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Computer-aided Environmental Design System for the Energy-using Product (EuP) Directive

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The importance of environmental designs has recently increased, mainly due to emerging green markets, required cost savings, and legislative pressure. The Energy-using Product Directive is the most important and urgent legislative pressure to cope with in environmental engineering. Therefore, we investigated this directive in depth. The directive contains essential items and generic requirements defined by the European Commission. Specific environmental design requirements are suggested to fulfill generic requirements, and ecological profiles are required to satisfy specific requirements. The life cycle components of all products are classified into five stages, with each stage requiring its own ecological profile. To fulfill these requirements, we developed a computer-aided environmental design system for energy-using products. Many input items and analysis results were prepared for our system, and several ecological profiles were generated. A personal computer was surveyed by our system as a case study, and its environmental impacts were scrutinized. Our system also allows one to select and compare mechanically and environmentally friendly materials in the advance stages of the design process.

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1. Introduction

Environmental considerations in product design and manufacturing process are increasing in importance, mainly due to emerging green markets, required cost savings, and increasing legislative pressure.[1-3] The increased amount of new equipment manufacturing has led to various proposed directives that require a range of environmental measures, mainly with respect to the management of waste products. These include the Waste Electrical and Electronic Equipment Directive (WEEE), Restriction of Hazardous Substances Directive (RoHS), Electrical and Electronic Equipment Directive (EEE), and the Energy-using Product Directive (EuP). Environmental design methodology effectively introduces environmental qualities into industry to minimize the environmentally harmful effects of equipment over its entire life cycle. At the same time, important cost savings and profits are generated.[4] Environmental design methodology identifies possible environmental improvement options in each stage of a product's life cycle. The methodology identifies environmental improvement options and the most critical environmental stages of a product's life cycle. Such a global viewpoint makes it possible to consider environmental issues beyond the depth of the product manufacturing boundaries and the pollution generated at this stage.[4,5]

The European Parliament and the Council have introduced a framework to set environmental design requirements for energy-using products. This is known as the EuP. Manufacturers that make energy-using products must set environmental design objectives and policies, and evaluate the environmental impacts of their products. Their findings will be reflected in the final product design.

2. Environmental Design

2.1 Introduction

Environmental design is a systematic way of incorporating environmental attributes into the design of a product. The aim of environmental design is to avoid or minimize major environmental impacts at all stages in the life cycle of a product, especially with regard to the sourcing of raw materials, the purchasing of components for use, and the end-of-life disposal. In this research, the life cycle components of all products are classified into five stages:[6] material extraction and production, manufacturing, distribution, use, and disposal and recycling. Each stage has its own steps that are detailed in Fig. 1. All of the life cycle stages and their individual steps are cyclical, as illustrated.

Environmental design is also known as “green design.” Traditional computational design tools dealt mainly with product quality and performance, but the shift toward “green design” has introduced new dimensions in product and process design. Environmental design is a process whose core concept considers environmental resources. The environmental properties of products, such as detachability and retrievability, are of primary importance. The goal is to complete the environmental and physical characteristics of products simultaneously. Environmental design is gaining more attention, and is a key technology to realize sustainable development in manufacturing industries. At the beginning of a product’s design, the environmental impact of each design alternative and corresponding resource utilization is assessed for the life cycle of the product, from the material selection to the disassembly of the components and recycling of the material. Designers can then compare the alternatives and optimize the design. Having exact assessment results is the key to a successful environmental design. Environmental manufacturing consists of developing and utilizing highly efficient pure manufacturing methods to meet the needs of green design goals, which include improving the converting efficiency of various resources, reducing the types and amount of contaminants, and reusing materials effectively.

Environmental design must consider cost savings and profits simultaneously. Many reasons exist to consider the environmental effects of products. In this study, both environmental and business points of view are considered.[4]

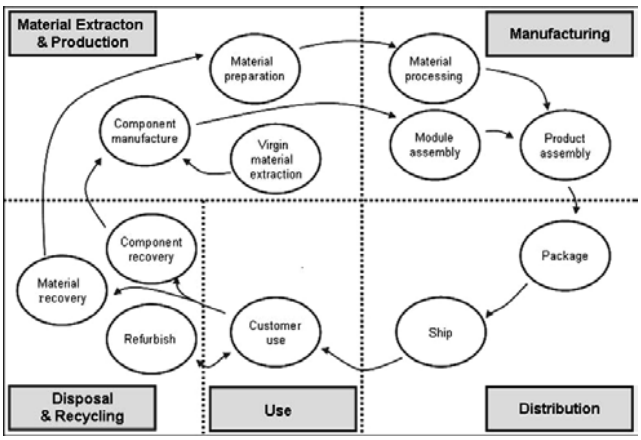


Fig. 1 Five life cycle stages of a product

2.2 Business Point of View in Environmental Design

Several important facts must be considered in environmental design. At present, most human activities have multiple environmental impacts on the environment. This situation is responsible for the constantly increasing environmental deterioration, emphasizing the need for responsible product design and development from an environmental perspective.[4] Many industrial activities contribute toward the continuous deterioration of the environment. In such a situation, industrial processes and activities have the following environmental impacts.[4] Industrial products consume both recycled and non-recycled resources. Hazardous and nonhazardous wastes are generated during the entire life cycle of some products, and are produced right from the raw material acquisition to the end of the product’s life. Immoderate material consumption produces both hazardous and nonhazardous wastes, causes pollution in many different forms that degrade global ecosystems, harm human health, and become both short and long term global environmental problems. Environmental issues usually appear at the end of a product’s life, and these clearly reflect past ineffective and expensive practices. Such issues are addressed by traditional end-of-pipe treatments. Most environmental impacts caused by a product during its entire life cycle are determined in the design phase, before the product has even been manufactured or used. Integrating environmental quality into the development and design process is an effective way of improving a product’s environmental behavior and minimizing harmful effects.

Environmental design is an effective way of introducing the quality of the environment into business activities, diminishing the environmental impacts of products during their entire life cycle without compromising other product properties, which results in important cost savings and profits. Several internal and external influences motivate the implementation of environmental design such as legislative regulation, competition, market pressure, and cost savings. For example, the environmental concerns of many companies are increasing in importance because of legislative pressure in their own country and in the countries to which they export. The EuP is the main focus of the present study.

2.3 ISO TR 14062

In environmental design process, ISO TR 14062 should be considered. ISO TR 14062 published in 2002 is focused on environmental management and describes concepts related to the integration of environmental aspects into product design and development. ISO TR 14062 can act as a reminder or a checklist for environmental subjects. The user of ISO TR 14062 should be familiar with the management components. Traditional product is broadened by links to other product systems, or even substituted by service approaches. Therefore, product in the sense of ISO TR 14062 means ‘any goods or service’ and includes also software. Service contains the chance to substitute hardware partly or totally with often less environmental impact. ISO TR 14062 describes details from the beginning till market sales for product life cycle inputs and outputs of each phase and tools application. The descriptions in the technical report are very precise so that everyone should be able to add the necessary elements to the existing system. The application of ISO TR 14062 and the feedback from applicants can help to fill in the missing information about useful tools. ISO TR 14062 is a very valuable guide for all who are interested or involved in the design and development of environmentally compatible products. It is recommended to transfer the general standard to the company specific management systems, tools and cultures.[7]

3. The EuP

3.1 Definition and History

Directive 2005/32/EC on the eco-design of energy-using products, such as electrical and electronic devices or heating equipment, provides coherent EU-wide rules for eco-design and ensures that disparities among local regulations do not become obstacles to intra-EU trade.

The EuP covers products that once placed on the market and/or put into service are dependent on energy input to work as intended, or are a product for the generation, transfer, or measurement of such energy. This includes parts dependent on energy input and intended to be incorporated into an energy-using product covered by the EuP. These products are placed on the market or put into service as individual parts for end-users, and their environmental performance can be assessed independently.[8] The directive requires the commission to propose "implementing measures" following a study phase and impact assessment as well as the consultation of a newly created body of stakeholders called the "consultation forum." The forum brings together interested parties to voice their opinions on intended EuP implementation measures under consideration. As a product-orientated directive, the proposal is based on article 95 of the EC Treaty to secure the free movement of energy-using products in the internal market.

The European Commission implemented an integrated product policy (IPP) and accelerated the move toward improving the environmental performance of energy-using products by encouraging manufacturers to design products that keep the resulting environmental impacts in mind for the entire product life cycle. After adopting the EuP, the commission, assisted by a committee, is able to enact implementing measures on specific products and environmental aspects, such as energy consumption, waste generation, water consumption, and lifetime extensions, after assessing impacts and broadly consulting with interested parties. This policy initiative is expected to increase the effectiveness and synergies of other EU legislative acts such as the WEEE and RoHS, and initiatives concerning environmental aspects of products.

3.2 The framework of EuP

The EU officially published the framework of the EuP on 11 August 2005. The European Commission was required to provide a working plan by 6 July 2007, and all EU member nations were required to prepare related legislation by 11 August 2007. Thus, environmental design is now obligatory by law. The WEEE or RoHS of the EU were limited to specific environmental areas or life cycle stages, but the EuP applies to various areas and affects all life cycle stages. A framework is a basic conceptual structure used to solve or address complex issues. The directive does not introduce directly binding requirements for specific products, but does define conditions and criteria for setting, through subsequent implementing measures, requirements regarding environmentally relevant product characteristics, such as energy consumption, and allows them to be improved quickly and efficiently. The eco-design of the EuP establishes a framework for product requirements regarding all environmental aspects (energy efficiency, water consumption, waste, emissions to soil, water, air or noise emissions) from the cradle to the grave. It is not the simple regulation, but it shows the guideline and assessment methods for the environmental effects. Examples of such energy-using products include lighting equipment, motors, pumps, refrigerators, washing machines, computers, and televisions.

3.3 Requirements

Research is required for the eco-design systems mandated by the EuP. These systems consist of implementing measures and harmonized standards. A brief description of each class contained in the EuP is given here. The contents of Class A include items that the European Parliament and Council adopt by joint resolution. The contents of Class B include items to which measures implemented by the EU apply. Target products are identified by the amount of sales and their environmental impact. Qualitative and quantitative environmental measures are applied based on EU research. The contents of Class C include items to which regulations apply that are adopted by the EU if required. The standards or measuring methods are specified, and are often dictated by international standards.

The EuP requires three actions from manufacturers: the product design requirements must be supplied, the system building requirements must be supplied, and information must be exchanged with the public. The product design requirements include design modifications to satisfy environmental technical purposes defined by the implementing measure. In other words, products must be modified to fulfill specific standards or restrictions. The system building requirements require management systems to be built and operated to provide for continuous administration and amendments for pre-achieving product design requirements. The information exchanged with the public provides a means for concerned people such as customers to suggest environmental improvements to products. The first two requirements promote environmental design by direct regulation, but the last requirement can be a method that promotes eco-design behavior of an enterprise using market functions.[9]

3.4 Environmental Design Methodology for the EuP

Essential items in the EuP include an ecological profile, an eco-design requirement, a generic eco-design, and a specific eco-design. The ecological profile consists of a description of the inputs and outputs associated with the product throughout its life cycle in accordance with the implementing measure applicable to the EuP. These are used to determine its environmental impact and are expressed in measurable physical quantities. An eco-design consists of any requirement of the product or design of a product intended to improve its environmental performance, or any requirement for the supply of information with regard to the environmental aspects of the product. A generic eco-design is any eco-design requirement based on the ecological profile as a whole of a product without set limit values for particular environmental aspects. A specific eco-design is a quantified and measurable eco-design requirement relating to a particular environmental aspect of the product such as energy consumption during use calculated for a given unit of output performance. The European Commission defines the generic environmental design requirements. After that, based on the generic requirements, a specified procedure is followed to obtain the measurable quantitative requirements. In other words, to produce an ecological profile, the generic requirements must be fulfilled, and to fulfill the generic requirements, specific environmental design requirements must be considered. The ecological profile is required to satisfy specific environmental design requirements.

3.5 Possible use and application of product EuP software

Basically, this software can provide the ecological profile, material information, and design guideline in each life cycle. Submitting the ecological profile of energy-using products is mandatory for exporting products to EU, so this software can support making the ecological profile of a product with the EuP database, and one can automatically make the ecological profile and manage the environmental data using the EuP database of this system. In addition, the ecological profile can show the environmental impacts with the whole life cycles, then one can compare the environmental aspects of other products with the same standard and units. For designers, the ecological profile shows the environmentally weak points in the life cycles, so they can focus on the life cycle in order to improve the environmental impact. For example, a product which has high energy consumption in the use stage, should be made more with high efficiency. On the other hand, a product which has high energy consumption in the manufacturing stage, should be manufactured by improved process. Using material information such as mechanical, electrical, and thermal properties, the designers can select the proper materials for the specific products and the environmental properties can be considered with the comparison graphs of two material properties. However, this software cannot provide any specific methods for improving the design, efficiency, reusability and so on. This application can help accumulating the design knowledge in each life cycle.

4. Environmental Design System for the EuP

4.1 Architecture

Our proposed environmental system uses three-tier communication so the designer can approach the system anytime and anywhere. The designer can receive ecological profile information and best available techniques through the EuP database to improve the environmental impact of a current product. The designers can also obtain substantial material information such as mechanical and electrical data through the material database. If the designer receives eco-profile data and determines that some materials must be changed, they can then select material that has similar mechanical and electrical properties immediately. Fig. 2 shows a schematic diagram of our proposed environmental design system for the EuP. The greatest advantage of this system is being able to manage the environmental data of many products and parts individually so that it is easy to obtain environmental data for many products.

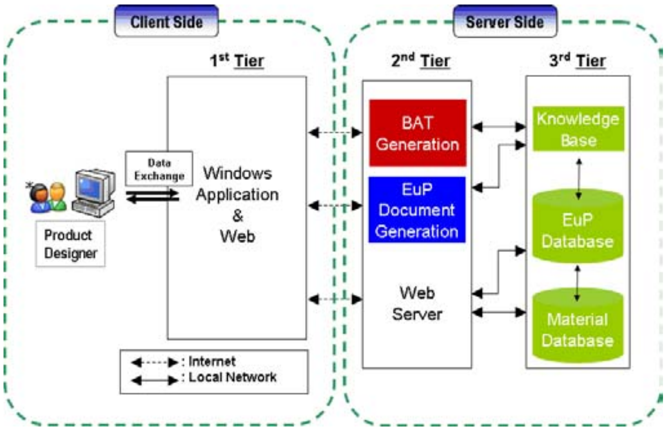


Fig. 2 Schematic diagram of proposed environmental design sysytem

4.2 Ecological Profile

According to the ecological profile definition, the detailed contents of the profile must be expressed in measurable physical quantities. To establish the environmental impact in physical quantities, the accounting units of measure must be established first because the measuring techniques and units of contaminants can vary widely. This requires selecting the measuring fields and accounting units, as well as the impact calculation method to be used for each classified field.

For example, different materials and manufacturing processes produce greenhouse gases. Some emit CO_2, while others emit CH_4. But only one accounting unit can be used to compare the greenhouse gas emissions from different processes. Therefore, one representative standard is selected and a weighting factor is calculated to convert the environmental damage expressed in one set of accounting units to the other. Here, emitting 1 g CH_4 equals to 21 g of CO_2. The weighting factor is based on the EU official information on the impact of emissions. If one material emits 10 g of CO_2 and 2 g of CH_4, then the total impact of that material is 52 g CO_2 equivalent. Environmental design systems use unit indicators to measure quantitative environmental impacts.[10] Unit indicators are based on environmental impact data measured in one set of units for important environmental fields.

4.2.1 Energy

The accounting unit used for the energy analysis is the combustion value of fuels consumed expressed in megajoules (MJ). The gross energy requirement (GER) is the primary energy kilogram. Electricity is used as an energy requirement, as is the net calorific value of feedstock. Electricity and feedstock are auxiliary parameters. The GER covers 90% of the material depletion.

4.2.2 Water

The accounting unit for water is the liter (ℓ). This includes process water and cooling water. The water data obtained for metals must be treated with caution because cooling water is not always considered by all sources, and process water is often underestimated, especially for mining and beneficiation.

4.2.3 Waste

The accounting unit for waste is the gram (g). Waste is subdivided in hazardous and nonhazardous categories. Nonhazardous waste quantities from metal production and various sources have been replaced by an independent set of waste data that allows for a better comparison.

4.2.4 Emissions to Air and Water

The Global warming protocol (GWP) includes the weighted emissions of greenhouse gases and fluorinated greenhouse gases. The CO_2 equivalent is obtained using the GWP-100 factors given by the Intergovernmental Panel for Climate Change (IPCC). The acidification potential (AP) derived from EU legislation gives SO_2 weighting factors for acidifying agents. Volatile organic compounds (VOCs) are indicators of smog and ground-level ozone, with accounting units of grams (g), and can also cause neurological health problems. Persistent organic pollutants (POPs) include the contents of dioxins and furans in the air that are relevant to the EuP, but no emissions to water. Heavy metals (HMs) are expressed in mg Ni-eq and weighted according to their emission limit values as specified in the current legislation under the Ambient Air Quality Framework Directive. The current accounting unit in legislation for polycyclic aromatic hydrocarbons (PAHs) is mg Ni-eq. Particulate matter (PM) is an indicator for human toxicity, such as respiratory problems, and is expressed in grams (g). PM is weighted according to its emission limit values as specified in current legislation and expressed in mg Hg/20. Eutrophication refers to substances that influence the oxygen balance of water, and are expressed in g PO_4.

4.3 Bills of Material

To create a bill of materials, which is part of the ecological profile required by the EuP, many data must be input into the product database. The stages of life cycle are classified as described in Section 2.1. Designers must enter some of the data into the system, but other data will be calculated automatically. Fig. 3 illustrates how the system is executed.

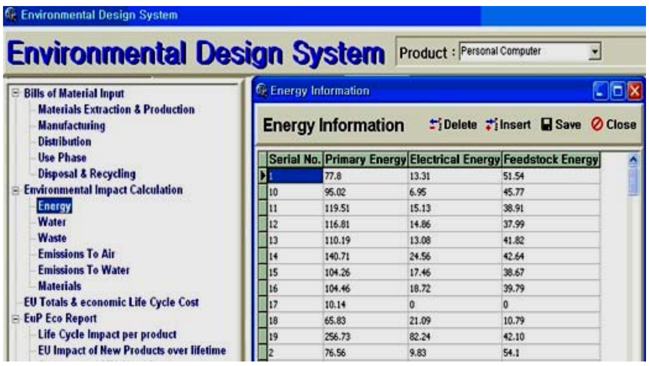


Fig. 3 Execution of the environmental design system

4.3.1 Material Extraction and Production

Fig. 4 shows the material extraction and production form, where designers input the product material data. All material categories and the material list are prepared in advance and refer to the unit indicators given by the method for evaluation of energy-using products (MEEuPs). The designer simply inputs the materials used in the product and selects the corresponding category and material from a list. The weight per component is multiplied by the environmental unit indicators. The product and the weight of its components are summed for each category. The summed parameters are used for the manufacturing, distribution, and end-of-life phases.[10]

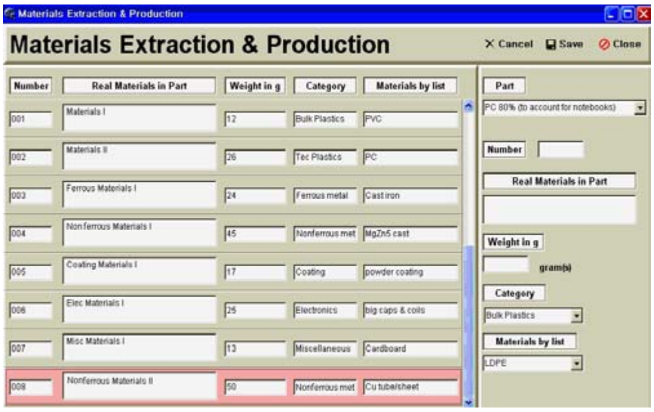


Fig. 4 Material extraction and production form

4.3.2 Manufacturing

Fig. 5 shows the manufacturing form with which designers select the details of the manufacturing process. After selection, if one presses the 'calculate' button, the system automatically shows the total weight of the material used by that process. The manufacturing processes considered by our system are as follows. The weight of an OEM plastic manufacturing process is the sum of the bulk plastics using the plastics category unit indicators. The weight of a foundry Fe/Cu/Zn process is the sum of the cast iron, CuZn38, and ZnAl4 materials. The weight of a foundry Al/Mg process is the sum of the Al die and MgZn5 cast materials. The weight of sheet metal manufacturing is the sum of the galvanized stainless steel sheet, ferrite, stainless 18/8 coil, Al sheet/extrusion, and Cu tube/sheet materials. The weight of PWB manufacturing is the sum of all material in the electronics category except LCDs, CRTs, and IC SMDs. The weight of other materials is the sum of all

Fig. 5 Manufacturing form

material not in the five preceding processes. The weight of sheet metal scrap is calculated using scrap percentage data and the total weight of the sheet metal process.

4.3.3 Distribution

The system only requires three pieces of data for the distribution form. The system needs to know whether the item is an ICT or a consumer electronics product under 15 kg, if it is an installed appliance, and the volume of the final package. If the item is an ICT or a consumer electronics product less than 15 kg, the program uses the CE and ICT impact data per square meter. If the product is over 15 kg, the program uses the appliance impact data per square meter. If the product is an installed appliance, the program uses the installed product impact data per square meter in the distribution and retail category of the unit indicator. If the product is not an installed appliance, the program uses the retail product impact data per square meter and per retail product. The volume of the packaged final product directly influences the total environmental impact of the distribution category.

4.3.4 Use

Fig. 6 shows the use form. The use stage has the highest environmental impact of all stages in most energy-using products. Designers must input detailed information for the electricity required, heat produced, consumables, and maintenance. The program requires the electricity consumption when the product is on and when it is off or in a standby mode so that a precise consumption result can be obtained. The program considers nine types of heat generating methods and the appropriate efficiency interval adjusted for each type. Therefore, precise heat consumption results can be calculated. Many consumable materials are used in this phase, so the program considers the impact of seven representative consumable materials, including water. The total distance traveled to repair the energy-using product and spare part information is also used by the program.

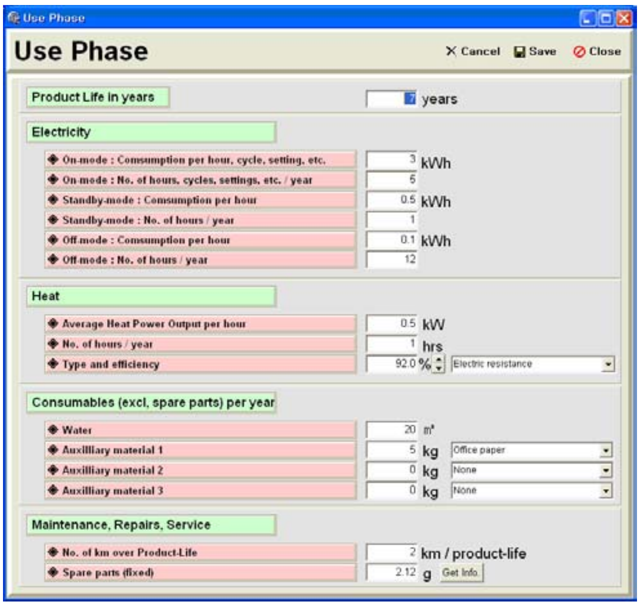


Fig. 6 Use form

4.3.5 Disposal and Recycling

Fig. 7 shows the disposal and recycling form. In this stage, most materials are divided into landfill, incineration, and recycling material. The designer is only required to input a fraction of the data. The recycling ratio of metals and glasses is set to 95%. The PWB disassembly level affects the final environmental impact.

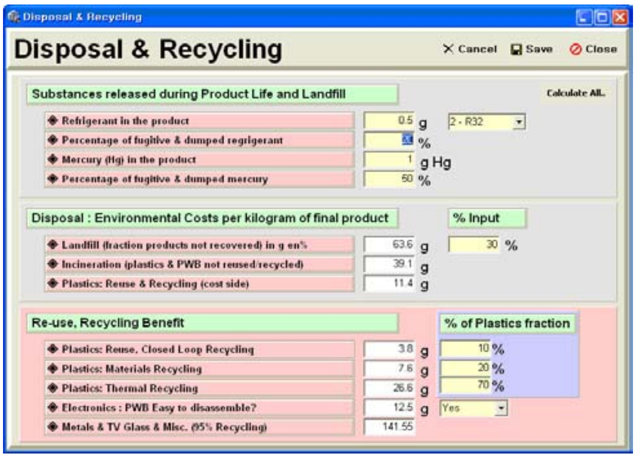


Fig. 7 Disposal and recycling form

4.4 Economic Life Cycle Costs

Fig. 8 shows the EU total and economic life cycle cost form. The product life in years is derived from the environmental section. Some default rates are given for energy and water. All the prices and rates, including the discount rate, can be adjusted. However, the present worth factor in years cannot be changed directly. This is calculated from the discount rate and the product life. The last input in the life cycle cost calculation is a rough indicator of the ratio between the average energy consumption of a new product and the average energy consumption of an old product still in use, or stock product. If no revolutionary growth or decrease in sales has occurred, the average stock product should correspond to a new product produced a certain number of years ago equal to half the product life. For example, for white goods such as refrigerators and dishwashers with a product life of 15 years, the stock product would be equivalent to the average new product produced 7 to 8 years ago.

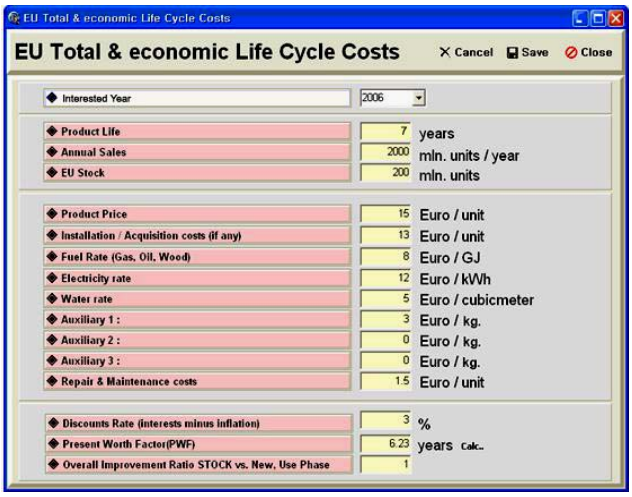


Fig. 8 EU total and economic life cycle costs form

4.5 EuP Eco-report

4.5.1 Life Cycle Impact per Product

Fig. 9 shows the life cycle impact per product form. This indicates the environmental impact per product over a product's entire life cycle. Using the product information and its related environmental impact data, supplied in the bill of material input (Section 4.3), each product's total environmental impact is calculated automatically and the final summed data are provided. Using these data, a designer can determine the environmentally harmful life cycle stages of the product and identify the key impacts.

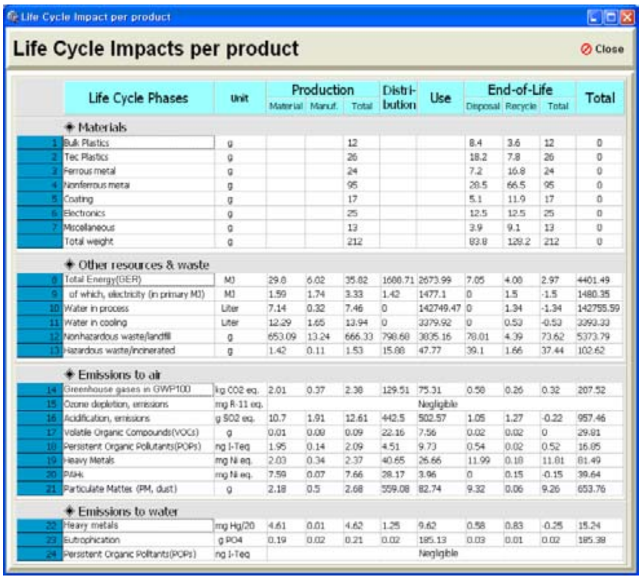


Fig. 9 Life cycle impact per product form

4.5.2 EU Total Impacts of New Models

Fig. 10 shows the EU total impact of new models form. The values contained in this table are calculated from the life cycle cost and impact per product data. Using this, we can determine the total impact of specific new models of a product sold in a selected year. The database allows us to compare data from different years.

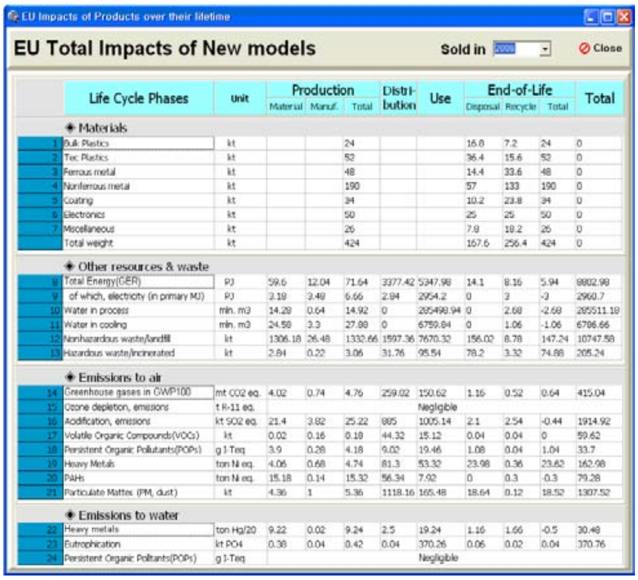


Fig. 10 EU total impacts of new models form

4.5.3 EU Total Impact of Product Stock

Fig. 11 shows the EU total impact of product stock form. This information is also derived from the life cycle cost and impact per product data. The use phase data are not calculated directly, but first multiplied by the 'overall improvement ratio' to indicate the difference between the new sales and the current stock. Policy makers cannot influence this because, on average, most of the impact was caused in the first half of the product's lifetime. The information, however, tells us how the product fits in the current statistics and how much progress the sector is making.

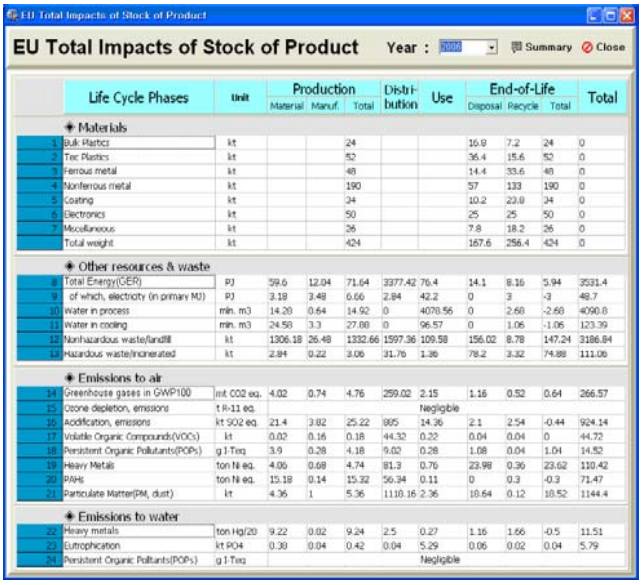


Fig. 11 EU total impacts of stock of product form

4.6 Best Available Techniques

Using ecological profiles, especially eco-reports, the designer can determine which stage has the most critical impact on the environment. Our system prepares environmental design guideline classified by the five life cycle stages. Fig. 12 shows the

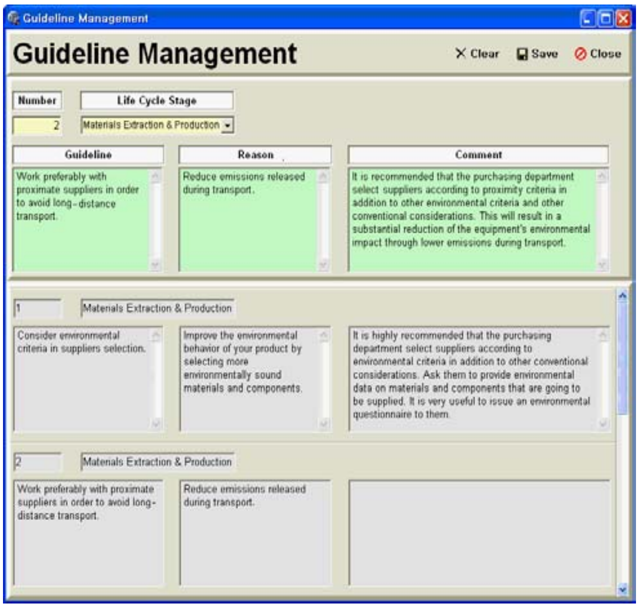


Fig. 12 Environmental design guideline management form

environmental guideline management system. Using this form, a system manager who is well aware of the environmental design guidelines can manipulate the data freely. Most of the data are produced in advance so that product designers do not need to be aware of the guidelines—they only have to use the data. Fig. 13 shows the form supplied to designers who want to investigate the best available techniques. Designers can see the detailed environmental design checklists, and the program allows them to add a guideline into the best available techniques. Since many designers work on one project, only one environmental specialist may be able to identify the necessary guidelines for a product. In this case, all the designers can identify the guidelines that must be improved.

Fig. 13 Design guidelines to search for improvement form

4.7 Case Study

The target product of this case study is a personal computer (but not a workstation). This is a representative energy-using product and an interesting target object.[11] All of the data required by the environmental design system were input, and the following is a real analysis of the results. Life cycle impacts per product is a major result of this system and one of the ecological profiles that EuP directive needs. All of these values can be calculated by using former inputted Bills of Material (BOM) data and data of unit indicators. Specific impact values can be seen in Fig. 14. Graphs of the environmental impact of four important areas are shown in Fig. 15. These four areas are energy, global warming potential, acidification, and heavy metals released into the air. All of the graphs consist of four life cycle stages (they do not include the material preparation stage). The use phase was the weakest life cycle stage. In Fig. 16 and 17, total environmental impacts of EU is introduced. These values can be obtained from per product data and economic life cycle cost data. In these data, all environmental impacts of EU member nations can be searched. In summary, main environmental impacts of stock in 2006 is following. All environmental impacts caused by PC are that total energy

Life Cycle Impact per product

Life Cycle Impacts per product

No.	Life Cycle Phases	Unit	Production Material	Production Manuf.	Production Total	Distribution	Use	End-of-Life Disposal	End-of-Life Recycle	End-of-Life Total	Total
	Materials										
1	Bulk Plastics	g			1488.17			1339.35	148.817	1488.17	0
2	Tec Plastics	g			1586			1427.4	158.6	1586	0
3	Ferro metal	g			9570			478.5	9091.5	9570	0
4	Non-ferro metal	g			917			45.85	871.15	917	0
5	Coating	g			54.2			2.71	51.49	54.2	0
6	Electronics	g			1238.15			1021	217.15	1238.15	0
7	Miscellaneous	g			1176.33			58.8165	1117.51	1176.33	0
	Total weight	g			16029.8			4373.62	11656.2	16029.8	0
	Other resources & waste										
8	Total Energy(GER)	MJ	1906.96	358.66	2265.62	2868.15	16804.76	257.58	194.09	63.49	22002.02
9	of which, electricity (in primary MJ)	MJ	793.92	178.1	972.02	2.27	16767.72	0	26.34	-26.34	17715.67
10	Water in process	Liter	641.78	7.62	649.4	0	1123.69	0	23.5	-23.5	1749.59
11	Water in cooling	Liter	665.85	93.25	759.1	0	44695.59	0	11.04	-11.04	45443.65
12	Non hazardous waste/landfill	g	72101.43	1344.1	73445.5	1407.46	19441.65	983.58	77.49	906.09	95200.73
13	Hazardous waste/incinerated	g	1168.33	1.98	1170.31	27.97	1120.61	2983.92	29.05	2954.87	5273.76
	Emissions to air										
14	Greenhouse gases in GWP100	kg CO2 eq.	114.9	20.85	135.75	216.3	734.56	19.2	13.35	5.85	1092.46
15	Ozone depletion, emissions	mg R-11 eq.					Negligible				
16	Acidification, emissions	g SO2 eq.	921.63	95.5	1017.13	738.4	4327.26	38.47	33.42	5.05	6087.84
17	Volatile Organic Compounds(VOCs)	g	27.64	1.57	29.21	35.55	7	0.68	0.47	0.21	71.97
18	Persistent Organic Pollutants(POP)	ng I-Teq	261.61	26.38	287.99	7.95	112.72	6.85	0.28	6.57	415.23
19	Heavy Metals	mg Ni eq.	220.08	62.05	282.13	71.64	295.52	70.29	3.19	67.1	716.39
20	PAHs	mg Ni eq.	136.25	1.18	137.43	43.77	39.6	0	2.69	-2.69	218.11
21	Particulate Matters(PM, dust)	g	153.59	17.93	171.52	895.16	182.08	333.41	1.32	332.09	1580.85
	Emissions to water										
22	Heavy metals	mg Hg/20	369.34	0.21	369.55	2.21	111.74	21.5	14.48	7.02	490.52
23	Eutrophication	g PO4	10.41	0.44	10.85	0.04	0.52	1.23	0.23	1	12.41
24	Persistent Organic Poltants(POP)	ng I-Teq					Negligible				

Fig. 14 Life cycle impacts of per product for Personal Computer

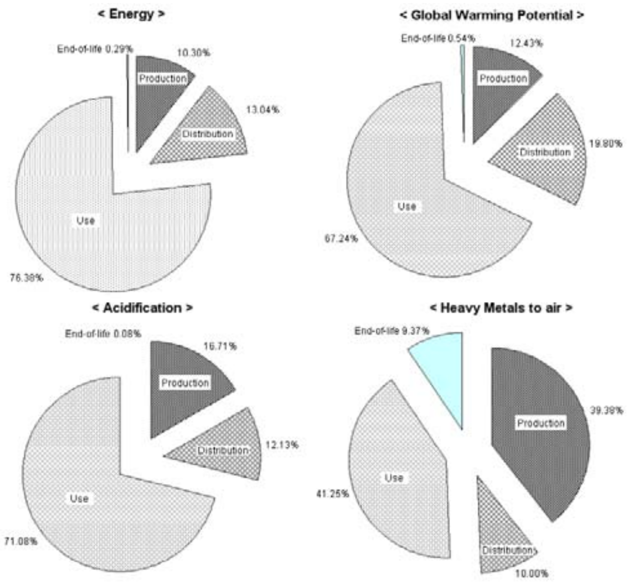


Fig. 15 Graphs of four environmental impact areas of a personal computer

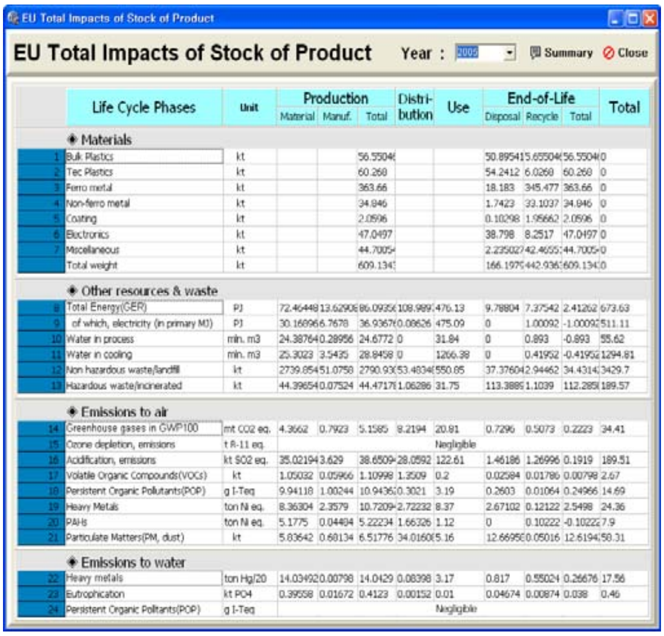
EU Impacts of Products over their lifetime

EU Total Impacts of New models Sold in

No.	Life Cycle Phases	Unit	Production Material	Production Manuf.	Production Total	Distribution	Use	End-of-Life Disposal	End-of-Life Recycle	End-of-Life Total	Total
	Materials										
1	Bulk Plastics	kt			56.5504			50.89541	5.65504	56.5504	0
2	Tec Plastics	kt			60.268			54.2412	6.0268	60.268	0
3	Ferro metal	kt			363.66			18.183	345.477	363.66	0
4	Non-ferro metal	kt			34.846			1.7423	33.1037	34.846	0
5	Coating	kt			2.0596			0.10298	1.95662	2.0596	0
6	Electronics	kt			47.0497			38.798	8.2517	47.0497	0
7	Miscellaneous	kt			44.7005			2.235027	42.4655	44.7005	0
	Total weight	kt			609.134			166.1975	442.936	609.134	0
	Other resources & waste										
8	Total Energy(GER)	PJ	72.46448	13.62906	86.0935	108.989	638.58088	9.78804	7.37542	2.41262	836.07676
9	of which, electricity (in primary MJ)	PJ	30.16896	6.7678	36.9367	0.08626	637.17336	0	1.00092	-1.00092	673.19546
10	Water in process	mln. m3	24.38764	0.28956	24.6772	0	42.70022	0	0.093	-0.093	66.48442
11	Water in cooling	mln. m3	25.3023	3.5435	28.8458	0	1698.43242	0	0.41952	-0.41952	1726.8587
12	Non hazardous waste/landfill	kt	2739.854	51.0758	2790.93	53.4834	738.7827	37.37604	2.94462	34.4314	3617.6277
13	Hazardous waste/incinerated	kt	44.39654	0.07524	44.4717	1.06286	42.58318	113.3886	1.1039	112.285	200.40288
	Emissions to air										
14	Greenhouse gases in GWP100	mt CO2 eq.	4.3662	0.7923	5.1585	8.2194	27.91328	0.7296	0.5073	0.2223	41.51348
15	Ozone depletion, emissions	t R-11 eq.					Negligible				
16	Acidification, emissions	kt SO2 eq.	35.02194	3.629	38.6509	28.0592	164.43588	1.46186	1.26996	0.1919	231.33792
17	Volatile Organic Compounds(VOCs)	kt	1.05032	0.05966	1.10998	1.3509	0.266	0.02504	0.01706	0.00798	2.73486
18	Persistent Organic Pollutants(POP)	g I-Teq	9.94118	1.00244	10.94362	0.3021	4.28336	0.2603	0.01064	0.24966	15.77874
19	Heavy Metals	ton Ni eq.	8.36304	2.3579	10.7209	2.72232	11.22976	2.67102	0.12122	2.5498	27.22282
20	PAHs	ton Ni eq.	5.1775	0.04484	5.22234	1.66326	1.5048	0	0.10222	-0.10222	8.28818
21	Particulate Matters(PM, dust)	kt	5.83642	0.68134	6.51776	34.0160	6.91904	12.6695	0.05016	12.6194	60.0723
	Emissions to water										
22	Heavy metals	ton Hg/20	14.03492	0.00798	14.0429	0.08398	4.24612	0.817	0.55024	0.26676	18.63976
23	Eutrophication	kt PO4	0.39558	0.01672	0.4123	0.00152	0.01976	0.04674	0.00874	0.038	0.47158
24	Persistent Organic Poltants(POP)	g I-Teq					Negligible				

Fig. 16 EU total environmental impacts of new models for personal computer

expenditure is 673 PJ and 76% are used in use phase, total amount of generated Global Warming Potential is 34 Mt CO_2 eq. and 67% are generated in use phase, total amount of acidification material is 189 kt SO_2 eq. and 71% are generated in use phase and total amount of heavy metals to air is 24 ton Ni eq. and 41% are generated in use phase.


EU Total Impacts of Stock of Product

	Life Cycle Phases	Unit	Production Material	Production Manuf.	Production Total	Distri-bution	Use	End-of-Life Disposal	End-of-Life Recycle	End-of-Life Total	Total
	◆ Materials										
1	Bulk Plastics	kt			56.5504			50.89541	5.65504	56.5504	0
2	Tec Plastics	kt			60.268			54.2412	6.0268	60.268	0
3	Ferro metal	kt			363.66			18.183	345.477	363.66	0
4	Non-ferro metal	kt			34.846			1.7423	33.1037	34.846	0
5	Coating	kt			2.0596			0.10298	1.95662	2.0596	0
6	Electronics	kt			47.0497			38.798	8.2517	47.0497	0
7	Miscellaneous	kt			44.7005			2.235027	42.4655	44.7005	0
	Total weight	kt			609.134			166.1975	442.936	609.134	0
	◆ Other resources & waste										
8	Total Energy(GER)	PJ	72.46448	13.62906	86.0935	108.989	476.13	9.78804	7.37542	2.41262	673.63
9	of which, electricity (in primary MJ)	PJ	30.16896	6.7678	36.9367	0.08626	475.09	0	1.00092	-1.00092	511.11
10	Water in process	mln. m3	24.38764	0.28956	24.6772	0	31.84	0	0.893	-0.893	55.62
11	Water in cooling	mln. m3	25.3023	3.5435	28.8458	0	1266.38	0	0.41952	-0.41952	1294.81
12	Non hazardous waste/landfill	kt	2739.854	51.0758	2790.93	53.4834	550.85	37.37604	2.94462	34.4314	3429.7
13	Hazardous waste/incinerated	kt	44.39654	0.07524	44.4717	1.06286	31.75	113.3889	1.1039	112.285	189.57
	◆ Emissions to air										
14	Greenhouse gases in GWP100	mt CO2 eq.	4.3662	0.7923	5.1585	8.2194	20.81	0.7296	0.5073	0.2223	34.41
15	Ozone depletion, emissions	t R-11 eq.					Negligible				
16	Acidification, emissions	kt SO2 eq.	35.02194	3.629	38.6509	28.0592	122.61	1.46186	1.26996	0.1919	189.51
17	Volatile Organic Compounds(VOCs)	kt	1.05032	0.05966	1.10998	1.3509	0.2	0.02584	0.01786	0.00798	2.67
18	Persistent Organic Pollutants(POP)	g I-Teq	9.94118	1.00244	10.9436	0.3021	3.19	0.2603	0.01064	0.24966	14.69
19	Heavy Metals	ton Ni eq.	8.36304	2.3579	10.7209	2.72232	8.37	2.67102	0.12122	2.5498	24.36
20	PAHs	ton Ni eq.	5.1775	0.04484	5.22234	1.66326	1.12	0	0.10222	-0.10222	7.9
21	Particulate Matters(PM, dust)	kt	5.83642	0.68134	6.51776	34.0160	5.16	12.66958	0.05016	12.6194	58.31
	◆ Emissions to water										
22	Heavy metals	ton Hg/20	14.03492	0.00798	14.0429	0.08398	3.17	0.817	0.55024	0.26676	17.56
23	Eutrophication	kt PO4	0.39558	0.01672	0.4123	0.00152	0.01	0.04674	0.00874	0.038	0.46
24	Persistent Organic Poltants(POP)	g I-Teq					Negligible				

Fig. 17 EU total environmental impacts of stock for personal computer

4.8 Material Selection for the EuP

Selecting material while considering the environment is another application area of our proposed environmental design system. Using the material selection program, a designer can evaluate the environmental impact data of various materials in advance and select appropriate material having good mechanical properties and a low environmental impact. Consider a case in which one must select a good polymer material that can be used as a structure. The polymer must have a low environmental impact, and a good strength and modulus. Using the Web-based material database developed by Seoul National University, a designer can draw a modulus versus strength graph, which is similar to an Ashby chart, and then select plastics that have a high modulus and strength.[12-14] These include epoxies such as PVC, PMMA, PS, Phenolic, PU, ABS, PA, and POM.

Various methods are used to compare the eight plastics. Fig. 18 shows a spider diagram of the selected material. In this diagram, each environmental category has its own accounting units, and relative values are used. The spider diagram allows a designer to compare and select more environmentally friendly materials.

The spider diagram is not useful for comparing each plastic in a specific environmental category. The graphs shown in Fig. 19 and 20 are helpful for more serious comparisons. If the materials have similar strengths, having a lower energy consumption is more desirable. From Fig. 19, PS, ABS, and PMMA are good selections. If the materials have similar strengths, having less hazardous waste is better. From Fig. 20, PS and PMMA are good selections. By integrating these results, PS is the best selection with regard to energy, hazardous waste, and tensile strength. Using this procedure, a designer can compare any environmental impact and mechanical property, and obtain good advice.

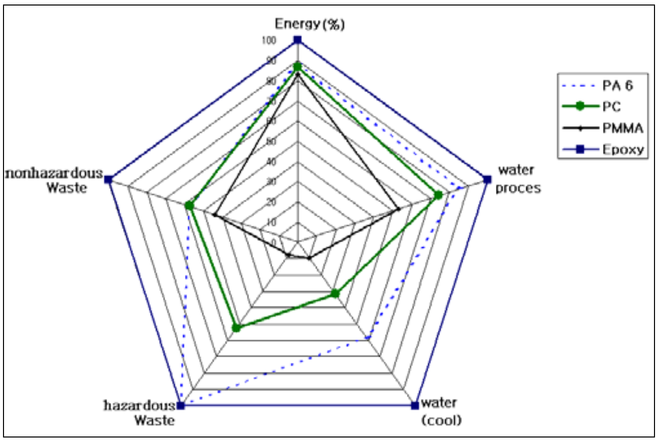


Fig. 18 Spider diagram for selected epoxies

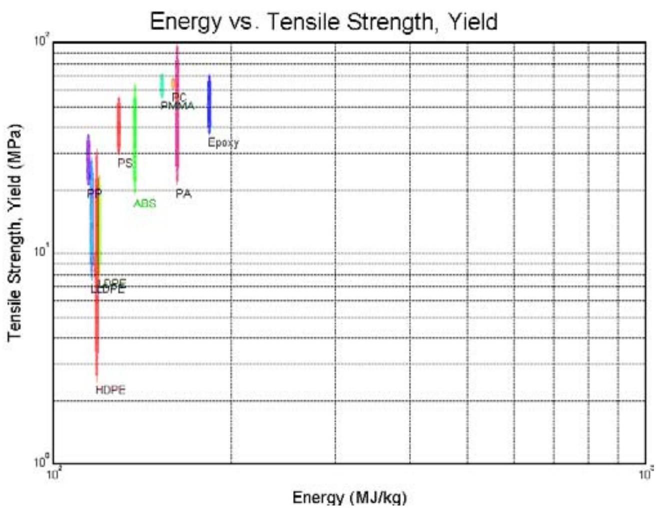


Fig. 19 Graph for energy vs. strength

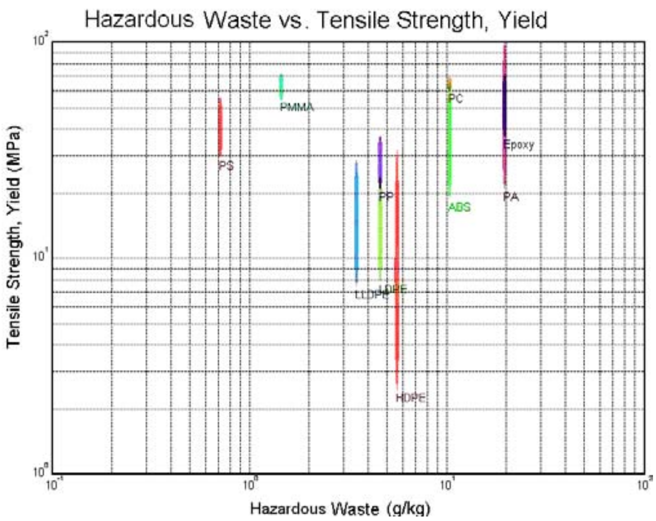


Fig. 20 Graph for hazardous waste vs. strength

5. Conclusion

The concept of environmental design was introduced and its importance in the framework of the environment and business was described. Legislative regulation, the EuP, was the main focus of this study. The aim and history of the EuP were examined, and its requirements were surveyed to create an environmental design system. The architecture of this system was introduced, and the most important ecological profiles were examined. The same accounting units for contaminants must be used when classifying the life cycle stages. Each stage of the life cycle was introduced and the accounting units were given in detail. The environmental design system was developed using all research results, and the individual programs were described. Through case studies, we demonstrated that a designer could identify the environmentally weak stages of a product's life cycle from the final environmental impact results. Designers could obtain eco-design guidelines from the system to reduce the environmental impact of the weak stages. The system also aids in material selection and comparison from an environmental viewpoint.

REFERENCES

1. Park, C.-W., Kwon, K.-S., Kim, W.-B., Min, B.-K., Park, S.-J., Sung, I.-H., Yoon, Y. S., Lee, K.-S., Lee, J.-H. and Seok, J., "Energy consumption reduction technology in manufacturing - A selective review of policies, standards, and research," Int. J. Precis. Eng. Manuf., Vol. 10, No. 5, pp. 151-173, 2009.

2. Hwang, J. and Chung, E.-S., "Analysis of Cutting Fluid Atomization and Environmental Impact through Spin-Off Mechanism in Turning Operation for Environmentally Conscious Machining (I)," International Journal of Korean Society for Precision Engineering, Vol. 4, No. 1, pp. 49-55, 2003.

3. Hwang, J., Hwang, D.-C. and Chung, E.-S., "Analysis of Cutting Fluid Atomization and Environmental Impact through Spin-Off Mechanism in Turning Operation for Environmentally Conscious Machining (II)," Int. J. Precis. Eng. Manuf., Vol. 6, No. 3, pp. 3-7, 2005.

4. Rodrigo, J., Castells, F. and Alonso, J. C., "Electrical and Electronic Practical Ecodesign Guide," University Rovira i Virgili, 2002.

5. Clark, T., Adams, G. and Charter, M., "Smart ecoDesign: Eco-design Checklist for Electronic Manufacturers, System Integrators, and Suppliers of Components and Sub-assemblies," Version 2, Center for Sustainable Design, 2002.

6. Graedel, T. E., Comrie, P. R. and Sekutowski, J. C., "Green Product Design," AT&T Technical Journal, Vol. 74, No. 6, pp. 17-25, 1995.

7. Quella, F. and Schmidt, W.-P., "Integrating Environmental Aspects into Product Design and Development and new ISO TR 14062 Part 2: Contents and Practical Solutions," Gate to EHS, Life Cycle Management-Design for Environment, pp. 1-7, 2003.

8. "Directive 2005/32/EC," the European Parliament and the Council, 2005.

9. Lee, S. Y., "Requirements Analysis of EuP directive," Sustainable Industrial Development, Vol. 9, No. 1, pp. 18-27, 2006.

10. Kemna, R., van Elburg, M., Li, W. and van Holsteijn, R., "Methodology Study Eco-design of Energy-using Products," VHK, 2005.

11. Kemna, R., van Elburg, M., Li, W. and van Holsteijn, R., "Methodology Study Eco-design of Energy-using Products: Final Report," VHK, 2005.

12. Chun, D. M., Ahn, S. H. and Jang, J. D., "Building Web Based Material Database and Example of Material Selection for Engine Pulley of Car," Transactions of the Korean Society of Automotive Engineers, Vol. 14, No. 4, pp. 107-114, 2006.

13. Ashby, M. F. and Johnson, K., "Materials and Design," Butterworth-Heinemann, pp. 49-88, 2003.

14. Chun, D. M., Kim, H. J., Lee, J. C., Ahn, S. H. and Jang, J. D., "Web-based material database for material selection and its application programming interface (API) for CAD," Key Engineering Materials, Scientific, Vol. 345-346, pp. 1593-1596, 2007.