WHICH GUIDELINE IS MOST RELEVANT? INTRODUCTION OF A PRAGMATIC DESIGN FOR ENERGY EFFICIENCY TOOL

Karola Rath[1], Herbert Birkhofer[1], Andrea Bohn[1]
(1) Technische Universität Darmstadt, Germany

ABSTRACT
Energy efficiency is a topic of high importance in companies nowadays. As a knowledge deficit exists concerning the design of energy efficient products there is a significant need for comprehensive tools and methods supporting the designer to integrate energy aspects into the design process. Existing methods, particularly guideline-based tools are only little user-friendly as they do not support a systematic and selective access to guidelines that are most relevant to solve a specific problems.
This paper introduces a new guideline-based tool that provides a hierarchical structure and clustered guidelines and therefore eases targeted access to guidelines most relevant in a certain development context. This tool is intended to allow product designers to reduce the energy consumption of products during material processing, manufacturing, use, recycling and disposal. It is moreover integrated into a design approach for energy efficient products and accordingly serves as a pragmatic tool.

Keywords: guidelines, Design for Energy Efficiency, design process

1. INTRODUCTION
There is hardly any other topic that preoccupies national and international energy policy discussion as intense as energy efficiency [1]. Implementing energy efficiency measures is an important step towards addressing challenges like increased import dependency, concerns over supplies of fossil fuels worldwide and clearly discernable climate change [2]. More and more states set themselves ambitious energy saving targets: The Chinese government for example has set the target of reducing the energy intensity by 20%, or 4.36% each year between 2006 and 2010 on the 2005 level [3]. The European Council determined to tap the full energy savings potential, estimated at 20%, through appropriate measures by 2020 [4]. An important measure hereby is the development of energy efficient products. In this context the EU has initiated a multitude of directives und regulations, in order to establish energy efficient products on the market. These include amongst others the ErP (Energy related Products) Directive [5] or the Labeling Directive [6]. But those directives and regulations are only one driving force behind the increasing importance of developing energy efficient products. Also price-sensitive customers more and more ask for energy efficient products. And companies have long since realized that it is of significant competitive advantage to offer products that are energy efficient both in the production and in the use phase.
The development of energy efficient products, that require small amounts of energy in all phases of the product life cycle (material processing, production, use, recycling/disposal), is therefore a topic of key importance in companies. Product developers are increasingly confronted with the challenge of developing new energy efficient products or improve existing products in terms of energy efficiency aspects. More and more companies develop energy efficient products and there are a lot of industry examples of successful energy efficient products. But still a deficit in knowledge concerning energy efficient design of products and a lack in methods and tools that support product developer in designing energy efficient products can be observed [7, 8].
During literature review still some tools could be found, that were mainly guideline-based. Such guideline-based tools – usually guideline lists – are a typical Design for X tool [9]. Guidelines can be defined as procedures or measures to orient a decision process towards given objectives [10]. There do exist guideline lists that help the designer to develop environmentally friendly products (e.g. [11]). These lists do contain some measures concerning the design of energy efficient products but don’t deal

comprehensively with this topic and therefore are only little target oriented. Moreover there exist special guideline-based tools for the development of energy efficient products, as the tool introduced by Bonvoison et al. [12]. However, this checklist-like tool doesn't enable the designer to identify the measures, which are relevant in his individual development context, in a concerted, well-directed way. Although different criteria are used to classify the guidelines, the selection criteria are less problem-oriented and supportive in the selection of guidelines but more descriptive and related to the situation in which the developer takes decisions (e.g. every guideline is linked to the department targeted by the guideline or decision level that refers to the hierarchic level where the decision is taken). Furthermore no tool could be found that is aligned to a certain Design for Energy Efficiency approach.
This paper therefore introduces a new, pragmatic, guideline-based tool, which supports the product designer to develop energy efficient solutions and eases the selective access to the most relevant guidelines. Compared to previous guideline-based tools in the field of energy efficiency, this tool is aligned to and embedded in an approach for the development of energy efficient products. Due to a hierarchical structure and grouping of the guidelines, the tool intends to improve the accessibility of guidelines that are most relevant for the developer's individual objectives and tasks, without having the developer work himself through a wide range of guidelines.
First in section 2 the guideline-based tool and its structure is presented. Section 3 presents the design approach for energy efficient products. On the basis of this approach the application of the guideline-based tool is described and it is demonstrated, how the tool is aligned to the different steps in the design process.

2. INTRODUCTION OF THE GUIDELINE-BASED TOOL

2.1 Guidelines – a definition

Guidelines are considered to be measures that support the product developer to orient a decision process towards given objectives [10]. The decision making process in this context is the design activity from planning and task clarification to the conceptual, embodiment and detailed design [9]. The overall objective in the context of design for energy efficiency is to develop products that fulfill a requested benefit with as little energy input as possible.
Based on matured experience and knowledge, guidelines should inspire the designer and assist him indicating those solutions that help to fulfill the given objectives. It is shown, that the use of guidelines during design makes the result of the designers' activities more predictable and presumably improve the results [20].

2.2 Structure of the tool

The core of the new developed tool is a list consisting of numerous guidelines, which support the designer to develop energy efficient product solutions.
However it may be insufficient and not target-oriented to provide only a list of numerous guidelines. The designer has to be able to identify the guidelines that are most relevant in regard of his project and has to be able to adapt those guidelines to his special development context. The longer the guideline list, the more likely there is a risk that the user is not able to identify the relevant measures anymore [13]. Therefore there is a need to structure guidelines in a way, so that the relevant measures are made readily identifiable for the developer. The hierarchical structure of the new developed tool is shown in the following figure 1.

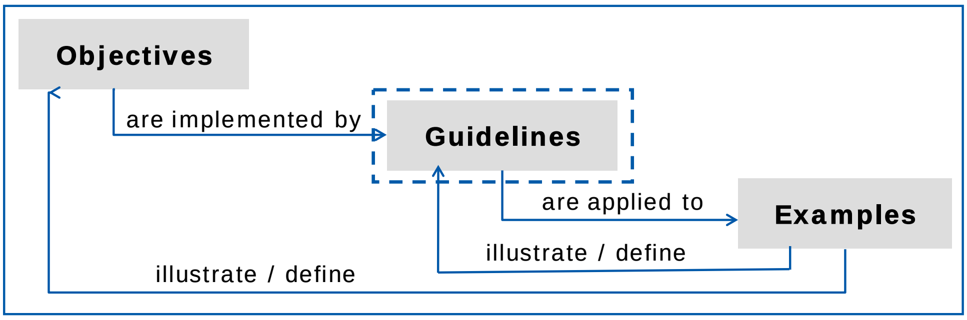

Figure 1: The structure of the guideline-based tool

According to the above mentioned definition, guidelines serve to achieve certain objectives. Depending on the individual development context, the overall goal of developing energy efficient products can be specified in (sub-) objectives. Within this tool the guidelines for developing energy efficient products are therefore assigned to different (sub-) objectives (see section 2.4). Those objectives are implemented by the guidelines. The guidelines on the other hand are applied to products, which therefore serve as examples. Thereby several examples can be assigned to each guideline.

Examples are an important element of the tool. They clarify the correct and intended application of a guideline, illustrate the generally worded guidelines and objectives and moreover serve as an inspiration for the designer to gather new ideas. At the same time, guidelines and objectives that have been successfully applied to products can be derived from energy efficient product examples. Examples therefore define and serve as valuable sources for objectives and guidelines.

As described in the following subsections, the objectives are subdivided concerning certain criteria and the guidelines are grouped to generic clusters, in order to additionally ease the access to guidelines for the product developer.

2.3 Guideline clusters and selection criteria

Guidelines should be simple and easy to understand, so that designers can integrate them in the design process without special training and matured experience in a certain field [12]. Therefore in this work attention was paid to provide clear and consistent guidelines.

Moreover guidelines should be preferably generic, in order to be relevant for a broad development context and in order to be generally applicable. Generic guidelines additionally leave more room for creative interpretations and can encourage product designers to generate all new ideas. Despite, more specific guidelines have the advantage that they can be used more efficiently by the designer in their day-to-day design job [10].

For this tool the intention was to unify the level of abstraction of the gathered measures. The goal was to provide general applicable measures that are not too specific to be for instance only relevant for a special problem with certain boundary conditions.

In addition the unified measures had been grouped to clusters in order to generalize them on an even more abstract level. Those generalized clusters do not only have the advantage of leaving the designer more room for creativity, but also lead to the advantage of summarizing a big amount of more specific measures to a small number of guideline clusters and therefore making the guideline tool more applicable for the designer.

For example the measures „Choose material combinations with low friction losses“, „Realize a smooth surface in order to avoid flow resistance”, „Provide insulation to reduce thermal losses“, etc. can be grouped to the cluster „Reduce losses“.

The guideline clusters with the more specific measures can be finally assigned to the goals they are intended to achieve.

In addition to the clustering, the specific measures had been described according to the steps in the design process they could become relevant for the designer. According to Pahl and Beitz (also according to the design approach for energy efficient products described in section 3) the steps of the design process are divided into planning and task clarification, conceptual design, embodiment design and detail design [9]. With this classification the designer is able to derive relevant measures according to the design step he is carrying out. For instance the measure „Choose material combinations with low friction losses“ is a measure that becomes relevant in the detailed design phase. The decision to implement the measure „Avoid the transmission of energy“ should be taken in an early design phase, for instance during the establishment of function structures in the conceptual design phase.

2.4 Structure of the objectives

The (sub-) objectives are determined in the early steps of design process within the planning and task clarification phase. It is recommendable to energetically analyze a reference product in this phase and derive the adequate energetic objectives out of this assessment (see section 3).

Energetic objectives can refer on one hand to the life cycle phases of a product. An energy efficient product is defined in this work as a product that fulfills a requested benefit with as little energy input as possible. Within its life cycle phases a product passes several processes that require energy input.

Therefore the energy efficiency of a product is determined by all relevant life cycle processes. According to this, designers have to consider all life cycle phases during the development of energy efficient products.
For this reason the objectives that are implemented by the guidelines of the tool are divided as follows:

- Energy efficient material processing
- Energy efficient production
- Energy efficient product use
- Energy efficient recycling/disposal

Within the individual life cycle phases the energy efficiency of products can be improved by different approaches. Those approaches are called “energetic levers” and are the basis for energetic objectives a product developer wants to achieve. Therefore, every life cycle based objective is further specified by the energetic lever. Those energetic levers within the different life cycle phases are dependent on the product, the used means of production and processes. A universally valid identification of energetic levers is difficult. The levers described herein are based on the general model of energy conversion in products and processes (see e.g. [14]) and are therefore segmented as follows:

- Decrease demand of useful energy
- Improve degree of efficiency
- Recover energy
- Improve primary energy balance via chosen energy source

In this context useful energy is defined as the portion of final energy which is actually available after final conversion to the consumer for the respective use. In final conversion, electricity becomes for instance light, mechanical energy or heat [14].
Those energetic levers listed above can be derived of energetic assessment with the help of different methods in the first steps of designing energy efficient products (see section 3).
For instance the energetic analyses of a product could reveal that a product has a high energy demand in the product use phase due to certain components not working efficiently compared to the state of the art. The energetic lever in this case would be to improve the degree of efficiency, which could be for instance realized by the measure cluster “Reduction of losses”.
If energetic analyses on the other hand reveal that a product works efficiently compared to the state of the art, but still needs a high energy input in the use phase, the energetic lever could for instance be to recover energy or to decrease the demand of useful energy. This could be for instance achieved by improving the intensity of product usage by the user. Measures like “Integrate displays informing the user about energetically inappropriate operation mode“ or “Integrate automatic switch-off“, which are linked to the objectives “Energy efficient product use” and “Decrease demand of useful energy”, could be relevant in this case.
The high energy demand of products in the production phase can be by analyses traced back to e.g. certain energy intensive processes. In order to improve the degree of efficiency, processes with a low degree of efficiency could be substituted (e.g. cold bonding instead of hot bonding process). Do analyses indicate that processes or processing machines are working efficiently the lever could be “Decrease demand of useful energy”. This could for instance be achieved by optimized product design: measures like “Design small cross-sections at welded joints” or “Provide less material for melting processes” could for instance be relevant. An energy efficient production could for instance also be achieved by the improvement of the degree of efficiency of processing machines. Moreover the need for useful energy in the production phase could be for instance reached by an improved job control that e.g. avoids idle time. These are levers and measures that are more in the sphere of responsibility of factory designer, process designer or logistician. Usually those levers are not directly addressable via the product designer. But as there cannot be drawn a clear line between the spheres of responsibility, those measures and objectives are also be taken into account within this tool as far as helpful. But the focus is still on measures that a designer can implement directly or indirectly by the product design.
An excerpt from the guideline-based tool is shown in figure 2. Objectives are not structured concerning certain products or components, as the tool should provide as much general applicability as possible and therefore should be applied to a broad range of product. But still the product designer has the possibility of getting more information about objectives and measures that already had been successfully applied to products or components via the listed examples in the tool.

2.5 Generation of the guideline-based tool

The core of the developed tool, the guidelines, has been gathered from different sources: professional journals, proceedings, standards, regulations and EcoDesign tools that contained energy efficiency aspects. The gathered guidelines were heterogeneous as they had been written for different purposes. After processing and unifying the guidelines (see section 2.2) the guidelines had been grouped to more abstract guideline clusters. Then the clusters had been aligned to the objectives they are implementing.
In a parallel process, examples of energy efficient products had been collected within the available channels, including professional journals, company information (brochures, press releases etc.) technology platforms and patent databases. The examples had been analyzed according to the implemented measures and achieved energetic advantages. They therefore also served as valuable source for guidelines and objectives.
At the moment the tool is a spreadsheet, comprising the objectives that are implemented by the measures and the examples (see figure 2). The tool currently consists of 26 guideline clusters that are specified by different measures. Further work is carried out to continuously enhance the tool and prove its consistency. The ideal size of the tool can hardly be predicted. The goal of the work is to provide guideline clusters and specific measures that are complete on their different level of abstraction and contain as less redundancies as possible. Moreover the example database should be continuously extended, so that the chance for the designer to identify a measure that has already been successfully applied to a similar product or problem is bigger. The goal for the tool is to collect as many examples specifying the general guidelines as possible. In order to still guarantee accessibility and clarity an intelligent access system will be necessary. Another research goal therefore is to develop a computer-based-tool with an intelligent access system, making the determination of relevant guidelines for the user even more effective.

Objective		***Guideline***		***Design process***				***Example***
Life-cycle phase	***Energetic lever***	***Cluster***	***Specific measure***	***Spec.***	***Con.***	***Emb.***	***Det.***	
Energyefficient Usage	Improve efficiency factor	Integrate and avoid processes	Avoid energy conversion		x			*link*
			Avoid energy transmission		x			
			Integrate different process in one process		x			*link*
		Substitute technologies, products	Choose technologies with high efficiency factor	x	x			*link*
			Substitute components with low efficiency factor		x	x	x	*link*
			Choose materials with high energy density				x	*link*
		Reduction of losses	Choose materialcombinations with low friction losses				x	*link*
			Provide insulation to					

Figure 2: The guideline-based tool – excerpt from the spreadsheet

3. THE DESIGN APPROACH AND APPLICATION OF THE GUIDELINE-BASED TOOL

3.1 Development of energy efficient products – an approach

The herein introduced approach for developing energy efficient products is based on the standard design process of Pahl und Beitz with the steps of “Planning and task clarification”, “Conceptual design”, “Embodiment design” and “Detail design” [9]. This process is supplemented by additional steps that should be carried out in the process of developing energy efficient product (see figure 3).
This approach can also be adapted and used for the development of environmentally friendly products in general. But here the approach is specifically addressed to the design of energy efficient products.
Starting with a product idea, first of all a reference product (e.g. a competitive product or a predecessor product) should be assessed concerning energy aspects. Energetic weak points can be

derived thereof which have to be, in a next step, evaluated concerning their potential. Only if weak points can be reduced or eliminated with reasonable effort they can serve as so called energetic levers.
The energy development objectives derived thereof have to be brought into agreement with further design criteria like for instance costs, customer requirements and technical requirements and are finally integrated as energetic requirements in the requirements list.
During the process of solution development the steps of conceptual design, embodiment design und detail design are carried out by the designer. During those design steps measures are implemented by the designer aiming at maximizing the energy efficiency of a product in accordance with the design specification determined in the requirements list.
Thereby product designers always have to consider that every decision they take and every measure they implement during solution development has to be holistically evaluated.
Design is a process where every decision is influenced by a large variety of criteria and dealing with the trade-offs between these criteria is an integral part of the developers' work. This integrated design approach is only mentioned herein and is not focus of this paper. This problem is addressed on a general level by different authors [see for instance 15, 16]. The tool introduced herein is rather expected to support the designer to include the aspect of energy efficiency in the design process.
In the following section the application of the guideline-based tool within the development approach are described.

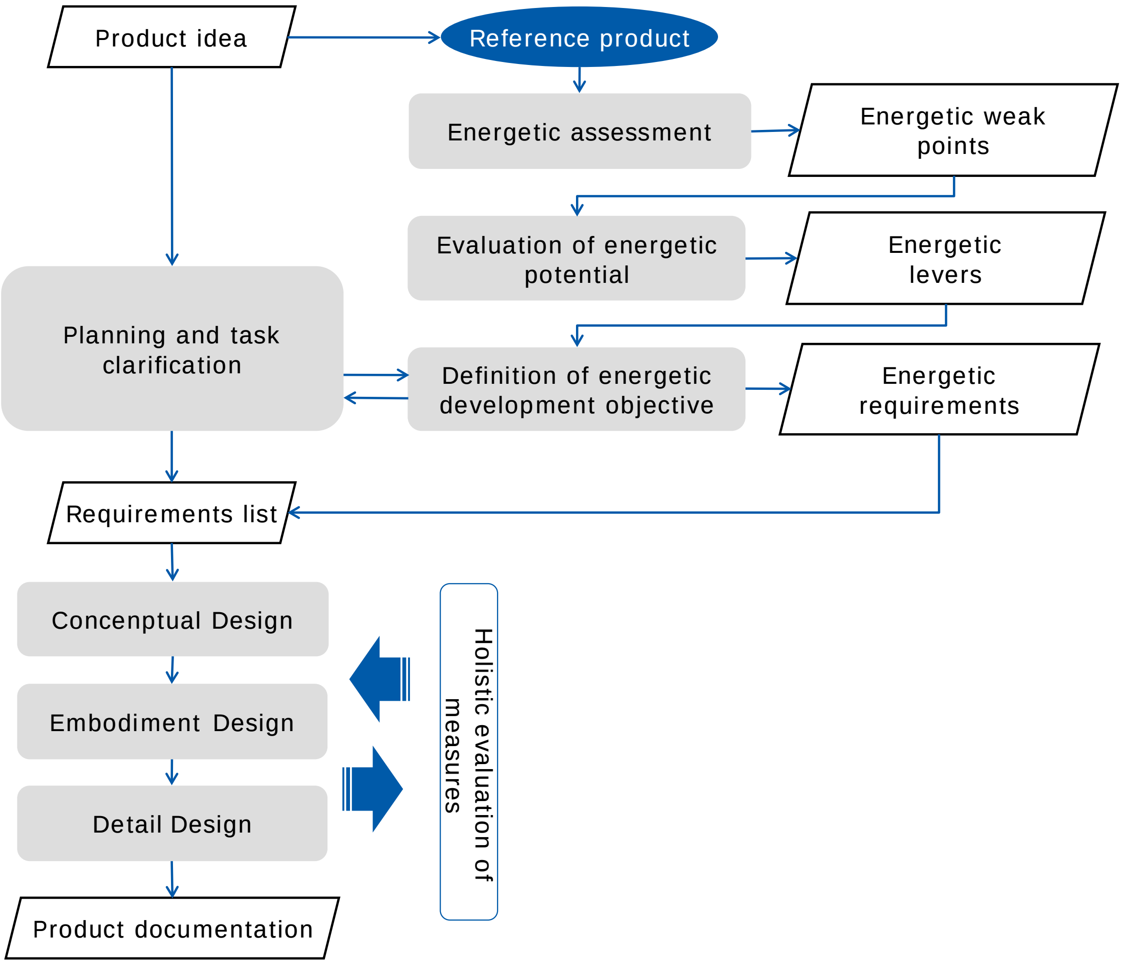

Figure 3: Energy efficient products – a design approach

3.2 Application of the guideline-based tool

The guideline-based tool supports the product designer to select appropriate measures in the design process from requirement determination up to the detailed design step.

Once the energetic objectives are determined after the energetic assessment and the evaluation of the energetic potential, the developer is able to systematically derive relevant measures with the help of the tool.
In the design steps „Energetic assessment“ and „Evaluation of energetic potential“ the designer has the possibility of making use of several other tools and methods, that help him defining the energetic levers and energetic development objectives. As shown in figure 4 the outcomes of those tools serve as starting points for deriving the most relevant measures in a certain development context. Moreover the access to measures can be achieved by the design step a designer is carrying out.
Some relevant tools and their exemplary outcomes are described subsequently.
An energetic assessment of a reference product can be for instance carried out by using the Life Cycle Assessment (LCA) method. By applying the impact assessment method „Cumulated Energy Demand“ (CED) within the LCA a designer can identify the direct and indirect energy demand of a product in every life cycle phase [17]. The following energetic weak points can be derived out of this method:

- The life cycle phase with the highest cumulated energy demand of a product
- The components of a product that have a high energy demand in the material processing, production and recycling/disposal phase of the life cycle

By using this method no conclusions can be drawn on the components with high energy demand in the use phase. In the case that the highest energy demand is based in the use phase of a product, it is recommended to carry out further energetic analyses. With the help of precise measurements the energy demand of different components can be derived and components with high energy demand can be classified as an energetic weak point.

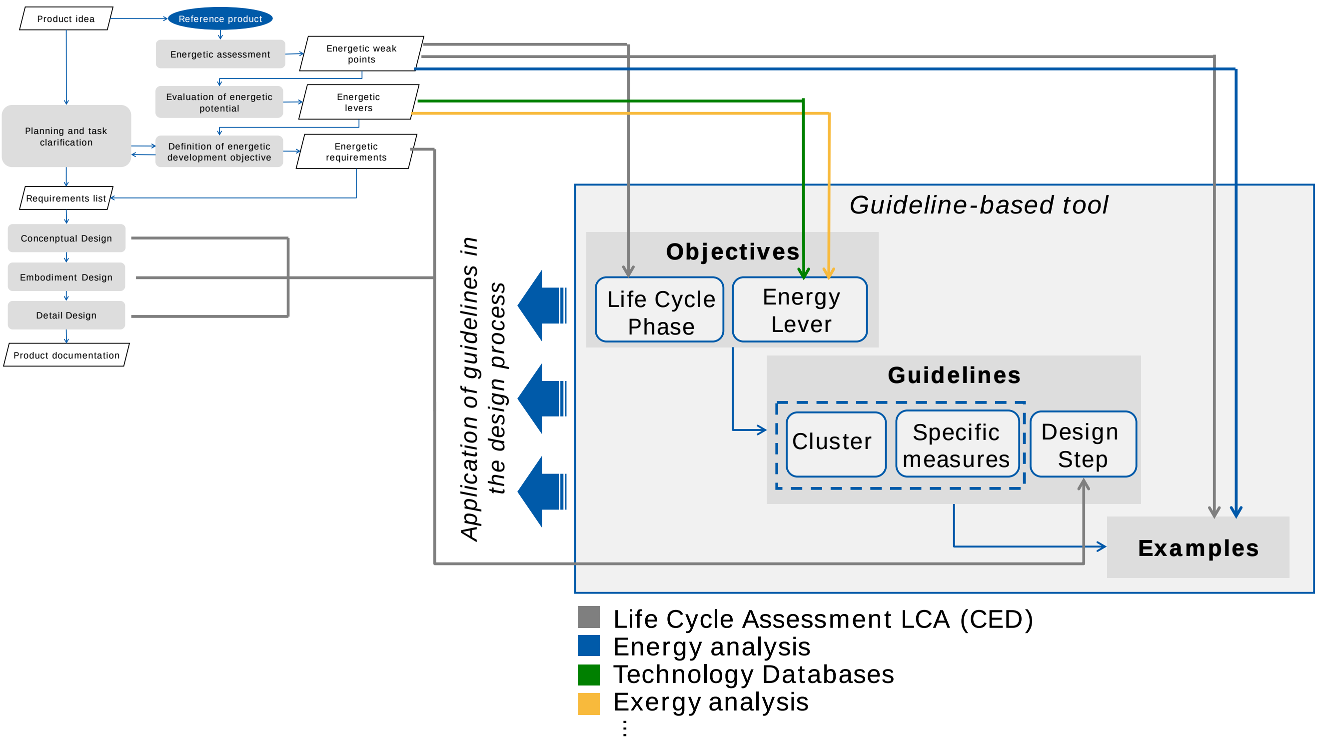

Figure 4: Integration of the guideline-based tool into the design approach

But only if a weak point can be reduced or eliminated with reasonable effort they serve as an energetic lever. Further evaluations can clarify, if a weak point truly serves as a lever.
For instance research in technology databases serve as a method in this evaluation process. This can help the developer to clarify if there are state of the art technologies, products and components with a lower energy demand that could be adapted for or integrated in the product with reasonable effort.
Also the experience of developers certainly plays an important role in this context. Beside technology databases also interviews with experts could serve as method for the identification of energetic levers.
Besides, also the herein described guideline-based tool with its collection of examples can serve as tool to identify energetic levers.

With the help of exergetic analyses (see [18]) it can be quantified how much energy is really being lost or whether energy released is necessary to maintain a thermal cycle. Some designs may not have a solution to improve the degree of efficiency. In these cases the designer should for instance seek for a better technology or try to decrease the demand for useful energy for instance by optimizing the intensity of product usage.

It should be noted, that the guideline-based tool can also be used as a conventional checklist. The complete list of guidelines can for instance serve as an inspiration during the first steps of energy efficient product development and can help the designer to derive levers and objectives in the design process. But as shown here the real benefit of this guideline-based tool can be derived of the integrated use within the design process, which allows targeted access to most relevant guidelines.

4. DISCUSSION

In this paper a guideline-based tool for the design of energy efficient products has been introduced. The so far developed tool does not claim to be complete concerning the number of guidelines and examples. The so far existing 26 guideline clusters with its specific measures are still checked for consistency and the tool is continuously enhanced. Especially new examples of energy efficient products are collected constantly in order to illustrate existing guidelines and objectives or serve as a source for new guidelines.

Clustering of measures and the hierarchical structure can support the designer to select most relevant guidelines dependant on the individual context. In the paper it was explained how the tool can be integrated in the design process and therefore can help to identify measures in a pragmatic way. It is criticized that there is no communication between different tools, for instance between quantitative methods like LCA and qualitative guideline-based tools [19]. The herein described approach presents a new tool that is aligned to different methods useful for the designer in the design process and therefore enhances the communication between different tools.

But the concept and usefulness of the tool with its hierarchical structure and guideline clusters still has to be validated in real design teams. Therefore studies and further research together with industrial partners has to be carried out in order to reveal improvement options of the tools. For instance it has to be revealed to what extend the herein supposed structure of the objective concerning life cycle phases and energy levers is consistent and helpful for the selection of measures in day-to-day design work and to what extend generic guideline clusters are useful for real design teams.

At the moment the guideline-based tool is only a spreadsheet, comprising the guidelines that fulfill certain objectives and the examples. A further research goal is to develop a computer-based-tool matched to the designers needs. An intelligent access system has to be developed making the determination of relevant guidelines for the user even more expedient.

REFERENCES

[1] Taylor, P. et. al., Final energy use in IEA countries: The role of energy efficiency. In: *Energy Policy*, 2010, 11(38), pp.6463-6474.

[2] International Energy Agency (IEA), *Energy Efficiency Policy Recommendations*. 2008 (OECD/IEA, Paris).

[3] Yang, M., Chinas energy efficiency target 2010. In: *Energy Policy*, 2008, 2(36), pp.561-570.

[4] Commission of the European Communities, *Action Plan for Energy Efficiency: Realising the Potential*, Official Journal of the European Union, Brussels, 19.10.2006.

[5] Council of the European Union, *Directive 2009/125/EC of the European Parliament and of the council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast).* Official Journal of the European Union, Brussels, 31.10.2009.

[6] Council of the European Union, *Directive 2010/30/EU of the European Parliament and the Council of 19 May 2010 on the indication by labeling and standard product information of the consumption of energy and other resources by energy-related products.* Official Journal of the European Union, Brussels 18.06.2010.

[7] Stevels, A. et al., *Adventures in Ecodesign of Electronics Products*, 2007 (Delft University Press).

[8] Li H., et al., Improvement of home appliances design based on energy-saving concept: Case

studies on hair dryer and coffee maker. In: *International Symposium on Electronics and the Environment*, San Fransisco, California, May 2008, pp.1-3.
[9] Pahl, G., Beitz, W., Feldhusen, J., Grote, K.H., *Engineering Design – A Systematic Approach.* 3rd English Edition, 2007, (Springer, London).
[10] Vezzoli, C., Sciama, D., Life Cycle Design: from general methods to product type specific guidelines and checklists: a method adopted to develop a set of guidelines/checklist handbook for the eco-efficient design of NECTA vending machines. In: *Journal of Cleaner Production*, 2006, 15-16(14), 2006, pp.1319-1325.
[11] Brezet, H., van Hemel, C., *EcoDesign. A promising approach to sustainable production and consumption*. 1st Edition, 1997, (United Nations Publications, Paris).
[12] Bonvoisin, F., Mathieux, L., et. al. Design for Energy Efficiency: Proposition of a guideline-based tool. In: *International Design Conference, Design 2010*, Dubrovnik, May 2010, pp.629-638.
[13] Dahlström, H., Company-specific guidelines. In: *The Journal of Sustainable Product Design*, 1999, 8(5), pp.18-24.
[14] Müller, E. et. al. *Energieeffiziente Fabriken planen und betreiben*. 2009, (Springer, Heidelberg).
[15] Lindemann, U., A vision to overcome “chaotic” Design for X processes in early phases. In: *Proceedings of the International Conference on Engineering Design, ICED 2007,* Paris, August 2007.
[16] Bauer, S., Meerkamm, H., Decision Making with interdependent objectives in Design for X. In: *Proceedings of the International Conference on Engineering Design, ICED 2007*, Paris, August 2007.
[17] *VDI-Guideline 4600, Cumulative Energy Demand - Terms, Definitions, Methods of Calculation,* 1997 (VDI-Verlag, Düsseldorf).
[18] Tsatsaronis, G., Park, M.-H.: On avoidable and unavoidable exergy destructions and investment costs in thermal systems. In: *Energy Conversion and Management*, 2002, 9-12(43), pp.1259-1270.
[19] Kota, S., Chakrabarti, A., Use of DFE Methodologies and tools – major barriers and challenges. In: *Proceedings of the International Conference on Engineering Design (ICED) 2007*, Paris, August 2007.
[20] Bischof, A., Blessing, L., Guidelines for the development of flexible products. In: *International Design Conference, Design 2008*, Dubrovnik, May 2008, pp.289-300.

Contact: Karola Rath
Technische Universität Darmstadt
Institut für Produktentwicklung und Maschinenelemente (pmd)
Magdalenenstraße 4, 64289 Darmstadt
Germany
Tel: Int +49 (0)6151 163058
Fax: Int +49 (0)6151 163355
Email: rath@pmdt.tu-darmstadt.de
URL: http://www.pmd.tu-darmstadt.de

Karola is Research Associate at the Institute for Product Development and Machine Elements at the Technische Universität Darmstadt. She works in the field of EcoDesign dealing with methodological support of designers in the development of environmentally-friendly products and is in particular focusing on the development of energy efficient products.