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Assembling Appliance Standards From a Basket of Functions

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ABSTRACT

Rapid innovation in product design challenges the current methodology for setting standards and labels, especially for electronics, software and networking. Major problems include defining the product, measuring its energy consumption, and choosing the appropriate metric and level for the standard. Most governments have tried to solve these problems by defining ever more specific product subcategories, along with their corresponding test methods and metrics. An alternative approach would treat each energy-using product as something that delivers a basket of functions. Then separate standards would be constructed for the individual functions that can be defined, tested, and evaluated. Case studies of thermostats, displays and network equipment are presented to illustrate the problems with the classical approach for setting standards and indicate the merits and drawbacks of the alternative. The functional approach appears best suited to products whose primary purpose is processing information and that have multiple functions.

Introduction

The classic, traditional approach for adopting product efficiency measures such as minimum energy performance standards (MEPS) and energy labels for individual products goes along the lines of Turiel et al. (1997); see also figure 1. After the general product selection, it is defined which specific products are in the scope of the measure, metrics that reflect the aspects to be regulated are defined, including test procedures to assess these metrics, and finally MEPS and/or labelling classes are established. Monitoring, verification and enforcement, and evaluation are essential to ensure that the expected energy savings are realized and to learn for subsequent policy cycles.

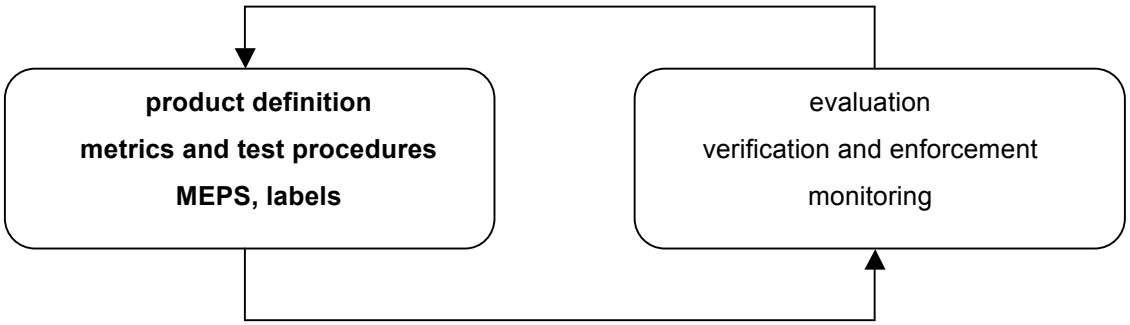

Figure 1. Process for adopting and evaluating product efficiency measures.

Figure 1 suggests that the process is dynamic, i.e. MEPS and labels are regularly revised. The practical set-up of the approach, including organizing stakeholder involvement, has been

documented in Wiel and McMahon (2005) and in Ellis et al. (2010) for the right hand side of figure 1. This paper focuses on MEPS and on the left hand side of figure 1 (steps in bold).

Evaluation studies (IEA (2000), Lowenberger et al. (2012)) show that MEPS and energy labels are successful policies. Because of the success of MEPS and labels, governments are regulating more products, e.g. in 2009 the European Union enlarged the scope of the ecodesign directive from energy-using products to energy-related products. Furthermore, because of the success of MEPS and labels, the energy consumption of the "classic" MEPS products - large household appliances - is decreasing. The impact of electronic products, consumer electronics (CE) and information and communication technology (ICT) products, on household and commercial electricity consumption is significant and expected to grow (Ellis 2009). In the EU, 17 % of residential electricity consumption is used by electronic products (Bertoldi et al. 2012, 35).

As we show in the next section, product development and especially development in ICT, including software, have posed challenges to the classic approach of setting MEPS. The goal of this paper is to respond to part of these challenges by proposing an alternative approach to setting MEPS. This paper is organized as follows. First we explore and analyze in more detail problems with the classic approach. Then we propose an alternative based on a modular functional approach to address some of the challenges. We apply the alternative in three case studies: thermostats, video displays and network equipment. Finally we discuss results, draw conclusions and provide recommendations for using a modular functional approach for minimum efficiency standard setting, and for further development of the approach.

Challenges for the classic approach

Introduction; energy services and functions of products

A product uses, amongst others, energy to produce energy services. Generating heat, cold, light, mechanical action and processing are basic energy services. These energy services deliver functions for the end-user, e.g. a clean wash, a comfortable environment, food preservation and entertainment. The distinction between energy services and functions is important. Functions, as defined here, require involvement of the user and energy services do not. A particular function might be realized in another way without using an energy-using product. Clothes can be dried with an electric dryer but also by a clothesline. The product might produce the energy service while there is no end-user to enjoy the function delivered by the service, meaning that the function of the service is zero.

Basic energy services have existed since the first energy using products were invented: water heaters, refrigerators, lamps, vacuum cleaners and radios. Two developments dramatically changed energy-using products. First, electronics, such as transistors and integrated circuits developed in the 1950s and 1960s, enabled smaller and more reliable products and better control. But especially the development of microprocessors and software from the 1970s and 1980s onwards provided flexibility and resulted in new products like personal computers and tablets where the software determines the function. Nowadays there is hardly any product in the home or office that is not equipped with a microprocessor and software. Second, in the last decade, connectivity has become an important function of ever more products. Although home networks existed previously, based on the X10 protocol developed in the 1970s, only with the arrival of the (wireless) Internet, including the Internet protocol (IP), connectivity became a "practical" and

widespread feature. Products become dependent on other products and functionality can easily change through software updates over the Internet.

The combination of software playing a major role in the function of the product and dependence on connectivity for the functionality of the product creates "virtual" products. The Internet-connected thermostat is an example of a virtual product. As a contrast, classical products can function without being connected to a network and the software is not definitive for the function of the product. Figure 2 depicts this topology; the trends described in this section suggest that products will migrate towards the upper right hand part of the graph. The next section looks into the challenges these developments pose on the classical approach of setting MEPS.

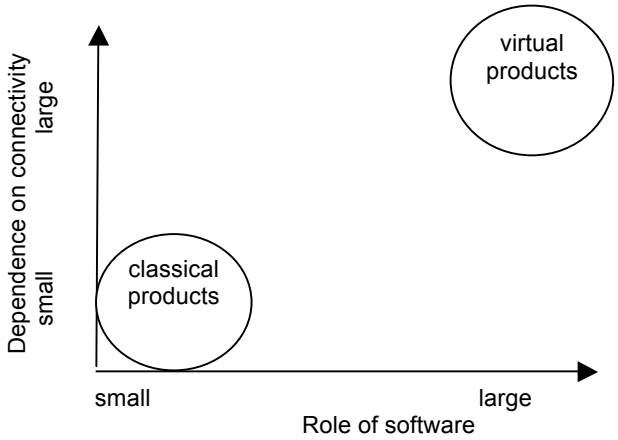

Figure 2. Product topology.

Challenges and impact on the classic approach

Product development in general, but especially the increasing role of software and importance of connectivity result in products that have multiple functions, are always connected to a network and can change or adapt functionality. In this section we analyze the consequences of these developments for the classical approach of setting MEPS.

The classical approach starts with the ***definition of the product***. An important function of product definition in policy measures is to define the scope of the measure, i.e. the product definition determines which products are subject to the measure and which products are not. In the past the definition of the product was identical to the main function of the product, e.g. a refrigerator provides one or more conditioned volumes at certain temperatures, a television receives broadcast signals and provides picture and sound. A consequence of multiple functions is that if the scope of a measure is defined in a restrictive way, it is easy for products to be out of scope by adding a function that is not in the definition. An example is the differentiation between televisions and monitors based on the presence of a tuner to receive broadcast signals. Nowadays it is easy to add a tuner to a monitor so that it becomes a television. Another example is the home gateway. If this product is defined as a product offering Internet connection, WLAN and telephone and router services, then a gateway with network attached storage (NAS) will be out of scope. The solution to these problems is to use more generic product definitions where everything that is not explicitly excluded is included. However this will move the problems to the next steps of the process, defining metrics and test methods and setting MEPS. In the example of the gateway, this would require defining metrics and MEPS for products with and without NAS.

Changing functionality – after the product has been placed on the market – is not a problem for the product definition, because the function and the definition of the product is in principle clear when testing the product (before placing it on the market). The set-top box is an example where software updates for deployed products are carried out to increase functionality; these updates can also impact power consumption. MEPS loose credibility and effectiveness

when changing functionality results in higher energy consumption, although the functionality might be improved.

MEPS and labels are based on ***metrics*** that operationalize the (main) functions of the product related to the energy or power consumption of the product. These metrics are assessed by appropriate ***test procedures***. Test procedures prescribe which measurements are needed and how these are to be performed to arrive at results. Then the results are used to calculate the metrics for which the MEPS levels are set. In most cases standards contain these test procedures, e.g. IEC 62552 for testing refrigerators. Standards prescribe in detail amongst others the input to the product, such as the load of dishwashers, the broadcast stream for a television or the power supply; the measurement conditions, such as temperature, humidity and position of the product; the measurement equipment and the actual measurements.

Multiple functions can be dealt with in several ways. Using several metrics increases the complexity of the test procedure and the costs, certainly if a separate test has to be performed for each metric. We describe two alternatives that use a single metric. The first is the use of an energy efficiency index where the power or energy consumption measured is normalized by a formula taking into account different functions. This approach is used by the EU ecodesign regulation for cold appliances which takes into account not only the volume and temperature of the compartments but also the climate class, the frost free function and whether the appliance is built-in (European Commission 2009). The second approach is using allowances, which does not involve the metric but the setting of the MEPS level. In this case the MEPS level is set based on the functions of the product. An example of this approach is the ENERGY STAR specification for computers where the maximum total energy consumption (TEC) requirement is composed of a base allowance plus functional adder allowances for e.g. graphics, memory and storage. Finally, with multiple functions the chance increases that not all functions can be taken into account and therefore a choice must be made which functions to include and which not.

Changing functionality, especially awareness of the test situation, is an increasing risk for test procedures. The product recognizes that it is being tested and adapts its functionality and performance to artificially improve the efficiency. Especially when performance is not tested at the same time, energy consumption can easily be decreased by lowering the performance. Examples are refrigerators that recognize being tested and then switch off features and thus use less energy for the cycle than they will in practice (Saito 2012). Since the performance is not measured, the impact on performance is not clear, but the energy consumption in the test will not occur in practice. Recognition of test conditions is a consequence of the very detailed prescription of test procedures in standards, e.g. regarding the timing of actions. This level of detail is driven by the aim to increase the repeatability and reproducibility of test methods. Solutions are to include a degree of randomness, or to measure the performance or critical parameters. However these solutions increase the complexity and costs of the tests whereas including randomness will decrease the repeatability and reproducibility.

The last step in the process of setting MEPS is to decide upon the actual ***MEPS levels***. Guidance for setting MEPS levels is provided by e.g. life cycle costs calculations, price developments of products or technical analysis; this is not the subject of this paper. Multiple metrics mean that multiple levels need to be defined. Where a single MEPS level is used with a generic product definition the tendency exists to set the MEPS at such level that products with the maximum possible functions under the definition will comply. This means that for other products the MEPS level is too generous. In case of (multiple) allowances the problem arises that it is difficult to take into account synergies between the different functions regarding power

consumption. Each of the allowances has to cover for the case that only this allowance is used which, in case synergies exist, results in a too generous total allowance when applying more than one allowance.

Summarizing the challenges; which of the challenges will be addressed in this paper

We can summarize the challenges for the classic approach to setting MEPS as follows. Multiple functions increase the number of product definitions unless more generic definitions are used. Each product definition has to be worded carefully to avoid circumvention of a measure by designing products out of the product definition. More generic definitions make it more difficult to set appropriate MEPS levels. Furthermore, multiple functions increase the complexity of metrics and test procedures, and in the case of using allowances problems occur with setting appropriate MEPS levels.

Changing functionality especially impacts test procedures. In order to deal with the issues, e.g. the product's awareness of the test procedure, the test procedures need to become more complex and probably less accurate. This leads to higher costs for product testing. Furthermore, changing functionality can impact credibility when it occurs after the product has been placed on the market, e.g. through software updates, and increases energy consumption.

In the alternative approach presented in the next section we focus on the challenges related to the multiple functions.

A modular functional approach to MEPS (basket of functions)

Basics of a modular functional approach

A modular functional approach consists of two parts: a generic part, which is product independent, and a specific part, which is product dependent. The generic part consists of the following steps:

- Step 1: Define the functions (or energy services) that are to be tested.
- Step 2: Define the test methods for determining the power or energy consumption for the functions, and define the energy or efficiency metrics.
- Step 3: Set requirements for the functions, based on the metrics.

The specific part consists of the following steps:

- Step 1: Determine the functions (or energy services) of the product that are to be tested.
- Step 2: Measure the power or energy consumption for the functions according to the test methods and calculate the energy or efficiency metrics.
- Step 3: Determine whether the functions meet the requirements.

We note the following differences with the classical approach. First, the focus is on functions or energy services, not on products. So, the definition of the product has become less important. Second, in the ideal case, the modular functional approach is horizontally applicable. Once a function has been defined, it should not matter in which product this function is used. In terms of regulatory efficiency one regulation could cover a large number of product categories; an example is the EU (networked) standby regulation that covers all products in more than 30

product categories. Third, it allows for testing part of the functions of a product. This stimulates power management assuming the MEPS level is specified for the function that is tested. To meet this level, the functions that are not used, i.e. not tested, need to be powered down by the product.

In the next sections, we first look at thermostats because this product illustrates many of the problems likely to be encountered when regulating the efficiency of future appliances. Second, we sketch the development of a display module. Displays are a component in ever more products not only in consumer electronics but also in white goods amongst others. But in products such as televisions and monitors, the display is the main functional component. Third, we look at a horizontal functionality, network connectivity and more specifically networked standby.

Regarding the steps of the approach we focus on the generic part step 1 and the definition of the metric in step 2, assuming that test procedures are available or can be derived from current standards. As indicated, this paper will not deal with setting requirements.

Domestic digital thermostats

The function of a thermostat is to regulate temperature in buildings supplied with heating and cooling systems. By definition, a thermostat has at least one temperature sensor, though some units also sense occupancy, humidity, and other environmental features. The means by which the thermostat regulates temperature can influence its own energy use, but more importantly the energy use of products downstream and upstream.

A thermostat itself consumes energy in order to sense temperature, process information, display information for the occupants, and communicate information to the heating system and other products. The thermostat may be powered by a replaceable battery, DC power delivered by a power supply, AC power directly, or even from a millivolt thermocouple in the case of gas-fired heating systems. In general the thermostat's own energy consumption is insignificant compared to the downstream energy use (the HVAC system) it controls. The quality of the thermostat's hardware and software will determine the behavior and energy use of the HVAC system. Traditional thermostats processed all information and made all heating and control

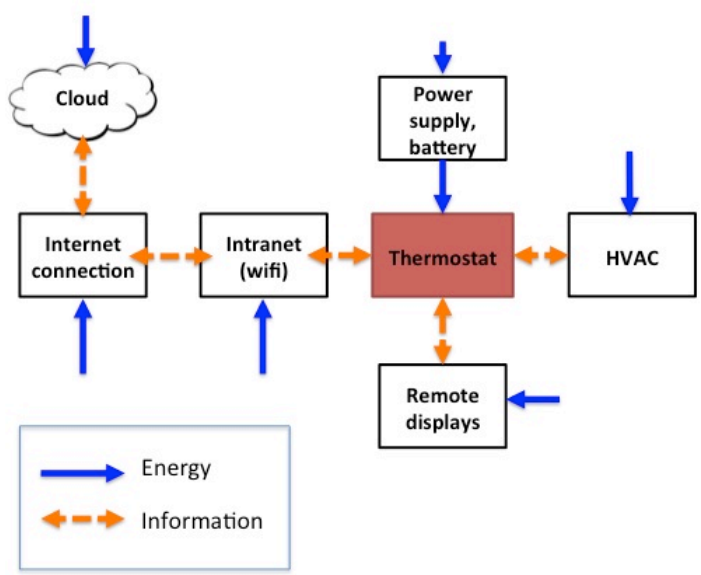

Figure 3. Energy and information flows in an Internet-connected thermostat.

decisions. Network-connected thermostats will share responsibility for decision making with local or even cloud-based services (Internet-connected thermostat). A networked thermostat causes upstream energy consumption, in the local network or in the cloud. The network-induced energy consumption is already significant since data centers are dedicated to providing thermostat services. Internet-connected thermostats also use smart phone and web displays as alternative user interfaces; indeed, these are often expected to be the primary interfaces. These displays are therefore part of a thermostat's related energy consumption. The energy and information flows are depicted in figure 3.

There is no recognized procedure for testing energy use of thermostats (Peffer et al. 2011). This is no surprise given the many different ways in which it is powered. Energy Star's original endorsement program for programmable thermostats avoided this problem by requiring compliant units to have specified features and a minimum accuracy of temperature measurement. When Energy Star abandoned this program, it considered a new specification based on usability of the interface. A test procedure for measuring usability was developed and applied to programmable thermostats (Perry et al. 2011). The methodology was independently tested (Herter and Okuneva 2014).

Internet-connected thermostats pose yet another challenge to testing, labeling, and regulating. Some of the temperature control is relinquished to a remote service provider communicating with the thermostat via the Internet. The service provider adjusts thermostat settings in directions so as to reduce energy use for cooling or heating. The service provider typically collects temperature settings, actual temperatures, and furnace on-time data - sometimes as frequently as every 5 minutes - and possibly external data from other, on-site sensors or local weather stations. The service provider applies an algorithm to these data to estimate each building's thermal performance. The performance parameters allow the service provider to optimize thermostat setbacks and resets and extract savings in heating and cooling energy. One manufacturer (Ecofactor 2014) claims up to 10 – 15% savings with these techniques beyond those achieved with a conventional programmable thermostat. The Internet-connected thermostat can also enable the home to participate in demand response programs. Thus, the energy savings achieved by Internet-connected thermostats will depend on the features and quality of the algorithm. An evaluation of the algorithm requires a software test rather than a traditional hardware test.

The boundaries for a measurement of an Internet-connected thermostat energy use also need to be established. Like many networked products, the thermostat's behavior can induce energy use elsewhere in other products in the home, on the person, or in the cloud. If the network connection was created solely to serve the thermostat, then the energy burden of the wifi system and Internet hub should be included. However, a more likely scenario is that the thermostat is added to an existing network, leading to an incremental increase in energy consumption. A similar situation exists further upstream with the service provider.

The measurement of a thermostat's energy use (or efficiency) will thus draw upon a collection of separate procedures depending on the basket of functions present. Some of these procedures already exist (such as for measuring energy use of small consumer electronics, displays, etc.), while procedures to calculate energy savings from control algorithms are still in their infancy. Procedures to calculate induced energy upstream in the cloud must still be developed.

In summary, the thermostat represents an extreme (but already existing) example of interconnected appliance energy use. Its own energy consumption is very small and generally

dwarfed by consumption that it controls directly or induces through a network. The Internet-connected thermostat is an example of a virtual product for which procedures to measure the efficiency have yet to be established.

Displays

A display can be an individual product, e.g. a television or a monitor, but also a component of a product that has another primary function than displaying images, e.g. a display on a refrigerator or washing machine. As an example of the application of the functional modular approach, in this section we develop a display module. Ideally, this module would be used for evaluating the display function of a range of products, including products where the display function is not the main function. Figure 4 shows a generic model for CE and ICT products with the components that are relevant for displays in boxes.

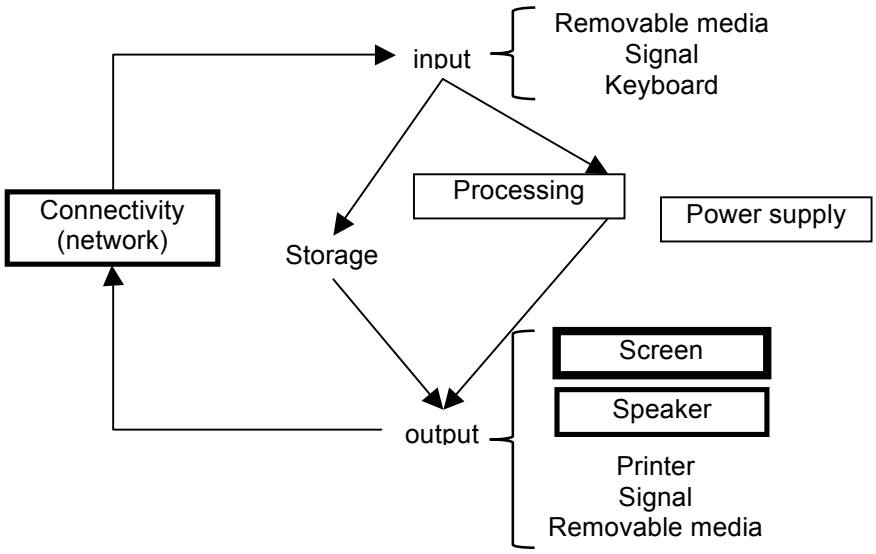

Figure 4. Generic model CE and ICT products applied to displays.

Following the generic steps, the main function of a display in active mode is to provide information or entertainment. However, it is difficult to operationalize this into a metric, also because the fulfillment of this function not only depends on the display but also on the content. Therefore the energy service is used to define a metric; this service is displaying (moving) images on an integrated screen. Other functions can be connectivity and producing the accompanying sound with the images. The power supply and processing are supporting functions.

For the second step of the generic part we concentrate on the metric for the display function; regarding the method for measuring the power consumption we refer to IEC 62087, third edition. The following characteristics determine the power consumption (Park et al. 2011): screen area, resolution and brightness. Since the brightness is set by the measurement method, we will not consider this aspect. The resolution influences the power consumption for processing but is also related to screen size: larger screens are more likely to have higher resolution. The

power consumption for processing is related to the resolution and other image processing aspects, e.g. scaling, quality improvement. With televisions the processing of the broadcast signal is done in the television, with monitors a large part of the processing can be done outside, by the graphic card of the computer to which the monitor is connected. To arrive at a metric for efficiency we need to relate the power consumption of the display to the energy service. We choose the screen size to represent the energy service, so $P_{display} = f(A_{screen})$. If the power consumption is proportional to the screen size, we can derive the following metric: $\alpha_{screen} = P_{display}/A_{screen}$ [W/m2]. If $f(A_{screen})$ is a more complex function we can use an energy efficiency index as metric: $EEI = P_{display}/f(A_{screen})$. The choice for a metric can be made based on further technical analysis of the product and/or by analyzing data on the relation between power consumption and – in this case – screen area. We look at data for televisions and monitors collected from manufacturers and independent laboratories for the revision of the television regulation in the EU (figure 5). All measurements were obtained using the dynamic test sequence of IEC 62087, third edition.

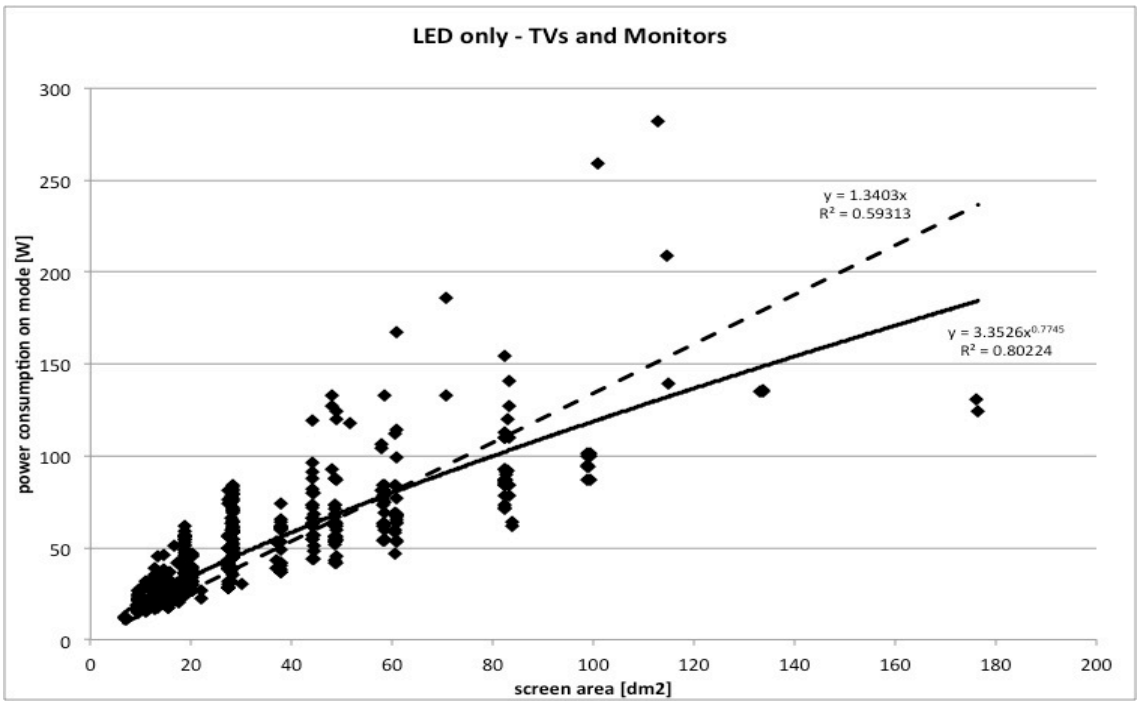

Figure 5. Displays: relation between power consumption and screen area.

From this data we learn that the metric α_{screen} is too simple and that the following function provides a better fit: $f(A_{screen}) = 3.3526\times(A_{screen})^{0.7745}$. Thus the metric becomes: $EEI = P_{display}/3.3526\times(A_{screen})^{0.7745}$.

In the third step, requirements for the function are set. As indicated, this involves more work than we can describe here, a technical-economical analysis and/or market analysis. Assuming that the MEPS level is set at EEI_{MEPS}, we can use this level in different ways. For display products the EEI_{MEPS} can be used for regulation based on the on mode: products with higher EEI than EEI_{MEPS} are not allowed on the market. If we consider a display component or if

we want to regulate the total energy consumption (TEC) based on the power consumption in different modes, then we can calculate the allowed power consumption by $P_{display} = EEI_{MEPS} \times 3.3526 \times (A_{screen})^{0.7745}$. The rationale for using the EEI_{MEPS} from monitors and televisions for display components as well is that these components should not be less efficient than an entire monitor or television product.

Connectivity, networked standby

Network connectivity is available in ever more products. For some products, e.g. routers, switches, providing network connectivity is the main function and for many others network connectivity is essential to use the Internet, download software etc. Furthermore it is often possible to access or reactivate the product through the network. For these products the risk is that they stay in idle or even on mode permanently to preserve the network connection awaiting reactivation or access via the network. So, connectivity is an important function in the on mode but also in the standby mode. In this section we first look at networked standby as a module under the modular functional approach and then at connectivity in the on mode.

Following the generic steps, the function of networked standby is to facilitate the activation of other modes by having at least one network function active. Networked standby allows the product to be in a mode with a lower power consumption thereby saving energy.

For the second step of the generic part we first deal with the relation of the power consumption in networked standby to the function delivered. The preparatory study for networked standby in the framework of the EU Ecodesign Directive (Nissen 2011) developed the concept of network availability. This is the capability of the product to resume applications after having received a trigger via the network. Network availability is expressed in the time that it takes to resume an application, the *resume time*. Although resume time is a clear concept, measuring resume time is not easy and would require specific instructions for individual products, something to be avoided in a modular approach. The implementation in the framework of the EU Ecodesign Directive used a simplified approach. It distinguished between products with functions that need a very short resume time, i.e. a high network availability (HiNA), and other networked products that do not require a very short resume time. The HiNA functions are: router, network switch, wireless network access point. The metric is the power consumption in networked standby. The measurement method specified by the EU regulation deals with the issues of multiple network connections. The product shall comply with the required value for all types of available network connections when one network connection is present. If there is more than one network port of a certain type of connections is available, one port is randomly selected for testing leaving the others disconnected. For the general conditions and set-up of measuring power consumption in (network) standby we refer to IEC 62301, second edition.

As an example of the third step, Table 1 shows the requirements for networked standby under the EU ecodesign regulation.

Table 1. Power requirements for networked products in networked standby.

Networked product	Tier 1 (1-Jan-2015)	Tier 2 (1-Jan-2017)	Tier 3 (1-Jan-2019)
HiNA network products Networked products with HiNA function(s)	12 W	8 W	8 W
other networked products	6 W	3 W	2 W

Source: European Commission 2013.

A modular solution for networked standby that is to be applied to a broad range of products has as drawback that the requirements are set to accommodate the most power hungry type of connections while not all products may have this type of connection. So, certain products can achieve lower power levels than required but are not stimulated to do so. Therefore, certainly when looking at the on mode of those products where connectivity is not the main functionality, we need a more fine-grained approach according to the type of connectivity. Both the ENERGY STAR specifications for imaging equipment and certainly the EU Code of Conduct for Broadband Equipment (European Commission 2013a) provide examples of requirements for different type of network connections. From a functional approach perspective it is important that the requirements for a certain type of network connection are the same regardless the product that has the connection.

Discussion, conclusions and recommendations

We started this paper by describing and analyzing some of the problems that the current methodology for setting minimum efficiency performance standards (MEPS) and labels faces. Due to rapid developments in electronics, software and networks, ever more products are connected to a network, have multiple functionality and can change functionality. Internet-connected thermostats are an example of a virtual product, where the actual function – regulating the temperature in a building – is dependent on software and a network connection. We introduced a modular functional approach to solve some of the problems and to move away from setting standards for individual products and instead focus on defining and evaluating functions that can be present in many products. A product then delivers a basket of functions that would be tested and evaluated individually.

Case studies for displays and network connectivity showed how (parts of) a modular functional approach could be applied. A modular functional approach puts less emphasis on the product definition, can simplify the treatment of functions over various product groups and stimulates power management. A general drawback is that requirements cannot be fine tuned for individual products. This means that for some products requirements will be less stringent than they could have been with the current approach. The modular functional approach does not bring advantages for appliances with a single main function, e.g. cold appliances, washing machines, water heaters; these appliances are already assessed by a functional approach, i.e. of their main function. However, an air conditioner that can both heat and cool – a heat pump – can be tested and evaluated separately for these two functions.

The case studies also showed aspects of the approach that should be developed further. Regarding test methods we note that no method exists for assessing the efficiency of an Internet-connected thermostat. Such method would need to take into account the downstream energy savings and the upstream energy consumption. Also we assumed that functions can be tested

separately; this might not always be the case, especially for products with many functions. In this case, the functions to be tested need to be chosen carefully; it is not realistic to test every single (auxiliary) function. Regarding displays, we ignored the processing function that will become more important with increasing screen resolution. To develop a metric and test procedure for processing it is also necessary to cover products like set-top boxes, computers and home gateways. Network connectivity is a functionality that will rapidly spread. To realize more savings, a more fine-grained approach according to the type of connectivity needs to be developed.

Finally, it remains difficult to operationalize the functionality of a product. This is true for a classic product like a refrigerator of which the function is food preservation but for which the efficiency metric is based on the energy to keep a certain volume at a certain temperature. However, operationalizing functions of CE and ICT products like entertainment and providing information is an even greater challenge.

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