Environmental Quality Function Deployment for Sustainable Products

18

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Abstract

The twentieth century saw remarkable progress in scientific technology that our way of life was drastically transformed; the products humans made and the processes used to manufacture them had a considerable effect on the natural environment. Being aware of this, manufacturers are now trying to develop and commercialize manufacturing processes that produce as little environmental impact as possible ("cleaner production"). In addition, manufacturers are conducting life-cycle assessments (i.e., assessments of the product's whole lifespan from cradle to grave) that specify processes that are considered to have the least environmental impact and maximum "eco-efficiency." However, these techniques cannot be properly evaluated unless attempts are made to understand what is presently unknown with the use of social science, corporate ethics, and science and technology. Even when these concepts are established, there is still a long way to go before theory can be put into practice. Since 1994, the Study on the Introduction and Promotion of Design for Environment (DfE) techniques has studied the evaluation criteria for environmentallyconscious products in Japan. After studying this aspect until the end of the twentieth century, the study continued to develop and examine techniques for DfE. In the twenty-first century, as a final step to developing activities associated with DfE, the development of a technique called QFDE (Quality Function Deployment for Environment) was completed.

This chapter presents a methodology to apply Quality Function Deployment (QFD) for environmentally conscious design in the early stage of product development. This methodology has been developed by incorporating environmental

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aspects into QFD to handle the environmental and traditional product quality requirements simultaneously. "QFD for Environment (QFDE)" proposed consists of four phases. Designers can find out which parts are the most important parts to enhance environmental consciousness of their products by executing QFDE Phase I and Phase II. Further, a methodology to evaluate the effects of design improvement on environmental quality requirements was developed as Phase III and Phase IV. The results obtained from the case study of IC package show that QFDE could be applicable in the early stage of assembled product design, because the most important component from the viewpoint of the environment is clearly identified and multiple options for design improvement are effectively evaluated.

1 Introduction

In recent years, environmental consciousness is rapidly becoming a fundamental product design focus for manufacturers. In 1997, environmentally conscious design (Ecodesign) dissemination project aimed at small- and medium-sized companies has been conducted jointly by UNEP (United Nations Environment Programme), Delft University of Technology and Syntens Corp etc. in the Netherlands (UNEP 1997). There are several design tools in evaluating a product's impact on the environment and disassembly time to enhance recyclability of a product (e.g., Rapoza et al. 1996; Jean et al. 1999). However, most design tools which need detailed data of a product cannot be used in the early stage of product design.

Quality Function Deployment (QFD) which is used to analyze functions required for a product or the product structure to realize these functions is a design tool applicable to the early stage of product development (Akao 1990). In this chapter, a methodology of QFD applied to environmentally conscious design and the result of practical case studies are introduced. Figure 18.1 shows general "Design for Environment (DfE)" flow. After a project team is organized, product concept will be discussed by using QFD, and then conceptual design, qualitative design review, detail design, and quantitative design review are following. "QFD for Environment (QFDE)" consists of four phases. The outcome of QFDE Phase I and Phase II is the identification of the components that should be focused in product design when environmental as well as traditional items are considered. After identifying the important parts and components, design engineers will try to improve the design of their products from the viewpoints of the environment. It is helpful for design engineers to evaluate the effect of their design changes on the environmental aspects of a product beforehand. Further, QFDE Phase III and Phase IV are also developed so that design engineers could examine the possibility of design improvements for each component and find out the improvement effects of their design changes. In the final section of this chapter, the results of verification through the case studies are discussed.

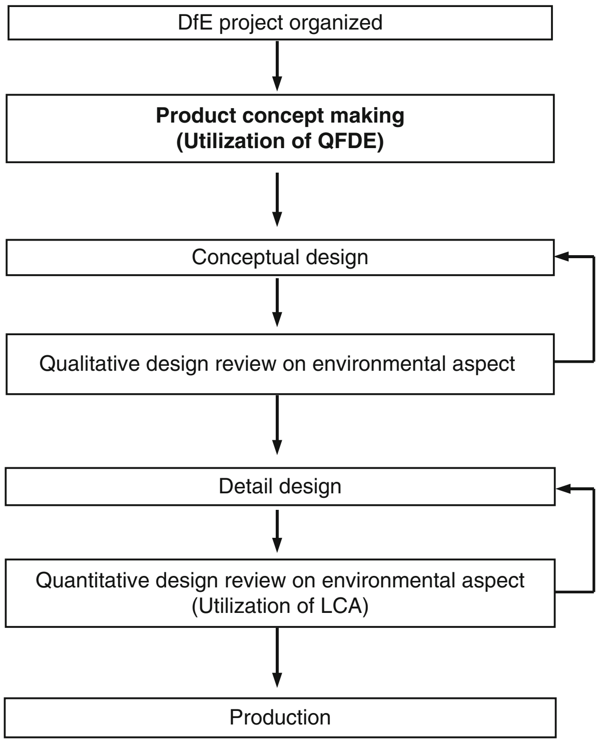

Fig. 18.1 DfE flow and design support tools

2 Applying QFD to DfE

2.1 Quality Function Deployment (QFD)

It is important to listen to the customer requirements to obtain market needs and tailor the product design accordingly. QFD is a method to collect vaguely expressed quality requirements (Voice of Customer: VOC) from the market and deploy them to actual design work.

While QFD needs many phases for deeper hierarchical deployment, only two phases are used in order to translate VOC up to parts characteristics. In Phase I, VOC for a product is deployed to more detailed Engineering Metrics (EM) to clarify their positions. In Phase II, the relationship between the above EM items and components of the product is clarified. Through these steps, the designer can identify which functions and components should be focused in order to satisfy customer requirements. The roles of QFD include the analysis between trade-offs items for design and identification of their product's market competence through benchmarking processes. However, to make it simple, the method to create quality tables is introduced here as they are the basic elements of this tool.

2.2 Voice of Customer (VOC) and Engineering Metrics (EM) on Environmental Aspects

When designers improve their products environmentally, they will listen to the voice of green consumers. There are several research works on green marketing (Stevels 2000); however, the requirements for the environment from the consumers are not strong so far. On the other hand, in recent years, many companies are extending their responsibility to consider the upstream environmental impacts of manufacturing and the downstream impacts of consumer use and disposal of products. OECD's (Organisation for Economic Co-operation and Development) work on Extended Producer Responsibility (EPR) began in 1994, and the trend is toward the extension of EPR to new product groups (OECD 2001). Here, EPR is a policy approach under which producers accept significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products. Assigning such responsibility to manufacturers could provide incentives to form partnerships with customers and recyclers to work on making changes that reduce the environmental impact. Eagan and Finster (2001) identified two categories of customers who might represent the environment. The first category includes the customers who speak directly for the environment like environmental regulators and green consumers. The second category includes the customers whose behavior and actions support the environment such as recyclers and end-of-life disposal plants.

Based on the EPR policy approach as mentioned above, not only consumers (users) but also recyclers, the government, the environment are considered to be customers in this chapter. The author investigated what kind of requirements and attributes should be considered from the environmental point of view through a whole product life cycle, and then integrated those environmental items into a set of feasible environmental VOC and EM, and their correlation factors. The selected environmental VOC and EM are to cover most of the environmental problems, so that designers have only to consider them to incorporate environmental aspects into product development. Also, they are designed for a generic, not specific product. Therefore, designers can use them effectively by ignoring some of them or dividing one into multiple items in more details depending on the type of the product. Furthermore, designers who are not familiar with the environmental science can understand the environmental VOC and EM. It should be noted that these VOC and EM can be employed by incorporating with VOC and EM for an ordinary design with no modification to the framework of traditional QFD. The environmental VOC and EM are explained below. In terms of the environmental VOC, it should be noted that several statements sound like rather technical solutions than typical customer requirements. When recyclers and the government are treated as customers, the voice of recyclers and regulation are often expressed as engineering terms directly.

2.2.1 Environmental VOC

1. Less material usage: using smaller amount of materials for the product.
2. Easy to transport and retain: easy to transport and retain during the logistics to retailers and reverse logistics from users.
3. Easy to process and assemble: easy to process and assemble during manufacturing.
4. Less energy consumption: consuming less energy and electricity during all the life-cycle stages.
5. High durability: slow to deteriorate and highly reliable during usage.
6. Easy to reuse: easy to reuse as a product or as a part.
7. Easy to disassemble: easy to disassemble in the maintenance stage during usage and in the end-of-life stage.
8. Easy to clean: easy to clean the exterior.
9. Easy to smash: easy to smash in the end-of-life stage.
10. Easy to sort: sorting products or parts easily from the viewpoint of material.
11. Safe to incinerate: releasing no toxics during incineration in the end-of-life stage.
12. Safe to landfill: releasing no toxics out of the sites after landfilling the parts or the remaining of incineration.
13. Harmless to living environment: harmless to the living environment of the users and the inhabitants of their neighborhood during the manufacturing and usage stages. For example, toxic substances, noises, vibrations, electromagnetic waves, or smells are not released.
14. Safe emission: safe emission from the manufacturing plants.
15. Possible to dispose of at ease: requesting no consideration of resource depletion or toxicity when users throw away.

2.2.2 Environmental EM

1. Weight: the weight of the product
2. Volume: the volume of the product
3. Number of parts: the number of parts in the product
4. Number of types of materials: the number of types of materials in the product
5. Likelihood to get dirty: the speed of change of the exterior color by the effect of dirt
6. Hardness: the hardness of the parts in the product
7. Physical lifetime: the physical lifetime of the product
8. Amount of energy consumption: the amount of energy consumption along all the life-cycle stages
9. Rate of recycled material: the rate of recycled materials in the product
10. Noise, vibration, electromagnetic wave: the volumes of the noise, vibration, electromagnetic wave given out during the use of the product
11. Mass of air pollutant: the mass of emission of air pollution substances along all the life-cycle stages

12. Mass of water pollutant: the mass of emission of water pollution substances along all the life-cycle stages
13. Mass of soil pollutant: the mass of emission of soil pollution substances along all the life-cycle stages
14. Biodegradability: biodegradability of the materials of the parts to be landfilled
15. Toxicity of materials: toxicity of the materials of the product

3 Identifying the Target of Design Improvement

3.1 QFDE Phase I

Tables 18.1 and 18.2 show examples where QFDE is applied to the design of a hair drier (Ishii 1997). Table 18.1 shows the deployment of VOC to Engineering Metrics (EM) (Phase I). VOC items in the table include the environmental VOC items such as "less material usage" as well as requirement items from customers such as "dries quickly" and "quiet." Usually VOC items are weighed based on market survey to show the "Customer Weights." "9" shows that it is very important, "3" shows it is important, and "1" shows it is slightly important. The degree of importance of environmental VOC is dependent on the concept of developed product or the context of product life cycle. Further, they might be decided based on the result of LCA, which is the quantitative evaluation method, applied to a similar product. On the other hand, EM items include new items such as "amount of energy consumption" as well as traditional items such as "air flow."

At crossing points between VOC items and EM items are shown numbers indicating magnitude of both factors called "Relational Strength" determined by the designer. Similar to the weighing of VOC items, "9" shows the relation is strong, "3" shows it is relatively strong, and "1" shows weak relation. Here, at the crossing points between the environmental VOC items and environmental EM items, the values of relational strength prepared by the author are provided for designer to help their decisions. The total of the sum multiplied by "Customer Weights" and "Relational Strength" is the "Raw Score" for each EM item. Furthermore, "Relative Weight" for each item is obtained by the Raw Score/Sum of the Raw Score. This example shows that "air flow," "air temperature," and "amount of energy consumption" are relatively important as EM items to satisfy customer requirements such as "less energy consumption," "high durability," and "harmless to living environment" as well as traditionally required quality items such as "dries quickly" and "comfortable to hold."

3.2 QFDE Phase II

In the second stage (Phase II) "Deployment of EM items to Components of Product," relative importance for each component of the product is obtained in the same way as in Phase I. As shown in Table 18.2, "motor" is judged most important

Table 18.1 QFDE Phase I of a hair drier

QFD for environment Phase I		Engineering metrics																	
Voice of customer	Customer weights	Air flow	Air temperature	Balance (torque)	Weight	Volume	Number of parts	Number of types of materials	Likelihood to get dirt	Hardness	Physical lifetime	Amount of energy consumption	Rate of recycled materials	Noise, vib., electromagnetic wave	Mass of air pollutant	Mass of water pollutant	Mass of soil pollutant	Biodegradability	Toxicity of materials
Dries quickly	9	9	9									9		9					
Quiet	3	9										9		9					
Operates safely	3	1	9	3					1	3	9			9					
Operates easily	1			3	1									1					
Comfortable to hold	9		1	9	9	9			1		3			1					
Reliable	3	1	1				3	3		9	9	1		1					
Portable	1				3	9													
Less material usage	1				9	9	1	3					9						
Easy to transport and retain	1				9	9						3							
Easy to process and assemble	3						9					9							
Less energy consumption	9	9	9									9							
High durability	9								1	9	9								
Easy to reuse	1								9		9								
Easy to disassemble	3						9	9				3							
Easy to clean	1								9			3							
Easy to smash	3									9		9							
Easy to sort	3						9	9				3							
Safe to incinerate	1							3							9	3	1		9
Safe to landfill	3							3							3	9	9	9	9
Harmless to living environment	9	9	9							3				9					
Safe emissions	1				9	9						3			9	9	9		9
Possible to dispose at ease	3				1	1							3						9
	Raw score	276	282	93	115	120	91	78	39	171	171	273	18	229	27	39	37	27	72
	Relative weight	0.13	0.13	0.04	0.05	0.06	0.04	0.04	0.02	0.08	0.08	0.13	0.01	0.11	0.01	0.02	0.02	0.01	0.03

followed by “housing.” To environmentally improve existing systems, compare the results obtained here with the QFD results without the environmental VOC and environmental EM items.

Table 18.2 QFDE Phase II of a hair drier

QFD for environment Phase II Engineering metrics	Phase I relative weights	Component characteristics Motor	Fan asm	Heater elements	Switch/wiring harness	Housing
Air flow	0.13	9	1	1	1	1
Air temperature	0.13	3	3	9	1	1
Balance(torque)	0.04	9	3			9
Weight	0.05	9	3	3	1	9
Volume	0.06	9	3	1	1	9
Numbers of parts	0.04	1	1		1	9
Numbers of types of materials	0.04	1	1		1	9
Likelihood to get dirt	0.02				3	9
Hardness	0.08					9
Physical lifetime	0.08	9	1	9	3	9
Amount of energy consumption	0.13	9	1	9		
Rate of recycled materials	0.01					9
Noise, vib., electromagnetic wave	0.11	9	3			9
Mass of air pollutant	0.01	9		9		1
Mass of water pollutant	0.02	3			3	1
Mass of soil pollutant	0.02	3			3	1
Biodegradability	0.01	3				9
Toxicity of materials	0.03	3			3	1
	Raw score	6.15	1.58	3.48	0.94	5.14
	Relative weight	0.36	0.09	0.20	0.05	0.30

4 Evaluation Method of Design Improvement

4.1 QFDE Phase III

When design engineers improve their product from a viewpoint of the environment, evaluating the effects of design changes on environmental aspects is an effective process after identifying the important components. In this section, a method to evaluate the effects of design changes for parts or components on environmental aspects (Phase III and Phase IV) is introduced.

In Phase III, the effect of a set of design changes on the engineering metrics (EM) items is estimated. In general, design engineers can make several alternative

Table 18.3 QFDE Phase III of a hair drier

QFD for environment Phase III	Component characteristics						
Engineering metrics	Motor	Fan asm	Heater elements	Switch/wiring harness	Housing	Score	Improvement rate of engineering metrics
Air flow						0	0.00
Air temperature						0	0.00
Balance (torque)						0	0.00
Weight						0	0.00
Volume						0	0.00
Number of parts						0	0.00
Number of types of materials						0	0.00
Likelihood to get dirt						0	0.00
Hardness						0	0.00
Physical lifetime						0	0.00
Amount of energy consumption	9		9			18	0.95
Rate of recycled materials						0	0.00
Noise, vib., electromagnetic wave	9					9	0.43
Mass of air pollutant						0	0.00
Mass of water pollutant						0	0.00
Mass of soil pollutant						0	0.00
Biodegradability						0	0.00
Toxicity of materials						0	0.00

plans. There are two approaches when design engineers decide where they should first focus on. One approach is originated from a target VOC. If they have already had a target of "less energy consumption" VOC for example, they should seek the parts which can suppress in terms of "amount of energy consumption." The other one is examining the most important components identified in Phase II. Table 18.3 shows an example of Phase III for a hair drier. Here, priority was assigned to the environmental aspects, and the design improvement plan was mainly set from the viewpoint of the amount of energy consumption. If it is assumed that the energy consumption of a motor and a heater is reduced and then the noises caused by a motor are reduced, the numbers indicating the relational strength in Phase II (Table 18.2), at crossing points between the target engineering metrics and parts, remained as shown in Table 18.3. The improvement rate to each EM item mr_j is obtained from (18.1):

$$mr_j = \frac{\sum_{k=1}^{K} b_{j,k} c_{j,k}}{\sum_{k=1}^{K} b_{j,k}} \qquad (j = 1, \ldots, J) \tag{18.1}$$

where

K: index number of a component
J: index number of an EM item
$b_{j,k}$: relational strength between jth EM item and kth component in Phase II
$\mathrm{C}_{j,k}$: improvement rate of jth EM item to kth component

Here, $\mathrm{C}_{j,k}$ is originally allowed to take the real number from 0.0 to 1.0. To make it simple, $\mathrm{C}_{j,k}$ can take binary numbers as shown in (18.2):

$$\begin{aligned} \mathrm{C}_{j,k} &= 1 \text{ (improvement possible)} \\ \mathrm{C}_{j,k} &= 0 \text{ (improvement impossible)} \end{aligned} \tag{18.2}$$

4.2 QFDE Phase IV

The mission of Phase IV is to translate the effect of design changes on EM into environmental quality requirements (environmental VOCs). Table 18.4 shows an example of Phase IV for a hair drier. In this table, the number of customer weight and relational strength between VOC items and EM items is same as shown in Phase I (Table 18.1). The improvement rates for the EM items obtained in Phase III are at the bottom of the table. The improvement rate for each environmental VOC vr_i is obtained from (18.3):

$$vr_i = \frac{\sum_{j=1}^{J} mr_j a_{i,j}}{\sum_{j=1}^{J} a_{i,j}} \qquad (i = 1, \ldots, I) \tag{18.3}$$

I: index number of a VOC item
J: index number of an EM item
$a_{i,j}$: relational strength between ith VOC item and jth EM item in Phase I

The improvement effect of the environmental VOC considering customer weight is obtained by multiplying vr_i by customer weight i. The authors consider that this evaluation method for design improvements can help design engineers select the most effective design changes' plan.

Table 18.4 QFDE Phase IV of a hair drier

QFD for environment Phase IV Voice of customer	Customer weights	Engineering metrics Air flow	Air temperature	Balance (torque)	Weight	Volume	Numbers of parts	Numbers of types f materials	Likelihood to get dirt	Hardness	Physical lifetime	Amount of energy consumption	Rate of recycled materials	Noise, vib., electromagnetic wave	Mass of air pollutant	Mass of water pollutant	Mass of soil pollutant	Biodegradability	Toxicity of materials	Improvement rate of customer requirement	Improvement effects of customer requirement
Dries quickly	9	9	9									9		9							
Quiet	3	9										9		9							
Operates safely	3	1	9	3					1	3	9			9							
Operates easily	1			3	1									1							
Comfortable to hold	9		1	9	9	9			1		3			1							
Reliable	3	1	1				3	3		9	9	1		1							
Portable	1				3	9															
Less material usage	1				9	9	1	3					9							0.00	0.00
Easy to transport and retain	1				9	9						3								0.14	0.14
Easy to process and assemble	3						9					9								0.48	1.43
Less energy consumption	9	9	9									9								0.32	2.85
High durability	9								1	9	9									0.00	0.00
Easy to reuse	1								9		9									0.00	0.00
Easy to disassemble	3						9	9				3								0.14	0.41
Easy to clean	1								9			3								0.24	0.24
Easy to smash	3									9		9								0.48	1.43
Easy to sort	3						9	9				3								0.14	0.41
Safe to incinerate	1							3							9	3	1		9	0.00	0.00
Safe to landfill	3							3							3	9	9	9	9	0.00	0.00
Harmless to living environment	9	9	9							3				9						0.13	1.16
Safe emissions	1				9	9						3			9	9	9		9	0.05	0.05
Possible to dispose at ease	3				1	1							3						9	0.00	0.00
Improvement rate of engineering metrics		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.00	0.43	0.00	0.00	0.00	0.00	0.00		
Amount																				2.09	8.10

5 Implementation of Case Study

5.1 Design of an IC Package

Shinko Electric Industries Co., Ltd., which is a medium-sized company in electronics industry in Japan, carried out this case study. IC packages are built in personal computers, cellular phones, video tape recorders, among others. In this case, the product is a type called BGA (ball grid array), which has been already developed and manufactured by Shinko. Figure 18.2 shows the structure of an IC package of BGA type.

5.2 QFDE Phase I and Phase II

Tables 18.5 and 18.6 show the matrices of Phase I and Phase II of QFDE, respectively. In the shaded parts, environment-related items are shown, while others are the items to be considered in traditional design. The results from Phase I show that the important engineering metrics (EM) in this product are (1) radiation capability, (2) high frequency characteristic, (3) toxicity of material, (4) physical lifetime, and (5) amount of energy consumption. The results from Phase II show that the important components are (1) core printed-wiring board (PWB), (2) insulation resin, and (3) inner wiring.

5.3 Design Options in QFDE Phase III

The study team proposed two DfE options with consideration of the results of Phase I and Phase II and an identical economic constraint.

5.3.1 DfE Option I

This option includes redesigning all the following combinations of components and EMs. Table 18.7 shows the process and the result of Phase III for this option.

- Making bonding wire from material with high Young's Modulus to make physical lifetime longer
- Employing lead-free solder in outer terminal to decrease mass of soil pollutant

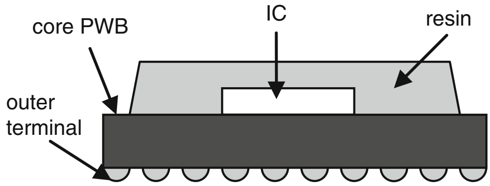

Fig. 18.2 The structure of the product

Table 18.5 The matrix of Phase I in IC package design

QFD for environment Phase I Customer requirements	Customer weights	Engineering metrics: Radiation capability	High frequency characteristics	I/O density	Weight	Volume	Number of parts	Number of types of materials	Likelihood to get dirt	Hardness	Physical lifetime	Amount of energy consumption	Rate of recycled materials	Noise, vibration, electromagnetic wave	Mass of air pollutant	Mass of water pollutant	Mass of soil pollutant	Biodegradability	Toxicity of materials
High I/O density	1	1	3	9	3	3					1			1					
Small size	3	1	1	3	3	9	3				1	3		1	1	1	1	1	1
Good radiation capability	1	9	1	3	1	3	1	1			9								
Ability of protecting IC	9	9	9	1						1	9			3					1
Light	3	1	1	3	9	3	3			1	1	3		1	1	1	1	1	1
Reliability	9	3	3	3			1	1	1	1	9			3					
Good high frequency characteristic	1	3	9	3				1			1			9					
Less material usage	1	3	1	3	9	9	9	9				9	9		9	9	9	9	9
Easy to transport and retain	1			3		3													
Easy to process and assemble	1	1	1	1			9					1							
Less energy consumption	9			3	1	1						9							
High durability	9	9	9						1	1									
Easy to reuse	1		1	1															
Easy to disassemble	1	1	1	1	1	1	9	9				3							
Easy to clean	1								1			1							
Easy to smash	3	1	1	1	1	1		1		9		9							
Easy to sort	3	1	1	1	1	1	9	9				3							3
Safe to incinerate	1	3	1		1	1		3							9	3	3	3	9
Safe to landfill	3	1	1		1	1		3							3	9	9	9	9
Harmless to living environment	9	1	1		1	1				3				1	1	1	1	1	9
Safe emission	1	3	1	1	9	9						9			9	9	9	9	9
Possible to dispose at east	3	1	1		1	1							3						9
	Raw score	240	235	112	90	95	82	71	19	84	179	158	18	79	51	63	63	63	186
	Relative weight	0.13	0.12	0.06	0.05	0.05	0.04	0.04	0.01	0.04	0.09	0.08	0.01	0.04	0.03	0.03	0.03	0.03	0.10

Table 18.6 The matrix of Phase II in IC package design

QFD for environment Phase II Engineering metrics	Phase I relative weights	Parts characteristics					
		Inner wiring	Bonding wire	Outer terminal	Insulation resin	Core PWB	Heat spreader
Radiation capability	0.13	3	1	1	3	3	9
High frequency characteristic	0.12	3	3	3	3	3	1
I/O density	0.06	9	3	9	3	1	1
Weight	0.05	1	1		3	9	3
Volume	0.05	1	1		3	9	3
Number of parts	0.04				1	1	
Number of types of materials	0.04				1	1	
Likelihood to get dirt	0.01			1		1	1
Hardness	0.04					9	
Physical lifetime	0.09	9	9	3	3	3	3
Amount of energy consumption	0.08						
Rate of recycled materials	0.01					1	1
Noise, vibration, electromagnetic wave	0.04	3			3		
Mass of air pollutant	0.03				9	9	
Mass of water pollutant	0.03	3		9	3	3	3
Mass of soil pollutant	0.03	3		9	3	3	3
Biodegradability	0.03						
Toxicity of materials	0.10	3	3	9	9	3	3
	Raw score	2.86	1.93	2.82	3.05	3.22	2.42
	Relative weight	0.18	0.12	0.17	0.19	0.20	0.15

- Changing solvents for insulation resin to decrease toxicity of materials
- Optimizing the thickness of heat spreader to decrease weight

5.3.2 DfE Option II

This option includes redesigns below.

- Employing lead-free ingredient in outer terminal to make physical lifetime longer
- Employing halogen-free resin in insulation resin to decrease mass of air pollutant

Table 18.7 The calculation in Phase III for DfE option I in IC package design

QFD for environment Phase III	Parts characteristics							
Engineering metrics	Inner wiring	Bonding wire	Outer terminal	Insulation resin	Core PWB	Heat spreader	Score	Improvement rate of engineering metrics
Radiation capability							0	0.00
High frequency characteristic							0	0.00
I/O density							0	0.00
Weight						3	3	0.18
Volume							0	0.00
Number of parts							0	0.00
Number of types of materials							0	0.00
Likelihood to get dirt							0	0.00
Hardness							0	0.00
Physical lifetime		9					9	0.30
Amount of energy consumption							0	0.00
Rate of recycled materials							0	0.00
Noise, vibration, electromagnetic wave							0	0.00
Mass of air pollutant							0	0.00
Mass of water pollutant							0	0.00
Mass of soil pollutant			9				9	0.43
Biodegradability							0	0.00
Toxicity of materials				9			9	0.30

- Employing halogen-free resin in core PWB to decrease mass of air pollutant
- Changing heat spreader materials to increase radiation capability

5.4 Evaluation of DfE Options Through Phase III and Phase IV

The improvement effect for the VOCs with their weights was calculated for each DfE option through Phase III and Phase IV. In this case study, the scores of 5.30 and 6.15 were obtained for option I and II, respectively. The team concluded option II to be the best.

6 Summary

“QFD for Environment (QFDE)” has been developed by incorporating environmental aspects (Environmental VOC and Environmental EM) into QFD to handle the environmental and traditional product quality requirements together intended to be used in the early stages of product design. Design engineers can identify components that should be focused in their product by carrying out Phase I and Phase II analyses, and then analyze which design changes among the various alternatives are most effective on the environmental improvement through Phase III and Phase IV.

From the case studies, it was proved that QFDE is applicable to an early stage of the assembled product design. At the same time, some critical points for successful use of QFDE were revealed. It was relatively easy for design engineers to decide the numbers which shows relational strength between engineering metrics and components in Phase II; however, it was difficult to give numbers to relational matrix in Phase I, especially to decide the numbers showing relational strength between the environmental requirement and engineering metrics due to lack of enough knowledge about the environment. Collaboration with environmental specialists is essential for successful use of QFDE.

Future works include an application of QFDE to the stage of developing brand new products, and extension of this method as a communication tool among the supply chain enterprises.

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