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DYNAMIC LOAD MANAGEMENT

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1 Introduction

Electricity utilities world-wide are undergoing a period of fundamental change with privatisation, de-regulation and the introduction of competition. Competition has resulted in renewed interest in the optimum utilisation of assets (for generation, transmission and distribution) with the aim of enhancing profitability and increasing shareholder value. Of particular importance is the dynamic manipulation of customer loads. This can provide mutual benefits with enhanced profit for the supplier and reduced cost for the user.

Demand Side Management (DSM) has been practised in many countries for a number of years, often as a regulatory requirement. The primary objective of most DSM programmes has been load reduction. However, in a competitive market load manipulation tends to assume a much higher priority than load reduction. A number of critical business drivers emerge in a competitive market, including:-

- Load defence/retention
- Strategic load growth
- Optimum utilisation of assets
- Deferment of infrastructure investment
- Growing non regulated income (often by the development of value added services)

This paper describes one example of load manipulation technology: a space and water heating system which is capable of modifying the demand load profile. This system comprising thermal storage and direct acting heating has been shown to guarantee thermal comfort conditions in a building whilst providing significant cost benefits to both the consumer and the utility. The technology can be readily modified to control other loads such as air conditioning (with and without ice storage), domestic appliances (e.g. dishwashing, home laundry etc) and commercial and industrial loads where time of day usage is not critical.

2 Background to Load Manipulation

Load shape is important in defining the cost and utilisation of Generation, Transmission and Distribution assets. Peak load growth drives up the installed capacity (and cost) of these assets, without necessarily bringing adequate revenue to provide a payback. Load management can allow reinforcement to be deferred and the optimum utilisation of assets to be achieved.

In a competitive market, load shape is also important in controlling the margin for Electricity Trading. There are times in the day (e.g. the UK scenario) when additional electricity load produces a negative margin (i.e. when it would have been better not to have sold further units). Similarly there are times in the day when margins are healthy. Load management helps electricity companies to shift load to periods with positive margins.

Load Management is already used quite widely to shift load from peaks to troughs, but often at the expense of customer comfort or convenience. In its worst application, the customer permits loads to be disconnected by the utility on a short warning basis. However, this type of load management will only be sustained by the most pro-active of users, as others will find the interruption too inconvenient. EA Technology has been developing and encouraging "Intelligent Load Management" in order to increase trading margins which may be shared between utility and customer. The primary objective of Intelligent Load Management is to increase operational efficiency and standards of customer service by providing benefits without any negative implications for the consumer.

In the UK, electric storage heating has been controlled for a number of years by means of the Radio Teleswitch System (RTS) in conjunction with tariffs offering cost incentives to use electricity during the night (Economy 7). This scheme has been extended by using advanced distributed control technology with algorithms embedded in heaters to optimise the load profile to the benefit of both the customer and the utility. This paper describes this example of load management: CELECT a heating and hot water system which:

- modifies the demand load profile
- comprises storage and direct acting heating
- provides low cost hot water
- guarantees thermal comfort conditions
- provides significant running cost benefits

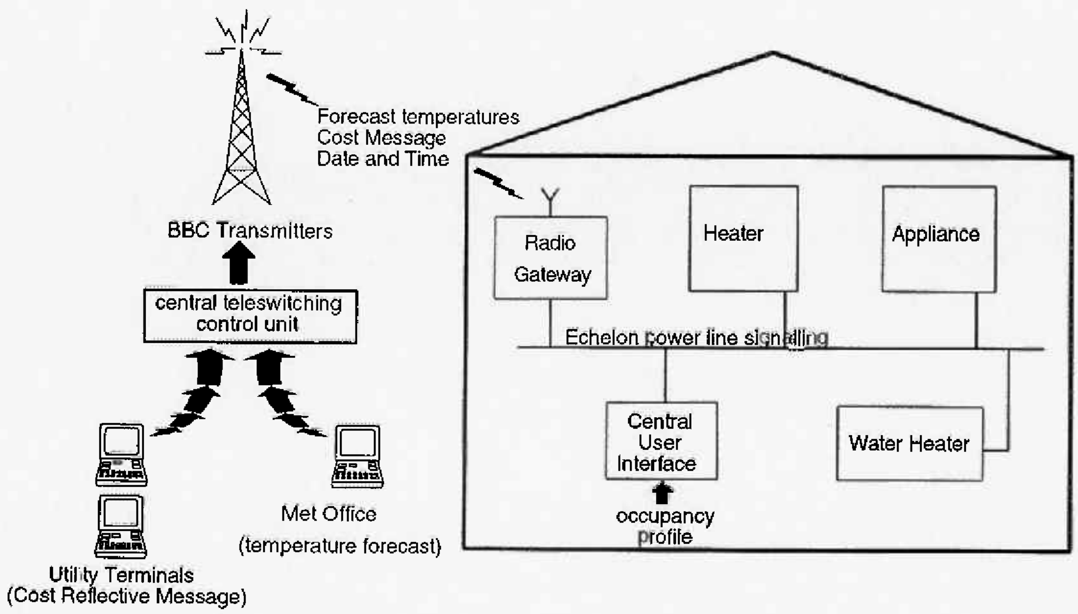
3 CELECT Space and Water Heating

CELECT is an advanced space and water heating system which has been developed by a consortium of 27 Electricity Utilities and Manufacturers led by EA Technology. It provides an integrated system for load management of electric heating and hot water in domestic and commercial buildings. It also provides a low cost framework for utilities to carry out domestic and other load management activities.

A typical CELECT heating system uses a mix of storage and direct acting heating offering unparalleled comfort and attractive running costs. Room temperatures are accurately controlled with the desired temperatures and occupancy times being set on a room by room basis by the user from a central user interface. Energy consumption is significantly reduced compared with existing 'off-peak' electric and wet systems.

For an electricity utility, the system provides a means of shifting load and minimising overall costs (i.e. including both supply and distribution costs) by using novel *Cost Reflective Messages* (CRM) to manipulate the daily load pattern. Changes can be made from one day to the next to reflect changes in system loading, inter-company electricity trading, regulatory changes, deferment of network reinforcement, etc. The ability to change load profiles dynamically is essential if electricity is to be sold profitably in an ever changing market.

Figure 1: Overview of CELECT Heating System



3.1 Detailed description

Typically a room will be heated with a combination storage and direct acting electric heater. The *optimising controller* situated within the heater calculates the minimum cost solution based on:

- the customer's comfort requirements
- the day's Cost Reflective Messages (CRM)
- the forecast outdoor air temperature
- the learned thermal characteristics of the room/building

The heating system is programmed from a 'set and forget' central user interface. *Occupancy profiles* (days, times and desired temperatures), are specified by the customer for each room.

The CRM is a 24 hour profile of the cost to the utility to supply electricity at a specific time of the day. The total cost to supply is based upon the sum of generation, transmission and distribution costs. Both cost and outdoor temperature prediction messages, plus time and date information, are supplied to the customer's premises using the Radio Teleswitch system (RTS). This system superimposes data signals on the BBC's Long Wave channel. Broadcast radio was chosen because additional infrastructure cost associated with the existing RTS system is marginal. As an alternative, power line, PSTN, CATV, or other communication systems could be used to convey the required data to the premises.

Locating an optimiser within each heater ensures that there is no central point of failure. The heater continues to maintain the customer's comfort requirements even if the central programmer fails or the radio teleswitch signals are not received, albeit at a reduced efficiency. The system also includes optimised water heating and is capable of extension to other applications such as home laundry, dish washing, security, HVAC, heat pumps, micro combined heat and power, etc.

The optimising heater controllers, central user interface and the Radio Teleswitch Gateway all use Echelon Neuron Chips and CENELEC "C" band power line carrier modems. The low cost Neurons are designed both to implement the application required and to communicate with other Neurons using the in-built protocol. Power line signalling is used within the building to avoid the need for dedicated signal wiring. The system is, therefore, ideal for both refurbishment work and new installations.

4 Performance Simulation and Modelling

At the outset of the project considerable effort was applied to develop sophisticated modelling tools which enables the performance of heating and control systems to be simulated. This permits the performance improvements (in terms of comfort control and economy of operation) provided by CELECT to be modelled and evaluated in detail. The modelling techniques used also provided an extremely cost effective and powerful method for control algorithm development, with a wide range of sophisticated control scenarios being assessed, prior to field trialling.

The following profiles demonstrate three load profile simulations. Figure 2 shows the load profile obtainable from an optimised Economy 7 system. (NB. This is an idealised Economy 7 control scenario and represents the optimum solution achievable by Economy 7.) It is important to recognise that no existing system provides this level of control, but it is useful in establishing a bench mark. Figure 3 represents a heating system which uses panel heating only (i.e. no storage). This system optimises the electricity usage to provide the minimum cost solution (based on a flat rate tariff). Figure 4 shows the load profile achieved by CELECT. This demonstrates the ability of the system to shift load away from the periods having a high cost to supply. The optimiser performs an "Energy Broker" role to provide the minimum cost solution for the supplier and customer whilst still maintaining the required room temperature control (within ±1°C of the user set points).

Figure 2. Optimised Economy 7: Simulated Load Profile

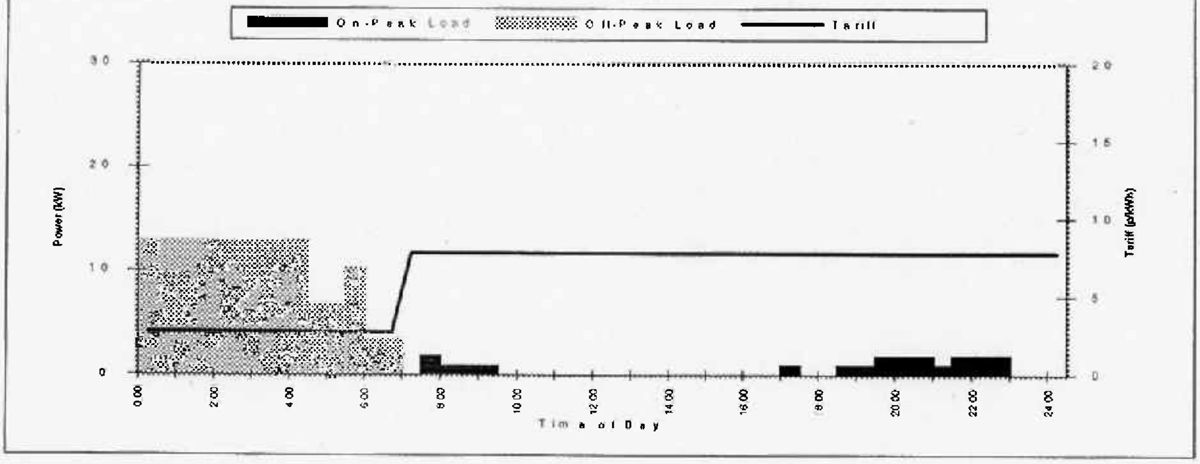


Figure 3. Panel: Simulated Load Profile

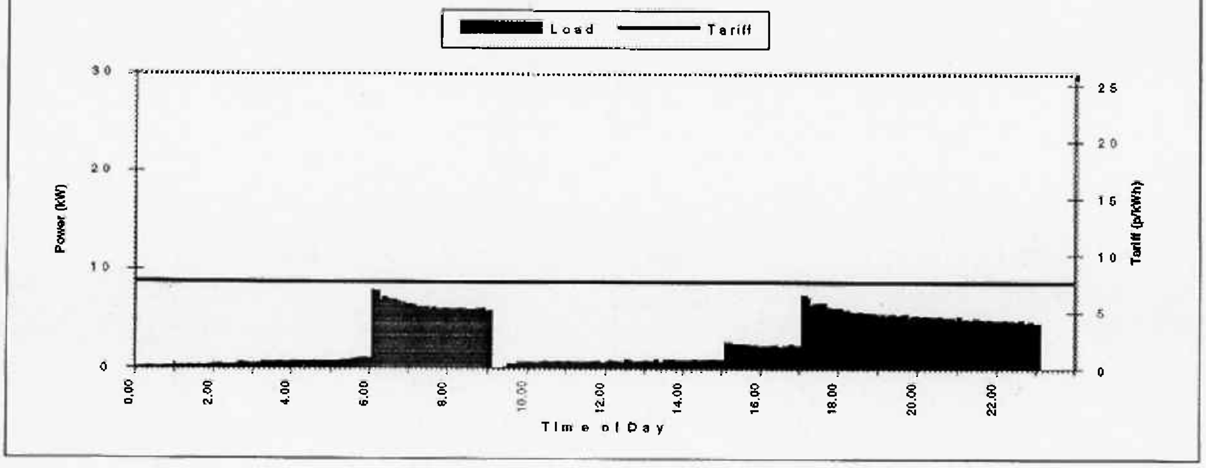
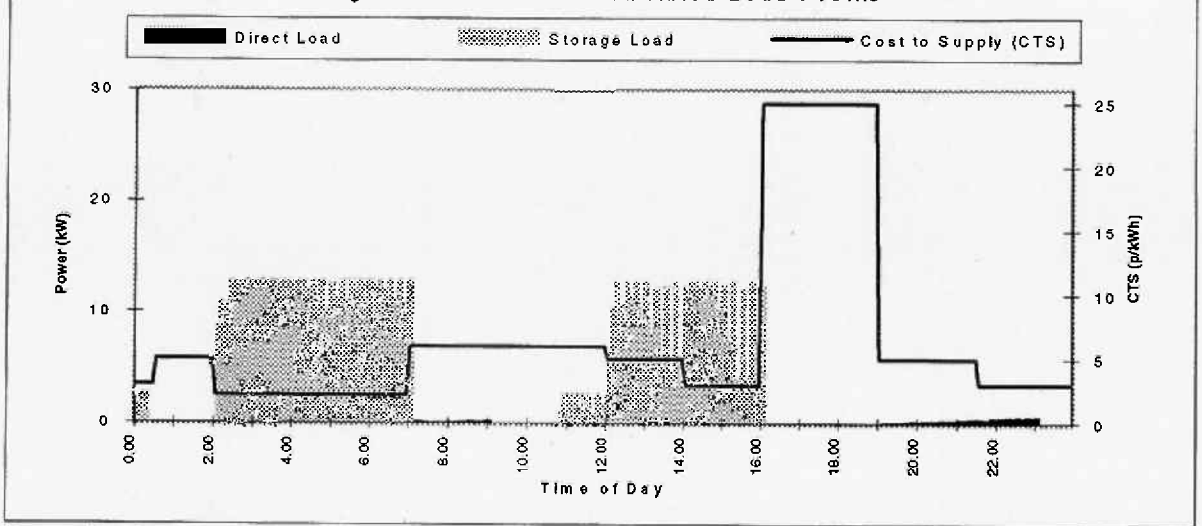


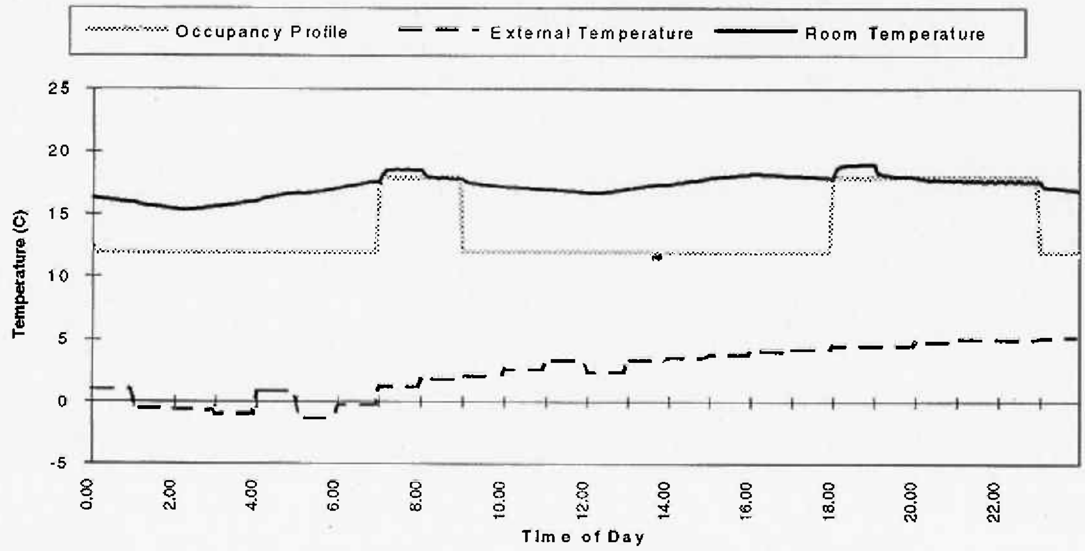
Figure 4. CELECT: Simulated Load Profile



Note: The above simulations are based on a 3 bedroom semi detached house having a moderate standard of insulation located in Manchester, England. Living rooms have a set point of 21°C with occupancy times of 07.00 to 09.00 and 16.00 to 23.00. The bedrooms have a set point of 18°C and occupancy times of 07.00 to 09.00 and 18.00 to 23.00. Set back temperatures in all cases are 12°C.

The internal temperature profile achievable by CELECT is shown in Figure 5. This demonstrates the effectiveness of using a predictive optimising controller with feedback to achieve the comfort requirements (set point temperatures) whilst still delivering the lowest cost solution.

Figure 5. CELECT: Simulated Temperatures



4.1 Cost to supply and Load Management Index

The cost to supply varies by time of day and season. Eight different generic cost to supply profiles were developed (weekday, weekend, summer, autumn, winter and spring), based upon data provided by a consortium of UK electricity companies. This enabled simulation and ten initial field trials to be undertaken over the winter of 1993/94. A further sixty installations were trialled by ten electricity companies over the winter of 1994/95 with dynamic cost to supply data being transmitted and updated daily via the RTS as a Cost Reflective Message (CRM). The CRM provides a forward pricing mechanism (in half hourly intervals for the next 24 hour period) to enable the participating electricity companies to modify their load profiles dynamically to optimise their prevailing electricity trading arrangements.

To enable the performance of load management systems to be compared, the concept of a Load Management Index (LMI) was developed. The LMI reflects the average annual supplier cost in p/kWh. It is based upon the measured energy consumption (load profile) in kW and the cost to supply in p/kWh (in each half hour period). Mathematically LMI is calculated as follows:

$$LMI = \frac{\sum_k (CTS_k \times \text{Electrical Energy}_k)}{\sum_k (\text{Electrical Energy}_k)}$$

Where: k refers to half hour intervals

CTS = cost to supply (p/kWh) for each half hour

Electrical Energy = Load (kW) in each half hour

The supplier's margin is the difference between the LMI and the tariff. It is important to recognise that the CRM and the tariff are quite separate and that CELECT does not require complex metering. The simplest CELECT tariff can be single rate (i.e. based on an LMI which is marked up to reflect profit, risk etc). However, more complex tariff arrangements including two rate or multi rate could be used. The Load Management Indices for the three systems shown in Figures 2 to 4 are:-

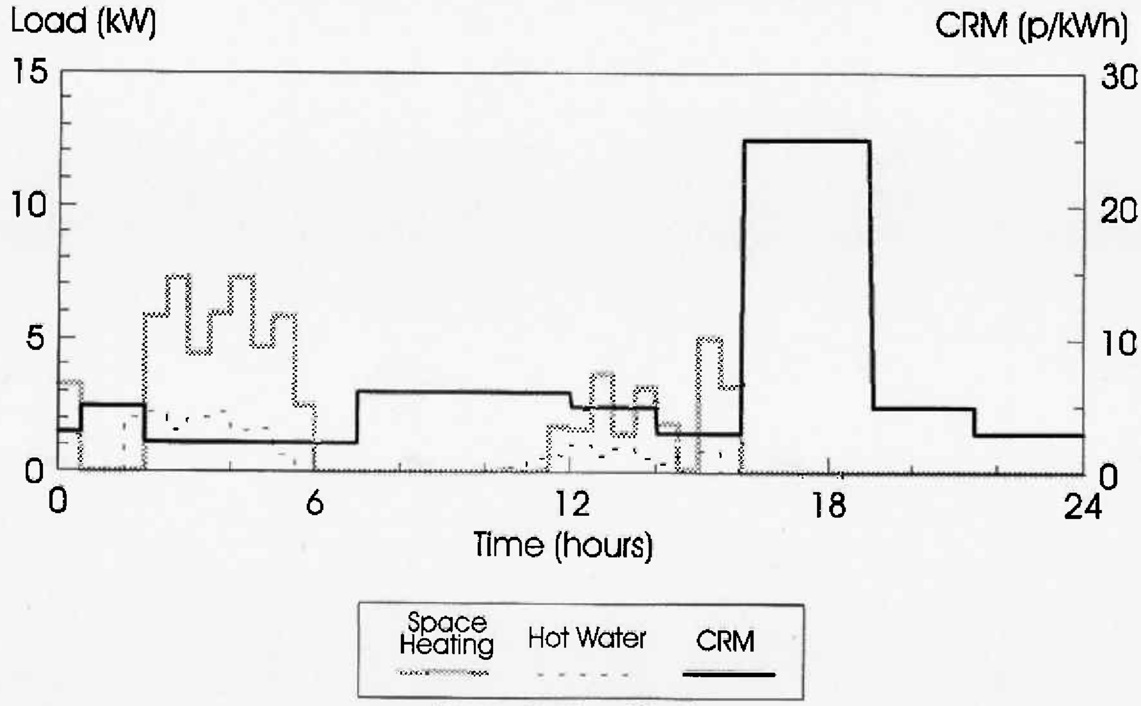
	LMI
Optimised Economy 7	3.15p/kWh
Panel heating	6.49p/kWh
CELECT	2.57p/kWh

These indices show the considerable potential offered by CELECT to enhance profit and/or provide customer savings. CELECT shows a cost to supply saving of over 20% when compared with Economy 7 and over 250% when compared with panel heating. It is important to note that the Economy 7 simulation is idealised and that the saving, when compared with CELECT, is likely to be greater in practice, since existing storage heater controls do not respond quickly to changing conditions or user requirements.

5 Field Trial Results

Typical results from a trial family home (in Northern Electric's area) are shown in Figure 5. The home is part of a major field trial undertaken during the winter of 1994/95. The majority of Electricity Companies were involved and equipment was supplied by a number of well known manufacturers. Initial feedback from these trials has been very good, with users experiencing enhanced levels of comfort and controllability, and electricity companies substantially shifting demand away from the 16.00 to 19.00 period.

Figure 6. CELECT: actual load profile



Source: Northern Electric

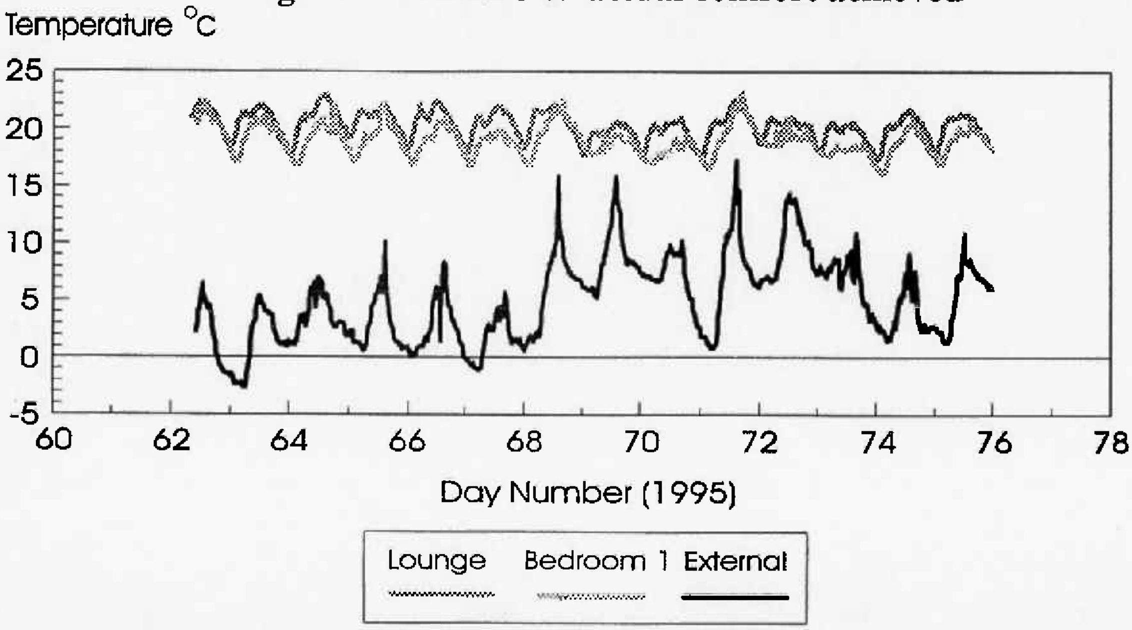
Temperature control and the achievement of comfort conditions showed considerable improvements over Economy 7 at all CELECT field trial sites. Typical internal temperatures associated with the load profile shown above are provided in Figure 7.

5.1 Results from Matched Pair of Test Houses

In addition to the field trials in occupied houses, EA Technology's Matched Pair of Test Houses were used to enable a performance comparison between the best available gas heating technology and CELECT to be undertaken.

The use of an unoccupied Matched Pair of Test Houses allows meaningful tests to be conducted over a relatively short period. A CELECT system comprising six combined storage and convector heaters, and two panel heaters was installed in one of the houses. A gas central heating system with condensing boiler, thermostatic radiator valves and an advanced Honeywell optimising controller was designed and installed in the other house by British Gas. The two systems were then programmed with the BREDEM standard occupancy profile and monitored over a period of two weeks. Energy use, room temperatures and weather data were collected.

Figure 7: CELECT: actual comfort achieved



Room Temperatures over the period 3-16/3/95

Source: Northern Electric

The CELECT system maintained room temperatures closer to the desired set points. In the house with gas central heating 5 of the 12 rooms showed an average difference of more than 1°C from the required temperature; there was only one such room in the house with the CELECT system. Both systems were affected by solar gain to approximately the same extent.
The gas system used 14% more energy than the CELECT system due to poorer system efficiency and a less sophisticated controller. It is important to note that the energy savings associated with the CELECT system would have been even greater had its ability to provide individual room temperature control been fully utilised.
The estimated annual running costs for the CELECT system (£290) are slightly cheaper than for the gas condensing boiler system (£304). It is estimated that a conventional gas boiler (i.e. non-condensing) would give an annual running costs of £331 (14% more than the CELECT system). The energy ratings of CELECT are higher than any previous storage systems and quite capable of meeting the 1995 England and Wales building regulations in typical new build houses.

6 Conclusions

The CELECT heating and hot water system provides comfort, energy efficiency and powerful load management by employing distributed intelligent control using predictive optimisation. Other Domestic appliances such as dish-washers, home laundry, hot water, air conditioning, freezers etc. can be readily adapted to incorporate load management through cost messaging. Communications and intelligence built into domestic appliances brings not only immediate operational benefits and cost savings, it also provides the basis for a home-bus which can be used for the provision of other value added services. Home automation is likely to penetrate the domestic market only when accompanied by real benefits from systems like CELECT.

The benefits of intelligent load management based upon CELECT for an electricity utility include:

- increased margins
- better utilisation of fixed assets
- development of non regulated business opportunities
- a very flexible demand side management tool
- opportunities to control other appliances
- an opportunity to provide other value added services - security, alarm handling, condition monitoring

For the customer, CELECT provides

- reduced energy costs for heating and hot water
- increased standards of comfort
- reliability and simplicity