Applied Energy 206 (2017) 222–239

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

A support approach for the conceptual design of energy-efficient cooker hoods

Paolo Cicconi*, Daniele Landi, Michele Germani, Anna Costanza Russo

Università Politecnica delle Marche, via Brecce Bianche, Ancona 60131, Italy

HIGHLIGHTS

- An eco-innovation approach to support the design of household appliances.
- The research is focused on the energy labelling for kitchen hoods.
- A software platform provides tools to configure and optimize new solutions.
- A tool can calculate the energy efficiency indexes of a product configuration.

ARTICLE INFO

Keywords:
Ecodesign
Energy label
Knowledge-based engineering
Product configuration
Virtual prototyping
Optimization

ABSTRACT

In Europe, kitchen hoods currently come with an energy label showing their energy efficiency class and other information regarding the energy consumption and noise level, as established by the European Energy Labelling Directive. Because of recent regulations, designs of cooker hoods must consider new issues, such as the evaluation of the energy efficiency, analysis of the energy consumption, and product lifecycle impact. Therefore, the development of eco-driven products requires Ecodesign tools to support eco-innovation and related sustainability improvements. The scope of the proposed research is to define a method and an agile and affordable platform tool that can support designers in the early estimation of product energy performance, including the calculation of energy efficiency indexes. The approach also considers the use of genetic algorithm methods to optimize the product configuration in terms of energy efficiency. The research context concerns large and small productions of kitchen hoods. The paper describes the methodological approach within the developed tool. The results show a good correlation between real efficiency values and calculated ones. A validation activity has been described, and a test case shows how to apply the proposed approach for the design of a new efficient product with an A-class Energy Efficiency Index.

1. Introduction

Household appliances represent 25% of European energy consumption [1]. The energy efficiency of major household appliances continually increases, and some researchers estimate energy savings of over 10% by 2020 [2]. The EU 20-20-20 Energy and Climate Package aims to improve the energy efficiency in all sectors by 20% by 2020 with a 20% reduction in consumption. Part of this savings can be achieved by changing consumer awareness, habits, and routines. However, it is very important to reduce the purchase of products with low efficiency and high energy consumption in terms of electricity, water, fuel, etc. The EU Commission (EC) has been regulating the requirements regarding the energy efficiency classes for labeling of different energy consuming products, such as several household appliances [3], as established by the EU Energy Labelling Directive (2010/30/EU) [4]. In this context, the first European milestone was the delivery of the EU Ecodesign Directive (Directive 2009/125/EC) [5], which establishes a framework for setting mandatory ecological requirements for energy-using (EuP) and energy-related products (ErP) sold in all Member States [3]. The energy efficiency and the general reduction of energy consumption are considered as key means for reducing greenhouse gas emissions (GHGs) [6]. Currently, energy labeling solutions are used worldwide for different purposes with the same scope to respond to the lack of information regarding energy consumption. Wang et al. showed that environmental awareness, social interaction and resident educational levels have significant effects on purchase intentions [7]. They detailed this result by analyzing the appliances market in China, where the energy efficiency labeling system

* Corresponding author.
E-mail address: p.cicconi@univpm.it (P. Cicconi).

http://dx.doi.org/10.1016/j.apenergy.2017.08.162
Received 21 June 2017; Received in revised form 6 August 2017; Accepted 14 August 2017

Nomenclature

AEC	Annual Energy Consumption
BEP	Best Efficiency Point
BiB	Big is Bigger
CAD	Computer Aided Design
CAE	Computer Aided Engineering
EC	European Commission
ECU	Electronic Control Unit
CFD	Computational Fluid Dynamic
EEI	Energy Efficiency Index
ErP	Energy related Products
EuP	Energy using Products
FEM	Finite Element Methods
FVM	Finite Volume Methods
FDE	Fluid Dynamic Efficiency
GFE	Grease Filtering Efficiency
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
GA	Genetic Algorithm
GHGs	Greenhouse Gas Emissions
MEPS	Minimum Energy Performance Standards
MRF	Multiple Reference Frames
OEM	original equipment manufacturer
O-O	Objected Oriented
UI	User Interface
SAEC	Standard Annual Energy Consumption
SiB	Small is Bigger

was developed in 2005. The use of energy labeling policies is also enhanced by the International Energy Agency [8], which recommends a suite of policies, including mandatory Minimum Energy Performance Standards (MEPS) and labels to promote energy savings in the residential sector. Shi presented an application for setting minimum energy efficiency standards in the case of air conditioners [9]. Shi also highlighted that a lack of incentives, awareness, and information, such as energy labels, may lead to low penetration of energy efficiency products, even when they are technically and economically feasible [10].

The environmental gains related to Ecodesign and energy labeling actions are clear in terms of social impact [11], but few studies are going to analyze the cost impact on the market to understand if the energy efficiency products are economically efficient or not. Household failure to minimize the total costs of energy-consuming investments has become known as the "energy efficiency gap." [12]. The delivery of energy efficient products requires the development of prototypes. Possible approaches can be bottom-up or top-down. A bottom-up approach is expensive and time-consuming and requires detailed manufacturing information [13]. In fact, this first approach is similar to developing a new platform for products. A top-down approach is less expensive than the first. This second approach focuses on study of the best solutions in terms of cost and energy efficiency [13] to support the decision-making process before starting the design process. Generally, configurator tools can support a top-down design process in several applications, from assembled-to-order products to engineered-to-order ones. The household appliances industry represents a case in which a family of products can include hundreds of codes [14]. Each code is a variant of a product, and its design can start from the study of a similar configuration. A top-down design approach, which uses configuration tools, can reduce time and costs related to the design phase and enhance the re-use of past configurations [14].

Some researchers have found that consumer willingness to pay a price for high-efficiency products depends on the back premium related to the energy savings [15,16]. Galarraga et al. analyzed a study concerning the willingness to pay focused on the dishwasher market in the Basque Country (Spain). They showed that people will accept paying up to 10% more for a product if it is A to A+ class [16]. Zhou et al. also proposed a willingness to pay from 5% to 10% for high-efficiency air conditioners in the Chinese market [15]. Generally, the energy money savings is a common metric from the consumer's point of view for comparing the purchase of an energy-consuming product. However, the price of energy does not reflect the true marginal social cost of the energy consumption. In fact, the cost due to all the environmental externalities associated with the production and consumption of energy is very difficult to estimate and is not included in the purchasing energy prices. A recent study showed that Chinese consumers are very conscious of electricity savings. They consider energy-savings an important factor when selecting appliances [17]. This study also showed that Chinese consumers are only willing to pay less than 10% more for energy-efficient appliances [17]. China, which is the world's largest producer and consumer of household appliances, has been developing and implementing energy efficiency standards and labels since 1989 for a wide range of domestic, commercial, and select industrial equipment [18].

Because of current EU policies, in Europe, several ErP and EuP come with an energy label that describes the energy efficiency using an Energy Efficiency Index (EEI). Because the energy labeling leads consumers to invest in energy-efficient products as discussed by Gillingham [6], OEMs and manufacturers must completely rethink their methods of designing, manufacturing and consuming by implementing a responsible innovation strategy [11].

The pursuit of more energy-efficient products introduces an additional cost and time in the design of every OEM involved. To reduce the time and cost impacts for the delivery of more efficient products, big OEMs have been investing in Eco-innovation activities since the delivery of the Ecodesign Directive [13]. This situation has enhanced the adoption of "Design for Environment" and "Ecodesign" studies in design processes [11]. As established by ISO 14062:2011, the Ecodesign approach, which is defined as the integration of the environmental constraints in the development process of product design, leads to two types of analysis: Life Cycle Assessment (LCA) and Design for Environments (DfE) [13]. The same standard defines "Eco-innovation" as a collection of actions that reduce the environmental impacts of a product. Several research studies show real difficulty in making clear the differences and similarities between Ecodesign and eco-innovation [19], as well as defining a boundary between the two concepts [20]. Sherwin underlines that a current Ecodesign approach is focused on preliminary studies such as LCA, which do not involve a functional analysis of the product [21]. In fact, there is a lack of tools that support the eco-innovation process considering different views of the product, including its functionalities and performance [22]. As a solution, Ecodesign tools should interact with the early phases of the product configuration related to household appliances [23]. Malatesta et al. proposed a matrix-based method to configure new variants of household appliances eliciting the requirement compatibilities from existing products [14]. This approach describes how to support the configuration of cookers and provide feedback regarding their cost and technical feasibility; however, they did not consider the calculation of product performance and efficiency. Brones et al. defined an innovative change management approach to evolve towards the "eco-innovation paradigm" considering the social aspect and business process but not the analysis of technical issues [24]. Kengpol and Boonkanit presented a design methodology to support the entire decision-making process in eco product design and re-design from an Ecodesign point of view [13]. They proposed a calculation model for determining an Ecodesign concept indicator. However, their approach did not consider the use of configuration design and simulation analyses to predict a reliable value