Transforming product efficiency policy into system efficiency policy

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Keywords

product policy, system efficiency policy, minimum energy performance standards (MEPS)

Abstract

Minimum efficiency performance standards (MEPS) and energy labels are amongst the most widely used policy instruments to increase energy efficiency, particularly for energy-using products in the residential and commercial sectors. These policy instruments are effective and cost-efficient. However, policies with a broader scope, such as a focus on systems, could address a larger share of the energy consumption in an integral way and increase energy savings. Policy makers need to consider diverse strategic issues when pushing for this next frontier in energy efficiency policy because of a range of regulatory issues.

This paper explores a methodological approach that can be used to transform product efficiency policy into system efficiency policy and discusses the regulatory challenges. It provides a definition of a system, and presents a classification of systems that is used to analyse options for regulating systems. The relevant elements of the existing regulatory approaches to product efficiency are highlighted and applied to examples of different systems to illustrate and discuss the regulatory challenges. The paper provides suggestions for overcoming these challenges and map the classes of systems to selected regulatory solutions. Examples from regulatory approaches in the EU (for water pump units), and in the US and Canada (for walk-in coolers and freezers) illustrate possible solutions. The main conclusion is that verification procedures and test methods in particular need to be more flexible to fit to energy efficiency policies dealing with systems. This paper concludes with recommendations for further development of the system approach in efficiency policy.

Introduction

Why would policy makers look at energy-using systems? The simple answer to this question is that systems seem to offer large(r) possibilities for energy savings than products. The EU preparatory study on lighting systems (van Tichelen et al, 2016) estimated a savings potential of 50 % by using e.g. motion sensors and daylight controls. The EU ICT impact study (Kemna et al, 2020) estimated savings between 15 and 27 % for energy monitoring and management systems in buildings. And where savings from more efficient electric motors can be estimated in the range of 3–5 %, savings for the motor system, i.e. the electric motor, variable speed drive and pump or fan, can easily and particularly as well economically amount to 20–30 % (IEA, 2016). Furthermore, in the EU and many other countries the energy efficiency of many products is already regulated through minimum efficiency performance standards (MEPS) and labelling, while systems are not; see (IEA 4E, 2016) for an overview of energy efficiency standards and labelling programmes. Therefore policy makers have an interest in exploring how systems could be regulated to increase energy efficiency.

However, the extension or transformation of efficiency policy to energy-using systems is not obvious. This paper approaches this problem by starting in the next section with a definition of a system. From this definition follow the essential characteristics of a system, i.e. where do systems differ from products. Based on these we provide a classification of systems. Then we address the main elements of energy efficiency measures and identify the challenges in regulating systems. We list approaches to regulate systems and map these approaches to the main elements of the classification. Also we describe two examples of regulatory approaches: water pump units (EU) and walk-in coolers and freezers (US, Canada). The final section presents conclusions and recommendations, including a mapping of regulatory solutions to a number of systems.

What is a system?

This section provides a general definition of a system, specifies this definition for the purpose of this paper and provides a classification of systems.

GENERAL DEFINITION OF A SYSTEM

According to Merriam-Webster's Collegiate Dictionary a system is "a regular interacting or interdependent group of items forming a unified whole". Or shorter: a whole, an entity, made of several parts. This definition allows for a large variation in systems: buildings, facilities, including processes, a whole economy all can be considered a system. In this paper the scope of a system is limited up to the equipment level.

The definition provides two perspectives to look at a system:

- The perspective of the individual items which will be called parts.
- The perspective of the unified whole, which refers to the functionality of the system, including the interaction between the different parts, and the interaction between the system and its environment.

Figure 1 summarizes the various aspects of systems. A system always interacts with its environment, in which other systems exist. It uses energy and sometimes other inputs, e.g. water and consumables, and it delivers a certain performance (functionality). It also delivers other outputs to the environment, e.g. (waste) heat, emissions. In most cases, these other outputs need to be avoided or minimized. Note that the same type of output, e.g. sound, in an audio system is part of the functionality (performance) whereas in an air handling unit it is considered as other output. Furthermore, the environment sets relevant usage conditions, e.g. ambient temperature, humidity, luminance level, or – the other way around – systems require certain environmental conditions to operate.

DEFINITION OF A SYSTEM FOR ENERGY EFFICIENCY POLICY

The definition above of an energy-using system is fairly generic: it would fit a refrigerator, a television, an electric motor or a lamp. These examples can be considered 'equipment products' or simply 'products' that are produced as such in a factory, i.e. the parts are assembled in an industrial process. In contrast, an 'equipment system', or simply 'system' has as essential and distinctive characteristic that (some of) the parts are assembled *on location* before the system can function; a system is produced not (only) in a factory but at a location where it will be used. Therefore, we propose the following technical definition of a system:

> a system is a functional unit that consists of two or more physical parts that need to be assembled at the location where the system is used.

This is a technical definition because it relies on the physical characteristics of the elements involved. As shown in the next section, a regulatory view looking at the addressees of the regulation may provide a different delineation between products and systems. In the following, several elements of the system definition are elaborated upon.

Functional unit

The concept of functional unit of a system enables a boundary to be drawn between the system and the environment (other systems). It does not mean that a system can have only one main function.

Parts

A part is a single, identifiable piece that provides a certain subfunction to the function of the system. E.g. a hydraulic pump, an electric motor, a VSD (variable speed drive) and water pipes are parts of a water pump system. The parts indicated in the definition of a system are *the parts that need to be assembled at the location*. Some of the parts of a system may have been already assembled in a factory, for example, an electric motor.

The parts of a system can be provided by several manufacturers, whereas for a product there is by definition a single manufacturer. In case of different manufacturers, interoperability of

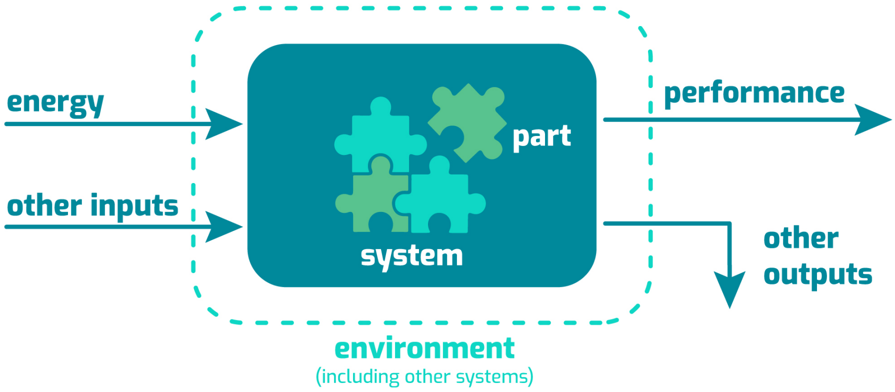

Figure 1. System aspects.

parts of a system is an important issue. Also, the role of system integrator may appear; this could be a large installer or a professional contractor.

A system can be extended during its lifetime by adding new parts to the system, e.g. to increase capacity, functionality or external, geographical coverage. In fact, this is an important reason why the system concept exists.

Assembly versus installation

In order to function on site, energy using systems need to be assembled *and* installed. Assembly means putting the parts together to form the system. Installation means connecting a system (or a product) to another system in the environment, e.g. an energy (electricity, gas) grid or a piping system (e.g. water or air).

What sometimes are called "installed products" are products that need installation by a professional. In the consumer sphere these are commonly hot water, heating, ventilation or air conditioning products. The distinction between assembling, putting together parts, and installation is not always clear. Consider a stereo set with separate loudspeakers (which could have their own power supply). In order to function – produce sound – the loudspeakers need to be connected to the amplifier. Although this fits with the definition of putting parts together, it would be normal to view this as the installation of the stereo set which would also include connecting the stereo set to the mains. Therefore, it may be useful to reserve the term "assembly" for activities of a professional actor.

CLASSIFICATION OF SYSTEMS

The definition of a system provides two main avenues to explore regarding the challenges of regulating systems: the concepts of "parts" and "assembly". We first list the attributes that can be relevant for a classification and second provide a proposal for a classification.

Attributes relevant for classification

Table 1 lists the following attributes that may be relevant for a classification of systems.

The relevance of attributes is guided by the possible influence on the "complexity" regarding the regulatory process, e.g. the effort and expertise needed to establish a regulation. This general idea will be elaborated upon in the next section, where the classification is confronted with the (main) elements of the regulatory process.

The number of parts to be assembled influences many of the other attributes. Parts that are identical will probably reduce regulatory burden for both regulators and market actors. Parts that are standardized are the same across systems, e.g. a power supply. If parts are already regulated, information on relevant characteristics will probably be available and in case of MEPS, a minimum efficiency level is ensured. Moreover, parts that are already regulated will probably also be standardized as this is where MEPS has typically been targeted. The number of possible combinations of parts to form a system, i.e. the number of possible systems, has a large influence on practical methods for verification of requirements. The same holds for the impact of the parts on the energy consumption (or any other regulated parameter).

The impact of the assembly on the characteristics of the system may also influence the verification and the type of requirements in a regulation. The impact of the location can probably be accounted for in other attributes, e.g. the number of parts (1) and the assembly of the parts (6). The number of the responsible actors involved is related to the number of parts being identical and/or standardized.

A classification of systems

The list of attributes in Table 1 would in principle result in 3^{10} (59,049) combinations, which is far too large for a practical classification and regulation. However, several attributes seem to be related. If the number of parts is large, e.g. in a building automation control system (BACS), it is likely that most of these parts are standardized and that many of them will be identical. If the number of parts is large, in principle the number of combinations is also large unless many parts are identical – although in that case the situation could be considered

Table 1. Attributes of a system relevant for classification.

	Attribute	Range of values	Remarks
1	Number of parts	small; medium; large	Indicative values e.g.: small: <5, medium: 6–10, large >10
2	Percentage of identical parts	small; medium; large	Indicative values e.g.: small: <25 %, medium: 25–75 %, large: >75 %
3	Percentage of standardized parts	small; medium; large	Indicative values e.g.: small: <25 %, medium: 25–75 %, large: >75 %
4	Regulated parts	all; mixed; none	
5	Number of possible combinations	small; medium; large	This includes situations with varying number of parts.
6	Impact of parts on energy consumption	all; mixed; none	At least one part should impact energy consumption.
7	Impact of assembly on energy consumption or performance	small; medium; large	Note that this does not concern the "sizing" of the system.
8	Impact of location	small; medium; large	
9	Number of actors involved	1; 2–5; >5	This may vary over time and depends on market conditions.
10	Likelihood of systems changes over lifetime	small; medium; large	

Attributes marked in grey will be the focus for the classification.

to be a small(er) number of *type of* parts. The number of combinations also depends on the variety for the individual parts and the interdependency. If parts are not identical and/or not standardized, it is more likely that the quality of the assembly will impact energy consumption or performance. The impact of the location can relate to the structure of the system but also to the number of parts. Consider a BACS for a location with a small number of buildings that show large difference in size and function versus a BACS for a location with a large number of identical buildings. The structure of the BACS will be more complex in the first case, whereas the number of parts will be larger in the second case. The number of actors involved will depend on the market situation and whether parts are standardized; with standardized parts it is more likely that they will be offered by a range of manufacturers.

In order to reduce the number of combinations we focus on the attributes marked grey in Table 1: the number of parts (1), the percentage of identical parts (2) and the impact of assembly (7). Furthermore, the range for the first two is reduced to two values: small (including medium) and large. If the impact of the assembly is large, it is likely that the percentage of identical parts will not be large. If the number of parts is small, it is likely that they will not be identical. This suggests the classification tree in Figure 2, where in general the complexity increases from left to right.

Some examples of systems in the various classes are:

1. An electric motor with variable speed drive (VSD) plus fan or water pump or a multi split air conditioning system with one outdoor unit and several indoor units.
2. A lighting control system (with standardized parts) for an office building.
3. A BACS for a home with standardized parts (impact of assembly is small) providing a large number of functions (heating, lighting, security etc.); therefore the number of parts is large but the percentage of identical parts is probably small.
4. A walk-in cooler or freezer.
5. A compressed air system for a factory, including piping.

Regulatory aspects and challenges in regulating systems

In general energy efficiency measures need to contain the following main elements:

- The ***scope***: which products or systems are included and/or which are excluded) and the ***addressees*** of the regulation.
- The (efficiency) ***metric***(s) and ***requirements***.
- The method for ***verification***, including test methods.

Furthermore, ***regulatory power*** regarding energy efficiency measures is an important aspect.

This section elaborates on each of these four elements and discusses the challenges of regulating systems.

SCOPE AND ADDRESSEES

The scope is mostly defined in relation to the (main) function(s) and/or the characteristics of the system. Focusing on the function(s) results in a "technology neutral" scope, i.e. all systems that fulfil the indicated function(s) are in scope regardless the technology used. For several applications, e.g. moving air or pumping liquid, both products and systems can provide the same function. In this case, a regulatory level playing field is only achieved if both can be in the scope of the regulation and are subject to the same requirements. Defining the system boundaries is an important part of specifying the scope for a regulation. The setting of the scope is also related to the impact

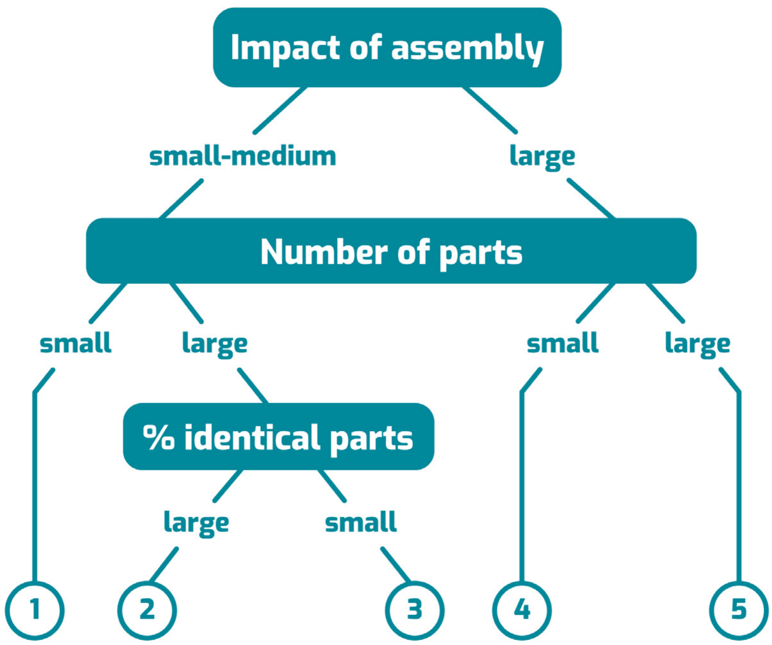

Figure 2. Classification tree.

of the conditions of use. Tying the scope too close to certain conditions of use, runs the risk of easily evading the scope and thereby the regulated requirements[1]. Therefore, the scope will have to be formulated in a general way which in turn could result in including even more usage conditions.

Contrary to products, the system definition suggests different types of addressees: the manufacturer of the parts, the company that offers the system to a customer or the customer that specifies the system, or the company that assembles (and installs) the system. In principle this could be the same company or several different companies. The impact of the assembly would influence the choice of the addressee: if the impact is large, it would be logical to include also the assembler as addressee. Finally, the number of addressees can be relevant for verification and enforcement. In general, the lower the number of addressees, the easier monitoring verification and enforcement activities are.

EFFICIENCY METRIC AND REQUIREMENTS

Efficiency relates output (performance) to input (energy) – or vice versa. However, it is not always easy to quantitatively define or measure performance, especially when related to the services that a system delivers. Whereas an efficiency metric can in principle always be formulated because by definition every system has a function and uses energy, the setting of requirements can be more difficult. The reason is that energy consumption and performance of a system depend on the assembly, the design and the location where the system is used. Therefore, the requirements need to account for these conditions and the test methods (see next section) need to reflect these conditions. A product example is setting a requirement (in kWh/year, the efficiency metric) for a refrigerator: assuming that the refrigerator is used in a warm room would lead to another requirement (and test conditions) than assuming that it is used in a cold room. Another example, where the metric and the usage conditions are combined, is a weighted average efficiency of a pump. In this case the efficiency is measured at a number of points on a load curve and the weighting of each point should reflect the usage of the pump at this load point in practice. Any requirement needs to take into account the conditions of use as reflected in the test method. It might not be easy to establish a single requirement that all systems in scope must comply with. Another aspect is the relation between requirements for parts of the system and requirements for the system. First, efficient requirements for individual parts may not always lead to achieve a high efficiency for the system. An efficient electrical motor and an efficient VSD can work together in a way that is inefficient. Only an optimal reciprocal alignment turns the two parts into an efficient system. This issue needs to be checked when setting requirements for the system.

Second, an argument may be that setting a requirement for the system makes requirements for the individual parts superfluous. If both the requirements for the parts and the system requirements can be measured, the requirements for the parts could be considered superfluous. However, as indicated above, verification may depend on testing parts of the system and deriving the result for the system via a model. To ensure the correctness of the input data for the model, setting requirements for the parts can be useful. More importantly, parts used in regulated systems may also be used as standalone or be used in other non-regulated systems. Since in practice it is impossible to differentiate between a part used in a regulated system and elsewhere, the parts used elsewhere would not be regulated.

VERIFICATION AND TEST METHODS

Verification relates to all elements discussed above: scope and addressees, efficiency metric(s) and requirements. Only systems in scope of the regulation can be verified for compliance with the requirements according to the metrics, and the addressee is responsible for compliance. If addressees are difficult to identify, a regulation is difficult to enforce. A verification method that requires cooperation of an addressee, may also be difficult to enforce especially if the cooperation itself cannot be enforced.

Although verification can be done in several ways, test methods are usually an essential part of the verification. Few authorities and manufacturers would rely on document inspection only without a test of the product or system involved at some stage. The purpose of a test method is amongst others to measure characteristics of a system, e.g. performance or energy consumption, in an objective way, i.e. the results of the test should reflect the characteristics of the system, and not the conditions of the test or the test equipment. Test results need to be reproducible if a test is done at different test laboratories.

Particularly, test standards specify in detail the test conditions, and define admissible deviations, the accuracy and handling of the test equipment. However, a test method should also be representative, i.e. the test conditions, including the prescribed operation of the system, should reflect the location where it is used. Repeating the test at various conditions to reflect the (prevailing) locations where the system is used is an option that quickly results in testing costs becoming prohibitive. Alternatives are using a worst case condition or test at a few conditions and use interpolation for results in other conditions.

The rest of this section discusses the challenges for verification and testing regarding the essential characteristic of a system, i.e. that it is assembled on location where it is to be used. First of all, if the impact of the assembly (and installation) on the energy consumption and/or performance of the system is large, it is less useful to only test the system in "laboratory conditions". This is especially true when one or more parts that impact the energy consumption are already regulated. Verification should focus on the (quality of the) assembly. However, this requires another verification method than normally applied for product regulation.

In other cases, where the assembly has some impact on energy consumption but other attributes do have an impact too, the following issues arise:

- Although the documentation of a system can be verified in the same way as for a product, a system can only be tested as such when it is assembled and installed on its intended location of use.
- The location where the system is tested can in some cases be a laboratory, although this becomes more difficult for physically large systems.

1. This is mostly a problem for mandatory measures where some manufacturers may try to position their products as out of scope. it is assumed that manufacturers that apply for voluntary measures want to position their products to be in the scope of these measures.

- When testing at a location where the system is actually used, the market surveillance authorities need to have access to that location.
- It is difficult to test a system that is already in operation, since this mostly disturbs essential processes at the location (e.g. in a factory or commercial site); so, systems on location have to be tested before starting operation. This would require that the market surveillance authorities know when a system is assembled.

A general issue of relevance of verification and test methods arises: relevance refers to the ability of the test method to reflect the results (e.g. energy consumption, performance) in practice, at the locations the system is in use. The issue is that the characteristics of all possible locations may vary to a large extent and that therefore the specifications of the system may also vary. Although this issue can arise for products too, it is likely to be more pronounced for systems because the system concept is specifically dealing with varying locations and functional requirements. However, if parts are standardized, it could be assumed that the adaptation of the system to the local conditions is not determined by the parts as such, but in the control or the number of parts. For example, in a BACS the number of parts in the system is proportional to the size of the building.

There are three levels of verification (including any combination of them) which could be used in a systems regulation:

- System level: the system as assembled is tested. Modelling can be used to cover the full extent of the "operational" range of the system.
- Part level: all parts of the system are tested; results for the system can be derived via a model.
- Assembly: the quality of the assembly is checked.

REGULATORY POWERS

The previous section covered the *content* of energy efficiency measures to regulate. Another important aspect is the understanding if the relevant authorities (e.g. ministries, surveillance authorities) have the regulatory powers to adopt, execute and enforce these measures. This can relate to the scope, territorial jurisdiction or powers of market surveillance authorities. Systems may not be in the scope of the regulatory powers. Federal authorities may not have jurisdiction over systems that are assembled in a state or province. Market surveillance authorities may not have the power to enforce cooperation in case of testing or assessing a system on location.

While regulatory powers can be changed, it mostly involves changing higher order legislation and this is a slow and often difficult process.

Approaches to regulating systems

This section starts with a short overview of methodological approaches to assess systems, since assessing the efficiency and performance of systems is at the heart of regulating energy efficiency. Then we map the approaches to the main elements of the classification, and provide examples of regulating systems form the EU and the US.

METHODOLOGICAL APPROACHES FOR ASSESSING SYSTEMS

The following methodological approaches for assessing systems exist, see Table 2, noting that in practice a blend of these may be used.

A first indication of the applicability of the various approaches follows from mapping them to the main elements of the system classification and the variation in usage or operational conditions; see Table 3 where the X marks the situation that is most suitable.

From this brief analysis we notice first, that in case the impact of assembly is large, the procedural approach should be included. Furthermore, modular and modelling approaches can cover the different situations regarding number of parts, % of identical parts and variations in conditions (usage, operational). The black box approach can cover situations that come close to testing a product.

EXAMPLES OF REGULATING SYSTEMS

Water pump unit

Currently in the EU the (hydraulic part of) water pumps is regulated through Commission Regulation (EU) 547/2012; products placed on the market have to meet a certain minimum efficiency, expressed as minimum efficiency index (MEI). Electric motors which are used to drive the water pump, are regulated through Commission Regulation (EU) 2019/1781. In the revision of the water pump regulation, it is proposed to extend the scope to a 'water pump unit', i.e. the hydraulic part (pump), the electric motor and the VSD (variable speed drive). In the classification of Figure 2 this case fits to a class 1 system.

The efficiency requirements for the water pump unit are based on an energy efficiency index (EEI) which is the ratio of the average measured electric power input (P_{avg}) and the reference power input (P_{ref}). P_{avg} is the weighted average of measured electric input power over four operating points, each weighted for its relative share in the flow-time. P_{ref} is the nominal input power of a fictitious water pump unit running at nominal 100 % load point with a compliant water pump and an IE3 induction motor. Although the use of a VSD is not directly mandated, the EEI requirement on the water pump will be set at such level that they can only be met with a VSD. The preparatory study for the review of the regulation estimates the savings for the EU at around 40 TWh/year in 2030 (Maya-Drysdale et al. 2018), which is an order of magnitude larger than for water pumps only (3.3 TWh/year). The reason is that applying a VSD ensures that load variations are matched by adjusting motor speed instead of using throttling values. In case of fixed load applications adjusting the water pump to the required load point can be done via motor speed control instead of pump trimming. Furthermore, the study indicates that testing methods for water pump units are available.

The main issue to be solved is the verification and enforcement. If a manufacturer is placing on the market a water pump unit, this unit has to comply with the requirements and verification by market surveillance authorities can be done in a laboratory; the black box approach as indicated in Table 3. However, also water pump units that consist of a water pump, an electric motor and a VSD – each individually placed on the market – that are put into service (assembled and installed) on location

Table 2. Methodological approaches for assessing systems.

Approach	Description
Black box approach	The black box approach does not care what is in the box (the system); the relevant inputs and outputs of the black box are assessed. This is the product testing approach applied to a system.
Modular approach	The modular approach focuses on assessing the parts (modules) of the system. Performance and energy consumption of parts are measured/assessed and then combined by a formula to provide the performance and energy consumption or efficiency of the system. This approach can resemble the modelling approach (see below), especially when a complex formula is used. The difference is that in the modelling approach usage conditions and/or operational range are included *in the model*, whereas in the modular approach these elements are assumed to be taken into account in the assessment of the modules (parts) and the applied formula is a mathematical operation to combine the results.
Procedural approach	The procedural approach focuses on the assembly (and installation) of the system. This could include rules for sizing the system and the parts. In principle no measurements on parts are needed (but information on parts may be needed). This approach resembles quality management. The assumption is that if the right procedure is followed then the efficient functioning of the system is guaranteed. The steps of the sizing, assembly and installation are documented and can be checked.
Statistical approach	The statistical approach relies on measurements of energy consumption and performance when the system is in use. Apart from energy or power consumption and performance, usage and operational conditions are assessed. The values for the relevant efficiency metric are then statistically extracted from this data, allowing e.g. to correct for variations over time. This approach is used in monitoring installations, but could also be used for certification, showing that a system performs as specified/calculated.
Modelling approach	The modelling approach comes in two main variants. The first uses a mathematical model of (parts of) the system to calculate the performance, energy consumption or efficiency based on design parameters of the parts. The second uses a scale model of the (parts of the) system on which measurements are done. The results are scaled up to achieve results for the system. The design parameters of parts could be checked independently.

Table 3. Mapping approaches for assessing systems to the classification and conditions of systems.

	Impact of assembly		Number of parts		% identical parts		Variation in conditions	
Approach	*small*	*large*	*small*	*large*	*large*	*small*	*small*	*large*
Black box	X		*		*		X	
Modular	X		X		X		X	
Procedural		X	*		*		*	
Statistical		X$^{\#}$	*		*			X$^{\#}$
Modelling	X			X		X		X

** Element not relevant for the approach; $^{\#}$ Approach can only be applied in once the system is in use.*

are in the scope of the revised regulation[2]. The challenges are to identify the actors that put into service water pump units (because these may differ from the manufacturers of the parts), and the verification on location (because some market surveillance authorities in EU Member States do not have the legal powers to visit installations).

Walk-in coolers and freezers (WICF)

In the US the Energy Policy and Conservation Act (EPCA) established the Energy Conservation Program for Certain Industrial Equipment, including components of walk-in coolers and freezers (WICF). EPCA also directed the US Department of Energy (DOE) to establish test procedures to measure the energy use of WICF and performance-based minimum efficiency requirements for WICF. These test procedures and requirements were developed in 2011–2017; see Title 10 (Energy), Chapter II, Subchapter D, Part 431, Subpart R. In the classification of Figure 2 a WICF is a class 4 system.

The requirements on components include minimum insulation requirements and labelling requirements for panels, doors and refrigeration units, and maximum energy consumption (kWh/day) requirements for doors related to the surface area of the door and including electrical components associated with the door. Manufacturers of components must test, certify and label their components. Catalogues and marketing material must include the R-value (panels) or energy consumption value (doors).

Manufacturers and private labellers of components and complete WICF are subject to the regulations; installers of WICF are considered to be manufacturers of (complete) WICF. Manufacturers that *only* assemble complete WICF can rely on data of

2. Note that the EU Ecodesign Directive 2009/125/EC only defines "products", but covers both products and systems (as defined in this paper). In the framework of the Ecodesign Directive a system would be defined as a product that is not placed on the market but only put into service, i.e. assembled and installed on location.

the component manufacturer to ensure compliance and must ensure that the completed WICF complies with the requirements. Manufacturers that both manufacture components and the complete WICF are responsible for both the compliance of the components and the complete WICF. Component manufacturers must certify each basic model and submit certification to the Compliance Certification Management System (CCMS) of DOE. The DOE Office of the General Counsel, Office of Enforcement enforces the requirements and may request complete test data from the manufacturer, and check certification information based on test data from the manufacturer or test data obtained through DOE testing, following a modular approach.

Canada considered adopting the US regulation on WICF. However, the legal authority only extends to products and not to systems as WICF were considered to be. Moreover compliance is verified at the border, not on-site.

Conclusions and recommendations

SUMMARY AND CONCLUSIONS

This paper focused on the main elements of regulating energy efficiency of products to investigate the challenges when transforming these elements for regulating the energy efficiency of systems. A system has been defined as a functional unit that consists of two or more physical parts that need to be assembled at the location where the system is used. A classification of systems is proposed based on three main elements: the impact of the assembly on the efficiency, the number of parts and the percentage of identical parts. Systems are more difficult to regulate than products because of the role of the assembly, and because the system concept is constructed to serve a large number of conditions regarding the locations where the system is assembled or the use of the system. The latter has two consequences: first a system can have a large number of variations and second the conditions in which a system operates can vary to a large degree. In general, systems open up for a larger variety of usage conditions which seems to be more difficult to handle in a regulatory context than it is for products.

Challenges for regulating systems are firstly associated with the verification in combination with the need for suitable test methods. Verification of systems in many cases will need to deal with the (quality of the) assembly process. Secondly, setting requirements on systems can be challenging when they operate in a large variation of conditions. Finally, a lack of regulatory power is a further challenge to regulate (certain) systems.

When mapping the approaches to regulate systems to the main elements of the classification and to the variation in usage or operational conditions where the system is used, we conclude that when the impact of assembly is large, the procedural approach should be included. Furthermore, modular and modelling approaches can cover the different situations regarding number of parts, percent of identical parts and variations in conditions (usage, operational). The black box approach can cover situations that come close to testing a product.

The impression from the examples is that enforcement poses the main challenge of regulating systems. In the EU water pump unit example, it will be difficult to check whether a VSD is included in the assembled and installed system because there is no register of installed systems. Furthermore, some market surveillance authorities in EU Member States do not have the legal powers to visit installations. In the US walk-in cooler and freezer example, enforcement is focusing on the components of the system (panels and doors). Lack of regulatory power was the main issue why Canada did not adopt regulation for walk-in coolers and freezers.

In the next section we discuss some recommendations.

DISCUSSION AND RECOMMENDATIONS

When the assembly of the system has a large impact on the efficiency (energy consumption and/or performance) the assembler should be (one of) the addressee(s) of the regulation and the verification needs to focus on the (quality of the) assembly. Another option would be to regulate standardization of the assembly with the aim to reduce the impact of the assembly on the efficiency. Examples of standardization are standard interfaces or compatibility of parts. Standardization could also be beneficial for optimizing assembly time and therefore costs. This approach could go as far as requiring assemblers to have a quality management system.

In other cases, i.e. when the assembly has a small(er) impact, the addressee(s) could be the manufacturer of the system or another company that offers the system to a customer. This could cover the (large) variations of systems, assuming that all system (variations) offered will comply with the regulation. The manufacturer or the company offering should be able to provide information on the efficiency of the system variant(s) manufactured or offered (according to the relevant test method; see below).

If the percentage of identical parts in a system is large, then it would be helpful to (only) regulate the parts. If the number of parts is large, but the percentage of identical parts is low or medium, the system consists of a medium to large number of different parts. Then it is possible to have a large number of system variants. In that case the regulation would need to include modelling. Another option is to check whether any of the parts are critical for the energy consumption, and regulate these parts. Verification and test methods have to deal with both, a variety in systems and a variety in usage conditions and operational range. If the variety is large, testing all variants may not be feasible regarding time and costs. In this case, modelling can be useful or even necessary. The following situations can be distinguished; see Table 4.

If modelling is included in the measures, the regulation should include the calculation or simulation model. Alternatively, the regulation should indicate how third party calculations or simulations should be verified in for compliance with the regulation.

Table 5 summarizes the recommendations by mapping them to the classes of systems distinguished in Figure 2.

A final recommendation is in case of systems in class 5, to look at approaches used in buildings. If a quality control system is used for checking the assembly and installation of a systems, this could be extended to take the owner that specifies the system into account.

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Table 4. Modelling approaches by type of measurement and variations.

	Variation in *usage conditions*	Variation in *operational range*
Measurement of *system*	Use test results at system level, measured for a limited number of usage conditions, to calculate system results at other usage conditions.	Use test results at system level, e.g. from a scale model, to calculate results for larger systems.
Measurement of *parts*	Use test results for parts as input for a model that covers different usage conditions; the model simulates the system, i.e. the energy or performance relevant interaction between the parts.	Use test results for parts as input for a simulation model that covers the total operational range.

Table 5. Mapping systems and regulatory solutions.

System class (see also Figure 2)	**Main elements of energy efficiency measures**		
	Scope and addressees	***Efficiency metrics and requirements***	***Verification and test methods***
①: impact of assembly: small-medium; small number of parts	Manufacturers of (parts of) the system.	Efficiency of the parts and of the system.	Measurements on the parts of the system; modelling to provide results for the system (in a variety of usage conditions).
②: impact of assembly: small-medium; large number of parts with a large % identical parts	Manufacturers of the parts.	Efficiency of the parts.	Measurements on the parts.
③: impact of assembly small-medium; large number of parts with a small % identical parts	Manufacturers of the identical and/or critical[a] parts of the system. Assemblers/installers of the system.	Efficiency of the (identical/critical) parts. Efficiency of the system as assembled and installed.	Measurements on the (identical/critical) parts. Modelling to calculate system efficiency as assembled and installed.
④: impact of assembly: large; small number of parts	Manufacturers of the parts. Assemblers/installers of the system.	Efficiency of the parts. Quality (control) of the assembly/installation.	Measurements on the parts. Check on the quality (control) of the assembly/installation.
⑤: impact of assembly: large; large number of parts	Assemblers/installers of the system.	Quality (control) of the assembly/installation.	Check on the quality (control) of the assembly/installation.

[a] *Critical with regard to energy consumption of the system.*

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Acknowledgements

This paper is based on work of the Systems Policy working group of the IEA 4E (energy efficient end-use equipment) Technology Collaboration Programme. However, the content of the paper is solely the responsibility of the authors only and does not reflect the views of the Systems Policy working group.