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DESIGN GUIDELINES FOR RENEWABLE ENERGY TECHNOLOGIES IN MOBILE PRODUCTS

J.C. Diehl, P. van Gennip and A. Mestre

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1. Introduction

The amount of (consumer) products that consume electricity is still increasing rapidly. Emerging technologies in the field of renewable energy, such as small fuel cells, flexible photo-voltaic solar cells and human power are promising new solutions for sustainable energy sources. As renewable energy sources develop and become smaller and more flexible, possibilities of integrating them into the product design have emerged. However, until recently, renewable energy technologies have been more or less „pasted" upon the products instead of being integrated into the design of the product. It is a big challenge to find the appropriate products or functions for these new technologies and to integrate them into the total design of the product. One of the challenges will be to select those products where the renewable energy technologies can create an added value for the user and for sustainability goals. This is for example the utilization of a high energy density of Fuel Cells for portable products and the creation of independence of the electricity grid.

1.1 Developments in renewable energy technologies

Renewable Energy (RE) technologies like Biomass-Installations, Hydropower and Wind-Energy have their application often on a system level. Other Renewable Energy technologies like Photo Voltaic (PV), Human Power (HP) and Fuel Cells (FC) are also being applied on a product (-system) level. This paragraph will describe in short the technological aspects and the potential benefits & disadvantages of PV, FC and HP in product (-system) applications.

1.1.1 Human Power (HP)

Human Power uses the (physical) energy of the user to support the (electronic) function of the product. There are two ways of generating electricity by means of human interaction: thermal (only low wattage) and physical. The physical human power of the user can be transferred by piezo technologies (0-0,5 Watt), linear (0,5-5 Watt) and rotation (0,5 –50 Watt) induction into electricity. This can be done e.g. by pushing, shaking, pulling, turning a part of the product which is connected to the electricity generating technology. The amount of produced energy depends on the power, frequency and period of the movements of the user and the efficiency of the applied energy conversion technology. Often the generated energy is being stored between the energy generation and use in rechargeable batteries, capacitors or mechanical storage systems like springs and flywheels.
To make use of the Human Power an interaction between the user and the product is needed. With HP technologies only a limited amount of energy can be produced up to around 50 watt. This makes the technology more suitable for low-energy consuming products. Also should be taken into consideration

that the operations needed to create the HP-energy should not conflict with the normal use of the product.

1.1.2 Photo Voltaic Technology (PV)

Solar Power is produced by the conversion of sunlight into DC (Direct Current) electrical power using PV cells. PV cells are modular and light, have no moving parts, have no direct impact on the environment, and require only minimal maintenance [Reinders 2002, Kan 2002]. They therefore offer many potential advantages compared with more conventional power generation systems, including easy installation, long life and durability and low operating costs. PV cells were originally developed in 1970s, at the time they were expensive and quite inefficient. Since then, PV technology has been further developed to improve the efficiency and to reduce costs. During the last decade an efficiency increase of PV cells from 4% to 16% has been achieved. Nowadays, three main types of PV are being applied: Monocreystalline Silicon, Multicrystalline Silicon and Amorphous Silicon PV cells.
The efficiency of amorphous silicon cells is significant lower than the efficiency of monocrystalline silicon cells (7% versus 15%). To produce the same amount of energy with amorphous silicon, twice as big surface of PV cells is needed. This is the reason that these cells are primarily used in low power equipment like watches or as facade elements (in buildings where a big area is available). On the other side, Amorphous Silicon has the particularity to function well at lower light intensities and to be less sensitive to temperature variances. These PV cells also can produce useful quantities of power in less than ideal conditions like in cloudy weather or indoor.
Photovoltaic technology continuous to develop rapidly, and several alternatives to silicon are already under development. The new technologies under development will use less material and energy in production (dematerialization) and are becoming at the same time lighter, this way the costs of the PV cells are becoming lower. New "Thin Film" technologies have made it possible to make PV-cells flexible. These cells are also suitable for different kind of light like indoor and outdoor light.

1.1.3 Fuel Cells Technology

Over the last ten years, there has been a huge global effort to develop Fuel Cells. Originally driven by the prospect of improved electrical efficiency and for improving air quality in urban and indoor environments, Fuel Cells are now seen as an important potential option for improving the sustainability of our energy use, reducing emissions of greenhouse gases and reducing emissions in energy use in sectors as transport or portable electronic products [Hellman 2003].
Fuel cells are electrochemical devices similar, in principle, to primary batteries, except that the fuel and oxidant (e.g. hydrogen and oxygen) are stored externally; they produce both electricity and heat directly. Cells are assembled in modules known as stacks to provide larger voltage and current. One of specific qualities of Fuel Cells is the high energy density compared to other conventional energy technologies.

2. Current applications of renewable energy technologies

A serious amount of RE product-system applications have been collected in order to learn from earlier experiences and problems encountered with the application of RE. These applications can be separated into 4 categories:

- Existing product designs with an "added" RE source;
- Redesign of existing products with "integrated" RE source;
- New products based upon RE technologies;
- New product-systems based upon RE technologies.

In general the following main findings could be made on the observation of "non-successful" integration of Renewable Energy sources in products:

- There is not always an added value for the user created by the RE technology (compared to conventional energy sources).
- There is no match between the generated energy by the RE technology and the consumed energy by the product.

- The PV-technology is not properly integrated into the product design resulting in unattractive product aesthetics.
- There is no insight in the environmental impact or benefits of the PV-technology in the new function.

2.1 PV-powered product-systems

During the last decade the amount of applications of PV-cells connected to products have been increased fast. A wide variety of electronic products are being powered nowadays by PV-cells like solar chargers, outdoors lightning, calculators, gadgets, ticket machines etc.:

<u>1. Existing product designs with an “added” PV source:</u>
In the case of for example a PV-powered weight-scale (see fig. 1) the PV cells have been “pasted” to the product by adding an additional surface. The added PV-cell is not integrated in the total design of the product (neither by shape or colour) and does not create an essential added value for the user (the battery normally only has to be replaced once in 3 years).

<u>2. Redesign of existing products with “integrated” PV source:</u>
If PV-cells replace another type of energy source in a product, it is very likely that the product design and the configuration have to be adapted and optimised for the new situation. The solar battery pack from Nokia (see fig. 1) is a product in which the solar cells, despite of the constrains in size and shape of the battery pack, are integrated well by choosing transparent plastic and hi-tech styling for the surface in which the PV cells are integrated. The added value of this product–technology combination is clear. However, the problem is the balance between generated and consumed amount of energy. Although the PV cell area is small, sufficient amount of energy could be produced in a full day of sun for the proper functioning of the mobile telephone. In reality, however, the mobile telephone will be most of the time disconnected from the sunlight, by the palm of the hand of the user or because of it is being carried inside a bag or the pockets of the user. The PV-cells characteristics and positioning do not match optimal with the user context and energy need.

<u>3. New products based upon PV technologies;</u>
Based upon the characteristics of the new RE technologies and the needs of the user new PV-powered products are being developed. For example several solar chargers (see fig. 1) take the advantage of creating energy everywhere independent from batteries or the electricity grid. The design is often developed around the new function and technology in shape and colour and there is an appropriate match between the energy generation and consumption.

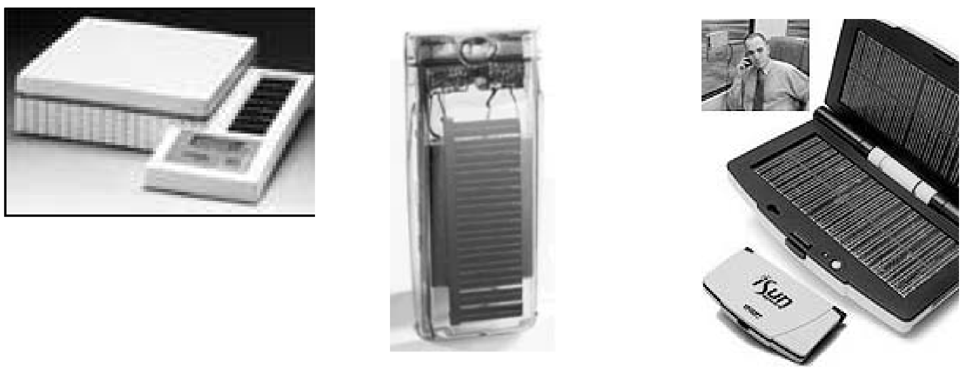


Figure 1. Examples of PV-powered products; weight scale, mobile telephone, PDA and a solar charger for mobile telephones

4. New product-systems based upon PV technologies;

One can observe a fast increase of low voltage and Direct Current (DC) appliances in the household like mobile telephones, Discmans etc. In order to power these products the 220 Alternating Current (AC) has to be converted two times (with efficiency losses) to the low-voltage DC. Renewable Energy technology like PV panels produce directly low voltage DC electricity that make them (more) appropriate to power these kinds of appliances. One of the current solutions under research is to integrate a PV-powered low voltage DC electricity grid in houses to power these products more efficient and to abandon the need of adaptors.

2.2 Human Powered Products

Human-powered products exist already for a long time. Since the introduction of the Freeplay radio in 1996 a new interest in HP has been created and a range of HP products have been introduced into the market (see fig. 2) In the case of the first example, a Freeplay wind-up torch with a metal spring for storage of the energy, one might question if the HP source is not creating any inconvenience because of the added weight and the big dimensions. In the second example, the technology has been integrated more sophisticated into the product (by shaking the torch linear induction within the torch will create energy). Finally several new HP-products have been developed to charge low power products like mobile telephones.

Figure 2. Examples of human-powered products: two torches and a mobile charger

2.3 Fuel Cell Powered Products

Since the miniaturisation and commercialisation of the Fuel Cell technology is more recent, the amount of product examples is much more restricted. Most of the examples (see fig. 3) are still in an experimental or prototype stage. This can be seen in for example the first example, a PDA fuelled by a Fuel Cell. As can be observed easily, the FC source is big in relation to the product and not integrated in the design. Within the second example, a racing cart, the FC has been integrated in the design, however it does not yet match the characteristics of competing technologies like combustion engines. The last one provides the cart with more speed and acceleration power. In the case of the integrated FC power unit into a laptop the FC technology creates an interesting added value for the user: because of the high energy-density of the FC, the user will be able to work at least the double amount of hours independent from the electricity grid.

3. PowerQuest

Existing tools to aid in designing the energy system of mobile products are only available in the form of and books, technical data or limited electronic tools. This results in time consuming and technical complex calculations in order to select a suitable energy system of a product. Today, software tools that could make extensive calculations on the energy yield of photovoltaic and wind energy conversion can be found (i.e. http://www.retscreen.net), but they are not useful for small and mobile applications. The problems with energy related tools such as tools to size photovoltaic or wind energy systems are mainly that these tools are very technology specific that usage requires you to be an energy expert. No tools have been found yet that can provide the product designer with an integral energy system solution [Flipsen et al. 2004].

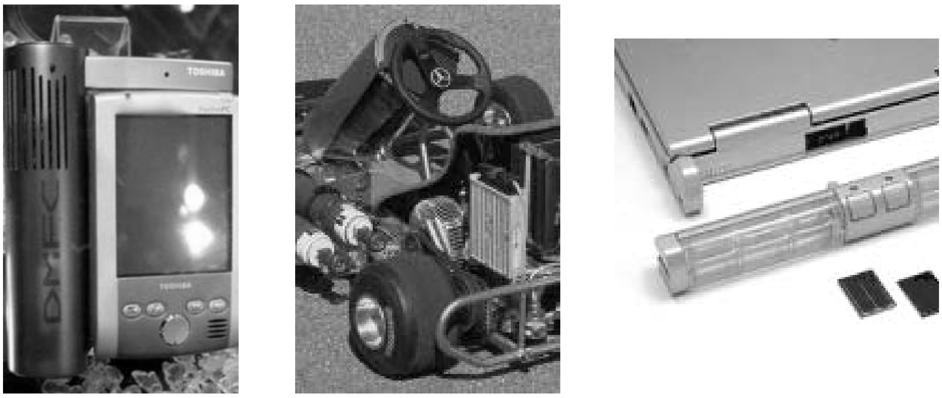


Figure 3. Examples of FC-powered products; PDA, racing cart and a FC-powered Laptop

To create a tool that aids in designing the integral energy system for a product considering product design demands, user context and product usage, a more versatile level of tool integration is needed than is available nowadays. To answer this need, since September 2004, the Design for Sustainability program of Delft University of Technology is developing the so-called PowerQuest tool. PowerQuest is an intuitive on-line tool that translates products design parameters into energy system parameters and vice versa. This design tool provides the user with technical data, design rules and trade-off options for integral product-energy system solutions. The tool comprehends an on-line database where data and design rules are stored in a modular way. This data can be easily updated by experts all over the world through the dedicated content management system.

Design tools should be useful for design engineers [Gennip et al 2006]. To create a useful tool, it should fit into the appropriate phase of the design process. A tool can only be useful if the input and output data respectively match problems and the required solution space. The PowerQuest tool is developed to be used in the early phases of product design, since different energy systems can provoke basic design decisions. PowerQuest is developed to interactively and 'creatively' communicate wit a tool user to suit the design process of thinking.

3.1 Energy system and user context

Products that uses energy to carry out its function needs an energy system to provide this energy. In mobile products, most of the time an energy system is physically coupled to the product, which it provides energy. A product is always used in a certain user context. In this way, the energy system, product and context have a physical interconnection (See figure 4).

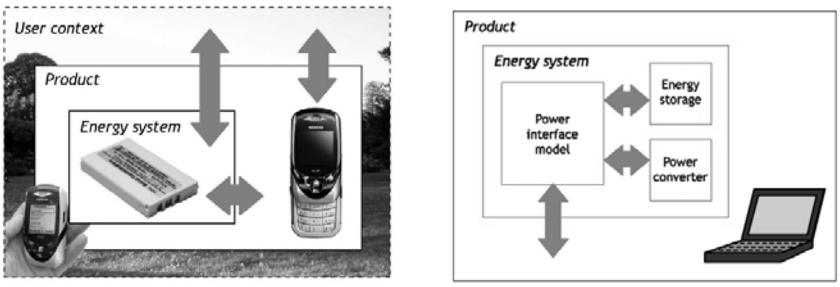
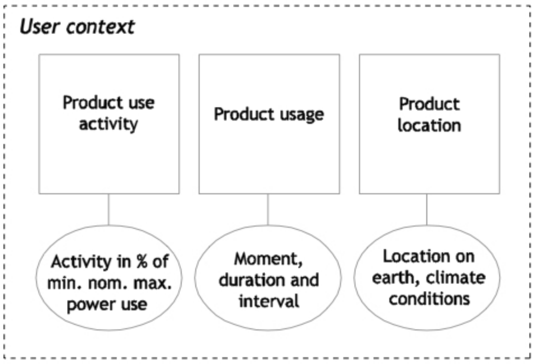


Figure 4. and 5. Product – Energy system – User context relation

Certain user context parameters have an important influence on the energy system operation and performance, so they have to be present in the data model of the PowerQuest tool. With a parameterized representation of energy system, product, user context and design rules, a modular way of data storage is provided by the database of the PowerQuest tool. To make the data modelling process of different energy system technologies modular and transparent, the energy system block can be split up into three parts (see figure 5). By splitting up the energy system up in these three parts, combinations of different technologies can be made in order to make a suitable well-balanced product-energy-user context match.

To be able to extract values from the user context specification, it is split up into quantifiable parameters (see next figure): the *activity* that a user carries out with the product (in percentage of maximum power demand), the *usage* (time) specification and the *location* where product usage takes place. When the activity and product usage specification data are combined, a power-time distribution graph can be extracted.



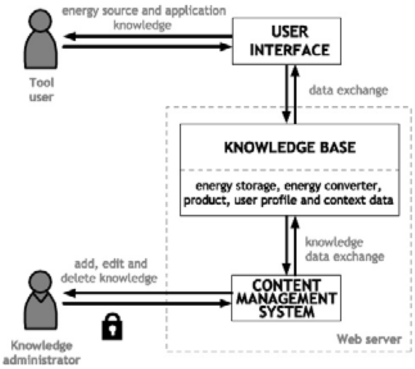


Figure 6. and 7. Product user context specification

3.2 Tool setup

The basis of the PowerQuest tool is the knowledge base that contains all design rules and data: different technology energy storage and energy conversion devices, product parameters, product usage data and user context data (see figure 7). Together with is content management system (CMS), it creates the knowledge management system. By combining the appropriate design rules in the knowledge base, tool users can instantly create and make trade-offs between suitable solutions for a product energy system. The process of using the PowerQuest tool by a design engineer and technology developer is as follows (see figure 8):

1. The tool user enters its products demands and desired user context (design engineer, see figure 7) or energy system parameters (technology developer).
2. The tool user selects which parameters to match.
3. The user interface provides combinations of suitable energy storage and energy conversion units in the desired user context (design engineer) or it provides suitable applications (technology developer) to form a synergic product-energy system.
4. The tool user outputs the desired data in an appropriate output format for use in the design process.

The current version can be found on line at the PowerQuest website: www.powerquest.info.

From the first PowerQuest usability tests can be concluded the PowerQuest, as it is available now (2005), is useful for technology developers. To make it more useful for product designers, the step of matching product parameters to energy systems needs to be implanted. Currently this part is being worked out and will be available on-line in February 2006. In case product designers will start using the PowerQuest tool on a big scale, it can contribute to the integration of potentially sustainable energy systems by bringing them to the attention by bringing them to the attention by making a trade-off between different energy systems.

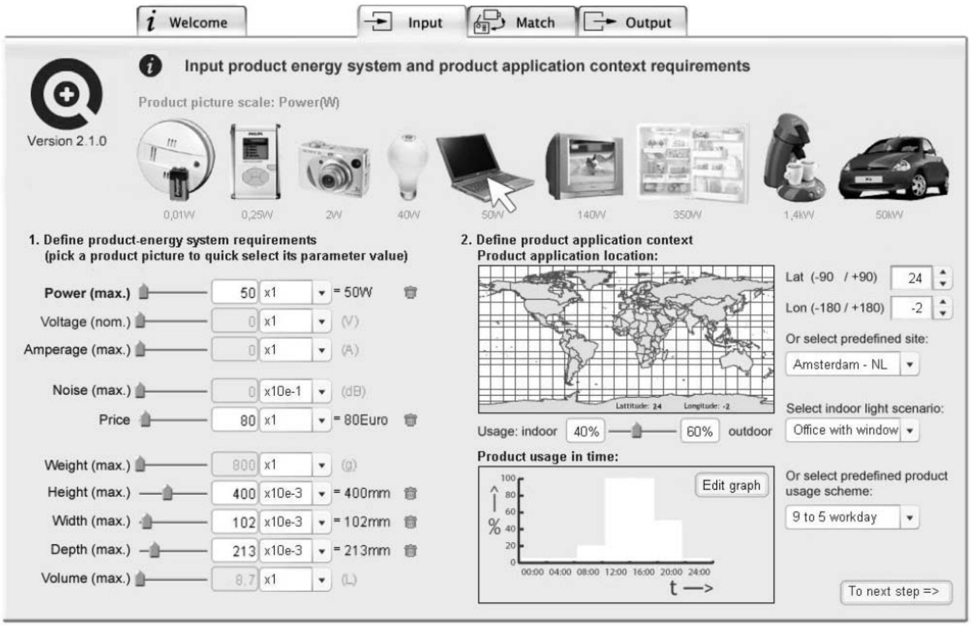


Figure 8. Screenshot of the user interface of PowerQuest

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M.Sc. J.C. Diehl
Delft University of Technology
Landbergstraat 15, 2628 CE, Delft, Netherlands
Tel.: 0031 614015469
Fax.: 0031 614015469
Email: j.c.diehl@io.tudelft.nl