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Technical energy systems — Methods for analysis —

Part 1: **General**

Systèmes d'énergie technique — Méthodes d'analyse —

Partie 1: Généralités

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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 the 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 the following parts, under the general title *Technical energy systems — Methods for analysis*:

— *Part 1: General*

Other parts are under preparation.

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

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 (TESs) at micro and macro levels. These tools enable the user to make objective choices of TESs in their total technical, economic, environmental and social contexts and thus to help consensus-building and decision-making.

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 can be used to describe and analyse subsectors at the macro level of energyware supply and demand, while ISO 13602 (all parts) facilitates the description and analysis of any technical energy systems with an emphasis on systems at the microlevel.

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 (TESs) 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 and labelling.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute 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 this part of ISO 13602 are encouraged to investigate the possibility of applying the most recent editions 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 14040:1997, *Environmental management — Life cycle assessment — Principles and framework*

3 Terms and definitions

For the purposes of this part of ISO 13602, the following terms and definitions apply.

3.1
embedded energy
total amount of energy directly used to produce or process inputs to make a 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 energy resources

NOTE TESs also include other resources, expanding the definition given in ISO 13600:1997, item 2.24.

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

NOTE See Table 4 for examples of energy resources.

3.4
energy service
useful, measurable output of any energy-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 and construction materials

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

4 Methods of analysis of TES

4.1 General

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

a) Combined TESs (macro level)

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

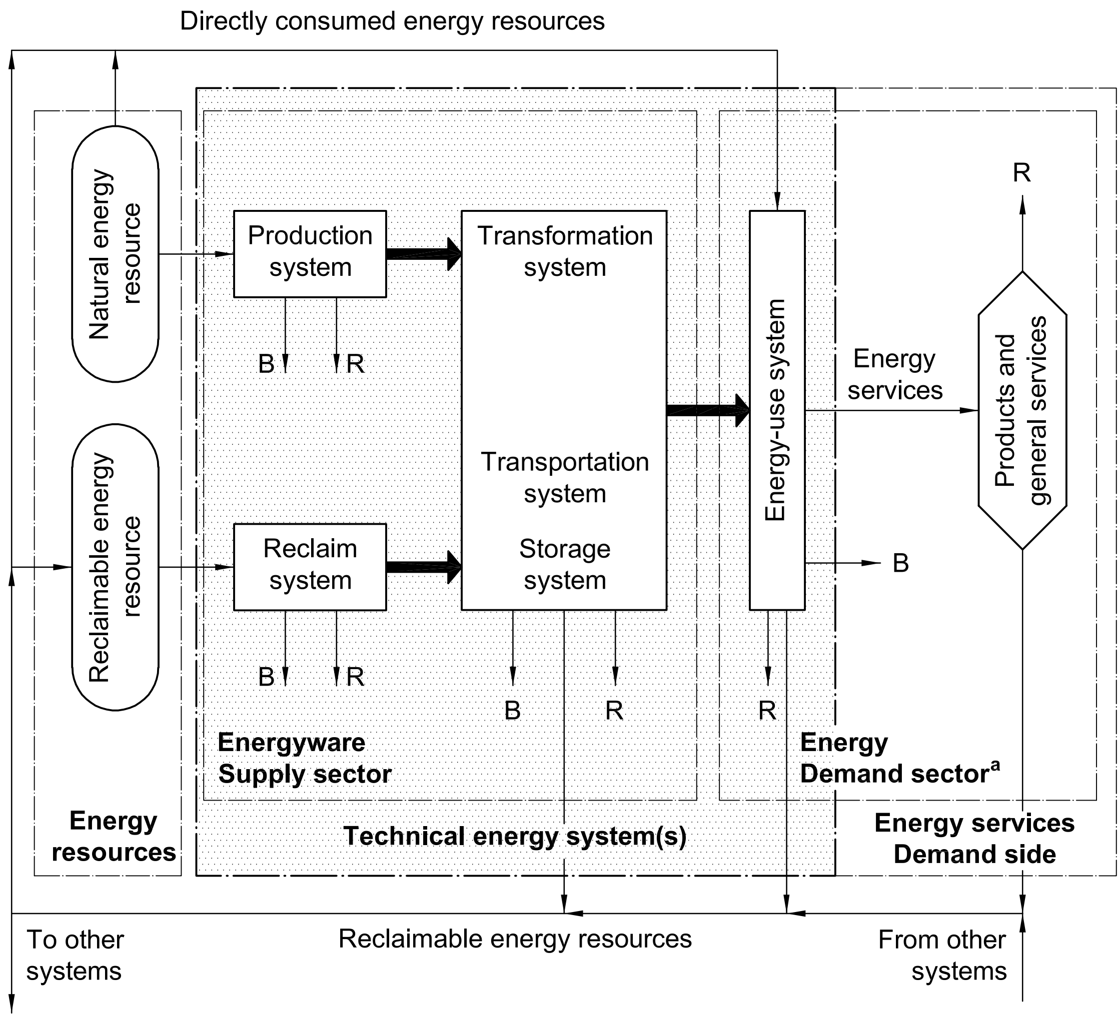
- technical (safety, feasibility, reliability);
- economic (competitiveness, availability);
- ecological (emissions, climate, biosphere).

This method of analysis enables the deduction of social impacts such as health, well-being and social costs. Strategic decisions about matters such as conservation of resources, saving foreign exchange, national security and traffic congestion may be made. Overall comparisons among coal, oil, gas, hydro, wind, bio, solar and hydrogen TESs 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 energyware production, conversion, refining, transformation, transport, handling or storage methods, or 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 telecommunications or medical services, are shown in Figure 1.



Key

R = Release
B = By-products

Energyware

Energy resources used for TES

TES or process units

Products and general services using energy services

[a] This term includes both energyware demand, in accordance with clause 7 and Figure 6, as per ISO 13600:1997, and direct energy resource demand.

Figure 1 — Energy flows within a generalized TES

4.2 TESs yielding comparable energy services

Examples of simplified alternative TESs are given in Table 1.

Table 1 — Simplified alternatives

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

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.

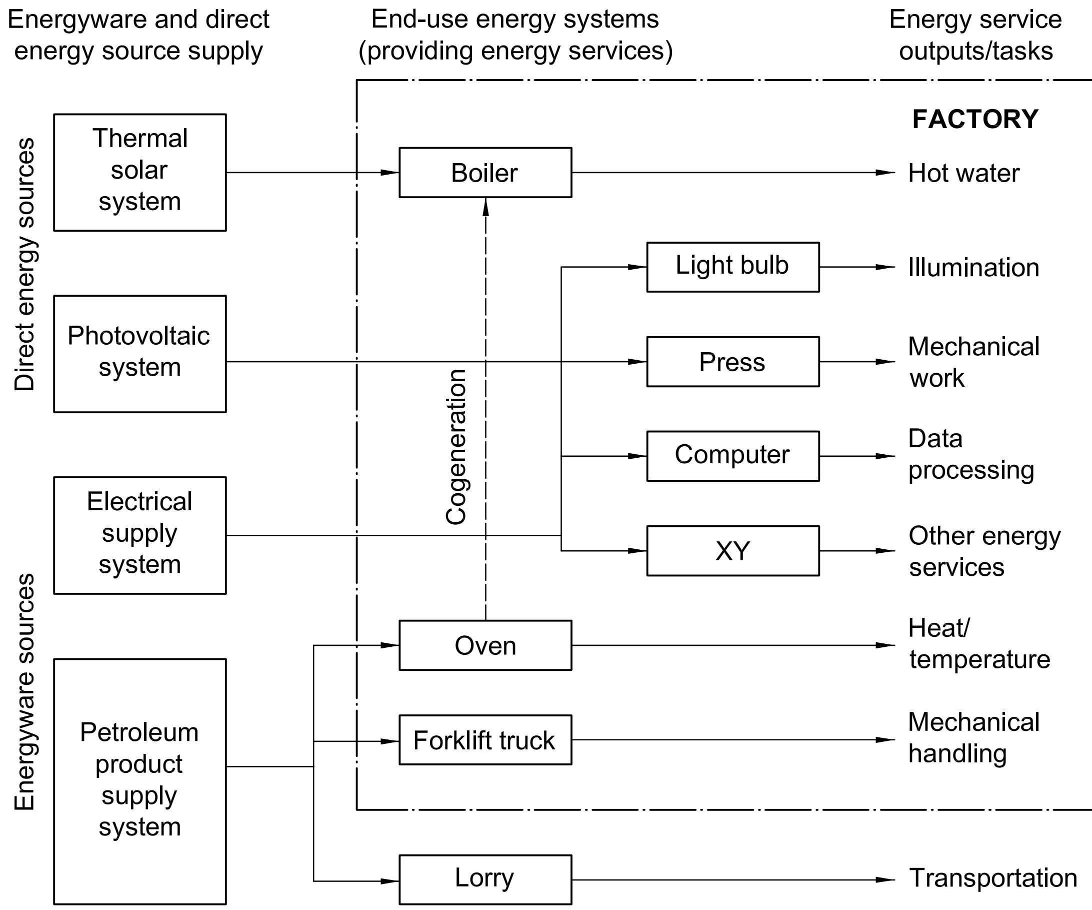


Figure 2 — Examples of possible combination of TESs in a factory

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

5.1 Elementary I-O model

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

Practical examples of applied and combined I-O models of an energy-saving lamp, a refrigerator and a co-generation unit are shown in annexes A, B and C, respectively.

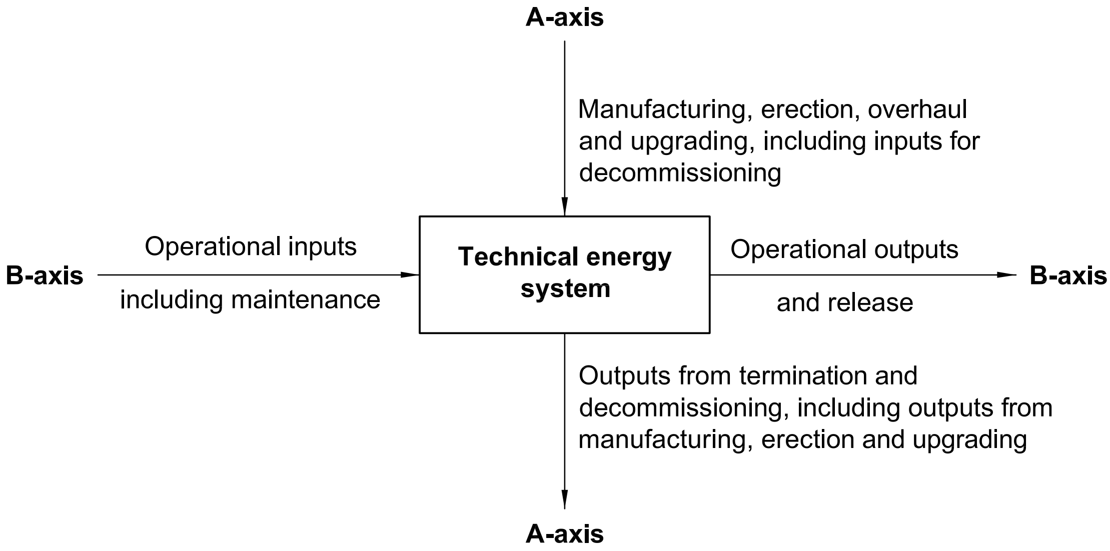


Figure 3 — Elementary I-O model

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, recyclable or waste and possible after-effects, including releases and environmental impacts of the terminated and decommissioned system, 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 or energyware, operational manpower, operational information and auxiliary materials such as lubricants, pass through the I-O model horizontally on the B-axis. Inputs such as energy resources (see Table 4) and inputs related to the maintenance of energy systems (see Table 2) enter from the left of the I-O box, and outputs such as energyware, energy services, releases and by-products including emissions or waste, exit to the right on the B-axis (Operational outputs in Table 3).

Table 2 — Examples of possible TES inputs

Operational inputs, including maintenance	Inputs related to the erection and upgrading of energy systems
Energy resources 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 (moisture) **Water** E.g. as a feedstock, cooling agent or energy carrier **Ancillary materials** E.g. catalysts, reagents, cathodes, lubricants, spare parts, maintenance materials **Human resources** On- and off-plant manpower, supporting staff and management **Animal power** Used as natural energy resource input **Information** Data acquisition, storage and processing, communication	**Space** • Land space (exploration, development, reclamation, flooding, fencing) • Water space (sea, lakes, rivers) • Air space (elevated, suspended or flying structures) **Capital goods and facilities** • Buildings (insulation, windows, shading, solar orientation, roofing, etc.) • Platforms, vessels, rafts, pipelines, dams, canals, etc. • Process plant equipment or machines or both • Mechanical handling equipment, e.g. elevators, conveyors, fork-lift trucks, pumps • Storage equipment for kinetic, thermal, chemical, biochemical, potential energy • Transport equipment for railroads, roads, waterways, air, cables, power lines, pipelines • Installations for manufacturing processes, safety and security **Information technology equipment** • Means for measurement data acquisition and transmission • Hardware and software for data processing • Telecommunication hardware and software

Table 3 — Examples of possible TES outputs

Operational outputs	Outputs related to the erection, upgrading, termination and decommissioning of TESs
Energyware See annex A of ISO 13600:1997. **Energy service (useful energy)** See details in Table 5. • Mechanical, e.g. handling, transport, machining, processing • Thermal, e.g. heating, cooling, freezing, melting, processing, welding • Electrochemical, e.g. electrolysing, galvanizing • Information and communication, e.g. dataprocessing, sound effects, scanning • Light, e.g. street lighting, illumination, projections from slide or movie projectors • Medical applications, physical therapies **By-products, including usable discharges** • Reclaimable energy resources (see Table 4) • Usable chemicals • Mineral oil residues, e.g. bitumen, tar, pitch • Biomass, e.g. fertilizer materials, sawdust • Coal and graphite for special applications, e.g. electrodes, filter media • Heat convection 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 • Thermal and humidity changes in the environment • Optical and radioactive radiation • Solids from industrial processes, e.g. unusable ash, solid waste • Liquids, e.g. contaminated water, waste chemicals, oil spills • Gases, e.g. pollutants, greenhouse gases, lost or spent steam • Residual waste from waste processing • Heat losses **Liquid and solids from equipment maintenance**	**Recyclable materials** (from production, erection and after replacement or decommissioning) **Waste materials, facilities, soils and space before and after decommissioning** **Decommissioned hardware** • Defunct parts, scrap and demolition waste, debris, wrecks **Residues and contamination** • Spilled liquids and solids, entrapped gases, contaminated ground water • Residual hazardous waste or pollutants or both • Radioactive matter (accident risks and decommissioned nuclear power plants)

Table 4 — Examples of energy resources

Natural energy resources		Reclaimable energy resources
Renewable	Non-renewable	
• Biomass, e.g. forests or energy crops • Biogas , e.g. sludge gas • Thermal energy, e.g. geothermal, ocean thermal and temperature gradients • Radiant energy, e.g. solar energy • Kinetic energy, e.g. wind, waves • Potential energy, e.g. hydro energy	• Hard coal (unexcavated) • Brown coal (unexcavated) • Peat (unexcavated) • Uranium, thorium (unexcavated) • Crude oil (unextracted) • Tar — pure, or in sand or earth • Natural gas (unextracted)	• 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 energy, e.g. recuperation from an elevated body

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 on 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;

— the recycling efficiency and embedded energy balance of the hardware of the TES.

5.3.3 On the B-axis

Plot on the B-axis the following:

— determination of the running cost and effects of a system;

— calculation of the TES day-to-day operational efficiency;

— operational mass balance and energy balance.

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. energy payback period or harvesting ratio.

5.4 Capital investments

5.4.1 A TES contains capital investment (3.9). The latter shall always be included in the TES being studied. Capital goods (3.8) are an input to the system. Labour and ancillary materials connected with construction activity are also inputs to the system.

5.4.2 Comparisons can be made in any constant unit of value, including energyware units. Assumptions made for bases of value comparisons shall be clearly defined.

5.4.3 All inputs connected with capital investments must be periodized in order to be commensurable 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 used mainly for micro studies, has the drawback that it is often difficult to estimate true 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”.

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, 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 only future capital investment into account. This is the sole method for the study of new 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 TESs are to be compared, it is necessary to define a functional unit which shall be the same in all 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 the functional unit. An example of a functional unit is the production of 1 kg of raw steel.

6.2 Energy services consisting of other phenomena, such as a maintained temperature, an illumination on a given surface or an energy service providing motion, are usually not expressed in terms of energy. Useful energy outputs may provide energy services that can sometimes be characterized in SI units other 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	Energy service	Quantity unit
1	Work, transportation, speed, acceleration, force	J, kg·m, $m \cdot s^{-1}$, $m \cdot s^{-2}$, N
2	Pumping, venting and vacuum applications	Pa, $m^3 \cdot kg^{-1}$
3	Specified thermal uses (heating or cooling)	°C or K, J
4	Audio and ultrasound applications	dB, Hz
5	Vibration for useful purposes	Hz, $Hz \cdot J^{-1}$
6	Lighting, illumination, magnification, colour-rendering index	lm, lx
7	Magnetic applications	T
8	Data processing, information	bit, $bit \cdot s^{-1}$, Sh
9	Telecommunication, television, visual display, resolution	$bit \cdot s^{-1}$, lx, dB
10	Physical therapy and diagnostic procedures	$C \cdot kg^{-1}$, Gy, Sv
11	Measurement and control, repeatability, etc.	$bit \cdot s^{-1}$, $m \cdot s^{-1}$, $m \cdot s^{-2}$, V, A, $kg \cdot s^{-1}$
12	Electrochemical and physical processing	A, W, J, C

NOTE These quantifiable TES outputs are not evaluated 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, 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 such as insulation.

6.4 Examples of how the use of the energy-service output of an energy-use system depends on individual circumstances are given below.

6.4.1 The luminous flux, measured in lumen (lm), creates different illuminances, measured in lux (lx), depending on the distance to 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 engine driver’s temperament, and thus will use quite different amounts of acceleration energy depending on the behaviour of the driver.

6.4.3 The effectiveness of a heating system supplying a certain heat flow rate, measured in watts (W), 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 opening of 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 on both axes shall be used to calculate external cost and risks of TESs. For possible inputs and outputs, see the 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 risk factors may depend on inadequate design, material fatigue or human error during operation of the TES, and might require a design analysis to determine the likelihood, prevention and insurability of such risks.

The environmental and economic consequences of technical energy system emissions and impacts in the life cycle analysis of systems in general are the subject of immission and impact analyses as elaborated in the ISO 14000 series of standards.

8 Loops

Part of the output of a TES may be used as an input to the same TES. When this is handled by consolidating (see ISO 13600:1997, clause 5) 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 thermoelectric power plant in which 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 can be eliminated by consolidating around the house transformer.

External loops occur when part of the output from a TES serves as an input to another TES, 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.

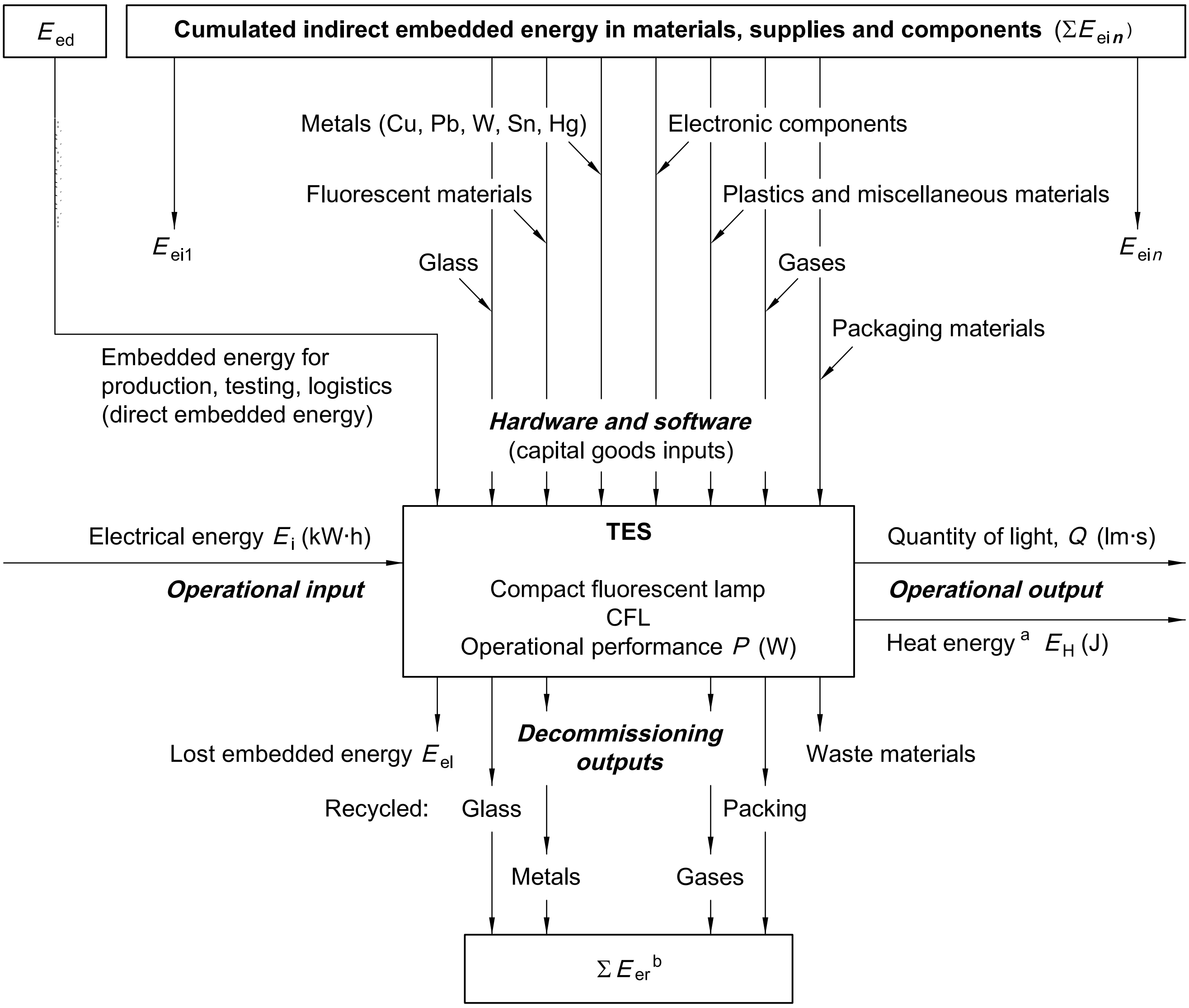
It is sometimes difficult to take all loops and sub-loops into account. The most important loops shall be identified and their influence on the final result shall be presented at least qualitatively.

9 Data quality requirements

The outcome of any TES optimizations and comparisons is largely dependent on the quantity and quality of data collected. In this respect, the time duration over which data were collected, their reliability and reproducibility, as well as the technology involved, are critical. Data quality indicators and sources, therefore, shall always be included in a TES analysis.

Annex A
(informative)

TES I-O model — 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).

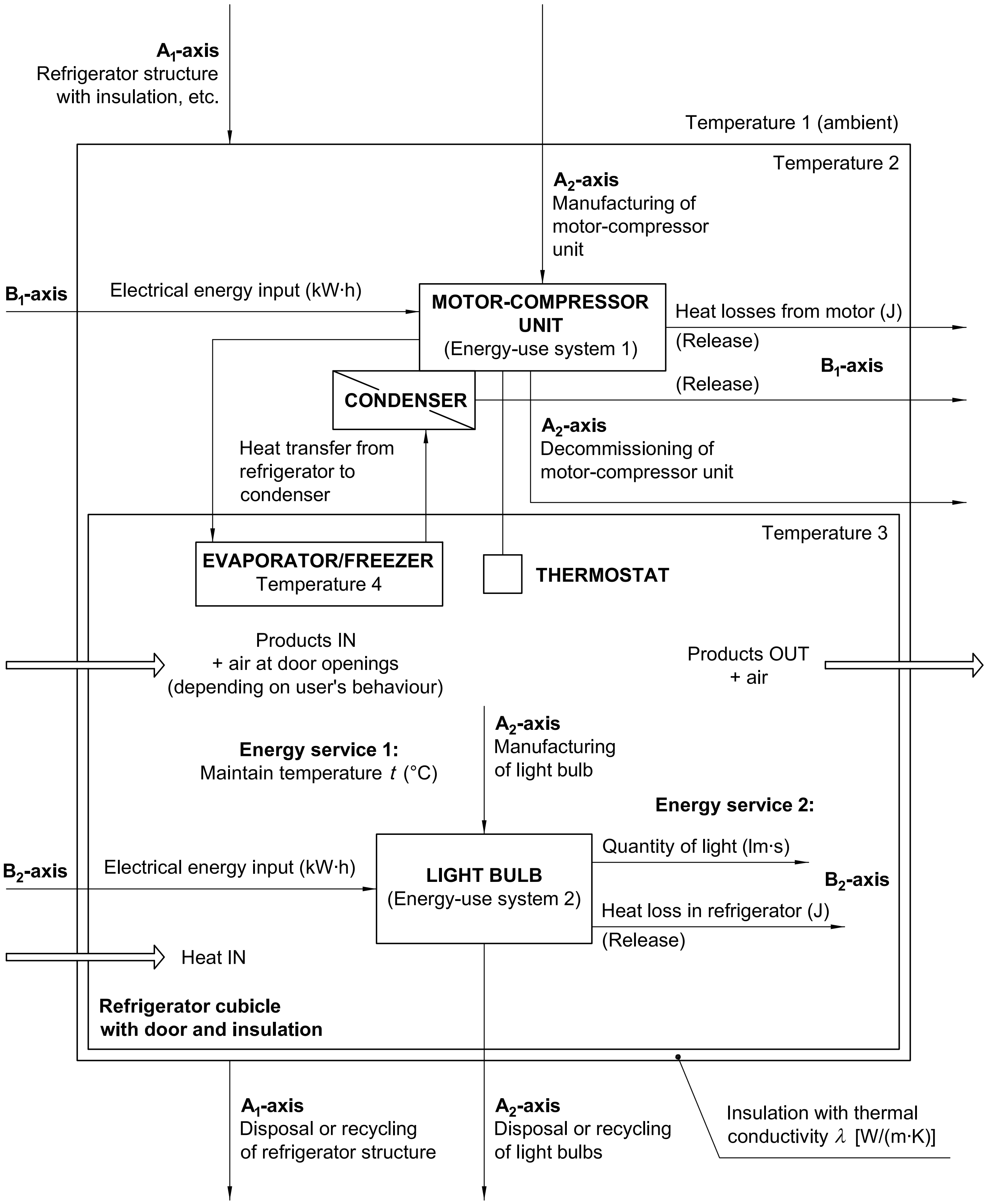
Efficacy of CFL system	$\eta_{\text{CFL}} = \Phi / P$	(lm/W)	
Relative efficacy ratio	$R_\eta = \eta_{\text{c}} / \eta_{\text{b}}$	(1)	(e.g. CFL vs light bulb)
Cumulated indirect embedded energy + direct embedded energy	$E_{\text{e}} = \Sigma E_{\text{ei}n} + E_{\text{ed}}$	(J)	(total embedded energy)
Net embedded energy balance	$E_{\text{en}} = E_{\text{e}} - E_{\text{el}} = \Sigma E_{\text{er}}$	(J)	(total reclaimed energy)
Energy payback ratio with CFL	$R_{\text{p}} = E_{\text{s}} / E_{\text{en}}$	(1)	(fraction of energy saved based on lifetime)

where

E_{e} is the total embedded energy
E_{ed} is the direct embedded energy
E_{H} is the heat energy
$E_{\text{ei}n}$ is the indirect embedded energy
E_{el} is the lost embedded energy
E_{en} is the net embedded energy
E_{er} is the reclaimed embedded energy
E_{i} is the electrical energy input
E_{s} is the energy saved over lifetime
P is the power
Q is the quantity of light
R_{p} is the energy payback ratio
R_η is the relative efficacy ratio
η_{CFL} is the efficacy of the CFL system
η_{c} is the efficacy of the compact fluorescent lamp
η_{b} is the efficacy of an incandescent light bulb
Φ is the luminous flux

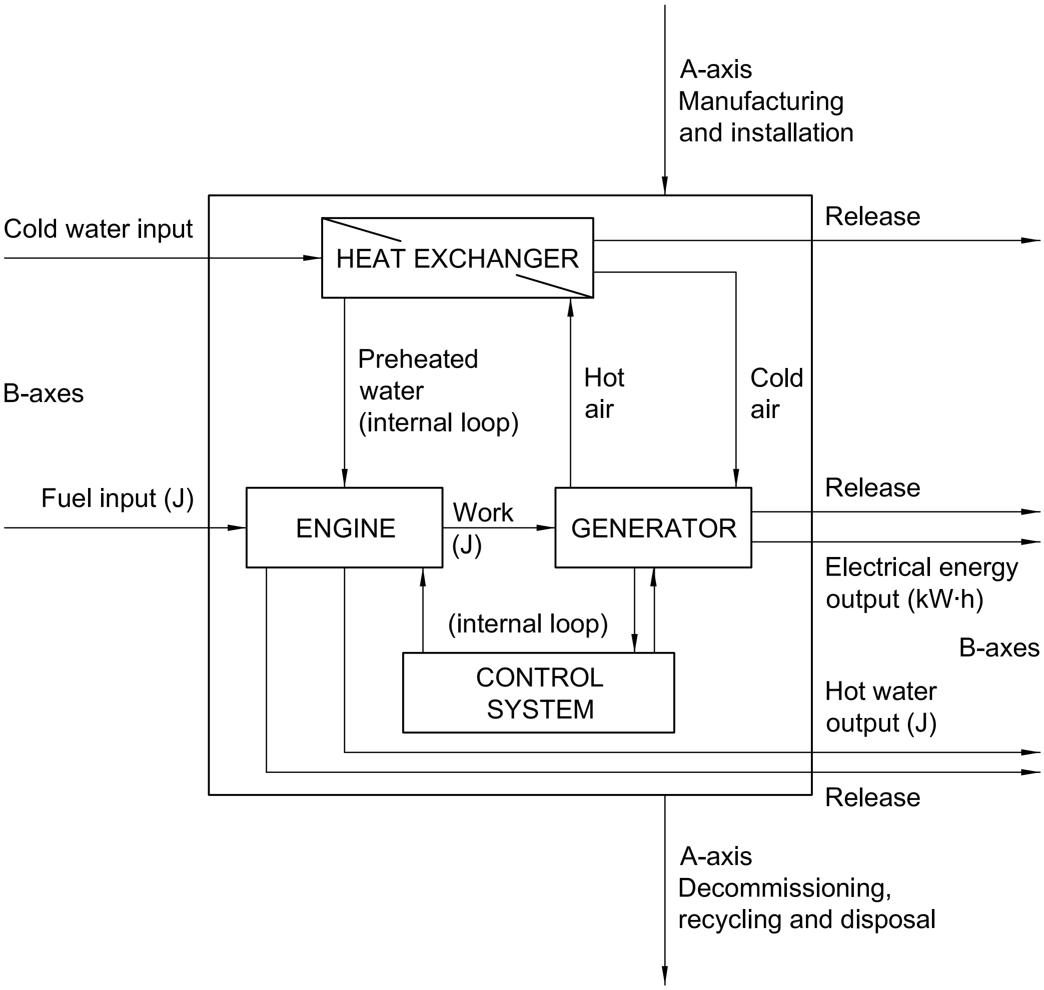
Annex B
(informative)

TES I-O model — Refrigerator



Annex C
(informative)

TES I-O model — Co-generation unit



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