Indicator for in Use Energy Consumption (IUE): a tool enhancing Design for Energy Efficiency of products

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Abstract: Environmental impact of non mobile electr(on)ic products is mostly due to energy consumption in use phase. Along with the growing concerns on energy supply, it explains the increasing interest on efficient management of energy during use of electr(on)ic equipment. This papers introduce a new indicator to follow the in use energy consumption from the earliest design stage to the beginning of the manufacturing stage. Energy in use is characterized by lifetime by power. Lifetime is defined as sequences of function and power as sequences of stable power consumptions of sub-assemblies. The use of the indicator is simulated in the redesign of a set top box.

Key words: Ecodesign; Energy Efficiency; Design Indicator; Energy using Product (EuP); Value Engineering.

1- Introduction: Environmental impact of Electric and Electronic Product and the potential of Design for Energy Efficiency in Use

The electric and electronic industry has faced in the last decade a significant among of environmental challenges: suppression of hazardous substances (heavy metals, brominates, halogenated fillers…), reduction of materials (weight and diversity), integration of end of life concerns… Nevertheless, one significant environmental aspect has not yet been systematically taking into account, at least for non mobile equipments: the energy performance during use.
The increasing pressure on fossil fuels demand and the pollution due to energy production from non renewable resources forced policy makers to take into account those growing concerns. European commission claims that with the adequate policy, the overall consumption of European Union can decrease by 27%. The potential for decreasing is based on the estimated wastage of energy related to building infrastructure, electr(on)ic equipments... The EuP (Energy using Product) directive [E1] is part of this policy that aims at identifying energy wastage and best practice in energy management for electr (on)ic product and makes it compulsory to implement such practice on all products.
In this context of political and social pressure, the electr(on)ic sector needs to decrease the energy consumption of it product in use.

"Some of the most important decisions with respect to environmental properties of a new product are taken during the product development" [NW1]. Energy performance during use is one of these properties directly influenced by the product development. Anticipating product performance in order to modify them while they are still flexible (ie. during design process) is a powerful way for changing the fundamental behaviour of a product.
All those observations led to the proposal of a project, jointly with two laboratories (G-SCOP and G2ELab) and two industrial partners from the electr(on)ic sector (Neopost Technologies and

SagemCom), funded by the French Environmental Protection Agency (ADEME). Synergico (Synergy-Energy-Design) project aims at developing a comprehensive method to integrate energy in use concerns in electr(on)ic product design [B1]. This research project started in 2008 and will end at the beginning of 2011.
Based on an integrated design approach, the method aims at supporting decision making process on energy efficiency in use as one of many design criteria. The method is construct as a typical DfX tool where Energy efficiency in use is one of many criteria to deal with (cost, qualities, time to market, security, recyclability…). The proposed method can be defined as a Design for Energy Efficiency tool: DfEE [KHZ1].

The preliminary phase of the project led to the formalization of two mains objectives: decrease the energy consumption in use with the underlying aim to decrease the environmental load of the product.
After a literature analysis and industrial review, we experience the need for tools meaningful at each design step.
In order to adjust the design process of electr(on)ic product, we currently develop 3 complementary tools, with the following specificity:

- an energy indicator, to fulfil designers' need to refer to quantitative value in order to experience improvements in product design.,
- a guide for improvement providing a database of technical solutions and strategies to modify product design [B1],,and
- a life cycle checking indicator on environmental impact, to verify the conformity with global environmental impact reduction. It is done by mean of a simple tool, reminding the designer with life cycle thinking concept and the trouble coming from pollution transfers.

The method wills phase the use of the different tools in the integrated design process.
Synergico project does not only development tools but also aims at testing them in real product design context at our two partners.
This paper presents the development of the energy indicator and a simulation of redesign for a set top box used in digital terrestrial television decoding.
Section 2 expose the research methodology adopted for constructing the scientific basis of the IUE. Section 3 illustrates it use in the design of a set top box and sub-section 3.4 discuss the different hot spot of the indicator emerging from it simulation.

2- Energy consumption during Use Indicator (IUE): the cornerstone of Synergico method

2.1- Defining the indicator structure

All effort to use energy-related indicators in design are based on two dimensions considered together: power and time [E1][L1][D1]. Focusing only on power issues leads to bury the problem of long lasting low power modes (such has stand by mode [E3]). Focusing only on duration of tasks leads to bury the problems of peak power consumption.
Commonly, the notion of energy is amalgamated to power, for two reasons. The first one deals with the uncertainty of defining time: power is an instantaneous value, easy to measure with simple protocols. When using the time dimension, it needs more formal protocol based on a scenario to propose a stable framework for measurements. The second one deals with the fact that the only information give to consumers about energy is the raw power consumption, which is why designers are used to reduce the scope of energy to power.

In order to "trace" energy in product design, the indicator must be based on existent product, both from the functional and the physical view point. Each product view represents a dimension of the indicator: function refers to time and physical part to power. Those dimensions are combined together, in a matrix, in order to give the in use total energy consumption (IUE), final value of the indicator:

$$IUE = \sum_{(i,j)} \vec{t}_{Fi} * \vec{W}_i(P_j) \quad (1)$$

- IUE: In Use total Energy consumption (in watt per hour.
- $\vec{t}_{Fi}$: vector of time duration of the function i (in hours)

- $\vec{W}_i(P_j)$: vector of power consumption of part j for realising the function i (in watt).

According to the specification, the indicator matrix will be addressed to the different departments that have an influence on energy performance in use phase. The analysis of the design practices of the industrial partners shows that in classic energy efficiency management in the electr(on)ic sector, the involved actors are traditionally the members of the hardware department who try to favour individual component with lower power. On the contrary, Synergico Method aims at implicating all the protagonists of the energy performance: hardware engineers, software developers and mechanical engineers as well as the design project management.

2.2 – Allocating time to functions: Use phase scenario

2.2.1- Functional splitting

In most of energy related documents (legislation [E1], energy label [U1]), time is usually managed by means of k mode splitting:

$$t_{life} = \sum_k t_k \tag{2}$$

Typically, there are 4 operating modes determined for a product:

- “On mode” where the product realizes the tasks it was bought for;
- “Idle mode” where the product actively waits for the next task;
- “Stand by mode” where the product only feature is to wake up to “On mode” at any time;
- and “Off mode” where the product does not perform any task.

$$t_{life} = t_{on} + t_{idle} + t_{stadby} + t_{off} \tag{3}$$

The new IUE indicator is based on the hypothesis that the power is stable during the period of time considered. But the standard definition of mode can cover a wide range of power consumption. For example, the on mode for a set top box covers two main power behaviours: decoding and stored the decoded information on hard drive. That means that we needed to go below mode splitting of time.

In order to have an almost stable power consumption Wi, the lifetime of the product should be defined as a chain of stable power time periods- $t_{k,(Wi)}$, all along it lifetime.

$$t_{life} = \sum_i t_{k(Wi)} = \sum_i t_{Fi} \tag{4}$$

Power remains stable as long as a specific user action or software task is in progress. By defining more precisely the k modes into i sub-modes, stable power time periods can be obtained.

In value engineering [A1], a function is defined has the action of a product, or one of it component, that is qualified by it purpose. Since value engineering is a wide spread method, we decide to use function has the marker of the different time period of product life.
Some basic concept of value engineering are used to defined the indicator, the most important being the definition of the product by means of basic function. By setting targets for energy consumption per function, it can be seen as an adaptation from cost management to energy management.

In the indicator, a function is a specific action of the product. A mode is the combination of a number of function that can be realize one after another, or simultaneously. The only restriction in function definition is that one function can be included only by a single mode. If an action takes place in two modes, it needs to be split into two “sub-modes”.

2.2.2- Defining product use scenarios

Now that the unit of time is defined, the next step is to allocate to each function the amount of hours that the product will spend realizing this function during it life.
For this purpose we need to separate the function in two categories: the first one called “independent function” and the second one “user dependent function”.
Independent function is defined by a software routine and it span is free of user influence. For example, whatever user does, the time spends to switch for one channel to another depends on processor speed.
User dependent function can vary depending on who is going to use the product. For example, a family with 3 children might watch the TV more than a couple with no child.

In order to illustrate the variety of users' attitude toward the same product, different scenarios are built. Each scenario defines a specific time vector, on which the indicator can be evaluate.
A scenario includes the span (in relative value) of a function and the lifetime of the product. The indicator is always evaluate over the entire use phase, ie. over a finite number of years:

$$\vec{t}_{S1} = \begin{pmatrix} t_1 \\ \ldots \\ t_k \end{pmatrix} = L_{lifespan} * \begin{pmatrix} \%_{F1} + \%_{F2} + \ldots \\ \ldots \\ \ldots + \%_{Fi-1} + \%_{Fi} \end{pmatrix} = \begin{pmatrix} t_{F1} + t_{F2} + \ldots \\ \ldots \\ \ldots + t_{Fi-1} + T_{Fi} \end{pmatrix} \quad (5)$$

- $\vec{t}_{S1}$ lifetime of Scenario 1
- t_1 to t_k: time by mode (usually k=4)
- $L_{lifespan}$: lifespan of the product
- $\%_{Fi}$: relative contribution in time of the function i to the overall product life.
- t_{Fi}: time spend over the lifetime in function i

Scenarios are based on different approximation: "primary data" from marketing based questionnaire, interview with consumers, "secondary data" from customer specifications, standards (like eco-labels), regulations… They all have a specific perception of how the future user will interact with the product. In order to have a "complete" vision of product life, it is interesting to use the different data that arise from the different methods in order to run the IUE evaluation on, at least, 2 scenarios.

2.3 – Allocating power to the product subcomponent

2.3.1- Architecture splitting

The objective of splitting product in small part is to track, into the product, which physical parameters influence the power behaviour of the product realizing a certain function.
Same as for the EuP directive switching from Energy Using Product [E1] to Energy Related Product [E2], the aim of this splitting is to cover all the product design parameters that influence the power consumption patterns at a given moment, and not only the electr(on)ic components that consume energy. The extension to the "Related" part helps emphasising the energy impact of, for example, the casing design: this part does not need to be "plug to the grid" but depending on it material and form, the product will need or not a change in fans' rotation speed.

This tool is developed to be used by product design teams, and this is why it is suggested to split the product into j subcomponents that are relevant for the various departments' organisations, vocabularies and work sharing. The indicator is based on the knowledge of 3 mains departments:

- For electronic parts: the hardware and software departments are usually associated. They must work very close to each other in order to tailor the energy consumption by adapting the software need to the hardware net and the other way round.
- For mechanical parts: the members of the mechanical engineering department are asked to document the information related to their design decisions.

The degree of precision of the splitting depends on the scope and the aims of the design project.
The criterion for part definition is that it is considered by designers has a scalable unit.

2.3.2- Power consumption

Designers do not often use power as raw data for there daily work. Nevertheless, power estimation was already needed to evaluate data like the power supply dimension. In order to fit department habits, each department can use rough power data or plough back there power dimensioning techniques.
Hardware designers usually define power P(W) by means of tension U(V), current I(A) and efficiency Eff (depending on the quality of current). All this information is defined on components datasheet. For the definition of hardware subassemblies' power, they can decompose it like:

$$P_{hardware}(W) = I(A) * U(V) * Eff \quad (6)$$

For software designers, they never manipulate raw data on power. The only parameters that have a significant influence on power are: opening or closing of logic gate and intensity of solicitation of the component. There influence is on the percentage of occupation %soft of a subpart for realising a specific function:

$$P_{Software}(W) = I(A) * U(V) * Eff * \%soft \tag{7}$$

When mechanical departments is using power, it does not refer to electric power but to it conversion in mechanical force. This conversion equation depends on the part that is defined.

$$P_{mechanic}(W) = \vec{F}(N) * \vec{v}(m.s) \tag{8}$$

For example, motor power is defined as the multiplication of torque C(N.m) by rotation Ω(rad/s) speed:

$$P_{motor}(W) = \vec{C}(N.m) * \vec{\Omega}(rad/s) \tag{9}$$

All those different definitions of power can be used in order to have more flexibility and to plough back information compulsory for other dimensioning of the product, reducing the time spent in documenting the indicator.

2.3.2- Collaboration between departments

To incite the designers in filling the indicators, it was design has an interface to solve some communication issues within design teams.
First, the indicator emphasis the need for close collaboration between hardware designers and software developers that are the two sides of the same medal. In DfEE, they have a complementary role in tailoring the choice of components to logic and calculation needs. The fact that the indicator is not completely useful without the collaboration of one of them makes it a powerful tool to initiate the dialogue between the design team members.
According to our industrial review, another challenge of this tool is to implicate departments that traditionally have little interests in energy efficiency: for example, although the mechanical engineering department is usually active for some aspects of ecodesign (for example recyclability issues), its members tend to think that they have very limited impact on the product energy consumption. By relating part of there day to day work to power, they can implicate themselves in the construction of a more efficient use of power by mechanical part.

3- Case Study: Simulation of the use of the IUE indicator during the redesign of a set top box

3.1 – Presentation of the product under study

The product we used for the simulation is a complex set top box for digital terrestrial television, develop by our partner.

Figure 1: Set top box SagemCom

Complex set top box aims at converting signal into content. Depending on the feature provide by the digital TV supplier, the box is more or less complex. The system we are considering in this study is a set top box with 2 tuners, a hard drive and 1 remote control. Product was redesign at our industrial partners some months ago on a reshape project. It was an adaptation of a platform built for another client with close requirements.
Major improvements has been done, such has automatic switch to low power mode, use of low power components. Nevertheless, it seems that there is still a huge potential for energy efficiency

improvements regarding customer requirements and product structure.
For confidentiality reasons, data on the product presented in this paper has been modified.

3.2- Indicator inputs

3.2.1- Functional splitting

A set top box has 4 operational modes: On, Idle (realising task without user direct intervention), Stand by and Off.
We define, according to the customer specifications, 8 functions. A set top box provides few functions, the most important from the user point of view, being: decoding signal, recording signal, and viewing recorded information. It proposes 3 ways to wake up the product from the stand-by mode. Figure 2 summarises the functional splitting of a set-top box.

The professional purchaser asks for Energy Star certification, so one of the scenarios is based on Energy Star base case, that is composed of: 5 hours of "live broadcasting", 2 hours of recording and 2 hours of recorded data viewing [E2].
The second one is based on another user behaviour, which does not use the recording function: "Watching 5 hours per day of digital TV".
For both scenarios, the lifespan was established based on TV cable provider renewal rate that is estimated to be 3 years, in average.

		Energy Star			Decoding Only		
Mode	Function	Time	During Lifespan		Time	During Lifespan	
On	Decoding	29%	7665	h	13%	3285	h
On	Watching record data	8%	2190	h	0%	0	h
On	Setting	0.35%	91.25	h	0.35%	91.25	h
Idle	Recording	8%	2190	h	0%	0	h
Stand by	Wake up on Infrared	29%	7621.2	h	99%	26143.13	h
Stand by	Wake up on Scart	29%	7621.2	h	71%	18615	h
Stand by	Wake up on timer	29%	7621.2	h	71%	18615	h
Off	Wake up on Switch	33%	8760	h	0%	0	h

Figure 2: Functional splitting for a set top box

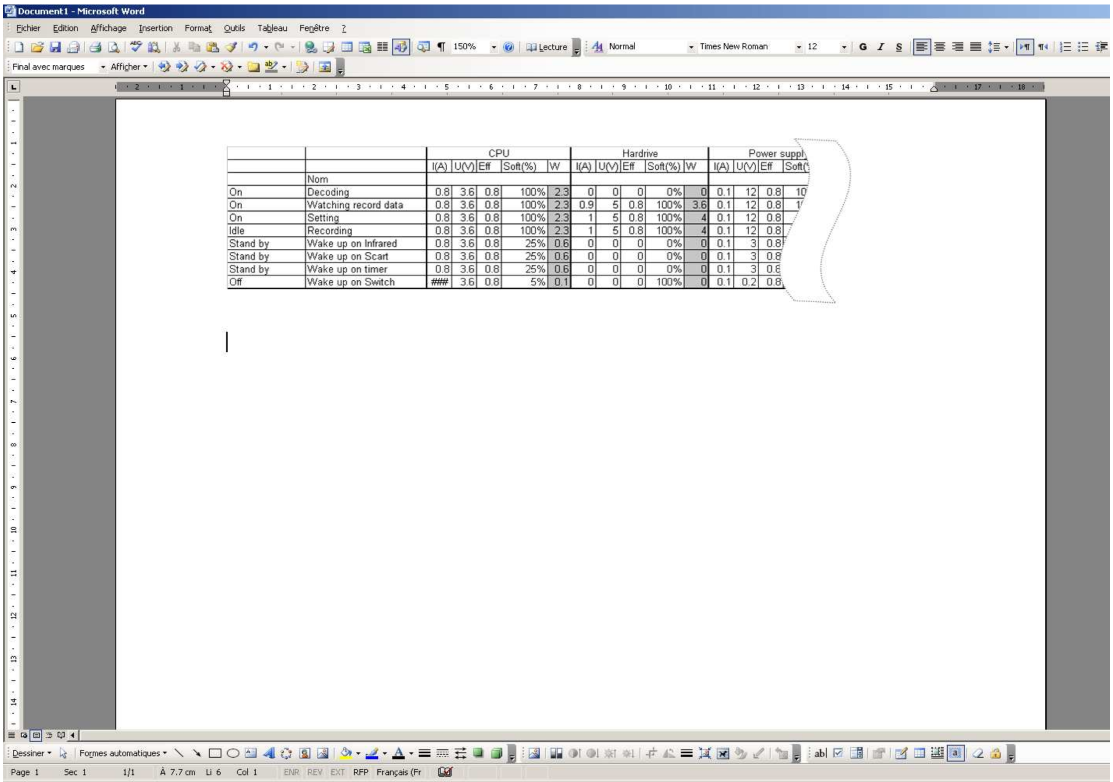
3.2.2- Architectural splitting

A set top box has very few mechanical parts. So, we focus the architectural division on electronic parts.
The energy consumption can be traced to 10 physical sub-assemblies of the product: remote control, tuners, CPU (central processing unit), sensors, scart connector, clocks, hard drive, on switch, power supply and display. Each sub-assembly is here named following the main component of the sub-assembly, ie. "on switch" does not only include the switch but also the components that are specific to relay the signal from the switch.

3.2.3 – Filling the matrix with data

The first version of the matrix is filled with data coming from the previous design information with few adjustments: implementation of a new generation of hard drive (less noisy, cheaper and less energy consuming), implementation of a CPU with less heat dissipation (allowing the suppression of fans).

The information used for hard drive power was available on supplier datasheet. For the performance of CPU, since it power consumption is very dependent on the function performed, the value is based on the experience of designs teams: hardware designers, according to software developers functional specification.
Information on all other parts, like power supply, are from the previous study without any modification.
Figure 3 resumes this information:



		CPU					Hardrive					Power suppl			
		I(A)	U(V)	Eff	Soft(%)	W	I(A)	U(V)	Eff	Soft(%)	W	I(A)	U(V)	Eff	Soft(
	Nom														
On	Decoding	0.8	3.6	0.8	100%	2.3	0	0	0	0%	0	0.1	12	0.8	10
On	Watching record data	0.8	3.6	0.8	100%	2.3	0.9	5	0.8	100%	3.6	0.1	12	0.8	1
On	Setting	0.8	3.6	0.8	100%	2.3	1	5	0.8	100%	4	0.1	12	0.8	
Idle	Recording	0.8	3.6	0.8	100%	2.3	1	5	0.8	100%	4	0.1	12	0.8	
Stand by	Wake up on Infrared	0.8	3.6	0.8	25%	0.6	0	0	0	0%	0	0.1	3	0.8	
Stand by	Wake up on Scart	0.8	3.6	0.8	25%	0.6	0	0	0	0%	0	0.1	3	0.8	
Stand by	Wake up on timer	0.8	3.6	0.8	25%	0.6	0	0	0	0%	0	0.1	3	0.8	
Off	Wake up on Switch	###	3.6	0.8	5%	0.1	0	0	0	100%	0	0.1	0.2	0.8	

Figure 3: Extraction of the matrix filling for CPU and Hard drive

3.3- Results and potential improvements

3.3.1 – Global results

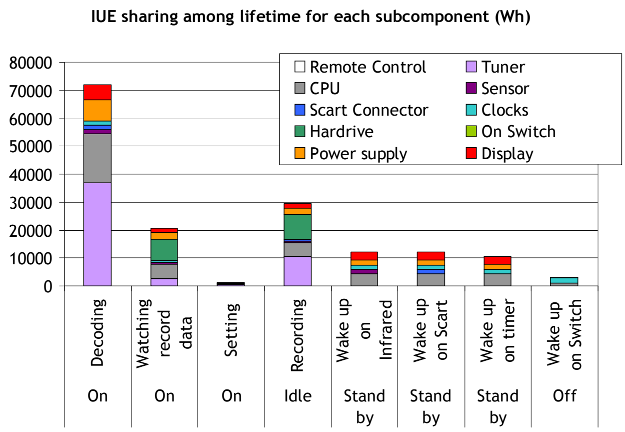


Figure 4: Contribution of Subcomponents to the IUE, divided into function

The global pattern does not outline any major problem: the most consuming function during the life time is “Decoding” that corresponds to 5 hours per day of live broadcasting. “Recording” is a transparent function for the product user: the product is active but it action (and consumption) is imperceptible for the user.

Table 1 presents the relative contribution over the lifetime of the product for each mode (a) and each sub-assembly (b). The 3 functions of the stand by mode contribute to 21% of the total energy consumption of the product (table 1), without performing any “constructive” action:

Mode	
On	58%
Idle	18%
Stand by	22%
Off	2%

(a)

Sub-Assembly	
Remote Control	0%
Tuner	31%
CPU	26%
Sensor	2%
Scart Connector	2%
Clocks	5%
Hardrive	11%
On Switch	0%
Power supply	11%
Display	11%

(b)

Table 1: Relative contribution of modes (a) and subcomponents (b) to the product IUE

3.3.2 – Power management versus Energy management

When screening the nominal power of component (figure 3), two of them are notable; tuners (4.8W) and hard drive (4W). Nevertheless, when considering the energy consumption (figure 5), the repartition is quite different: the CPU is contributing to 26% of the consumption over the life cycle. The power supply seems inefficient: it own operation contributes to 11% of the total energy consumption.
When crossing those results with figure 4 (Wake up on Scart Connector, Infrared and Timer), we can see that for keeping the 3 wake up option in stand by, the CPU is quite stressed.

3.3.3 – Evaluating energy among different scenarios

The comparison among the two scenarios (Figure 6) is very interesting: even if, with the second scenario, we spend less time in “On” mode, the global energy consumption is almost the same, due to high consumption in stand by mode.

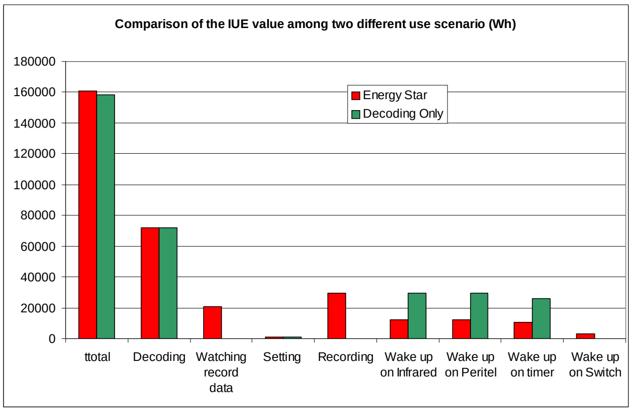


Figure 5: Variation of IUE among two scenarios

During design review, the team found out that the actual design did not comply with the Energy Star requirements. The “hot spot” was the relatively high power need to maintain the stand by functions (almost 4,5 W).
A solution can be to degrade the performance of CPU in stand by mode with the implementation of a new algorithm, and by that decreasing the energy consumption. The drawback of this kind of solution is the wake up speed: by degraded the CPU performance it drops down from 1 millisecond to 1 second. In the context of integrated design, project managers must decide if this increase of the wake up time is still acceptable to consumers.

3.4- Discussion

3.4.1 – Conclusions on case study

This simulation illustrates the interest of energy among power: the most powerful elements are not the ones that have the higher energy consumption.
Integration of time with different scenario helps discriminate what is due to specific use and what is common to every user’s behaviours. This multi-scenario approach is useful when balancing tradeoffs between energy and functional performance.

In this specific case study, the fact that the project starts on an already design platform made it easier for finding “mismatch” between product requirements and subcomponents to obtain simple improvement solutions.
The next step will be to check on a prototype the real energy consumption. It is of interest to see if there is no peak consumption as well as to use a thermal camera to illustrate the solicitation of each subassembly for realising a specific function.

3.4.2 – Source of data

With this simulation, it seems that the indicator fulfil it objective. It can decompose energy consumption for a product under design by means of function and sub-assemblies.
The time splitting for function, ie. submodes, was made easier because a standard exist. The functional assessment is mostly based on the Energy Star protocol.
The power splitting by portion of electronic cards was not very precise but, since the design was considered to be at it very beginnings, it was difficult to go beyond this sharing.

3.4.3 – Redesign versus design

In this redesign context, all was made easier because a close product already exist with similar functions and electronic architecture. The use of the indicator can be quite time consuming if use in design of a new product, with new functional requirements and few idea about architecture. Yet, design from “scratch” is not common in design, every project using knowledge from previous design experience.
Time sharing in product that never cohabite with user seems very difficult and huge mistake on function duration can occurs.
A real case implementation is under study at our partners but it seems difficult to carry on such a study in the few remaining months.

3.4.4 – Design process

The example was a focus on a specific moment of design. One of the major concerns is that the indicator will be used only as a final check for design conformity and not as a performance indicator to improve along the whole design process.
To probe the usefulness of this tool in product design, we plan the introduction of the global Synergico method in the formalized design process of our partners

4- Conclusion and Perspectives

Energy efficiency in use is a central issue for electr(on)ic product and it environmental performance can be highly modified by decreasing energy consumption. Construct this performance during design seems to be one of the most efficient way to decrease the overall consumption of the fleet of electr(on)ic equipments.
The indicator we propose links power to energy by introducing the lifetime of the product during design. In order to have an overview of energy consumption during the lifetime of the product, correspondences are made between function, ie. submodes, that represent a time period, and physical part, that represent power related to product architecture.
The propose model was illustrated through the redesign of a set top box. This simulation exemplifies the interest of energy management over power management applying value engineering to energy supervision during design.

Synergico being aimed at decreasing the environmental impact, this indicator needs to be interfaced with a tool that checks that no transfer to another environmental impact category nor to another life phase of the product occurs. Every improvement makes to decrease in use energy consumption must be evaluated in a lifecycle assessment perfective. This simplified LCA tool is under development at G-SCOP.
The final validation of the overall Synergico methodology will be the implementation in the integrated design process at our partners and the testing of it on a real case of product design.

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