Need-oriented Design for Energy Self-sufficient Households

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Abstract: Design efforts of the last decades remarkably improved consumer products in terms of functional features, user interfaces, and appearances. In innovating products, designers have been highly motivated to proactively search for better solutions, spur technological development, and create new styles, trends, and cultures. When it comes to the energy supply methods for products, however, it is surprising that the conventional electricity-based systems have hardly ever been questioned, but taken for granted. Regardless of the final energy services a product delivers, the device mostly has a plug for electricity. Consequently, consumers have the habit of plug-in. But, is electricity what we really need or want? Aren't there alternative solutions that can fulfil energy needs and demands in a more environmentally-friendly and more economical way? How can designers contribute to improving the efficiency and effectiveness of energy services?

This paper introduces the concept and mechanisms of the energy self-sufficient "Wireless House", which directly uses solar thermal and biomass energy. The design approach is not restricted to the current technical boundaries, but rather concerns actual energy needs and demands. The technical feasibility is illustrated by realised prototypes, and further design challenges are derived.

Key words: Energy self-sufficient house, renewable energy, need-oriented product design, energy supply, solar thermal energy, household appliances.

1. Introduction

Sufficient and stable energy supply is one of the global high priorities. Especially the current economic crisis, political instabilities, growing world population, and the apparent global warming phenomena call for sustainable solutions for energy production and consumption. Various technological innovations for renewable energy production have been achieved and energy-using products have been improved to be more efficient. Nevertheless the critical problem is unchanged: The overall energy consumption is drastically rising. Although the share of renewable energy is growing, the absolute amount of worldwide energy consumption is projected to double by 2050 [4]. This means the overall consumption growth offsets the savings achieved by efficiency improvement. Within the growing energy consumption, especially the demand for electricity is constantly increasing. Taking into account the high conversion losses, it is evident that electricity consumption is one of the main drivers for exploitation of primary energy resources.

This paper presents a radical system innovation approach to tackle these problems, with a focus on the need-side of energy services. Utilising other forms of energy for household appliances and *redesign* of the energy-using products is an important part of this system innovation. By fulfiling thermal energy demands with concentrated solar power (CSP), the strong correlation between the higher living standard and the constantly rising electricity consumption can be broken. Independence from electric energy through the application of appropriate technology also offers a sustainable development perspective for developing countries.

Lotker, in his documentation reflecting the failure of commercialization of large-scale solar electricity in the 90s stated as follows [8]:

> "[…] there is often a false confidence that the renewable energy technologies will be available if and when they are called upon to play a larger role in our energy economy. Unfortunately […], this may not be the case. It shows that a company and a technology must have room to grow if it is to survive […]"

After a long delay, the diversification of energy supply and utilisation of renewable energies is gaining momentum worldwide. Along with technological progresses, need-oriented design solutions will be able to bring real innovations and better use of the technologies. In this regard, the achieved results aim to inspire more designers and producers and to invite them for further actions.

2. Growing Dependence on Electricity and its Environmental Impact

World electricity consumption has never decreased since 1945 [9]. Between 2003 and 2008, it has been increased at an average of around 3-4 percent per year [1]. Although the figure is temporarily decreasing due to the global economic recession,[1] a 'normal' growth rate is expected to return in 2010 [7].

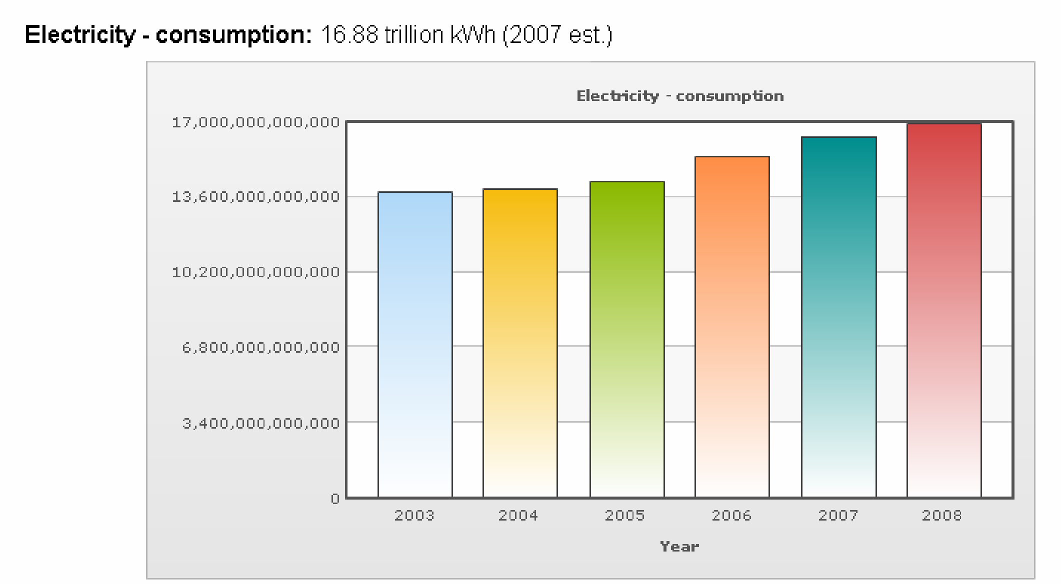

Figure 1. World electricity consumption (2003-2008) [1]

Electrical appliances such as air conditioners, lights, IT equipment, etc. are more frequently and widely used, and many new electrical devices have appeared in the market. Rising incomes and higher living standards of households in developed economies and the socio-cultural trend of smaller households also led to a growing demand for electrical appliances [2]. Especially, in developing countries, larger electricity consumption reflects their economic growth and the tendency towards more energy-consuming lifestyles. The increasing amount of

[1] Electricity consumption strongly correlates with economic growth [2,9].

appliances used offsets the progress achieved by increased energy efficiency, governmental policies and labeling schemes [6]. In developing regions, frequency of black-out and instable electricity supply is one of the biggest concerns. Rising peak load is an important trigger for these problems.

The European Environment Agency (EEA) further depicts the rise in electricity consumption as a serious concern for the environment. This is because about 80 percent of the supplied electricity is still generated from fossil sources such as coal, gas, oil, and from nuclear sources, and production and transmission of electricity involve a high level of efficiency losses [2, 4]. The most widely used coal fired power plants, for example, run at an efficiency of only 34 percent [5]. The generated electric energy is at a household level again converted into different types of energy services such as heating, cooling, lighting, etc. It is remarkable that a large share of these energy services can be summarised as thermal services providing either heat or coldness. Table 1 shows the detailed account of electricity used to operate household appliances in the U.S. [5]. Air-conditioning, space heating, and water heating accounted for an estimated 16 percent, 10 percent, and 9 percent respectively. As single appliances, refrigerators consumed the most electricity (14 percent of total electricity use for all purposes), followed by lighting (9 percent), clothes dryers (6 percent), freezers (3 percent), and color TVs (3 percent) [5]. With the appliances classified by the energy service types, it becomes obvious that most electricity is consumed for thermal energy services. The sum of the thermal energy consumptions exceeds two thirds of the total energy demand.

Table 1. Residential consumption of electricity by energy service types [5]

Energy services	End Use/Appliance	Energy consumption (billion kWh)	Percent (%)
Heating	Space Heating	115.5	10.1
	Water Heating	104.1	9.1
	Clothes Dryer	65.9	5.8
	Electric Range Top	32	2.8
	Dishwasher	29	2.5
	Electric Oven	21	1.8
	Microwave Oven	19.3	1.7
	Coffee Makers	6.0	0.5
	Electric Toaster Oven	1.8	0.2
	Others	16.8	1.5
Sub total		*411.4*	***36.1***
Cooling	Air-Conditioning	182.8	16
	Refrigerators	156.1	13.7
	Freezer	39.3	3.5
	Others	3.2	0.3
Sub total		*381.4*	***33.5***
Other energy services	Lighting (indoor and outdoor)	100.5	8.8
	Color TV	33.1	2.9
	VCR/DVD	11.3	1.0
	Furnace Fan	38.2	3.3
	PCs	18.5	1.6
	Others	63.3	5.6
Sub total		*264.9*	*23.2*
Undefined		83.1	7.3
Total		1,139.90	100

3. Need-based Energy System for Self-sufficient Households

While there are no viable alternatives to electricity for energy services such as lighting, electronic entertainment, communication and media, there are several such alternatives available for the above-mentioned thermal energy services. Taking this fact into account, it is apparent that electricity is not the most 'needed' type of energy in our daily lives. Heat and coldness are far more important when it comes to the final energy services demanded. Then, why have we been accustomed to using electricity? EEA analyses that this results from the attractiveness of electricity, especially its flexibility of use as an energy carrier [2]. Another important reason, however, is the fact that most energy-using household appliances have been *designed* to operate on electricity no matter what type of energy services they provide. These two facts, of course, show a mutual dependence (i.e. they are reason and consequence to each other). For example, standardised electric plugs and consents, as a convenient supply interface, invite more and more household products to use this interface. Having the electric grid readily available is perceived as a design boundary condition at least for immobile household products.

If we view the actual consumer demands and go beyond these boundary conditions of the conventional energy supply and consumption methods, totally different and more straightforward design solutions will be generated and a huge potential of efficiency increase can be mobilised. Direct generation and use of thermal energy at the different temperature levels required can essentially contribute to increasing energy efficiency and minimising the Carbon Footprint of our households.

As a first step, we need to analyse how much and what type of energy we need in our households. Is it heat or light? What is the expected final benefit for the user of those energy services? Based on this analysis of user demands, the household energy system is re-organised to smartly match and balance demand and supply, taking into consideration the various forms of energy required on the users' side. The planning of the energy flow balance also involves the dimensions of time and space. When and where is the particular form of energy needed? How and how long can it be stored? As a matter of fact, heat is much easier to store than electricity - 20 to 100 times more cheaply and with far greater efficiency. According to Romm (2009), this fact is the crucial advantage of CSP over wind and solar photovoltaic [11].

A cascade use of thermal energy throughout the temperature levels and heat storage systems at these different levels are essential parts of the developed solution. The so-called "Wireless House" project of the Center for Appropriate Technology (GrAT) is creating such new demand and supply scenarios. The goal is to realise an energy self-sufficient building that can operate independently from the grid-based electricity supply system and that consumes no fossil energy resources [14].

To achieve this goal, the Wireless House, first of all, minimises energy demand for space heating and cooling by means of passive solar housing technologies. Proper building design and orientation as well as efficient insulation reduce the energy demand for space heating and cooling by a factor of 20 compared to the current standards. This strategy has been proven to be successful throughout demonstration cases such as the "S-House", which reduced energy demand to 6kW/m2 per year [13] (see also www.s-house.at). Other thermal energy services such as hot water, cooking, refrigerating and freezing can be met by directly utilising solar thermal energy and biomass as illustrated in the following figure [16].

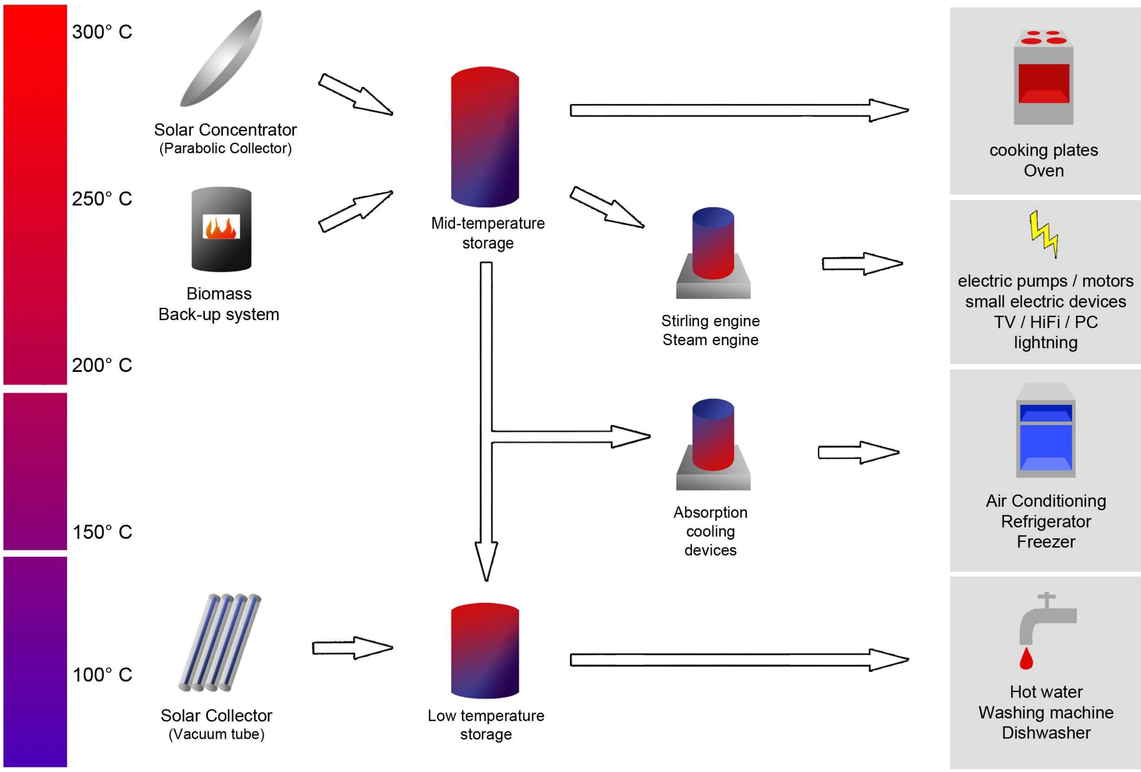

Figure 2. Solar thermal energy supply system of Wireless House [16]

Thermal energy obtained from solar concentrators is stored at a temperature of about 300°C. Oil and stone function as heat transporting and storage media. The highest temperature level serves energy services such as cooking and the Stirling engine that generates a small share of electricity for lighting, computers, AV devices, and so forth. For refrigerating, freezing and air conditioning, absorption chillers are operated at temperatures up to 150°C . The low-temperature level (below 90°C) covers hot water for shower, washing machines, and dish washers. A biomass stove serves as a back-up for occasions of temporarily insufficient solar gains.

The Wireless House concept is also suitable for developing regions in Africa, South America, and South East Asia, where abundant sunlight is available, but where hardly any infrastructures for electricity supply exist.

3.2 Need for Redesign of Household Appliances

It is not only important to generate the right amount of energy, but we also need the appliances that can transform the energy into the necessary services. Modifications of existing products will be necessary and even new household appliances may have to be generated to realise this approach on a large scale. That requires a strong transdisciplinary cooperation between designers, engineers, and users. Some products are already available on the market, such as washing machines with hot water supply instead of electric heating, absorption refrigerators, and solar chillers. In general, however, the use of non-electricity energy resources for household appliances to date is still at an early state. Especially solar cooling devices are fairly unfamiliar in the household goods market. Historical product designs show that the solar cooling had already proven to function (see Figure 3). However, the cheap and convenient electricity-based products excelled these environmentally friendly solutions.

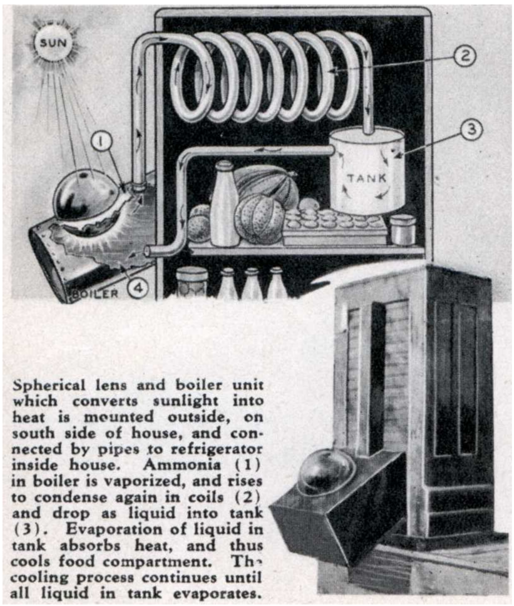

Figure 3. Early solar-thermal based refrigerator designs [10]

Furthermore, there are a number of small-scale devices that have been invented to utilise sunlight as an energy resource for cooling as shown in Figure 4. Yet, these consumer products have not reached the scale overrunning conventional products.


Figure 4. Small-scale cooling devices utilising solar energy (Left: [17], Right: [12])

On the other hand, consumer goods that adopt renewable sources or man-powered electricity (e.g. shaking, winding-up) are limited to small devices such as small radios, calculators, mobile phones and chargers. Available *industrial* products that utilise other types of energy carriers - for example, food industries sometimes develop large ovens for mass production operated with thermal oil - still consume fossil based resources such as gas. The dimension of these industrial products is not suitable for household use. When considering the electricity consumption scale of household equipment, the large-scale thermal devices including refrigerators, cooking ovens, and air-conditioners need to be actively replaced by the innovative energy products. Therefore, development and prototyping focused on these large household products.

The new energy products incorporated into the Wireless House might not have typical cables and plugs for electricity supply, batteries for electricity storage, and may appear fairly different from modern electric and electronic goods. According to the newly defined energy systems, new standards are required instead of the commonly used power plug.

3.4 Prototyping

A number of technical solutions based on existing components like absorption cooling devices and cooking stoves have been modified and adapted in order to verify the technical feasibility of using thermal oil as an energy carrier. The pictures below show the prototyping procedures. An absorption refrigerator was modified to run on thermal oil for producing coldness from the collected solar thermal energy.

Figure 5. Prototyping of a thermal oil based refrigerator and cooking stove [16] (Pictures: Atelier Schmidt)

An electric stove was transformed in the same way to run on thermal oil. The electric heat lines of a conventional kitchen stove were replaced by hard-soldered heat spirals (copper pipelines) similar in dimension, and the copper pipe was filled with the heat carrier oil. Finally, the components were assembled together with a storage tank in order to build a "kitchen module" providing the basic functions of cooking, baking and refrigeration. The flows are designed to work on the *thermosiphon* effect without any pumps. Users can control the device by opening and closing valves.

As shown in the pictures above, the prototypes were testing the basic technical performance of the concept. The design process is still ongoing and not yet determined in terms of shape, size, layout, and styles.

4. Conclusion

The prototyping of selected key components clearly showed that new boundary conditions for this product design are required. These products also need to be well integrated into the whole energy operation system of the Wireless House, in order to maximise the overall energy efficiency. This system integration is one of the most challenging design tasks. As the energy carrier is hot thermal oil, the length of pipes should be kept as short as possible. It is much more beneficial and efficient, therefore, to concentrate these products in a central place (e.g. module) that contains the storage units and appliances, instead of distributing them all over the house and providing supply interfaces in each room. If such a module is prefabricated, the production and installation costs can be reduced, while providing a high standard of safety and convenience.

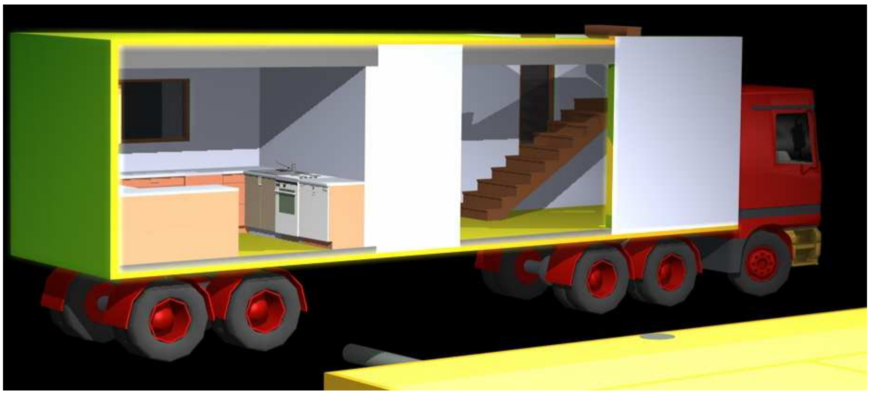

Figure 6. Example of prefabricated modules for energy supply [15]

As already explained, the suggested system is also suitable for many developing countries. Especially where solar thermal energy can be easily and sufficiently harvested, small-scale CSP collectors and direct use of thermal energy can reduce the dependence on electricity and fossil fuels. Another important aspect to be addressed is user acceptance and cultural norms: the new solutions should be as easy to use as the conventional devices, and appropriate for regional/local circumstances. To provide high-quality energy services, region and culture-specific user behaviour under different climate conditions have to be considered. For example, cooking temperature might be different according to traditional cuisine and common food processing methods. Likewise, consumer behaviour in using the new facilities will be also monitored through trials and demonstration projects, and the results will provide valuable input for further improvement.

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