The Essex iDorm: A Testbed for Exploring Intelligent Energy Usage Technologies in the Home

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Abstract: Today climate change and its connection with energy consumption is a matter of major concern. Whilst there are many causes of climate change, in this paper we consider how renewable energy sources such as wind and insolation can be combined with digital home technology (smart homes) to lower electrical energy consumption and, in turn, reduce the carbon footprint by management of the resource. In particular, the paper is motivated by the belief that by empowering the domestic consumer, to be better able to visualise and control their energy consumption, a significant impact on the problems of energy consumption and climate change will follow. The platform also facilitates technological intervention at the power system level if the user has no regard for a conservational policy. To these ends we describe a testbed, the iDorm, which explores future possibilities for innovative intelligent energy technologies and usage strategies within the home environment, together with some of the key technologies involved.

1. Introduction

The arrival of digital homes, intelligent domestic power systems and micro-generation offer a significant opportunity to empower ordinary people, home-owners, with a powerful means to address the issue of global warming. These technologies open up the possibility that living spaces can be both consumers and producers of energy; and that by closing this gap, and involving ordinary people in some of the decisions, more energy can be saved. In addition, our homes and workplaces are becoming increasingly 'wired', with appliances such as heating systems, washing machine and other major appliances having a network connection [1]. This opens the opportunity for computers to be used to monitor their state and control them in some automatic way so as to minimise their power consumption. The move to a more technology-oriented society brings with it an increasing demand for power, as our homes and workplaces are filled with an ever-increasing number of appliances, many of which draw power when in standby or "supposedly" switched off. Ironically, the solution to this problem might be in the technology itself as, through refinement of design, it can be made more efficient with the possibility of near-zero standby consumption. In the past, efficient energy production has equated directly to large power plants supplying electricity for many millions of people. To address the issues of global warming [2], and meet the requirements of the Kyoto Protocol [3] which assigned mandatory targets for the reduction of greenhouse gas emissions to signatory nations there has been an increased interest in generation from renewable sources, resulting in advances in technologies such as heat exchanger (recovery) systems, photovoltaic cells and wind turbines. These units are now physically small enough to open-up realistic possibilities for them to be fitted in domestic environments, reducing the amount of power that would be consumed from the energy distributing grids and polluting fuel. The use of mains balancers and the ability to use the grid system as a storage medium makes distributed generation even more attractive. Using these technologies to maximise the inhabitants' comfort, whilst minimising energy consumption is a difficult challenge as it requires analysis of usage patterns, user needs, weather conditions and generator and consumer characteristics, many of which are dynamic and partially non-deterministic. This problem can be solved using intelligent agents that have been successfully developed, deployed and tested in the iDorm testbed. This paper describes these technologies and explores intelligent energy use in the home. Although we do not set out to review related work, we contribute to a body of research that is exploring environmental friendly communities, novel architectural design, innovative technology and political considerations [4] [17].

2. Digital Homes and the iDorm

A digital home is one where there is wired and wireless network access throughout, with network access being as pervasive as power. Everything can be controlled by a computer and appliances can cooperate transparently, to enhance and simplify usage in the home. The concept of the digital home has the vision that our homes will be filled with "intelligent" devices, reducing energy consumption, ministering to our comfort, health and security, saving us time and keeping us entertained and in-touch. Already, numerous digital homes exist; our iDorm2 takes the form of a two bed roomed apartment see Figure 1. It is a full size domestic apartment

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containing the usual rooms for activities such as sleep, work, eating, washing and entertaining. It comprises numerous networked appliances such as heating, lighting and entertainment systems. iDorm2 devices are networked using IP and Universal Plug & Play (UPnP). UPnP is a distributed middleware that employs event-based communication, supporting automatic discovery and configuration.

Figure 1 – The iDorm2

3. Intelligent Domestic Power Systems

3.1 Motivation

The number and complexity of electronic systems within the home have expanded dramatically in the last five years, and this growth is set to continue and even accelerate. Whilst the technical sophistication of these, devices is ever increasing, bringing with it many benefits for the consumer, it seems that the power supply systems on which they sit remain rather unsophisticated; the world is now full of the ubiquitous wall plug transformer, inefficient, uninterruptible but extremely low cost. The issue of standby power consumption has recently come into focus with the increasing awareness of its overall contribution to energy utilisation in the domestic environment. Standby power currently amounts to approximately 5 - 10% of the overall residential energy consumption in the EU and is growing rapidly [5]. With this in mind there are three possible routes to a reduction of the overall energy budget:

1. A reduction in the energy consumption of products (particularly in standby)
2. A people-centred approach, i.e. to persuade people to switch things off!
3. Technological intervention at the power system level

The first approach is being pursued through voluntary and legislative constraints on manufacturers and by governments using their buying power. It is at best expected to result in a levelling-off of the overall standby power consumption. The people-centred approach relies on creating incentives for people to switch things off, either financial (the cost of the energy they are wasting) or altruistic (the carbon they are needlessly releasing etc). Studies in this area [6] have shown that initial enthusiasm for switching-off unused items tends to be rapidly overtaken by boredom and apathy. Many products are remarkably difficult to switch off, especially when power sockets are relatively inaccessible as is often the case in the domestic setting. The present and future shortcomings highlighted above argue strongly for additional technology at the level of the domestic power distribution system itself, if for no other reason than to help a person to quickly shut down unused devices. This kind of infrastructure would also lend itself to some level of autonomous energy reduction based on a variety of sensor inputs.

3.2 Power control devices

Re-wiring the domestic electrical system, whilst it may have significant long-term benefits, is not in any way viable in the short term, since any additional technology that is proposed must be retro-fitted by the consumer. We divide the various domestic products into different categories, each requiring a different solution.

1. Large domestic appliances such as televisions, washing machines etc are inherently capable of consuming very low standby power by design if a mains-side switch is incorporated or the internal power systems are suitably optimised. These expensive items are also capable of absorbing the small increased cost that this would imply.
2. Lighting systems already have a potential solution in the form of remotely controllable switches or dimmers that replace the standard domestic wall units. Currently the static power consumption of these switches is overly high but we are actively working on ultra low power wireless techniques to address this [7].

3. The last category is electronic devices operating from a DC supply that require a wall plug transformer. It is these that are responsible for the increasing overall standby power consumption and it is these that are the most profligate energy wasters. Currently no solution is known to tackle this category of product. However, we are now developing a wall plug transformer with the following features which will be tested in the iDorm2: (a) Ultra low 'off-state' power consumption implemented as a mains side switch or as part of a 'switch-mode' configuration. (b) Wireless or 'mains-borne' connectivity to a central server that enables the unit to be switched off. (c) Support for remote monitoring of the power consumption during the active state.

By monitoring the power being consumed through the wall-plug transformer, we can not only switch the device into a low power 'off' state but also gain valuable information about what state the device is in while active. For example for most set top boxes, audio systems etc it is possible to determine when the user has set them into their standby mode and thus potentially signal the wall plug transformer to de-activate. Of course when the user wishes to turn a particular device on, a command will first be needed to activate the wall plug transformer or a reset must be provided on the plug assuming it is accessible.

This illustrates that this methodology only really starts to make sense when viewed in a holistic intelligent environment. It is this type of intelligent control and its interaction with the human occupants of the space that represents the greatest challenge and is addressed in section 5. The platform should permit the following questions to be addressed: (i) What sensory inputs are required in order to control autonomously the power system to minimise its energy consumption? (ii) How does this control interact with the human occupants of the space. (iii) Do they perceive it as helpful or unhelpful? (iv) How much can such a system impact the overall energy consumption?

4. An Energy Farm

An 'energy farm', comprising a bank of photovoltaic panels, hot water heat exchangers and a wind turbine is being fitted to the roof of the iDorm to provide a micro power generation capability. The provision of the facility is an opportunity to educate, demonstrate and research into the intelligent use of finite resources [8].

The facility will: (i) educate in the operational use of renewables, (ii) provide public demonstrations, (iii) show the importance of source diversity, (iv) illustrate the relationship between the different resources, (v) predict near-term future energy production (based on meteorological forecasts), (vi) measure domestic appliance consumption in real time, (vii) evaluate individuals' power use profile, (viii) deliver controlled domestic services (ix) subject users to a fiscal energy policy, (x) produce a governing policy for renewable energy delivery.

Studying the effects of power constraint on the individual will lead to the development of a set of control policies and ultimately a system which balances production and consumption. The algorithms employed by the controlling agents will have significant value to the emerging renewable energy industry.

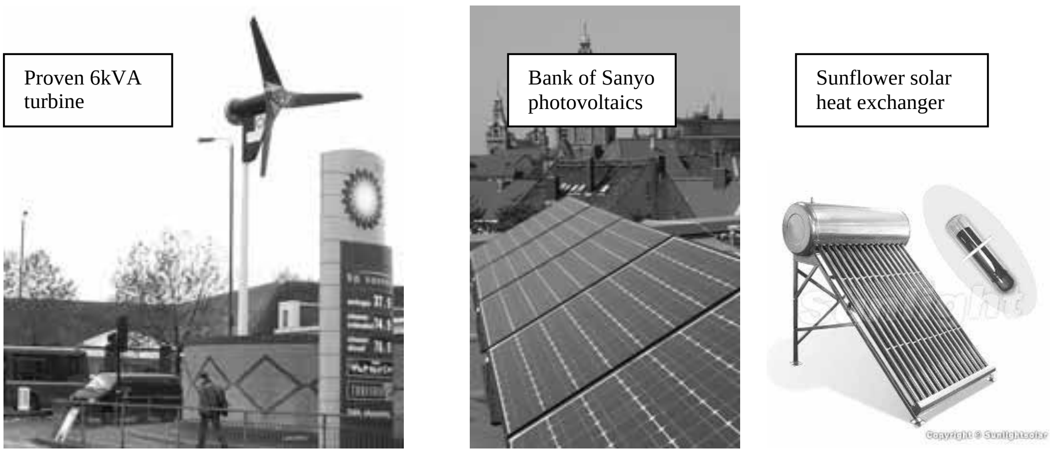

Figure 2 - Three primary forms of renewable generation

The Energy Farm consists of: a bank of ten Sanyo HIP-210-NHE1**,** 210 Watt photovoltaic panels [9], a Proven 6kVA wind turbine [16] and two Sunflower evacuated tube water heating systems [10] having a total area of 5 m^2 and capable of supplying peaks of 15kWh/day under optimum conditions [11]. A bank totalling 2500 A/h of lead-acid accumulators provides a base direct current supply at 48 v, having a total potential energy capacity of 120 kWh. A 5 kvA sinewave grid-tie inverter will provide a standard 240 v 50 Hz alternating current supply for the facility. The grid-tie capability will enable us to investigate the use of the public supply grid as a 'store' for surplus energy, which can later be drawn-upon in times of shortage. A water storage tank containing

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300 litres will be heated by the solar water heating system - this also provides an alternative sink for surplus electrical energy when it is available.

True displaced energy can only be established after installation, but the following table uses the manufacturers' specifications to show predictions based on maximum and typical values for the iDorm which is based at a 51.40 degree latitude. The table shown below gives an indication of the solar energy reaching UK latitudes and has been used to calculate the power generated and the CO_2 equivalent.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
MJ/m^2 day	2.3	4.2	7.0	11.6	15.0	18.0	16.0	13.0	10.0	6.0	2.8	1.7
$kWh/day/m^2$	0.64	1.17	1.94	3.22	4.17	5.0	4.44	3.61	2.78	1.67	0.78	0.47

Table 1: monthly irradiation figures for UK latitudes

Device	Annual Power produced in kWh		Annual Domestic cost equivalent @10p/kW/h		Annual CO_2 reduction in tonnes	
	max	Typical	Max	typical	Max	typical
Sanyo HIP-210-NHE1 225 watt photovoltaic panels x10	6,168	2,058	£616.80	£205.80	2.652	0.885
Proven wt6000 wind turbine	19,000	9,000	£1900.00	£900.00	8.17	3.87
Sunflower hot water solar system	2,000	1258	£200.00	£125.80	0.86	0.54
total	27,168	12,316	£2,716.80	£1,231.00	11.68	5.3

Table 2: Projected power, and equivalent financial and CO_2 costs

5. Intelligent Agents

To oversee the analysis and control of the iDorm energy system we employ intelligent agents. Intelligent agents can be regarded as computers that are endowed with some reasoning, planning and learning processes which, if provided by a person, we would regard as requiring intelligence [12]. Embedded-computers (eg computers integrated into a heater) that contain such an intelligent capability are normally referred to as "*embedded-agents*" [13]. Typically researchers have employed approaches such as neural networks, based on traditional machine learning theory, to control the users' environment.

In Essex we employ fuzzy logic based agents as these are able to deal with the vagaries of the real world (imprecise sensors, noisy data etc) and provide linguistically interpretable rules which are readily understandable by people (neural networks form connectionist structures that are difficult, if not impossible to interpret). One of the most successful real-time intelligent control agents built at Essex is the *Associative Experience Engine* [British patent 99-10539.7]. In this behaviours such as minimising energy and dealing with emergencies are all encoded as fuzzy logic controllers (FLCs), all of which run concurrently competing for control of the agents actuators (eg heater). Thus behaviours set a goal for the agent which can be multi-dimensional such as minimising energy and maximising comfort. Each fuzzy controller has two parameters that can be modified; a *Rule Base* (RB) and its associated *Membership Functions* (MF).

In learning we modify the rule-base for dynamic behaviours (there are also fixed behaviours which generally relate to safety requirements). The behaviours receive their inputs from networked appliances or sensors (eg temperature) and provide outputs to the actuators (eg heaters) via a co-ordinator that weights their effect. Over the course of the agents life, it learns how to adapt the systems it controls to meet the users needs (ie it is a self programming system. Thus over time the agent builds a large set of experiences that is able to call on whenever a new situation is encountered. The agent is always searching for better solutions (ways it can adapt to get better performance for a given situation) thus it can continually track changing circumstances such as weather, faulty equipment or changing users needs.

This agent has been successful applied to the control of building services (eg heating and lighting) in the iDorm. In general, this agent can take any arbitrary set of inputs and enforce both pre-determined and dynamically learnt control rules. The operation of the agent adheres to the metaphor "The User is King" meaning that, except for safety related issues, the system will always and immediately respond to the user's commands (which, if it is a habitual behaviour) is learnt as a required action by the agent, which is continually adapting to changing weather conditions, equipment ageing characteristics and users needs.

Our agents, supporting theory and experimental results are described in detail elsewhere [14] [1] [15]

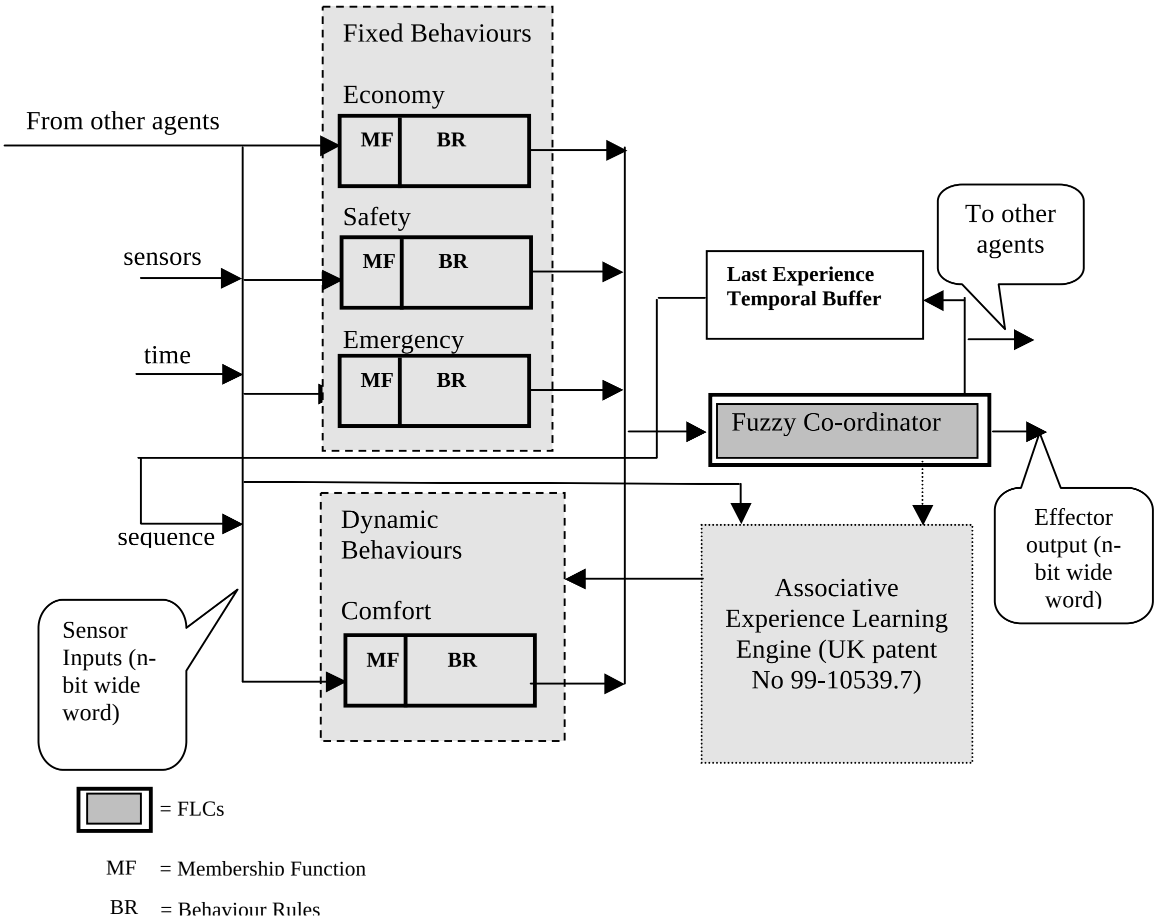

Figure 3: Embedded-Agent Architecture

6. Summary:

In this paper we have described an innovative testbed for exploring intelligent energy usage technologies for the home, the Essex iDorm. We have explained how the testbed is a combination of a digital home, intelligent power and micro-generators whose operation is orchestrated by intelligent agents. Essex has a successful track record in the development of agents to control digital homes and we are now embarking on a research programme whereby we will integrate this work with the emerging power generation and control technologies.

The goal of this work is to address the climate change issue at its roots, by enabling ordinary people to have a more direct say over their carbon usage by making the power they consume more visible and giving them the technological tools to be able to exercise their will in the most efficient ways possible. The role of the agents is to remove the cognitive load associated with the underlying technical complexities from people, freeing them to think about energy management at a much higher level.

A factor we do not consider in detail in this paper is the need to change personal consumption habits in a way that is not seen as excessively coercive: such would be doomed to failure. The need to do so has to be recognised at the personal level, and from an early age, so input to the primary and secondary education systems is vital. To this end we expect to collaborate with other disciplines specifically Psychology, Sociology, Government and Biological Sciences.

Whilst this is seminal work, we hope that the vision it represents will prove popular and inspire others to collaborate in this venture. It is our conjecture that empowering ordinary individuals with centralised control over distributed functions may be the most effective way to encourage a significant change to people's energy consumption habits.

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