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Technical energy systems — Methods for analysis

Part 1:

General

Systèmes d'énergie technique — Méthodes d'analyses

Partie 1 Généralités

Reference number
ISO 13602-1:2009(E)

Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare international standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this part of ISO 13602 may be subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13602-1 was prepared by Technical Committee ISO/TC 203. *Technical energy systems.*

ISO 13602 consists of following parts, under the general title *Technical energy systems - Methods for analysis*

- Part 1: General

Other parts of ISO 13602 for *energy systems labelling,* and *weighing and aggregation of energywares,* and

ISO 13602-3 *Technical energy systems - Methodology for statistics and forecasting* are under preparation.

Annexes A, B, C, D and E of this part of ISO 13602 are for information only.

This revised edition takes latest developments and terms in the energy sector into account.

Introduction

International Standards ISO 13600, ISO 13601 and ISO 13602 (all parts) are intended to be used as tools to define, describe, analyse and compare technical energy systems (TES) at micro and macro levels. These tools enable the user to make objective choices of technical energy systems in their total technical, economic, environmental and social contexts and thus to help consensus-building and decision making.

International Standard ISO 13600 covers basic definitions and terms needed to define and describe TESs in general and TESs of energyware supply and demand sectors in particular. ISO 13601 covers structures that shall be used to describe and analyse sub-sectors at the macro level of energyware supply and demand, while ISO 13602 (all parts) facilitates the description and analysis of any technical energy systems.

The rapidly advancing development of renewable energy systems for economic, environmental, global climate and health protection reasons is causing a shift from tradable, non-renewable energywares, mostly produced in centralized power plants and refineries, distributed over power lines, substations or fuel storage and transport infrastructures to the energy users, towards decentralized, independent energy systems using renewable energy sources, often operating off-the-grid, such as solar systems on roofs, private mini wind power, sail ships, wind pumping, independent biomass and bio fuel cultivation, heating by private heat pumps, passive solar architecture and solar air conditioning, hydro or wind powered electric or hydrogen cars, benign novel energy systems producing fuels, heat and electricity independently, muscle energy for work and clean mobility au lieu of fossil fuel powered vehicles or electricity grid-fed energy systems.

However, decentralized energy systems may also produce more than what is consumed for local needs and therefore may feed the energy surplus into the power grid, store it or sell excess fuels to the local market, then to be accounted for as tradable energyware. Excess hot water might be sold to neighbours or to district heating systems.

Economic evaluations of technical energy systems and energy statistics have to take the total energy production into account to avoid that some parts of energy supply and demand are appearing or disappearing in statistics and plans, such as the substitution of bicycles by motor cycles, or motor boats by sail ships, or jet fuel propelled aeroplanes by clean air ships, or work animals by tractors, or of fossil fuelled heating systems by biomass boilers, heat pumps or solar collectors etc.

Technical energy systems — Methods for analysis

Part 1: General

1 Scope

This part of ISO 13602 provides methods to analyse, characterize and compare technical energy systems (TES) with all their inputs, outputs and risk factors. It contains rules and guidelines for the methodology for such analyses.

This part of ISO 13602 is intended to establish relations between inputs and outputs and thus to facilitate certification, marking, labelling, comparable characterizations, coefficients of performance, energy resource planning, environmental impact assessments, meaningful energy statistics and forecasting of the direct natural energy resource or energyware inputs, technical energy system investments and the performed and expected future energy service outputs.

2 Normative references

The following normative energyware-related documents of the ISO 13600 series contain definitions which, through reference in this text, constitute some provisions of this part of ISO 13602. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on ISO 13602 are encouraged to investigate the possibility of applying the most recent edition of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 13600:1997, *Technical energy systems — Basic concepts*.

ISO 13601:1998, *Technical energy systems — Structure for analysis — Energyware supply and demand sectors.*

The ISO 14000 standard series, in particular

ISO 14040:1997, *Environmental management — Life cycle assessment — Principles and framework*

plus the hundreds of ISO and IEC standards on various energy systems, on normative environmental parameters like quality of water and air, and safety, have to be applied for the planning, specification, design, production, installation and use of technical energy systems. See ISO and IEC catalogues.

3 Terms and definitions

For the purpose of this part of ISO 13602, the following terms and definitions apply, in addition to the basic definitions relating to the specific energyware flows and structures, given in ISO 13600.

3.1
embedded energy
total amount of directly used energy and energyware required to produce or process inputs to make a technical energy system (TES)

NOTE Upon decommissioning and in recycling the materials, some of the embedded energy can sometimes be reclaimed.

3.2
technical energy system (TES)
combination of equipment and plant interacting with each other to produce, consume, or in many cases transform, store, transport or handle energyware and other forms of energy from natural resources

3.3
energy resource
any matter or phenomenon that can be converted into tradable energyware or directly into locally used energy services, which can be classified as renewable, non-renewable or reclaimable resource

NOTE See Table 4 for examples of energy resources.

3.4
energy service
useful, measurable output of any intermediate or energy end-use system

NOTE See Table 5 for examples of energy services for defined functional units.

3.5
energy-use system
part of a technical energy system converting energyware or other energy sources into energy services

3.6
functional unit
quantified performance of a technical energy system for use as a reference unit

3.7
renewable resource
natural resource for which the ratio of the creation of the natural resource to the output of that resource from nature to the technosphere is equal to or greater than one

3.8
capital goods
input to a technical energy system composed of investment goods, software, services and facilities

3.9
capital investment
investments in capital goods and construction or installation activities composing a technical energy system

3.10
coefficient of performance (COP)
ratio of the energy input to the useful energy output of a TES

3.11
exergy
maximum amount of useful energy or work potential in a TES which becomes available when the system is brought into equilibrium with the surrounding natural environment = zero entropy energy

3.12
enthropy energy that is not available for work

3.13
energy pay-back (period)
recovery (period) of the energy spent for manufacturing of the respective TES, also called harvesting ratio

3.14
potential energy
stored energy that the mass of an object posses by virtue of its gravitational position, by elastic properties, or stored by chemical bonds, that is potentially transformable into another form of energy or be harnessed to do work

3.15
kinetic energy
the energy of an object by virtue of its motion. equal to one-half the product of its mass times its velocity squared

3.16
power characteristics (power graph)
performance characteristics of a TES over its whole output range, depending on wind speed, water pressure and flow, insolation, Carnot cycle, time cycles etc. See examples in Annex D

3.17

passive and low energy architecture (PLEA)
buildings with optimized energy systems which might be energy self-sufficient or even energy producing

3.18
zero-energy building
self-sufficient building that does not need any operational energy from outside, except embedded energy in the building materials and systems

3.19
energy-plus building
building that produces excess energy which can be stored or delivered to outside users

3.20
total final energy consumption (TFC)
This designation is the sum of final energy uses of the end-use sectors.

3.21
Combined heat and power (CHP)
The heat output of power plants also called co-generation

4 Methods of analysis of technical energy systems (TES)

4.1 General

The methods for the analysis of TES have two distinctly different but complementary purposes.

a) Combined TES (macro level)

Chains combining TESs using energyware or direct energy sources may be compared and optimised from different viewpoints:

— technical (life, efficiency, COP, safety, feasibility, reliability, vibrations, technical side effects, decommissioning)

— economic (competitiveness, availability, reliability, mounting cost, maintenance, longevity, pay-back time)

— ecological (emissions, radiation, waste disposal, recycleability, climate, biosphere & health side effects, noise)

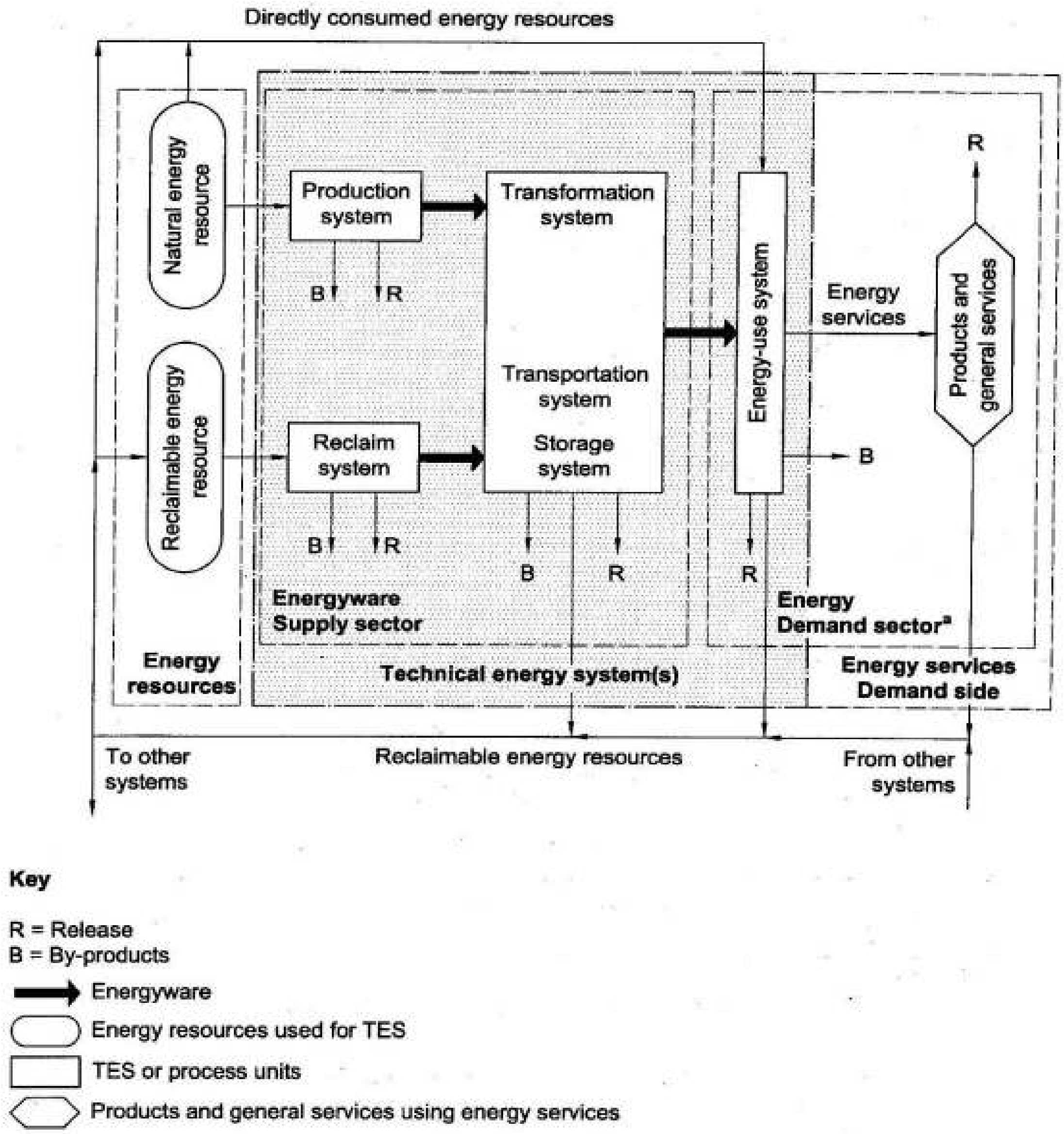
This method of analysis enables to deduce social impacts, such as health, well-being and social costs of a whole energy concept like coal. Strategic decisions about matters, such as conservation of resources, saving foreign exchange, national security and traffic congestion may be made. Overall comparisons of coal, oil, gas, nuclear, hydro, wind, bio, geo, solar and hydrogen technical energy systems constitute examples of this method of analysis.

b) Alternative systems within combined TESs (micro level)

A TES can be composed of one or several subsystems, which may be combined, analysed or compared with an alternative TES at various stages. These alternative combinations may concern tradable energyware production, conversion, refining, transformation, transport, handling or storage methods, and cooling with public water or air and the hazardous waste disposal, or non-tradable decentralized clean, renewable energy production and final energy-use processes.

Energy flows within a generalized TES ranging from the energy resource inputs to the final energy service outputs, which are needed to manufacture products or render services of a general nature such as transport, cooking, heating, cooling, illumination, defence, entertainment, data processing, telecommunications or medical services, are shown in Figure 1, whereby:

TFC = total final energyware consumption complemented by privately produced and privately consumed sustainable energy *



igure 1 –

Energy flows within a generalized TES

4.2 TESs yielding comparable energy services

Examples of simplified alternative technical energy systems (TES) chains are given in Table 1.

Table 1 — Simplified TES alternatives

Example	Energy resource	Transport / Conversion / Distribution	Energy-use system	Energy service
4.3.1	Beeswax	Horse cart - Candle maker - Truck	Candle	Lighting
4.3.2	Sunlight	Light duct	Building	Lighting
4.3.3	Natural gas	Pipeline - Power station - Cable - Transformer	Light bulb	Lighting
4.3.4	Wind	Propeller - Generator - Transformer - Cable	Fluorescent lamp	Lighting

A possible combination of TESs in a factory with their various energy inputs and energy service outputs is shown in Figure 2, whereby each energy-use system can be analysed and alternatives compared.

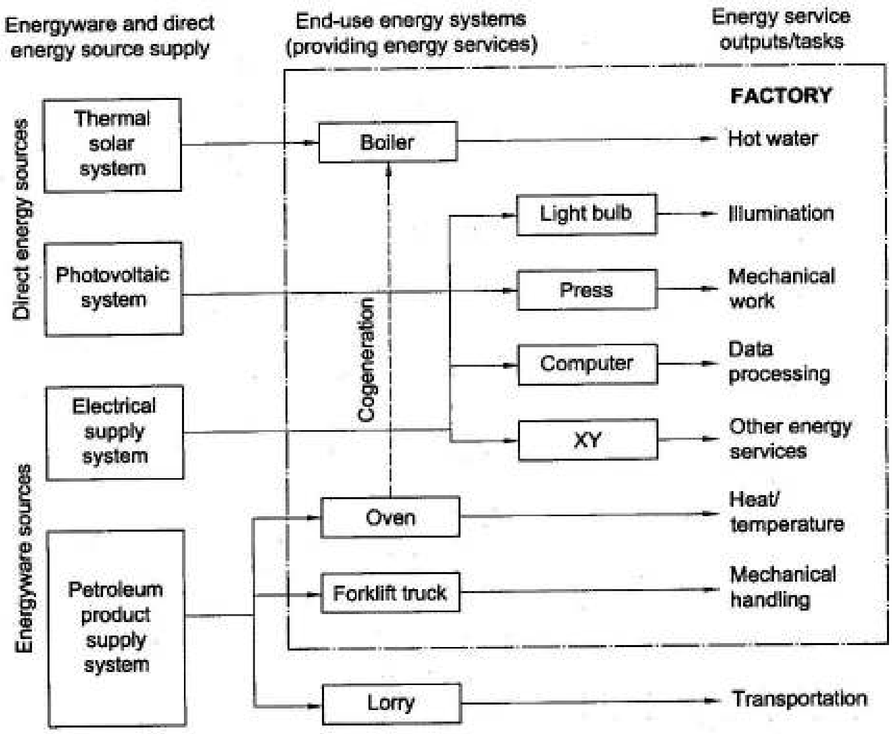


Figure 2 — Examples of possible combination of TESs in a factory

5 I-O (input-output) analysis of TES

5.1 Elementary input-output (I-O) model

TESs shall be analysed by means of standardized I-O models which allow systematic quantitative and qualitative comparisons. This elementary I-O model is defined in Figure 3. It is applicable to any TES, including all factors determining the internal and external costs and impacts. It distinguishes two different I-O categories, shown on the vertical (A) and horizontal (B) axes.

Practical examples of applied and combined I-O models on the demand side, such as an energy saving lamp, a refrigerator and co-generation unit are shown in Annexes A, B and C, respectively.

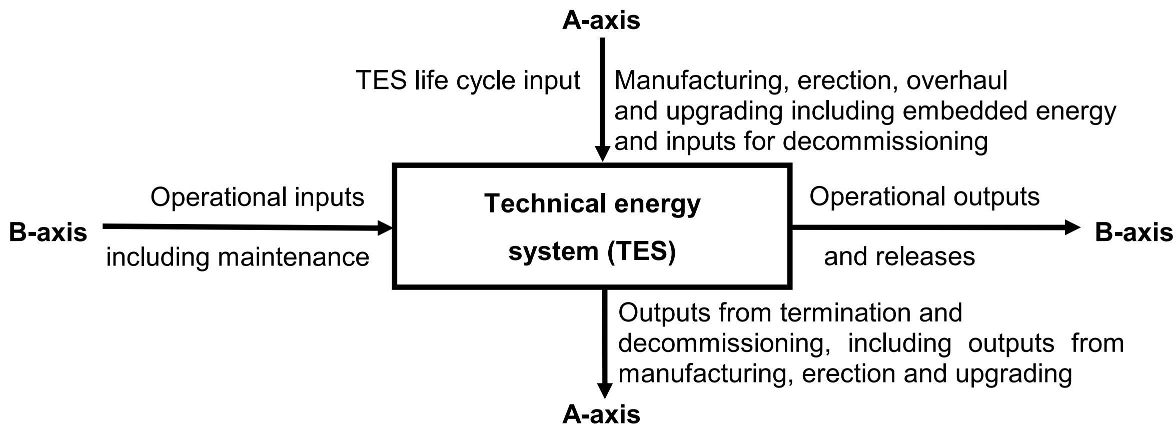


Figure 3 Elementary I/O Model

5.2 Life cycle and operational I-O categories

5.2.1 Capital goods and related service inputs needed to set up a TES, such as construction materials and labour, hardware and software, space and predefined information enter the I-O model on top on the A axis (see column 2 in table 2). Residues, re-usable or recyclable materials or waste and possible after-effects including releases and environmental impacts of the terminated and decommissioned systems and possibly affected facilities like contaminated soils, irreparable landscapes or biospheres and radioactive items, leave the box at the bottom on the A axis (see column 2 in Table 3).

5.2.2 Operational inputs such as energy resources (see Table 4) or energyware (see Annex A of ISO 13600:1997) and inputs related to the maintenance of TES (see Table 2), operational manpower, operational information and auxiliary materials like lubricants, pass through the I-O model horizontally on the B axis entering on the left, and outputs like energyware, final energy, energy services, releases and by-products including emissions or waste, exit to the right on the B axis (operational outputs in Table 3).

The outputs of power generation systems depend on the time and flow ranges and variations as well as on the physical properties of the inputs. Typical I-O characteristics of power generation systems are shown in Annex D.

Table 2 — Examples of possible TES inputs

Operational inputs including maintenance	Inputs related to the erection and upgrading of energy systems
Energy resources Details see Table 4. **Energyware** See Annex A of ISO 13600:1997. **Air or its components** E.g. O_2, N_2, CO_2, H_2O (misture, vapours) **Water (also in the form of steam and ice)** E.g. as a feedstock, cooling agent or energy carrier **Ancillary materials** E.g. catalysts, reagents, cathodes, anodes, electrolytes, lubricants, spare parts, maintenance materials **Human resources** On- and off-plant manpower, supporting staff and management **Animal and human muscle power** used as natural energy resource input **Information** Data acquisition, storage and processing, Communication and man-TES interface (SCADA)	**Space** Land space (exploration, development, reclamation, flooding, fencing), roof and façade space Water space (seas, lakes, ponds, rivers) Air space (elevated, suspended, rotating or flying structures) **Capital goods and facilities** Buildings (insulation, windows, shading, solar orientation, roofing, facades, insulation etc.) Platforms, vessels, rafts, pipelines, dams, canals, wave, sea current and tidal structures etc. Process plant equipment, generators, machines Mechanical handling equipment, e.g. elevators, conveyors, fork-lift trucks, cranes, pumps Storage equipment for kinetic, thermal, chemical, biochemical, potential and electric energy Transport equipment for railroads, roads, waterways, air, cables, power lines, pipelines Installations for manufacturing processes, safety and security **Information equipment** Measurement data acquisition, storage, conversion and transmission means Hard- and software for data processing Telecommunication hardware and software

Table 3 — Examples of possible TES outputs

Operational outputs	**Outputs and effects related to the erection, upgrading, termination and decommissioning of TESs**
Energyware See Annex A of ISO 13600. **Energy service** **(useful energy)** See more details in Table 5. • Mechanical, e.g. handling, transport, machining, processing • Thermal, e.g. heating, cooling, freezing, melting, hot processing, welding • Electrochemical, e.g. electrolysing, galvanizing • Information and communication, ~~e.g.~~ data processing, sound effects, scanning, GPS • Light, e.g. street lighting, illumination, projections from slide or movie projectors, beamers • Medical applications, physical therapies **By-products, including usable discharges** • Reclaimable energy resources (see Table 4) • Usable chemicals and water • Mineral oil residues, e.g. bitumen, tar, pitch • Biomass, e.g. fertilizer materials, sawdust, bio waste • Coal and graphite for special applications, e.g. electrodes, filter media • Heat convection or radiation or transfer by a medium **Release, including waste and losses** • Acoustic phenomena, e.g. audible noise, sound and ultrasound • Mechanical shock, vibration • Electric and magnetic fields • Waste heat and heat losses • Thermal and humidity changes in the environment • Optical and radioactive radiation & neutron emissions • Solids from industrial processes, e.g. unusable ash, residual solid waste, spent ore • Liquids, e.g. contaminated water, waste chemicals, oil spills, sludge • Gases, e.g. pollutants, greenhouse gases, lost or spent steam • Residual waste from waste processing • Volatile particles, including heavy metals **Liquid and solids from equipment maintenance**	**Recyclable and re-usable materials** (from production, erection and after replacement or decommissioning) **Wasted materials, facilities, soils and space before and after decommissioning** **Decommissioned hardware** • Defunct parts, scrap and demolition waste, debris, wrecks **Residues and contamination** • Spilled or entrapped liquids, solids and gases, contaminated soils, air, ground water, water ponds and seas, nano-particles. • Residual hazardous waste or pollutants or both • Radioactive matter (accident risks and decommissioned nuclear power plants) **Affected landscapes and habitat** • Defigurations from open-pitch mining • Buried cultural treasures and historic sites • Spoilt fertile lands and touristic sights • Displaced rivers, roads and communities • Flooding of landscapes and sea shores • Loss of natural habitat, such as forests • Landslides due to global warming • Melting polar ice caps and glaciers • Health effects on life in habitats and on farms • Endangered coral reefs and rare sea species • Retracting ground water levels • Obstructing power lines and masts **Negative effects on life and biodiversity** • Loss or degeneration of rare plants and bacteria • Loss or degeneration of sea life and sweet water • Damage to mangroves and their habitat • Loss or degeneration of land species • Loss or degeneration of birds and insects • Disturbances of bird and fish migrating routes • Disturbances of the natural bio balance • Health hazards and genetic damages

Table 4 — Examples of energy resources

Natural energy resources	**Reclaimable energy resource**

Renewable	Non-renewable (finite)	
• Biomass, e.g. woods, agriculture residues or energy crops • Biogas and sludge gas • Thermal energy, e.g. geothermal, ocean thermal, solar infrared spectrum and temperature gradients (e.g. for heat pumps) • Radiant energy, e.g. for solar PV • Kinetic energy, e.g. wind, waves • Static energy, e.g. for hydro power • Food, feed and drinks for human and animal muscle energy	• Hard coal (unexcavated) • Brown coal (unexcavated) • Tar Sands • Peat (unexcavated) • Uranium, thorium (unexcavated) • Crude oil (unexcavated) • Tar - pure or in sand or earth • Natural gas (unextracted) • Deuterium etc. (for fusion) • Electrodes for transmutations	• Animal, plant and human waste • Industrial waste, e.g. used solvents, sawdust, ash, slag, spent ore, tires • Domestic waste, e.g. liquid, solid • Waste heat, e.g. from cooling towers or process heat • Plutonium • Kinetic energy, e.g. recuperation from a moving body • Gravitational or elastic tension energy, e.g. recuperation from an elevated body or from a spring (potential energy)

5.3 Quantification of I-O on the A- and B-axes

5.3.1 General

The distinction of quantitative, operational, and capital goods parameters in two different axes permits the calculation and comparison of relevant TES characteristics as follows.

5.3.2 On the A-axis

Plot on the A-axis the following:

- the life cycle assessment (LCA) of the TES in accordance with ISO 14040 etc.;
- the recycling efficiency and embedded energy balance of the hardware of the TES.

5.3.3 On the B-axis

Plot on the A-axis the following:

- determination of the running cost and possible negative effects of a TES, including exergy and enthropy.
- calculation of the TES day-to-day operational efficiency, coefficient of power (COP) and power characteristics.
- operational mass balance, energy balance, cooling by air or rivers and possible chemical transmutations.

5.3.4 A- and B-axes combined

The viability of a TES can be assessed by comparing the A and B inputs against the A and B outputs, to obtain e.g. the energy payback period or energy harvesting ratio and the power yield characteristics.

5.4 Capital investments

5.4.1 TESs are enabled by of capital investments (3.9). The latter may be included in the TES being studied. Capital goods (3.8) are an input to the system (A-axis in Fig. 3). Labour and ancillary materials including their embedded energy connected with construction activity are inputs to the system.

5.4.2 Comparisons may be made in any constant unit of value, including energyware or direct energy resources units. Assumptions made for bases of monetary value comparisons shall be clearly defined.

5.4.3 All inputs connected with capital investments have to be periodized in order to be commensurate with other inputs of the system. There are three different methods of doing this. In all studies it shall be clearly indicated which of these methods has been used.

a) The *"historical*" method consists in summing up all investment-related inputs occurring during the lifetime of the system, divided by the expected lifetime. This method, which is to be used mainly for micro studies, has the drawback that it is often difficult to estimate true technical lifetimes. There are, moreover, situations in which the environmental load of the initial capital investment is of limited relevance to the goal of the study, for instance when it is correct to regard it as "sunk cost", which however must be included in the total equation.

b) The *"instant*" method, which is used mainly in macro studies, consists of noting the capital investment-related inputs that occur during a chosen time period, for instance one year, and relating the result to all other inputs and outputs during the same period. The underlying assumption is that in very large industrial establishments, industry branches or economic sectors, TES investments are made continuously at a steady rate. Therefore, it shall be checked for cyclical variations in capital investment activity and adjustments made accordingly.

c) The *"forecast*" method takes estimated future capital investment only into account. This is the only method for the study of new TES technologies because historical data do not exist yet. The results of such a study are based exclusively on assumptions for the future.

6 Uses of functional units

6.1 When TES are to be compared, it is necessary to define a functional unit which shall be the same in all the cases studied and which may contain several I-O models. For energy-use systems normally an energy service is chosen as the useful output and common denominator of functional units. Examples of a functional units are the production of 1 kg of raw steel or 1 kgkm transport of goods or 1 dm^3 (1 litre) of hot tea at 40°C.

6.2 Energy services of other phenomena, such as a maintained temperature, ~~an~~ illumination on a given surface or an energy services providing motion, are usually not expressed in terms of energy. Useful energy outputs may provide energy services that can sometimes be characterized in other SI units, than the energy unit Joule (J), including, among others, qualitative aspects. Examples of energy services are given in Table 5.

6.3 Examples of functional unit characteristics are the shading of a light source-screen affecting the luminous flux, the ambient temperature around a refrigerator or a building, the rate and frequency of venting a room, the insulation, the number, volume and temperature of warm bodies or objects which are introduced, etc.

Table 5 — Examples of energy services for defined functional units

Example	Functional task	Quantity unit
1	Work, transportation, speed, acceleration, force	J, kg m, m s^{-1}, m s^2, N
2	Pumping, venting and vacuum applications	Pa, m^3 kg^{-1}
3	Specified thermal uses (heating or cooling)	°C, or K, J
4	Audio and ultrasound applications	dB, Hz, sound fidelity
5	Vibration for useful purposes	Hz, Hz J^{-1}
6	Lighting, illumination, magnification, colour rendering	lm, lx, R_a
7	Magnetic applications	T
8	Data processing, information	bit, bit s^{-1}, Sh
9	Telecommunication, television, visual display, resolution	bit s^{-1}, lx, dB
10	Physical therapy and diagnostic procedures	C kg^{-1}, Gy, Sv
11	Measurement and control, repeatability, etc.	bit s^{-1}, m s^{-1}, m s^2, V, A, kg s^{-1}
12	Electrochemical and physical processing	A, W, J, C

NOTE These quantifiable TES outputs are not valued by this part of ISO 13602 regarding their economic, cultural, moral, social or medical effects. The definition of these TES outputs is limited to the measurable quantities needed to determine objectively the physical performance, efficiency, efficacy, effectiveness and environmental impacts of such systems and is of course related to performance criteria such as speed, acceleration, quality of light, intensity, etc., and surrounding conditions like insulation, shading and varying ambient temperatures.

6.4 Examples of how the use of the energy service output of an energy-use system depending on individual circumstances are given below and in Table 5.

6.4.1 The luminous flux measured in lumen (lm) creates different illuminances – measured in lux (lx) – depending on the distance of the illuminated surface.

6.4.2 An engine powering a vehicle of total mass *m*, can be accelerated depending on the engine performance and the driver's temperament, and thus, will use quite different amounts of acceleration energy depending on the behaviour of the driver, thus affecting the average fuel consumption per km.

6.4.3 The effectiveness of a heating system supplying a certain amount of heat flow rate, measured in watts (W) or expressed in Joule (J), depends on the insulation of the room to be heated, the number of windows and doors, and the number and behaviour of its occupants (heat loss through open windows and doors) which determine the temperature, i.e. the comfort of the room – measured in degrees Celsius (°C).

7 Calculation of external cost and risks

The quantification of the inputs and outputs in both axes shall be used to calculate external cost and risks of TES. For possible inputs and outputs see examples in Tables 2 and 3. Some risks depend on the nature and impacts of operational factors and end-of-life emissions, which might be continuously or potentially hazardous to the health, climate and biosphere. Other risks factors may depend on inadequate designs, material fatigue or human error during operation of the TES, and might require a design analysis to determine also the likelihood, prevention and insurability of such risks, also as regards acts of terror, meteorite impacts, earth quakes, flooding, rising oceans and weather disasters like typhoons and other extreme climates.

The environmental and economic consequences of emissions and impacts on technical energy system in the life cycle analysis of technical systems in general are the subject of immissions and environmental, climate change and health impact analyses as elaborated in the ISO 14000 series of standards and standards on water and air quality.

Such external cost and risk analyses, also called social cost assessments, may serve the purpose of better legislation and law enforcement, insurance risk calculations and insurability determinations.

8 Loops within a TES (micro level) or in combined TESs (macro level)

Part of the output of a TES may be used as an input to the same technical energy system. When this is handled by consolidating around the loop, it is known as an internal loop. The output before consolidation is called gross output, whereas the output of the consolidated system is called net output. (See example in Annex C.)

An example of an *internal loop* is a thermo-electric power plant in which the gross output from the generator is partly diverted back through a house transformer to satisfy the internal power requirements of the plant. This internal loop is eliminated by consolidating around the house transformer.

External loops occur when part of the output from a technical energy system serves as an input to another technical energy system, the output of which partly serves as an input to the first one. An important external loop in the previous example is the electricity needed as an input to the fuel production, preparation and transport that is the main input to the power plant. Other external loops start with the electricity needed to produce capital goods and ancillary materials which are inputs to both, the power plant and the fuel production operations.

It is sometimes difficult to take all loops and sub-loops into account. The most important loops shall be identified and their influence on the final result shall be presented at least qualitatively.

9 Data quality requirements

The outcome of any TES optimisations and comparisons is largely dependent on the quantity and quality of data collected. In this respect, the time, frequency and duration over which data were collected, their reliability, measurement traceability and reproducibility, as well as the technology involved, are essential.

Data precision quality indicators and sources, therefore, shall always be included in any TES analyses.

10 The energy complexity of buildings

Buildings may become energy self-sufficient or even producing an energy surplus, if a combination of active and passive energy systems, energy management and insulation measures are applied, allowing **zero-energy** or **energy-plus** buildings by respecting following factors and applying the respective principles and technologies such as:

- Orientation of the buildings towards the sun cycles and respecting wind directions
- Situation opposite neighbouring objects like trees, other buildings and the topography
- Sun or shade oriented windows and special glazing with variable shading characteristics
- Insulation of the outside walls, roofs, lofts and basements to minimize heat transfers
- Number, sizes, types and geographic orientation of windows, cupolas and doors
- Natural and artificial lighting depending on types, efficacies and lighting control
- Integral energy management systems with load control adapted to the energy cycles
- Venting through heat exchangers to reduce heat losses and maintain comfort levels
- Solar-active roofs and facades equipped with PV, solar-thermal or hybrid solar panels
- Mini and micro wind turbines complementing solar panels for electricity generation
- Heat pumps and/or biomass heating systems substituting hazardous fossil fuel systems
- Seasonal and day-night heat or cold storage in the building body and/or underground – see Annex E
- Solar air conditioning and refrigeration, i.e. by application of the adsorption principle
- Natural air conditioning by air drafts, night-day cycles and natural shading concepts
- Recovery of the inhabitant's waste for energy and application of geo or air heat pumps
- Electric batteries or hydrogen storage for power supply and charging or fuelling vehicles – see Annex E

Each of these subsystems and energy efficiency measures can be analyzed and characterized individually and may have interactive effects, like a venting systems with heat exchanger recovering waste heat, or a heat pump recovering heat from waste water before it is drained, a light source or a refrigerator contributing to the heating of the building with their heat losses, proper insulation avoiding heat transfers in both directions – heating energy conservation in winter and reduction of air conditioning energy in summer.

Annexes A and B illustrate at the examples of a compact fluorescent lamp and a refrigerator typical sub-systems of a building, which can greatly influence the total energy consumption and heat management.

On the operational time axis B of the I-O model in chapter 5 load management systems may reduce peak power consumptions and may save energy by moving liquids to and from thermal energy storage systems intelligently.

Refrigeration and air conditioning systems may even produce water, according to Table 3 – outputs, as useful by-product to make a building fully self-sufficient.

A computerized energy management system can substantially reduce expensive peak energy consumption.

11 Energy storage

To assure continuous or at least extended or temporarily useful energy availability, energy storage devices are needed to enable certain energy systems to operate satisfactorily. The need for energy storage may range from bridging short power interruptions by UPS (uninterruptible power supply) systems - for security or safety reasons - to transport fuels or off-the-grid traction electricity for sufficient vehicle, ship or aeroplane ranges, to portable electronic devices or lamps, daily or weekly storage to even-out discontinuous power from solar or wind power sources and in extremis to the seasonal storage of heat in buildings or water in reservoirs for peak hydropower.

There exist electrical, thermal, chemical, mechanical and organic storage means for the whole range of time and peak energy requirements. See examples in Annex E.

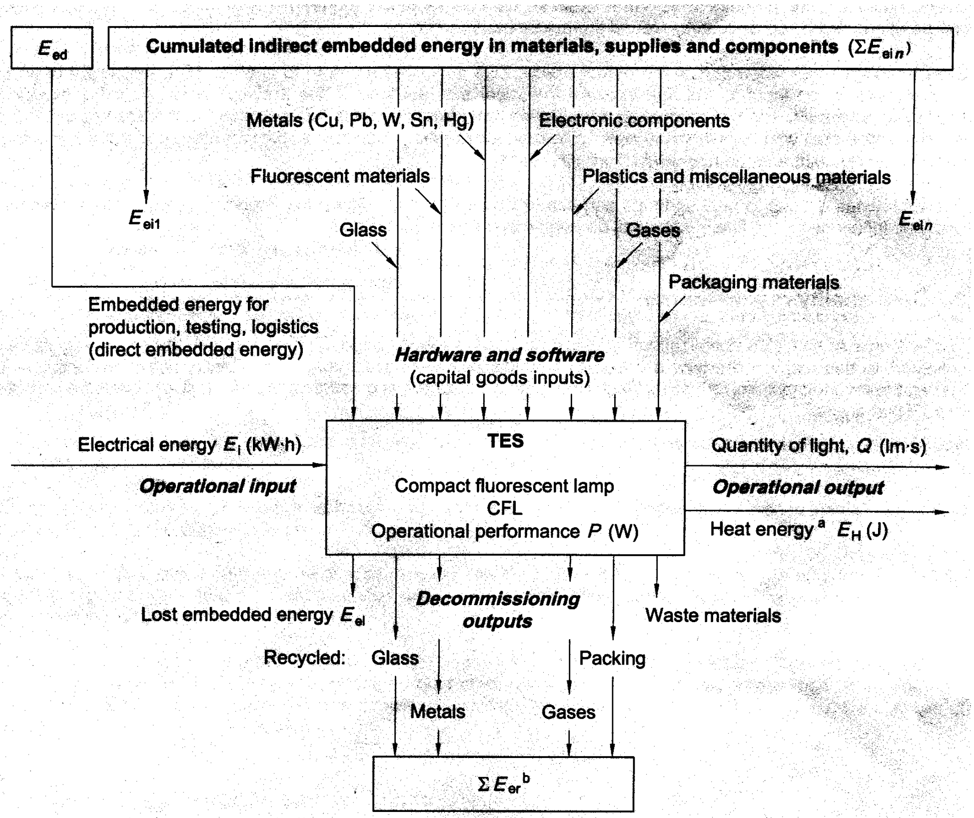
The I-O efficiency and possible losses during the storage period are part of the total energy chain equation from the prime energy to the final energy services according to the calculations in chapter 5.3 of this standard.

ANNEX A
(informative)

TECHNICAL ENERGY SYSTEMS (TES)

INPUT-OUTPUT (I-O) MODELS

EXAMPLE: COMPACT FLUORESCENT LAMP (CFL)



[a] The by-product heat may be regarded as a gain or a loss, depending on the environment.

[b] Some embedded energy reclaimed (ΣE_{er}) will be equivalent to the energy which would be needed to produce these materials or the energy regained from residual energy conversion (e.g. incineration of packaging materials).

Efficacy of CFL system	$\eta_{CFL} = \Phi / P$	**(lm/W)**
Relative efficacy ratio	$R_\eta = \eta_c / \eta_b$	**(1) (e.g. CFL vs. light bulb)**
Cumulated indirect embedded energy + direct embedded energy	$E_e = \Sigma E_{ein} + E_{ed}$	**(J) (total embedded energy)**
Net embedded energy balance	$E_{en} = \Sigma Ee - Eel = \Sigma E_{er}$	**(J) (total reclaimed energy)**
Energy payback ratio with CFL	$R_p = Es / E_{en}$	**(1) (fraction of energy saved based on lifetime)**

where

E_e	is the total embedded energy	P	is the power
E_{ed}	is the direct embedded energy	Q	is the quantity of light
E_H	is the heat energy	R_p	is the energy payback ratio
E_{ein}	is the indirect embedded energy	R_η	is the relative efficacy ratio
E_{el}	is the lost embedded energy	η_{CFL}	is the efficacy of the CFL system
E_{en}	is the net embedded energy	η_c	is the efficacy of the compact fluorescent lamp
E_{er}	is the reclaimed embedded energy	η_b	is the efficacy of an incandescent light bulb
E_i	is the electrical energy input	Φ	is the luminous flux
E_s	is the energy saved over lifetime		

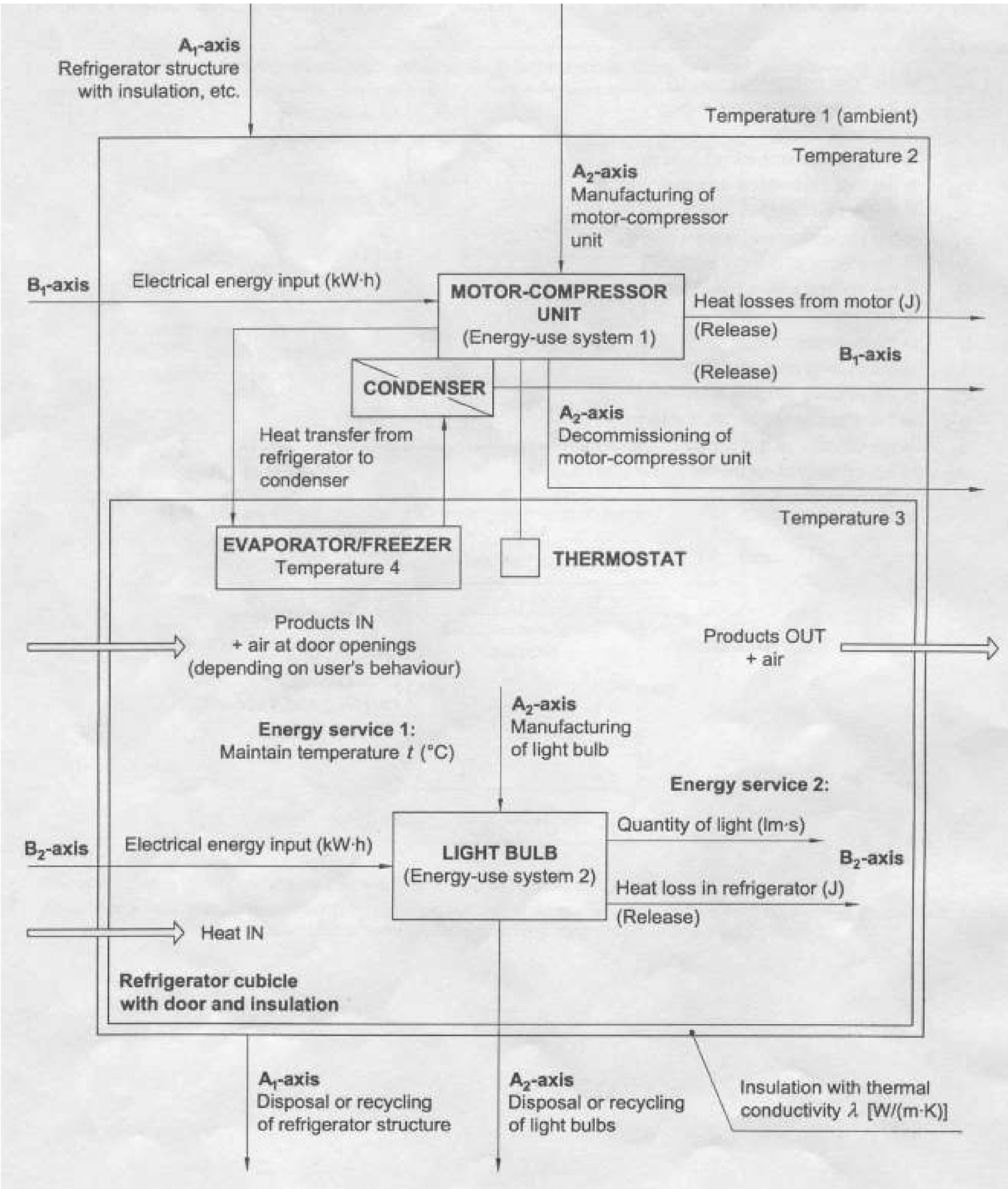
ANNEX B

(informative)

TECHNICAL ENERGY SYSTEMS (TES)

INPUT-OUTPUT (I-O) MODELS

EXAMPLE: REFRIGERATOR



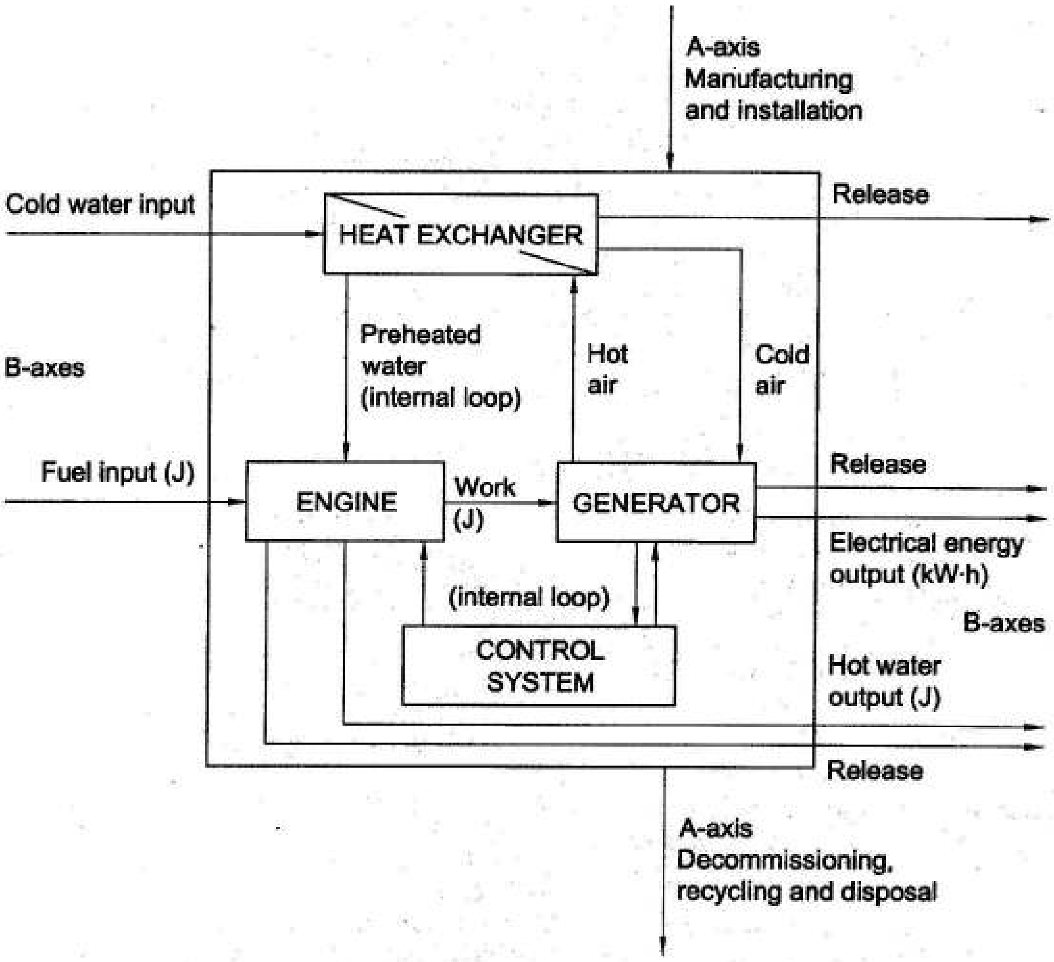
ANNEX C

(informative)

TECHNICAL ENERGY SYSTEMS (TES)

INPUT-OUTPUT (I-O) MODELS

EXAMPLE: CO-GENERATION UNIT



ANNEX D

(informative)

Examples of power characteristics of technical energy systems (TES)

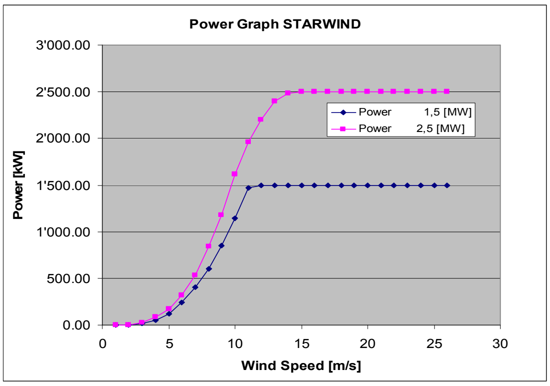


Fig. 1 Wind turbine power characteristic relative to wind speed

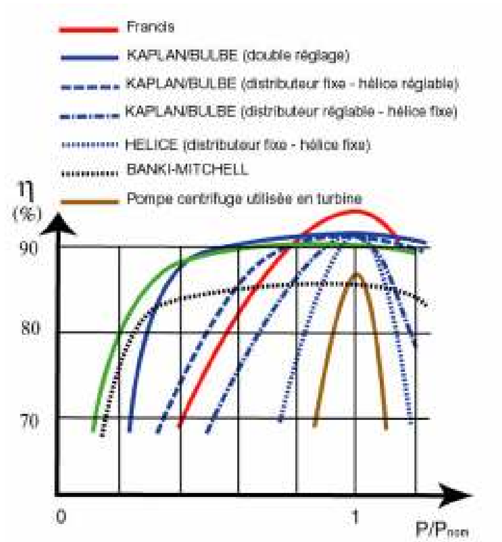


Fig. 2 Hydro turbine efficiency characteristics relative to flow

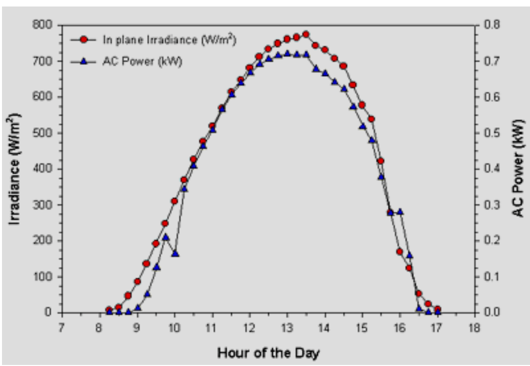


Fig. 3 Photovoltaic power characteristics during daytime

ANNEX E

(informative)

TECHNICAL ENERGY SYSTEMS (TES)

ENERGY STORAGE SYSTEMS

ENERGY STORAGE MEANS	ELECTRICAL STORAGE		THERMAL STORAGE	CHEMICAL STORAGE	MECHANICAL STORAGE	ORGANIC STORAGE
SYSTEMS	base load	peak power	heat or cold	fuels solids, liquids, gas	peak energy	organic matter solids, liquids, gas
Electrochemical batteries (electrolyte)	**X**	**(X)**				
Physical batteries (e.g. nuclear resonance)	**X**	**X**				
Super capacitors (ultra capacitors)	**X**	**X**				
Super conductors (at low temperatures)	**X**	**X**				
Tanks, underground heat or cold storage			**X**			
Building mass (passive energy in building.)			**X**			
Water (boilers, ice storage etc.)			**X**			
Hydrogen (liquefied, compressed, metal hydride)				**X**		
Hydrogen peroxide (diluted liquid)				**X**		
Methanol (synthetic)				**X**		
Potential (static) energy (elevated mass)					**X**	
Kinetic energy (moving mass)					**X**	
Hydraulic storage * (including pumping)					**X**	
Mechanical springs (spirals, torsion bars etc.)					**X**	
Air, steam, gases (compressed)					**X**	
Food for & in humans (for muscles & heat) *						**X**
Biomass (including fodder) (solid, liquid, gases) *				**X**		**X**
Metals (aluminium, zinc, magnesium etc.)				**X**		
Salt (molten) (e.g. storing solar heat)			**X**			

Remarks: UPS = uninterruptable power supply by suitable electricity storage systems

* Hydropower is a prime energy source but when pumped up also an energy storage system

** Biomass and food are often considered as prime energy sources but are stored solar energy

Bibliography

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[2] ISO 13601:1998, *Technical energy systems . Structure for analysis-energyware supply and demand Sectors*

[3] ISO 14040:1997, *Environmental management — Life cycle assessment — Principles and framework*