A Survey and Thought-Provoking Impulses on Tackling Energy Efficiency in Households and Office Spaces

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Abstract
This paper is divided into two parts. First, it conducts a survey on how information and communication technology (ICT) have recently been applied for gaining more energy efficiency in households and office spaces. And second, it moots some new thought-provoking impulses on how to proceed with applying ICT to support more sustainable energy-efficient developments for domestic and corporate environments.

Keywords
Energy efficiency, productivity, wasted energy, LEED, context-awareness

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Survey, Thought-provoking Impulses, Human Factors

Introduction
Energy is an integral part of almost all actions of our lives. Although energy is such a valuable resource, it might become in the long-run scarcely available to

humans: Estimates yield that for the year 2030 the global energy demand will double. And in addition, energy related greenhouse gas emissions are expected to rise up to around 55 percent than today [7]. In particular, the building sector constitutes a significant portion of the overall consumed energy; and, this fact refers to both developing and industrial countries [17].

In the style of *Taherian et al.* a *human-centric* approach will be applied to examine energy efficiency. At this, the focus of this paper is on households (domestic) and office spaces (corporate). Although, domestic and corporate environments are partly different, both also complement each other by involving humans strongly in actions taking place that demand energy [14].

This paper is divided into two parts. First, it conducts a survey on how information and communication technology (ICT) have recently been applied for gaining more energy efficiency in households and office spaces. And second, it moots some new thought-provoking impulses on how to proceed with applying ICT to support more sustainable energy-efficient developments for domestic and corporate environments.

Survey

Fortunately, in the recent years the *research community* realized several mobile and ubiquitous prototypical applications that demonstrate examples for driving energy efficiency [3,8,9,10,16]. Solely, the European Union has funded several research projects dealing with how to apply ICT for gaining more energy efficiency, only to name a few: BeAware[1], beywatch[2], or CITY-NET[3]. Summing up their broader focus is on saving energy and by this reducing the global carbon footprint as well. In this sense, many applications have been designed and evaluated that manage the user-centric intelligent monitoring and interactive control of energy consumption in domestic or corporate environments. Basically, often the electrical energy has been the main focus—with good cause, as 40% of energy consumed is electrical energy, and moreover this figure is estimated to rise for the next few decades [15]. In general, the outcome of those scenarios is to reveal energy hogs in households or office spaces. For this technically often off-the-shelf smart meter plugs are deployed that can capture in near real-time consumed energy and communicate this with wireless communication radio, e.g. Bluetooth or ZigBee to some application specific gateway; suppliers of smart meter plugs are Plogg[4], or Plugwise[5]. All those applications [3,8,9,10,16] differ in their specifics, though in their essentials all target mainly two goals. First, to visualize energy consumption from a human-computer interaction perspective through intuitive or user-friendly interfaces respectively. And second, as a cause of this newly created transparence, to increase energy awareness of users within a given space.

In the last decade, in *industry* many start-ups and spin-offs have started to emerge setting themselves the goal to build smart energy solutions. These solutions shall facilitate to reduce the overall energy consumption following the vision of becoming a green world. Several

[1] BeAware Project, http://www.energyawareness.eu/beaware/

[2] beywatch Project, http://www.beywatch.eu/

[3] CITYNET Project, http://citynet.zafh.net/

[4] Plogg, http://www.plogginternational.com/

[5] Plugwise, http://www.plugwise.com/

companies, e.g. Crestron[6], Honeywell[7], or Lutron[8] offer already customized solutions that are often summarized under the term *building management* or *home automation* systems. Further, large network providers, telecommunication and software companies, or not least energy providers have built small joint ventures dealing specifically with energy efficiency. Often those machined solutions represent sophisticated set-ups that are fine-tuned against a specific user profile. For instance, a little part of such a smart energy system could be a mechanism that regulates the electrical light inside a building according to the daytime and calendar date, or amount of brightness.

Energy relevant parameters

Below some energy relevant parameters will be defined to avoid any misunderstandings in the next chapter.

Energy consumption
This describes the amount of energy, expressed in kilowatt per hour (kW / h), that is required, e.g. to use different appliances in private households. Physically the term energy efficiency is incorrect, as in an integrated circuit energy cannot be consumed, but only be transformed. Correct notations should rather be *energy demand* or *energy requirement*. Though, for the sake of simplicity energy consumption has permeated. Energy consumption in households or office spaces typically comprises: heating, cooling, lightning, cooking, or miscellaneous electric loads resulting from using electric devices or appliances.

Productivity
Productivity is one *essential* economic characteristic number. It forms the quotient: *output / input*. Energy costs belong to the input. For a company it is important to keep this figure high in order to run a business that is profitable, i.e. mathematically formulated: Productivity>1. Hence, from a business perspective for a company it might be unimportant if the energy consumption rises, as long the productivity rises proportionally.

Wasted Energy
This figure refers to the amount of energy that is used ineffectively while providing a certain service. For instance, if an air condition would cool an empty office room for the next two hours, as the person by whom the room is generally occupied forgot to switch it off.

Varying energy pricing
In future, energy providers will charge customers for varying energy prices, e.g. ‘time of day pricing’, or depending on the amount of natural resources that has been used to produce energy. In the United States flexible energy price tariffs are already in practice, e.g. at Alabama Power[9] or ComEd[10]. For customers who agreed on a real-time pricing tariff the price changes are projected at least one day in advance. Customers have already been able to cut costs up to 15%, and by this at the same time contributed to reduce the total pollution from power plants [13].

[6] Crestron Electronics, http://www.crestron.com/

[7] Honeywell, http://www51.honeywell.com/honeywell/

[8] Lutron, http://www.lutron.com

[9] Alabama Power, http://www.alabamapower.com/

[10] ComEd, http://www.thewattspot.com/

Leadership in Energy and Environmental Design
Leadership in Energy and Environmental Design[11] (LEED) is a classification scheme for an energy- and eco-friendly development of buildings. A building can be classified into four quality levels: certified, silver, gold and platinum.

Discussion & Approaches

All referred approaches represent good examples how ICT can drive energy efficiency in households and office spaces. Further, these applications may achieve a certain sustained success. For instance, these scenarios may help to detect energy guzzlers in private households that can be replaced by more efficient appliances. Also, a newly created energy awareness of users may help to change their personal behavior towards being more saving. In effect, the study of [2] showed that feedback on domestic energy consumption helped to yield savings in the range of 5-15%. However, future enhancements are required for tackling *sustainably* energy efficiency.

Gap between research and industry
Actually, academic research in energy efficiency is becoming somehow *insular*. A lot of systems are more or less redundant and built from scratch rather than on top of existing solutions. This is unfavorably fostered by existing industrial solutions that are often too expensive or *per se* reflect a too specific design, and thus constraining any openness. Hence, a rather *lively* exchange between research and industry would be more appropriate. Therefore, an approach would be to analyze available off-the-shelf solution in industry that can be extended by novel concepts conceived in research.

Middleware
The *use* of a middleware layer hiding the details of the different technologies *dealing with energy literacy and control* is fundamental to exempt programmers from details that are not directly pertinent to their focus, which is the *application* development *itself* enabled by *a* given infrastructure. For instance, in [8] a generic middleware for networking embedded systems has been applied successfully for this purpose.

Exchange Standard
So far, no common data exchange standard does exist for energy efficiency systems. However, a high degree of interoperability can establish data transfer, or beyond this the execution of distributed programs among coherent and isolated applications. A certified standard, something like the DLNA[12] standard for multimedia, which solves to use digital media between different consumer electronic devices, is missing. The DLMS[13] standard proves that it works to provide interoperable energy relevant data on the lower layer. Why do not provide something appropriate at the application layer?

Control of Energy Usage
Even if the user has the access to control and monitor in near real-time his energy consumption by the use of smart home applications, it is arguable that end-users will not be constantly able to update their specific profile due to time and further preferences; even, if energy providers will project prices one day in advance. A negative cause of fluctuations in real-time energy pricing could be that customers must fear to pay twice or three

[11] LEED, http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1988

[12] DLNA, http://www.dlna.org

[13] DLMS, http://www.dlms.com

times more than they normally would. However, by hindsight energy savings are not only favorable for customers to reduce their bills, but also for energy providers in order to cope better with peak hours. In fact, an alternative is that energy providers would have the permission to regulate specific electric appliances *subtly* for inhabitants in households and office spaces; for instance, in conjunction with telecommunication providers in order to benefit from an already available infrastructure. For example, an imperceptible regulation could be that an intelligent control unit of an energy provider initiates to reduce during peak hours only a little the strength of an air condition in households and office spaces. Indeed in Canada, there is already an endeavor in this direction. There, the nation's public broadcaster aims at easing the pressure on the power grid by operating household appliances during off-peak hours from afar. The system is designed to use FM radio frequencies in order to send directives to household appliances, e.g. to turn on during night a wash machine, thus saving energy and reducing monthly bills [4].

Context-Awareness

Eye-catching tools for supporting energy efficiency or even tools that simply require some *explicit* interaction with users might quite well support to improve the energy awareness of users. Though, at the same time such tools might distract users permanently from their intended actions and actual work focus. For instance, in office spaces such a distraction may affect negatively workers influence on the productivity of an enterprise. At this, context-awareness [1], as a fundamental cornerstone of ubiquitous computing, may help to put things right. Hence, it is interesting to start in rather single office rooms to study usual habits and actions of inhabitants helping to evolve a certain user profile. Against this user profile and common interactions a context-aware framework may act *implicitly* [12] on behalf of users to support more energy efficiency, but at the same time balancing properly between the energy awareness of users and their effect on the productivity. A challenging task would be to figure out how to detect actions or behaviors that cause wasted energy. For instance, if an air condition is cooling an office room preparatory or for nothing. In this regard the empirical study of [5] shows how hard it is to employ a context-aware power management system for workers in office spaces that use desktop PCs, and further adding more sensors to improve context inference can actually increase the overall energy consumption.

Physical Computing and HCI

Physical Computing is an approach to learning how humans communicate through computers that starts by considering how humans express themselves physically [6]. There exist several sensor platforms, such as the Arduino[14] platform or Contiki[15]. When trying to bring more energy efficiency into actions occurring in the daily routine of humans, sensors combined with an appropriate communication radio build an excellent fundament for a *context-aware sensing module* that can be linked over a dedicated protocol to an end-user (handheld) device. For instance, at [11] is explained how to build your own home-power monitoring system. Besides, establishing the sensing and connection between devices, the interaction of the system with its users needs to be addressed as well. Hence, users would be informed about consumed or wasted energy.

[14] Arduino, http://arduino.cc/

[15] Contiki, http://www.sics.se/contiki/

Depending on their context (e.g. busy or unengaged) the application would apply an adequate notification mechanism (unobtrusive or eye-catching).

Sustainable energy standards
The LEED standard is a good strategy to start for being energy efficient from the very beginning. Though, to provide a future-proof solution a further standard is required. Hence, a new challenge will be to define a sort of LEED for post-build occupancy, i.e. a standard that controls how energy- and eco-friendly the habitation and maintenance after the establishment of a building evolves. For this sensors can be installed to support the classifying of a building in such post-build occupancy LEED. Concerning this matter in planned new buildings sensors can be installed right from the start into the insides of a building.

Conclusion

Energy efficiency is a fast growing research area and driver for industry as well. In this regard, some valuable contributions have already been developed, and further ongoing research projects indicate promising approaches.

In this paper a survey is conducted on how ICT has been applied yet to foster energy efficiency. Furthermore, it is explained how ICT can support energy efficiency to yield more sustainable results. For this a number of diverse thought-provoking impulses are raised:

- To bring better together endeavors and results from research and industry.
- To build applications on top of a middleware to ease application development.
- To jointly agree upon an exchange standard at the application layer for a harmonized communication.
- To permit energy providers to operate building equipment and appliances from afar in order to avoid breakdowns of power grids during peak time.
- To employ context-aware applications those strive for increasing the energy awareness of users, but also do not hinder their influence on the productivity.
- To use context aware sensor modules those communicate with an end-user device (PDA, smart phone).
- To establish a ‘post-build occupancy’ LEED for gathering the energy efficiency of a building during habitation.

There is a great potential that ICT can contribute to foster energy efficiency in domestic and corporate environments. However, we need to view things with a broader horizon in order to yield *sustainable* results that will enable us to make greater leaps towards even more energy efficiency.

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