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IMPROVING ECO-EFFICIENCY IN OFFICE ENVIRONMENTS. DESIGN FOR GOOD USE.

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ABSTRACT
Eco-efficiency has been analyzed for many industrial activities, although some environments such as office have been disregarded. Even though with a low relative impact, the high amount of office equipment can represent an environmental problem. This project assesses office spaces and proposes alternatives to improve their Eco-efficiency. Worth of products and systems, as well as environmental considerations, were identified inside two companies. This paper describes the experiment, and points out the user activities that can potentially be changed in order to reduce the high impact on the use phase. Some of those prospective improvements are explained, and some ground rules are set for what in this paper is called Design for Good Use.

Keywords: Eco-efficiency, Ecodesign, Worth, Environmental Impact, Design for X.

1. INTRODUCTION: CALCULATING ECO-EFFICENCY, THE WORTH AND THE IMPACT

In order to be efficient and to contribute to business development, systems must obtain more results and spend fewer resources. However, to contribute also sustainable development, eco-efficiency [2] has been considered as an integral strategy through which those improvements are possible.

In spite of this, studies based on Eco-efficiency have been focused on industrial activities (such as production processes) or organization schemes. This has been named industrial eco-efficiency. Nevertheless, up to now that parameter has not been assessed for other contexts such us office environments, where products and processes also coexist and whose use phase is critical both economically and environmentally.

On the other hand, definition of Eco-efficiency used in this paper includes two concepts: (a) the worth of the product as a variable to maximize and (b) its environmental impact as a variable to minimize. They can be understood as a mathematic formula where the first concept is the numerator and the second one is the denominator [1] [2].

To evaluate Eco–efficiency, those additional concepts must be further studied with the aim of enriching and supporting the main understanding. Worth refers to the benefit that any element represents for its user (independently of the paid price) [3] and it requires quantification of the relevance level of using or having that specific element [4]. The purpose is to get the best performance with a lowest possible investment of resources.

In contrast, to define environmental impact it is necessary consider the Product's Life Cycle, evaluating its phases step by step. This requires a global view of the system and at the same time a particular look over each one of its elements. In the same way, that evaluation demands figures trough which the effect can be compared, and decisions can be taken. In this case, to obtain and define those figures, eco-indicators have been used to calculate the impacts. Finally, for adjusting and reducing those impacts Ecodesign has been considered as the approach for improvement, since it has been prove useful by a number of previous cases.

Therefore, to solve that formula and with the aim of evaluating and improving Eco-efficiency in office environments, the purpose of this study is to identify the factors and elements that represent a higher worth for the office workers, and to calculate their environmental impact at the same time. Two real offices were taken as case studies. After this estimation, new strategies of improvement will be proposed.

Background

The PROMISE manual states Ecodesign as “a promising approach to sustainable production and consumption” [5]. This concept has been described by ID&EA Group [2] as “a design methodology that derives from the concurrent engineering model and its purpose is to design products and processes to decrease the environmental impact throughout their Life Cycle”. This description fits with the statement by IHOBE [6] which defines its purpose as “to reduce the products environmental impact along its Life Cycle, that is, every stage all through the life of a product, from obtaining the raw materials and components to disposal once it is thrown away”.

Eco-efficiency engages economic and environmental issues. As a measurement parameter it helps to accomplish goals but requires tools for its assessment and optimization.

According to World Business Council for Sustainable Development, Eco-efficiency is: “achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the Earth’s estimated carrying capacity”. This concept recognizes not only ecological and monetary factors but also benefits for users. In this way, it is essential establishing a balance between the impacts of any element in nature and how useful and valuable it is for a person. These factors are summarized in several formulas trough which they become clear indicators. The general formula divides the usefulness of the product by its environmental impact.

Equation 1 Eco-efficiency = worth / environmental impact

Nonetheless, there are other formulas based on the former one, which include cost as a new variable in different ways, such as:

Equation 2 Eco-efficiency = Functionality / Cost · Environmental Impact [7]

Equation 3 Eco-efficiency = Functionality / (Cost + Environmental Impact) [8]

Equation 4 Eco-efficiency = Functionality / (Internal Cost + External Cost) [9]

Equation 1 has been used to develop Eco-efficiency as a concept in this study because of the special interest in defines worth.

There are techniques, methodologies and Ecodesign tools to evaluate those factors, through which decisions are taken more easily to improve a system’s performance and to maximize Eco-efficiency. Some of those ones are: Environmental Accounting, Life Cycle Cost, Value Analysis (VA), Design for X (DfX), Eco-indicators, Life Cycle Assessment (LCA), the LiDS Wheel, MET matrix, and others [2].

Environmental indicators are based on LCA measurements. With the resulting information one can take decisions about environmental aspects of the product, but does not comprise any other important aspect needed to make design changes [3]. Therefore two factors have been considered in this study: the worth of the product (numerator) and its environmental impact (denominator). The worth estimation is taken as the importance of each office element for workers, surveying their opinion of them. In contrast, environmental assessment involves a Life Cycle consideration of products. Environmental impacts of devices and systems were quantified by eco-indicators. Comparison between them was carried out with the aim of defining their individual incidence.

Office spaces involve specific rooms or areas where people work and develop their particular duties. These ones include specialized devices, systems, supplies and elements which make their business activities possible. All these are studied in the experiment in order to be able to apply the mentioned techniques.

2. THE EXPERIMENT

2.1 Studied companies

Research was made within two companies in Valencia (Spain), which facilitated their offices and related information. The contributing companies were:

- Varmys Trading: this is an SME that has over 40 years experience in developing labeling solutions. It's works mainly on the clothing industry. The study was made in the office where administration and commercial activities take place. Nine people work for this enterprise, but just seven of them took part in the study because of their specific activities.
- Environmental office of Universidad Politécnica de Valencia, called Area de Medio Ambiente or AMA: this is the institute that manages and controls the environmental impact of university activities. Its main goals are monitoring and minimizing the effects of university's research work and making students aware of environmental aspects. It is located in the university campus.
  In the building where this institute is placed, also other entities are located, although, the study was mainly made in the space where its work activities occur. Ten people belong to this teamwork but only seven of them participated in the research.

2.2 Structure

The project was divided in three parts:

- The first part was COLLECTING AND RECORDING INFORMATION from each one of the companies. The existing documents were verified and other complementary data were gathered trough different tools.
- The second one was called RESULTS: PROCESSING THE DATA; information was evaluated to identify the importance of different systems, their environmental impact, and finally to be able to compare them. Results and partial conclusions were defined.
- The third part was the development of DESIGN PROPOSALS, by applying ECOREDESIGN and ECO-CONCEPTS to results of the previous phase.

2.2.1 Collecting and recording information

The research process of the first part of the project was developed by using three different tools in order to collect the needed information. These were: power measurements, surveys and image capture. These tools are complementary to each other, and were chosen with different purposes depending on the expected results.

Power Measurements

Energy consumption (industrial, commercial, and residential) represents at least 55% of the effect in greenhouse emissions [10]. A great share of those comes from electricity consumed during the products use. This measurement was taken to evaluate the incidence of different appliances into the activities of an office, especially in accordance to their required electric energy and consumables. The spaces area and the power required for performance of existing devices and systems were measured. To define the electric energy consumption of each equipment, the average current in amperes and the total power were calculated, knowing the measure of the voltage. The measurements were made separately in each company using an ammeter clamp (Silver Electronics model: HT-202). The voltage defined was 228 volts, measured at the same place and with the same instrument.
Most of the areas were measured. An average electrical consumption was defined for each kind of device (those ones with similar features), and subsequently these consumptions were compared with the product's lifetime. In VARMYS these represent 66% and the whole set of products in AMA it corresponds to 90%.
The companies provided a list with the products that they possessed. Nonetheless, just a part of them were analyzed. The selection depended on how relevant they were for the research and the possibility access to carry out the measurement testing.
Two categories were established: office appliances and electric products. The first category comprises all hardware equipment required directly for processing information inside office environments (such as screen, CPU, telephone, printer, scanner, copier, fax, speakers, PBX phones and laminating machine). The other one engrosses all elements that are incorporated into the physical installations but they have no connection with work activities (such as air conditioning system, light, refrigerator, coffee maker, microwave, water dispenser and paper shredder)
Recording information about devices and systems includes:

- Individual electrical consumption per working day and per month measured in KWh.
- Electrical consumption in their three modes: *On* (user is using the product), *Off* (product is off, but it is still plugged) and *Stand-by* (product is turned on but user is not using it).

- Total consumption estimated for each user in relation to each product.

For products of individual use, the time of use and the electrical consumption were calculated to obtain the total power consumption. For products of shared use, the most critical scenario was defined considering the maximum amount of time that any product stays in *Stand-by* mode and the minimum amount of time that any product stays in *Off* mode, for a given number of hours in *On* mode. All devices are turned off at the end of the workday, VARMYS workday has: 10.5 hours and AMA: 8 hours.

Surveys

This second tool was applied in order to compile significant information about employee's activities during a work day. The other aim was to evaluate behaviour patterns (related with products) such as: their usage frequency, their performances according to user perception and to find out if their behaviour in the office has any relation with their knowledge and interest about environmental issues.
The general characteristics of this part of the experiment are:

- Kind of investigation:
  Descriptive positivist research. One can detect characteristics of the population based on primary information without previously consult any theory.
- Method:
  Questionnaire. The questionnaire format had identical questions and options for answers for both groups. Similarities and differences between the companies were analyzed before designing this standard format.
- Procedure:
  Surveys were carried out in each company. Following the instructions (given in advance) workers filled in their questionnaires by themselves. After verifying the answers, surveys were prepared for their analysis.
- Population sample:
  The sample corresponded to the entire population because it was a small group and a very specific study. The survey was addressed to each and every worker from VARMYS and AMA.
- Response rate:
  This concept refers to the ratio of people who answered the survey.
  - VARMYS: 77% of the expected rate.
  - AMA: 70% of the expected rate.
- Information Treatment:
  Data were processed trough tables (by using Excel spreadsheet and SPSS statistics software) and evaluated separately for each company. Those tables' data were compiled and became the end result; the final analysis was based on this one.
- Development:
  Each one of the questions was analyzed in each one of the case studies. After their analysis, the importance or level of relevance of the elements for users was determined in relation to a specific inquiry. Then, these assessments were analyzed globally.
  The data mentioned above became key information to identify the worth and potential targets for optimization.

Image capture

The third tool consisted of taking a continuous stream of pictures of the employees while they were working in the offices during a normal workday. This graphic recording showed, in a more objective way, movements and user's behaviours. The intention was to complementing the data collected by surveys.

- Procedure:
  The device used was an IP camera (Rimax IP Cam 7100). It takes and saves digital pictures second by second or when it detects any movement. This testing was authorized by both teams.
  Due to space distribution and the camera features, just a specific area was analyzed. Despite this, it was possible to watch the use of most products and the activities of some people.

2.2.2 Results: processing the data

After recording information the data were processed in order to determine the Eco-efficiency indicators.

Identifying the worth

To define the numerator of the formula, Collado-Ruiz [3] recommends the use of the word *worth* as opposed to *value* to analyze the importance of a product for users. In English, value usually indicates a relationship between quality and price, while worth connotes significance in the perception of a service independently of its price.

Value Analysis (VA) is a well established technique in product development. The term value is used in it, and increasing it implies both maximizing functionality and minimizing cost. If functions are understood in a more general sense, then it can be assumed that the product's worth is defined by those functions, and therefore that maximizing functionality is the same as maximizing worth. When approaching Eco-efficiency, it is generally accepted to use the word *value*, but not necessarily referring to the price, and considering it defined at worth instead of value delivers better results [3]. Hence, this approach involves a special conception about Eco-efficiency, in which the target is to get the highest worth or performance with the lower environmental impact. This is the main reason to use such wording, as the concept of value can have different connotations for people working in Value Engineering or in other fields.

Worth, as a numerator, was based on the benefit that each element represents for users. It also represents the link between features of products and the satisfaction that they entail for users.

This indicator is complex to evaluate. In this study, a special criteria was used with the aim of analyzing worth. The importance of the different devices and systems were established by defining categories of relevance. The conditions to evaluate the relevance of any component were: its higher frequency of use and how indispensable it was according to the user perception. All this information was taken from the surveys and double checked with the image capture.

Throughout the analysis of surveys, a level of relevance was established for each product. This means the extent to which a specific product is useful for workers. Relevancy was assessed for each particular query. Each evaluated element had different rankings. They were classified in a qualitative way from very to non relevant.

However, in order to define a numeric value that supported such classification, a score was assigned to each level of relevance: Very relevant (4 points), moderately relevant (3 points), slightly relevant (2 points) and non relevant (1 point).

Both companies were analyzed by a single kind of assessment because of their similarities in both considerations (frequency and indispensable).

Each one of the products was assessed for each one of both considerations. The averages of both offices were considered. Partial results were added-up to define the most to the least valuable elements, giving a final scale between 2 and 8.

In this way, relevancy of each and every appliance gives an indicator of their worth, and allows to conclude the significance of them into office environments.

- Results:
  Light and air conditioning systems got the highest impacts inside the electric devices group. (See Figure 1) Within office appliances, CPU and screen obtained the top values. Telephone has an important impact too. The importance of printing products (printed, scanner and copier; See Figure 2) is also remarkable.

The elements that achieved top level of relevance correspond, also, to those elements which provide the most benefits for office workers. In this way, the time of use represent the concept of benefit for developing their activities.

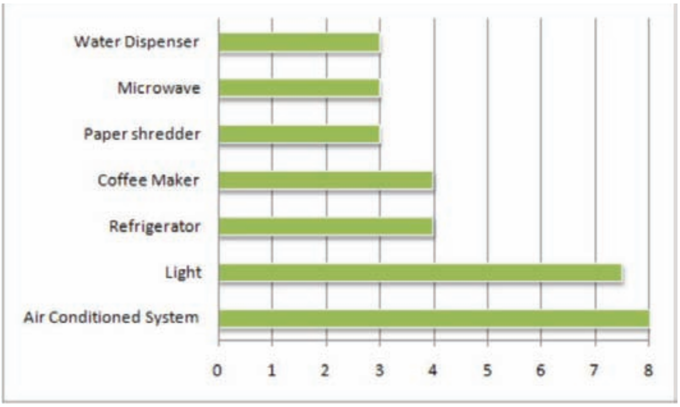

Figure 1. Worth of electric products

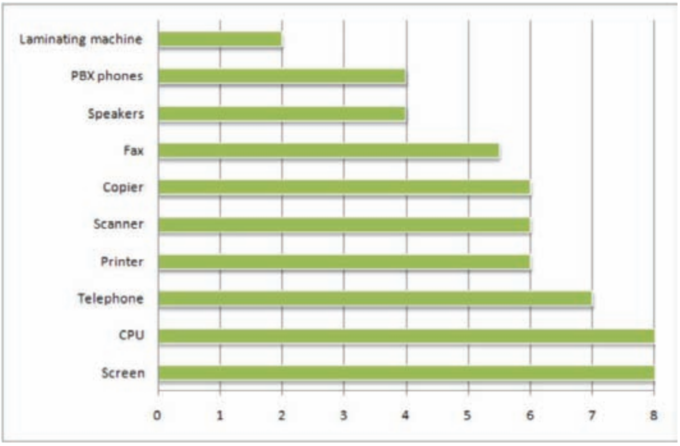

Figure 2. Worth of office appliances

Defining the impact

The impact estimation, as denominator, was based on an environmental assessment of all of elements (devices and systems). It was calculated by eco-indicators (as numeric values) which show the level of incidence, environmentally speaking, of those elements in the whole office space.

In order to define any environmental impact, Life Cycle Assessment (LCA) indicates a specific procedure, according to standards [11]. However, this evaluation does not follow strictly that procedure: it was simplified in accordance with the aim of the study.

The Life Cycle Considerations were:

- Goal:
  Evaluating the products during the Life Cycle in every single phase, and detecting which one or ones of those phases are the most critical in order to propose design changes.
- The addressees:
  The companies supplied the information, and thus they are also the addressee. This refers not only to environmental assessment but also to the whole project. Other research groups could be addressees too, if this instead to use the proposed concepts in similar studies.

- Functional Units:
  Two different functional units were proposed to evaluate the elements. The first one was an entire life cycle of each and every product, defining the amount of hours of use. It was determined in proportion to their expected lifetime (based on the warrantee time offered by manufacturers). However, due to the large differences between expected lifetimes of all products, it was necessary create a second functional unit that could compare them.
- Inventory analysis:
  Life cycle estimation included four phases: production (materials and processes), use (energy and consumables), transportation and disposal.
  The analysis was focused on electric and electronic office appliances. Furniture was not evaluated because of their features (expected lifetime; they are necessary elements and their use does not allow a measurable evaluation).
  Assessed products were organized by brands, kinds of device and users. Nevertheless, for environmental evaluation, groups of products were defined by common functional units (or sets of functions). In each group, the device with the highest energy consumption was considered as the most critical scenario and given a reference value of 100%. In this way, conclusions could be extended to the rest.
  The inventory included the main components of selected products. This is due to the difficulty of getting information about specific parts, materials, amounts and productions processes.
  Eco-indicator 99 [12] was used as database to evaluate each and every one of the inventory aspects. The measurement unit was miliPoints (mPt). Information was processed by using ECOSCAN software.
- Results:
  The use phase generates the highest environmental impact according to the analysis of most of elements. It is essential to notice the difference between *On* and *Stand-by* modes. Although this last one has low relative power consumption, the amount of time compensates this. Stand–by mode of nearly every product represents at least 17% of the total use effect. Indeed, in devices such as scanner, water dispenser, and paper shredder it represents about 70%.
  Incidence of *Off* mode is worth special attention since many products keep consuming energy while they are plugged, in spite of being turned off. (See Table 1)

Table 1. Consumption of devices in *Off* mode

Devices in OFF MODE

	Inventory			Consumption
	Item	W	KwH	Time after workday
VARMYS	SCREEN LG 17" FLATRON LI730S	4,56	0,005	0,062
	CPU HP	9,12	0,009	0,123
	PRINTER HP laserjet 1320	1,00	0,001	0,014
	PRINTER HP color laserjet 3800	11,40	0,011	0,154
	PRINTER MATRICIAL OKI 521	4,56	0,005	0,062
	SCANNER HP 64010	2,28	0,002	0,031
	COPIER OLIVETTI 9910	9,12	0,009	0,123
	PRINTER HP 1215	4,56	0,005	0,062
	PAPER SHREDDER YOSAN 205B	6,84	0,007	0,092
AMA	MONITOR TFT SONY 17"	4,56	0,005	0,066
	CPU SIEMENS FUJITSU	12,54	0,013	0,182
	MONITOR EIZO	1,14	0,001	0,017
	CPU TIPO TORRE	9,12	0,009	0,132
	IMPRESORA OFFICEJET PRO KB600 A	5,70	0,006	0,083
	MONITOR FUJITSU FCM 372	7,98	0,008	0,116
	CPU TIPO TORRE B	12,54	0,013	0,182
	MONITOR SAMSUNG 901N	5,70	0,006	0,083
	IMPRESORA HP DESKJET 970 CXI	5,70	0,006	0,083
	MONITOR SAMSUNG 940 BW	4,56	0,005	0,066
	MICROONDAS LG	2,28	0,002	0,033

After products were analyzed individually, they were evaluated as a group, to identify which elements cause a higher impact inside the entire office environment. The second functional unit was used (hours).

Two groups of products were analyzed separately. In the first group (office appliances) CPU and printing devices (especially the copier, see Figure 3) have high impacts. In the second group (electric products) the refrigerator, the light and air conditioning system have the most significant impacts. (See Figure 4) After these, both groups were compared and the result revealed that electric products achieve a much higher environmental impact than the office appliances. (See Figure 5)

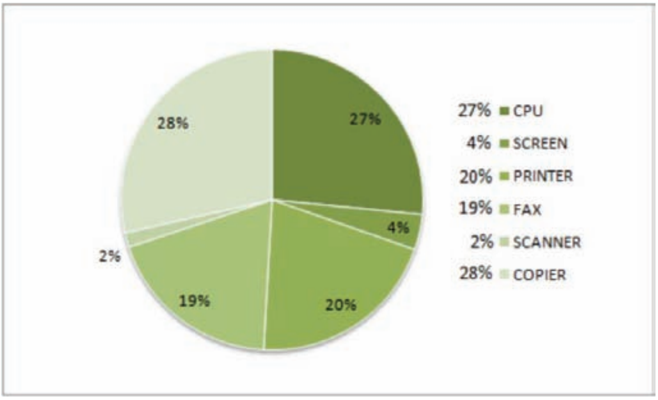

Figure 3. Percentage of Impact. Milipoints/hour. Office appliances

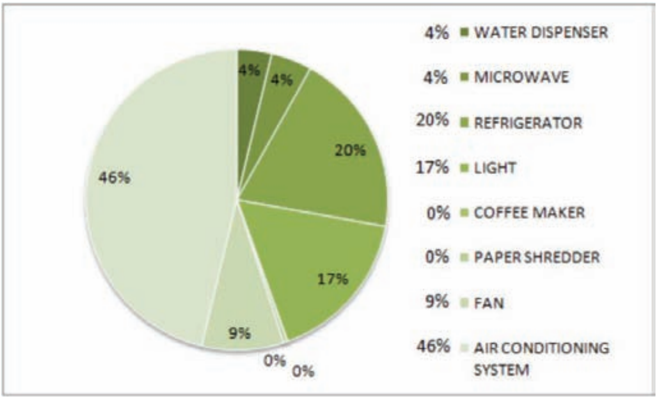

Figure 4. Percentage of Impact. Milipoints/hour. Electric products

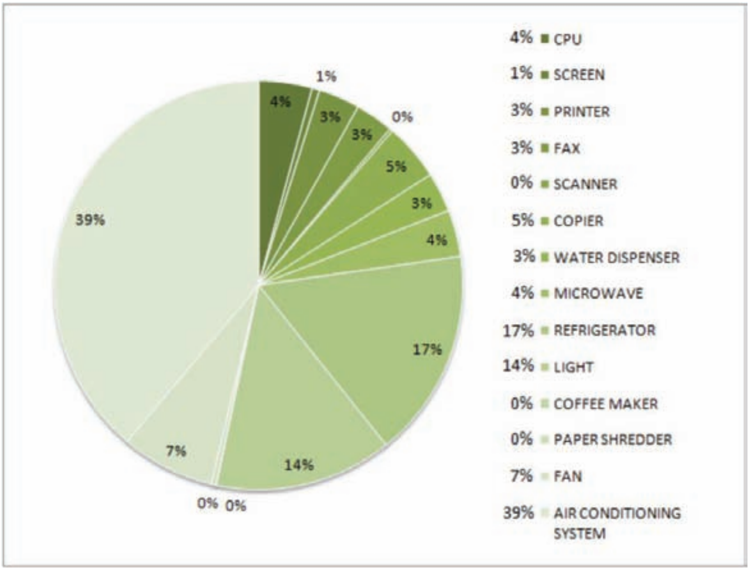

Figure 5. Percentage of Impact. Milipoints/hour. Whole system

2.2.3 Design proposals

Indicators for calculating Eco-efficiency are: the worth of products (according to their benefits for working) and the level of environmental impact that they generate.
In line with these results, the improvement must be focused on the use phase and conditions of devices. Potential improvements are related to: reduction of energy consumption and consumables, dematerialization of components, taking advantage of technology and removal of unnecessary items.

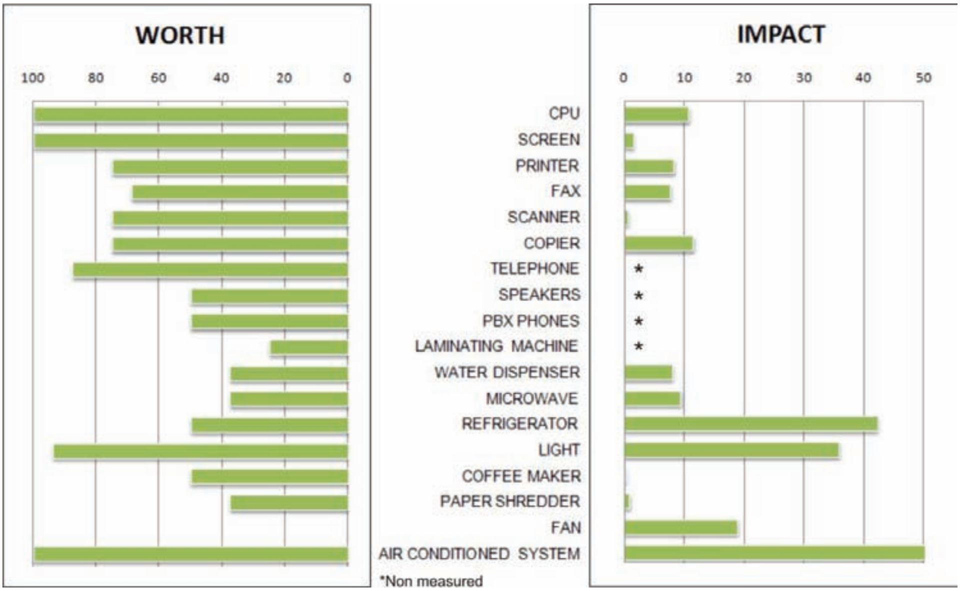

Figure 6. worth Vs impact

In Figure 6, a comparison between both indicators can be seen, based on independent assessment of worth and impact.
The characteristics of the project open the possibility of proposing not only one specific solution for these case studies, but also to make proposals in a general way, to be used in similar researches related to Eco-efficiency in offices environments.
The main conclusion of this part consists of formulating proposals toward optimization the use phase, particularly in how devices are used and how the relationship between user and those devices is. For instance:

From indifference to programming	Frequently, people forget or don't think about turning off devices. If these ones provide tools for managing the start and the finish of activities. Why omit it? The solution is to use the software potentials available in appliances
An unplugged touch	To turn off is not enough: also it is crucial to unplug. Power strips with switches let not only order the cable system but also interrupt the energy consumption just pushing a button.
Electric stuff better than physical stuff	To adopt digital signature could reduce the usage of printing devices and consumables, and make some activities easier.
Time on air	Air conditioning systems have the highest electrical consumption. Timers and sensors are a way of customizing devices and adjusting them to the needs of users. Those appliances can "know" the environment conditions and keep the suitable temperature.
Virtual comments	The new word processors and the storage formats make edition and correcting activities easier. Digital documents let write notes and comments and mark specific parts. This condition reduces the print consumables and warrants, at the same time, a record of changes where all users understand the written text and the data.

In order to keep the reliability of products and at the same time make consumers aware of their environmental responsibility, a new form of DfX (Design for X) is proposed:

DfGU Design for Good Use	**The interaction between user and product must promote, through the use, a change toward good practices, and generate consciousness about how these considerations contribute to increase the efficiency of a system or environment. Its core concepts are:** • **Self-regulation and identification.** • **Understandable indicators.** • **Visibility and feedback.** • **Recording actions.** • **Towards No consumption - No waste.**

3. CONCLUSIONS

The main conclusion of this project is that it is possible to optimize Eco-efficiency in office environments looking at the whole system instead of at each one of its products. Although, it was assessed device by device, the most important results were obtained evaluating their common influence inside the space. In this way, it's guaranteed that improvements will have a deeper and bigger effect.
These proposals have a broader view, and open the way for better ideas. General recommendations can be applied in many office spaces as well as used in implementation of Eco-efficiency projects. Therefore, communication and interaction strategies should be considered, since they are by far more efficient that small changes in the product's performance material wise.

Use phase is critical when it comes to office environments; both regarding environmental and worth. The way how products are used has a great influence on this. To know their possible settings and to change the minds of users is the best strategy to reduce those negative effects.

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