INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITÉ DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

AN INTEGRATED APPROACH FOR THE SUSTAINABILITY MEASURE OF INDUSTRIAL PRODUCTS IN DESIGN STAGES

Mario Fargnoli, Fumihiko Kimura
The University of Tokyo

ABSTRACT

Nowadays, companies have to deal with ever more complex environmental concerns, which affect a wider cause-effect chain, due to the pressure of both stricter environmental regulations and the new green awareness of customers. From designers' point of view, the development of sustainable products leads engineers to take into considerations environmental aspects in concurrency with traditional technical and economical aspects since the beginning of design activities. This change of direction brings to light the importance of operating from the first stages of the products' development.
The research work carried out is an attempt to define an integrated methodology for the assessment and the improvement of environmental performances of products based on the use of the Environmental Effect Analysis (EEA) method. For these reasons, several checklists aimed at reducing the gap between theory and practice in the use of traditional ecodesign tools were defined. The methodology was tested by means of its application to an industrial case study.

Keywords: Design for Sustainability, Environmental Legislation, Environmental Effect Analysis, Environmental Assessment.

1 INTRODUCTION

Nowadays, the need of developing more and more sustainable products has become a mandatory issue for companies. This leads to consider the environmental performances of industrial products as "default requirements" in design activities. Moreover, such a trend is underlined by the significant effort which has been made by the public bodies of different countries in recent years in issuing new indications and regulations aimed at both increasing the awareness of producers and regulating their legal responsibility in the matter of pollution and waste production. Following such an approach we can distinguish at least four different categories of requisites that the product has to satisfy:

- The requests of the direct users.
- The needs of manufacturers and other companies involved in the product development (e.g. suppliers, dealers, etc.).
- The requisites concerning the application of laws and regulations affecting the specific product (e.g. the Machine Directive, the RoHS Directive, etc.).
- The requisites aimed at reducing and/or optimizing the burdens of the product on the society.

For these reasons the competitiveness of products has not to be individuated only in comparing the eco-products' characteristics with the ones related to the traditional products, but mainly among the eco-products themselves.
Needless to say, the experience in sustainable design has increased in recent years. Different approaches and methodologies have been proposed in literature in the field, but the large number of such tools, together with the need to comply with stricter and stricter environmental regulations, often represents an hindrance for engineers [1, 2, 3]. In spite of the large number of design tools provided, in fact, very often engineers are not able to use them in a rationale and effective way because of lack of knowledge or experience. The research work carried out is an attempt to define an integrated methodology for the assessment and the improvement of environmental performances of products based on the use of the Environmental Effect Analysis (EEA) method.

More in details, in section 2 an overview concerning the “state of art” in the field of Sustainable Design is presented. In section 3 the proposed research approach is discussed. An example of the use of the proposed methodology is given in section 4, throughout a case study. Then the discussion of main results is presented in section 5.

2 BACKGROUND AND MOTIVATIONS

In last years, a considerable research work has been carried out in order to investigate different ways of supporting engineers in the development of environmentally friendly products. The industrial world has changed its approach to the Environment, gradually shifting from the end-of-pipe approaches, which have characterized last decades, to the trend of Ecodesign approaches, starting from early 90s’ and after. In fact, the importance of the environmental sustainability of industrial products and processes has become more and more significant because of the ever stricter environmental legislation in the field, as well as because of the higher awareness of customers concerning environmental problems [4, 5, 6]. The latter aspect has not to be underestimated at all: for example, just recently several important U.S. companies made an agreement joining the US Climate Action Partnership, asking the Government for stricter environmental regulations [7].

It is clear, then, that beside prevention and control activities of local pollution from factories, the companies have to deal with more and more complex environmental concerns, which affect a wider cause-effect chain. From designers’ point of view, the development of sustainable products leads engineers to take into considerations environmental aspects in concurrency with traditional technical and economical aspects since the beginning of design activities. This change of direction brings to light the importance of operating from the first stages of the products’ development.

The requisites, which an industrial product should be in compliance with, have become more numerous and stricter than in the past, involving also social aspects, i.e. the impact that the product has on the society in general, considering for example its performances from the safety and the environmental point of view [8].

The evolution of the concept of Sustainability in the industrial world has brought to light the importance assigned to the early stages of the product’s development. It is of common knowledge that making decisions in these stages allows producers both to: guarantee the products’ optimization from the performance point of view, and be more market competitive. This guarantees to drastically reduce the costs related to subsequent modifications and corrections of the product during the manufacturing phases or even after its introduction in the market [9]. Such a need is strongly underlined by the latest issue of regulations and guidelines at international level, such as:

- EuP [9], RoHS [10] and WEEE [11] Directives;
- ISO/TR 14062:2002 [12];
- IEC Guide 114:2005 [13];
- etc.

which focus the attention on the integration of environmental aspects into the design and development activities of most common categories of industrial products. Such indications concern, more or less, most of industrial products thanks to the ever greater integration of electronic components into modern mechanical systems. A significant effort has been made also by researchers and companies in promoting ecodesign activities; numerous tools and guidelines have been provided to help engineers in performing such a difficult task. Nowadays a large number of methods and techniques, characterized by different approaches and level of difficulty are at the designers’ disposal, starting from simple checklists, to complex methodologies, which require experienced users to be applied. In such a context, many examples can be given.

In fact, many of these often fail because they do not focus on design activities, but are aimed at management or at retrospective analyses of existing products, or they are too specific to be applied in different contexts from the ones where they were developed for. The most significant difficulty, as underlined by many Authors in the field, is the lack of coordination of design activities, i.e. how to put into practice the indications provided by the ecodesign tools and guidelines [14, 15, 16].

The goal of the study was the development of an easy-to-use methodology that allows engineers to perform eco-design activities in a more effective way, foreseeing their integration within a well defined design process and the conformity with Environmental Regulations. More in details, it consisted in an attempt to define a series of criteria able to address designers in defining a set of indicators by means of whom, the environmental performances of the products can be assessed taking into account the expectations of all stakeholder involved. Such an analysis brought us to develop a series of checklists tailored for the assessment in the different stages of the product development process. In order to take into account all attributes that characterize the product from the engineers point of view, the attention was focused on the use of the Environmental Effect Analysis (EEA) method [17], because of its efficiency in identifying and evaluate the most significant environmental impacts related with a product since the initial stages of its development.

3 THE PROPOSED APPROACH

The starting point of the research work consisted in the development of an integrated methodology, based on the use of a flow diagram of a general nature (as the ones proposed in the above mentioned standards and guidelines), considering all environmental needs and burdens that affect each phase of such a process throughout the use of the Environmental Effect Analysis method. In order to make the product development process more homogenous and oriented to the life cycle thinking approach, the development of "ad hoc" checklists was carried out. The methodology derives from the coordinated use of such tools, as shown in Figure 1.

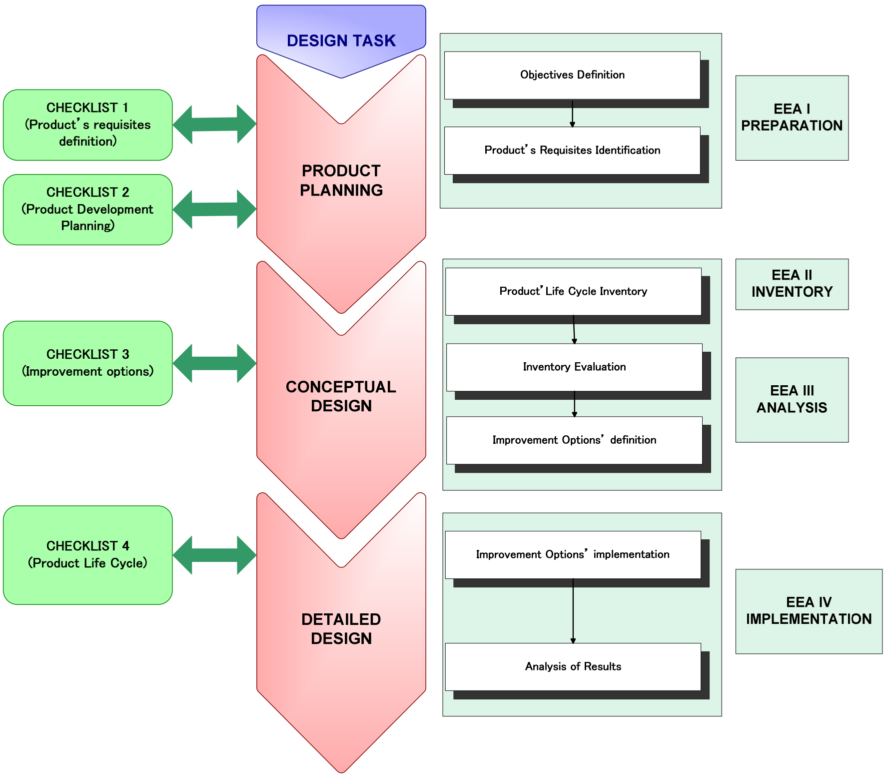

Figure 1. Scheme of the methodology developed

3.1 The Environmental Effect Analysis

The Environmental Effect Analysis (EEA) method was developed at the University of Kalmar a few years ago as one of the output of the NUTEK project [17].

The method takes inspiration from the well known FMEA-FMECA method, mainly used in reliability and safety engineering [18], and from the Life Cycle Assessment (LCA) which probably represents the most spread method for the assessment of environmental burdens of a product/process [19].

The method allows designers to identify and evaluate the most significant environmental impacts related with a product since the initial stages of its development. Its application, following the approach of the LCA, is based on the development of five main stages:

1. Preparation, consisting in: the goal and scope definition, the creation of an EEA working team and in the identification of product related environmental demands.
2. Inventory, consisting in performing the inventory of the product's life cycle.
3. Analysis, based on the assessment of the inventory data, and the working out of proposal for action.
4. Implementation, consisting in the implementation of selected proposal.

5. Follow up, i.e. the review of the results obtained.

The assessment of the external and internal influences caused by the product on the environment is carried out by the means of several qualitative techniques depending on the designer needs, such us: the SIO-3, the SIO-9, the KEE, etc. [17]. Such tools are quite similar one from the others, and use a series of checklists that allow the designer to take into account different evaluation criteria, bringing to light the environmental impacts caused by the product as well as the possible interventions to reduce them.

Among the all, the main reasons why the EEA was selected are:

- The use of the method is quite easy, both because of its structure (based on two well-known and largely spread methods, such as FMEA and LCA), and the terminology.
- The use of the EEA particularly fits with the implementation of Environmental Management Systems (EMSs) and allows designers to monitor continuously the effectiveness of the design activity.
- It explicitly includes the evaluation of marketing and customer satisfaction parameters.

On the other hand, as emerged from research work previously carried out [20], the method results not so effective in providing new design solutions, as well as the more precise results are needed, the more the EEA requires the support of other design tools.

For these reasons, with the aim of maintaining the high level of "handiness" that the EEA assures, and at the same time improving the effectiveness of its outputs, we developed a series of checklists, that can be used at different stages of the design process in synergy with the EEA method.

3.2 The Eco-Design Checklists

The development of the checklists for supporting the application of the EEA was motivated by the attempt to make more effective the integration of the method into the design process, providing useful suggestions for designers at different levels.

Needless to say, the use of checklists in the field of ecodesign is not a novelty. Several good examples were introduced in the last years by academic researchers, e.g. [21, 22]; by industry associations, e.g. [23]; by public bodies, e.g. [24]. This solution is always aimed at providing easy-to-use tools for the analysis and the improvement of the design activities.

In our case, we tried to focus more on the following aspects:

- <u>The adaptability of the checklists with the various stages of the design process.</u>
- <u>The compliance with Environmental Regulations.</u>
- <u>The definition of assessment criteria able to guarantee an objective evaluation of the system.</u>

In detail, the development of checklists was based on the definition of:

- Ecodesign rules, based on the analysis of the most significant properties which influence the environmental performances of the industrial products [25], as well as on the indications provided by the guidelines mentioned in section 2.
- the influence on the design activity of Environmental legislation, based on the analysis of the EU Directives EuP, WEEE and RoHS mentioned above.

The integration of such information brought us to the development of four different checklist, concerning respectively:

Checklist 1: Product's requisites definition, to be used in the Product Planning Phase.

Checklist 2: Product development planning, to be used in the Product Planning Phase.

Checklist 3: Improvement options, to be used in the Conceptual Design Phase.

Checklist 4: Product life cycle, to be used in the Detailed Design Phase.

The first three checklists are aimed at information and review activities. The control is carried out throughout a simple qualitative evaluation of the achievement of each indication, considering a score between 0 (no achievement) and 5 (full achievement).

Moreover, each checklist provides a space to be used to describe the situation and give a comment concerning the implementation level of each action. In Table 1 an excerpt of the Checklist 2 is shown. The shadow parts concern actions, which derive from law requisites.

Instead, since the application of the Checklist 4 is foreseen in the Detailed Design Phase of the design process, its goal consists not only in providing designers useful information for the development of the project, but also in assessing the level of environmental sustainability achieved.

Table 1. Excerpt of Checklist 2

2	Actions	Source
1	Select in those product strategies that take into account environmental concerns	ISO/TR 14062 (8.2.1)
2	Analyze the product's system from the environmental point of view, considering all its environmental characteristics	ISO/TR 14062 (7.1, 8.2.1)
3	Identify the most relevant environmental aspects concerning the product system	ISO/TR 14062 (7.2)
5	Carry out a cost benefit analysis in order to set the intervention priorities	ISO/TR 14062 (8.2.1)
7	Verify the availability of components, sub-components and materials, including re-used components and recycled materials	ISO/TR 14062 (6.4; 8.2.2)
8	Verify the availability of data bank concerning the product system	ISO/TR 14062 (8.2.2)
10	Take into account the collection, treatment and recovery of the waste of electrical and electronic equipment, foreseeing the implementation of opportune measures.	Directive WEEE (art. 8 , 9)
12	Take into account the collection and the treatment of all substances mentioned in the RoHS directive	Directive WEEE (art. 6)
16	Priority should be given to the reuse of WEEE and its components, subassemblies and consumables.	Directive WEEE (art. 4)
18	Foresee the minimum use of natural resources in the material acquisition.	Ecodesign (14)
22	Optimize the logistic and distribution system reducing the material and energy use.	Ecodesign (40)
25	Reduce the amount of waste in all phases of the product's life cycle.	Ecodesign (15)

For these reasons, its structure is more complex, and it is based in five different parts, in accordance with the main phases of the product's life cycle:

- Checklist 4.A: Material Acquisition,
- Checklist 4.B: Production,
- Checklist 4.C: Distribution,
- Checklist 4.D: Use,
- Checklist 4.E: Disposal.

These checklists also provide an evaluation system, able to lead designers in the selection of the best solutions to carry out in order to improve the level of sustainability of the product. In this way, the results which can be obtained by using the EEA methods can be analyzed more in details, translating the outputs from general issues into more practical actions.

In order to make the use of the Checklists more effective and objective, and at the same time as much flexible as possible, several evaluation criteria were introduced.

3.3 The Assessment Criteria

The assessment of the level of Sustainability of the product is based on the evaluation of the aspects included in the Checklists 4, i.e. all the characteristics that affect the environmental performances of the product along its life cycle. Such an evaluation system is based on the following formula (1):

$$Ms = \sum_{j=1}^{n} k_j \cdot CL_j \qquad (1)$$

where:

Ms Sustainability Level;

k_j importance factor of the j checklist;

n number of Checklists ($n = 5$);

CL_j Sustainability Level concerning the Checklist *j*, based on the assessment of the fulfilment of each action. The higher the value is, the more environmentally friendly the product is.

In order to take into account the different level of importance of each one of these aspects, depending on the nature of the product analyzed, as well as the company's needs, and the peculiar necessities of the project, hierarchies criteria were introduced by means of the application of the method AHP [26]. In detail, the definition of the value of each k derives from the following vector relationship (2):

$$A \cdot k = \lambda_{MAX} \cdot k \qquad (2)$$

where:

A is the Comparison Matrix;

λ_{MAX} is the dimension of the matrix and the eigenvalue;

k is the weight vector and the eigenvector.

In order to better explain how to use such tools, their application to an industrial case is described in the following section.

4 CASE STUDY

The research approach was applied to the redesign of a refrigerator for domestic use. The project, developed in collaboration with a producer of this kind of machines, consisted in the definition of feasible improvements to apply to the system "domestic refrigerator" in order to optimize its life cycle. With this aim in mind, the application of the methodology consisted in several steps:

- Definition of an "Average Product" (AP), on the basis of the state of the art in the field, taking into account the needs of the average customer.
- Assessment of the Sustainability Level of the AP, using the Checklist 4 and the AHP method.
- Application of the EEA method, in order to find out the system's "hot spots", and the actions to perform in order to improve it.
- Definition of an optimal solution and evaluation of its Sustainability Level by means of the Checklist 4.

The project concerned the development of the first two phases of the design process, and the definition of the general layout of the system (at the beginning of the Detailed Design phase), as described in Figure 2.

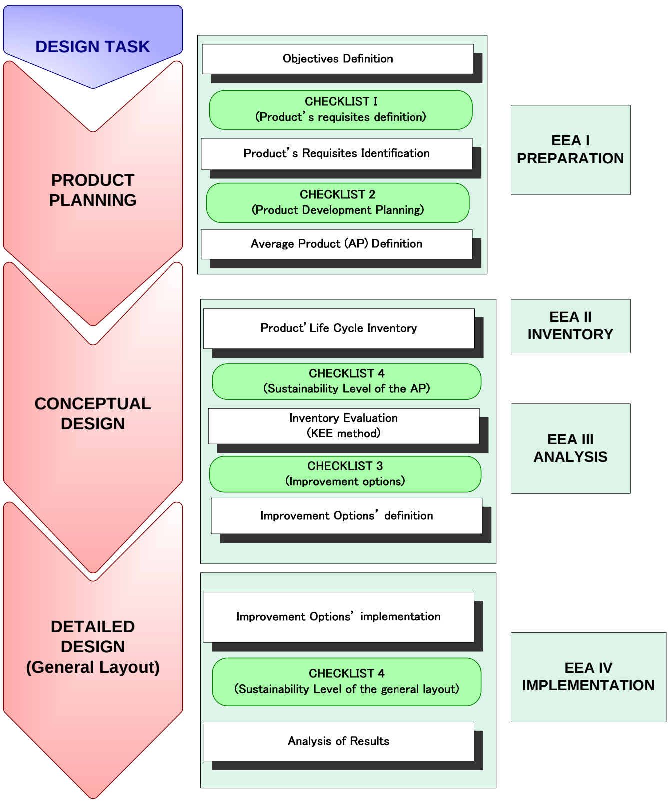

Figure 2. Scheme of the methodology applied in the case study

4.1 EEA I - The Average Product

The study of an Average Product was carried out in order to define the input data for the application of the EEA method. The analysis was performed both considering the data provided by the company Indesit S.p.A. [27] concerning their non built-in, bottom-freezer products, as well as taking into account the best competitors in the market. Moreover, Checklist 1 was used by company's technicians in order to better define the product's requisites; the output of this analysis is summarized in Table 2.

Table 2. Characteristics of the Average Product

Characteristics	
Life span	10-12 years
Energy-saving class	A
Compressors	1 (100 ÷ 150 W)
Working hours per day	18
Cooling liquid	iso-butane R600a
Insulation material	Polyurethane foam
Expansion gas	Cycle-pentane
Noise	40 dB(A)
Products per year	10000 units
Doors	2 (reversible)
Size (H/W/D)	1750/600/600 mm
Fridge volume	260 lt
Freezer volume	70 lt
Rated fridge temperature	4 °C
Rated freezer temperature	- 18 °C
Temperature regulation	separated

4.2 EEA II - Product's life cycle inventory

The application of the EEA method requires, after the definition of the product's environmental requisites, to carry out the inventory of the whole product's life cycle, starting from the identification of the life cycle flow of the system. In Figure 3 an excerpt the flow diagram concerning the supply and production stages is shown.

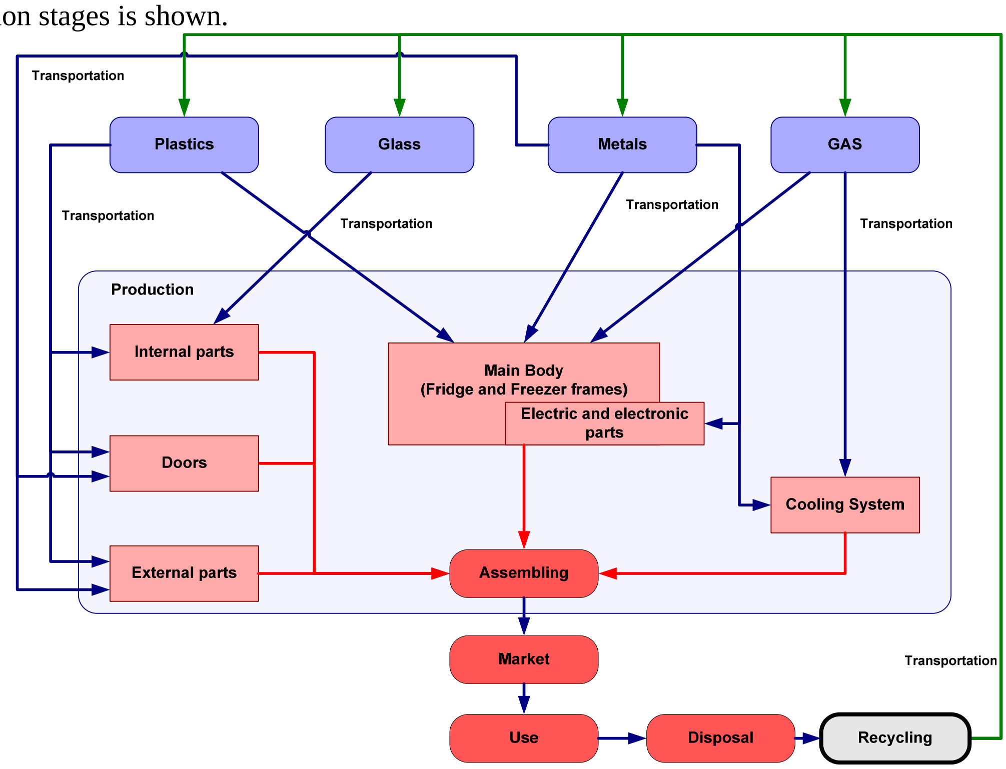

Figure 3. Excerpt of the life cycle flow of the system

Following the indications given in Section 3, a preliminary evaluation of the Sustainability Level of the Average System was carried out with the aim of better define the environmental burdens of the system. In Figure 4 main results are summarized.

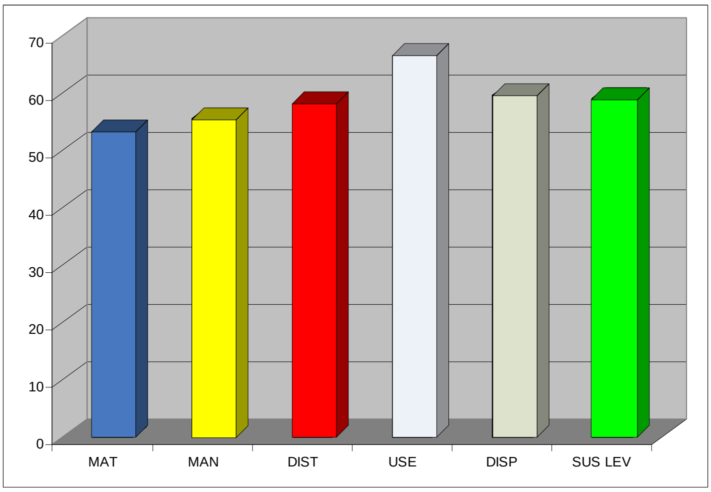

Figure 4. Sustainability Level of the Average Product

4.3 EEA III - Analysis

The evaluation of the life cycle inventory data was carried out using the method KEE [17]. The decision to choose such a supporting tool among the ones foreseen by the Authors of the EEA is due to the fact that both the legislation requisites and the modification costs are explicitly taken into account in the analysis. In Table 3 the evaluation criteria used are summarized. As "hot spots", the activities which obtained an *EPN* higher than 12 and an improvement possibility (*F*) higher than 5 were considered. Such aspects were grouped in five main categories of problems, respectively concerning:

- the cooling circuit,
- the insulation system,
- materials recycling
- the life span,
- the distribution system.

Table 3. Evaluation criteria for the use of the KEE method

Evaluation Criteria − KEE method					
ENVIRONMENTAL DEMANDS (K)	k	**Customers**	0, 1, 2	**K = (*k* + *i* + *l* + *a*) x 2**	Max 12
	i	**Internal**	0, 1		
	l	**Authorities**	0, 1		
	a	**The Public**	0, 1, 2		
ECOLOGY (E)	m	**Quantity**	1, 2, 3	**E = *m* x *s***	Max 9
	s	**Seriousness**	1, 2, 3		
IMPROVEMENT POSSIBILITY (F)	kf	**Modification cost**	1, 2, 3	**F = *kf* x *p***	Max 9
	p	**Improvement possibility**	1, 2, 3		
EPN		**Environmental Priority Number**		**EPN = *K* + *E***	Max 21

Not all environmental burdens emerged from the analysis can lead to an explicit improvement intervention. Moreover, some problems are interwoven one to the others, so that the definition of practical solutions appear a difficult task for designers. Beside such difficulties, also the limitations given by the technologies nowadays available have to be taken into account. For example, problems related to the cooling circuit, the cooling fluid and the insulation system are all affected by the pollution caused by the type of gases used.

This problem, regulated by the WEEE and RoHS directives, concerns both the type of foam used for the insulation of the refrigerator's frame (usually expanded PUR), as well as the gas used in the cooling system (in our case the isobutene R600a is used). In both cases, considering the best technologies available on the market, a very few alternative options can be found.

In order to define more practical solutions for the improvement of the system, the Checklist 3 was applied, focusing our attention on the following aspects: reduction of different plastic materials, improvement of the foaming process, and improvement of the modularity of the system.
As far as plastic materials are concerned, the possibility to use an unique material (formed PUR) was foreseen, considering at the same time its reuse (in percentage) for the production of new machines.
The modularity of the system was considered by means of the complete separation between the fridge and the freezer parts, equipped with independent circuits and motors (compressors). Even if such a solution might appear more resources-consuming, it has to be underlined that from a more detailed analysis of the data it emerged that numerous "hot spots" can be improved, such as: the reduction of maintenance and repairing operations, the disassembling operations, the energetic efficiency of both fridge and freezer, the transportation and distribution activities. Moreover, the selection of easy-to-disassemble joint systems improves the compliance with legislation requisites concerning the separation of materials. At the same time, the possibility to reuse parts and/or components was rejected considering the quite long life period of use of the refrigerator (usually more than 10 years).
The foaming process was analyzed, taking into account the possibility of using the "Foiled PUR Technology". Such a solution brings to remarkable environmental improvements, but at the same time, it requires an "ad hoc" production process and plant. For these reasons, it was accepted by the company technicians with reservations.

4.4 EEA IV - Implementation

The implementation of the results obtained from the analysis phase concerned the definition of a general layout (general dimensioning) of the new system and its life cycle model. The main characteristics are summarized in Table 4.

Table 4. Main characteristics of the new product

Frame	Non built-in, modular
	2 doors
	Foiled PUR
Thermostat	With automatic regeneration
	2 (1 for the fridge, 1 for the freezer)
Doors insulation	PUR rigid and F. P. T
Compressors	2
Energy-saving class	A +
Cooling liquid	R600a
Accessories (shelves, trays, etc.)	Foiled PUR, Glass
Cooling systems	2, static
Handles	embedded
Size (H/W/D)	1750/600/600 mm
Total Capacity	330 lt
Display	external

Moreover, following the indications of the directive 96/57/EC concerning "energy efficiency requirements for household electric refrigerators, freezers and combinations thereof", the value of the maximum energy consumption was performed obtaining: E_{max} = 1,80 kWh per 24 hours (V_{adj} = 552,88 lt). Such a value is one of the parameters that the company has to respect in order to comply the EuP directives. With the aim of verifying the validity of the solutions adopted, the Sustainability Level of the new system was evaluated by means of the Checklist 4. In Table 5 an excerpt of the Checklist 4 concerning the evaluation of the Material stage both for the Average Product (A.P.) and for the New Product (N.P.) is shown; in brackets the source of each action is reported.
Results of the overall evaluation of the Sustainability Level, carried out using the Checklist 4, are shown in Figure 5, together with the ones obtained in the evaluation of the Average Product.

5 DISCUSSION OF RESULTS

The application of the methodology proposed, as mentioned above, was carried out in collaboration with the company technicians, who also contributed to the definition of the possible improvement solutions. From the technical point of view, the new system lead us to achieve an improvement of the Sustainability Level of about 11,6 %, as shown in Figure 5.

Table 5. Excerpt of Checklist 4

4.A	Actions	A. P.	N. P.
1	Transport hazardous substances using specialized and certified operators (WEEE art. 5).	2	4
2	Materials are not arbitrarily excluded (ISO/TR 14062, art. 7.2.2)	2	4
3	Avoid potentially hazardous substances and materials in the product, checking for human health, safety, environmental aspects, lower impact of materials and transportation (ISO/TR 14062, art. 7.4).	2	3
4	Avoid the use of lead, mercury, cadmium, hexavalent chromium, polybrominated, biphenyls (PBB) or polybrominated diphenyl ethers (PBDE). (RoHS, art. 4)	4	5
5	Reduce the use of resources obtained by the supply of raw materials, such as water, energy, materials (Ecodesign 14).	3	3
6	Reduce the amount of waste deriving from the supply operations, (Ecodesign 15)	3	3
7	Improve materials efficiency: e.g. by minimal use of materials, use of low impact materials, use of renewable materials, and/or use of recovered materials (ISO/TR 14062, art. 7.4).	3	4
8	Reduce the use of non renewable materials (Ecodesign 19).	3	4
9	Avoid the use of potentially hazardous substances during setting up and maintenance operations (Ecodesign 26).	4	4
10	Establish, as necessary, maximum concentration values up to which the presence of hazardous substances shall be tolerated (e.g. 0.1% of Pb, Hg, Cr VI, PBB e PBDE; 0.01% of Cd - RoHS, art. 5)	4	5
11	Reduce the use of different materials (Ecodesign 21).	2	5
12	Reduce the use of low-availability materials (Ecodesign (20).	3	3
13	Increase the use of plastic materials of the same kind for different purposes (Ecodesign 22).	2	5
14	Increase the use of ease-to-recycle plastics, such as thermoplastics and polyolefin (Ecodesign 23).	2	4
15	Increase the use of plastics, which do not produce noxious substances during incineration processes (Ecodesign 24).	3	3
16	Reduce the use of PVC (Ecodesign 25).	2	3
17	Increas ethe efficiency of materials throughout optimal product and processes design (ISO/TR 14062 art. 7.2, 7.3, and 7.4)	2	2
18	Publish communication materials on environmental aspects, best use and disposal of the product; consider possible environmental declaration and its requirements (ISO/TR 14062, art. 8.2)	2	4

More in details, the best improvement were obtained in the first and last phases of the product’s life cycle, i.e. material acquisition and disposal. At the same time, the complete compliance with the environmental legislation was guaranteed. Beside such positive aspects, it has to be considered also the problem related to the costs due to the investment for replacing the production system of the refrigerator frame. The obstacle could be overtaken foreseeing a different volume of production, i.e. an larger number of units produced per year and/or the application of the same technology also to different products oriented to different market sectors. Thus, the complete feasibility of the project needs a further analysis involving also company managers and stakeholders.

An other remarkable aspect emerged from the research work concerned the definition of the real period of use of the machine: as a matter of fact, its length largely varies not only from one country to an other one, but also from one area to an other one in the same nation. This problem, related with the ever faster development of more efficient models from the energetic point of view [28], leads to shorten the product life cycle, improving the taking back strategies. In our case study, such an option could not be further analyzed, limiting us to consider a standard life period (10 years).

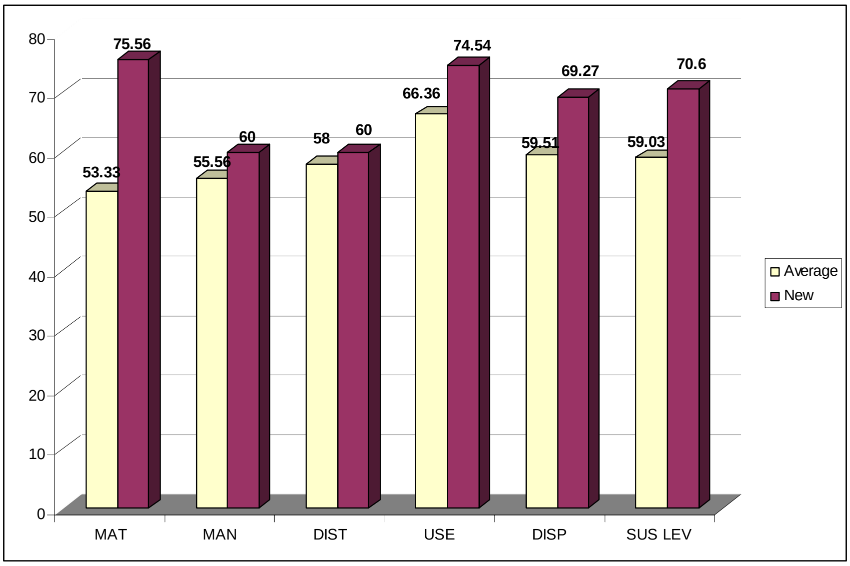

Figure 5. Comparison of results obtained in the evaluation of the Sustainability Level

6 CONCLUSIONS

In this paper a design methodology aimed at improving ecodesign activities has been presented: the approach developed allowed us to optimize the environmental performances of the system and at the same time make its development economically feasible. Furthermore, the design approach could also be applied to any type of product. In fact, it allows a systematic development of product design and development, which makes the occurrence of mistakes or the pursuance of wrong solutions difficult.

Preliminary results confirmed the importance of considering the entire life cycle of products during the first stages of the design activity, and underlined the importance of the improvement of the environmental performances of industrial products.

The study performed also allowed us to develop a set of ecodesign checklists, the use of which resulted in being very effective in the evaluation of design solutions both from the environmental and from the technical point of view, as well as helping designers to be in compliance with recent European environmental legislation. Such checklists turned out to be very suitable for their integration within the design process, and easy to use even in the analysis of complex systems. The choice of the design tools used in this case study comes from previous research works and studies carried out, as well as from the ones by other Authors in the field. Nevertheless, the flexibility of the checklists allows designers to use alternative design methods and techniques (i.e. Quality Function Deployment based methods instead of Environmental Effect Analysis) depending on the necessity as well as on the level of information at their disposal.

At the same time, further research work is needed in order to make easier the calculation of the sustainability level (and in particular the use of the AHP method).

Acknowledgements

This research work was supported by the JSPS Research Fellowship Program in Japan. Authors wish to thank also Eng. Simona Bisillo and Eng. Romeo Rocco for their contribution.

REFERENCES

[1] Prudhomme G. et al. Integrating into the design process needs of those involved in the product life cycle. *J. of Engineering Design*, 2003, 114/3, 333-353.

[2] Gruner, C., Birkhofer, H., 1999, Decision Support for Selecting Design Strategies in DFE. In *International Conference on Engineering Design, ICED 99*, Munich, August 1999, Vol. 2, pp. 1089-1096.

[3] Lee, K-L, (2002), "Integrating environmental aspects into product design and development", Journal of ISO Management Systems – November-December 2002, pp. 13-16.

[4] Dewulf W.and Duflou J. Integrating Eco-Design into Business Environments: A multi-level approach, *Product Engineering: Eco-Design, Technologies and Green Energy Sources*, 2004

(Talaba, Roche Eds, Springer).
[5] Stevels A. L. Moving companies towards sustainability through Ecodesign: conditions for success. *Sustainable Product Design*, 1997, (3) 47-55.
[6] Fargnoli M. An Integrated Approach for the Development and Management of Environmentally Conscious Products. *In EcoDesign 2005*, Tokyo, December 2005, 2A-3-3F.
[7] USCAP, *A Call for Action*, http://www.us-cap.org/
[8] Stevels A. L. Traditional EcoDesign in Proactive Electronic Companies will be soon Dead! Long live Ecovalue!, 1*0th International Conference Towards Sustainable Product Design*, October 2005. Farnham Castle.
[9] EU, *Directive 2005/32/EC* establishing a framework for the setting of ecodesign requirements for energy-using products", (EuP).
[10] EU, Directive *2002/95/EC* on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic equipment", (RoHS).
[11] EU, *Directive 2002/96/EC* on Waste Electrical and Electronic Equipment (WEEE).
[12] ISO/TR 14062:2002. *Environmental management - Integrating environmental aspects into product design and development*, 2002.
[13] IEC, Guide 114. *Environmentally conscious design – Integrating environmental aspects into design and development of electro technical products*, 2005, http://www.iec.ch/.
[14] Bygget S. and Hochschorner E. Handling trade-offs in Ecodesign tools for sustainable product development and procurement, *Cleaner Production*, 2006, 14(2006), 1420-1430.
[15] Lofthouse V. Ecodesign tools for designers: defining the requirements, C*leaner Production*, 2006, 14(2006), 1386-1395.
[16] Finnveden G. and Moberg A. Environmental system analysis tools – an overwiev, *Cleaner Production*, 2005, 13(2005), 1165-11173.
[17] Lindhahl U. and Tingstrom J. *A small textbook on Environmental Effect Analysis*", 2001 (Department of Technology, University of Kalmar, Sweden).
[18] Davidson J. *The reliability of mechanical systems*, IMechE Guides for the Process Industries, 1988 (Mechanical Engineers Publications Ltd., London).
[19] SETAC, Guidelines for Life Cycle Assessment", 1993, Bruxelles, http://www.setac.org/.
[20] Fargnoli M. and Kimura F. Evaluation of design methods for sustainable product development, *TMCE 2006*, *Vol. 2*, Ljubljana, April 2006, pp. 669-680 (CIP)
[21] Luttrop C. and Lagerstedt J. Ecodesign and The Ten Golden Rules: generic advise for merging environmental aspects into product development. Cleaner Production, 14 (2006) 1396-1408.
[22] Wimmer W. and Züst R. *ECODESIGN PILOT, Product-Investigation, Learning- and Optimization-Tool for ...*, 2003 (Kluwer Academics Publisher B.V., Netherlands).
[23] ECMA, Standard 341, Environmental design donsiderations for ICT & CE products. www.ecma-international.org
[24] MOEA, Design for Environment Toolkit, http://www.pca.state.mn.us/.
[25] Pighini U. et al. An Integrated Procedure for the Design of Sustainable Products, In *International Design Conference, Design 2002*, Dubrovnik, May 2002, Vol. 2.,pp.1351-1356.
[26] Saaty T. *Group Decision Making and AHP*, The Analytic Hierarchy Process: Applications and Studies, 1989 (Springer-Verlag, New York).
[27] www.indesit.com
[28] JEMAI, "Eco-efficiency Indicator Handbook" for Products, 2004, http://www.jemai.or.jp

Contact: Mario Fargnoli
The University of Tokyo
Department of Precision Engineering, Engineering bldg. 14
Hongo 7-3-1, Bunkyo-ku
113-8656, Tokyo
Japan
Phone: (+81)-03-5841-6459
Fax: (+81)-03-5689-7357
e-mail: fargnoli@cim.pe.u-tokyo.ac.jp