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Energy efficiency through automation systems

National foreword

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Energy efficiency through automation systems

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ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ENERGY EFFICIENCY THROUGH AUTOMATION SYSTEMS

FOREWORD

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IEC 62837, which is a technical report, has been prepared by IEC technical committee 65: Industrial-process measurement, control and automation.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
65/513/DTR	65/517/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

Energy efficiency has received an ever growing attention worldwide since it is considered a major lever to help secure a sustainable society in view of climate change, growing population and security of supply [1][1]. Additionally the sustainability and conservation of resources need to be considered. Automation is the enabler of measures, solutions and systems for demand/response and energy efficiency. In the context of this TR we will only consider energy efficiency. IEC and ISO have both identified energy efficiency as one of their main areas of activity.

The current focus of the Standard Development Organisations (SDO) is harmonised terminology, calculation methods, indicators, energy management systems and standards for assessment and ratings (e.g. for buildings and industrial plants). For this purpose IEC SMB Decision 128/20 “New initiatives for IEC” work endorsed the SMB Strategic Group 1 on Energy Efficiency and Renewable Energy. This strategic group has since then developed 34 recommendations for future work in different domains. The three following recommendations cover the area of automation:

- Recommendation #7: IEC/TC 2, SC 22G and TC 65 together with ISO/TC 184 should develop guidelines for the design and operation of energy efficient systems in the field of industrial automation and industrial process control from a system point of view.
- Recommendation #27: In order to support the optimisation of automation and production processes already during the planning phase of production systems, SG1 recommends that all relevant product TC/SC include key data in their components/devices standards that are vital for a priori simulation of the component/device behaviour in an intended production system, as such simulation leads to optimised processes from an energy efficiency perspective.
- Recommendation #28: In order to support the optimisation of automation and production processes already during the planning phase of production systems, SG1 recommends that TC 65 and its SCs consider the development of simulation tools from a system point of view, to allow a priori optimisation of automation and production processes on the factory floor in terms of energy efficiency.

In line with the recommendation #7, a workshop organized by the quoted committees and by SC 17B reached the consensus to create JWG 14, settled in TC 65, to cover the objectives and perform the tasks specified in the above mentioned recommendations. This document identifies a number of technology areas in the scope of various technical committees that need standardisation.

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[1] Numbers in square brackets refer to the Bibliography.

ENERGY EFFICIENCY THROUGH AUTOMATION SYSTEMS

1 Scope

This Technical Report provides to the technical committees a framework for the development and adaptation of documents in order to improve energy efficiency in manufacturing, process control and industrial facility management.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62264 (all parts), *Enterprise-control system integration*

IEC 62264-1:2013, *Enterprise-control system integration – Part 1: Models and terminology*

ISO 20140-1:2013, *Automation systems and integration – Evaluating energy efficiency and other factors of manufacturing systems that influence the environment – Part 1: Overview and general principles*

ISO 22400-2, *Automation systems and integration – Key performance indicators for manufacturing operations management – Part 2: Definitions and descriptions*[2]

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1 Energy

3.1.1
energy
capacity of a system to produce external activity or perform work

Note 1 to entry: Commonly, the term “energy” is used for electricity, fuel, steam, heat, compressed air and other like media. Energy can take a wide variety of forms, for example: chemical energy, mechanical energy, thermal energy, electric energy, gravitational energy, nuclear energy, hydraulic energy, etc.

Note 2 to entry: The SI unit for energy is joule (J), and for electric energy also watt-hour (W·h).

[SOURCE: CEN/CLC/TR 16103:2010, 4.1.1]

3.1.2
energy conversion
transformation of the physical or chemical form of energy

Note 1 to entry: The term “energy transformation” may be employed in this sense.

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[2] To be published.

[SOURCE: CEN/CLC/TR 16103:2010, 4.1.7]

3.1.3
energy source

source material or natural resource from which energy in a useful form can be extracted or recovered either directly or by means of energy conversion

[SOURCE: CEN/CLC/TR 16103:2010, 4.1.2]

3.1.4
final energy

energy as received by an energy using system

Note 1 to entry: Final energy may be either primary or secondary energy, or both.

[SOURCE: CEN/CLC/TR 16103:2010, 4.1.12]

3.1.5
primary energy

energy that has not been subjected to any conversion process

Note 1 to entry: Primary energy includes non-renewable energy and renewable energy. The sum of primary energy from all energy sources may be called total primary energy.

[SOURCE: CEN/CLC/TR 16103:2010, 4.1.6]

3.1.6
secondary energy

energy resulting from energy conversion of primary energy

EXAMPLE Electricity, gasoline, process steam, compressed air.

[SOURCE: CEN/CLC/TR 16103:2010, 4.1.8]

3.2 Energy use and energy consumption

3.2.1
energy baseline

quantitative reference(s) providing a basis for comparison of energy performance

Note 1 to entry: An energy baseline reflects a specified period of time.

Note 2 to entry: An energy baseline can be normalized using variables affecting energy use and/or consumption such as production level, degree days (outdoor temperature), etc.

Note 3 to entry: Energy baseline is also used for calculation of energy savings, as a reference before and after implementation of energy performance improvement actions.

[SOURCE: ISO 50001:2011, 3.6]

3.2.2
energy consumption

amount of energy used

Note 1 to entry: Although technically incorrect, energy consumption is a widely used term.

Note 2 to entry: The manner or kind of application of energy is expressed as energy use.

[SOURCE: CEN/CLC/TR 16103:2010, 4.2.5]

3.2.3

energy demand
necessary supply capacity for the projected level of energy use

Note 1 to entry: When considering future trends, energy demand is often used in the sense of potential energy consumption.

Note 2 to entry: Energy demand is often used in the context of supply-demand interaction where demand is not given but dependent on external factors such as energy prices.

[SOURCE: CEN/CLC/TR 16103:2010, 4.2.3]

3.2.4

energy end user
entity consuming final energy

Note 1 to entry: The energy end user may differ from the customer who might purchase the energy but does not necessarily use it.

[SOURCE: CEN/CLC/TR 16103:2010, 4.2.2]

3.2.5

energy saving
reduction of energy consumption following implementation of energy efficiency improvement action(s)

Note 1 to entry: The reduction is obtained by comparison against the baseline taking into account all adjustment factors.

Note 2 to entry: Energy savings can be potential following an assessment or actual after implementing an action(s).

[SOURCE: CEN/CLC/TR 16103:2010, 4.2.8]

3.2.6

energy use
manner or kind of application of energy

Note 1 to entry: Examples are ventilation, lighting, heating, cooling, transportation, processes, production lines.

[SOURCE: ISO 50001:2011, 3.18]

3.2.7

energy using system
physically defined energy consuming item with boundaries, energy input and output

Note 1 to entry: An energy using system can be a plant, a process, part of a process, a building, a part of a building, a machine, equipment, a product, etc.

Note 2 to entry: Boundaries must be clearly delimited.

Note 3 to entry: Output can be energy, service, product.

[SOURCE: CEN/CLC/TR 16103:2010, 4.2.4]

3.3 Energy efficiency

3.3.1

energy efficiency
ratio between an output of performance, service, goods or energy, and an input of energy

Note 1 to entry: Both input and output have to be clearly specified in quantity and quality, and be measurable.

Note 2 to entry: Examples are conversion efficiency, energy required/energy used, output/input, theoretical energy used to operate/energy used to operate.

[SOURCE: CEN/CLC/TR 16103:2010, 4.3.1, modified – omitted notes 2 and 3 from original and added a new note 2]

3.3.2
energy efficiency improvement programme
set of activities focusing on energy end users with the intent of providing energy efficiency improvements that are verifiable, measurable or estimable.

Note 1 to entry: In the context of an energy management system, the definition would be, “action plan specifically aimed at achieving energy efficiency objectives and targets”.

[SOURCE: CEN/CLC/TR 16103:2010, 4.3.5]

3.3.3
energy efficiency indicator
value indicative of the energy efficiency

Note 1 to entry: Mainly used as a metric in policy evaluation and in macroeconomic studies.

[SOURCE: CEN/CLC/TR 16103:2010, 4.3.8]

3.3.4
energy intensity
energy consumption per financial unit of output

EXAMPLE Gigajoule (GJ) per euro of GDP (gross domestic product). Gigajoule per unit of turn over.

[SOURCE: CEN/CLC/TR 16103:2010, 4.3.9]

3.3.5
intrinsic energy efficiency
energy efficiency of a component which is achieved by design

3.3.6
load shedding
process of deliberately disconnecting preselected loads from a power system in response to an abnormal condition in order to maintain the integrity of the remainder of the system

[SOURCE: IEC 60050-603:1987, 603-04-32]

3.3.7
managed energy efficiency
energy efficiency achieved by systematic energy management

3.3.8
peak shaving
process in an electrical system intended not to exceed a maximum overall energy demand

Note 1 to entry: Peak shaving can be obtained by planning of the energy needs within the manufacturing system or load shedding or autonomous energy production.

3.3.9
rational use of energy
energy use by consumers in a manner best suited to the realization of economic objectives, taking into account technical, social, political, financial and environmental constraints

[SOURCE: CEN/CLC/TR 16103:2010, 4.3.12]

3.3.10
specific energy consumption
energy consumption per physical unit of output

EXAMPLE Gigajoule (GJ) per ton of steel, Btu/ton of product, annual kWh per m^2.

[SOURCE: CEN/CLC/TR 16103:2010, 4.3.10, modified – added in the example "Btu/ton of product".]

3.4 Energy performance

3.4.1
energy performance
measurable results related to energy efficiency, energy use and energy consumption

Note 1 to entry: In the context of energy management systems, results can be measured against the organization's energy policy, objectives, targets and other energy performance requirements.

Note 2 to entry: Energy performance is one component of the performance of the energy management system.

[SOURCE: ISO 50001:2011, 3.12]

3.4.2
energy performance indicator
EnPI
quantitative value or measure of energy performance, as defined by the organization

Note 1 to entry: EnPIs could be expressed as a simple metric, ratio or a more complex model.

[SOURCE: ISO 50001:2011, 3.13]

3.5 Energy management

3.5.1
energy management
coordinated activities directing and controlling the energy use of an entity

[SOURCE: CEN/CLC/TR 16103:2010, 4.5.1]

3.5.2
energy management profile
set of energy related application parameters and/or energy saving modes

3.5.3
energy managed unit
EMU
unit of asset for energy management, identified by an energy related functional partitioning

3.6 Automation process equipment

3.6.1
asset

physical or logical object owned by or under the custodial duties of an organization, having either a perceived or actual value to the organization

Note 1 to entry: In the case of industrial automation and control systems the physical assets that have the largest directly measurable value may be the equipment under control.

[SOURCE: IEC 62443-1-1:2009, 3.2.6]

3.6.2
automation asset
asset with a defined automation role in a manufacturing or process plant

Note 1 to entry: It would include structural, mechanical, electrical, electronics and software elements (e.g. controllers, switches, network, drives, motors, pumps). These elements cover components, devices but not the plant itself (machine, systems). It would not include human resources, process materials (e.g. raw, in-process, finished), financial assets.

[SOURCE: IEC/TR 62794:2012, 3.1.4]

3.6.3
component
asset used as a constituent in equipment, system or plant

[SOURCE: IEC 61666:2010, 3.6, modified – changed product to asset]

3.6.4
device
entity that performs control, actuating and/or sensing functions and interfaces to other such entities within an automation system

[SOURCE: ISO 15745-1:2003, 3.11]

3.7 Automation system

3.7.1
direct influence
environmental influence resulting from actual product production by direct operation of manufacturing equipment

[SOURCE: ISO 20140-1:2013, 3.1.4]

3.7.2
indirect influence
environmental influence resulting from activities that support actual product production by direct operation of manufacturing equipment, in indirect mode of manufacturing equipment and operation and maintenance of the manufacturing support system

[SOURCE: ISO 20140-1:2013, 3.1.17]

3.7.3
input
product, material or energy flow that enters a unit process

[SOURCE: ISO 14040:2006, 3.21]

3.7.4
manufacturing support system
system which is used for providing the necessary other resource to a manufacturing system

[SOURCE: ISO 20140-1:2013, 3.1.30]

3.7.5
output
product, material or energy flow that leaves a unit process

[SOURCE: ISO 14040: 2006, 3.25]

3.7.6
process

set of interrelated or interacting activities that transforms input to output

[SOURCE: ISO 14040:2006, 3.11]

3.7.7
product

result of labour or of a natural or industrial process

Note 1 to entry: This term is defined by "any goods or service" in IEC 62430 and ISO 20140-1:2013. The European Commission adopts a similar understanding in the directive "Ecodesign requirements for energy-related products". In the context of this standard, the term "product" does not cover the automation assets but only the output of the manufacturing or process plant.

[SOURCE: IEC 61082-1:2006, 3.1.11, modified – a note to entry has been added]

3.7.8
releases

emissions to air and discharges to water and soil

[SOURCE: ISO 14040:2006, 3.30]

3.7.9
unit process

smallest element considered in the life cycle inventory analysis for which input and output data are quantified

[SOURCE: ISO 14040:2006, 3.34]

3.7.10
waste

substances or objects which the holder intends or is required to dispose of

[SOURCE: ISO 14040:2006, 3.35]

4 Abbreviations and alphabetical index

4.1 Abbreviated terms

APC	Advanced process control
BTU	British thermal unit
CEN	European Committee for Standardization
CLC	CENELEC, European Committee for Electrotechnical Standardization
CV	Control variable
DCS	Distributed control system
EMU	Energy managed unit
EnPI	Energy performance indicator
FC	Function variable
IEA	International Energy Agency
KPI	Key performance indicator
MV	Manipulated variable
SV	Set variable

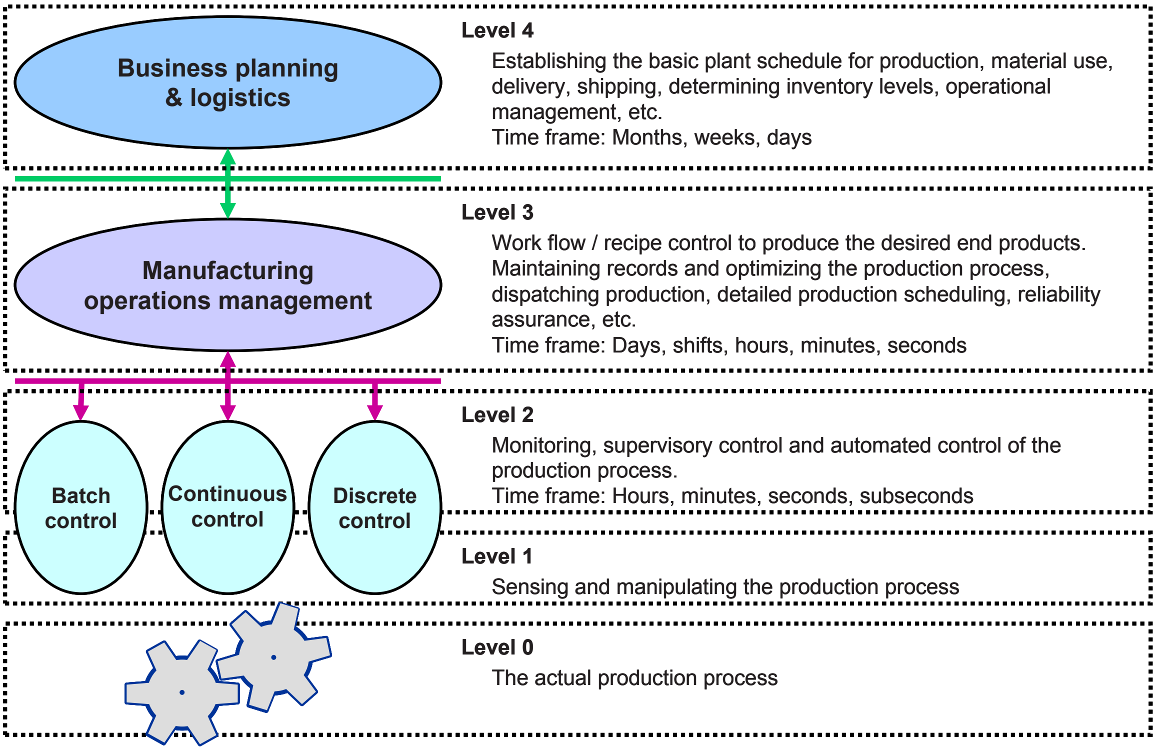
4.2 Alphabetical index of terms

5 Generic models

5.1 Functional hierarchy of production systems

This document applies the description of the applications given by the hierarchy model of IEC 62264 which is shown in Figure 1. The main levels of the hierarchy are business planning and logistics, manufacturing operations management and control (batch, continuous, or discrete control). The levels provide different functions and work in different time frames.

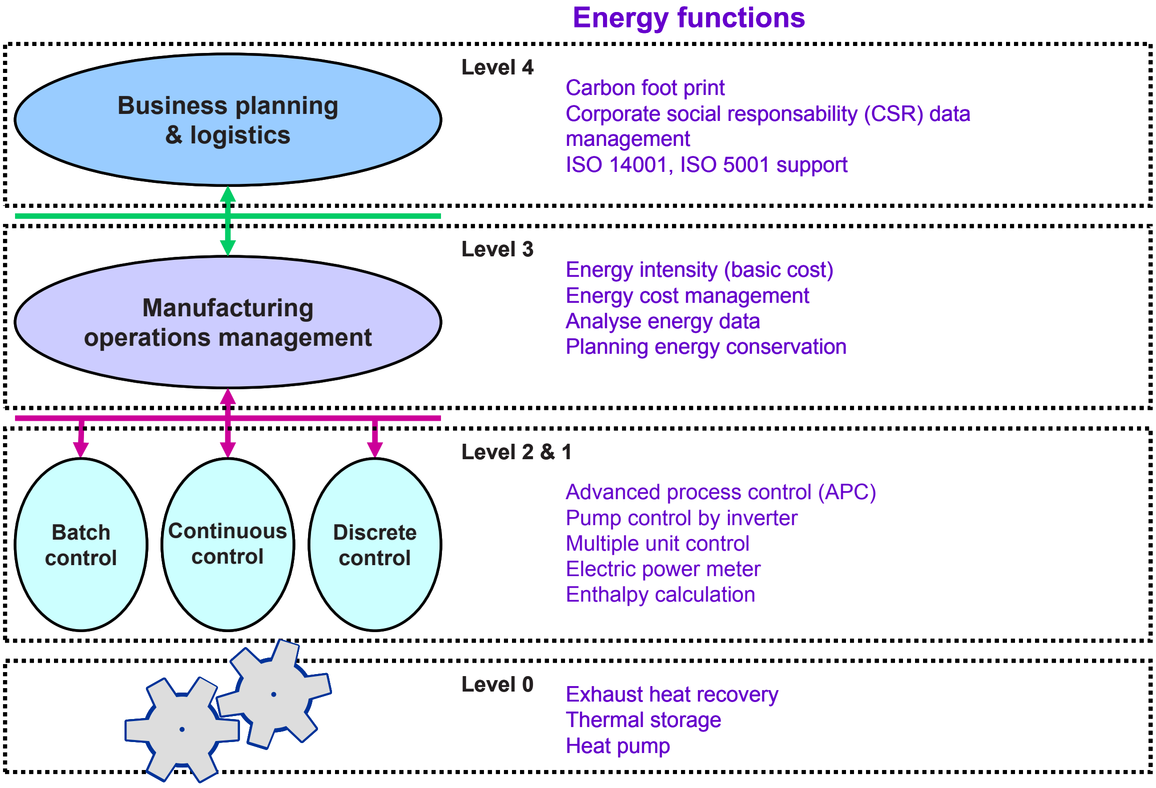
Level 4 may also include enterprise resource planning (ERP) and supply chain management (SCM), level 3 may also include manufacturing execution systems (MES) and plant information systems (PIMS).



IEC 2326/13

Figure 1 – Functional hierarchy of production systems according to IEC 62264

Figure 2 shows the energy functions that may be installed in these levels. In the lower levels, there are energy functions like real time measurement and control. In the higher levels, optimisation and management functions are installed, including energy management.



IEC 2327/13

Figure 2 – Energy functions mapped over the functional hierarchy levels (IEC 62264)

5.2 Functions in level 4

The level 4 of the functional hierarchy of production systems in IEC 62264 can be split into two parts:

- Energy efficiency related to demand/response:

  The activities of the factory may change taking into account the outside environment conditions.

  The outside environment communicates the energy availability using pricing and time segments; this is the (supply side) demand. The system can react with planning and scheduling of activities; this is the (consumer side) response.

  NOTE Supply side demand is not an energy demand in this context.

- Energy efficiency related to internal plant management:

  Depending on the internal status of the plant, decisions may be made related to consumption, generation and storage of energy.

  EXAMPLE Events that influence the status of the plant include raw material availability, breakdowns, staff planning, delivery planning.

5.3 Functions in level 3 or lower

In the context of level 3 and lower of the functional hierarchy of production systems in IEC 62264, two basic aspects of energy efficiency are considered:

- intrinsic energy efficiency
- managed energy efficiency

Intrinsic energy efficiency is achieved by the design of components. Managed energy efficiency is achieved by a systematic energy management, supported by automation systems and systems integration.

Whereas automation components usually account for only a small part of the overall power consumption of a plant, they are key elements for building an infrastructure allowing energy consumption control.

Levers to improve energy efficiency through automation include:

- measurement of energy consumption,
- qualification, control, testing, and certification of components and systems,
- condition monitoring for predictive maintenance,

and accompanying issues like:

- training and qualification of personnel, and
- organisational issues and local regulations.

Energy efficiency measures should not compromise:

- safety,
- security,
- the level of services.

5.4 Application function and automation function

In order to identify the relevant production systems subsets to target for energy efficiency improvement, it is important to analyse and describe the involved assets in a structured way.

In different industry segments the energy use and the automation systems are different. So for the analysis an application specific approach is important.

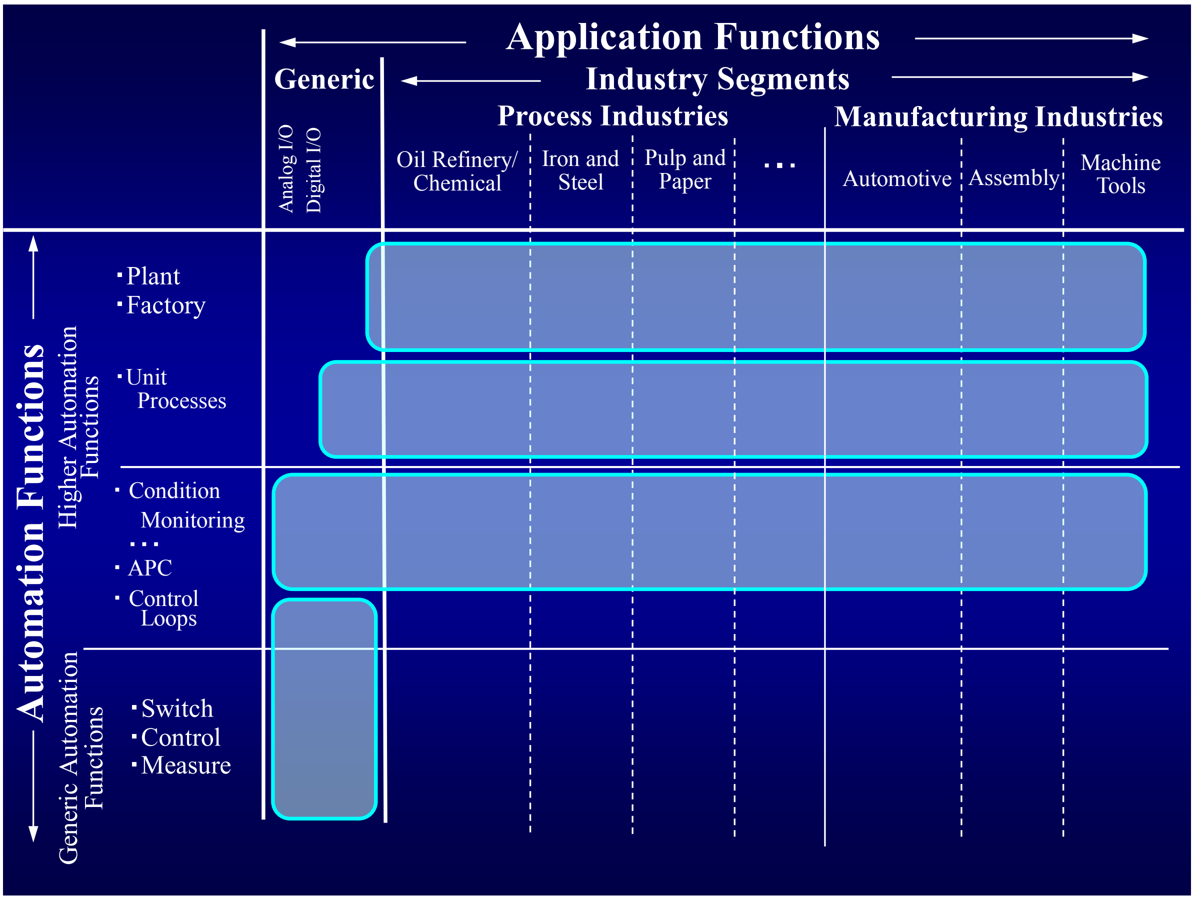
Applications are realized by combining automation assets, for example sensors, transmitters, switches, power drive systems, controllers, PLCs, valves. The hierarchical structure of automation systems is on the other hand quite similar throughout the industrial segments.

The two major structural dimensions to analyse and influence the energy consumption of a production system are identified as:

- application functions:
  - the function which is provided by an application device,
  - example: closing/opening of a valve,
- automation functions:
  - the function which controls an application device,
  - example: control of the closing/opening of a valve.

Figure 3 shows the two-dimensional structure of automated industrial plants for the design and analysis in regard to energy efficiency:

- the horizontal axis shows application generic and industry segment specific application functions,
- the vertical axis shows the relevant automation functions.



IEC 2328/13

Figure 3 – Structural overview of automated industrial plants

The term “generic” refers to general purpose application functions such as, for example, analog I/O or digital I/O. All other application functions are dedicated to industry segments, for example, in process industries: oil refinery, chemical, iron and steel, pulp and paper and pharmaceutical; in manufacturing industries: automotive, assembly, discrete manufacturing and machine tools.

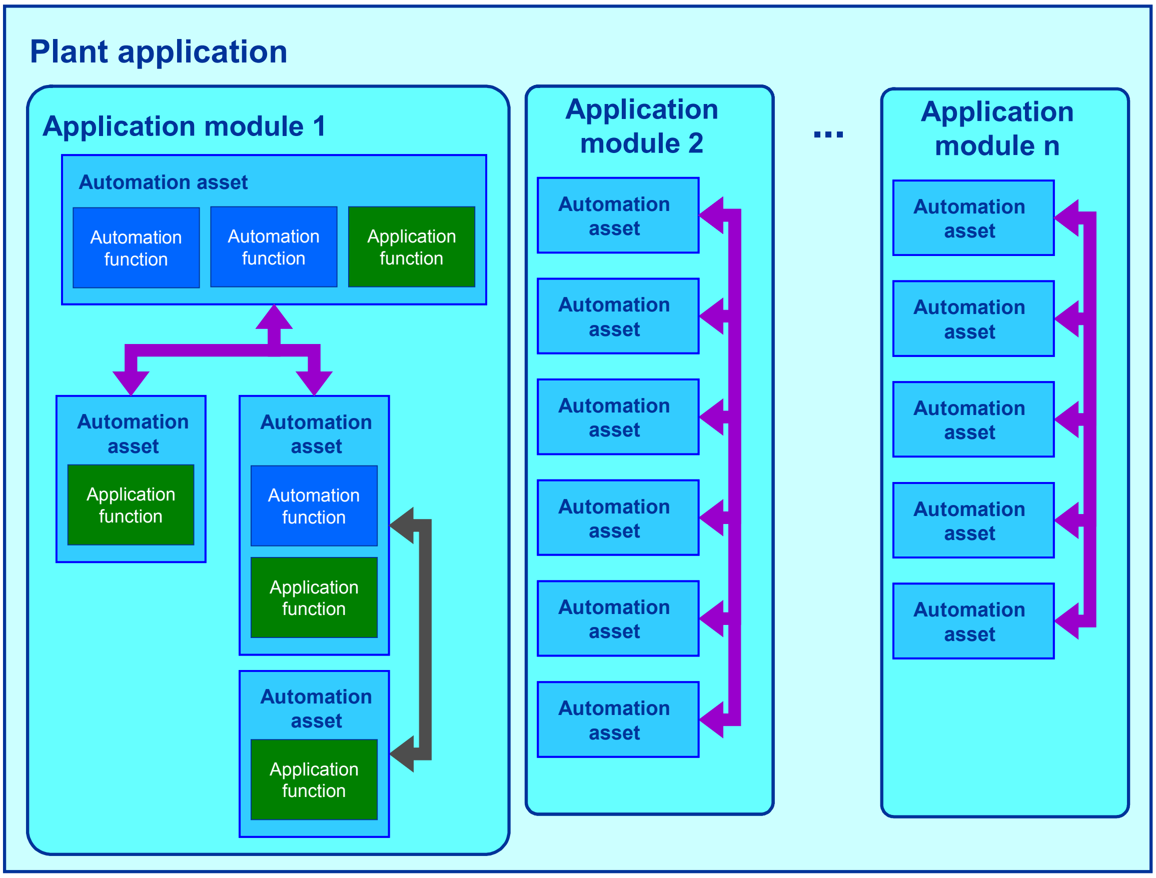
During the design phase, the designers should choose a combination of automation assets with the application and automation functions which are the most appropriate in terms of energy efficiency for the specific application.

In the regular case, the application function consumes most of the energy. How much it consumes depends on:

- its basic properties,
- its energy saving modes.

Depending on the sequence of the automation functions, the application function can be controlled in terms of energy efficiency by maintaining the reliability of the overall application.

Each automation asset realizes at least an application function and contains one or more automation functions (see Figure 4).



IEC 2329/13

Figure 4 – Plant application with automation assets

EXAMPLE 1 The automation asset pressure transmitter realizes the application function “analog I/O” using the automation function “measuring”.

EXAMPLE 2 The automation asset closed loop controller executes the automation function “closed loop controlling” delivering the application function “input/output”.

EXAMPLE 3 A valve in a fluid application realizes the application function “controlling flow” (by digital I/O and analog I/O) and can contain one or more automation functions such as “condition monitoring” and security functions for other applications.

The same application function can be controlled by different automation functions. These automation functions deliver an equivalent application outcome, but may differ with respect to energy efficiency.

6 Generic tools and methods

6.1 Organisational issues

An important issue is the incorporation of the energy efficiency topic into the daily work of standardisation. Each committee or working group should consider the energy efficiency issue and if appropriate explicitly mention it in its standards, including the proposed measures. This is in agreement with the IEC Directives Part 1: 2012, C.4.

6.2 Energy managed unit (EMU)

In order to evaluate the energy efficiency of a system, its boundary should be clearly defined. The system could be a device, a production line or the entire factory depending on the requirements for energy management.

EMU is introduced as an energy related functional partitioning that allows us to define the system boundary and provides generic methodologies for energy management in production systems.

Figure 5 shows the architecture of EMU. In order to define energy efficiency, all input and output across the system boundary of the concerned EMU should be quantified and evaluated. Materials and energy which are necessary to produce a product are counted as the input to the EMU. Products, reusable material, waste, release and energy are counted as the output from the EMU. KPI can be defined as a function of input, output and driving parameters that affect the energy efficiency of the EMU such as production volume and outside temperature.

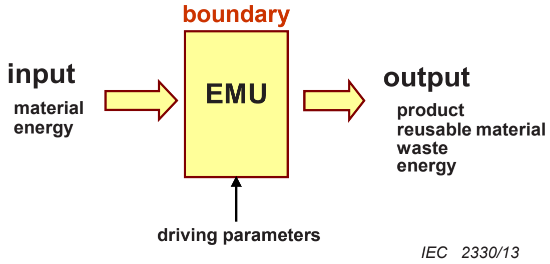


Figure 5 – Energy managed unit (EMU)

In the process of energy efficiency improvement, it is important to find the most inefficient subsets of a production system. The concept of EMU can be used effectively to focus on the subsets by flexibly adjusting the EMU boundary. From the boundary around the entire factory, the boundary of EMUs should be focused successively around the most energy intensive subsets of the production system. This allows to direct the energy efficiency improvement efforts where it matters and with the required detail.

Benchmarking should be done under the same boundary conditions and KPI. Examples of industrial sector specific benchmarking are shown in B.5.

ISO 20140-1:2013 provides a unit process model defining the system boundary. The concept of EMU is derived from the unit process model of ISO 20140-1:2013 (see Annex A) and enables to define the system boundary for all levels of the functional hierarchy defined in IEC 62264.

6.3 General recommendations

6.3.1 Architecture of energy sourcing

Status

The results of analysing the efficiency depend on the scope of the system. This means that optimising every subsystem and its components does not necessarily lead to the best overall efficiency.

In the past the amount of energy for each process step was not relevant. This leads to an unstructured way of energy feeding.

Recommendations

EMUs are the energy related functional entities.

The architecture of energy sourcing should be structured according to the EMUs in order to facilitate dedicated energy control and measurement:

- EMUs should have a single point of energy feed for each form of primary energy,
- EMUs should have standardised abilities to measure energy flows,
- relevant EMU components should have a standardised interface to read out energy flows.

Product committees are encouraged to develop and harmonise the work items corresponding to the three recommendations above.

6.3.2 Managed energy efficiency

In the operating phase, to manage the energy consumption in a plant, the supervision and control system should be able to address commands on certain parts of the application, which implies that:

- the existing communication systems should be adapted to answer the new needs of the energy management,
- energy management profiles for the devices and equipment should be defined.

For the design phase and system integration (selection, installation, identification, configuration), the device description and modelling should include new aspects of the energy efficiency profile such as:

- operating modes (list of supported energy saving states, power consumption of states, time to reach the states ...),
- energy efficiency data (standardised set of energy characteristics and parameters for a dedicated application area),
- energy efficiency classes for devices, equipment and systems taking into account the application, possible measurement and control of classes by establishing limits if relevant.

Common definitions, vocabulary and semantic should be developed. This should be done in close coordination with ISO/IEC JPC2, “Energy efficiency and renewable energy sources - Common international terminology”.

For each application, at the device or the machine level, the following should be defined for the application data:

- the nature of the measurement (e.g. current, power...),
- the characteristics (unit, accuracy, tolerance, sampling period...),
- the test methods.

These definitions should be done independently from the specific communication network technologies.

The measurement of energy consumption should be appropriate to the levels described in 5.1:

- “metering” for billing purposes, linked to the utility provider, usually applied at level 4;
- “cost allocation” for relationships between departments in the company, usually applied at level 3;
- “energy awareness” for optimisation purposes, usually applied at level 2.

“Metering” is already standardised at the national or international level. “Cost allocation” and “energy awareness” have to be standardised to permit the energy efficiency interoperability of the control systems with the devices.

6.3.3 Low power states

Status

Switching off parts of a system during scheduled or unscheduled inactivity leads to a dramatically better energy efficiency.

Recommendations

Components should have multiple energy states. Energy states often correspond to operating modes.

EXAMPLE The IEC 61800-7 series defines operating modes, such as "not ready to switch on", “ready to switch on” and “operation enabled”.

The state may be controlled externally (by a command) or internally (but, for example, pause time may be sent by the controller).

This can lead to a totally different architecture of components with multiple power domains:

- low energy power management controllers with network interface (always active),
- main controller and visualisation,
- high energy functions for operation.

6.3.4 Standardised component interface

Status

Some manufacturers provide proprietary interfaces to read out energy data and manage energy states.

Currently there are some (proprietary) implementations: SNMP (private MIB) on standard TCP/IP, ProfiEnergy on PROFINET, OEU on EtherNet/IP® and other CIP networks, and others on BACnet™, Konnex (KNX®), LonWorks®, and Modbus®.[3]

Recommendations

Standardise a unique abstract model to access energy data and to control low energy modes. The model should describe the common concepts of the energy profile, the minimum set of data (current power consumption, current energy state) and abstract services (read a data, write a parameter, send a command, etc.). The abstract model should provide interfaces for metering, cost allocation and energy awareness, as appropriate.

This model may be derived from existing implementations.

The standardised model should then be supported by the existing and future industrial network protocols.

6.3.5 Control systems

Status

Currently many production systems used in the process industry and the discrete manufacturing industry are managed independently. This leads to:

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[3] The products described here are given for the convenience of users of this document and do not constitute an endorsement by IEC of these products.

- multiple sensors measuring the same value

  (e.g. ambient temperature for the manufacturing process and for facility control),
- concurrent close loop controls producing overshoot and undershoot of the process parameters.

Recommendations

Control systems should integrate energy efficiency elements into normal control functions and optimise energy consumption on the condition of not giving rise to any recede in normal control functions, e.g. improving close loop controls performance via reduced overshoot and undershoot. Control systems should collect relative energy data which are necessary to realize energy consumption optimisation.

Define data items (format, semantics) for common interchange and global process visualisation.

6.3.6 Classification and energy labels for components and systems

Status

In the area of industrial automation components there is currently only an energy classification for electric motors.

Recommendations

For each components and systems family, the corresponding responsible technical committees should define, as an international standard in the automation community:

- unified energy efficiency classes and data,
- standardised test conditions for energy efficiency measurements.

The basis for informing end users about the energy efficiency of products is the data from the manufacturers' catalogues. Energy labels should be considered as complementary information, they are likely the responsibility of local governments (see Annex D).

Technical committees should define methodologies to classify a system by using the energy efficiency data or class of its components depending on the application use.

6.3.7 Simulation of systems and components

Status

Today, simulation of energy flows is challenging because of missing energy data of the components and relevant simulation tools.

Recommendations

Enable the simulation of the power consumption of the complete system. Objectives include optimal process design, peak shaving, load balancing and allocation, process improvements, scheduling and negotiating with the energy supplier.

This requires:

- standardised component energy data supplied by the component manufacturer (see below),
- standardised data format (e.g. in AutomationML),
- appropriate simulation tools.

To enable simulation there is a need for component models that incorporate energy considerations. Component suppliers need to deliver the characteristics of their components:

- load-dependent power consumption (table based or algorithm based),
- power saving states with the declaration of
  - power consumption,
  - time to reach the state,
  - time to reach operative state (restart).

Figure 6 is an example of energy data for the start up phase of a system and its power consumption.

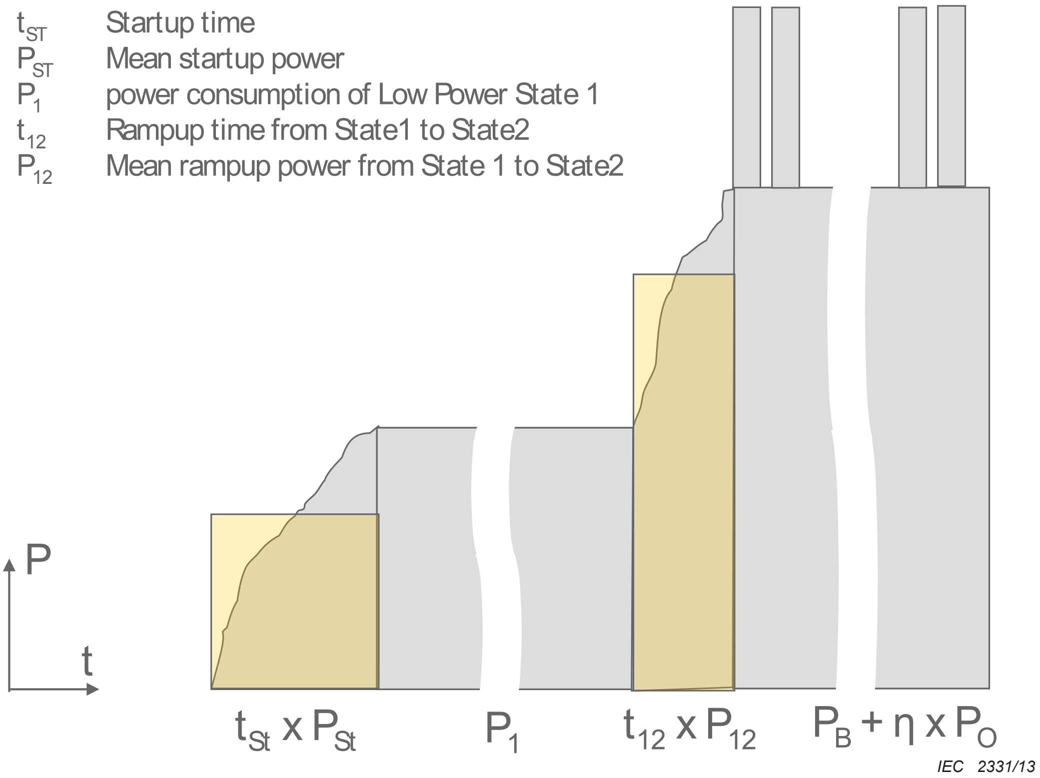


Figure 6 – Start up phase of a system and its power consumption

6.4 Key performance indicators (KPIs) for energy efficiency

6.4.1 Basics for defining KPIs for energy efficiency

6.4.1.1 Definition of energy efficiency

Energy efficiency indicators should be defined and managed with measurements for the EMU as a pre-defined system boundary that is focused for immediate energy management.

The energy efficiency of industries and the relevant KPIs have been defined for each domain separately. This TR recommends a standardised approach that relies on practical methodologies to improve energy efficiency in all kinds of industries by defining specific KPIs.

Defining a KPI and its target values will help to validate energy efficiency.

Energy efficiency according to the standardised approach of this TR is defined as benefit divided by the energy consumption:

energy efficiency = benefit / energy consumption

Since the benefit of a system is application specific it is not possible to describe generic KPIs for energy efficiency.

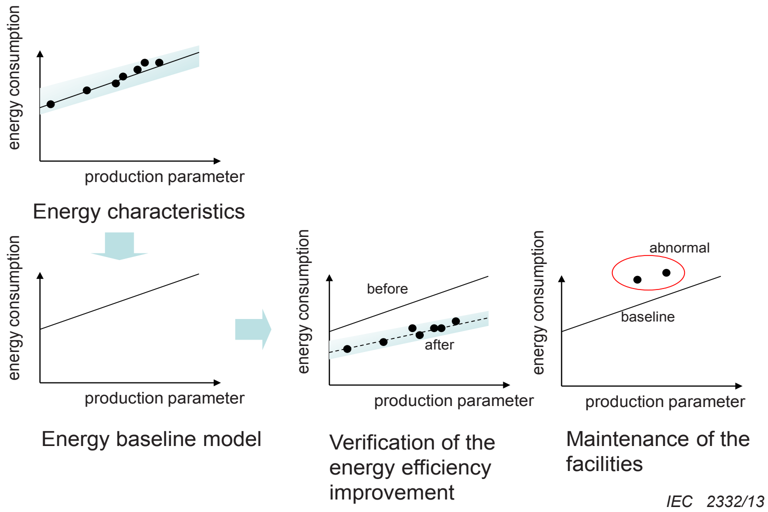
6.4.1.2 Energy baseline model for EMU

The energy baseline model for EMU is the reference model that is used to calculate the energy related KPI of an EMU.

The basis for the energy baseline model is the definition of energy efficiency in 6.4.1.1. If in a graph the energy consumption is plotted over the benefit, this graph shows the relationship from 6.4.1.1 for a variation of both parameters (see Figure 7). The benefit for the industry is some production related parameter, here called “production parameter”.

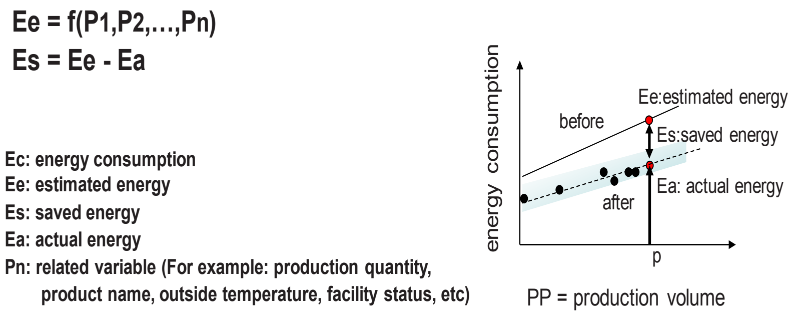
In the practical approach, the energy baseline model is derived from the existing energy characteristics of facilities before any action for improvement is taken. When such parameters as production volume are applied to the model, the estimated energy consumption can be calculated (see Figure 7). This model enables the verification of the effectiveness of an action plan for improving a facility’s energy efficiency and the detection of an abnormal facility status. The baseline period should be defined according to the facility characteristics. The resulting energy savings amount can be computed as shown in Figure 8.

A detailed but generic guideline of the energy baseline model is provided in Annex C.



IEC 2332/13

Figure 7 – Creation of an energy baseline model



IEC 2333/13

Figure 8 – Measurement of energy savings

The horizontal axis of the energy baseline diagram is the “production parameter” PP. For each specific energy baseline model defined, the specific and characteristic production parameter used for PP should be clearly indicated in a legend close to the graph or directly as a descriptor for the horizontal axis.

6.4.1.3 Energy data for EMU

Energy data is reported to a higher level production system for the calculation of total energy efficiency. This information includes the data set of actual energy consumption and its key drivers such as production volume that are reported to the higher level system at designated time intervals. It is desirable for the higher level system to provide optimised information to lower level facilities that can be used to control set values and optimise total energy consumption. The reporting of information at shorter time intervals enables more precise energy management. This makes it easier to identify where energy is being wasted.

This TR recommends the creation of international standards for the structure of facility energy data.

Table 1 – Guideline for EMU energy data

Objective	Means	Guideline
– Reporting for the optimised control of EMUs by higher level systems. – KPI management by higher level systems (L2 ~ L4) NOTE Defined by IEC 62264 (ISA 95) – Reporting for the optimised control of related EMUs.	Reporting of EMU energy characteristics. Reporting of energy consumption and its drivers such as production volume at predefined time intervals.	– It is recommended that higher level systems have reference ranges with upper and lower limits for EMU energy consumption and drivers such as production volume. – It is recommended to examine the reported information at each time interval and to verify the effectiveness of the energy efficiency improvement plan and EMU maintenance. – Time intervals are defined based on EMU characteristics. – Shorter reporting time intervals will enable more precise energy management and make it easier to identify where energy is being wasted. A shorter time interval may incur in added equipment, disturbances and operational cost.
	NOTE Time intervals: second, minute, hour, day, month, year, batch, etc.	

Example of EMU energy data:

- ID of facility
- time: e.g. year, month, day, hour, minute, second
- time interval of report: e.g. 3 600 seconds
- production volume: facility production volume (cumulative total)
- unit of production volume: e.g. ton, kg
- energy consumption: facility energy consumption (cumulative total)
- unit of energy: e.g. MJ
- number of related variables: n
- value of variable 1: value of variable relating to facility energy consumption
- unit of variable 1: e.g. °C
- value of variable 2: value of variable relating to facility energy consumption

- unit of variable 2: e.g. %RH
- value of variable n: value of variable relating to facility energy consumption
- unit of variable n: e.g. h (cumulative operation time after start-up)
- reference information: optional
- type of facility: facility category
- operation status: defined by ISO 22400-2
- status specific to facilities: defined for individual facility categories

While the energy intensity, as defined, is used in many contexts to compare the energy efficiency of production systems, its dependency on financial values makes the term unsuitable for stating any generally valid metrics for energy efficiency.

To safeguard against disruptions in communications, it is recommended to calculate a cumulative total for energy consumption and production volume. It is recommended to automatically reset the cumulative value if a calculation overflow occurs. Table 1 contains suggestions for EMU energy data.

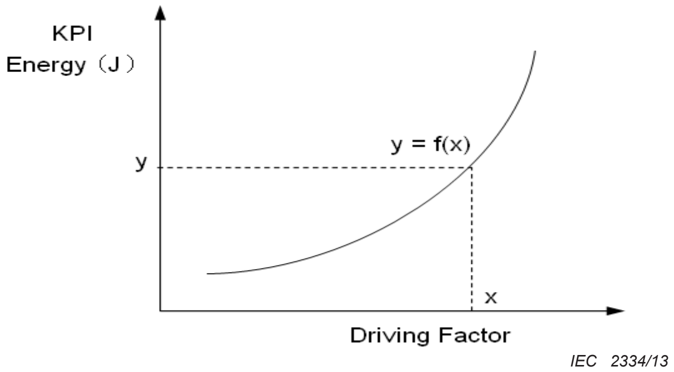
6.4.2 Recommendations for defining KPIs for energy efficiency

Toward the goal of defining specific KPIs and target values, this TR provides a standardised methodology for defining KPIs for energy efficiency. Some actual examples will be attached for reference.

Four categories of KPIs are recommended:

- by EMU – for operations optimisation, benchmarking and process improvement;
- by product – for improving the energy efficiency for similar products;
- by economic factors – for reporting to management;
- by local regulation – for legal conformity.

Figure 9 shows a KPI as a function of a driving factor. Energy used by the production equipment varies depending on the product amount and model. Production volume is a key driving factor of KPIs. The energy consumption of production equipment is also affected by environmental conditions such as outside temperature. Environmental conditions should be taken into consideration as a driving factor for the energy efficiency.



IEC 2334/13

Figure 9 – KPI and its driving factor

KPIs should be defined by production parameters that are measurable and controllable for process improvement. KPIs should be visualized and reported periodically for the verification of validity.

KPIs can be defined for various levels of production system hierarchy as shown in Figure 11. A KPI and its target value can be specified for optimised operation by a higher level function of production hierarchy. Optimisation of individual equipment will not necessarily provide plant wide total optimisation.

For optimisation calculation, mathematical or experimental models of EMU should be provided that include their energy consumption characteristics. Figure 12 shows an example of energy consumption characteristics of EMU. The mathematical models are verified by real-time measurement data during the actual operation.

Specific energy consumption should be a practical KPI. Deterioration of equipment in an EMU over time should be taken into account. Monitoring of KPIs provides useful information for predictive maintenance that can prevent problems that interrupt plant operations.

There are two aspects to comparing energy efficiency using a KPI. The first is that this is a tool for the deployment of energy efficient best practices. Benchmarking should be equitable and universal. The second is that a KPI should be used to measure the degree by which efficiency is improved in individual organisations. In this case, a KPI is required to provide continuity for the comparison without being affected by driving factors.

Measures for improvement should be equitable when used as a credit for reduction activities. It is necessary to generate an international KPI standard for this purpose.

Standardisation of indicators for energy efficiency will invigorate activities to improve energy efficiency and make effective use of natural resources. These activities should result in greenhouse gas reduction and also improve the profitability of companies.

When there is a change in the production volume or the products, it is necessary to improve energy efficiency by optimising total energy use throughout a factory, rather than independently optimising individual devices and facilities. As there are various production conditions, various kinds of KPIs are necessary to measure and improve energy efficiency.

KPIs that indicate the total energy efficiency should be analysed by drill-down functions to find specific managing points that are effective in improving total efficiency.

It is effective to define KPIs for each level of a production system hierarchy, not only for individual devices at the lowest level but also for EMUs in higher level production systems.

In order to improve internal production processes, it is necessary to properly define KPIs that can be flexibly and appropriately used in existing processes. To do this, it is also desirable to standardise the set of necessary information that is used to calculate a KPI. Defining an EMU as a flexible boundary for KPIs will make it possible to find effective actions that can be ranked by priority for the improvement of energy efficiency.

6.4.3 Guidelines for defining KPIs

6.4.3.1 Specific energy consumption

Specific energy consumption has been used widely as a practical KPI for the energy management of EMUs, including entire factories or plants.

Objectives

- Overall energy management at macro level.
- Detection of wasted energy consumption.
- Detection of abnormal EMU status due to deterioration.
- Predictive maintenance of EMUs.

- Evaluation of the effectiveness of actions taken to improve energy efficiency.

Means

- Reporting specific energy consumption for a complete factory.
- Managing specific energy consumption of EMU (by measuring the deviation from a reference value).
- Reporting specific energy consumption of product.

Guidelines

- As a first step, it is recommended to implement specific energy consumption KPIs for the management of all the energy consumed by a factory.
- Depending on the required level of management, the boundary for defining specific energy consumption can be set at various levels of EMU, e.g. factory, production line, facility. It is recommended to push ahead the management by drilling the boundary down into the detailed level.
- If required, a time interval for measuring specific energy consumption can be designated. It is easier to detect wasted energy consumption and facility deterioration if KPIs are measured at shorter time intervals (e.g. from year to month, month to day, day to hour, hour to minute).

The specific energy consumption KPI is a good and valid indicator for comparison only when the EMUs are dealing with very similar products, with similar processes. Cross comparison with dissimilar EMUs may lead to gross errors.

B.5 shows examples of target values of per unit energy consumption (benchmark) by industry sectors.

6.4.3.2 Energy baseline model

As explained in 6.4.1.2 and Annex C, an energy baseline model represents the relationship between energy consumption and the key drivers. The relationship between production (number of units produced, or quantity of product) and energy consumption is in general a curve. In many cases the equation for the “best fit” line can be easily determined through linear regression analysis. A linear approximation is practical to describe the relationship and to compare EMUs from the point of view of energy consumption and product outcome. Figure 10 shows an energy baseline model described by the linear equation $y = ax + b$ with the following important parameters, which can be used to perform the comparison:

b is the fixed energy consumption; it represents the energy consumption needed to operate the EMU for a product outcome of 0;

a is the multiplier; the multiplier is production (number of units) independent, and represents the incremental energy consumption per unit.

When there is a non-zero fixed energy consumption, the energy efficiency of an EMU is greater for large production volumes. In Figure 10 production X_0 is less energy efficient than production X_1.

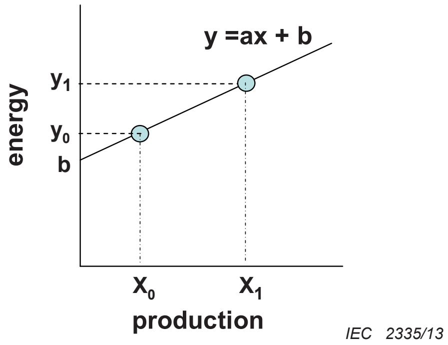


Figure 10 – Characteristics of the energy baseline model

6.4.3.3 KPI for plant wide optimisation

Figure 11 shows a hierarchy of production systems with reference to IEC 62264-1:2013.

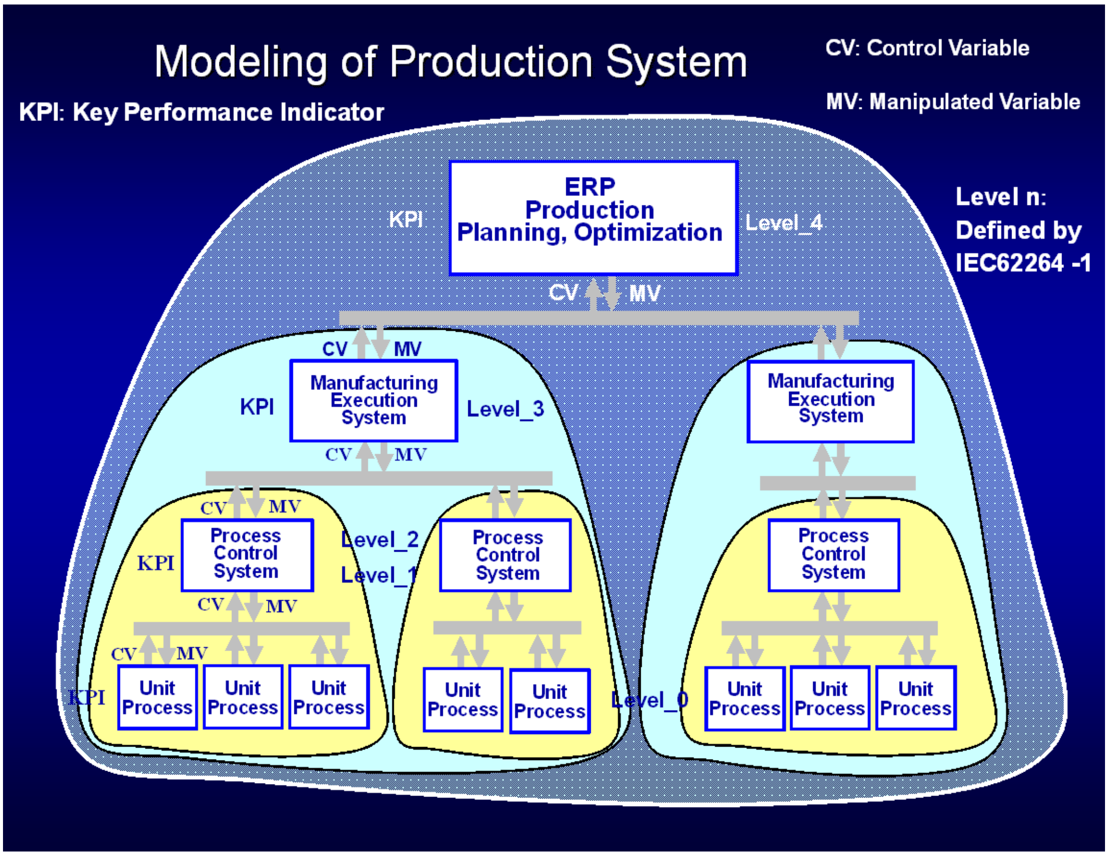
The changing economic environment such as market demand, energy cost, and environmental requirements has pushed manufacturing industries to optimise their production processes to satisfy the constraints that are not compatible. Energy efficiency has become an important constraint that should be satisfied in addition to the others. It is required to minimize the energy consumption without loss of production.

As shown in Figure 11, a manufacturing enterprise is organized into a multilevel hierarchy by functions. The total system may be divided into subsystems and equipment. Generally, an enterprise operates the total factory to maximize or minimize an objective function. Examples of objective functions are profit, cost, quality, energy efficiency and so on. Usually, the different objectives are not compatible. So, an optimum operation of the total factory is necessary by finding the values of the variables that minimize or maximize the objective function while satisfying the constraints.

Figure 11 shows the information flow between subsystems using the notation of CV and MV.

CV (controlled variable) and MV (manipulated variable) are the terminologies in process control. In Figure 11, CV represents a set of present status including KPIs in the layer that is reported to the upper layer. The upper layer system calculates MV that is sent back to the lower layer as a target value for control. The level 4 system can execute the calculation for plant-wide optimisation using the CV from the lower level systems. KPIs are defined in each level and controlled to their optimum values by the system. However, controlling individual KPIs to their optimum values does not necessarily result in the optimisation of a KPI in the higher level system. When the production volume of a corporation is changed, for example, Level_4 system calculates an optimum MV to minimize the total energy consumption while energy efficiency is the objective function. Figure 12 shows a typical load versus efficiency characteristics of equipment that is used for optimisation.

This MV is a command for the lower level systems to operate for the plant-wide optimisation. As KPIs and the measured values are key information for plant-wide optimisation, it will be efficient to use a common structure of information. It is recommended that the structure of KPI description is standardised making reference to ISO 22400-2 as shown in Table 4.

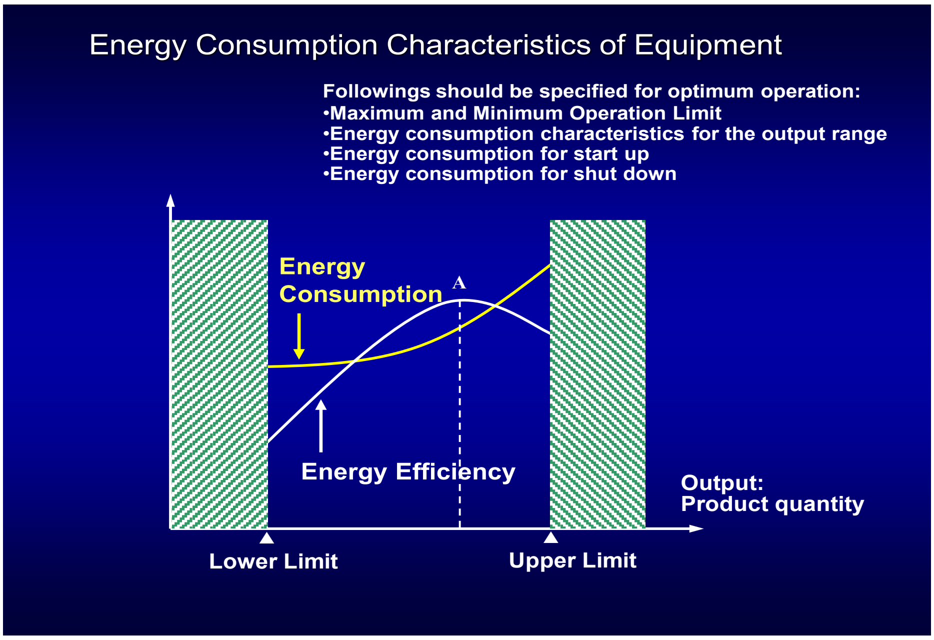


IEC 2336/13

Figure 11 – Production system hierarchy

The optimisation of the total energy consumption of a factory is an energy management requirement.

“RENKEI” control, explained in Annex E, is a generic concept of optimisation control technology that maximizes the total energy efficiency by controlling individual equipment entities to work in concert with each other and by harmonising the demand and supply of energy.


Energy Consumption Characteristics of Equipment

Followings should be specified for optimum operation:
•Maximum and Minimum Operation Limit
•Energy consumption characteristics for the output range
•Energy consumption for start up
•Energy consumption for shut down

IEC 2337/13

Figure 12 – Energy consumption characteristics of equipment

The energy consumption characteristics of equipment shown in Figure 12 should be provided as a kind of energy information of equipment for applying RENKEI control for equipment level.

The following should be specified for optimum operation:

- maximum and minimum operation limit,
- energy consumption characteristics for the output range,
- energy consumption for start up,
- energy consumption for shut down.

6.4.3.4 KPIs for EMU

The definitions for two KPIs for equipment and the related EMU energy data are provided as examples.

KPI 1: Current status of energy characteristics of EMUs

This KPI indicates the current status of EMU energy characteristics such as instantaneous power, energy consumption, demand, and fuel consumption rate.

KPI 2: Deviation from energy baseline model for EMUs

This KPI indicates the deviation between the actual energy consumption and the value estimated by an EMU energy baseline model. It is used to detect wasted energy consumption and abnormal EMU status and to verify improvements in energy efficiency. This KPI is calculated by an upper level system or by a facility’s embedded processing function, and is reported to related organisations or other upper level systems. Upper level systems calculate the KPI based on EMU energy data and optimize production scheduling using the calculated KPI. This KPI is also used to verify EMU maintenance.

Table 2 summarizes the definition of the two KPIs.

Table 2 – Guideline to define KPIs for EMU

Objective	Means	Guideline
– Comprehend the current status of EMU energy characteristics.	KPI 1: Current status of energy characteristics of EMUs: a) EMU output and specific energy consumption, corresponding to key drivers; b) indices such as energy conversion efficiency and production power rate that indicate current status of EMUs; c) EMU energy characteristics.	The selection of proper indices for EMU functions and characteristics is recommended.
– Detection of wasted energy consumption. – Detection of abnormal EMU status and performance of predictive maintenance. – Verification of effectiveness of improvement actions.	KPI 2: Deviation from energy baseline model for EMUs: a) deviation between the actual energy consumption and the production volume value estimated with the energy baseline model; b) deviation between the actual energy consumption and the value for related driving variables estimated with the energy baseline model; c) deviation between the actual energy consumption and the operating status value estimated with the energy characteristics model.	It is recommended to study the adoption of a), b) and c) in this sequence. The deviation can be detected as an absolute value or a rate of deviation (in case of linear approximation ($y = ax + b$), $\Delta a/a$ and $\Delta b/b$ are the deviation factors). The EMU operating status should be defined based on the concept of the time model defined in ISO 22400-2.

6.4.3.5 KPIs for products

KPIs for products can be used to calculate a product's energy footprint, manage product costs, and evaluate improvement actions. It is noted that intermediate products are included as well as the final product.

The following two KPIs are proposed:

a) Energy consumption to produce a unit product (energy intensity of a product).
b) The deviation between the actual consumption per unit product and the consumption estimated based on its energy baseline characteristics.

A product unit is selected, e.g. ton, kg, unit, and lot, depending on product properties and delivery. Examples of practical KPI units are GJ/ton and J/unit. The product energy intensity can be used to determine the energy footprint and carbon footprint of a product. This will improve the cost management for each product.

The energy consumed to produce a unit product can be a precise index for energy management. It is derived from a model that is based on the relationship between energy consumption, production volume, and other driving factors.

Deviation from estimated consumption based on a product's energy baseline characteristics is represented as an absolute value or a degree of deviation (%).The deviation can be managed to improve the energy efficiency of the production processes and evaluate the effectiveness of an improvement action plan. It also facilitates the detection of unexpected abnormal operations during the production processes.

Measuring the basic energy consumption for each product will become more difficult as production processes increase in complexity due to factors such as product materials and parts. Contributing to this is the fact that many production facilities are operated in parallel and/or in sequence, requiring intermediate stocks between production processes.

It becomes difficult to allocate energy consumption for each product based on the driving factors in the production process. So, it is practical to measure the energy consumed by the key driver in the product production process. It is recommended to perform a prorated allocation of other energy consumption to the product based on production volume or number of units sold.

Table 3 summarizes the definition of the two KPIs.

Table 3 – Guideline for the definition of KPIs for products

Objective	Means	Guideline
– Energy footprint of a product. – Carbon footprint of a product. – Cost management.	1) Energy used for producing a unit product. NOTE 1 Ton, kg, unit, lot, etc.	Production processes involve many kinds of facilities. With batch processes that produce a variety of products, it is generally difficult to measure energy consumption for a specific product. It is practical to measure the energy consumed by the key production driver. It is recommended to allocate other energy consumption to the product based on production volume or number of units sold. When a reference value *f* or the production of a unit product is provided, it is easy to verify overall improvement in production processes.
– Verification of effectiveness of production process improvements.	2) Deviation of actual energy consumption from the energy baseline characteristics of the product. NOTE 2 GJ/t, kJ/unit.	

The energy baseline characteristics should be provided for a product.

How to measure the energy consumed to produce a product is explained in B.6.

Specific energy consumption has been used as a practical benchmark that is generally application specific. It is recommended to develop a standardised methodology to measure the energy consumed to produce a product.

6.4.3.6 KPIs for local regulation

KPIs should be defined so as not to violate local regulations and should be good proofs of energy management compliant with local regulations. Local regulation such as the "Energy Efficiency Act" in Canada requires energy using products to meet the requirements that may vary depending on the circumstances in each country. Energy efficiency of a final product is one of the key requirements of local regulations and is performed by its design. Local regulation may require a factory to report the energy consumption to produce the product. In such cases, specific energy consumption can be a KPI that can be broken down into detailed KPIs defining the boundaries of energy management units in the lower layers as described in 6.4.3.3. Target values of KPIs, as provided in the Act on the Rational Use of Energy (METI, Japan) are shown in B.5. Environmental requirements should be considered to define KPIs as well as energy efficiency.

6.4.3.7 KPI description based on ISO 22400-2

Table 4 represents the comprehensive energy consumption KPI, as described in ISO 22400-2, and based on the ISO 22400-2 model.

Table 4 – KPI description based on ISO 22400-2 model

Name/title of index:	**Comprehensive energy consumption**
Description	
Benefit / application:	Comprehensive energy consumption is the ratio between all the energy consumed in a production cycle and the produced quantity
Time behaviour:	Demand-oriented, periodic
Definition and calculation	
Formula:	$e = E/PQ = (\Sigma Mi \times Ri + Q) / PQ$ e: unit energy consumption of statistical object, standard quantity / ton E: comprehensive energy consumption, standard quantity Mi: actual consumption of certain kind of energy, ton (kilowatt hour) Ri: conversion coefficient of certain kind of energy, standard quantity / ton Q: algebraic sum of effective energy exchanges with environment, standard quantity PQ is expressed in tons
Unit/dimension:	Standard quantity / ton
Rating:	Min.: 0 Max.: related to product Trend: the lower, the better
Analysis / drill down:	Related to product, to statistics unit
Remarks	
Notes / explanation:	Energy consumption is an important factor impacting the production costs and final profits
Corporate level	Worker, master, chief, management
Effect model:	To be determined
Production type:	Continuous, batch, discrete
NOTE The conversion coefficient Ri is used to unify the measurement modes of different energy types, by which a certain kind of energy can be changed into standard quantity (e.g. the unit of Ri for water is standard quantity/ton; for electricity the unit of Ri is standard quantity/kilowatt-hour.) The comprehensive energy consumption indicator is used with a collection of standard quantity conversion tables, which are unique for different industries.	

7 Applications

7.1 The application point of view

7.1.1 Energy consumption in industry

Investigations in machinery have shown that the basic energy consumption in a plant is about three quarters of the whole amount of energy consumption. Only one quarter is needed for operation of the process. Experience shows that the machines really produce only between 15 % (in lower volume production) and 40 % (in higher volume production) of the whole operating duration. The rest of the time the machines are just waiting or in a tool change state. However during this time the basic energy consumption continues. Thus there may be energy savings of 10 % to 25 %.

The portion of energy consumption of automation components is relatively small in comparison to the whole machines and plants. This is true especially in plants with high volumes of thermal and/or mechanical energy conversion, like heaters/coolers/pumps, etc. However in plants without these high consuming components the portion of energy consumption of the automation equipment may be more significant.

The manufacturing infrastructure today consumes a large volume of energy for itself due to today's designs and working concepts. Almost all of the electrical energy consumed by a manufacturing plant is finally converted into heat and dissipated into nature. Only a very small portion is stored somehow in the product and available for further use.

Therefore it is an important starting point to analyse the energy consumption that is needed by the manufacturing infrastructure while it is not manufacturing any products. The manufacturing systems engineering will change the construction of machines and plants significantly in the next decade in order to reduce the large mismatch between the minimum energy consumption needed for manufacturing and the energy demand of the real system. This will have effects on the automation technology.

Another important starting point affects the process design itself: which steps and in which sequence are taken.

In machines and plants (without the heating of buildings) electrical and chemical (fuel) energy is consumed. Automation technology traditionally only serves for the transport and control of electrical energy. This reflects only a very small portion of the totally consumed energy.

In the conversion from electrical to mechanical energy (drives), the intermediate hydraulics and pneumatics are not covered by automation technologies. In these areas only the intrinsic energy efficiency can be improved. Energy saving motors are already stretching the limits of physics. The drive electronics has been optimised for efficiency through design for some time already (compactness, reduction of cooling efforts). In gearboxes a further reduction of all kinds of friction, including oil splashing losses, is expected. The total energy efficiency in electrical drives (consisting of electronics, motor and gear) is at a very high level today, about 80 % to 90 %.

Automation traditionally does not cover:

- Efficient use of the mechanical energy in machines and plants. This is determined by process and machine design. This is where the main efficiency potentials are. The influence of automation is marginal.
- Application of frequency converters in the transport of fluids. This reduces the friction losses which accrue extremely at mechanical restrictions of the volume flow.
- Application of frequency converters in the transport of piece goods and bulk goods. The mechanical restriction of mechanical movements is frequently used today at smaller transport tasks.
- Reasonable use of other energy forms in machines and plants. This is determined by process and machine design. This is also where the real efficiency potentials are. The influence of automation is practically zero.

Automation technology is the main carrier of all algorithms and actions which can reduce the energy consumption of machines. Due to the energy efficiency issue the management of machines and plants will become significantly more complex and directly affects the automation technology.

The pressure from politics and competitors and finally from the machine OEMs will increase.

Six areas of actions can be identified:

1) securing that automation technology in future can handle all algorithms and behaviours of the machines,
2) equipment for measurement of energy and power flow,
3) energy efficient operation of manufacturing by operation and control tools comprising the energy efficiency,

4) design tools for energy efficient machines and plants (engineering of the support process “energy savings”),
5) new energy efficient automation components and components for energy efficiency support processes,
6) reduction of energy self-consumption of automation components.

7.1.2 Characteristics of production processes

In the industry supply chain, upstream industries such as iron, steel and oil refining process raw materials into intermediary products, which are converted into finished products by downstream industries such as automobiles and consumer electronics.

Table 5 depicts the production processes categorized in continuous, batch and discrete processes by their corresponding controlled objects, industry sectors and type of control. Batch processes are located between continuous and discrete processes, and they are often hybrids.

Table 5 – Characteristics of production processes

Types of process	Continuous	Batch	Discrete
Controlled objects	Gas Liquid	Liquid Powder	Solid
Industry sectors	Oil refinery Chemical Iron and steel Pulp and paper etc.	Chemical Pharmaceutical Food and beverage etc.	Automotive Appliance etc.
Type of control	PID control	PID Sequence control (PLC)	Sequence control (PLC)
Types of automation	PA (process automation)		FA (factory automation)

In continuous processes, the controlled objects are mainly gas and liquid. Process parameters are controlled mainly by PID control performed by a distributed control system (DCS). In discrete processes, solid parts are assembled into products on a production line that is controlled by sequence control performed by PLC. Chemical, pharmaceutical, food and beverage are categorized in the batch process that is controlled by some combination of PID and sequence control.

7.2 Discrete manufacturing

7.2.1 Description

7.2.1.1 General

Discrete manufacturing is described by using examples from the automotive production.

7.2.1.2 Structure of the automotive production

Automotive production is split up into several production shops. Each of these has different requirements, machinery and technologies to be used. In addition they are different in the usage, form and amount of primary energy. To reflect as many topics as possible the authors interviewed members of the planning and operations group of each shop and analysed documents describing the processes of the shops.

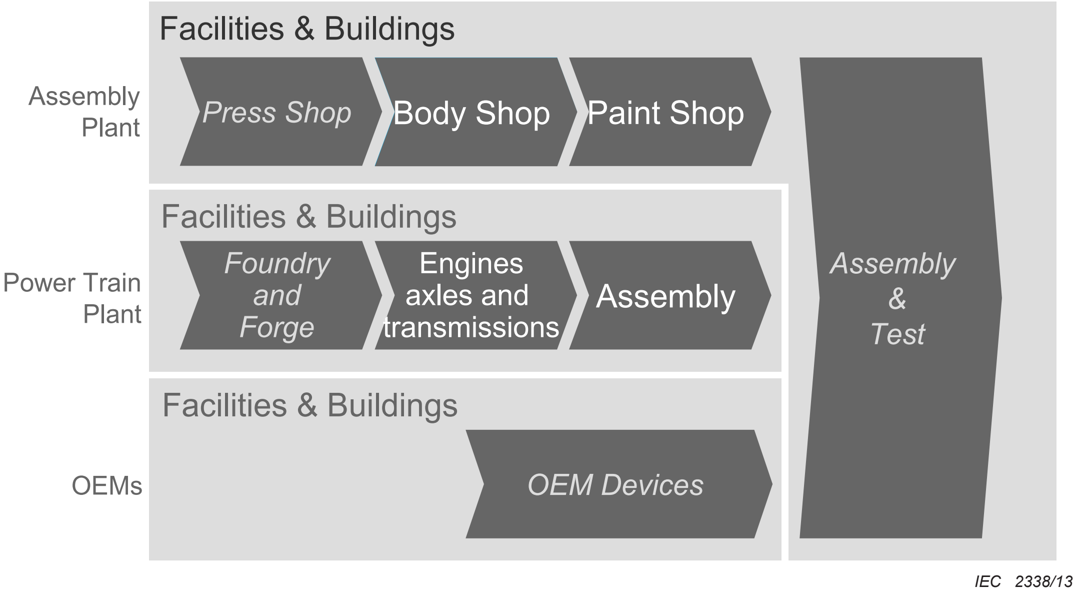


Figure 13 – Model of automotive production

In Figure 13, the shops described in 7.2.1.3 to 7.2.1.5 are marked in bold.

To reduce complexity, we have focused on the following areas:

- building automation and facility management (see 7.4.2);
- power train manufacturing (engines, axles and transmissions);
- paint shop;
- body shop.

The descriptions below only list items specific to the particular shop.

7.2.1.3 Power train manufacturing

Several studies show that switching off unused components of a line during inactivity leads to large energy savings.

Efficiency is best when operating the lines and systems in “impulse mode” (100 % on when needed, off when not needed) rather than partly loaded.

Experiments were made where components are switched off externally. The controller and display functions have to remain on because of software and configuration updates during the night. This leads to a lower efficiency.

Known issues

When designing new lines, currently the most driving factor is the component price.

When designing new lines and systems, components are often oversized due to:

- lack of knowledge of the system application;
- uncertainty of later applications (changes).

7.2.1.4 Paint shop

The system architecture today is not arranged for controlling the energy consumption of specific lines. For instance, stations of multiple lines are connected to one transformer station. Therefore it is not possible to measure the energy consumption of a single line.

The amortisation time of improvement programs has been increased from 1½ years to nearly 3½ years.

There are certain simulation and calculating models for:

- material flow;
- manpower (8 h shifts, week-end work).

These models should be enriched by:

- energy consumption (currently only peak values are considered);
- emissions.

7.2.1.5 Body shop

Known issues

Currently there is not enough “pressure” through legislation towards energy efficiency.

There are not enough energy efficient products on the market.

7.2.2 Recommendations for discrete manufacturing

7.2.2.1 Production management

Today factories are designed only according to material flow. Factories should be designed also according to the flow of energy. This requires sufficient models of the components and tools to simulate these system process parameters.

Systems should have dedicated interfaces to measure the energy flow.

- Ideally these should be incorporated into the devices.
- If not possible a standard measuring interface should be provided.
- Most electrical and electronics device have and provide this information today but only in a proprietary way. Here a standard data interface should be provided.
- Having a self-learning function within the devices, these could alarm to the controller when diagnostic parameters go out of a predefined range.

7.2.2.2 New technologies

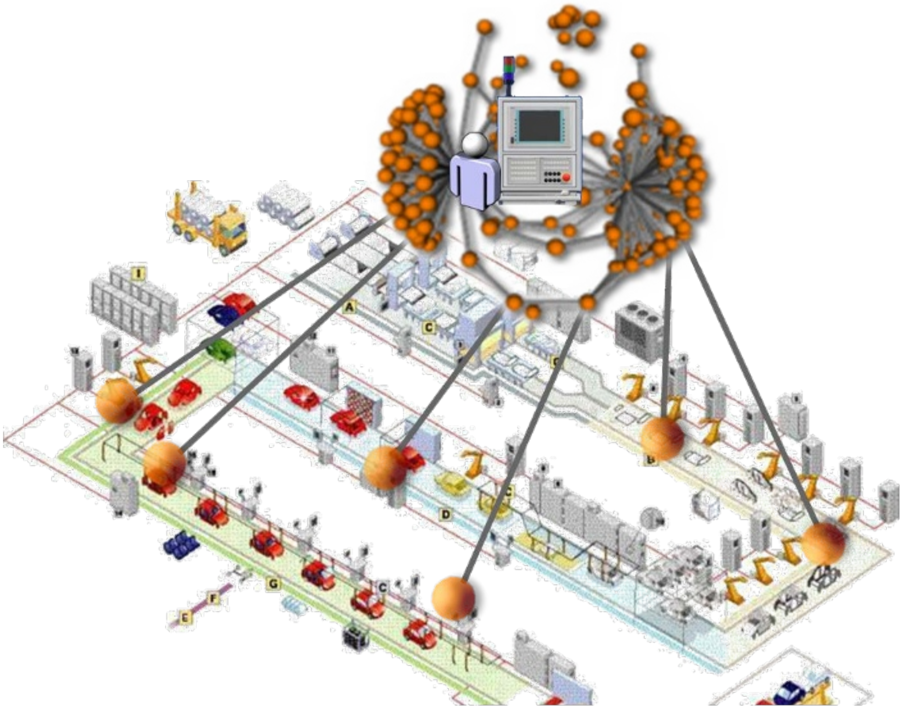
The usage of advanced technologies improves the energy efficiency on the component and system level:

- the use of “cold” technologies to dry and harden adhesive and varnish;
- the use of regulated drives;
- the use of frequency inverters instead of unregulated motors improves the efficiency when components are not fully loaded.
  But: This increases the amount of reactive power and energy loss within cables.

7.2.2.3 Closed loop controls

A closer measurement of the energy flow enables a closer control of process parameters (e.g. room temperature).

Using a “supervisory controller” (see Figure 14), instead of multiple closed loop controls influencing each other, leads to a better performance (no oscillation). A negative effect is the increasing dependency of the systems.



IEC 2339/13

Figure 14 – Supervisory control

7.2.2.4 Optimal dimensioning of systems

When current and future energy consumptions are available, they should lead to:

- cost and energy reduction because of optimal dimensioning of components and systems;
- lower price for purchasing energy because of exact forecasts associated with peak shaving;
- a need for a strategy for switching off lower privileged systems during power peaks (load shedding).

7.2.2.5 Components

Simple and cheap external sensors are needed with:

- a powerline communication interface, line powered;
- wireless communication and energy harvesting supply.

7.3 Process industry

7.3.1 Description

7.3.1.1 Characteristics of process industry

Most process industries are energy intensive and need both thermal and electric energy.

So, thermal energy management is quite important for improving the energy efficiency of process plants. The following are key points for the rational use of thermal energy in factories:

- rationalisation of combustion of fuels,
- rationalisation of heating and cooling as well as heat transfer,
- recovery and utilisation of waste heat,
- rationalisation of conversion of heat into power, etc.,

- prevention of energy loss due to emission, conduction, resistance, etc.,
- rationalisation of conversion of electricity into power, heat, etc.

It should be emphasized that process automation has been playing an important role in improving energy efficiency through the provision of solutions for rationalisation.

7.3.1.2 Automation function

Process industries such as oil refining, chemical, iron and steel, pulp and paper, and cement are energy intensive. Energy efficiency in the process industries has been improved significantly through the use of process automation technologies. In process plants, there are many kinds of process variables such as temperature, pressure, level, and flow rate. These process variables are monitored and controlled to the target values by process automation systems with the primary goal of process improvement. A subsequent goal is that the energy efficiency of the plant is improved. These process variables are reflected to the real time verification of KPIs for energy efficiency.

In many plants, production processes such as heating, cooling, vaporisation, and condensation are widely used. As those processes are usually operated by thermal energy, the energy efficiency is quite dependent on the efficient utilisation of thermal energy including heat recovery. Compressed air and steam are key energy sources as well as electricity. There are many field devices that are operated by compressed air and steam. Detection of leaks in compressed air and steam supply systems is important to reduce the useless consumption of energy.

Process plants often operate at varying load conditions such as production volume and/or product grade change due to market conditions. When load conditions change, set points of related process variables will be changed to optimum values to optimise the load balance of equipment throughout the plant. Plant wide optimisation is done, taking total energy efficiency into consideration.

In the pulp and paper industry, for example, many mills make different grades of paper on a single paper machine that is highly energy intensive. In the grade change process, all of the paper machine’s equipment is stopped in a programmed sequence to carry out the necessary procedures such as draining, washing, filling, and so on. After these procedures the system is restarted again. Automated grade change minimizes the downtime and reduces the energy consumption.

In summary, precise measurement and control of the process status by process automation systems have been making great contribution to improving the energy efficiency of the process industries.

It is recommended to generate a technology list of measurements and automation functions that should be versatile and effective for different types of applications. Some examples are shown in Annex F.

7.3.2 General recommendations for the process industry

As stated in 6.4.1 and in Figure 3, process industries consist of a wide range of industry sectors. A production system is configured in a functional hierarchical architecture as defined in IEC 62264-1:2013. It is difficult to develop a single generic standard that can be applied to all industry sectors and production system hierarchies.

It is recommended to develop some generic methodology that enables to define specific performance indicators by which “Plan, Do, Study and Act” type of continuous improvement cycles can be propelled effectively. The methodology for defining the system boundary and KPIs to manage the energy efficiency is also recommended. In order to manage plant wide optimisation, it is recommended to standardise the energy data of automation assets.

7.3.3 Existing standards

There are no specific standards at this time. There are some energy efficiency related existing KPIs (shown in B.1) and target values of KPIs by industry sectors in Japan (B.5). Other useful related information can be found in:

IEC 62264 (all parts), *Enterprise-control system integration*

ISO 20140-1:2013, *Automation systems and integration – Evaluating energy efficiency and other factors of manufacturing systems that influence the environment – Part 1: Overview and general principles*

ISO 22400-2, *Automation systems and integration – Key performance indicators for manufacturing operations management – Part 2: Definitions and descriptions*[4]

ISO 50001:2011, *Energy management systems – Requirements with guidance for use*

7.3.4 Gaps

Regulations are different in every country and may be product specific. There is no accepted industry standard for developing energy efficiency performance metrics for process automation.

There have been a lot of automation functions implemented in the process industries. Some of the controlled parameters/values in the automation function can be re-positioned as energy efficient KPIs.

More energy efficient automation functions can also be designed where new process technology is introduced and/or a RENKEI solution is needed.

7.3.5 Specific recommendations

It is recommended:

1) To define energy efficiency as a component, as part of a system, and as part of a facility's energy management systems and practices. Improving industrial energy efficiency requires a mix of compatible standards and policies.
2) To standardise a methodology for defining the boundaries of a facility so that it may be handled as an energy management unit. It is practical to start energy management using broadly defined boundaries. When key factors for improving Energy Efficiency are analysed, the initial boundaries can be narrowed down by focusing on the specific factor that is to be improved. Flexibility in defining such boundaries enables practical improvements in energy efficiency that can maximize the utilization of existing facilities.
3) To define KPIs for appropriate function levels and subsystems by taking the approaches proposed in 6.4. Through the use of these management indexes, it is possible to confirm the implemented automation functions and the results achieved in improving energy efficiency.
4) To develop and standardise a methodology for the measurement and verification of energy efficiency. When making comparisons, it is necessary to ensure fairness.
5) To set a numeric KPI target for benchmarking. KPIs are provided for products, equipment, facilities, industry sectors, and other levels. B.5 shows examples of KPI target values by industry sector.
6) To standardise the energy performance test procedure.

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[4] To be published.

7) To generate a list of automation functions that enable improvements in energy efficiency and to link each automation function with a specific energy efficiency improvement.

7.4 Support functions

7.4.1 General

Many different support functions exist, e.g. for logistics and material handling. Examples here are given for building automation and facility management.

7.4.2 Building automation and facility management

There are a lot of different and specialized control systems in use today. Especially the smaller systems often do not have a network interface because of price reasons. This fact results in many small control applications which are only manageable manually.

Bus/network interfaces in use today are[5]:

- BACnet™
- EtherNet/IP™, DeviceNet™ and other CIP networks (IEC 61784-1 and IEC 61784-2, CPF 2)
- Konnex (KNX®)
- LonWorks®
- Modbus® (IEC 61784-2, CPF 15)
- PROFIBUS and PROFINET (IEC 61784-1 and IEC 61784-2, CPF 3)

There are advantages when facility controls are interconnected with production systems. This is the case in some of the newer plants and it is seen as a big advantage.

EXAMPLE Air condition and lighting can be switched adaptively even when the production schedule is changed dynamically.

Known issues

There are not enough sensors (area-wide) for a closer control and measurement due to:

- the component price, and
- the lack of sufficient (low cost and standardised) interfaces.

Systems and components do not have proper means to measure their current inrush/power consumption.

8 Components

8.1 The component specific view

There are different potential solutions for achieving the lowest power consumption as possible depending on the character of a device. The following different classes of devices can be identified:

- transmitters (sensors);
- actuators (electrical drives...);

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[5] The products described here are given for the convenience of users of this document and do not constitute an endorsement by IEC of these products.

- control devices;
- power supplies;
- specific devices related to energy efficiency applications.

Examples here are given for actuators only.

8.2 Actuators

8.2.1 Electrical drives: regulate or self-learn optimal energy efficiency

Status

System designers have to specify drive parameters without knowing all (dynamically) changing parameters of the motor, gear box, belts, reels, etc., and the load.

Recommendations

Electrical drives should regulate or self-learn the parameters for optimal energy efficiency.

8.2.2 Electrical drives: standardised intermediate current link

Status

Intermediate current links of different manufacturers are incompatible.

Recommendations

Define a standardised intermediate current link for electrical drives (voltage, connector and synchronisation).

Annex A
(informative)

System boundary

ISO 20140-1:2013, Figure 4, shows the unit process model that has been developed for environmental impact evaluation, based on the standardised life cycle assessment (LCA) method. The unit process model provides a means to clearly define these boundaries.

Environmental influences through the manufacturing system life cycle phases are classified into the three categories of “direct influence”, “indirect influence” and “manufacturing system life cycle influence”. Inputs and outputs in the horizontal direction constitute the “direct influence”, they are the inputs and outputs directly involved in the operation of manufacturing equipment to produce individual products. Inputs and outputs in the vertical direction constitute the “indirect influence” and the “manufacturing system life cycle influence”. “Indirect influence” is made of the inputs and outputs associated with the maintenance of a production system, while the “manufacturing system life cycle influence” represents the support provided over the entire life cycle of the production system.

Figure A.1 and Figure A.2 are derived from ISO 20140-1:2013, Figure 4. Figure A.2 illustrates the focus of this technical report.

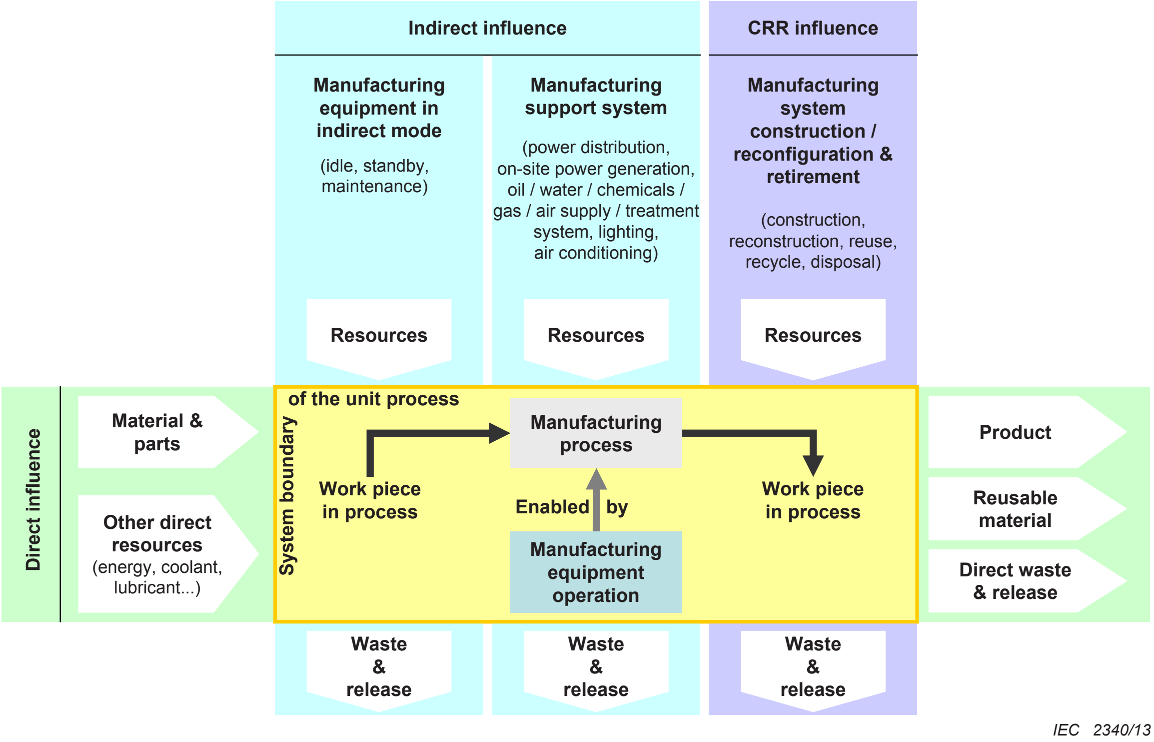
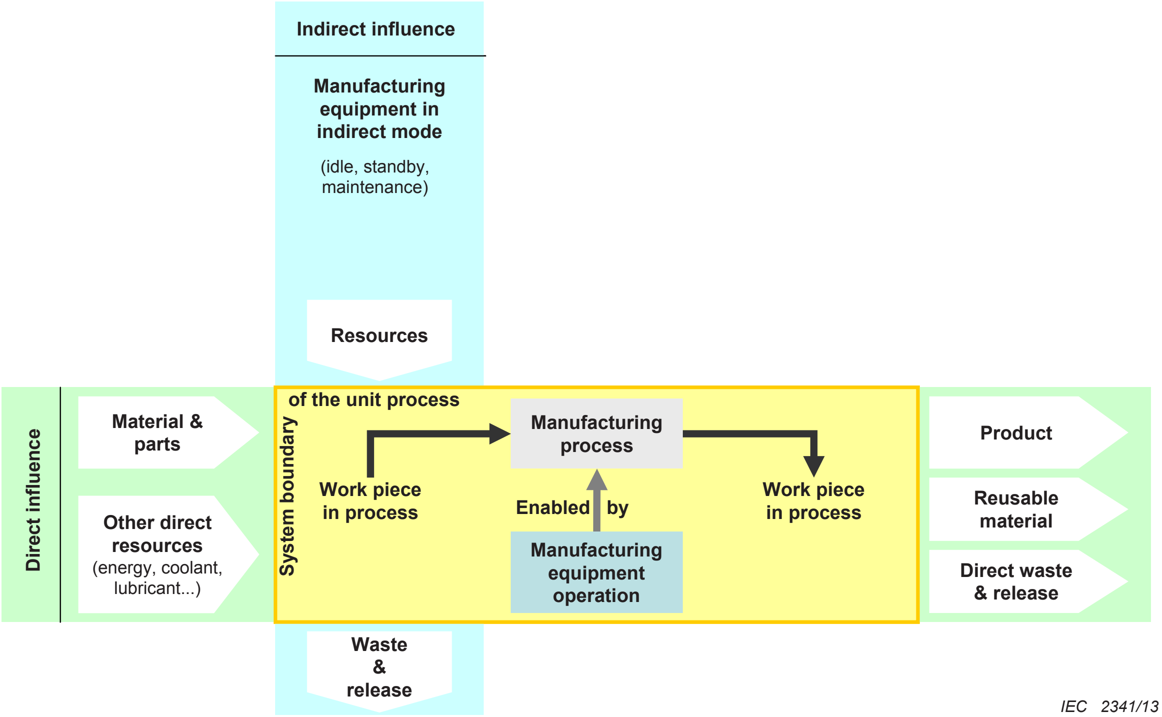


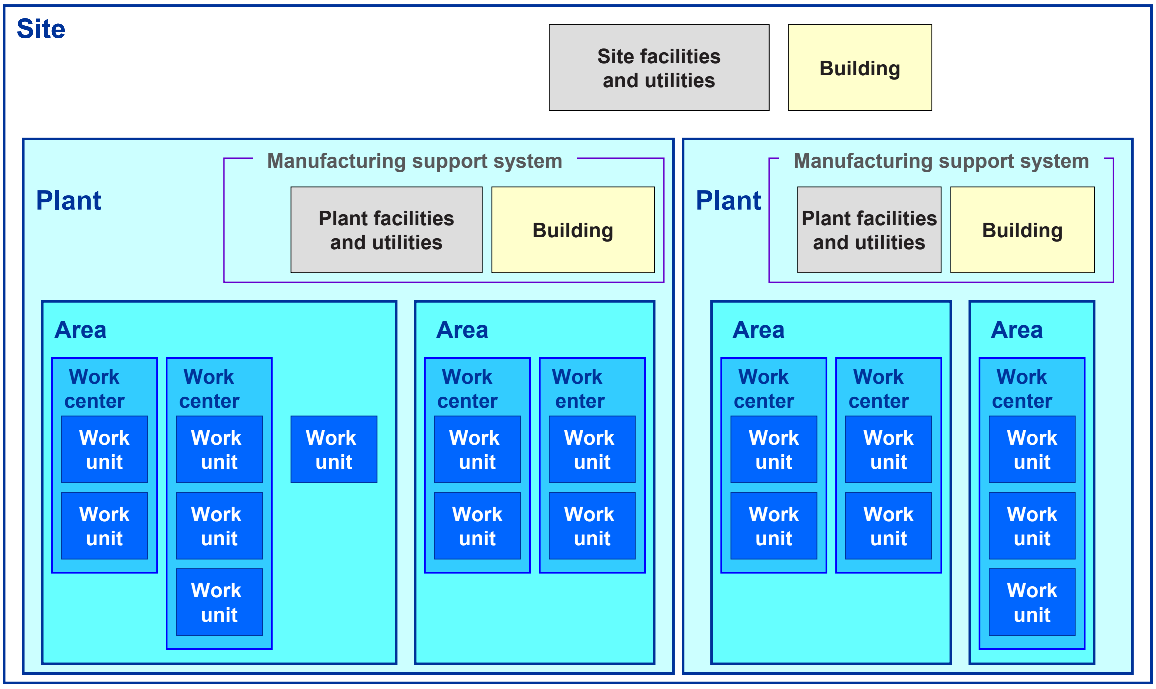
Figure A.1 – Unit process model



IEC 2341/13

Figure A.2 – Unit process model dealing with the direct and indirect influences

Figure A.3 shows the process unit role in the definition and context of a plant. Figure A.4, taken from IEC 62264-1:2013, Figure 5, shows how process units provide a common model for equipment in plants from different industrial sectors, arranged in a hierarchy describing a generic enterprise.



IEC 2342/13

Figure A.3 – Process units in the definition and context of plants

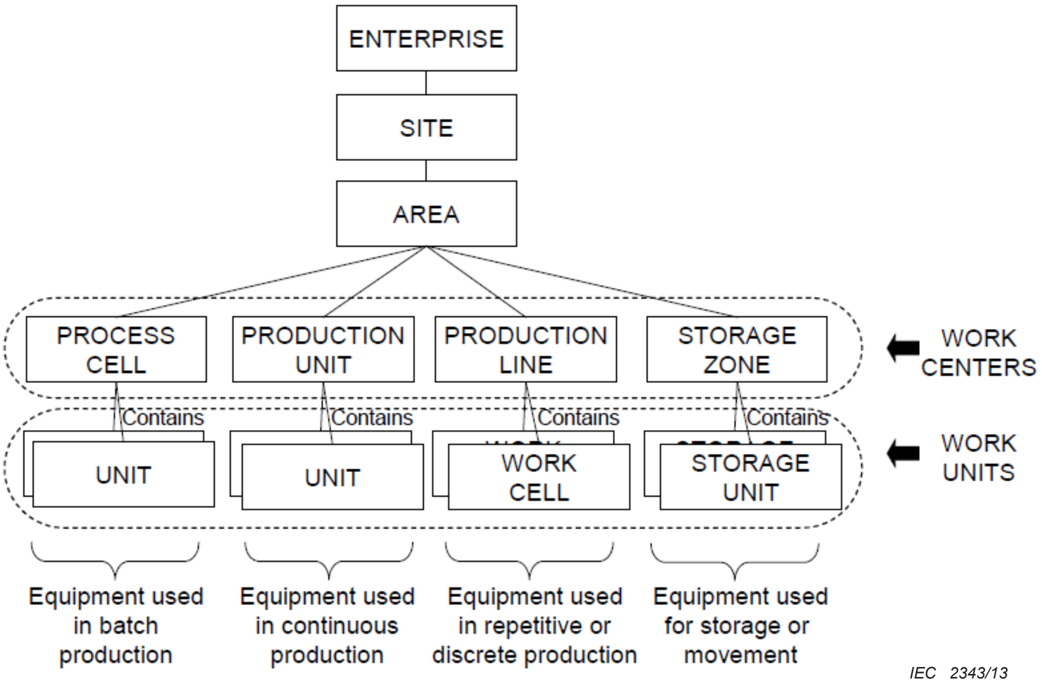


Figure A.4 – Typical expanded equipment hierarchy

Annex B
(informative)

Current approaches for KPIs for energy efficiency

B.1 Existing KPIs

The following list gives examples of already existing KPI for energy efficiency.

- **European Directive 2010/31/EU** (2010-05-19)
  Energy performance of buildings (recast of 2002/91/EC Directive)

The Directive concerns the residential sector and the tertiary sector (offices, public buildings, etc.). The scope covers all aspects of energy efficiency in buildings in an attempt to establish a truly integrated approach.

- **European Directive 2005/32/EC "EuP"** (2005-07-06)
  Framework for the setting of ecodesign requirements for energy-using products
- **European Directive 2006/32/EC** (2006-04-05)
  Energy end-use efficiency and energy services
- **European Directive 2009/125/EC "ErP"** (2009-10-21)
  Ecodesign requirements for energy-related products

These directives concern the need for improved energy end-use efficiency and managed demand for energy. Improved energy end-use efficiency will also contribute to the reduction of primary energy consumption, to the mitigation of CO_2 and other greenhouse gas emissions. Implementation measures within the framework of the 2006/32/EC Directive are published to cover areas in which energy efficiency improvement programmes and other energy efficiency improvement measures may be developed and implemented. For example: Commission Regulation (EC) No 640/2009, implementing the Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for electric motors.

- **2006/32/EG**
  Until 2016: 9 % reduction of energy compared to 2001 to 2005
- **EN16001** (targeted beginning 2012)
  Energy Management Process within Companies
- **IEC 60456**
  Washing machines
- **Energy efficiency ratio for air conditioners (seasonal EER= SEER)**
  Output/input in BTU/Wh, heating (annual fuel utilisation efficiency, AFUE)
- **Energy Star (USA)**
  Computers, servers, appliances, heating/cooling, lighting, home office
- **MEPS**
  Minimum energy performance standard (Americas, Australia & New Zealand)

B.2 KPIs for components

For energy transforming components, today often only the nominal or best efficiency factor is stated. Dynamic efficiency factors should also be provided (cut-off, stand-by, partial load).

B.3 KPIs for products

Examples of KPI definition possibilities from a global view (amount of energy used or amount of CO_2 output for the production of a single unit):

- for all purchased parts
  - purchase of parts
  - transport of parts
  - stock of parts
  - direct production related
  - proportional (see below)
- directly production related
- proportional
  - production facilities
  - plant facilities
    1. management
    2. marketing
    3. ...
  - per employee

Examples of existing KPIs:

- kg CO_2 per unit produced
- efficiency factor

B.4 KPIs for systems

Examples of KPI definition possibilities from a system perspective:

- Benefit: input energy.
- Problem: benefit for every system is different.
- Only possible solution: comparison only of systems with the same benefit.

B.5 Target values of KPI by industry sectors in Japan

Table B.1 represents the target values of KPI by industry sectors in Japan.

NOTE Source: Act on the Rational Use of Energy (METI, Japan).

Table B.1 – Target values of KPI by industry sectors in Japan

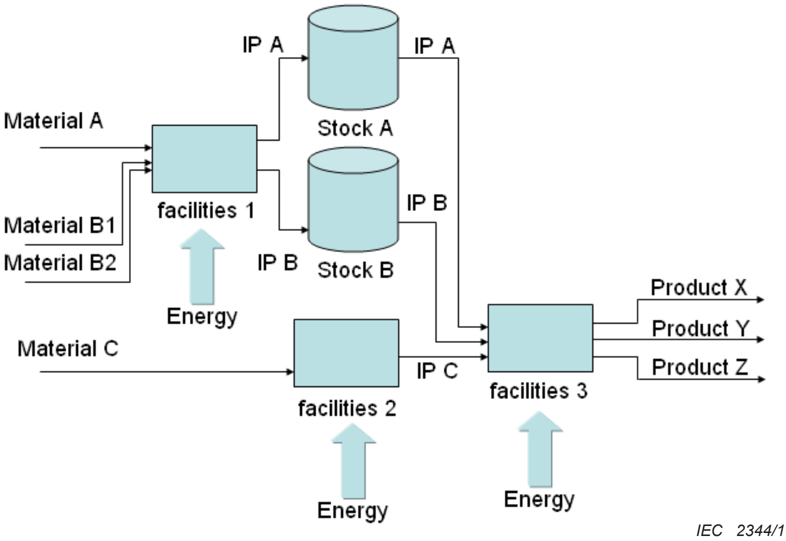
Classification	Business field	Benchmark index	Target level
1A	Iron manufacturing using blast furnaces (business to manufacture pig iron using blast furnaces to manufacture products)	The value obtained by A/B A: Energy consumption in the blast furnaces for steel business B: Amount of raw steel	0,531 kl/t or less
1B	Common steel manufacturing using electrical furnaces (business to manufacture pig iron using electrical furnaces to manufacture rolled steel products, excluding iron manufacturing using blast furnaces)	Sum of 1) and 2) 1) The value obtained by A/B A: Energy consumption in the process to manufacture raw steel using electrical furnaces B: Amount of raw steel 2) The value obtained by A/B A: Energy consumption in the process to manufacture rolled common steel products from billet B: Amount of rolled steel	0,143 kl/t or less
1C	Special steel manufacturing using electrical furnaces (business to manufacture pig iron using electrical furnaces to manufacture special steel products (rolled special steel products, hot special steel pipes, cold-drawn special steel pipes, cold-finished special steel products, forged special steel products, casted special steel products), excluding iron manufacturing using blast furnaces)	Sum of 1) and 2) 1) The value obtained by A/B A: Energy consumption in the process to manufacture raw steel using electrical furnaces B: Amount of raw steel 2) The value obtained by A/B A: Energy consumption in the process to manufacture special steel products (rolled special steel products, hot special steel pipes, cold-drawn special steel pipes, cold-finished special steel products, forged special steel products, casted special steel products) from billet B: Amount of shipped (sold) steel	0,36 kl/t or less

Classification	Business field	Benchmark index	Target level
2	Electrical supplier (industry that supplies electricity determined by 2.1 of Act on the Rational Use of Energy among general electricity industry determined by 2.1.1 of Electricity Utilities Industry Law or wholesale electricity industry determined by 2.1.3 of Electricity Utilities Industry Law)	The value obtained by A/B (thermal efficiency standardised index) A: Thermal efficiency obtained by a performance test of rated output at thermal electric power generation facilities of factories that run this business (excluding low power facilities) B: Designed efficiency of the rated output In the case of plural facilities in the factory, the value is determined by a weighted average method based on the rated output. The value obtained by A/B (thermal electric power generation efficiency) A: Total electrical energy generated by thermal electric power generation facilities of factories that run this business B: Higher calorific value of the fuel that was required to generate the total energy	100,3 % or more of thermal efficiency standardised index
3	Cement manufacturing (business to manufacture portland cement (JIS R 5210), blast furnace cement (JIS R 5211), silica cement (JIS R 5212), fly-ash cement (JIS R 5213))	Total of 1) to 4) 1) The value obtained by A/B A: Energy consumption in the raw material process B: Production volume in the raw material part 2) The value obtained by A/B A: Energy consumption in the pyroprocess B: Production volume in the pyroprocess part 3) The value obtained by A/B A: Energy consumption in the finishing process B: Production volume in the finishing part 4) The value obtained by A/B A: Energy consumption in the shipping process, etc. B: Shipping volume	3 891 MJ/t or less

B.6 How to measure the energy consumed to produce a product

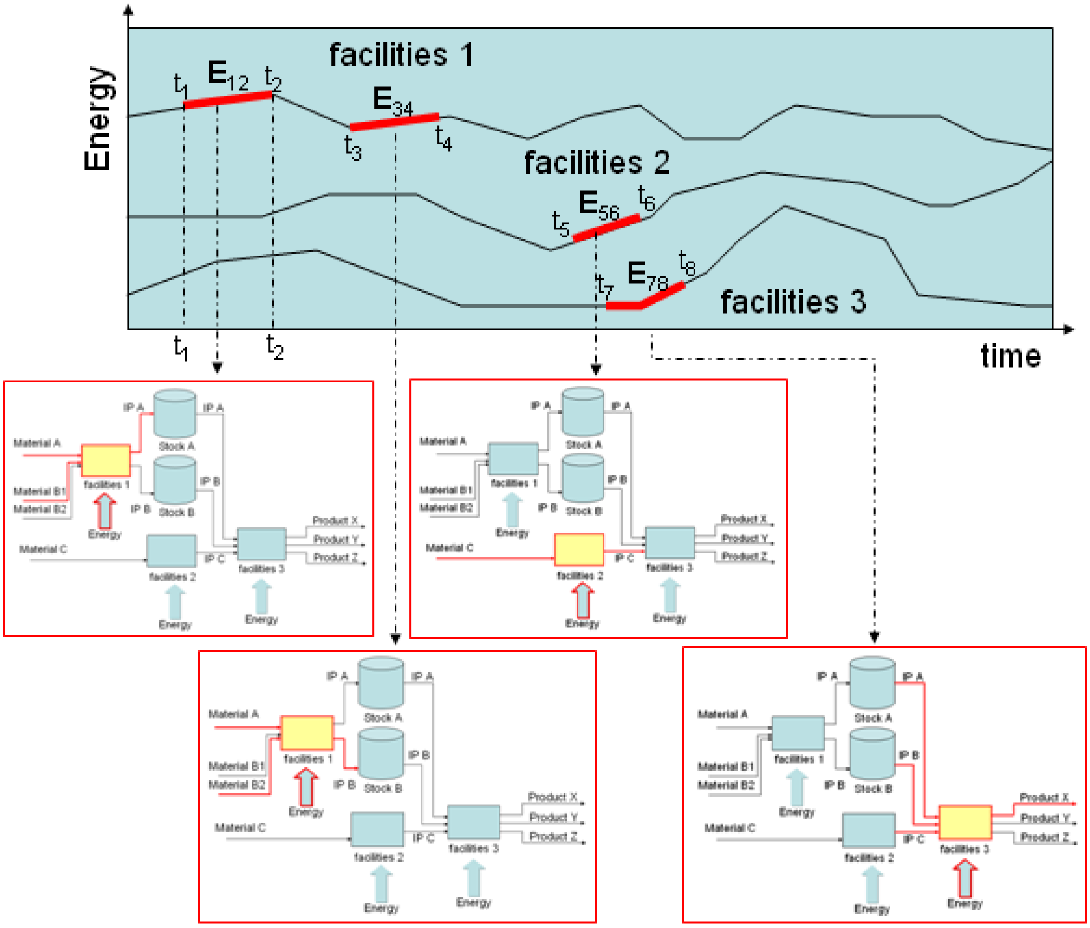
Figure B.1 shows an example of a product production process. Materials are processed into products by facilities that are operated with the necessary amount of energy. Figure B.2 shows the process flow, with the help of a marker on miniature reproductions, of the four bottom snap-shots pointed by the upper trend. From t_1 to t_2, facilities1 process material A and B1 with energy E_{12} into intermediate product A, which is stored in stock A. From t_3 to t_4, facilities1 process material A and B2 with energy E_{34} into intermediate product B, which is stored in stock B. From t_5 to t_6, facilities2 process material C with energy E_{56} into intermediate product C. From t_7 to t_8, facilities3 process intermediate product A, B and C with energy E_{78} into product X. The energy consumed to produce product X is calculated using E_{12} through E_{78}.

It is necessary to record E_{ij} to calculate the total energy used to produce a product. This is the energy trace function.



IEC 2344/13

Figure B.1 – Product production process



IEC 2345/13

Figure B.2 – Production process flow

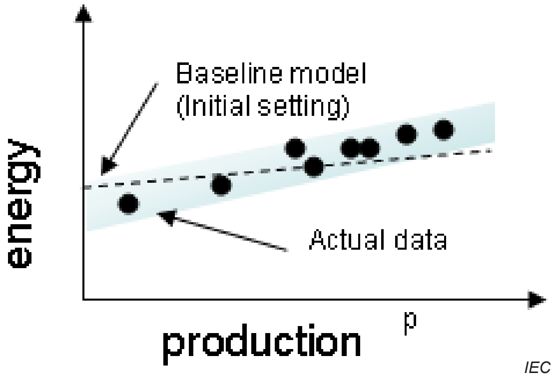
Annex C
(informative)

Energy baseline model

C.1 Guidelines for the creation and usage of an energy baseline model

An energy baseline model represents the relationship between energy consumption and a production parameter which is a key driver. It can be expressed as an approximation, a relational expression, or a data set in a spread sheet. With simple facilities, it can be determined by a linear approximation (see Figure C.1). With an entire plant or some complex combination of facilities, facility operating conditions are not necessarily related to the production volume and it is sometimes difficult to create an approximation. In such a case, the model needs to be broken down into several smaller models for equipment or other items that can be expressed by an approximation. An energy baseline model should be created using actual measured values. In actuality, output values from facilities will not change in a short time period. To obtain the most accurate model possible, the baseline period needs to be long enough (at least one year) to capture normal variations in production volume and seasonal factors across all seasons. Therefore management should be initially performed using a theoretical characteristic or an initial characteristic that comes from the vendor of the facility. The initial model can then be modified using actual measured values.

It is recommended to periodically update the energy baseline model, with the update interval depending on the facility characteristics. It is recommended that standardised notation be used for the energy baseline model.



IEC 2346/13

Figure C.1 – Energy baseline model

The accuracy of a mathematical model needs to be determined based on the required level of energy management. When a facility is renovated to improve its energy efficiency, a reasonably accurate theoretical model can be used to evaluate the effectiveness of the renovation. If the model is capable of real time calculation, the difference between the calculated value and the actual measurement can be a real time KPI that indicates the effectiveness of the measures to reduce energy consumption.

Table C.1 summarizes the guidelines to define an energy baseline model.

Table C.1 – Guidelines for defining an energy baseline model

Objectives	Means	Guidelines
– Verification of effectiveness of improvements. – Maintenance and renewal of facilities.	1) The modelling of facility energy consumption characteristics. (Characteristics that represent the relationship between energy consumption and key drivers such as production volume)	An energy characteristics reference model should be defined based on the following: – purpose of the equipment, – principle of operation of the facility, – products produced by the facility. It is desirable to define the reference model based on actual measurements. Theoretical data or initial characteristic data provided by the vendor is also acceptable. With simple facilities, it can be determined by a linear approximation. With an entire plant or a complex combination of facilities, prediction will be more accurate if the model is broken down into several smaller models.
	2) Energy characteristics for each operating status. Operation status of a facility and the energy consumption for each operating status NOTE Energy consumption characteristics: energy baseline model for facility operating status defined by ISO 22400-2.	It is desirable to create an energy consumption model for each operating status, factoring in key drivers such as production volume.

C.2 Examples of a facility energy baseline model

C.2.1 General

Two examples of a facility energy baseline model are given below.

It is recommended that both simple and detailed baseline models be provided for a range of facilities that take into consideration the energy consumption and the energy characteristics of the facilities.

C.2.2 Cooling water pump with parallel pumping control

Figure C.2 shows a pump control system that controls the number of activated pumps depending on the discharge flow of water. Discharge pressure P is controlled at a constant value by a return valve that returns the excessive water back to the suction side. This system has three levels of power consumption, depending on the discharge flow Q. The formula below is used to calculate how much power is consumed to provide the discharge flow Q so that P remains constant.

Condition:

Three pumps are used. The rated power consumption of each pump is 15kW.

The number of activated pumps is dependent on the flow Q.

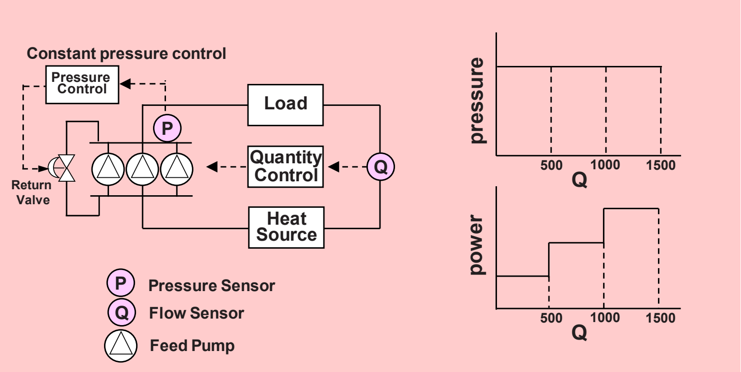
The default power of this system is 2kW.

Formula:

Power consumption (kW) = $n \times 15 + 2$

Where n = number of working pumps,

n = 1 for 0 < = Q < 500 m^3/h, n = 2 for 500 < =Q <1 000 m^3/h, n = 3 for 1 000 < = Q < 1 500 m^3/h



IEC 2347/13

Figure C.2 – Cooling water pump facility with parallel pumping control

C.2.3 Cooling water pumps with variable frequency AC drive

This system, shown in Figure C.3, controls P (the discharge pressure) to a constant value by controlling the pump speed corresponding to Q (the discharge flow). This is a general energy-saving method. It has higher energy efficiency than the system described in C.2.2 because cooling water is not returned using the return valve. The energy consumption of this facility is proportional to the product of Q and P. When Q and/or P are outside the ranges defined below, the pump will stop automatically. It is necessary to operate the pumps at maximum capacity for a certain time period after start-up. It is generally sufficient to use the defined model based on $Q \times P$ (formula 1) below). If the facility is frequently started up and shut down, the calculation model should be modified accordingly.

Condition:

Three pumps are used. The rated power consumption of each pump is 15kW.

The number of activated pumps is dependent on the flow Q.

The variable frequency AC drive is attached to each pump.

The default power of this system is 0,5 kW.

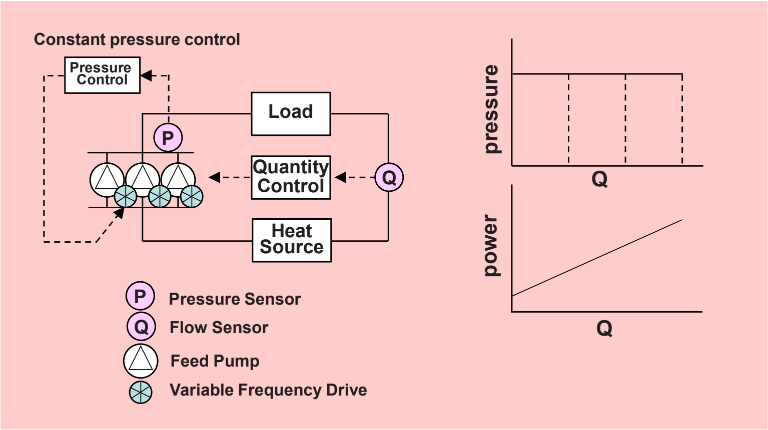
Formula:

1) Power consumption (kW) = Q (m^3/h) × P (MPa) × K + 0,5

   Where K = 0,334 for 4 m^3/h < Q < 1 500m^3/h, 0,5 MPa< P <1,1 MPa

   K = 0 and pump stops when Q and/or P are out of above ranges.

2) Power consumption of 45 KW is needed for 10 min after the start-up of the pumps.



IEC 2348/13

Figure C.3 – Cooling water pumps with variable frequency AC drive

Annex D
(informative)

Energy labels

D.1 Examples of energy labels

Energy labels are in general different for different countries. Figure D.1 shows some examples.

EU Japan Australia US China

IEC 2349/13

Figure D.1 – Examples of energy labels

D.2 Energy label for electrical motors

IEC/TC 2 already has an efficiency classification standard, IEC 60034-30.

IEC 60034-30 defines the energy efficiency class with a label made of the letters “IE” (short for “International Energy-efficiency Class”) and a number.

IE1 is standard efficiency. IE2 is high, IE3 is premium, and IE4 is super-premium. IE4 has the highest efficiency.

The IE code and the rated efficiency should be durably marked on the rating plate, for example “IE2 – 84,0 %”.

Many countries (US, EU, China, Canada, etc.) decided on a mandatory motor efficiency regulation at the IE3 level.

Annex E
(informative)

“RENKEI” control

E.1 Background of “RENKEI” control

"RENKEI” means to work in concert with something. “RENKEI” control is a generic concept of optimisation control technology that maximizes the total energy efficiency by controlling individual equipment to work in concert with each other and harmonising the demand and supply of energy.

“RENKEI” control is an effective way to cut wastes of energy due to the mismatch between demand and supply.

The following list gives some background:

- In order to avoid the shortage of energy supply, the supply side tends to supply more energy than actually needed.
- Wasted energy is not visible.
- It is difficult to adjust the output to the changing demand.
- As equipment is generally designed to have a maximum efficiency for the rated output, it operates less efficiently at a load lower than the rated output.

E.2 “RENKEI” control

Figure E.1 shows an example of an enterprise that has three factories A, B, and C. Level 1 through level 4 refer to the functional hierarchy defined by IEC 62264. Each factory is organized in three levels. The level 4 system is for the enterprise-wide management. Various production equipments and energy supplying equipments in the factory are categorized as level 1. Production lines or utilities that include these equipments are categorized as level 2. A factory that has these production lines is categorized as level 3. Figure E.2 shows the physical details of factory C in Figure E.1 as an example. Factory C has three production lines, an energy supply utility and an office. E_{21}, E_{22},..., E_{2i} are production equipments for line 2 and E_{31}, E_{32},..., E_{3j} are for line 3. E_{U1}, E_{U2}, E_{U3},..., E_{Uk} are equipments for the utility that supplies energy to production lines. As shown in Figure E.2, there are 3 types of RENKEI control:

1) Demand and supply RENKEI is an operation mode that controls an equipment of utility to supply the optimised amount of energy for the demand of production lines. Figure E.2 shows that the utility is supplying energy to lines 2 and 3 in “demand and supply RENKEI” mode.
2) Supply and supply RENKEI is an operation mode of utility that supplies energy to the production lines with an optimised load balance among the equipments in the utility. Minimizing the total cost of energy is a typical index for optimisation that is the best mix of fuel oil, gas, electricity for utility plant. The efficiency characteristics of each equipment are taken into consideration to find the optimised operation point. Figure E.2 shows the case where E_{U1},E_{U2} and E_{U3} are working in “supply and supply RENKEI”.
3) Demand and supply bidirectional RENKEI is an operation mode that optimises the total energy consumption for both the demand of production lines and the energy supply from utilities. The production management system works for “demand and supply bidirectional RENKEI” adjusting the production scheduling to optimise the production volume and necessary energy supply, taking the economic factors such as the changing price of energy into account.

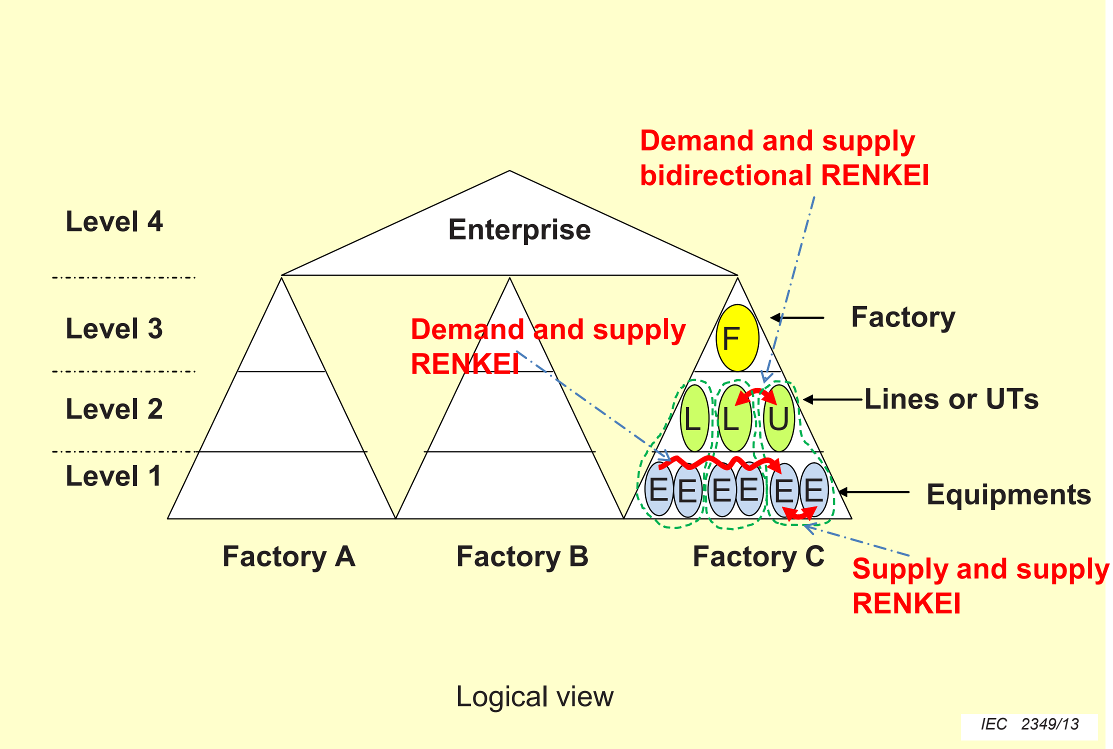


Figure E.1 – “RENKEI” control

Figure E.3 shows a typical energy flow in a factory. A utility plant provides production lines and offices with necessary energy such as electricity, steam, compressed air, hot water, chilled water and so on. These are generated by purchased electricity, fuel and gas with an optimised mixture depending on the price and delivery conditions. The horizontal yellow arrow is a demand-supply “RENKEI” and the vertical yellow arrow is a supply-supply “RENKEI”.

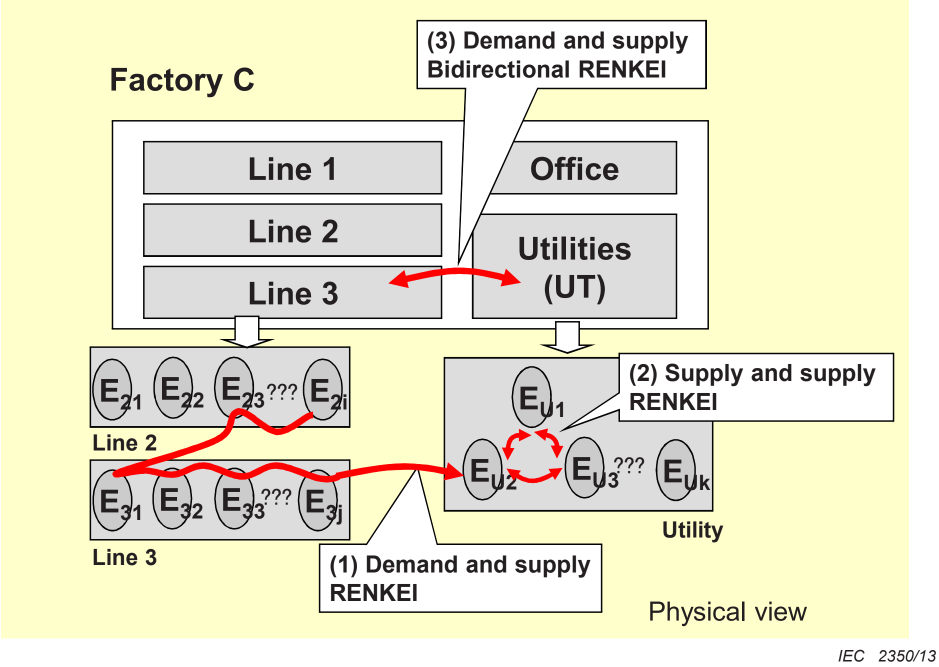
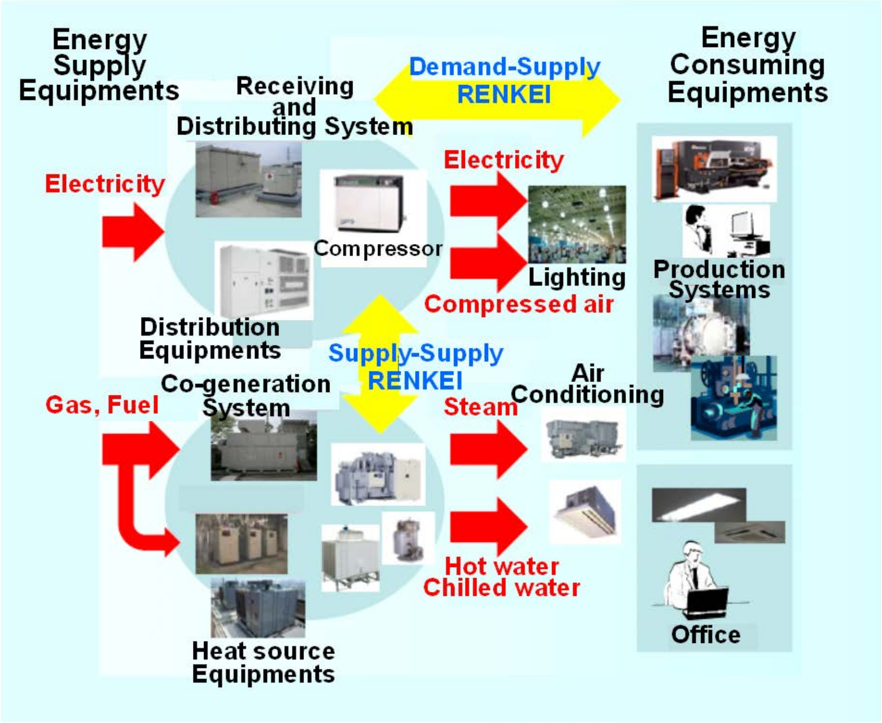


Figure E.2 – “RENKEI” control detail

As described above, RENKEI control is effective to improve total energy efficiency by plant-wide optimisation. In order to apply RENKEI control, an EEI (energy efficiency indicator) for RENKEI control should be developed. EEI should be defined for an energy management unit such as equipment, a production line and a factory. An EEI for product should be defined as well.



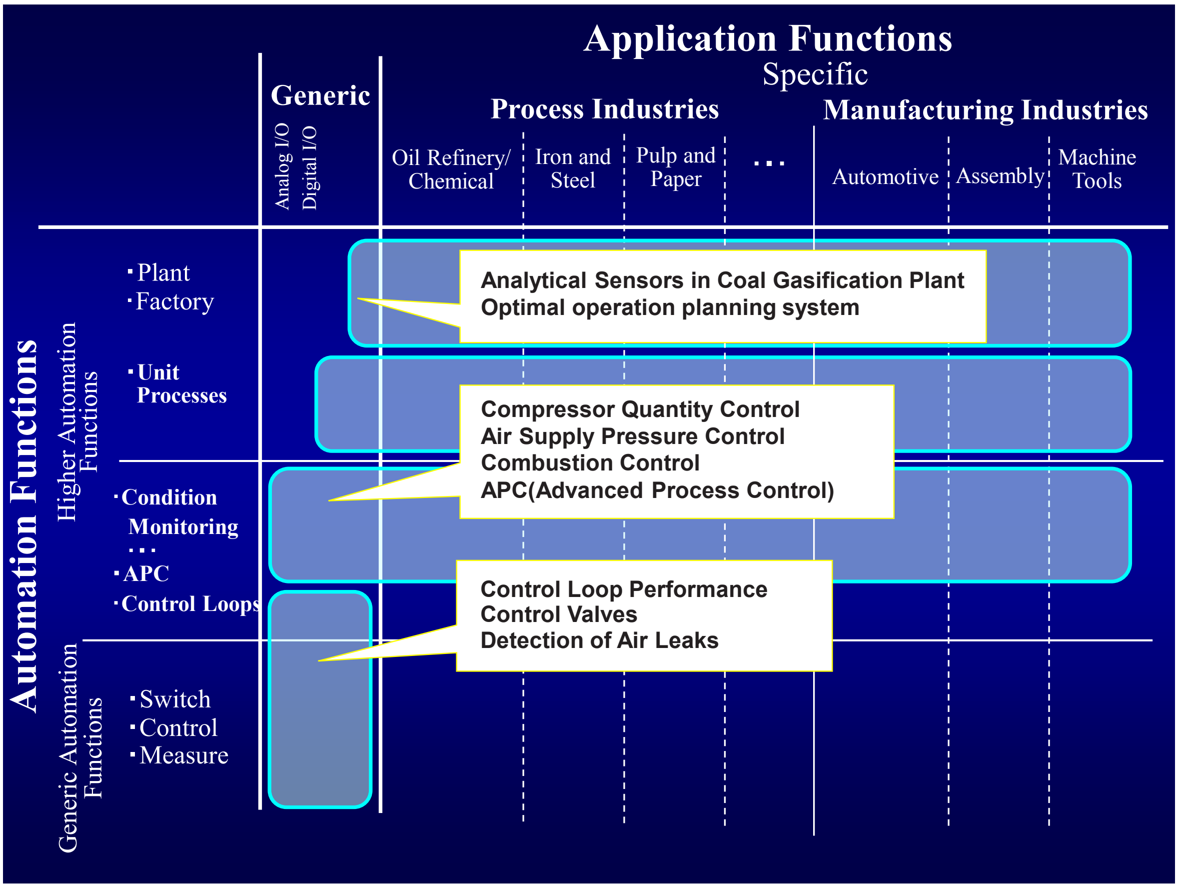
IEC 2351/13

Figure E.3 – Energy flow in a factory

Annex F
(informative)

Measurement and control technologies that support energy efficiency improvement

F.1 Technologies to improve energy efficiency



Analytical Sensors in Coal Gasification Plant
Optimal operation planning system

Compressor Quantity Control
Air Supply Pressure Control
Combustion Control
APC(Advanced Process Control)

Control Loop Performance
Control Valves
Detection of Air Leaks

IEC 2352/13

Figure F.1 – Components and automation functions

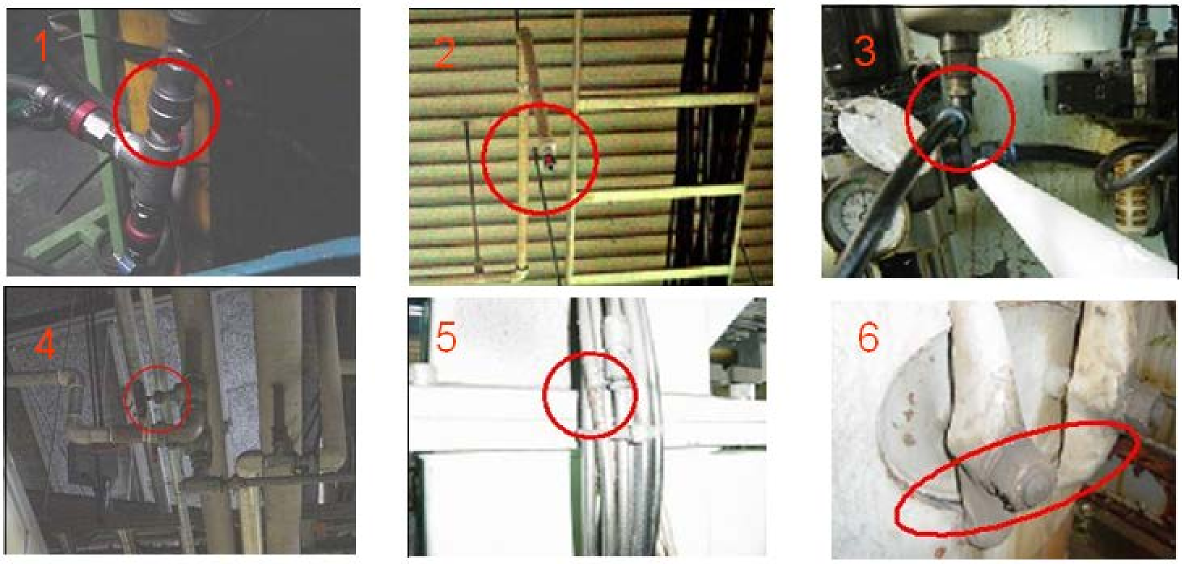
Figure F.1 shows a map of the technologies to improve energy efficiency. Items are positioned in a vertical hierarchy. The items are explained in F.2 to F.10.

F.2 Detection of air leakage

In process plants, there are many field devices and types of equipment that operate with a supply of compressed air. Compressed air is fed to the devices through pipes and joints. As the compressed air distribution network in a plant can extend over a wide area and be in a rugged environment, there is a possibility that leaks will develop. Table F.1 and Figure F.2 show an actual example of compressed air leaks at the level of coupler, T-joint, stop valve, air tube and maintenance hatch. The leaks can be detected at an early stage by ultrasonic detectors, electrochemical detectors, infrared point detectors, semiconductor detectors, holographic detectors, flow-pressure sensors and software based system/component diagnosis/monitoring and so on. Repairing a detected leak improves the energy efficiency of a plant.

Table F.1 – Pipe air leaks detected by ultrasonic sensing device

	Identified point	Measurement distance (m)	Sensitivity level	Air leak (Nm^3/h)	Annual loss (Nm^3/year)
1	Coupler	2,0	6	0,7	5 880
2	Coupler	4,0	5	0,6	5 040
3	T-joint	0,3	6	0,7	5 880
4	Stop valve	3,0	6	0,5	4 200
5	Air tube	1,0	1	1,4	11 760
6	Maintenance hatch	2,0	1	1,8	15 120



IEC 2353/13

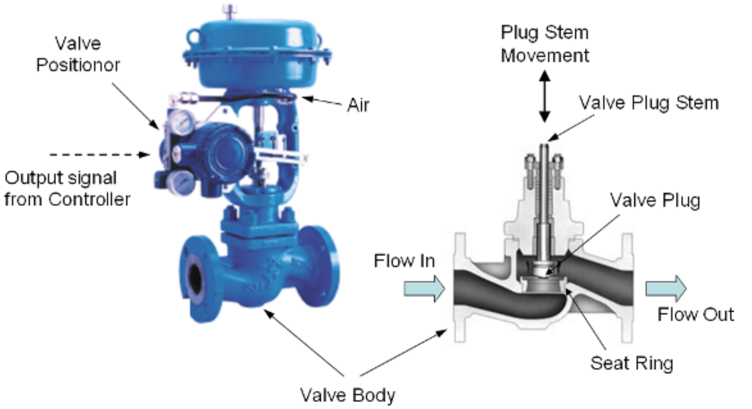
Figure F.2 – Pipe air leaks

F.3 Control valves

Control valves are widely used as the final control elements for process control, manipulating a flowing fluid, such as gas, steam, water, or chemical compounds. Figure F.3 shows the structure of a control valve. The positioner converts the output signal from a controller to air pressure that manipulates the valve plug stem up or down. The control is done by adjusting the clearance between the plug and the sheet ring in the valve body. A well-tuned control loop will decrease unnecessary movement of the control valve and the air consumption of the control valve. Decreasing unnecessary movement increases the life of the valve.

Control valves installed in industrial processes usually manage high pressure fluid flow. Various dynamic phenomena, such as acoustic noises, mechanical vibrations, cavitations, and flow fluctuations, frequently become intense due to a high rate of energy conversion within the valves. One of the serious consequences of the cavitations is material erosion. These mechanical motions cause valves to wear out, which can cause a plant shutdown. Microprocessor based intelligent valve positioners have diagnostic functions that sense valve motion and provide predictive maintenance information that can prevent a plant shutdown. The status information of a control valve is sent back to the process control system via a fieldbus or some other interface and used for maintenance.

Status monitoring of control valves and well-tuned control reduce the amount of energy consumed by the valves, and a stable control of processes reduces the amount of energy consumed by a plant.

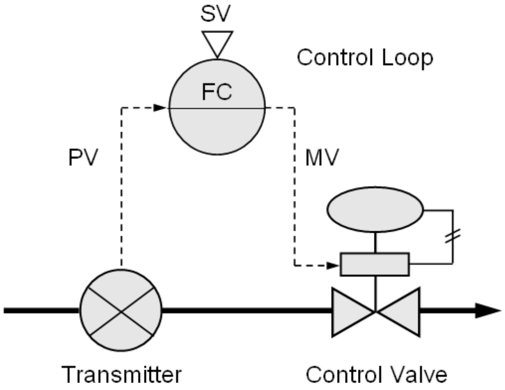


IEC 2354/13

Figure F.3 – Structure of control valve

F.4 Control loop performance improvements

In process plants, there are many kinds of control variables (CV) such as temperature, pressure, level, and flow rate, which are measured and controlled to the target values. Figure F.4 shows a basic control loop that is widely used for many kinds of industrial process applications. Control loops consist of a measurement element (transmitter, sensor), an actuator (most commonly a control valve), and an executed control algorithm (control function FC with set variable SV) such as a PID control. Efficient and effective execution of basic plant control loops is essential to successful operation of a plant and to other functions such as advanced control and real-time optimisation. Improvements in each of these elements can lead to reduced energy usage.



IEC 2355/13

Figure F.4 – Control loop performance improvements

Figure F.5 shows the actual improvement from control performance analysis and tuning. Line speed changes disturb the control loops. If a control loop is not well-tuned for PID control parameters, the disturbance causes unstable output with some overshoot and oscillation. That consumes more energy than a well-tuned control.

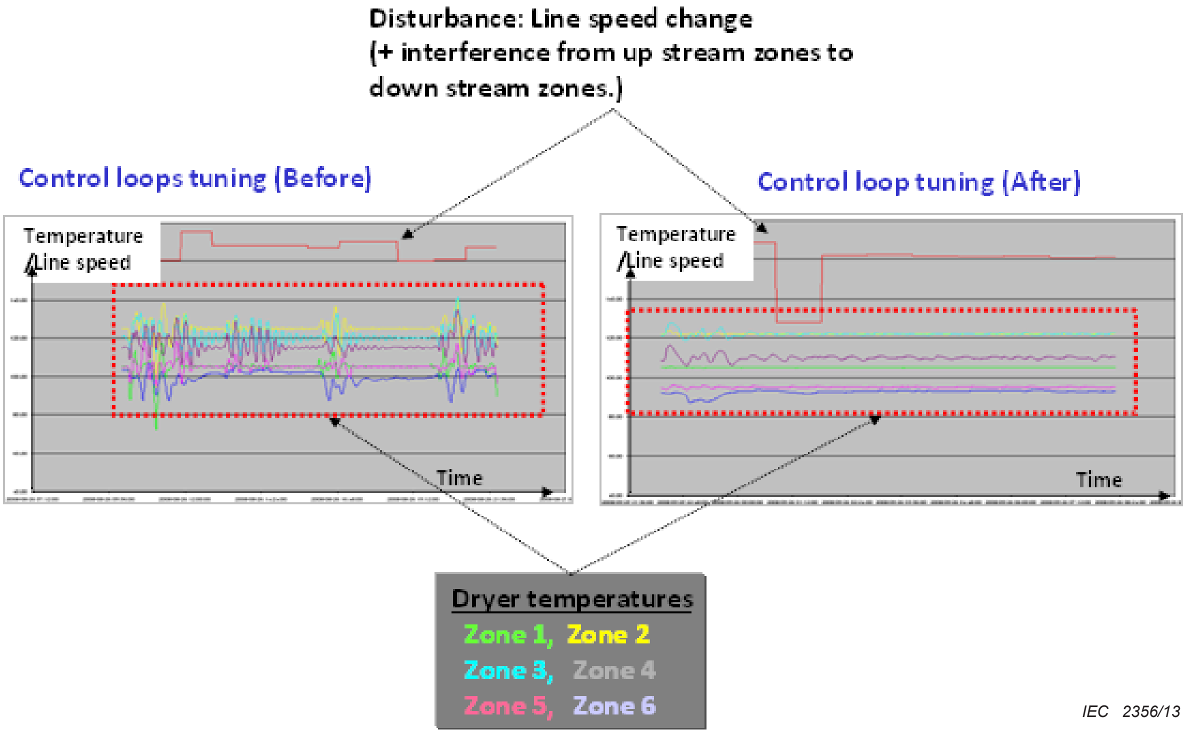


Figure F.5 – The effects of control performance analysis and tuning

F.5 Combustion control

Combustion requires fuel and air (oxygen), and a lean air-fuel mixture causes incomplete combustion with soot and smoke. On the other hand, a rich air-fuel mixture causes problems, such as the emission of excessive amounts of exhaust gas and the heating of the excessive air, resulting in lower fuel efficiency. Figure F.6 shows the principle of the air-fuel ratio and the state of combustion. The air-fuel ratio plotted on the horizontal axis shows the ratio of actual supply air to the theoretical amount of air required for fuel combustion (theoretical air amount).

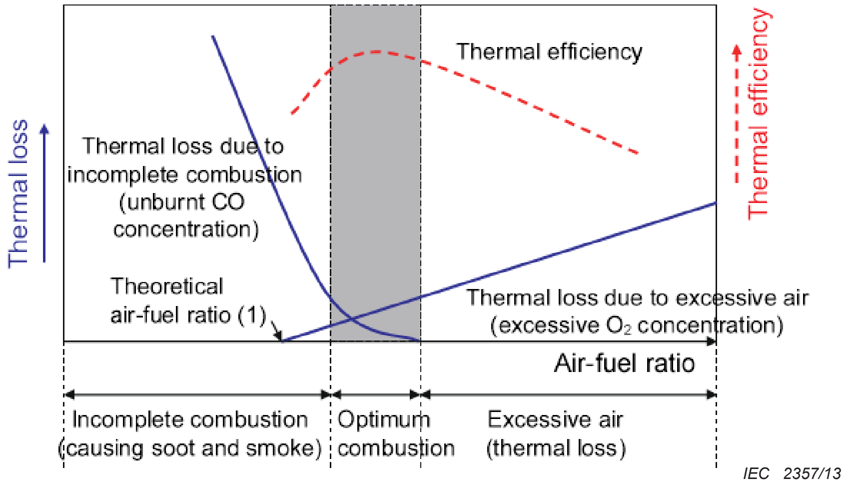
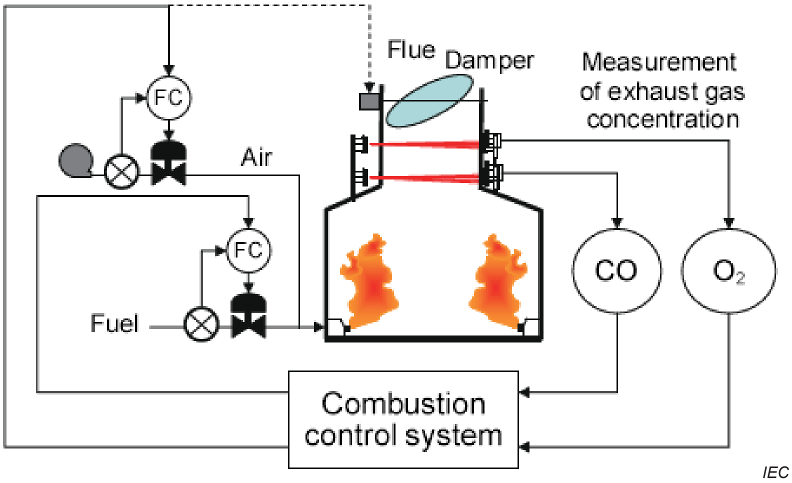


Figure F.6 – Relationship between air-fuel ratio and heat efficiency (combustion)

For combustion furnaces such as heating furnaces and boilers in plants and factories, small-scale controllers such as single loop controllers are employed to optimise the air-fuel control ratio for improving combustion efficiency (see Figure F.7). In large combustion furnaces, distributed control systems (DCS) and advanced control (multivariable predictive control, etc.) are used. These mainly control the air-fuel ratio and internal pressure of the furnace to prevent CO, CO_2 and NOx (nitrogen oxide) from being emitted and apply a cross limit circuit to prevent incomplete combustion while controlling combustion to maximize efficiency.

Changes in ambient air temperature and relative humidity have a strong effect on combustion conditions, even when fuel composition is held constant. When fuel composition varies, direct CO measurement is the best way to monitor combustion efficiency and enable tight furnace control.



IEC 2358/13

Figure F.7 – CO and O_2 control system for combustion furnace

The amount of air supplied to a burner is controlled by two methods: using a forced draft fan (FDF) and damper as shown in Figure F.7 or using natural air intake by controlling how far the damper of an induced draft fan (IDF) is opened. The O_2 and CO concentrations are measured by a concentration meter at the entrance of the flue and then supplied to the control system. The measured CO concentration can be used for combustion control by two methods: controlling O_2 when the O_2 concentration exceeds a prescribed value and overriding to CO control when the O_2 concentration falls below the value, or giving a CO concentration bias (compensation) to the O_2 concentration. Real time measurement of CO and O_2 concentration in the flue enables optimised combustion control.

F.6 Advanced process control (APC)

Figure F.8 explains what APC is. The figure shows an example in which less energy is consumed by reducing the allowance as much as possible within a range not exceeding the operational limit of the target process.

The period with large amplitudes on the left of the trend data in Figure F.8 is the one during which APC is not activated (before APC is introduced). Basic control loops such as those for flow-rate, temperature, level, and pressure are controlled during this period by systems such as a distributed control system (DCS), and the operator adjusts the set-points manually to achieve energy consumption targets. Accordingly, the data usually varies significantly, so a large allowance is required against the operational limit in case unexpected changes occur during operation.

As shown during the period in which APC is activated, the introduction of APC improves the control performance and results in the reduction of data variation. A decrease in data variation results in an increase in the gap between the fluctuating data and the operational limit, so optimisation of control makes it possible to bring the set-point even closer to the operational limit as shown during the period in which the optimisation of control is activated.

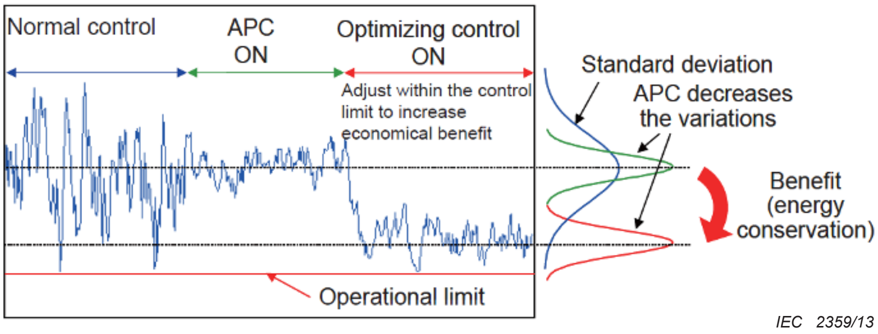


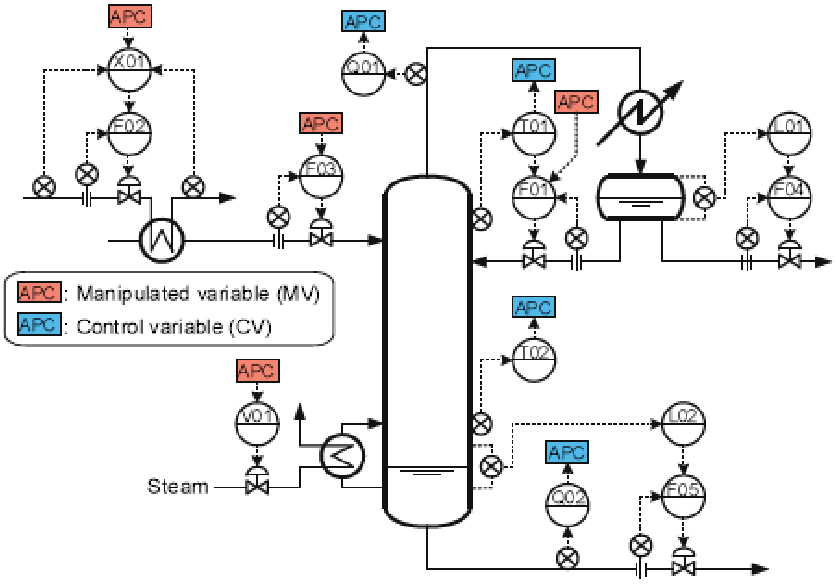
Figure F.8 – APC

As described above, APC can be defined as a control methodology that not only aims at improving control performance but also maximizes effects such as energy conservation by automatically bringing the operation closer to the optimum level.

Figure F.9 shows an example in which APC is applied to a distillation column to reduce energy consumption.

Application examples of oil and chemical processes:

- heating furnace;
- pass balance control;
- exhaust gas oxygen concentration control;
- distillation column;
- reactor;
- application examples in other processes;
- utility facilities (boiler, turbine, and generator), electrolyze.

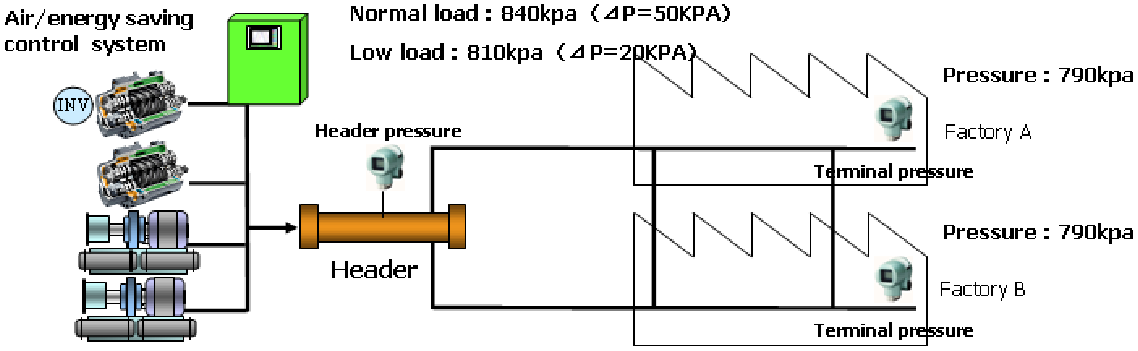


IEC 2360/13

Figure F.9 – Example of APC application for distillation column

F.7 Air supply pressure control

By measuring the required terminal pressure at the production line, it is possible to reduce the load of compressors by lowering the header pressure, as shown in Figure F.10. Around 3 % of energy-saving is possible by changing the header pressure value when the load is low.



IEC 2361/13

Figure F.10 – Air supply pressure control by pressure transmitter and compressor

F.8 Steam header pressure control

Figure F.11 shows the control of steam header pressure by means of compressor quantity control. Operating the minimum quantity of the compressors is achieved by predicting the compressor load based on header pressure.

Compressor no. 1: 15 kW with inverter.

Compressor no. 2: 11 kW.

Compressor no. 3: 22 kW.

Compressor no. 4: 22 kW.

Compressor no. 5: 37 kW.

In case of load-up:

1) Compressor no. 1 at 100 % < air consumption:

   Start up compressor no. 2. Compensate for deficiency with compressor n°1.

2) Compressors no. 2 and no. 1 at 100 % < air consumption:

   Start up compressor no. 3, and stop compressor no. 2. Compensate for deficiency with compressor no. 1.

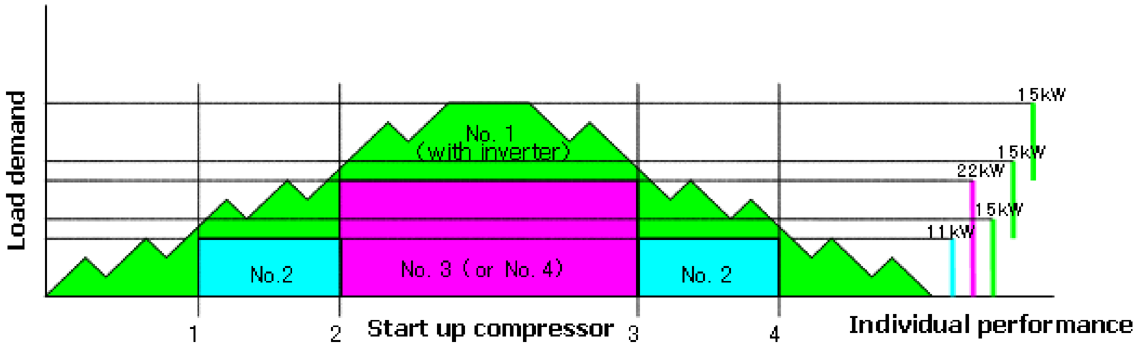
In case of load-down:

3) Compressors no.2 and no.1 at 100 % > air consumption:

   Stop compressor no.3, compressor no.1 at 100 %.

4) Compressor no.1 at 100 % > air consumption:

   Stop compressor n o. 2.

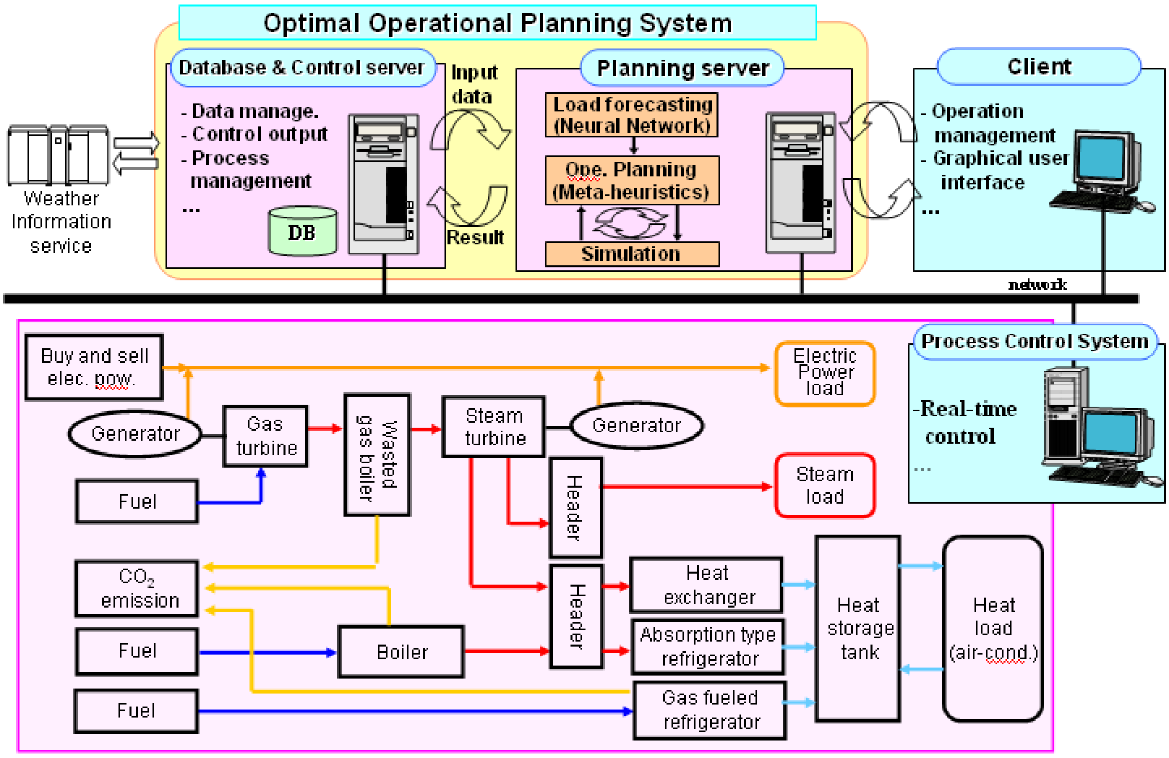


IEC 2362/13

Figure F.11 – Control of steam header pressure by means of compressor quantity control

F.9 Optimal operational planning system

Figure F.12 shows an optimal operational planning control system for a power plant. In manufacturing plants, the main energy sources are electricity, heat, steam and compressed air that are supplied to the manufacturing plants by such power equipment as boiler, turbine and generator. The amount of energy supply depends on the demand for production volume. It is also affected by such conditions as outside temperature and other operation status of the factory. This system calculates an optimum operating condition of individual equipment to get the highest energy efficiency as a total plant taking these factors into consideration. Modeling and simulation function, load prediction, load balance function and so on are used in the system. Individual equipment is controlled at the optimum point by the process control system. This is an example of plant-wide optimisation that is explained in 5.3.1.



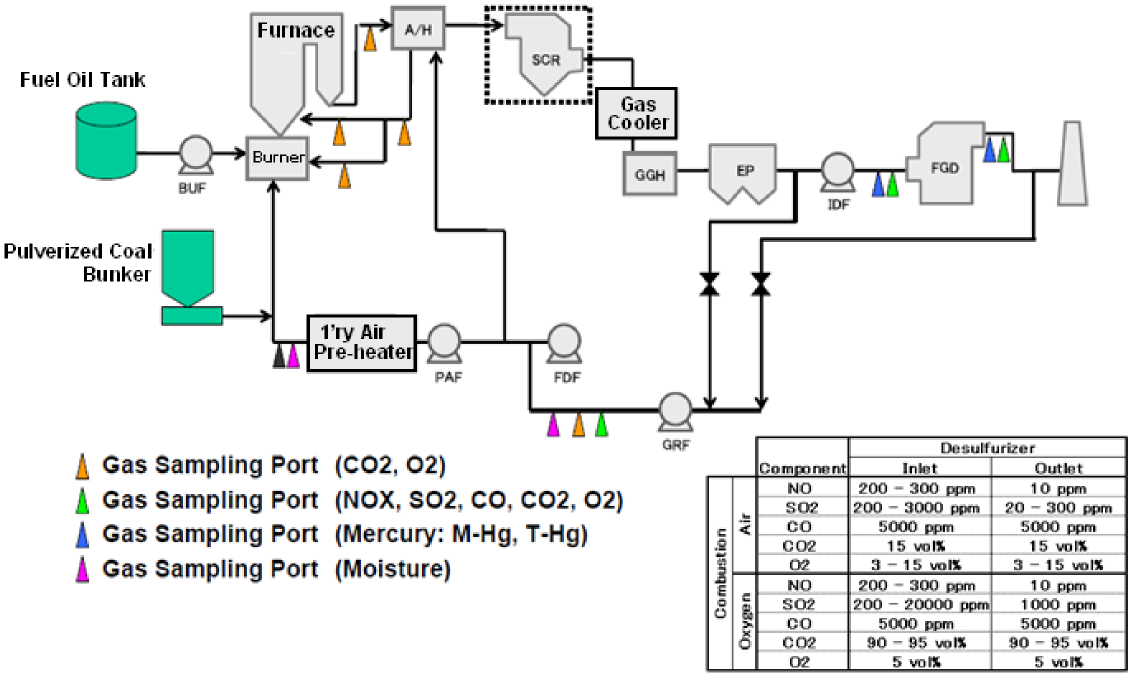
IEC 2363/13

Figure F.12 – Optimal operational planning system

F.10 Analytical sensors

Figure F.13 shows an application example of analytical sensors for coal gasification plants that burn coal with only oxygen to get the flue gas that does not practically contain other than CO_2. The objective of this plant is to accelerate carbon dioxide capture and storage (CCS) technology that has been receiving attention as one of the promising technologies for CO_2 reduction.

In order to control the balance of outgases such as NOx, CO, CO_2 and O_2, in-line analytical sensors are installed in the plant to measure the concentrations of these gases. Analytical sensors play a key role in enabling the plant.



		Component	Desulfurizer	
			Inlet	Outlet
Combustion	Air	NO	200 – 300 ppm	10 ppm
		SO2	200 – 3000 ppm	20 – 300 ppm
		CO	5000 ppm	5000 ppm
		CO2	15 vol%	15 vol%
		O2	3 – 15 vol%	3 – 15 vol%
	Oxygen	NO	200 – 300 ppm	10 ppm
		SO2	200 – 20000 ppm	1000 ppm
		CO	5000 ppm	5000 ppm
		CO2	90 – 95 vol%	90 – 95 vol%
		O2	5 vol%	5 vol%

IEC 2364/13

Figure F.13 – Coal gasification plant

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