.8 General Requirements

<u>Submission of EEOA Report</u>

The report detailing the EEOA process and results of the assessment must be:

a) Submitted by Qualified Person[3] (QP) or authorised company representative, using the emails provided below;

b) Signed off by the person and company principally responsible for conducting the EEOA; and

c) Endorsed by the Chief Executive of the NV.

<u>Records to be kept</u>

Any record including information or data used for the EEOA must be kept for at least 5 years after the date of creation and receipt of the records.

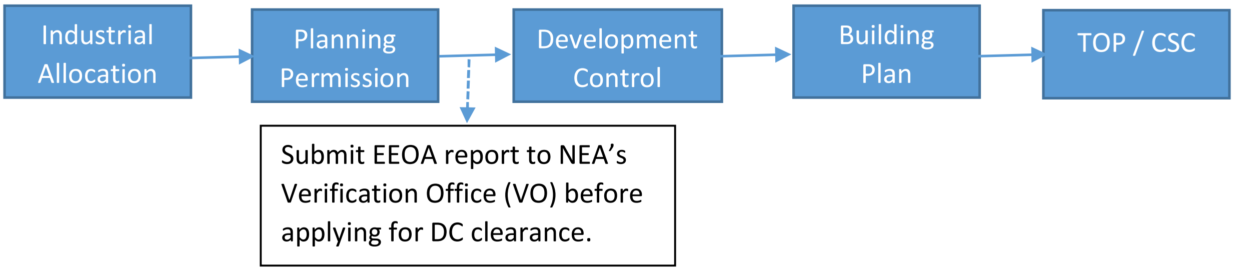
2.8 Submission Process and Approval

The EEOA report must be submitted before applying for a Development Control (DC) Clearance Certificate from NEA. To expedite the approval process, new ventures should ensure that their report has sufficient details, by engaging NEA's VO early for discussion, preferably during the concept engineering and FEED stages. New ventures are encouraged to submit the report to NEA's VO early via emails provided below, to obtain early approval on the EEOA report. QPs or authorised company representatives are encouraged to encrypt the EEOA report using Netrust before report submission if the NVs have confidentiality concerns.

QP shall make a declaration of the estimated Annual Energy Consumption (AEC) based on 24 hours per day, 365 days of operations at 100% of designed production capacity on behalf of the new venture in the EEOA declaration form from https://www.nea.gov.sg/our-services/building-plan/overview. This declaration form must be submitted via e-Corenet for DC clearance.

[3] Appointed under section 8 or 11 of the Building Control Act (Cap. 29) in respect of the building works for the new venture facility

Figure 3: Submission of EEOA report before applying for DC clearance



To ensure that the scope and quality of the EEOAs are adequate, NEA's VO will review the EEOA reports. After the review, VO may offer suggestions for improvement and recommendations for voluntary adoption or further study by the company. A clearance letter will be issued to the QP upon approval of the EEOA report.

QP can then proceed to apply for DC clearance via BCA's Corenet e-submission system with the EEOA declaration form.

For NVs who have declared estimated annual energy consumption (AEC) to be <54 TJ in Development Control stage, new ventures **must** contact NEA's VO immediately in the event their AEC increase to ≥54TJ.

Verification Office (VO) contacts		
Mr. Samuel Ponnuraj Principal Engineer Contact: NA Email: Samuel_PONNURAJ@nea.gov.sg	Mr. Fang Sixun Principal Engineer Contact: NA Email: fang_sixun@nea.gov.sg	Mr. Liow Chean Siang Principal Engineer Contact: NA Email: LIOW_Chean_Siang@nea.gov.sg

2.8 General Guidelines

The post-implementation report of the new venture should contain the following information:

(a) Summary of EE Measures implemented in New Venture:

i. Summary of implemented EE measures from EEOA and other implemented EE measures not identified in the EEOA, including comparison between the estimated and actual annual energy and cost savings and actual implementation cost.

ii. List of EE measures that were identified in EEOA for implementation, but were eventually not implemented, and the reason for non-implementation

(b) Measurements and Calculations:

i. Details of the measurement, calculation and verification system adopted to measure and compare actual savings and system energy performance to those estimated in the EEOA report

ii. Detailed instrumentation plan

iii. Parameters reported to be monitored at 100% designed capacity or other stable state for a duration of at least 2 weeks. Include plant performance test data at maximum capacity if available.

iv. Other findings and observations

The VO will review the post implementation reports. VO may contact the company for verification of data.

3 Energy Performance Measurement (EPM) Guide

3.1 Rationale for Energy Performance Measurement Requirement for New Ventures

Measurement is critical to continual energy efficiency improvement as managing energy use is a data-driven activity. Measured data also facilitates benchmarking and comparison of energy performance of similar systems across facilities within a sub-sector and across sub-sectors, thereby highlighting the potential for improvement for poorer performing systems.

Improved measurement of energy and materials use will enable companies to:

- Shift and reduce demand when it is in their financial and operational interests to do so through demand response programs
- Benchmark key energy consuming systems across sectors
- Understand where distributed renewables and use/ sale of waste heat/ materials could reduce costs

As the cost of metering, energy mangement systems, sensors, interconnected data platforms, data analytics and artificial intelligence become more affordable, digitalisation of energy will enable further improvements in energy productivity at lower cost.

These energy and materials (eg. water, product, waste) data measurement and management systems can also be integrated into other core business data systems.

As it is less disruptive and more cost-effective to install such measurement systems in NVs, owners of NVs will be required to plan for and install instruments and meters for energy-consuming systems and report energy use and energy performance indicators based on measured values in their future ECA submissions.

3.2 Details of Energy Performance Measurement Requirement for New Ventures

The eligibility of EPM requirement is applicable to the owner of new venture who

- applies planning permission to URA on or after 1 October 2018;
- carries out business activity at a single site and attributable to one of the following industry sectors:

  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.

- has an estimated annual energy consumption (AEC) of 54 TJ or more based on 24 hours per day, 365 days of operations at 100% of designed production capacity.

The owner will need to indicate its intent to install meters, parameters to be measured and type of meters to enable tracking of energy use and energy performance indicators[4] of energy-consuming systems that make up at least 80% of the calculated total energy consumption of the new venture in the EEOA report. These instruments and meters will be used to report energy use and energy performance indicators based on measured data in the future ECA submissions.

When new ventures commence operations and is part of a relevant business activity[5], such corporations will have to report the following as measured values[6]:

a) Total energy consumption of the new venture; and

b) Annual energy consumption, intended output and specific energy consumption figures of energy-consuming systems that make up at least 80% of the calculated total energy consumption of the new venture.

3.3 Recommended Measurement Instruments and Uncertainty Range

Table 1: Table of various meters and their recommended uncertainity range

Parameter	Sensor Type	Uncertainty[7]
Temperature	10kΩ, four-wired Thermistor/ Thermocouples	± 0.05 ºC for chilled water system/ ± 1-2 ºC for heating systems
Power	Power meter (including current transducer)	± 1 %
Flow	Flow meter	± 1-2 %
Pressure	Pressure transmitter	± 0.5 %

Examples of recommended instruments, uncertainity range and location of these instruments can be found in Appendix. It is recommended that the measurement intervals should be on per minute basis for trend logging.

4 The energy performance indicators refer to the specific energy consumption (SEC) of energy-consuming systems in the energy use report specified in the ECA.

5 When new ventures commence operations and consumed 54TJ or more of energy annually in at least 2 out of the 3 preceding years, they will be regulated as a Registered Corporation under the ECA.

6 Measured value refers to means a numerical value collected using an appropriate instrument or device in a relevant unit of measure over the full period of time as reported, and does not include values obtained from simulation.

7 Refers to the uncertainty of the entire measurement system including the sensor, any signal conditioning (if present), data accqusition system and wiring connecting them.

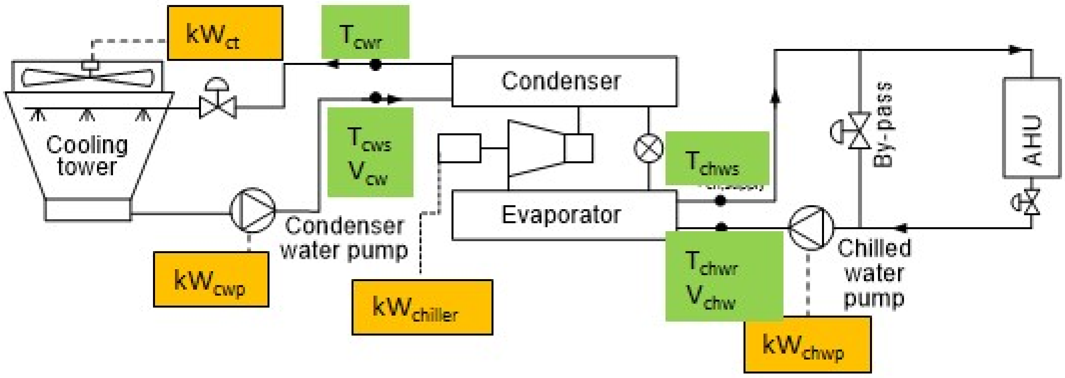
Appendix : EPM examples at energy consuming system level

i. Chilled water system

Specific energy consumption (kW/RT)

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

Figure 4: 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, ^{o}C
T_{chwr} = Chilled water return temperature, ^{o}C
V_{cw} = Volumetric flow rate of condender water, L/s
T_{cws} = Condenser water supply temperature, ^{o}C
T_{cwr} = Condenser water return temperature, ^{o}C
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 Uncertainity 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

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

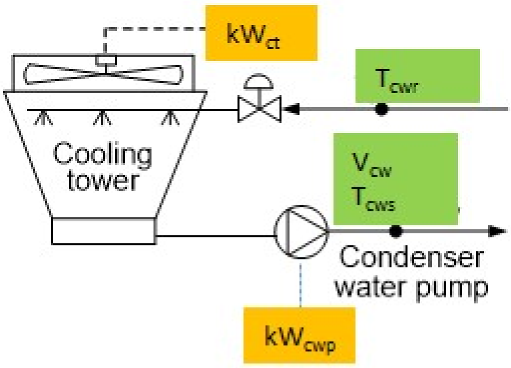
Measured Parameters:

Parameter	Sensor type	Location	Uncertainity	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. Cooling Tower Systems

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

Figure 5: 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

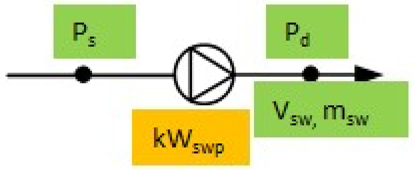
ii. Seawater cooling system

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 6: 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	± 0.05°C	Trend log
T_{cws}	10kΩ, four-wired Thermistor	± 0.05°C	Trend log
T_{wb}	Ambient temperature & RH sensor	± 0.5°C 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)

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

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

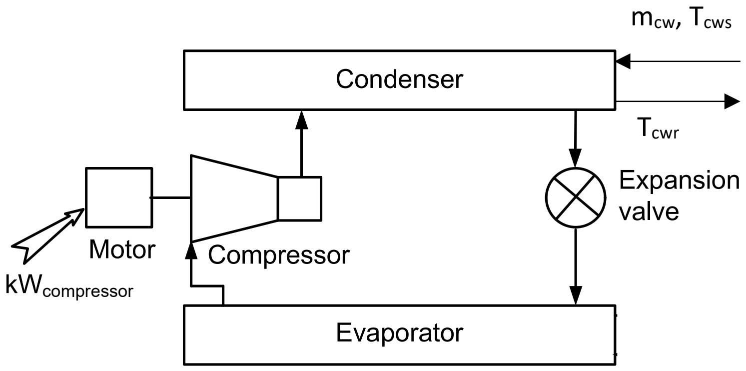
Measured Parameters:

Parameter	Sensor type	Uncertainity	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 7: 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 = $(Q_{heat} - kW_{compressor}\ x\ F)$

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 = 4.19 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

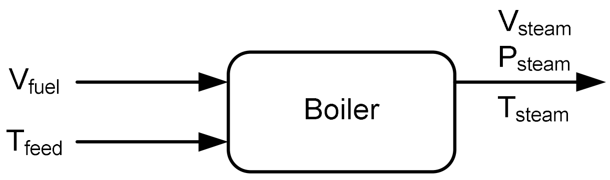
Measured Parameters:

Parameter	Sensor type	Uncertainity	Measurement type
m_{cw}	Ultrasonic flow meter/ Orifice Flowmeter	± 2%	Trend log
T_{cwr}	10kΩ, four-wired Thermistor	± 0.05°C	Trend log
T_{cws}	10kΩ, four-wired Thermistor	± 0.05°C	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 8: Schematic diagram of boiler system sensor location



Description of Parameters:

Energy output (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 = 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	$\pm$ 0.2^{o}C/ $\pm$ 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

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

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, °C
T_{air} = Surrounding air temperature, °C

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, °C
(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).

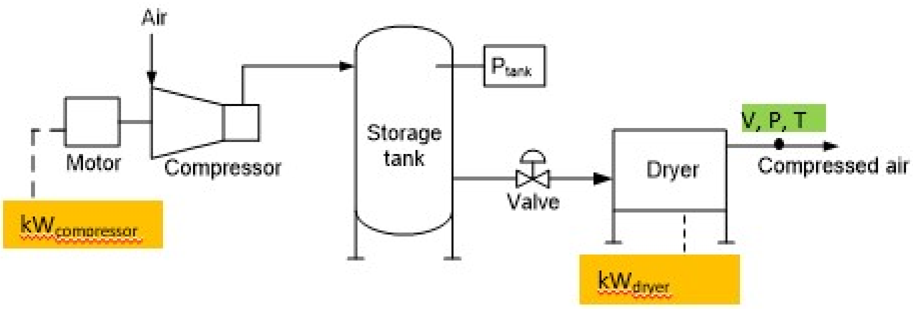
Measured Parameters:

Parameter	Sensor type	Uncertainity	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

$$\text{Specific energy consumption (kWh/Nm}^3\text{)} = \frac{\textit{Power consumption of compressors, dryers and cooling system, kW}}{\textit{Compressed air production, } \frac{Nm3}{h}}$$

Figure 9: Schematic diagram of a compressed air system showing sensor location



Description of parameters:

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

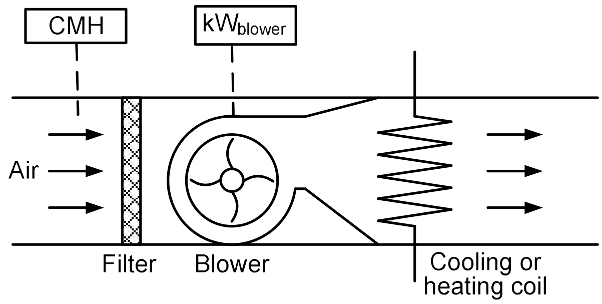
Measured parameters:

Parameter	Sensor type	Uncertainity	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

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

Figure 10: Schematic diagram of typical fan system showing sensor location



Description of parameters:

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

Measured parameters:

Parameter	Sensor type	Uncertainity	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

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

Measured parameters:

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