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ENERGY EFFICIENCY AS DESIGN OBJECTIVE USING UTILITY-BASED INDICATORS

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ABSTRACT

In engineering design, Energy Efficiency (EE) has been part of systems of objectives mainly due to economic relevance of the energy required to provide a desired utility value or by ecological aspects with holistic claim and intention. However, increasing economic impact, power intensities and legal regulations related to EE as well as the raising number of mobile systems lead to various motivations and according understandings of EE as a design objective. This causes a need for methodical approaches to support designers and deciders in handling EE as a design objective in a differentiated and target-oriented manner.

This paper discusses the different motivations and perspectives regarding the relevance of EE as a design objective and presents an approach to systematically quantify targets for in-use EE. This is achieved by means of utility-based indicators, that describe the efficiency's numerator by an operational reference characteristic and the sum of weighted utility values as functions of fulfillment of task-specific utility-characteristics. Further validation must conclusively prove its consistency and suitability to represent in-use EE as a design objective.

Keywords: design to X, energy efficiency, requirements, indicators

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1 INTRODUCTION

Energy efficiency (EE) describes the economical usage of energy in order to generate a certain desired output that is to fulfill a certain use. Sometimes it is argued that efficiency is just a characteristic of good engineering practice. However, the general improvability is broadly accepted, especially for in-use energy efficiency of mobile and energy-sensitive or –intensive systems. Improved EE either means an increase in utility value in terms of fulfillment of utility-characteristics, the reduction of the energetic effort or both at the same time.

The perspective (economic, ecologic, legal, etc.) from which EE is treated considerably impacts EE as a design objective. An increasing relevance of energy efficient products is caused by the rising number of mobile applications, i.e. energy related products that draw energy from a limited mobile storage as well as by more severe energy saving regulations and specifications. Due to numerous energy-related political measures and the rising demand and market potential for in-use energy-efficient products, EE is seen as a rapidly growing sales segment for innovative products. According to Ziegler (2011) a quadrupling of the revenue is expected in the global market for energy-efficient products. Today's methodology regarding EE is either bound quite strictly to specific perspectives and corresponding approaches and measures or it is of generic character but lacks a systematic identification and consideration of different motivations for EE behind the design task.

Our research approach on *utility-based* Design to Energy Efficiency (DtEE) aims to facilitate the handling of EE as a design objective by means of systematization and operationalization. Systematization means the identification of specific motivations and contents under consideration as well as the structuring of the design objective EE in order to derive a corresponding understanding of EE. Operationalization particularly means that designers shall be supported in choosing and adapting appropriate indicators for the objective *in-use EE* in order to be able to make a better use of the constant rising demand of in-use energy efficient products. This is supposed to provide a systematic basis on which methods aiming to generically or specifically improve systems' EE can build on.

2 ENERGY EFFICIENCY – DEFINITION AND PERSPECTIVES

2.1 What actually is Energy Efficiency?

From its basic origin (Latin *efficere* = to effect, to bring about, to execute) efficiency is almost synonym to effectiveness. The actual and common meaning of efficiency, however, is the assessment of a relation between effectiveness and effort. Thus by the ratio of a desired (generated) output to an input effort, which is required to generate the corresponding output, it describes the adequacy of the effort with respect to the benefit or utility value.

According to this rather broad definition of efficiency, there are various possibilities of interpretation or corresponding definition of energy efficiency. The most established ones are thermodynamic, physical or economic points of view and combinations thereof, as well as holistic or product lifecycle phase specific perspectives on different levels of abstraction (Pehnt, 2010; Patterson, 1996).

The in-use EE of technical systems is commonly described by the 'efficiency ratio' as the ratio of energetic output to energetic input, which offers maximal comparability. The meaningfulness, however, of such comparisons is in dispute. Different perspectives on EE of technical systems mainly can be assigned to different definitions of system borders, i.e. what counts for the energetic input or output. However, we believe that in engineering design the desired output of a system should be bound very tightly to the fulfillment of customers' requirements, which in turn should also be found within the system of objectives. If EE shall not be a pure 'property after development' this must be considered throughout the entire design process in order to enable EE being a consistent and target-oriented objective. This perspective is not new in theory, however, it still lacks of corresponding definitions, understanding and systematic approaches as well as suitable indicators. Thus *efficiency* in product design should describe the ratio of a measure for meeting customers' requirements to the specific effort. Hence, in our research EE is described by the ratio of satisfaction of utility-characteristics instead of 'useful energy output' to the energetic effort. The difference is a matter of system borders drawn either at a location where energy can still be quantified easily or further where the 'useful' energy is transformed into function fulfillment or utility value, which is not necessarily expressible energetically. In research, EE and corresponding indicators are until now mainly studied and discussed focused on policy, macro- and micro-economy or product-specific EE improvements.

2.2 Perspectives

As already discussed in the context of EE definition, there are very different perspectives regarding the motivation behind EE as a design objective. This motivation or perspective defines or at least strongly impacts communication, prioritization, interpretation and finally further handling of EE during the design process.

The perception of the relevance of EE as an objective in product design can vary significantly for one specific system to be designed depending on the observer's perspective. Hence, there are various reasons and motivations why EE is identified as relevant for a product or rather a utility profile or is allocated to certain relevance from different perspectives. Those perspectives can for example be of economic (e.g. operating costs), ecologic, marketing, technical or functional (e.g. mobility) character or based on legal requirements. The study of interrelations of importance of EE as a design objective and energetic properties for one product (schematically illustrated in Figure 1) are also content of our research but are too extensive to be discussed in detail within this paper.

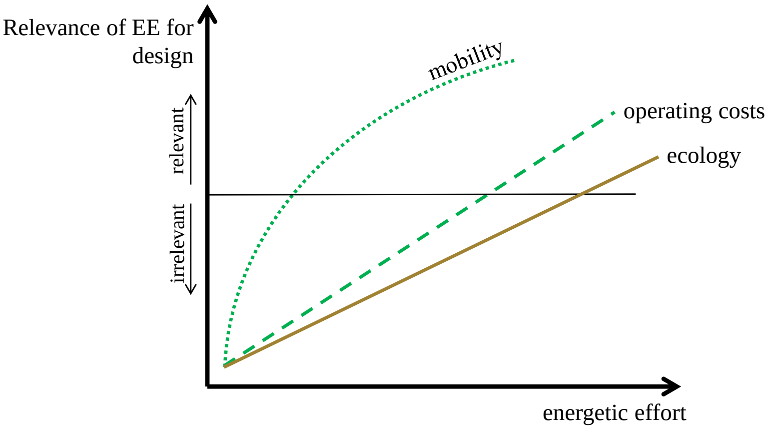

Figure 1. Qualitative illustration of possible interrelations between the relevance of EE as design objective and expected energetic effort from different perspectives.

The actual relation of importance and energetic characteristic depends on strategic decisions and weightings, known solutions of the illustrated utility profile and are product- and company-specific.

3 RESEARCH QUESTIONS

Within our research on DtEE we study the general importance and system-specific relevance of EE as a design objective. Basing on that, we aim to support designers in systematically identifying and assessing EE-relevance as well as in operationalization of EE as a design objective including its representation by means of indicators. Both activities and corresponding solutions are to be seen as utility-profile-specific. Our research questions are:

1. How can designers systematically identify the relevance of EE as a design objective?
2. How can in-use energy efficiency as a design objective be sufficiently described in indicators?
3. How can such a differentiated transfer into EE-indicators be supported by methodical procedures?

Within this paper we will discuss our hitherto existing findings regarding research questions two and three stated above. Regarding research question one the authors gained first insights (section 2.1) and continue according to the outlook in section 7. Within our research approach it is not intended to give proposals of how to technically improve the EE nor to decrease the lifetime energy consumption by providing generic guidelines, best-practices or methods of holistic energy assessment. Those important topics have already been dealt with in numerous research works (among others Rath et al., 2011; Reichel et al., 2010; Rünger et al., 2011; Bonvoisin et al., 2010; Domingo et al., 2011).

4 MOTIVATIONS FOR DESIGN TO ENERGY EFFICIENCY

4.1 Different Motivations and Corresponding Approaches

Depending on which motivation causes the EE to be a relevant design objective for a specific design task, the methodical approaches being suitable to support the designer are different.

If the motivation is dominated by *ecological* reasons (DfE = Design for Environment), appropriate methods are to be of holistic character in order to cover all influences and interrelations, that are ecologically relevant. Life Cycle Assessment (LCA) is the probably most established tool within DfE to analyze and assess environmental impacts of products over the entire life-cycle (Telenko et al., 2008). Within LCA or Life Cycle Design (LCD) EE is only considered in terms of the general efficiency of resource usage and thus is not studied in depth with respect to different perspectives.

If EE is motivated by an *economic* or *cost* perspective, this perspective is usually not holistic as for ecological motivation, since costs are a much more specific aspect with respect to system borders and affected parties than environmental influences. Here, indicators can even be described solely by financial parameters so that the desired output as well as the energetic effort is measured in terms of economic value (Patterson, 1996). There are approaches to integrate holistic EE and economic aspects in a Life Cycle Cost Analysis (LCCA) and in combination with Target Value Design, e.g. (Lee, 2012). The economic perspective is too narrow to consider the entire character of in-use EE and thus does not provide a suitable basis for EE as design objective. If the economic motivation is caused by the operational costs due to operational energy demand and thus to operational losses, it is the actual in-use energy efficiency of the utility profile or its solution what is concerned. In this case it makes sense to focus on the *in-use energy efficiency* of the system.

If EE is motivated by *legal* conditions the specific objective-boundaries and details are usually also described within the corresponding law or guideline and limit the suitable guiding methodical approaches. Legal conditions and labeling obligations for EE mostly are defined for *in-use EE*, for instance e.g. (EU, 2010).

If EE is motivated by *technical* and *functional* matters, the perspective is characterized by very limited possibility to abstractly illustrate technical and functional problems and transfer solutions in an appropriate manner. This is why in this case usually product-specific research is carried out in order to improve EE. Nevertheless there are many checklists and guidelines aiming to provide product-independent support to improve product-specific EE (Rath et al., 2011). Those can be a useful source of inspiration and best-practice information but their final effectiveness is rather limited by their generic nature. One aspect of technical motivation is the mobile application, i.e. the limited availability of mobile energy. Again this motivation causes a focus on the *in-use EE*.

Those different perspectives and corresponding methodical approaches do not include any systematic procedures of how to differentiate between motivations for EE and appropriate guiding or indicators. From various perspectives *in-use energy efficiency* is identified as a dominant aspect of EE.

4.2 Indicators for Energy Efficiency

A lack of sensitiveness in using the term *energy efficiency* was already stated by Patterson (1996). He aimed to operationalize EE at the policy level. However the awareness in principle of EE being actually a generic term and the need for specific indicators before being able to increase EE, as well as the essential problem to describe the ‘useful output’ of a system can be transferred to our research focus.

Indicators are aggregated values that are used to summarize and provide the information of the underlying data and values. They can be seen as one level of formal description and quantitative representation of complex interrelations. Namkoong et al. (2002) see indicators as embodiment of criteria (e.g. energy efficiency), which in turn are supposed to describe different sides of a principle (e.g. company strategy, sustainability, etc.). Hence, EE-Indicators are a combination of various related factors that are supposed to condense comprehensive energy data and other application-specific numbers into one significant characteristic (Grabowski, 2009).

In general there are two types of indicators: *absolute numbers* (single values, totals, differences, averages, etc.) and *relationship numbers* (relative numbers, relation numbers and index numbers) (Löffler, 2011). EE-indicators usually are relationship numbers, i.e. either relative numbers (EE ratio) or relation numbers (non-energetic output/energetic input).

Patterson (1996) discussed the problem of inconsistent use of the term *energy efficiency* as well as several problems arising by applying indicators aggregating multiple influences and physical outputs. He also stated the need for physical-thermodynamic indicators that are supposed to “adequately encapsulate the end user service required by consumers in the output measurement”. This is why the output is measured in physical units instead of thermodynamic ones. For purely physical indicators, for which also the energetic effort is measured in physical terms, he emphasized their limited comparability. This might be critical due to the fact that he primarily considered EE as a system's property in terms of analysis, not as a design objective. Comparability is an important requirement for indicators used for analysis reasons. For EE-indicators serving as design objectives comparability is much less important than the utility-oriented and measureable description of the desired output. Furthermore, if an indicator is supposed to suitably represent a specific design objective, its utility-neutral comparability is not useful. Nevertheless, the more abstract the energetic effort is formulated, the more solution-neutrality is given.

With the EU Directive 2010/30/EU the European Union established an energy consumption label (EU, 2010). On this label the in-use energy efficiency is valuated in energy classes (A to G) and additional information regarding energy consumption and appliance as well as performance details are given. The performance measurements show a practical attempt to assess real consumers' requirements and thus utility-characteristics within an EE-indicator. Additionally the composition of appliance-specific criteria and corresponding weightings in definition of standard use seem target-oriented. However, the label bases on a ratio to a reference value, definition of which also bases on political decisions. Furthermore there are some difficulties in definition of standard use.

While the EU-label primarily serves the customers for orientation and product comparison it does not suit as a measure for the design objective energy efficiency. In section 4.1, it was stated that for many products and from many perspectives the in-use energy efficiency is a particularly important aspect of EE. Hence, we focus on the development of indicators as a measure for the design objective in-use energy efficiency.

5 INDICATORS FOR IN-USE ENERGY EFFICIENCY IN PRODUCT DESIGN

Is EE a legitimate design objective? Apart from the designer's or company's perspective, this question must be answered with respect to the operationalizability of EE as a design objective. The operationalizability bases on its three preconditions: ability of *concretization, measurability* and ability of *aggregation* (Mamberer and Seider, 2009). An objective can be concretized, if there are real phenomena that can be used as defining characteristics and represent the objective adequately. Those phenomena are for instance energy consumption and utility value. Measurability in turn is given by the measurability of the defining phenomena. The measurability of an appliance's utility value or utility-characteristics is not simple though. Finally, the ability of aggregation is to be proved by developing appropriate indicators including a prescription of aggregation merging the defining characteristics. The defining characteristics in turn are parameters that are derived from a utility description, e.g. in terms of functions.

5.1 Towards a Utility-Based Understanding of In-Use Energy Efficiency

Several authors (Wilkens et al., 2011; Grabowski, 2009) state that to every characteristic or indicator a corresponding objective is to be found or formulated in order to ensure the validity of the indicator. The authors propose a converse approach and proceeding so that EE-indicators should actually serve for representation of design objectives. This way, suitable and *target-oriented indicators* can be found, characterizing the objectives that are relevant and significant for design. In addition it should be argued in the opposite way: there should be no objective without corresponding measure/indicator that allows for validation during design. This is especially significant for EE-related objectives.

In order not only to have consistent and communicable definitions for EE as well as corresponding indicators, but also to apply the objective EE in a target-oriented way, a change is necessary: EE-objectives should not be forced into indicators that might be established, easily quantifiable and comparable, such as the thermodynamic efficiency ratio. Instead, to the authors it seems much more favorable to lead the term *energy efficiency* back to its original meaning: *utility value per energetic effort*. In order to be able to derive such indicators describing the in-use EE of a product as a design objective two aspects are to be clarified: *How to express the desired utility-characteristics?* and *How to express the energetic effort?*. The energetic effort is established to be needed for most indicators describing EE and usually can be defined and quantified in a quite simple way. The distinctly more difficult part is the description of the desired utility value, which is the efficiency's numerator.

Additionally, *utility value* is another generic term and must be interpreted individually according to the specific design task. However, it describes an essential element of EE as design objective. Hence, there is a need for adequate indicators for *utility-based in-use EE*. Such an indicator must be application-specific in order to support target-oriented development of in-use energy-efficient products.

Additionally the indicator should be applicable for validation and testing and even marketing to compare the product with stated targets and relevant competitors of the same utility-profile.

The desired utility value, which is linked very tightly to the customers' requirements and thus to the utility-profile, cannot solely rely on the fulfillment of one main function assigned to the profile as this does not satisfy customers' expectations. Hence, it cannot sufficiently describe the effectiveness of the desired solution. It is important to consider task-specific utility-characteristics in order to derive meaningful defining phenomena. Parameterization of those defining phenomena enables the setup of target-oriented indicators. However, deriving parameters directly from utility-characteristics is difficult and not always possible. Instead it is established to derive parameters from functional flows according to (Stone and Wood, 2000). In this paper the term *function* is used as *expected behavior*. The utility-characteristics and main functions of a system are known already in the earliest stages of product design, long before the embodiment design is chosen or worked on. The sum of functions and corresponding flows representing the utility-characteristics abstractly describes a system's behavior in order to satisfy customers' requirements. Moreover, the use of *utility-characteristics* makes it possible to consider additional aspects (e.g. from Quality Function Deployment (QFD) or the Kano model) by describing the *desired output* more detailed. In order to describe the efficiency's numerator, the description of utility-characteristics is promising. Additionally, a functional description can deliver the parameters needed to create suitable indicators.

By means of a systematic procedure, relevant parameters are to be derived from a description of utility-characteristics according to the utility profile, a product is designed for. The aggregation of those parameters is supposed to represent the utility. An *indicator for in-use EE* in terms of its basic meaning can be built by means of a measure of the fulfillment of utility-characteristics in relation to the energetic effort. Dealing with utility-characteristics as well as deriving parameters thereof is difficult to formalize. The designer needs certain degrees of freedom in order to be able to formulate utility-characteristics, functions and correlations of utility value and utility characteristic reasonably. Furthermore, it is important that the designer is able to assess and select appropriate parameters also considering implicit objective aspects that are specifically valid for the design task.

5.2 The Utility-Based Energy Efficiency Indicator (UBEEI)

A well-known example for an indicator is the fuel consumption indicator for passenger cars that describes the relation between the energetic effort in fuel volume (liter) and the distance the car can drive with the amount of fuel (km). The difference between such an indicator and the thermodynamic or thermodynamic/physical efficiency ratio (%) in its informative value is obvious. This kind of description already has a certain target oriented character with respect to an automotive design task. Furthermore it can be used for comparison between cars of the same utility-profile from the customer's perspective. However the authors propose essential adjustments. The covered distance does not sufficiently describe the overall customers' requirements. Instead it should be possible to consider as much utility-characteristics in the indicator as it suits the *specific profile and design task*. Again, in case of the passenger car much more utility-characteristics are decisive for its utility value (e.g. size in number of persons, driving pleasure, meeting prescriptive emission limits etc.).

If those aspects are also part of the initial utility profile e.g. *individual mobility for families in urban area*, some exemplary corresponding utility-characteristics could be: short-haul transport of 3-5 persons, reasonable driving pleasure, low pollutant emissions.

The developed indicator that is supposed to describe EE as a design objective is the *Utility Based Energy Efficiency Indicator* (*UBEEI*). Its numerator, i.e. the utility value, contains two main factors: One describes the basic operational reference. The second contains the sum of weighted (g_i) functions of fulfillment of utility-characteristics ($f(p_i)$) as shown in (Equation 1).

$$UBEEI \;=\; \frac{utility\, value}{energetic\, effort} = \frac{(operational\, reference\, characteristic)\;\frac{1}{\sum g_i}\sum g_i f(utility\, characteristics_i)}{energetic\, effort} \tag{1}$$

Since the values of additional utility-characteristics are summed up due to weighting reasons, the scaling factor ($\frac{1}{\sum g_i}$) is necessary. Every single utility value is described as a function of the utility-characteristic's parameter and additional influence variables if necessary. Those functions might require a piecewise definition for example in case of range requirements and target requirements. The function's value (i.e. utility value) is defined at 1 for target fulfillment (cp. Figure 2). As the utility value is linked to customer satisfaction, in case of performance requirements and excitement requirements it is also possible to assign more utility value than 1.

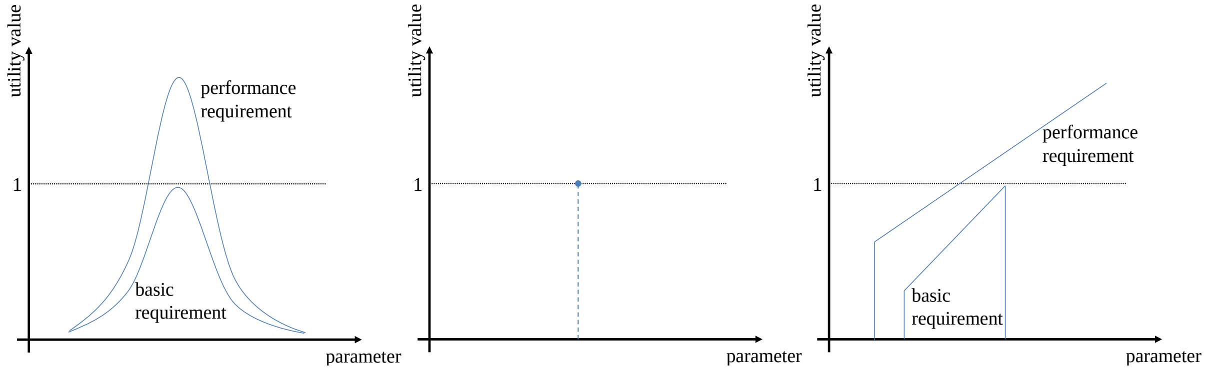

Figure2. Schematic illustration of utility value as a function of a parameter describing the corresponding utility-characteristic in case of target requirement (left), fixed requirement (middle) and range requirement (right).

In order not to consider too many aspects and thus too many parameters, it is usually helpful to analyze existing systems matching the same or similar utility profiles in order to gain insights about the energetic relevance of single utility-characteristics and corresponding sub-functions or subsystems. This can for instance be done by applying a sort of *Energy Function Deployment* on the basis of the classical Quality Function Deployment (QFD). Only parameters of certain energetic relevance are to be considered if this relevance is known.

In section 5 three preconditions for operationalizability were mentioned. Their fulfillment could be shown in 5.2. *Ability of Concretization* was shown by expressing energy efficiency with a ratio of utility characteristics and energetic effort. *Measurability* is given for the energetic effort as well as for the utility characteristics' parameters. *Ability of Aggregation* is shown with the indicator UBEEI (see Equation 1).

6 A SYSTEMATIC PROCEDURE TO SET UP UTILITY-BASED INDICATORS FOR IN-USE ENERGY EFFICIENCY

Within this section a systematic procedure is presented, with which the designer shall be guided towards a utility-profile-specific indicator. This indicator describes the *operational or in-use energy efficiency* as design objective by means of the ratio of *utility value* in terms of fulfillment of utility-characteristics to *energetic effort (Equation 2).*

$$in - use\ energy\ efficiency = \frac{product\ utility}{energetic\ effort} \qquad (2)$$

The indicators' parameters are derived from functional descriptions of the utility-characteristics or directly of the characteristics themselves. Along with the conceptual procedure (Figure 3), the exemplary utility profile *individual mobility for families in urban area* will accompany throughout the steps of the procedure.

Figure3. Schematic illustration of procedure.

1. Derive utility characteristics from utility profile

First of all, system borders are to be drawn in order to define the scope. The choice of system borders has significant impact on further solution space and resulting indicators. Regarding the functional view, several authors (Szykman et al., 1999; Stone, 1997), in their various fields, have engaged in compiling databases of standard functions that can express functions comprehensively. Stone and Wood (2000) propose a standard vocabulary known as the *functional base*, which contains a set of functions and flows where the functions are described in the form 'verb' plus 'complement'. In the proposed procedure on hand, parameters that will be used in the EE-indicator are not derived from the function´s formulation since especially this formulation is found to be inconsistent (Eckert et al., 2011). Instead they are derived from the corresponding functional flows or directly from the utility-characteristics if possible. Focusing the utility-characteristics supports to find and choose the most meaningful parameters.

Example: System borders are chosen according to actual means of transportation, i.e. the energy enters the system in form of fuel and the main output is the translational movement, i.e. displacement. Traffic infrastructure and driver are not to be designed and thus are outside the system borders. For the utility profile *individual mobility for families in urban area*, some of the corresponding utility-characteristics could be: *3-5 persons*, *low pollutant emissions*, *reasonable driving pleasure.*

2. Derive measureable parameters and define reference characteristic

For the sum of utility-characteristics an overall function is formulated and the flows are defined. According to Pahl and Beitz (2007) a function can be defined as the desired interrelation between the basic *material*, *energy*, *or signal* inputs and outputs of a system aiming to fulfill a task. Once the overall function has been formulated, it can be depicted by a block diagram including the flows of energy, material and signals, expressing the more or less solution-neutral relationship between inputs and outputs. Afterwards, measureable parameters are derived that are expected to impact the system's utility value most on this level of abstraction. Essential components for this purpose are the input and output flows' quantities (Stone and Wood, 2000). The authors of the paper on hand use an extended collection based on (Stone, 1997) which can be adapted for task specific purposes.

Example: The overall function can be formulated as *displacement of human material (3-5 persons) by mechanical translational energy (at reasonable accelerations) with low gas/solid material output (pollutant emissions)* and corresponding flows are added as it is exemplarily shown in Figure 3.

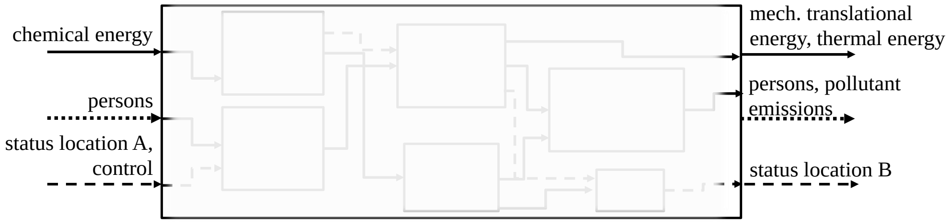

Figure 4. Description of exemplary utility-characteristics by a systemic view and corresponding function with solution-neutral transfer of input to output flows.

From the collection the parameters are chosen according to the functional flows: chemical *energy* (Volume V_{fuel}), human *material* (Number $\#_{pers}$), mechanical translational *energy* (acceleration a_{max}), gas/solid *material* (mass $m_{emission}$). A meaningful operational reference characteristic for the utility profile is the *covered distance*.

3. Define and weight utility values

In this step the utility-characteristics are weighted and the impact of their occurrence on the utility value is defined. Every desired utility value is to be described as a scaled function of the flow parameter's value and of some other interrelating parameters' values if necessary (Figure 5).

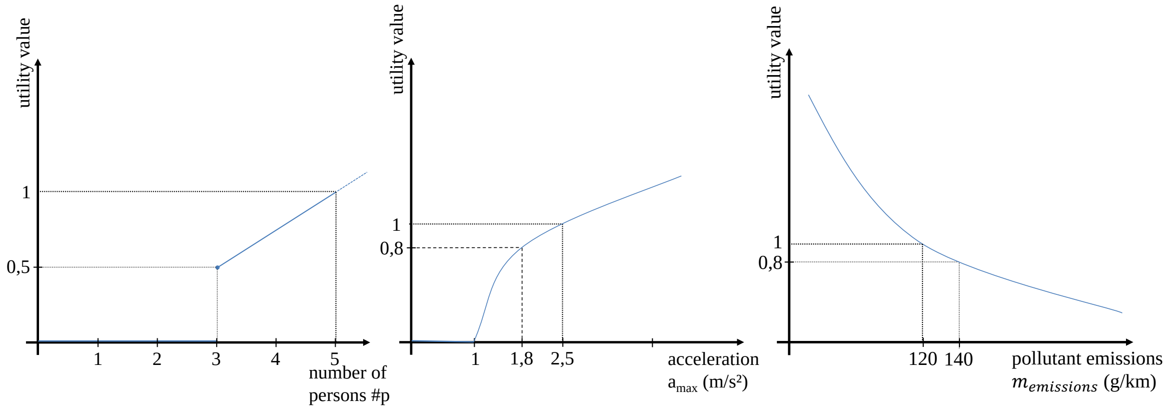

Figure 5. Schematic illustration of utility value as a function of number of persons (left), maximum acceleration (middle) and pollutant emissions (right).

For target fulfillment of the parameter’s occurrence the utility value is defined as one. For some other significant parameter values the utility is to be rated. Between those defined values the correlation are to be inter- and extrapolated.

Example: In case of the desired acceleration properties, the target value might be 2.5 m/s². Hence, the corresponding utility value is defined as one. For an acceleration of 1.8m/s², the utility value is rated with 0.8 and for 1m/s² with no utility value. This rating is done by answering the question ‘How much utility value is added or lost by the deviation of the parameter from its target value?’. This change in utility value is to be assessed in relation to a corresponding virtual change in energetic effort.

The weighting of the parameters and hence of the utility characteristics is carried out by means of job ranking method. This method is chosen because of its simplicity and the number of necessary weightings to be carried out.

4. Aggregate utility-based indicator

Once the correlations of utility value and utility-characteristics are defined, a full indicator can be derived. In order to set up a suitable EE-indicator of adequate abstraction, the authors propose different levels of abstraction. The *full indicator* provides the operational reference characteristic as well as the single utility values with their weighting factors still distinguishable. If suitable for comparison the entire indicator can be united into a *reduced indicator*, i.e. one value with the dimension of reference characteristic per energetic effort.

Example: For the exemplary and simplified utility profile, a corresponding indicator can now be set up this way:

$$UBEEI = \frac{OpRefChar\,\frac{1}{\sum g_i}(\sum g_i\, f(p_i))}{energetic\ effort} = \frac{distance(s)(\frac{1}{7}(4\,f(\#_{persons})+1f(m_{emission})+2f(a_{\max})))}{Vol_{fuel}} \qquad (3)$$

The definition of target values for the entire indicator can be done by defining the basic ratio of reference value (e.g. 100 km) to the target energetic effort (e.g. 4 l) and multiplication with the sum of additional utility values. If all single utility targets are met, the basic ratio will remained unchanged.

However, for reasonable objective definition and later validation of this measure for in-use energy efficiency, an application or definition of standard use cycles is necessary. Finally, suitability and consistency of the indicator should be reviewed regarding its adequate representation of the utility profile. After these concluding reflections, the indicator might require adaption by revising the correlations of utility characteristics and corresponding utility values.

7 CONLUSION AND OUTLOOK

With the systematic procedure proposed within this paper, indicators can be set up in order to describe the design objective *in-use energy efficiency*. The indicators are derived from utility-characteristics and corresponding functional descriptions of abstract utility profiles. They describe the ratio of utility value to energetic effort. This ratio provides a suitable possibility to consistently and manageably represent in-use EE as a design objective. Thus, first steps are done to answer research questions *2* and *3* (cp. section 3). Coming from theoretical considerations, this approach is currently adapted and validated through application on further utility profiles in exemplary and real design tasks. Furthermore the consistency regarding a fragmentation of functions, solutions and corresponding indicators requires the possibility to continuously validate sub-solutions during design and is thus content of further research. Here, the application of QFD promises practical benefit.

Additionally, this research must be connected with questions and studies regarding a systematic identification and weighting of EE as design objective. In this field of studies again the diversified set of possible perspectives on and motivations for EE as a design objective plays a major role. This part of our research will support our approach described in this paper by allowing the designer to choose or create EE-indicators even more differentiated for different utility-profiles and EE-motivations. Within this research we are for example studying the application of influence matrices, with which energy-related influence factors on the design can be evaluated regarding their relevance and meaningfulness for the design process.

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