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AN ENERGETIC ECODESIGN AT CONCEPTUAL DESIGN PHASE

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The objective of this research is to propose an energetic methodology for developing eco products at the conceptual design phase based upon Concurrent Engineering concept. The contribution of this research lies in the decision support methodology for enhancing product development team to generate the new alternative design ideas at conceptual design phase. The methods, integrating Analytic Network Process (ANP) and the distance-to-target method are used for calculating a single score Ecodesign concept indicator which can deliver ease a single number and ease to understand the new product development process. Magnitude of the single score depicts eco effectiveness compared with baseline product. This methodology highlights the model that can reduce bias and facilitate the decision making process as well as helping in presenting the new idea to stakeholders. A case study, recommendations, limitations and further research are also presented.

Significance: In Ecodesign, the methodology to enhance design concept and quantify alternatives is usually difficult to perform. This methodology aims to propose a way is that can help designers with redesign analysis to create the Eco product.

Keywords: Analytic Network Process; Distance-to-target; Concurrent Engineering; Quality Function Deployment; Theory of Inventive Problem Solving; Patent Mapping.

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1. INTRODUCTION

Currently, environmental concerns have brought new trends of environmental product designs with lower energy consumption, less pollution, minimum end-of-life waste, and improved energy efficiency to global demands. Measures to regulate product design in regarding to environmental impacts or other related issues are currently in place in various regions of the world including the European Union and Japan (Boks, 2006). In addition, Ecodesign makes good business sense and has many other positive effects. For example, reduce material application, improvement packaging design, reduced number of manufacturing processes and the opportunity to promote business to social environmental concern. Thus, many companies have realized the need to become more environmentally responsible. However, considering from a number of the literature reviews have been found that previous studies were often limited by the lack of robust methodology and decision making tool to support the Ecodesign activity, particularly in the early phases of product development that potentiality to reduce environmental impact is the greatest (ISO/TR 14062, 2002). Hence, the objective of this research is thus to propose an appropriate methodology and calculation model to support the entire decision-making process in eco product design in the conceptual design phase based upon CE concept mostly for the electrical and electronics industries that have the intense pressure from Ecodesign point of view.

2. LITERATURE REVIEW

The study on literature reviews defined the term “Environmental product design integration” encompassing the American term “Design for Environment” (DfE) and the European term “Ecodesign” (Baumann et al., 2002). Ecodesign was initiated in 1980 as part of the World Conservation Strategy and focuses on sustainable development for meeting present and future needs (Charter and Tischner, 2001). The emphasis in Ecodesign has been on the early stages of product design and development due to the impact on the cycle of product. ‘Ecodesign’ is the combination of ‘economics’ and ‘ecology’ merged with ‘design’; and the heart of Ecodesign, or ‘Green Design’ is the concept of the product life cycle (Karlsson and Luttropp, 2006). In the past ten years, concerns about the Ecodesign decision support methodologies at the early phase in recent years have been growing such as researcher paper have been published concerning in this stage. Stevens and Burley (1997) investigated about 3000 raw ideas are required to produce sustainability with a newly successful industrial product. Sherwin and Evans (2000) concluded that for industrial design, the ‘best’ place to integrate Ecodesign would be in the product development processes as they were the earliest design stage. Heo (2001) presented a decision making methodology for prioritizing Design for Environment strategies based upon Life Cycle Assessment (LCA) and Analytic Hierarchy Process (AHP). Hsiao (2002) designed a concurrent method for developing a new product using AHP, Quality Function Deployment (QFD), Failure Mode and Effect Analysis (FMEA), and Design for Assembly (DFA). Aoe (2003a) investigated the term "Factor X" amongst well-known Japanese industry leaders such as Fujitsu, Toshiba, and Canon. Kobayashi (2006) designed a systematic approach to eco innovative product design based upon life cycle planning. However, many companies have been struggling with the questions what is the suitable methodology to develop Ecodesign at the early phase and how to measure the Ecodesign concept particularly focused in the conceptual design phase. Due to the most obstacles that product developers face in analyzing the best alternative solution within the limited product is the knowledge available at this stage (Lindahl, 2006).

Hence, the objective of this research is to develop Ecodesign methodology to solve the research questions which have been raised. The challenge for the authors was to consider the core needs of a product whilst minimizing cost and ensuring the integration of environmental aspects within the time constraints of product development.

3. MODEL OF DECISION SUPPORT METHODOLOGY IN CONCEPTUAL ECODESIGN

This model, called **Energetic Ecodesign at Conceptual design phase model** (EEC Model) as illustrated in Figure 1, has been developed based upon "Concurrent Engineering" in green design Implementation (Kusar et al., 2004) and merged with the Ecodesign strategy wheel of Brezet and Hemel (1997) in a conceptual design to perform the near completion of eco product design at an early phase. Various appropriate techniques are included in conceptual design phase as illustrated in Figure 1 following;

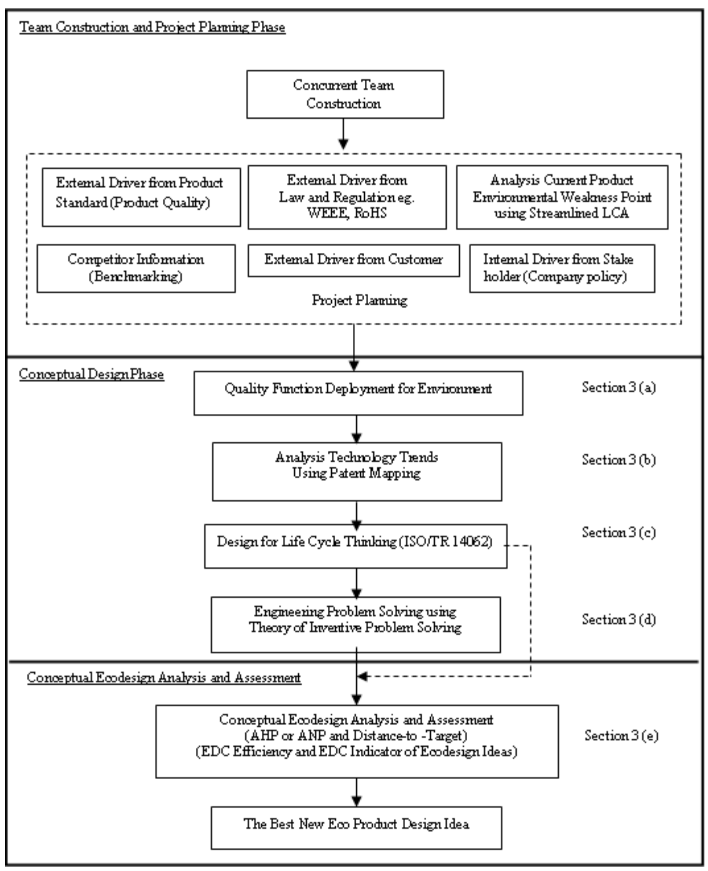

Figure 1. The decision support methodology for developing eco products at conceptual design phase or Energetic Ecodesign at Conceptual design phase model (EEC Model)

The first step, in team construction and project planning phase is Concurrent Engineering, also known as Simultaneous Engineering. This is performed primarily to increase competitiveness by shortening the lead-time, and at the same time improve quality and cost. After that, laws and regulations relating to product review are integrated into the analysis, such as WEEE, RoHS, EuP, IPP regulations, and other standard requirements for each product line or industry concern, market and social demands to manufacture an eco product meeting customers and market needs, as well as product trends (Boonkanit and Apikajornsin (2005a).

Details of this study are collected to deduce the external and internal drivers in order to develop additional eco products. Then, various appropriate techniques are performed to enhance development Ecodesign. The series tools of this stage are following;

(a) Quality Function Deployment for Environment (Sakao et al., 2001). This study applies only phase I and phase II in order to find the component for improvement before applying the engineering solution techniques with further concepts.

(b) Patent mapping technique (Dou, 2004). This method can be used to benchmark the area of R&D of various firms in the sector of development or application.

(c) Life Cycle Thinking (LCT) as standardized by IS0/TR 14062 is the most advanced approach for Eco product improvement, taking into account all life cycle phases from idea design to end-of-life management (Quella1 and Schmidt, 2003).

(d) Theory of Inventive Problem Solving by Altshuller (2005). TRIZ Method can be enhanced problems solving method of engineering design conflict. For more research technique of TRIZ can be study in Tong et al. (2006).

(e) The final important stage, decision making method using AHP or ANP (Saaty, 1996) and Distance- to-Target to quantify Eco Design Concept indicators (EDC indicators). This step perform to calculate "How much of each Ecodesign concept?" In this research, we attempt to quantify an Ecodesign concept indicator illustrating the improvement ratio between new and existing products developed from the concept papers of James (1987) and Aoe (2003b). This equation has been extended from the studies of the ANP decision-making model (Saaty, 1996) and the distance-to-target model (Seppala and Hamalainen, 2001). In terms of the application of Decision Support System (DSS), there are a number of applications using AHP or ANP, for example, Pandey and Kengpol (1995), Kengpol and O'Brien (2000, 2001), Boonkanit and Apikajornsin (2005b) and Kengpol (2006). The series of steps for the calculation conceptual Ecodesign analysis and assessment is illustrated in Figure 2.

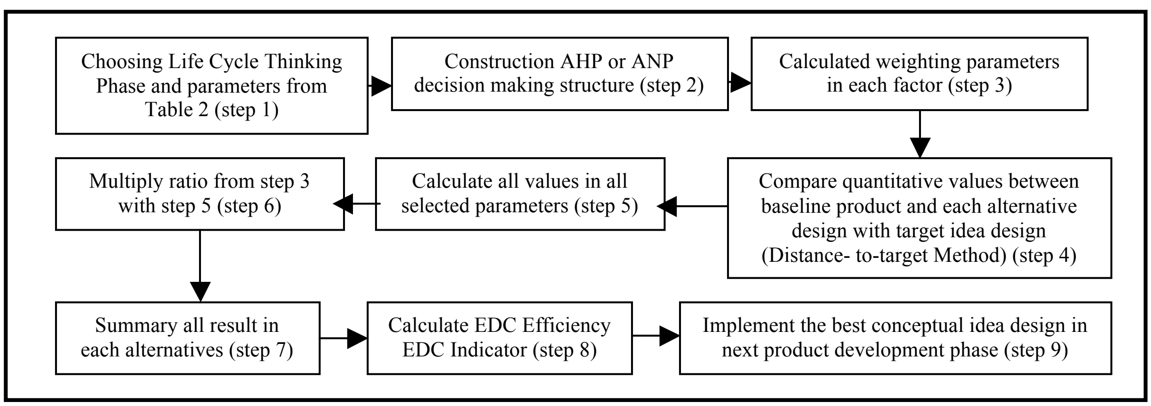

Figure 2. Illustration steps for calculating EDC Efficiency and EDC Indicator (Developed by the authors)

The equations for the calculation of the Ecodesign concept efficiency (EDC efficiency) and Ecodesign concept indicator (EDC Indicator) are as follows:

Ecodesign concept efficiency is calculated by;

$$\text{EDC efficiency} = \sum_{i=1}^{n} WF_i DT_i$$

$0 \leq$ EDC efficiency≤ 1, 0=Non Design, 1.000 = Target Design ... (1)

The best Ecodesign idea is selected by;

The Best Ecodesign Idea = Max $_{\text{(Alternative Design)}}$ $\sum_{i=1}^{n} WF_i DT_i$ ... (2)

Best Ecodesign > Baseline Design
$DT = T_i / P_i, 1(T_i / P_i)$

Ecodesign concept indicator is calculated by;

$$EDC_{Indicator} \quad \frac{EcoEfficiency\_Newproduct}{EcoEfficiency\_Baselineproduct} \quad \ldots \quad (3)$$

Whereas

WF_i = Weighting Factors from Analytic Network Process (ANP)
DT = Distance- to- Target Weighting Method. (Absolute target 1.0)
T_i= Target reference (Base upon stakeholder satisfactions)
P_i =Product reference (Baseline product)
i = Alternative comparing criteria

4. A CASE STUDY

From the introduction and literature reviews, electrical and electronic industries has been received a significant impact by Ecodesign, specifically green product improvement to follow related regulations and customer requirements if they want to export products to European Unions or Japan countries. Accordingly, this study has selected electrical and an electronic industry in Thailand to assess the models with the test model is on a split type industrial air conditioner size 30,000 BTU (British Thermal Unit, BTU). In order to integrate Ecodesign into this model, the decision support methodology base upon CE is applied below,

After the product development team selected and studied the pilot air conditioner, the product development team or called green concurrent engineering team (Member included the authors, research and development engineers, marketing team, financing team, production team, and environmental team) setup new improvement directions with the targets as follows: 1) Decrease the environmental impact at the competitive level 2) Primarily function with engineering efficiency and, 3) Increase the profitable for the company.

The green concurrent team has to consider all Ecodesign project drivers from internal and external issues such as law and regulation related of this model, cost, technology, end use requirements and ease of handling. Increasingly, environmental performance is included as an important consideration. Indeed, the advantage of easy or desirable used is difficult to separate from environmental considerations. As an aid in making design decisions in this step, the authors used the method of Streamlined LCA (SETAC, 1999) in EEC model that we advised in the methodology section. Key outputs of this step include the identification of appropriate parts and environmental impacts of the current product, and an information compilation strategy. The authors identified environmental hotspot causes as: 1) condenser (13.9%) 2) compressor (12.6%) 3) evaporator (10.8%).

The next step, QFDE technique (Sakao et al., 2004) and Kengpol (2004), was utilized in an early phase of product design planning in order to analyze customers' needs and cross check with the results from streamlined Life Cycle Assessment in project planning phase. The review of QFDE from the two phases provides the high Coefficient of Performance (COP), energy saving, new technology design, and price of product as the most important factors from Voice of Customers (VOCs) with effects from compressor, fin coil, condenser, and evaporator. Therefore, the development team directed their attention COP value and energy saving ability. Logical supports from stakeholders' described usually marketing key indicators for air conditioner are energy consumption and new technology design. The measurement of marketing key indicators of air conditioner can be measured by terms of COP and Energy Efficiency Ratio (EER) describes heating and cooling efficiency of air conditioner. During the green concurrent engineering team meeting, we need to consider technology trends to achieve the marketing key indicators. In this step, we have performed with patent mapping method to analyze the potential of technology improvement and its strength and weaknesses.

From various studies on patents, trends in air conditioner development reveal increments of COP and EER values.
Leading companies often use the following technologies are concluded following;

- Solution 1: Cooling pad.
- Obstruction of solution 1: A decreased temperature in the sided air conditioner similar to use in winter with a condenser cooling pad. The heat ventilates to a condenser pad controlling the pressure of solution in the system and the dynamic of compressor not only leads to the electricity saving caused uncontrolled temperature or parameter at nights, but a good ventilation of heat causing the faster cooling and a faster cut-off compressor also reducing the electricity consumption period and the energy utilization..
- Solution 2: Reducing pressure equipment.

- Obstruction of solution2: Difficult to design an input reducing pressure equipment because this solution is a new knowledge of this case study.
- Solution 3: Inverter system.
- Obstruction of solution 3: An adjusted compressor functional level in order to fine-tune operating steps upon the required cooling level, defined as Inverter system, was related to size and location of installment instead of the more efficient air conditioner (Same as technology of competitor A, the competitive analysis found that company A has developed inverter technology to the market; however, the high cost of such research and the investment of inverter system development extended development timeline).
- Solution 4: New fin coil design.
- Obstruction of solution 4: Changing a fin coil to good ventilation for heat was not ready to operate due to future impacts on a production process amendment. (Same as technology of competitor B, with the support of large fin coil industry as the main supplier, the fin coil study could be well developed.)

The above improvement directions were considered and agreed with Design for Life Cycle Thinking concepts to improve the redesign concept based upon group discussion by green concurrent engineering team. According to improvement directions in Table 1 after patent analysis, found that to reduce the pressure before input into the compressor as shown in option 2 was the most appropriate alternative, followed by options 1, 3, and 4. Hence, with in-depth research direction, the product development team focused more on how to designs for a system reducing pressure into a compressor (option 2). In this step, we used the method ascertained resolutions for Theory of Inventive Problems Solving, known as TRIZ. As referred to the Table of TRIZ and the contradiction matrix of Altshuller (2005) in columns 17 (Temperature) and 22 (Loss of energy), finding values of 21, 17, 35, and 38 were obtained as the solution to the problem. In order to solve this problem, the team developer selected option involved transformation of the properties (Transformation of the properties key word in number 35) by adjusting the solution temperature before input to the compressor. According to the guideline solutions from TRIZ method, the conceptual idea option 2 was developed in order to release compressor loading, leveling by the pressure input to the system. Hence, the new equipment has been developed includes 70w air compressor, hydrant system, 5 litters ABS plastic tank, solenoid valve, water level electronic float, water pipe, hosepipe, water spray ABS plastic set 60 cm x 5 cm, and the 100% recycled fin coil.

According to the product development team designed the selected improvements as a good solution for the air conditioner in two directions, namely 1) used condenser Cooling Pad (Option 1) and 2) reduction of the input pressure into the compressor (Option 2). The conceptual Ecodesign analysis and assessment of these two alternatives and those of other competitors was performed as follows: The scoring part was made by Individual Ranking, a responsibility of the product development team leader (Managing Director) who added to the Super Decision software for decision making. The control hierarchy for a case study is contains the overall goal and control criteria (life cycle thinking) with control sub-criteria for evaluation under each criterion included six clusters of life cycle. Six clusters of life cycle stage are illustrated in Figure 3 with Life Cycle Thinking Concept in this model: 1) the Planning cluster (P) containing two elements, namely, Functional optimization of product (P1) and Hazardous materials content (P2); 2) the Concerns of the eco product design, i.e. Marking of Hazardous components (D1), Weight of product (D2), Ratio of weight/length of cable wire (D3), Number and weight of accessory part (D4), and Number of parts (D5); 3) Manufacturing (M) factors including Design for manufacturing (M1) and Environmental effect in manufacturing (M2); 4) Use stage of product life cycle (U) in this phase comprising Weight of total product including Packaging (U1) and Amount of consumer needs (Energy and environmental) (U2); 5) Disposal phase (DS) consisting of Recycle material content (DS1), Recyclable material content (DS2), Number of tools for disassembly (DS3), and Disassemblability (DS4); 6) Other important factors (O) including ways to achieve Product design, the Safety factors calculated by FMEA technique (O1) Aesthetics, (O2) and Economics (O3).

The results of this step from the ANP Model of a case study developed by Super Decision software was used as illustrated in Figure 3 and Table 1, and the results weighting priority from the ANP calculation of each factor in a layer are input to Table 2.

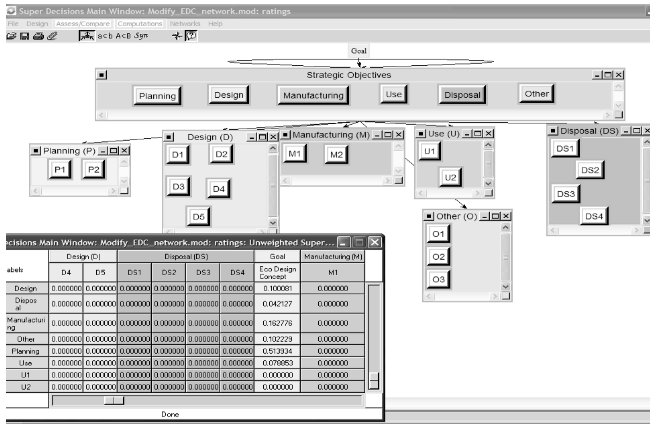

Figure. 3 ANP Model in Super Decision software

Table 1. Priorities and synthesis results of a case study

Planning **(0.514)**	Design (0.100)	Manufacturing (0.163)	Use (0.079)	Disposal (0.042)	Other (0.102)
P1 0.350	D1 0.114	**M1 0.691**	**U1 0.716**	Ds1 0.046	O1 0.238
P2 0.650	D2 0.046	M2 0.309	U2 0.284	Ds2 0.186	O2 0.290
x	D3 0.263	x	x	Ds3 0.220	**O3 0.472**
x	D4 0.063	x	x	**Ds4 0.547**	x
x	**D5 0.514**	x	x	x	x

Table 2. An example of calculation EDC Efficiencies for this study.

Life Cycle Thinking (ANP level 1)	Benchmarking parameters (ANP level 2)	Relation to UNEP Strategy Wheel Relative Importance	Evaluation Value Comparison (Distance- to- Target, DT)						Normalized Improvement Ratio WF_iDT_i					
			Baseline Product (P_i)	Alternative Design 1	Alternative Design 2	Competitor A	Competitor B	Target Product (T_i)	Baseline Product (P_i)	Alternative Design 1	Alternative Design 2	Competitor A	Competitor B	Target Product (T_i)
Planning (0.514)	(P1) Functional Optimization of Product (0.350) (Kg.)	Reduction of material input all Life Cycle Phase	35	44	38	36	42	30	0.155	0.122	0.140	0.140	0.120	0.180
		Optimization energy content materials	0.860	0.680	0.790	0.830	0.710	1.000						
		Reduction of material input all Life Cycle Phase												
	(P2) Hazardous material contents (0.650)	Avoidance of toxic materials and Ozone Depletion (unit milli-point, mPt)	1.9	1.7	1.4	2.2	2.6	1.0	0.176	0.197	0.230	0.150	0.120	0.334
			0.526	0.590	0.710	0.450	0.380	1.000						
Calculate all of life cycle thinking from planning, design, use, disposal, and other phase base upon requirement of team development														
Other	(O3) Safety (0.0471)		74	75	74	75	80	60	0.039	0.038	0.039	0.038	0.036	0.048
			0.81	0.80	0.81	0.8	0.75	1						
								EDC Efficiencies	**0.660**	**0.609**	**0.715**	**0.607**	**0.559**	**1.000**

According to the calculation in Table 2, an example of calculations is presented; the first column is the planning phase; the development team's selection of benchmarking parameter attributes includes the Functional optimization of product and the Hazardous material content. The results of priorities and synthesis in industry collaboration are calculated in Table 2 with the following values: the Planning phase (0.514), the Functional optimization of product (P1 = 0.350) and the Hazardous material contents (P2 = 0.650). Hence, Relative Importance value is multiplied by planning weighting, P1 is 0.514 x 0.350 = 0.180, and planning weighting and P2 is 0.514 x 0.650=0.334.

Next, the evaluation value comparison (Distance-to-Target or DT) of the functional optimization benchmarking parameter is equal to (Target product) 30 kg. / (Baseline product) 35 kg. = 0.860 and the target product of hazardous material content is equal to (Target product) 1.0 mPt. / (Baseline product) 1.9 mPt. = 0.526. Therefore, relative importance is equal to 0.180 (as illustrated in Relative Importance column in Table 2) is multiplied with 0.860 (as illustrated in Evaluation Value Comparison of baseline product (P1) column in Table 2) = 0.155 and 0.334 x 0.526 = 0.176 (as illustrated in Normalized Improvement Ratio of baseline product (P1) column in Table 2).

After Calculations of all number values are completed, the consequences present Option 2 as the most appropriate design, with a score of 0.715. In the calculation of Ecodesign Concept Indicator in this industry collaboration, the manufacturer calculates according to equation number 1, 2 and 3 as example follows:

$$EDC_{\text{Efficiency baseline product}} = \sum_{i=1}^{18} 0.155 + 0.176 + 0.003 ... + 0.039 = 0.660 \quad ... \quad (1)$$

$EDC_{\text{Efficiency}}$ = 0.660 (Baseline), 0.609 (Option 1), **0.715** (Option 2), 0.607 (Competitor A), 0.559 (Competitor B), 1.000 (Target Design)

Best Ecodesign Idea = $\text{Max}_{\text{(Alternative Design)}}$ 0.609, ... (2)
0.715 = 0.715 (Alternative design option 2)

According to Table 3, this value, 0.715 (71.5%), represents the completeness of alternative design concept option 2 compared to its ideal design target value 1.000 (100%).

The last stage of calculation can be obtained through the compare function, i.e.

$$\text{EDC Indicator}_{\text{alternative design1}} = \frac{EcoEfficiency\_Newproduct}{EcoEfficiency\_Baselineproduct} = (0.609/0.660) = \mathbf{0.922} \quad ... \quad (3)$$

$$\text{EDC Indicator}_{\text{alternative design 2}} = \frac{EcoEfficiency\_Newproduct}{EcoEfficiency\_Baselineproduct} = (0.715/0.660) = \mathbf{1.083}$$

The result of computing the EDC Indicator of alternative design option 1 in Table 3 is equal to 0.922, alternative design option 2 is equal to 1.083, competitor A is equal to 0.920 (Option 3), competitor B is equal to 0.846 (Option 4) and the target design is equal to 1.513 which depicts new product development idea alternative 2 is better than alternative design option 1 (1.083-0.922 = 0.161) and approximately 1.083 times better than the baseline product. The EDC Indicator values higher than 1.000 indicate that the new product development idea has been developed better than the baseline product. However, if the EDC indicator values less than 1.000 depicts that the new alternative design is rather not good enough for the investment compared with the baseline model.

Table 3. Result from calculation EDC Indicators of an industrial collaboration

EDC Values	Baseline Product (Current model)	Option 1 (Cooling pad)	Option 2 (Reducing pressure equipment)	Competitor A (Inverter system)	Competitor B (New fin coil design)	Target Design (Ideal Target)
EDC efficiency	0.660 (66%)	0.609 (60.9%)	0.715 (71.5%)	0.607 (60.7%)	0.559 (55.9%)	1.000 (100%)
Best EDC alternative	-	**0.609**	**0.715**	-	-	-
EDC Indicator	1.000	**0.922**	**1.083**	0.920	0.846	1.513

The results of 2 selected alternatives prototype testing are shown in Table 4, i.e. functioning by reducing pressure from spraying water in atom level to the coil pipe and causing steam as heat exchange from the coil to decrease the pressure of solution in the pipe before input being into the compressor. This reduces the compressor loading and also increases efficiency since the experiment with the prototype found changes in Coefficient of Performance (COP) value from 2.76 to 3.78, Energy Efficiency Ratio (EER) value (Btu/h)/ W) from 9.43 to 12.89, electricity consumption saving increased to 26.84%, profit per unit (Sale price – cost) increased 25%.

Table 4. Prototype testing results

Testing Criteria	Baseline Model	Option 1 (Cooling pad)	Option 2 (Reducing pressure equipment)	Percent Difference (%)
Coefficient of Performance (COP)	2.76	3.312	**3.78**	36.95
Energy Efficiency Ratio (EER) (BTU/h)/W	9.43	11.316	**12.89**	36.69
Electrical (kWh/year)	5,497.35	4397.88	**4,021.72**	26.84
Profit per unit (Baht)	8,000	6,000	**10,000**	25

5. CONCLUSIONS AND RECOMMENDATIONS

This methodology is one of the alternatives that can help designers with redesign analysis to create the Ecodesign product development. This methodology can be used to assist product development teams to develop new eco products which can meet stakeholder needs. The conclusions from applying this decision support methodology are following; 1) The ability to reduce time, cost and difficulties in redesigning products is based upon the concurrent engineering concept 2) Major project planning issues can be able to deploy into the strategy improvement using the ability of streamlined LCA technique and Quality Function Deployment for Environment method particularly in energy and environmental perspectives 3) Problems in the conceptual design stage are solved more simply with this method than with other current methods by applying the TRIZ method and patent mapping techniques 4)This methodology fits well in the decision- making step of finding the best solution for the development of an Ecodesign concept with the ANP method and the distance-to-target method. Additional, the authors suggest using more than 3 digits decimal for reducing calculation error.

In terms of the contribution, this research divides into four-fold as follows;

1. This methodology can consolidate design for life cycle thinking, the core concept of Ecodesign, to the early phase of conceptual thinking which is the lowest cost and impacts greatly on the design.
2. Team development can apply Decision Making Method in this Methodology for supporting an efficient decision making in the investment guideline for new product development. This method presents the comparison of redesign option and the comparison of stakeholder's expected target value between competitive products and existing product.
3. The stakeholder can decide an appropriate redesign option for further product development by simply monitoring the maximum design value higher than 1.000 which will be best worth the development.
4. This concept can widely apply to all industries in creating eco labeling type 2 (ISO 14021, 1999) since the entrepreneur can define systematic guideline in communicating all concerning factors to product development and this method is particularly convenient to communicate via the industrial eco labeling on their products.

In terms of limitations, the authors experienced difficulties with companies that lacked data support for the streamlined Life Cycle Assessment method, Voice of Customer (VOCs) for Quality Function Deployment for Environment, results from laboratory test, information from the competitors' products; and understanding concept of Ecodesign and decision making method. Therefore, it is possible that the firms lacking Ecodesign experience may face difficulties when using the model.

For further studies, this research could also conduct to production process improvements or Ecodesign technology initiatives, including other program software commercialization variables in the process of product design particularly in terms of Computer Aided Design software integration.

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