
**Machine tools — Environmental
evaluation of machine tools —**

**Part 1:
Design methodology for energy-
efficient machine tools**

*Machines-outils — Évaluation environnementale des machines-
outils —*

*Partie 1: Méthode de conception pour l'efficacité énergétique des
machines-outils*

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 39, *Machine tools*.

This second edition cancels and replaces the first edition (ISO 14955-1:2014), which has been technically revised with the following changes:

- the former Annexes A and B have been combined into a new [Annex A](#), on energy efficiency improvements, which includes woodworking machine tools.

A list of all parts in the ISO 14955 series can be found on the ISO website.

Introduction

As environmental impact is a common challenge for all products and as natural resources become scarce, environmental performance criteria for machine tools need to be defined and the use of these criteria specified.

Machine tools are complex products for industrial use to manufacture parts ready for use or semi-finished products. The performance of a machine tool as key data for investment is multi-dimensional regarding its economic value, its technical specification and its operating requirements which are influenced by the specific application. Therefore, the same machine tool can show quite different energy supplied to the machine tool depending on the part which is being manufactured and the conditions under which the machine tool is operated. Therefore, the environmental evaluation of a machine tool cannot be considered in isolation from these considerations.

This document proposes to analyse machine tools considering the delivered functions, in order to highlight the commonalities in the huge variety of existing machine tool types. Machine tool components that realize the various functions are objects of specific improvements, keeping in mind the application of the system under evaluation. These improvements are subject for quantification, together with the overall system design to achieve a product with an improved environmental performance. The approach specified in this document is also intended to support environmental improvements on a multi-national level and across different manufacturers/suppliers and users.

Based on a list of positive environmental features which can be built into a machine tool, the performance of the product is intended to be evaluated in order to quantify the environmental improvements achieved over a defined period.

This document provides guidelines for the design and engineering of machine tools with reduced environmental impact, focusing on the energy supplied during the use stage.

Machine tools might have a significant influence on the environmental performance of the manufactured products.

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Machine tools — Environmental evaluation of machine tools —

Part 1: Design methodology for energy-efficient machine tools

1 Scope

This document constitutes the application of eco-design standards to machine tools, mainly for automatically operated and/or numerically controlled (NC) machine tools.

This document addresses the energy efficiency of machine tools during the use stage, i.e. the working life of the machine tool. Environmentally relevant stages other than the use stage and relevant impacts other than energy supplied to machine tools are not within the scope and need special treatment (e.g. according to ISO/TR 14062).

Elements of eco-design procedure according to ISO/TR 14062 are applied to machine tools. Reporting of results to users and suppliers and monitoring of results are defined.

Evaluation of energy efficiency implies quantification of the resources used, i.e. energy supplied, and of the result achieved. This document provides guidance for a reproducible quantification of the energy supplied. It does not suggest a methodology for quantifying the result achieved due to the lack of universal criteria. The result achieved in industrial application being machined workpieces, their properties (e.g. material, shape, accuracy, surface quality), the constraints of production (e.g. minimum lot size, flexibility) and other appropriate parameters for the quantification of the result achieved are intended to be determined specifically for each application or for a set of applications.

This document defines methods for setting up a process for integrating energy efficiency aspects into machine tool design. It is not intended for the comparison of machine tools; also, this document does not deal with the effect of different types of user behaviour or different manufacturing strategies during the use phase.

Lists of environmentally relevant improvements and machine tool components, control of machine tool components and combinations of machine tool components are given in [Annex A](#). [Annex B](#) provides an example of application of the methodology.

NOTE Certain machining processes and specific machine tools can allow significant changes in the environmental impact of machined workpieces, e.g. material reduction for aluminium cans by application of special press technology, higher performance of compressors by machining on precision form grinders^[10] [13]. The environmental impact of such processes or machine tools might be less important compared to the environmental impact of the machined workpieces and their application. These changes in the environmental impact of machined workpieces are not subject of this document, but might be important if different machining processes or different machine tools are compared related to environmental impact of products. For instance, the accuracy of a machined workpiece might be a significant parameter for the environmental impact of the workpiece in its use stage, and any attempt to compare machine tools is intended to take this into account necessarily.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TR 14062:2002, *Environmental management — Integrating environmental aspects into product design and development*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 14062 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 design and development

set of processes that transforms requirements into specified characteristics or into the specification of a product, process or system

Note 1 to entry: The terms “design” and “development” are sometimes used synonymously and sometimes used to define different stages of the overall process of turning an idea into a product.

Note 2 to entry: Product development is the process of taking a product idea from planning to market launch and review of the product, in which business strategies, marketing considerations, research methods and design aspects are used to take a product to a point of practical use. It includes improvements or modifications to existing products or processes.

Note 3 to entry: The integration of environmental aspects into product design and development may also be termed design for environment (DFE), eco-design, the environmental part of product stewardship, etc.

3.2 environment

surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans and their interrelation

Note 1 to entry: Surroundings in this context extend from within an organization to the global system.

[SOURCE: ISO 14001:2015, 3.2.1]

3.3 environmental aspect

element of an organization's activities or products or services that interact or can interact with the environment

Note 1 to entry: A significant environmental aspect is an environmental aspect that has or can have significant environmental impact.

[SOURCE: ISO 14001:2015, 3.2.2]

3.4 environmental impact

change to the *environment* (3.2), whether adverse or beneficial, wholly or partially resulting from an organization's *environmental aspects* (3.3)

[SOURCE: ISO 14001:2015, 3.2.4]

3.5 life cycle

consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to the final disposal

Note 1 to entry: The stages of a product's life cycle are raw material acquisition, manufacture, distribution, use and disposal (introduction of ISO/TR 14062 based on ISO 14040:2006, 5.2.3).

[SOURCE: ISO 14040:2006, 3.1]

3.6 mode of operation

method of operating and controlling a *machine tool* (3.16), whereby different modes of operation are defined by safety standards for machine tools

Note 1 to entry: Examples for modes of operation are manual mode, automatic mode, setting mode.

Note 2 to entry: Different machine tool activities require certain modes of operation as laid down in safety standards for machine tools.

3.7 operating state

combination of ON, HOLD and OFF etc., settings of mains, peripheral units, machine tool control, machine tool processing unit and machine tool motion units including relevant machine tool activities

Note 1 to entry: Peripheral units are, for example, units for machine tool cooling/heating, process conditioning, workpiece and tool handling, recyclables and waste handling.

Note 2 to entry: Machine tool processing units are, for example, main spindle of a turning machine, tool spindle of a machining centre, generator for electro-discharge machine, slide of a press, draw cushions of a press.

Note 3 to entry: Machine tool motion units are, for example, linear axes of a turning machine, linear and rotary axes of a machining centre, linear axes of a wire electro-discharge machine.

Note 4 to entry: Reference to operating states (e.g. OFF, STANDBY, EXTENDED STANDBY, WARM UP, READY FOR PROCESSING, PROCESSING and CYCLING) requires definition of these states. An example for such a definition for a metal-cutting machine tool is given in [Annex C](#).

Note 5 to entry: Examples for machine tool activities are tool loading, workpiece loading, axes movements, waiting, machine tool operation or cycling, or complete test cycles.

Note 6 to entry: Depending on the operating state and the machine tool activities, a mode of operation is selected as defined by relevant safety standards of machine tools.

3.8 environmental claim

statement, symbol or graphic that indicates an *environmental aspect* (3.3) of a product, a component or packaging

Note 1 to entry: An environmental claim may be made on product or packaging labels, through product literature, technical bulletins, advertising, publicity, telemarketing, as well as through digital or electronic media such as the Internet.

[SOURCE: ISO 14021:2016, 3.1.4]

3.9 environmental claim verification

confirmation of the validity of an *environmental claim* (3.8) using specific predetermined criteria and procedures with assurance of data reliability

[SOURCE: ISO 14021:2016, 3.1.5]

3.10

explanatory statement

explanation which is needed or given so that an *environmental claim* (3.8) can be properly understood by a purchaser, potential purchaser or user of the product

[SOURCE: ISO 14021:2016, 3.1.7]

3.11

functional unit

quantified performance of a product system for use as a reference unit in a *life cycle* (3.5) assessment study

[SOURCE: ISO 14021:2016, 3.1.8]

3.12

machine tool function

machine tool operation (machining process, motion and control), process conditioning, workpiece handling, tool handling or die change, recyclables and waste handling, machine tool cooling/heating

Note 1 to entry: Any machine tool function may be realized by one machine tool component or by a combination of machine tool components. Some machine tool components may realize more than one machine tool function.

Note 2 to entry: [Figure 7](#) shows an example of the relationship between machine tool components and machine tool functions.

Note 3 to entry: Machine tool functions may be used for identifying machine tool components (3.13) relevant for energy supplied to the machine tool.

3.13

machine tool component

mechanical, electrical, hydraulic, or pneumatic device of a *machine tool* (3.16), or a combination thereof

3.14

qualified environmental claim

environmental claim (3.8) which is accompanied by an *explanatory statement* (3.10) that describes the limits of the claim

[SOURCE: ISO 14021:2016, 3.1.15]

3.15

self-declared environmental claim

environmental claim (3.8) that is made, without independent third-party certification, by manufacturers, importers, distributors, retailers or anyone else likely to benefit from such a claim

[SOURCE: ISO 14021:2016, 3.1.16]

3.16

machine tool

mechanical device which is fixed (i.e. not mobile) and powered (typically by electricity and compressed air), typically used to process workpieces by selective removal/addition of material or mechanical deformation

Note 1 to entry: Machine tools operation can be mechanical, controlled by humans or by computers. Machine tools may have a number of peripherals used for machine tool cooling/heating, process conditioning, workpiece and tool handling (workpiece feeding excluded), recyclables and waste handling and other tasks connected to their main activities.

3.17

energy efficiency

relationship between the result achieved and the resources used, where resources are limited to energy

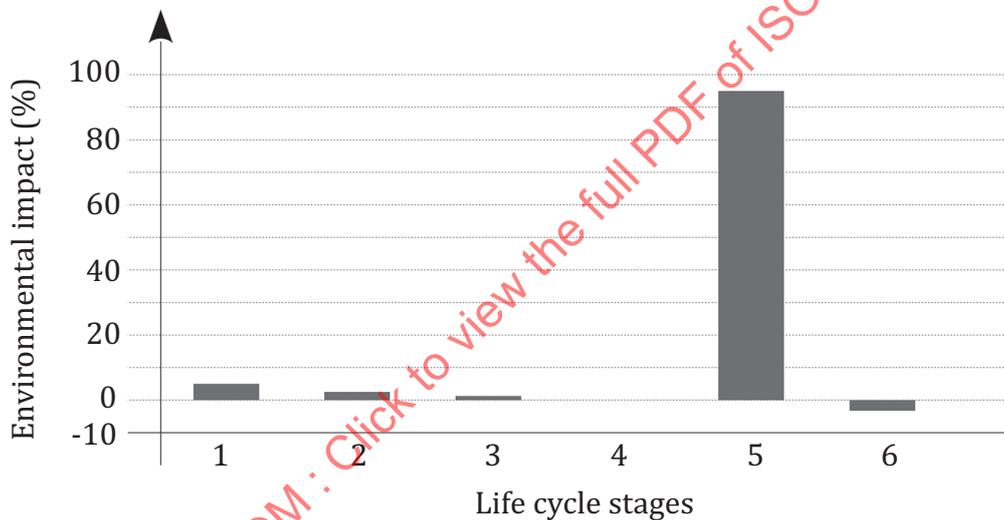
Note 1 to entry: Efficiency is defined as relationship between the result achieved and the resources used (ISO 9000:2015, 3.7.10).

Note 2 to entry: Statements of energy efficiency can be given e.g. in cycles per total energy supplied, in workpieces per energy supplied. If machining of test pieces is involved, specification of workpiece machining and quality of workpiece are part of the definition of the result.

4 Restriction to energy efficiency during use stage

For the environmental impact of a machine tool, different stages of the product life cycle shall be investigated: acquisition of raw material for the machine tool, manufacturing of the machine tool, transportation of the machine tool, installation of the machine tool, use of the machine tool, and recycling of the machine tool (for more details on life cycle assessment, see ISO 14040).

If the environmental impacts are compared in the different stages of a machine tool, the typical profile is as shown in Figure 1, which gives the profile of a NC milling machine. The largest impact is in the use stage, and the largest contributor in the use stage is the energy supplied to the machine tool. This is the result of many life cycle assessments for machine tools [8][11][12][14] if the machine tool is used for 8 h a day/5 d a week or more, which is typical for the use of machine tools in an industrial manufacturing environment.



Key

1	raw material	4	set-up
2	production	5	use
3	transport	6	recycling

Figure 1 — Typical environmental impacts during life cycle stages for an NC milling machine tool

Therefore, ISO 14955 concentrates on the evaluation and improvement of machine tool energy efficiency during the use stage.

If the machine tool is not used in a typical industrial manufacturing environment, a complete life cycle assessment, e.g. according to ISO 14040, might be needed in order to identify the relevant environmental impacts. Measures other than increasing energy efficiency during use stage to change the environmental impact might be of importance.

5 Integrating environmental aspects into machine tool design and development (design procedure for energy-efficient machine tools)

5.1 General

This is the application of ISO/TR 14062 for achieving energy-efficient machine tools in the use stage.

5.2 Goal and potential benefits

The goal of integrating environmental aspects into machine tool design and development is the reduction of adverse environmental impacts of machine tools, especially the increase of energy efficiency during the use stage of the average machine tool in an industrial manufacturing environment.

Benefits for the machine tool supplier/manufacturer and user may include the following:

- energy efficiency during use stage;
- cost reduction in machine tools operations;
- potential cost reduction of machine tool components, e.g. by downsizing of drives and electric components;
- increased competitiveness of the metal working sector;
- stimulation of innovation and creativity;
- enhancement of organization image and/or brand;
- attraction of financing and investment, particularly from environmentally conscious investors;
- enhancement of employees' motivations;
- increased knowledge about the product;
- improved relations with regulators.

5.3 Strategic considerations

Strategic considerations that are taken into account for integration of environmental aspects into machine tool design and development may include the following:

- organizational issues, (e.g. competitor's activities, machine tools user's needs, requirements and demands), organization's environmental aspects and impacts, activities of regulators and legislators, activities of industry associations;
- product-related issues such as early integration, (i.e. addressing the environmental aspects early in the design and development process), functionality (i.e. how well the product suits the purpose of the machine tool user in terms of usability, useful lifetime, productivity, accuracy, etc.), multi-criteria concept (i.e. consideration of all relevant impacts and aspects), and trade-offs (i.e. seeking optimal solutions);
- communication (e.g. internal communication to employees on product-related environmental impacts, training courses on environmental issues, programmes, and tools, site-specific impacts on the environment, and feedback from employees), external communication on product properties (performance and environmental aspects), and proper use of machine tool.

5.4 Management considerations

Top management support and action should enable effective implementation of procedures and programmes to integrate environmental aspects in design and development of machine tools, including

allocation of sufficient financial and human resources and time for the tasks involved. An effective programme should engage those involved in product design and development, marketing, production, environment, procurement, service personnel, and machine tool users. More detailed aspects on the multidisciplinary approach are given in ISO/TR 14062:2002, 6.5.

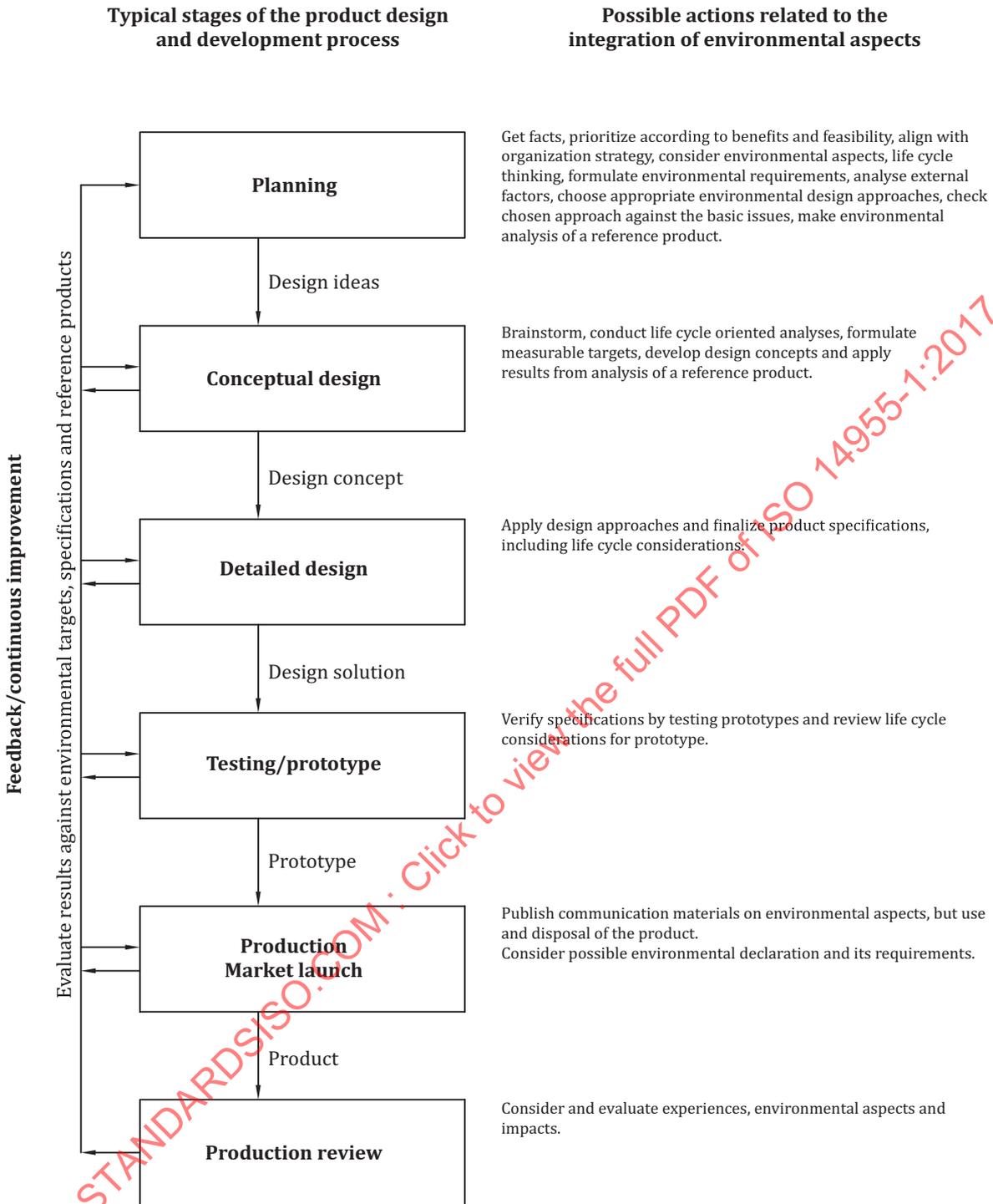
Details on how to formalize management's commitment and how to establish the organization's framework to integrate environmental aspects into machine tool design and development are given in ISO/TR 14062:2002, 6.2.

The integration of environmental aspects in machine tool design and management can be supported by existing management systems, e.g. management systems according ISO 14001 or ISO 9001. This integration can also influence the supply-chain management; for details, see ISO/TR 14062:2002, 6.6.

5.5 Machine tool design and development process

An overview of integrating environmental aspects into the design and development process of machine tools is given in [Figure 2](#).

NOTE Additional details are listed in ISO/TR 14062:2002, Clause 8. Eco-performance indicators, e.g. according to ISO 14031, might be rather useful for formulating measurable targets and transferring the targets into specifications.



NOTE Source: ISO/TR 14062.

Figure 2 — Example of a generic model of integrating environmental aspects into the machine tool design and development process

6 Machine tool and machine tool functions

6.1 General

The functional description of a machine tool (see 6.3) shall identify which machine tool function(s) are relevant for energy supplied to the machine. The functional description of machine tools is general and independent from the design of the machine tool, and independent from the machining process implemented. Generalized functions of a machine tool, as given in 6.3, allow a general approach for identifying relevant energy flows of machine tools.

For a specific machine tool, the machine tool functions shall be assigned to machine tool components. This assignment is specific to each machine tool and corresponds to a transition from total energy supplied to the machine tool via machine tool functions and functional mapping to machine tool component level. This procedure is shown in an example in 6.3 and results in identifying energy relevant machine tool components (see 6.4).

Important parameters for this observation are the operating states of the machine tool and their duration in time, the accuracy of machined parts, and productivity of the machine tool, e.g. expressed by workpieces per hour. When comparing machine tools, these parameters shall be defined clearly.

Often, measurement of power instead of energy is carried out. In these cases, times defined together with operating states shall be taken into account.

Some machine tools are equipped with internal compressors for pressurized air, hydraulic fluid and/or for lubricant supply; other machine tools use centralised supply units for these. When comparing a machine tool using internal compressor(s) with a machine tool using centralised supplies, any comparison shall be made on the same basis, i.e. for both machine tools including all supplies. For this aim system boundaries (see 6.2) shall be defined.

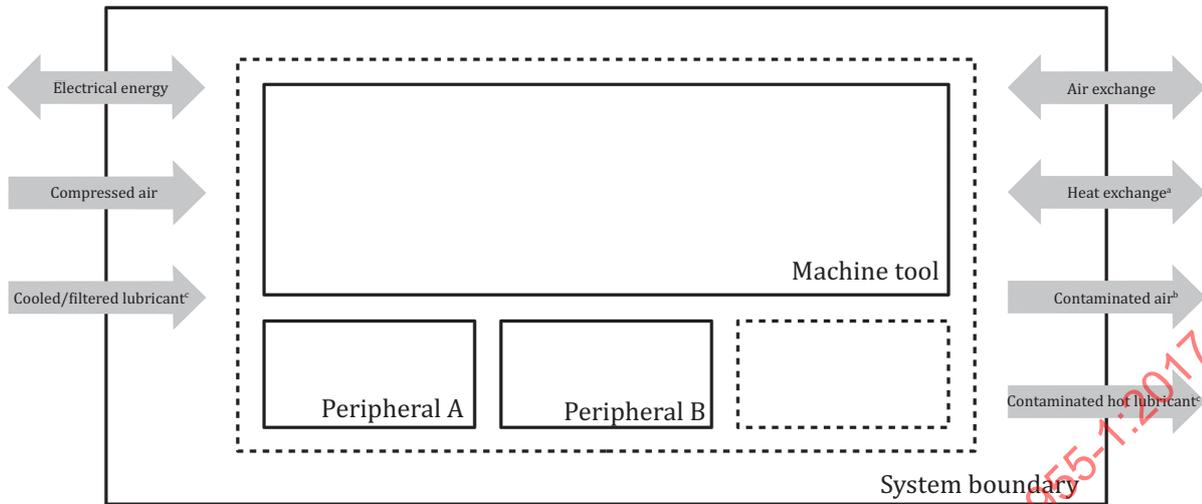
6.2 System boundaries

For evaluating the environmental impact of a machine tool the machine tool is looked at only. The environmental impact of product(s) machined on the machine tool is not taken into account (see also [Clause 4](#)).

ISO 14955 addresses the energy efficiency of machine tools in the use stage.

In order to deal with the energy efficiency of a machine tool during the use stage, system boundaries shall be defined in such a way that a system that is capable of a machining process is considered (see [Figure 3](#)). System boundaries are chosen in order to be able to measure energy flows with reasonable effort.

The machine tool and peripheral units are within the system boundaries. In general, electrical energy and compressed air are relevant energy inputs to the system. In some cases, air exchange is a relevant input and/or output. In cases where liquid heat exchangers are applied, heat exchange can be a relevant energy input and/or output of the system. If there is no mist filtering system within the system boundaries, any treatment of contaminated air will need energy that shall be considered, if relevant. If a centralized lubrication system is applied, cooled and filtered lubricant will be an input to the system and contaminated, hot lubricant will be an output; any energy used for lubricant treatment shall be considered, if relevant. Input of raw parts, new tools, new lubricant, auxiliary substances and output of machined parts, used tools, chips and any other aspects shall not to be considered if it does not represent a relevant energy flow across the system boundary.



- a Applies to cases with liquid heat exchangers.
- b Applies to cases without internal mist filtering.
- c Applies to cases with centralized lubricant management only.

Figure 3 — System boundaries related to relevant energy flows of a machine tool

6.3 Generalized functions of a machine tool

6.3.1 General

As machine tools cover a wide range of different types, subtypes, and sizes, a machine tool shall be described by its functions, which might be realized by different machine tool components. This allows a generalized approach for a wide range of machine tools in order to evaluate their environmental impacts and its change over time.

A machine tool should be described by the following functions:

- machine tool operation (machining process, motion and control);
- process conditioning;
- workpiece handling;
- tool handling or die change;
- recyclables and waste handling;
- machine tool cooling/heating

as shown in [Figure 4](#), in relation to energy efficiency during the use stage. These functions cover the vast majority of machine tools in a generalized view, independent from the implemented machining process and/or design of the machine tool.

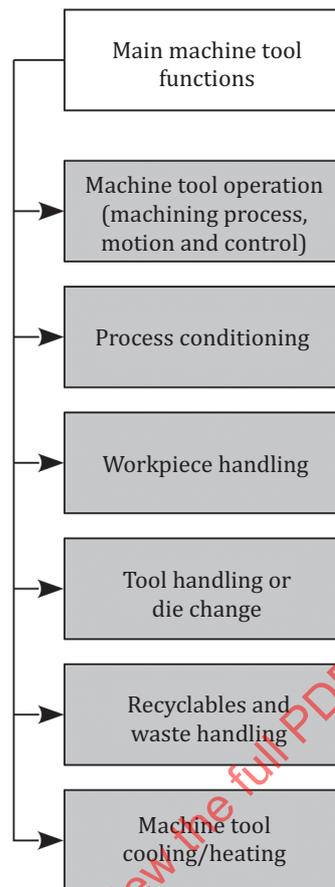


Figure 4 — Generalized functions of a machine tool in relation to energy efficiency at functional level, machine tool and process independent

NOTE This functional description is a proposal to facilitate analysis and problem solving in relation to the energy efficiency of a machine tool during the use stage.

6.3.2 Machine tool operation (machining process, motion and control)

“Machine tool operation” summarizes the target function of the machine tool, i.e. all energy supplied needed to realize the primary machining process.

6.3.2.1 Machining process

“Machining process” summarizes the realization of the machining processes, e.g. cutting velocity, electro-discharge process, laser beam for a cutting machine, process force, and working stroke of a press.

Typical machine tool components for the function “machining process” are the main spindle of a turning machine, the tool spindle of a machining centre, the generator of an electro-discharge machine, and the slide of a press.

6.3.2.2 Machining motion

“Machining motion” includes motions needed during machining a workpiece except machining process motions (see [6.3.2.1](#)). Examples for “machining motion” are feed motion of a turning machine, positioning motion of a rotary table, feed motions of a laser cutting machine, and closing and opening of a press.

Typical machine tool components for the function “machining motion” are linear and rotary axes of a machining centre with their drives and power supply systems, rolling and sliding guideways, ball screws, bearings, gears, couplings, belts, pulleys, and axis clamping.

6.3.2.3 Machine control

“Machine control” summarizes the control of the machine, generally the numerical control, for automatic sequence control, monitoring systems, and measuring systems. “Machine control” may also contribute to non-machining functions, e.g. tool handling.

Typical machine tool components for the function “machine control” are the numerical control systems, PLCs, displays, sensors, decoders and encoders, lighting of the work space, frequency converters, voltage transformers, relays, and touch probes.

6.3.3 Process conditioning

“Process conditioning” comprises all cooling, heating, and other conditioning that is process-related in order to keep the temperature and other relevant conditions of the working volume, the tools, the fixtures and/or the workpieces within limits. Process conditioning may be seen as a value adding function in order to achieve a constant machining process, e.g. lubrication for grinding, die lubrication for presses.

NOTE Process conditioning is sometimes combined with machine tool cooling/heating (see [6.3.8](#)).

Typical machine tool components for the function “process conditioning” are cooling pumps related to process coolant, cutting/forming fluid cooler, die lubrication fluid cooler.

6.3.4 Workpiece handling

“Workpiece handling” may include workpiece changing, workpiece grasping, workpiece clamping, workpiece lifting, in-feed of raw material, and measuring of workpieces on the machine tool.

Typical machine tool components for the function “workpiece handling” are pallet changer, workpiece handling robot, hydraulic clamping devices, and pneumatic chucks. On forming machines, “workpiece handling” is mostly done by destacker, centring stations, workpiece lifters in dies, workpiece ejectors, workpiece handling devices (e.g. robots, gripper bar transfer systems), and stacker.

6.3.5 Tool handling

“Tool handling” may include tool changing, tool grasping, tool clamping, tool storage, and probing of tools on the machine.

Typical machine tool components for the function “tool handling” are turret of a turning machine, hydraulic clamping devices, pneumatic chucks, tool changer, tool magazine, and system with compressed air to clean tool holder.

6.3.6 Die change

“Die change” may include die and automation tooling transport to/from interconnection points into the machine tool, die clamping, die storage, preparation of tooling for automation systems, coupling/decoupling of energy needed for, e.g. part forming in hydro-forming processes or auxiliary die functions, such as lifters, coupling/decoupling of die lubrication supply.

Typical machine tool components for the function “die change” are moving bolster or die cart, die pusher/puller, die clamps (hydraulic or electric or electro-hydraulic or hydro-pneumatic or magnetic), manually operated mono-couplings, and automatically operated docking systems equipped with multi-couplings and/or electric plugs.

6.3.7 Recyclables and waste handling

“Recyclables and waste handling” summarizes handling of chips or scrap, handling of cutting fluids including separation and filtering, handling of dust and fumes, and handling of dirt.

Typical machine tool components for the function “recyclables and waste handling” are a chip conveyor or scrap conveyor, filter systems, exhaust systems, and systems with compressed air for chip transport.

6.3.8 Machine tool cooling/heating

“Machine tool cooling/heating” summarizes all cooling and heating that is independent of the machining process. “Machine tool cooling/heating” does not add value to the machining process itself. “Machine tool cooling/heating” is applied in order to keep temperature within limits, so that machine tool components are not damaged or distorted, e.g. keep the temperature of the control cabinet within operational limits, keep the temperature of a high speed spindle within safety limits, keep the temperature of the machine tool within limits in order to prevent any thermal influences on the kinematic structure of the machine tool, keep oil temperature within operational limits.

Typical machine tool components for the function “machine tool cooling/heating” are fans, cooling system for control cabinet, water cooler, cooling pumps, and cooling/heating of guideways.

6.3.9 Subfunctions

The generalized functions may be divided into subfunctions in order to detect relevant energy flows. [Figure 5](#) shows one possible division into subfunctions.

NOTE Generalized functions might be also called first-level functions (see [Figure 4](#)), subprocesses second-level, third-level, etc. functions (see [Figure 5](#)).

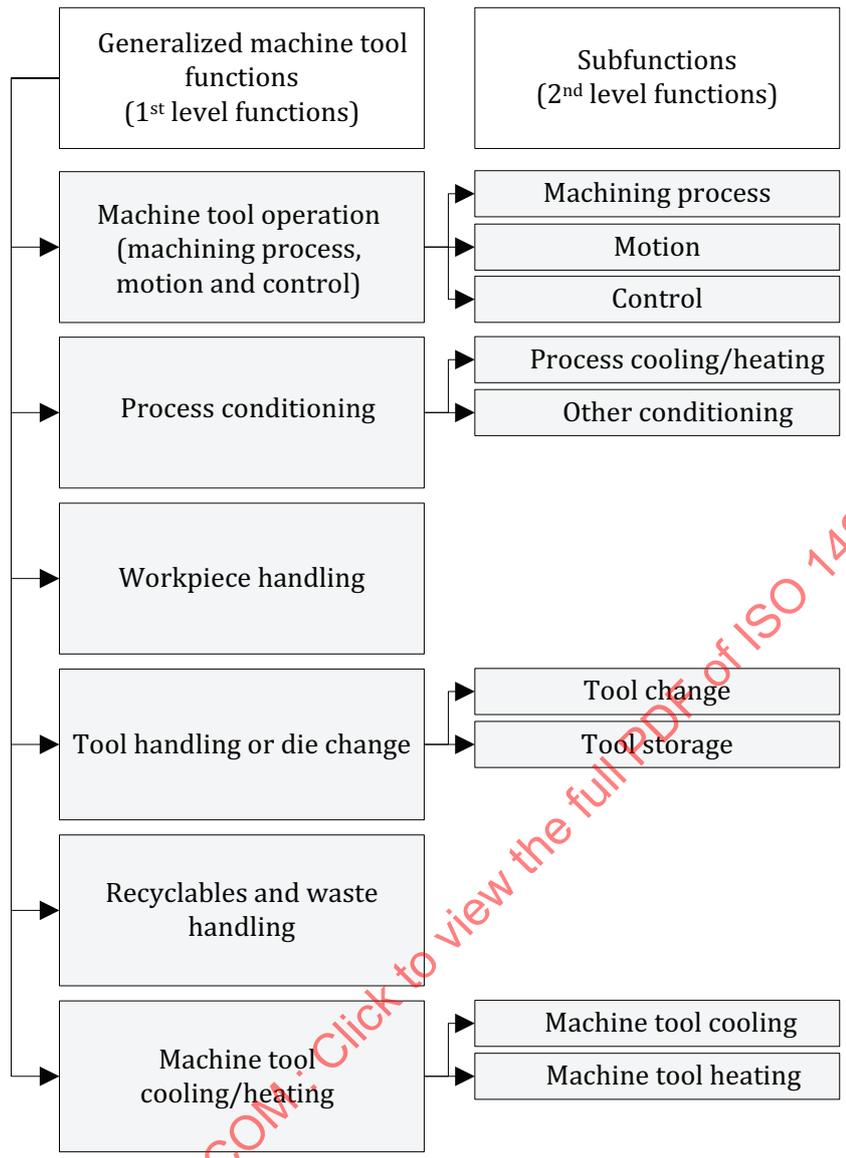


Figure 5 — Example of generalized machine tool functions and subfunctions in relation to energy efficiency (first- and second-level functions)

6.3.10 Machine tool functions and machine tool components

Sometimes machine tool components fulfil several functions, e.g. a coolant system is used for machine tool cooling (according to 6.3.8) and for process conditioning (according to 6.3.3). Then, the energy supplied to this machine tool component can be assigned to different generalized machine tool functions or subfunctions. Figure 6 gives an example of such assignments for a metal-cutting machine tool. Similar mapping can be performed for a metal-forming machine tool. For such a mapping, the operating states of the machine tool and/or the specific test cycle shall be considered.

Significant exchange of energy in some operating states, e.g. during warm up, needs a defined time period in those operating states.

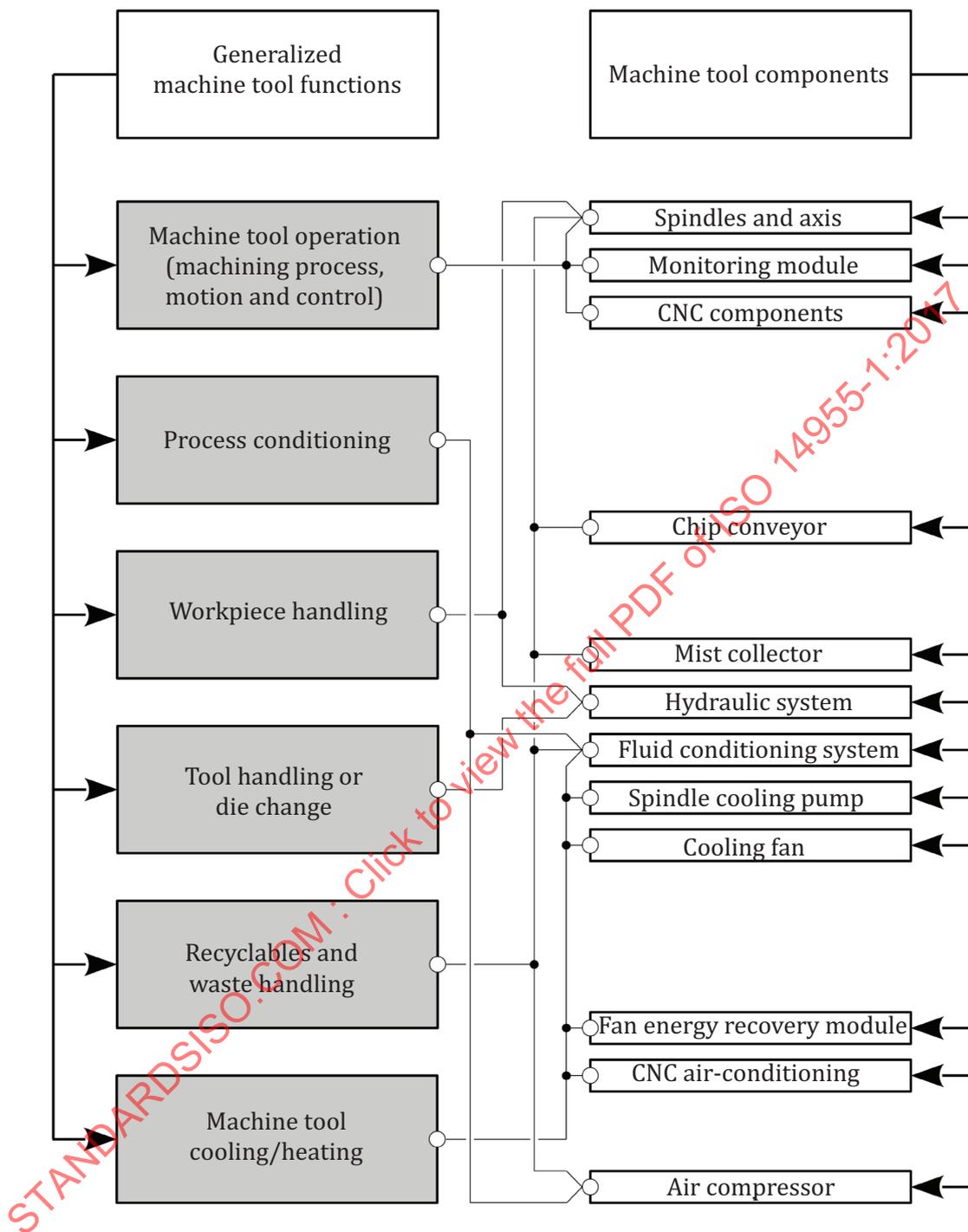


Figure 6 — Example of assigning machine tool components to machine tool functions (functional mapping) for a metal-cutting machine tool

This functional mapping finally shall be done quantitatively. An example is given in [Figure 7](#), where the quantitative mapping is given in per cent (%) and where each line shall have a sum of 100 %.

		Machine tool functions						Mapping based on
		Machine tool operation (machining process, motion and control)	Process conditioning	Workpiece handling	Tool handling or die change	Recyclables and waste handling	Machine tool cooling/heating	
Machine tool components	Spindles and axis	80%		10%		10%		typical operating times
	Monitoring module	100%						
	CNC components	100%						
	Chip conveyor					100%		
	Mist collector					100%		
	Hydraulic system			80%	20%			typical activation of hydraulics
	Fluid conditioning system		50%			25%	25%	
	Spindle cooling pump						100%	
	Cooling fan						100%	
	Fan energy recovery module						100%	
	CNC air-conditioning						100%	
	Air compressor		75%			25%		typical use of pressurised air

Figure 7 — Example for quantitative functional mapping, data given in per cent (%)

NOTE When mapping machine tool components to more than one generalized function, the determination of the respective shares may appear as an imprecise procedure. However, the assignment of machine tool components to a single generalized function does not allow an appropriate system analysis if machine tool components are linked with more than one generalized function. In lack of measurement data and/or scientific grounds, an educated guess still gives a better insight for the system analysis than ignoring the complex dependencies between machine tool components and generalized functions.

6.4 Relevant machine tool functions and relevant machine tool components

6.4.1 Relevant machine tool functions

By examining the energy supplied for the different machine tool functions or subfunctions, the function(s) most relevant for energy supplied during use stage of a machine tool shall be identified. Most relevant functions for energy supplied to the machine tool are those - if sorted in descending order - which are on top of this sorted list and whose cumulative total accounts for at least 80 % of total energy supplied to the machine.

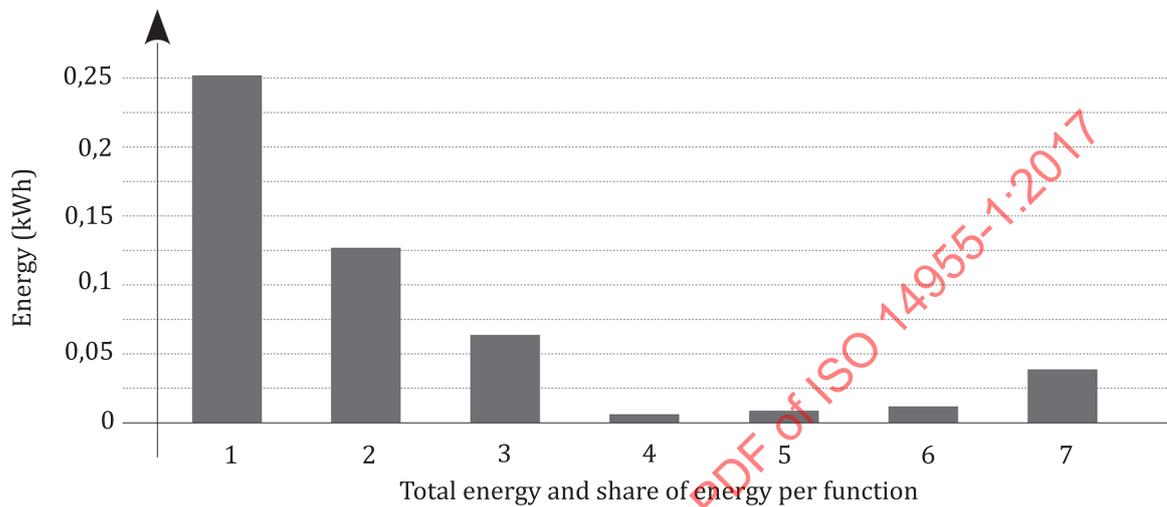
NOTE The limit of 80 % is chosen due to available information and due to measurement uncertainties for measurement of energy or power.

Energy supplied to the machine tool shall be measured. During the design phase, energy supplied to the machine tool might be also calculated or simulated. A profile of the energy supplied to the machine tool as shown in Figure 8 can be used for presenting the results of this examination. Such profiles shall be presented together with a statement on the operating state(s) and/or the test cycle of the machine tool under test and/or the test piece machined; operating state(s) and test cycles and/or workpieces shall be specified by standards or shall be agreed upon between manufacturer/supplier and user of machine tool.

For comparisons, operating states and test cycles or test pieces shall be comparable, including additional parameters such as environmental conditions, operating times, and accuracy of test piece.

It is recommended to measure power instead of energy, so that the statistical duration of time spent in the different operating states (according to 3.7) can be taken into account. For this purpose, however, a time study is required. For this purpose, time studies compiling statistical distributions of time spent

in the respective states can be used as statistics that are based on observations of machine tools in industrial use environments (e.g. according to Reference [11]). Even with such statistics available, it is still required to determine the total period over which the energy use is to be determined. A total period of use or a total period of effective machining can be examples of functional units (according to 3.11) to be used for this purpose.



Key

- 1 total energy
- 2 machine tool operation (machining process, motion and control)
- 3 process conditioning
- 4 workpiece handling
- 5 tool handling
- 6 recyclables and waste handling
- 7 machine tool cooling

NOTE Machining parameters are: turning of steel, cutting speed 180 m/min, feed speed 0,35 mm/rev, volume cut 1 564 331 mm³, cutting time 440 s.

Figure 8 — Example presentation of profile of energy supplied to the machine tool when cutting a specified test piece with specified machining parameters

6.4.2 Relevant machine tool components

The most relevant functions and the components related to these are the first targets for improvement related to energy efficiency of machine tools. They should be furthermore evaluated in respect of their value added to the machining process, their relative improvement potential through measures such as listed in Annex A, their state as compared to the state-of-the-art, and the impact of modification of the component on the machine tool as a whole.

6.5 Result achieved

For the evaluation of energy efficiency, quantification of the “result achieved” is a prerequisite. It shall be quantified by observation (e.g. unit ON or OFF), by counting (e.g. number of tool changes), by time measurement (e.g. cycle time, machining time), or by other measurements (e.g. feed speed of axis, or flow and pressure of lubricant supplied).

When measuring of energy efficiency includes machining of workpieces, the machining time, workpiece accuracy, and any other workpiece characteristics produced by the machining process shall be defined. Workpieces not complying with the requirements shall not be counted as result achieved, but the energy assigned to these workpieces (e.g. energy content in material, energy content to pre-machining) shall be considered as resources used.

6.6 Efficiency evaluation

Statements of energy efficiency shall be given in result per energy supplied to the machine tool, e.g. in cycles per energy supplied, in workpieces per energy supplied.

Any statement of energy efficiency shall be accompanied with information on operating states, machine tool activities, and environmental conditions during the test procedure. Measurement uncertainties should be stated with the test results.

7 Design procedure for energy-efficient machine tools

In order to fulfil design procedures for energy-efficient machine tools, as shown in [Figure 9](#), the following requirements shall be satisfied:

- the machine tool is described in its generalized functions or subfunctions, and machine tool components are assigned to generalized functions or subfunctions according to [6.3](#);
- function(s) relevant for energy efficiency during the use stage are identified (see [6.4.1](#));
- relevant function(s) is (are) assigned to machine tool components (see [6.4.2](#));
- relevant machine tool components, their control, and their combinations are compared to the state-of-the-art (see [Annex A](#)) or to the previous generation of that machine tool component, control, and/or combination (see [Clause 8](#));
- relevant machine tool components and/or function(s) are monitored (see [Clause 8](#)).

NOTE 1 If a machine tool under investigation has other relevant environmental impacts than energy supplied to the machine tool during use stage, this is not addressed by this document. Other standards or reports, such as ISO/TR 14062, could be of guidance.

NOTE 2 The methodology for energy efficient machine tools according to [Figure 9](#) is a definition of the design procedure, not an evaluation of machine tools.

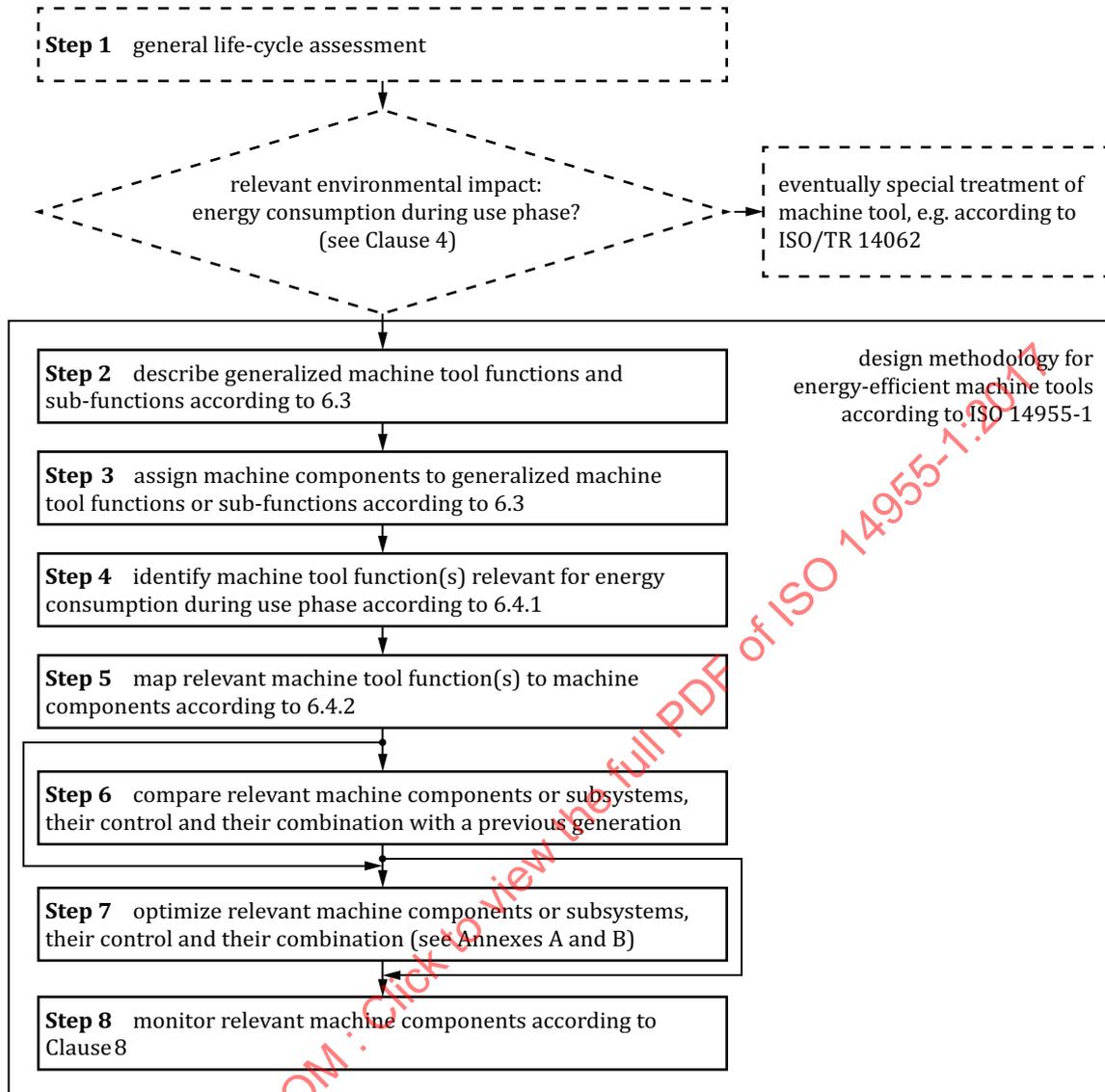


Figure 9 — Design methodology for energy-efficient machine tools

8 Reporting and monitoring of results

Reporting and monitoring of results shall include one of the following options:

- comparison with the state-of-the-art (e.g. qualitative comparison based on [Annex A](#));
- comparison with previous generation of machine tool of similar functionality (performance, productivity, accuracy);
- monitoring of results, including parameters covering higher productivity, higher accuracy, higher functionality of new generation machine tools.

Principally, the evaluation is done by the machine tool manufacturer. This enables the manufacturer to monitor their individual improvements with special attention to the most relevant machine tool function(s) and machine tool component(s).

If results are reported in the form of an environmental claim or a qualified environmental claim, the following requirements shall be fulfilled:

- the claimant shall be responsible for evaluation and provision of data necessary for the verification of the claim;
- prior to making the claim, evaluation measures shall be implemented to achieve reliable and reproducible results necessary to verify the claim.

More details are given in ISO 14021, especially to topics such as evaluation of comparative claims, selection of methods, access of information (see ISO 14021:2016, Clause 6), recovered energy (see ISO 14021:2016, 7.6), and reduced energy supplied to machine tool (ISO 14021:2016, 7.9).

NOTE Some machine tools and their applications can require a temperature-controlled environment outside the machine tool components. The introduction of the closed-loop process control has, in some cases, eliminated this requirement, with consequent environmental energy savings which might not be directly accounted for by a measurement of the energy supplied to the machine tool. The energy saved would depend on the factory location and local climate. In such cases, it is legitimate to include a qualifying statement to avoid an over-simplistic interpretation of any energy figures quoted.

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Annex A (informative)

List of energy efficiency improvements for machine tools

[Table A.1](#) is a non-exhaustive checklist of energy efficiency improvements for machine tools. Although the measures are generally apt to improve energy efficiency, their implementation should be considered within the given circumstances, the system design, the technologies used, and the application of the machine tool under investigation. Decisions about their implementation might be further subject to consideration of multiple criteria including functionality, standardization, reliability, cost, and others.

“X” in column “A” of [Table A.1](#) indicates applicability for metal-cutting machine tools, in column “B” for hydraulic presses, in column “C” for mechanical servo presses and mechanical presses and in column “D” for woodworking machine tools (different technologies of woodworking machine tool technologies are considered).

Table A.1 — Well-tried design principles for machine tool components, control components and combinations of machine tool components for energy-efficient machine tools

A: metal-cutting machine tools, B: hydraulic presses, C: mechanical (servo) presses, D: woodworking machine tools						
No.	Feature for improvement	Description	A	B	C	D
1	Overall machine concept					
1-1	Minimization of moved masses	If masses are accelerated, the energy required depends on the mass ($E = 1/2 * m * v^2$). Even if some part of the energy is recovered during braking, energy is supplied and recovered with an efficiency factor below one. The best way to reduce energy needed for acceleration is mass reduction.	X	X	X	X
1-2	Reduction of friction	Reduction of friction means less mechanical wear and higher quality and also should lead to energy reduction; various types of bearings possible (rolling bearing, sliding bearing, hydrostatic bearing, magnet bearing); ecological aspect is considered by the choice of bearing as well. Reduction of speed-dependent friction should be optimized with respect to the characteristic of the chosen drive technology.	X	X	X	X
1-3	Optimization of the overall machine design	Check if the machine tool has been designed according to customer requirements and operational range has been specified close to optimal working point; avoid adding up spare capacities (avoid oversizing/over-engineering).	X	X	X	X
1-4	Design for instant machining without warm-up	Provisions for automatic temperature compensation.	X			
1-5	Workpiece clamping	Eliminate or minimize energy required to maintain workpiece clamping.	X			X
1-6	Tool unclamping	Minimize energy to unclamp the tool.	X			X

Table A.1 (continued)

A: metal-cutting machine tools, B: hydraulic presses, C: mechanical (servo) presses, D: woodworking machine tools						
No.	Feature for improvement	Description	A	B	C	D
1-7	Multi-spindle/multi-workpiece machine tools	Depending on the application, consider multi-spindle or multi-workpiece machine tools. One-time mounting, shared auxiliary units and lower part transfer time could deliver higher energy efficiency, compared to several independent machine tools.	X			X
1-8	Minimizing the number of re-clamping	Reduction of non-productive time increases energy efficiency.	X			
1-9	Combination of various processing technologies	Combination of various processing technologies in one machine tool, one-time mounting and adjusting may result in higher quality and higher yield and also causing increased energy efficiency (consider e.g. "turning and milling", "milling, boring and edge banding").	X			X
1-10	Axis clamping	Usage of axis clamping instead of active motor brake.	X			X
1-11	Redundant axis	High acceleration with short-stroke axis reducing acceleration for long-range, heavy axis.	X			
1-12	Increased productivity	Without utilization (production) or low output, the efficiency will be degraded, e.g. maximize productivity by adaptive optimization of cutting parameters.	X			
1-13	Provide customer interaction to reduce consumption of resources	Give the operator provisions to intervene when he expects downtime, e.g. button to activate standby condition.	X	X	X	X
1-14	Tool change during running spindle	Provision to allow a tool change (e.g. boring head) during running spindle to avoid deceleration and acceleration of spindle (milling machine tools used in a way to change tools very frequently).	X			X
1-15	Reduce tool changing	Consider allowing multi-profile tools or different tools mounted on the same spindle (e.g. double shaft).	X			X
1-16	Counterbalance system for vertical axes	Counterbalancing systems reduce the potential energy in vertical moving systems. Additional reduction of accelerating and decelerating (consider e.g. spring-type mounting).	X	X	X	X
1-17	High efficient cushion	Cushions are needed for restraining material flow. Without energy efficiency the energy required is mostly transferred into heat. Minimize energy transferred into heat by using a cushion control system with low-energy consumption or regenerative feedback.		X	X	
1-18	Use regenerative circuit for differential cylinders	Reduction of pressure drop on control valves.		X		
1-19	Die clamping	Choose clamping system with best efficient technology. Prefer passive clamping systems (consider e.g. spring loaded clamping, electric clamping, magnetic clamping).		X	X	
1-20	Handling technologies	Use of handling robots and/or automated handling devices to optimize non-production and setup time.		X	X	

Table A.1 (continued)

A: metal-cutting machine tools, B: hydraulic presses, C: mechanical (servo) presses, D: woodworking machine tools						
No.	Feature for improvement	Description	A	B	C	D
2	Drive units					
2-1	Regenerative feedback of inverter system (e.g. servo motor, spindle, active front end technology (AFE))	The in feed unit is capable to feed back the braking energy to the main power supply.	X	X	X	X
2-2	Motors					
2-2-1	Use of energy efficient motors	Use of an energy efficiency class according to IEC 60034-30 and the motor size (IE/capacity), or use of variable reluctance motors.	X	X	X	X
2-2-2	Use of magnetic flux control	Magnetic flux to be controlled in order to reduce losses, e.g. on asynchronous motors	X			X
2-3	Use of high-quality reducers	— Use of gear sets quality as defined in ISO 1328 — Use of low-friction seals — Optimize lubrication	X		X	X
2-4	Use of brake for non-moving axes	Axes that are not involved in the interpolation during the part program are switched off (pulses deleted) and clamped by a brake.	X			X
2-5	Highly efficient inverter	Use of inverter with highly efficient power device.	X	X	X	X
2-6	Higher voltage systems (e.g. 400 V) to substitute 200 V systems (where applicable)	Higher voltage systems (e.g. 400 V) lead to higher energy efficiency due to reduced ohmic losses.	X			X
2-7	DC voltage link to balance the energy between different drives	The DC voltage link balances the energy between different drives and may reduce the size of the in-feed unit.	X			X
2-8	Optimization of the dynamic parameters	Option to limit the acceleration or speed in the set point signal results in a better exploitation of the motors' efficiency or speed optimization according to the process. In this case, the overload capability of the motor is not utilized.	X	X	X	X
2-9	Optimization of installed motor power	Select motor operating close to optimum of efficiency factor, oversizing and overloading creates energy losses.	X	X	X	X
2-10	Provide most efficient drive system	Provide most efficient drive system for operating conditions in which the machine tool is mostly working. Compare energy efficiency of different types of drive systems (consider e.g. direct pump drive for processes with short cycle time, accumulator drive for processes with long cycle time); see 3-1.		X		X
2-11	Use of multi-pressure accumulator system for main axis	Multi-pressure accumulator systems reduces pressure drop between accumulator and actuator.		X		X
2-12	Direct coupled energy storing drive systems for main drives	Direct coupled energy storage support may reduce installed power of main motors (consider e.g. flywheel).			X	
2-13	Indirect coupled energy storing drive systems for main drives	Use energy-storing drive systems to reduce power peaks (consider e.g. electrically coupled flywheels, capacitor banks).		X	X	

Table A.1 (continued)

A: metal-cutting machine tools, B: hydraulic presses, C: mechanical (servo) presses, D: woodworking machine tools						
No.	Feature for improvement	Description	A	B	C	D
2-14	Intelligent management of drives	Intelligent management of drives turns off energy users when not needed (consider e.g. electric motors).	X	X	X	X
2-15	Minimization of spare capacity/customer specific layout of inverter system	Select an appropriate inverter: — select inverter close to motor size; — oversizing can create energy losses.	X	X	X	X
3	Hydraulic systems					
3-1	Selection of the optimal drive sub-system (motor-pump system)					
3-1-1		Different functions/sequences create the need for pump systems which match the requirements profile (pump combinations, e.g. high pressure/low pressure, variable or fixed-displacement pumps).	X	X	X	X
3-1-2		Power on demand depending on the load cycle (constant speed in intermittent operation, variable speed (pole change, speed control/regulation) with servo motors or asynchronous motors).	X	X	X	X
3-1-3		Select the correct size and type of motor and pump to avoid over dimensioning and to operate the pump in the optimal efficiency range.	X	X	X	X
3-1-4		Temporary storage of hydraulic energy to achieve the best possible match between the pump drive and the load cycle and to compensate for demand peaks (potential downsizing) (consider e.g. accumulator charging operation).	X	X	X	X
3-1-5		Speed-controlled pumps and variable displacement pumps allow pressure control with variable speed instead of control valve.	X	X	X	
3-2	Match the pressure level to the load cycle and to the different actuators on the machine tool					
3-2-1		Pressure adjustment using a variable displacement pump, speed controlled pump or zero-pressure circulation.	X	X	X	X
3-2-2		Use actuators which are designed to operate at the same pressure level (no pressure reduction losses).	X	X	X	X
3-2-3		Pressure adjustment using pressure-controlled drive systems (consider e.g. variable speed drives, adjustable-pressure variable capacity pumps).	X	X	X	X
3-2-4		Use pressure intensifiers for individual actuators which require higher pressure.	X	X	X	X
3-2-5		On/Off or standby mode, giving due consideration to safety criteria.	X	X	X	X
3-3	Reduce hydraulic losses/leakage					
3-3-1		Use displacement control systems in place of throttle control systems.	X	X	X	X

Table A.1 (continued)

A: metal-cutting machine tools, B: hydraulic presses, C: mechanical (servo) presses, D: woodworking machine tools						
No.	Feature for improvement	Description	A	B	C	D
3-3-2		Reduce internal leakage (consider e.g. seat valves in the accumulator charging unit or the clamping hydraulics).	X	X	X	X
3-3-3		Optimize the design of the hydraulic lines and reduce hydraulic resistance.	X	X	X	X
3-3-4		Consider distributed supply strategies.	X	X	X	X
3-3-5		Use of pilot operated valves with low pilot oil consumption.		X	X	X
3-3-6		Use of manifolds with low pressure drops.	X	X	X	X
3-4	Dimensioning of tubes and pipes	Optimize the design of piping (length, diameter, etc.) and reduce flow resistance. Tubes and pipes cause friction losses and thus energy losses. Finally, the tube or pipe causes a pressure drop which negatively affects the energy efficiency of the machine tool. Length, inner diameter, flow rate, and installation radius of tubes, pipes, and fittings to be optimized to the application. Functions to be identified and described where this requirement is applicable.	X	X	X	X
3-5	Increase energy efficiency on solenoid operated valves					
3-5-1		Use pulse valves (with detent) which only draw power during switching.	X	X	X	X
3-5-2		Use valve connectors with built-in automatic reduction of holding current, e.g. Pulse Width Modulation.	X	X	X	X
3-5-3		Use valves with 8 W solenoids when applicable. The possible use of low Watt solenoids is depending on the function, because of reduced switching forces.	X	X	X	X
3-6	Leakage monitoring	Internal leakage leads to energy losses. Leakage monitoring detects exceeding flow (consider e.g. loose fittings in reservoir, worn valves or pumps).	X	X	X	X
3-7	Low flow resistance	Avoid losses caused by flow resistance (consider e.g. by choosing valve dimension and spring characteristics in respect to optimized pressure drop).	X	X	X	X
3-8	High efficient auxiliary pressure generation	Avoid pressure relief valves or pressure reducing valves for pressure adjustment, generate pressure at appropriate level (consider e.g. speed controlled pumps, pumps with variable flow, discontinuously operating pumps), see 3-1.	X	X	X	X
3-9	Warm-up cycle	End warm-up cycle as soon as possible, use actual oil temperature to control warm-up. If applicable change to hydraulic heating instead of electrical heaters in respect to start temperature.	X	X	X	X

Table A.1 (continued)

A: metal-cutting machine tools, B: hydraulic presses, C: mechanical (servo) presses, D: woodworking machine tools						
No.	Feature for improvement	Description	A	B	C	D
3-10	Oil temperature	Operate in optimal temperature range. Select oil viscosity grade suitable for the expected ambient temperature range.	X	X	X	X
3-11	Oil cooling	Use water cooling instead of air cooling. Water cooling is more efficient and water may be used in facility for other purposes. Recovering cooling energy can be used for floor heating, warm water supply, etc.	X	X	X	X
3-12	Overall system	Optimization of total hydraulic system, e.g. amount of required oil.	X	X	X	X
4	Pneumatic systems					
4-1	Optimized compressed air system with minimum losses (differentiation between sealing air and pneumatic drives)					
4-1-1		Single master switch-off.	X	X	X	X
4-1-2		Individual switch-off capability for specific modules.	X	X	X	X
4-1-3		Intelligent shut down procedures.	X	X	X	X
4-1-4	Leakage prevention	Leak indicator, on demand monitoring. One of the main avoidable causes of poor energy efficiency is leakage in pressure piping and tubes. Leakage and condition monitoring systems as part of the control system of the machine tool to be implemented in order to easily locate leakage and eliminate leakage.	X	X	X	X
4-1-5	Reduction of dead volume	Distance between valve and cylinder should be kept as short as possible. Long tubes are dead volumes which cause a major loss of energy in each switching cycles as they are pressurized and exhausted. This amount of compressed air will be wasted.	X	X	X	X
4-1-6	Directed switch off of not needed branches.	Check if all branches of pneumatic circuits need to be pressurized in all operating states of the machine tool. If not, consider to switch these branches off in order to prevent energy losses caused by not needed volume.	X	X	X	
4-1-7	Dimensioning of tubes and pipes	Optimize the design of piping (length, diameter, etc.) and reduce flow resistance. Tubes and pipes cause friction losses and thus energy losses. Finally, the tube or pipe causes a pressure drop which negatively affects the energy balance of the machine tool. Length, inner diameter, flow rate, and installation radius of tubes, pipes, and fittings should be optimized to the application.	X	X	X	X
4-1-8	Correct layout of pneumatic drives	Pneumatic drives, e.g. cylinder forces, should not be oversized. Less needed air consumption and thus less use of energy are the result. The layout of the pneumatic system and its components should be tailored to suit the machine tools need.	X	X	X	X

Table A.1 (continued)

A: metal-cutting machine tools, B: hydraulic presses, C: mechanical (servo) presses, D: woodworking machine tools						
No.	Feature for improvement	Description	A	B	C	D
4-1-9	Reduction of pressure	The interaction of pressure supply reduction to machine tool performance should be verified. (Depending on the application, 1 bar reduction can result in up to 10 % increased efficiency). The reduction of pressure should not have any negative influence on the correct function of the machine tool.	X	X	X	X
4-2	Optimize cylinder force for the required function		X	X	X	X
4-3	Sealing air	When larger lots of sealing air ($P < 0,2$ MPa) are needed (more than $0,3$ m ³ /min), a small low-pressure compressor or similar means usually gives a much better efficiency than compressed air from a pressure-reducing regulator.	X			
4-4	High efficiency cleaning blowers	Optimized design of cleaning blowers reduces need for air supply.				X
4-5	Switch off cleaning blowers when not needed by the process	Direct switch off of not needed cleaning blowers prevents air pressure supply losses when cleaning is not needed.				X
4-6	Optimized position of sensors	Optimized position of sensors avoids using sensor cleaning blowers.				X
4-7	Overall system	Optimization of total system after optimization of subsystems.	X	X	X	X
5	Vacuum systems					
5-1	Use of energy-efficient vacuum pumps	Different pump principles lead to different pump efficiencies. Dry claw pumps are more efficient than rotary vane vacuum pumps.	X			X
5-2	Use of speed controlled vacuum pumps (with inverter)	Self-optimized rotation of pump motor according to the vacuum request (with help of a vacuum meter).	X			X
5-3	Optimized vacuum control on workpiece support	Manage different vacuum areas on workpiece support.	X			X
6	Electric systems					
6-1	Minimize energy losses in power supplies	Usage of high-efficiency transformer or voltage-proof converters instead of conventional transformers (consider e.g. controlled switching power for auxiliary power 24 V).	X	X	X	X
6-2	High efficiency transformer	Load requirement of a machine tool is not constant during the cycle. Therefore, it is more efficient to install transformers optimized on low Fe-losses instead of transformers optimized on low Cu-losses.		X	X	
6-3	Apply the simultaneity factor when designing the power system	Avoiding oversizing of power supply leads to lower absolute energy losses. Avoid overload as well.		X	X	X
6-4	Converter/inverter with power factor correction	Regenerative drives can be used to correct the supply line power factor, reducing related power losses	X	X	X	X
6-5	Thermal management regarding control cabinet					

Table A.1 (continued)

A: metal-cutting machine tools, B: hydraulic presses, C: mechanical (servo) presses, D: woodworking machine tools						
No.	Feature for improvement	Description	A	B	C	D
6-5-1		Minimization of waste heat, e.g. use of high efficient components.	X	X	X	X
6-5-2		If waste heat is not avoidable, it is dissipated (air cooling or water cooling). For reuse of thermal energy water is given a preference compared to air. Further use of waste heat is checked/discussed with customer.	X	X	X	
6-5-3		Use controlled ventilation (fan) when applicable.	X	X	X	X
6-5-4		Use low maintenance air conditioner (no air filter) and thermostatic air conditioning with open-door-shutoff.	X	X	X	X
6-6	Lighting systems					
6-6-1		Use of energy efficient lighting systems.	X	X	X	X
6-6-2		Automatic switch off of lighting systems when not needed.	X	X	X	X
6-7	Overall System	Optimization of overall system after optimization of subsystems.	X	X	X	X
7	Process heating system					
7-1	Automatic switch off of infrared lamps according to the process					X
7-2	Automatic switch off of hot air jet to low consumption mode according to the process	Switch to low consumption mode instead of switching off allows fast reach of working temperature.				X
7-3	Automatic switch off of glue pot heating to low consumption mode according to the process	Switch to low consumption mode instead of switching off allows fast reach of working temperature.				X
7-4	Instant process heating system	Consider e.g. usage of laser technology for edge-banding.				X
7-5	Automatic switch of plates heating system to low consumption mode according to the process	Switch to low consumption mode instead of switching off allows a quick return to the processing temperature.				X
8	Cooling/lubrication system					
8-1	Thermal management of all cooling devices including cooling device for machine tool and/or its modules	Optimized concept for thermal management of all cooling devices regarding the following:				
8-1-1		Minimization of thermal power losses.	X	X	X	
8-1-2		If thermal power loss is not avoidable, it is dissipated by air or water cooling. For reuse of thermal energy, water is given a preference compared to air. Further reuse of thermal energy is checked/discussed with customer (consider e.g. standardized interface).	X	X	X	X
8-1-3		Use controlled ventilation (fan) when applicable.	X	X	X	X
8-2	Temperature controlled components	Apply direct cooling of components depending on process (cooling at the source).	X	X	X	

Table A.1 (continued)

A: metal-cutting machine tools, B: hydraulic presses, C: mechanical (servo) presses, D: woodworking machine tools						
No.	Feature for improvement	Description	A	B	C	D
8-3	Demand-depending cooling	Apply demand-depending cooling (consider e.g. substituting line connected motors by inverter motors, temperature controlled coolant water flow, etc.).	X	X	X	
8-4	Consideration of applied subsystems with regard to synergies	To obtain the maximum possible energy savings, it is often not sufficient to only look at the individual components and modules that are used for the individual functions. In addition, it should be checked if it is possible to extend the use of a supply unit (e.g. hydraulic), particularly during idle periods where other machine functions could be supplied or driven by it. In addition to the increase in the total efficiency of the supply unit due to the improved utilization, a complete drive unit can be omitted (e.g. generation of high-pressure coolant) and a large part of the previous energy requirement saved (avoidance of electrical and mechanical losses).	X			
8-5	Lubrication pumps	Active mode of cooling and lubrication system, depending on demand:				
8-5-1		Use of discontinuous operating pumps.	X	X	X	X
8-5-2		Use of controlled flow rate.	X	X	X	X
8-5-3		Use of adjustable pressure.	X	X	X	X
8-5-4		Install not more than sufficient pump flow and distributor instead of orifices.	X	X	X	
8-6	Minimal quantity lubrication (MQL)	Use of MQL when applicable and advantageous.	X			X
9	Chip and dust extraction hoods					
9-1	Optimized design of chip and dust extraction hoods	With optimized design pressure drop can be reduced and hood efficiency increased.				X
9-2	Automatic management of gate valve of each extraction hood according to the process	Closing of gate valves of unused units allows energy savings.				X
10	Other pumps					
10-1	Use of energy efficient pumps	Different pump principles lead to different pump efficiencies.	X	X	X	X
10-2	Use of energy efficient pump-motor units	Pump principle and sizing in combination with the electrical motor influences the efficiency of the unit. Pump principle, size and speed to be selected so that the pump system operates near to its optimum efficiency for as long as possible; see 3-1.	X	X	X	X
11	Other peripheral devices					
11-1	Optimized control of other peripheral devices according to the process	Consider control of peripheral devices depending on operating state, e.g. chip and scrap conveyor, mist extraction system, and markers.	X	X	X	X
12	Guidance for energy efficient use					
12-1	Optimization of workpiece processing					

Table A.1 (continued)

A: metal-cutting machine tools, B: hydraulic presses, C: mechanical (servo) presses, D: woodworking machine tools						
No.	Feature for improvement	Description	A	B	C	D
12-1-1		Workpiece processing by simulation off-machine; avoidance of inefficient operating time; use also possible in conceptual phase of machine tool design. Non-productive time can be minimized if a simulation environment is provided for virtual setup allowing for simulative exclusion of possible collisions and simulative optimization of tool paths.	X			X
12-1-2		Workpiece processing by tryout off-machine; avoidance of inefficient operating time; use also possible in conceptual phase of machine tool design.		X	X	
12-2	Provisions to reduce scrap production	Die monitoring, in-process control, optimised use of raw material - minimize waste, zero defect production.		X	X	X
12-3	Provide customer information to reduce consumption of resources					
12-3-1		Information to user on energy efficient use of the machine tool (e.g. on/off programming of auxiliary devices by user manual and training) Provide operator information, e.g. how to intervene when downtime is expected.	X	X	X	X
12-3-2		Information to user on optimized movements of axis. Means for optimization of movements of multiple axis systems, (e.g. feeders, robots) to follow energy optimized trajectories; see 12-3-1.	X	X	X	X
12-3-3		Provide information to the user on recoverable heat power (e.g. flow rate and temperature of medium).	X	X	X	X
12-4	Minimize non-productive time	Without utilization (production) or low output the efficiency will be degraded. Means of improving output may be automatic die/tool change systems, condition monitoring to prevent component failures, good diagnostic for quick trouble shooting, etc.	X	X	X	X
12-5	Optimize productivity by reducing cycle time per part	An improved productivity reduces the portion of required basic load per part.	X	X	X	X

Table A.1 (continued)

A: metal-cutting machine tools, B: hydraulic presses, C: mechanical (servo) presses, D: woodworking machine tools						
No.	Feature for improvement	Description	A	B	C	D
13	Control systems					
13-1	Control parameters for different operating conditions	<p>A method for increasing energy efficiency by adapting control parameters to the active type of processing is provided. The type of method can follow different concepts or a combination of these concepts:</p> <p>A) Static Methods for manual selection of a parameter set of control parameters (e.g. including velocity limits, acceleration limits, feed forward, and feedback control coefficients) according to a target application (consider e.g. different parameter sets for roughing and finishing).</p> <p>B) Dynamic Methods for automated adaptation of control parameters to process conditions on a dynamic basis (consider e.g. applying adaptive feed control, advanced position control).</p> <p>C) Methods by adapting control parameters based on energy efficiency commands in the part program (consider e.g. STEP-based, such as roughing, finishing, boring, thread cutting).</p> <p>A provision to configure conditions for automatic switch over between different operating conditions.</p>	X			X
13-2	Energy optimized default setting for operating condition -energy level- (customer specific drive management)	<p>possible operating conditions -energy levels-:</p> <ul style="list-style-type: none"> — switched off — standby - ready to be started (mains on, controls running, auxiliary and peripheral units stopped) — halted - ready for production (auxiliary and peripheral units on) — production possible - means depending on mode of operation — screen saver and lighting for control panel — intelligent drive management — etc. 	X	X	X	X
13-3	Automatic operating state switching	Switching between different operating states helps drive management to choose most efficient mode.	X	X	X	X
13-4	Optimization of manufacturing process depending on manufacturing conditions	Provision of motion control features for minimization of energy supplied (consider e.g. time-optimized manufacturing vs. energy-efficient manufacturing, accuracy-optimized manufacturing vs. energy-efficient manufacturing).	X			X
13-5	Recording or monitoring of energy supplied together with production data	The knowledge of the energy supplied to the machine tool under different operating conditions (e.g. workpieces/kWh) helps the user to implement energy management systems.	X	X	X	X

Annex B (informative)

Example of how to apply the methodology on a machine tool

Specific machine tool under test:

- machine type: 5-Axis machining centre;
- axis travel: X: 1 000; Y: 1 000; Z: 800 mm;
- machine mass: 14 000 kg;
- spindle power: 35 kW nominal;
- auxiliary machine accessory: integrated tool changer.

The following steps refer to the design methodology as shown in [Figure 9](#).

Step 1: Supplied energy during use phase is the most relevant environmental impact

Step 2: Describe generalized machine tool functions and subfunctions

- Machine tool operation: spindle and axis; 230 V AC and 24V DC supply
- Process conditioning: interior and exterior lubricant supply, re-cooling of lubrication, air convection by mist extraction
- Workpiece handling: manual loading → No machine tool function
- Tool handling or die change: tool changer, hydraulic clamping
- Recyclables and waste handling: chip purging, chip conveyor, chip filtering, seal air, mist extraction
- Machine tool cooling/heating: lubricant supply, electrical cabinet cooling