Final Technical Report

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Project Co-ordinators: Ericsson/ University of Strathclyde

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- Ericsson Radio Systems
- Kungliga Tekniska Högskolan
- Gävle Energi
- Gävle City Council

UK
- University of Strathclyde
- ScottishPower
- The Highland Council
- Rutherford Appleton Laboratory

Greece
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- Intracom
- Association of the Municipalities of Western Athens

Czech Republic
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Part 1: Publishable final report

1.1 Executive publishable summary

Broadband connection to homes has commenced in many countries and, although the timescale is uncertain, is expected to become commonplace within the EU. The market drivers for this are communications, home security, multimedia and healthcare access. Such home connections offer the opportunity to develop a range of Internet-based energy services.

The SmartHomes project was initiated in February 2001 as a collaboration between technology, local authority and academic partners operating within 4 EU member states. The aim of the project was to implement and test a range of new energy services suitable for widespread delivery using the emerging electronic gateway technologies being developed by the telecommunications industry. Despite a recession in the communications sector and the bankruptcy of the company responsible for the delivery of a key component, the project proceeded to plan and gave rise to several outputs as follows.

The state-of-the-art in sensor, actuator and communications technology, as suitable for home/office deployments, was reviewed and the results used to inform the design of an e-service delivery prototype – hereinafter referred to as the 'SmartHomes' system.

A range of beneficial energy and environmental services were identified and a sub-set selected for demonstration within project field trials.

A service delivery prototype was established and subjected to robustness testing - in relation to sensor capabilities to enable the capture of data relating to temperature, humidity, electrical power etc; actuator capabilities to enable the local control of alarms, appliances and general information systems; and the processing of data from large numbers of distributed sites to enable the system to be deployed commercially.

The largest effort was expended on the implementation of field trials. Despite many practical problems and a limited hardware fabrications budget, the project partners were able to exceed the target of 240 field deployments. The tested procedure for field installation represents a major project deliverable.

A comprehensive market study was undertaken by the industrial partners and comparisons made between the situations prevailing in the partners' countries.

An evaluation of the costs of e-service deployment was undertaken in order to provide information on the commercial viability of each service both now and in the near-term.

In addition to the dissemination activities implicit within the project's field trials, a Technology Implementation Plan was devised and agreed by all partners.

1.2 Publishable synthesis report

The technical content and outcomes are described in Part 2, which may be treated as the publishable report. The project partners were as follows.

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Part 2: Detailed final report

2.1 Objectives and strategic aspects

Many companies in Europe, the USA, Japan and Korea are developing capabilities for providing home services using broadband connections, mostly focused on the tele-communications, home entertainment and security markets. Much of this effort is fragmented and proprietary. The SmartHomes project stemmed from the realisation that there is a need to promote integrated projects so that standard protocols can be adopted and new energy/environment/health services established and proved in relation to citizen-derived value. The project builds on previous pilot projects, most notably the Swedish Energy Barometer project (Westergren *et al* 1998), which addressed the provision of actual and projected energy consumption data to home owners/occupiers.

The project set out to demonstrate that buildings using modern communication technologies may be adapted to acquire and transfer variable frequency fuel, power, appliance operation and environmental state data in support of a range of new e-services of benefit to citizens (whether at home or at work), utilities and local authorities. Examples of such services include the remote control of appliances, appliance fault detection, large scale load management, gas leak detection, care for the vulnerable and building stock performance rating. Such services require the development of data acquisition and remote actuation protocols that can deliver services offering value at appropriate cost.

The project utilised Ericsson's home gateway technology (Lindfors *et al* 1998) and the University of Strathclyde's EnTrak energy management software (Kim 2004) as the basis of a new communications system, hereinafter referred to as the 'SmartHomes' system, which is able to capture relevant data and use this to enable and support the new on-line services. It is envisaged that such a system will enable future service providers to contribute technical, social and economic benefits through

- the real-time monitoring of homes to enable better care for the elderly and other vulnerable groups;
- the management of electrical loads as a mechanism to improve the efficiency of supply;
- the attainment of a better match between local demands and renewable energy supplies as a means to reinforce power quality of supply in areas where the electricity supply network is fragile;
- the development of local authority/utility/telecommunications company partnerships as an apt response to the challenges of an integrated energy market and sustainable development;
- the construction of city-scale databases for use in local authority and utility service planning; and
- the development of procedures for prioritising home improvements based on detailed consumption data.

2.2 Scientific and technical description of the results

2.2.1 SmartHomes system overview

Work Package (WP) 3 addressed the establishment of a system prototype for deployment within the field trials of WP 4. Appendix 3 describes the outcome from WP 3 in terms of the technical content of the SmartHomes system. In summary, and with reference to Figure 3 below, related sets of building-embedded sensors and actuators exist to support the needs of particular energy services, while an electronic gateway device exists to receive/send information from/to the sensors/actuators and send/receive data to/from an e-service centre located elsewhere on the Internet. Within the project Ericsson's 'e-box' device (Lindfors *et al* 1998) was employed as the electronic gateway. This Linux box is designed for always-on operation with high availability. It offers local IP and non-IP network support, internal fault management, and remote configuration. The employed version of the e-box has 32Mbyte DRAM and 24Mbyte flash memory with 10Mbps TP Ethernet for both the access and local networks. It also has a RS232 serial port for connection to wire or wireless sensor/control networks. An e-service centre, established at some arbitrary location on the Internet, receives and organises the returns from registered e-boxes. Both the e-service centre and e-boxes provide an Open Services Gateway Initiative (OSGi 2002) compliant application environment, enabling secure and transparent communication. For security, all HTTP connections are based on two-way authenticated SSL-connections. Software agents operate on the data returns to extract data-sets corresponding to the particular energy services being supported at any time. These data-sets are either aggregate e-box data, for onward transmission to a service provider, or actuation requests from a provider for transmission back to homes (via the e-boxes). Finally, distributed Web sites, one for each energy service, are up-dated by service providers as required.

2.2.2 Project achievements

The project comprised 8 complementary WPs as depicted in Figure 1.

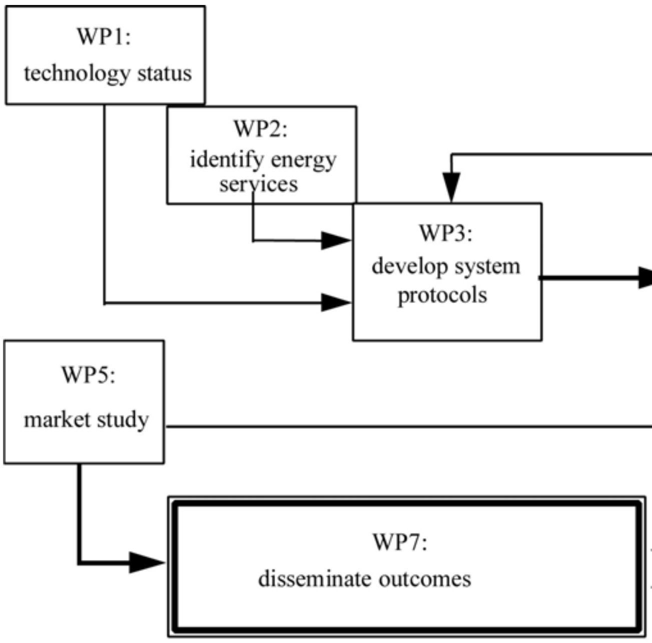


Figure 1: Project work packages and deliverables.

WP 1 (Appendix 1) comprised a review of the electronic gateway, Web and instrumentation technologies that are suitable for the domestic sector, including how these technologies might develop in the short term.

WP 2 (Appendix 2) comprised the identification of the range of possible new energy services - as considered desirable from government, citizen and business viewpoints - and a prioritisation of their deployment on the basis of best value to service recipients.

WP 3 (Appendix 3) comprised the rapid prototyping of the SmartHomes system. This, in turn, involved the configuration and laboratory testing of the software and hardware components as depicted in Figure 3 below.

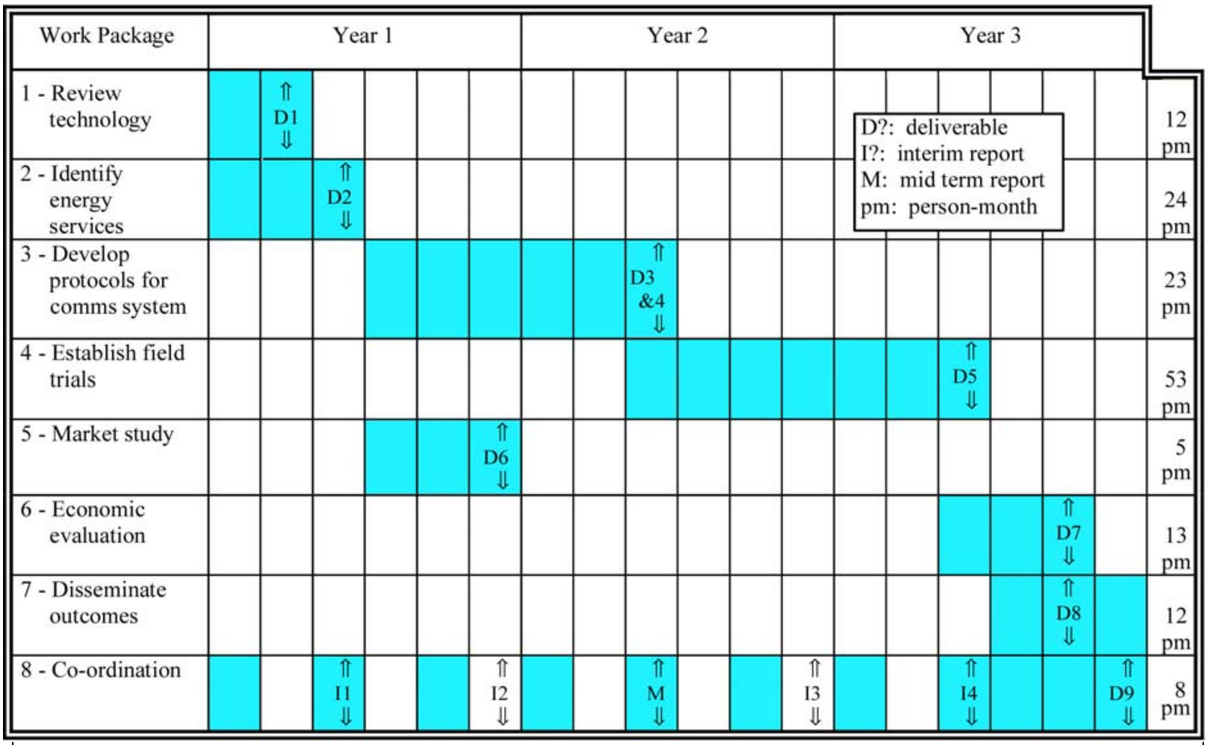
WP 4 (Appendix 4) comprised the field deployment of the SmartHomes system and its configuration to support the specific e-services being enacted. This work was undertaken in two stages. An initial small number of e-boxes were installed and, from the results obtained, a number of technical refinements were implemented, in particular to overcome firewalls and improve acquisition times. Such refinements required changes to the programs running on the e-boxes, the e-service centre and the core database management system. In the second stage some 282 e-boxes were deployed, each with a related set of sensors designed to demonstrate and test a specific e-service.

WP 5 (Appendix 5) comprised an evaluation of the market prospects for each e-service demonstrated within WP 4. From the market study data relating to each country, a clear picture of the current and future potential for e-services was extracted.

WP 6 (Appendix 6) comprised an economic appraisal of those e-services for which the market prospects were deemed high. A methodology for evaluating the commercial potential of the e-services was devised and applied to the specific e-services deployed in the national field trials of WP 4.

WP 7 (Appendix 7) addressed the dissemination of project outcomes beyond the influence of the national field trials. The well-established SOSTAM methodology was adopted to comprehensively address the routes by which the SmartHomes system may be progressed to market.

WP 8 related to the overall project management and Commission interfacing activities. Despite some setbacks as detailed in §3.3, all milestones were met, the project adhered to the original plan as shown in the Gantt chart of Figure 2 and all envisaged deliverables were produced. These achievements were assisted by two plenary meetings per year and by bilateral group meetings arranged as required.



Deliverables: D1 - technology status and development plan; D2 - potential on-line energy services; D3 - protocols for data capture and analysis; D4 - protocols for remote actuation; D5 - prototype evaluation outcome; D6 - market study report; D7 - economic evaluation report; D8 - technology implementation plan; D9 - final report.

Figure 2: Project work plan.

2.3 Assessment of results and conclusions

Appendices 1 through 7 detail the outcomes of each technical WP, while this section summarises the main conclusions from each WP.

2.3.1 WP 1, Technology review

The purpose of this WP was to review the technologies that may be used to support the e-box configurations to be tested within the field trials of WP 4. Past projects were reviewed in relation to various critical aspects as follows and the result delivered as a report (Appendix 1) providing an overview of the technology options available to implement the envisaged SmartHomes system.

Services delivered: The focus and content of previous, related projects were examined in relation to user types, service provider capabilities, the form of the required information and the nature of any applied control.

Home network communication: The service-dependent data collection types were researched and the related sensors identified. The work detailed the technical characteristics of existing sensor technologies. The actuation (i.e. switching) devices associated with the control of appliances were identified and their technical characteristics elaborated. Such devices exist to control the operational state of the energy consuming equipment associated with heating, cooling, ventilation, lighting, washing machines, fridges *etc*. The local network technologies were examined with regard to technical characteristics such as capacity and installation requirements. Finally, the possible approaches to local network configuration were reviewed and summarised.

External network access: Different possibilities exist for connecting to the external network, including wire-based and wire-less connection. The available communication technologies were examined with regard to characteristics such as capacity, cost and standards compliance.

E-box technology: The technical capabilities of the e-box were examined in relation to the demands of the envisaged e-services. Alternative home gateway devices were reviewed in order to ensure that the present project adopted, where possible, an open architecture approach.

Linking environmental conditions, fuel use and control: A specification was drawn up for the environmental parameters to be monitored, the criteria to be used to represent occupant comfort, and the algorithms to be employed to effect control.

Based on the WP 1 outcomes, recommendations were made in relation to building data acquisition and appliance control, and the home access network communication technology to be deployed.

In undertaking the work, it was noted that several patent applications have been lodged that address Internet-based hardware and sensors for delivering e-services to homes and commercial environments. However, these applications cover only the principles of such a system and do not correspond to a working system: at the present time there are no commercially available systems. It was also noted that while radio frequency based sensors presently exists, these are focused on home security applications, not energy and environment. Such security systems start at €350, with advanced 5-zone protection systems with control panel costing €1350 (e.g. see http://www.wireless-alarms.co.uk/).

2.3.2 WP 2, Possible energy services
This WP considered the possible energy services (e.g. plant control, building security, environmental monitoring, remote sensing and load management) on a per country basis, in each case identifying the parties involved. Such services may be arranged into five categories: telemetric, information, entertainment, e-commerce and communication. For each service the participating players and technical systems were identified. Appendix 2 details the WP outcomes.

The players involved in the chain of services were identified as:
- home owners/occupiers and their organisations;
- property owners/managers/operators;
- energy suppliers and distributors;
- local and national authorities;
- service providers; and
- telecommunications operators.

The review addressed three issues within the field of energy services: the quantification of the benefits obtained from previous related projects; an assessment of the services being presently directed to ‘smart’ homes; and the quantification of the impact of district load control.

Furthermore, the review showed that energy savings can be obtained either by influencing the behaviour of occupants and/or by implementing technical actions. An estimate is that the influence of occupant behaviour corresponds to some 10-20% of the residential sector energy consumption. Similar figures may be obtained from the application of technical measures. An important issue is to increase the energy awareness of occupants; this can be achieved both via technical measures and by economic inducements and personal competition.

A significant conclusion from the review was that little is being done with monitored data other than using it for visualised feed-back purposes (e.g. energy use over time) to individual occupants. An Internet service reaches many residences and organisations simultaneously so that decision-support may usefully relate to the large, aggregate scale. While impacts at the home scale will be of interest to the occupant, the impacts at the large scale will be of interest to local authorities and utilities.

The identified energy services - when categorised into information, monitoring with alerts or alarms, monitoring with feedback and monitoring with actuation - include:

- environmental monitoring, e.g. detection of CO, smoke, temperature and humidity;
- metering, e.g. of gas, electricity and water consumption;
- fuel consumption monitoring, e.g. for reporting to occupants and energy suppliers;
- weather-related services, e.g. heating control, night cooling, use of rain water *etc*;
- performance evaluation, e.g. of city energy consumption by fuel type and emissions;
- appliance control on a small scale, e.g. for heating, lighting and small power within one residence;
- remote switching of appliances on a large scale, e.g. for district load manipulation and HVAC operation control; and
- new and renewable energy trading as a function of electricity prices and demand.

From the list of potential energy services, each national partner selected those services that are most applicable to their local need and present IT infrastructure as follows.

Czech Republic: Individual metering of energy use and thermal comfort in multi-family buildings with remote actuation of set-point temperatures of heating systems for entire housing blocks. Data is reported to occupants, the energy supplier and authorities.

Greece: Prediction of cooling energy consumption based on real-time data input to neural networks, control of cooling equipment, energy rating for cooling consumption and reporting indoor temperatures/energy consumption to users.

Scotland : The services target the public housing sector and comprise cold condition alarms, CO-level monitoring, fuel use metering and the matching of renewable energy supplied to demand, with reporting to energy suppliers, health care agencies, local authorities and energy managers.

Sweden: Individual metering of space and domestic water heating and electricity, plus electricity use in multi-family buildings. The coupling of metered values to a simulation program allows estimates of the heat exchange between neighbouring apartments, thereby providing information for energy consumption debiting models. The data are reported to occupants, the energy supplier and local authority.

The value and benefits of these services were then evaluated within the national field trials as input to WPs 5 and 6.

2.3.3 WP 3, Laboratory prototyping

The aim of the WP was to elaborate and test the components of the SmartHomes system including the sensor/actuators used, the communication protocols employed and the database-to-Web connectivity. Appendix 3 details the outcome from this WP.

Based on a technology review, sensor and actuator devices from the Mikroklima company (www.mikroklima.cz) were selected because these provided the required functionality at acceptable cost. These devices were tested both singly and in groups corresponding to anticipated e-services. Access codes were established to allow device control by the service-specific software bundles resident on the e-box. The approach improves system robustness by allowing new data streams to be added to a service without the need to reconfigure sensor/actuator arrangements. A SmartHomes system prototype was then established and subjected to performance testing. Figure 3 shows the components of the system, which comprises a communications infrastructure, remotely deployed sensors/actuators and service-specific Web interfaces.

An Internet-enabled gateway device acts to co-ordinate home/business/industry data acquisition and actuation using sets of sensors/actuators that are customised to the particular service(s) being enacted.

The data obtained for a given site is transferred, by wireless and/or cable technology, to a central e-service centre placed at some arbitrary location on the Internet. There, these data are transferred to a central database where they are conflated with the private data arriving concurrently from the other sites within a given serviced region. Software agents then operate on these aggregated data in order to extract service-specific information for onward transmission to a corresponding service provider. This provider adds value by interpreting the data and providing the actual service. For example, information comprising home temperatures and CO levels would permit the provider to offer a progressive care for the elderly service, while an information set comprising appliance operational status would support the remote control of home appliances.

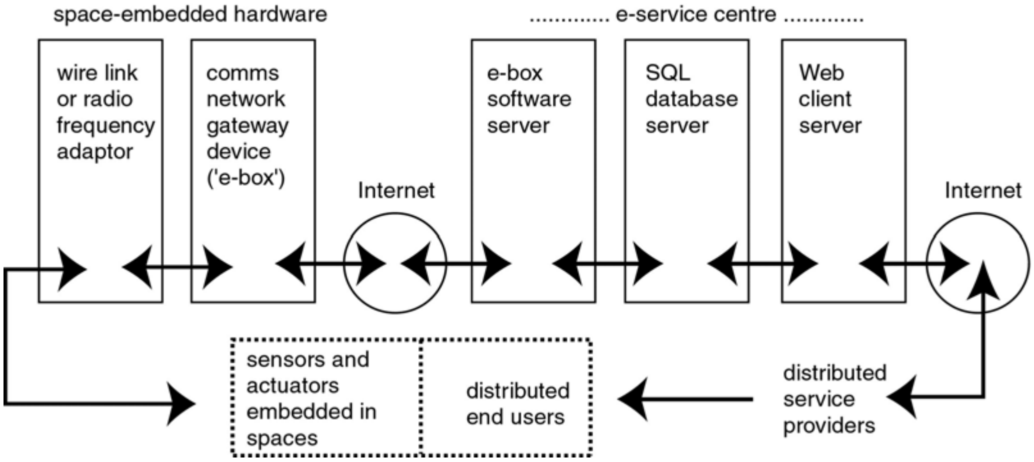


Figure 3: Components of the SmartHomes system.

Where the outcome from a service requires the imposition of control action, the transaction request is transmitted back to the relevant sites via the service centre to ensure that the actuations are authentic (i.e. that they are a valid component of the service selected by the customer).

Within the project, the gateway device is Ericsson's 'e-box': a low cost device utilising the Linux operating system within a solid-state, commercially secure architecture.

To support the targeted e-services, sensors were acquired or fabricated and related software installed within the e-box. Sensors were acquired for temperature, humidity, movement, CO and electrical power flow, while an actuator was developed to enable the switching of small power appliances. The form of these devices, and their relationship with the e-box and e-service centre, is shown in Figure 4, which depicts a project poster established to support the dissemination activities of WP 7.

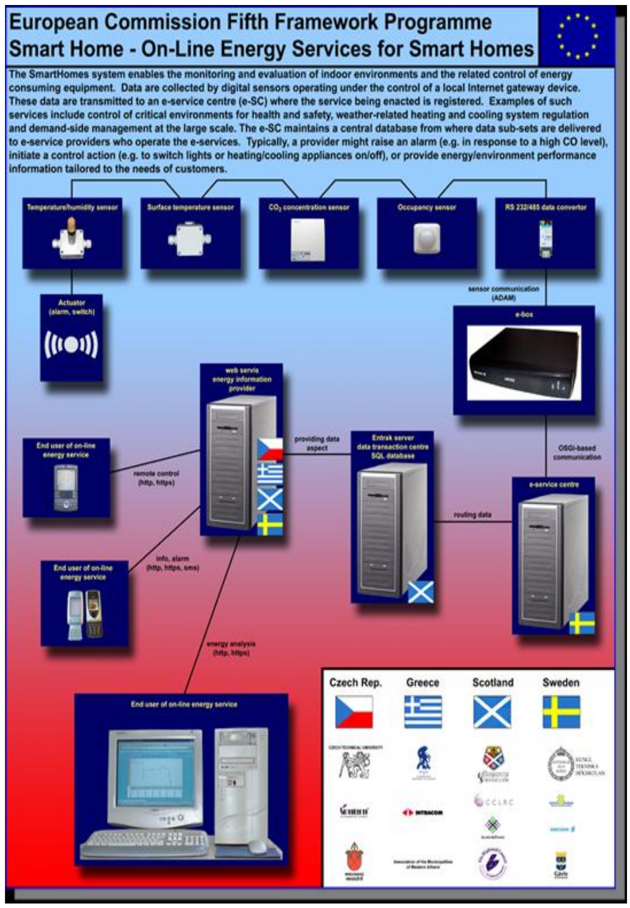


Figure 4: Sensors developed for the SmartHomes system (colour original).

All e-box data is transferred to the service centre where it is held within an SQL-compliant database. To keep track of these data, a generic Web interface was developed as depicted in Figure 5 and described in Appendix 4. This allows the project and field trial partners to observe the data associated with particular e-boxes (see Appendix 4 for further details).

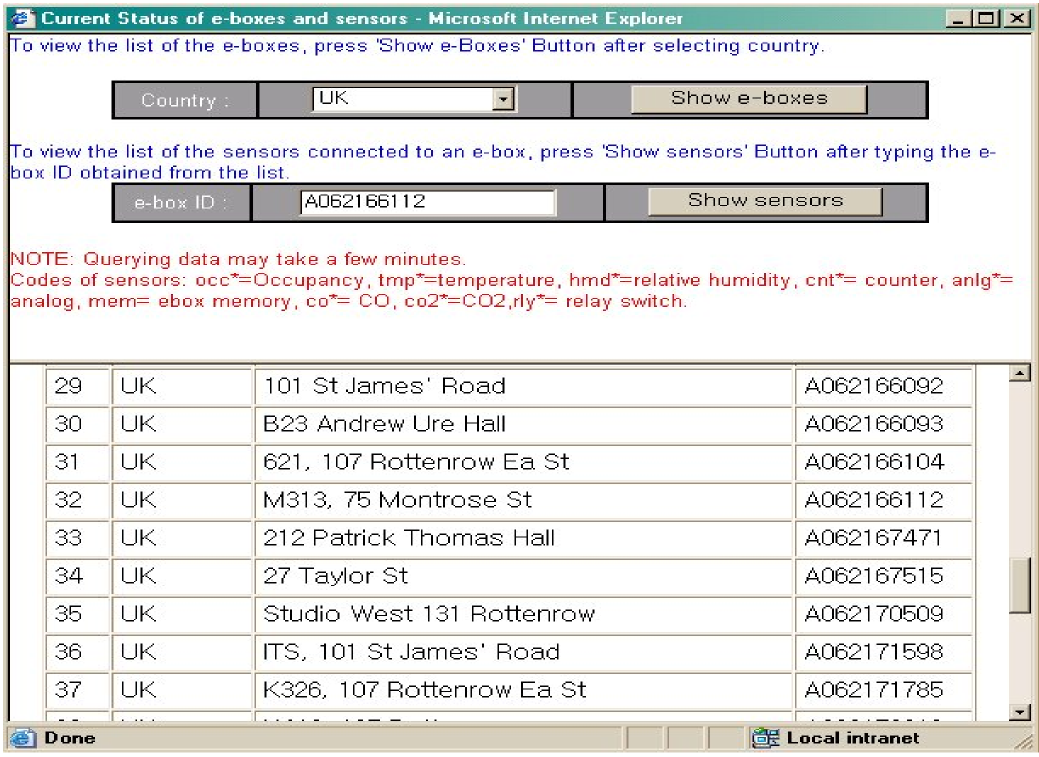


Figure 5: The generic Web interface (colour original).

To support the targeted e-services identified in WP 2, service-specific Web interfaces were established. Figure 6 shows an example corresponding to a customer information feedback service (see Appendix 4 for further details).

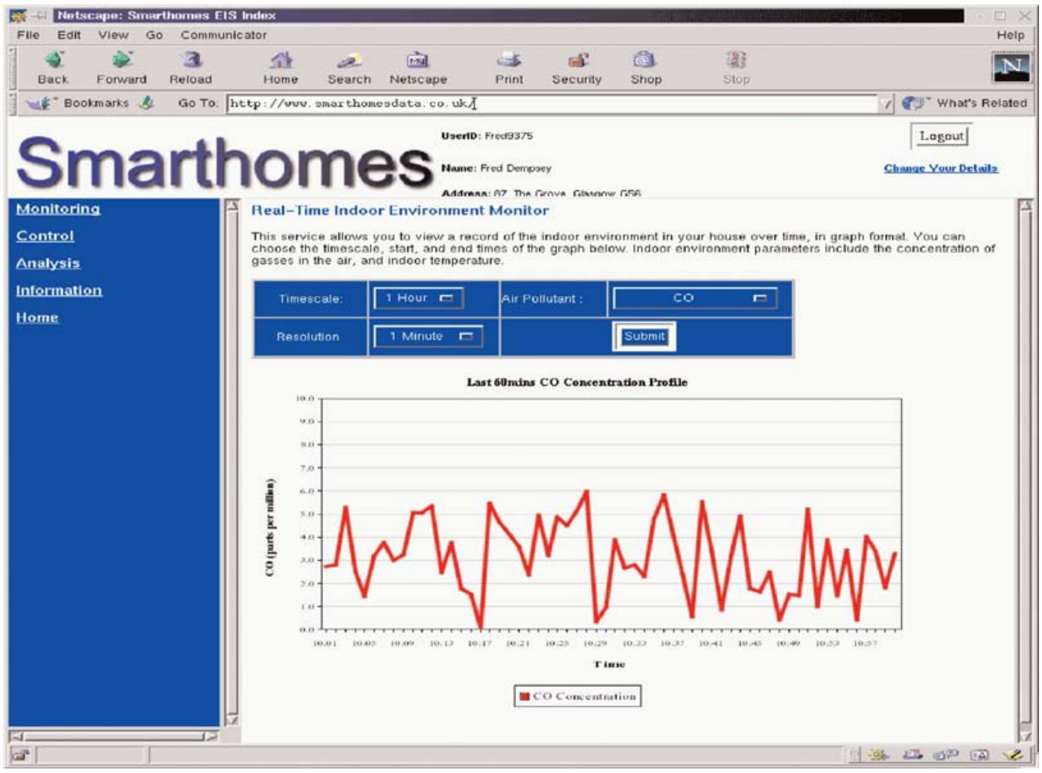


Figure 6: An example, service-specific Web interface (colour original).

In addition to the poster shown in Figure 4, a demonstration panel was established as shown in Figure 7. This is equipped with an operational e-box and set of sensors with a link to a Web interface. This enables immediate demonstration of the SmartHomes system and serves as a portable resource for school-based projects and the like.

Figure 7: The SmartHomes demo panel.

2.3.4 WP 4, Field trials

As elaborated in Appendix 4, this WP entailed the development and proving of a procedure for e-service deployment, and application of the procedure to examine the applicability of specific e-services deemed appropriate to the different national contexts. The procedure is fully elaborated in Appendix 4.

Prior to deploying the e-boxes, an e-service centre was established in Gävle, Sweden (under the control of Rivermen Plc (www.riverman.se) and connected to the EnTrak data management system. Together, these systems provide e-box authentication and data transaction management.

In total, 282 e-boxes were deployed within the project as follows.

Czech Republic: 49 e-boxes were deployed in support of domestic temperature monitoring, comfort control in schools and temperature/relative humidity/CO_2/occupancy monitoring. Due to the high cost and low availability of broadband connectivity, some deployments were made within buildings owned by the Czech Technical University in Prague.

Greece: 46 e-boxes were deployed in support of residential cooling load reduction through Internet-enabled predictive control. Due to the high cost (currently €60 for installation and €90/month) and low availability of broadband, some deployments were made within buildings owned by the University of Athens.

Sweden: 133 e-boxes were deployed in support of 'thermal justice' within multi- and single-family buildings in Gävle and Stockholm, with sensors configured to measure temperature, humidity and electricity consumption in each apartment and thereby provide a virtual metering capability. Some problems were encountered with network stability.

Scotland: 54 e-boxes were deployed to monitor temperatures, occupancy and electricity consumption within Highland Council’s and Scottishpower’s headquarters buildings with the aim of providing energy management information. Temperatures, occupancy and CO monitoring was also performed in houses as part of progressive healthcare provision. Due to the high cost and low availability of broadband, some deployments were made within premises owned by the University of Strathclyde.

Despite several deployment problems with firewalls and with e-service centre software, most of the installations have successfully run for extended periods (e.g. several months).

As described in Appendix 4, several Web sites were established to support the deployment e-services. These sites are essentially of two types: those that support e-service providers by giving them access to the e-box data returns (e.g. temperature, power consumption *etc*), and those that support end-users by providing them with derived information such as alarms, alerts and advice.

2.3.5 WP 5, Market study

As detailed in Appendix 5, market studies were performed within each partner country. The work examined the public acceptability of e-services and estimated the end-user value of each e-service. Table 1 summarises the studies undertaken.

Table 1: Studies completed in WP 5.

	Czech	Greece	Scotland	Sweden
Customer investigation	x	x		x
Potential for a cold alarm e-service	x	x		
Acceptance of the Internet	x	x	x	x
Laws and legislation	x	x	x	x
E-service value		x	x	
Implications for e-service providers	x	x	x	x
Environmental impact of e-services	x	x	x	x

Based on the collected data, conclusions were drawn under several categories as follows.

Energy and the Internet

The Czech team interviewed 250 people in the city of Mnichovo Hradiste. 39% of people living in rented flats were interested in the regular monitoring of their energy consumption, 69% were positively disposed to the remote control of their appliances, and 8% were connected to the Internet while 60% were planning a connection.

The Greek team conducted a survey in Athens on Internet usage and e-services. More than 20% of Greeks above the age of 15 years are using PCs while 13% are using Internet services. Of 120 tenants asked for their views on energy consumption, 72% responded that they were concern about energy use monitoring for economic reasons. The service of most interest was determined to be the raising of an alarm under threatening conditions.

The Swedish team employed the TEMO company to carry out a telephone survey. The results demonstrated that 50% of tenants consider the individual metering of energy use an effective way to influence running cost, but only one out of three would accept lower indoor temperature as an outcome of apartment metering. In an investigation from 2002 performed by Sweden Statistics, 8,000 people were asked about PC and Internet usage. About 80% had home PCs, while 75% of 16-64 year olds routinely accessed the Internet.

In the UK, 47% (11.75 million) of homes had Internet access via a fixed telephone line in 2003. Although some 67% of consumers are within an area covered by a DSL-enabled exchange, with a potential to reach 16.5 million homes, the actual number of British Telecom subscribers was 1,180,000, the number of cable modem service users was 1,141,000, and the number of broadband users was 2,321,000 and growing rapidly (Oftel 2003). Further, the 2001 census showed that 52% of Internet-connected homes had used the Internet to purchase tickets, goods or services, indicating a growing confidence in e-services in the UK.

Market potential

The question addressed here was 'what number of e-boxes and associated instrumentation would be required if all possible consumers decided to use the e-services targeted in each country?'. Table 2 summarises the outcome.

Table 2: E-box and sensor requirements by country and e-service.

	Czech Energy manage.	**Sweden** Energy manage.	**Sweden** Care for elderly	**Sweden** Cooling control	**UK** Energy manage.	**UK** Care for elderly	**UK** Utility load manage.	**Total**
e-box	75,000	230,000	50,000	50,000	160,000	6,000		811,000
Pulse counter	75,000		2,600,000					2,675,000
Humidity sensor	75,000	2,600,000						2,675,000

	Czech Energy manage.	**Sweden** Energy manage.	**Sweden** Care for elderly	**Sweden** Cooling control	**UK** Energy manage.	**UK** Care for elderly	**UK** Utility load manage.	**Total**
Temperature sensor			50,000	50,000	720,000		160,000	980,000
CO + smoke sensor			50,000			160,000		210,000
Current sensor							1,000	1,000
High voltage sensor							1,000	1,000
Low voltage sensor							5,000	5,000

To demonstrate the process by which the above estimates were made, consider the e-box estimate corresponding to the 'care for the elderly' service in Sweden. Today, Sweden has about 800,000 people older than 75 years and by 2020 this figure is estimated to rise to about 1,000,000. If 50% live alone and 50% are married, the potential for e-box deployment is about 530,000 systems today and 670,000 systems by 2020. If one e-box can service 10-20 apartments, then 50,000 e-box deployments would be required.

Laws and legislation

The Czech Republic does not have legislation that would restrict the roll-out of the e-services considered in this project. All services are possible on the basis of mutually signed contracts.

Likewise in Greece, there are no specific legislative constraints affecting e-services.

According to Swedish law, heating must be included in the rent. To enable the virtual metering e-service an agreement was reached between the Swedish Union of Tenants and the estate owners. The Swedish Housing Act is unclear regarding this issue.

In the UK, the domestic sector is covered by legislation and initiatives aimed at meeting the Kyoto targets. There is a requirement on each local authority to report the annual energy consumption of the houses in their region and propose target reductions. At present, data collection methods are rudimentary.

Consequences for energy and environment

The environmental impact of the envisaged e-services depends on the energy system they address. The more environment-friendly the energy system is today, the less the influence of the new e-service.

In the Czech Republic, embedding e-boxes in homes has been shown to decrease heating energy consumption with a favourable impact on CO_2 emission. However, the estimated savings are only theoretical and exclude the impact of occupant behaviour. The Czech Republic is a signatory to the Kyoto Protocol. In the context of joining the EU, the country has pledged through directive 2001/77/EU to increase the rate of production of electric power from renewable sources to 8% by 2010. This is intended to reduce CO_2 emissions by 2200 tonnes/year relative to 2000 levels. The demand/supply matching e-service is applicable here..

In Greece, the energy consumption for cooling in residential buildings represents 2-3% of total consumption. Of the supplied electrical energy, about 10% is produced from renewable sources of energy. Thus, the reduction of CO_2 emissions will be about 0.45%, if the saving of cooling energy is 20%.

In the UK, individual energy measurement is a way for local authorities to fulfil their obligations under the UK Home Energy Conservation Act. The domestic sector is covered by legislation and initiatives aimed at meeting Kyoto targets. All fuel suppliers with over 15,000 customers have an energy reduction target imposed by the regulator, OFGEM, under the Energy Efficiency

Commitment. This totals 62TWh for the UK over the period 2002-5 and a further reduction is likely for the period up to 2010. The saving by improved control is estimated at 10% when related to heating and air conditioning. Such a saving is equivalent to 1.3 million tonnes of CO_2 per year, which is approximately 1% of the total emissions in the UK (152 million tonnes in 2000).

In Sweden, the environmental impact on saving heat in apartments is low because the energy system in Sweden is relatively environment friendly. This situation will further improve with an expansion of the biomass and natural gas co-generation plant. The amount of waste heat will then be larger than the demand for district heating. Many experts believe that under this scenario the Swedish nuclear plants will close. If all apartments in Sweden had individual energy measurement, the CO_2 emissions could possibly be reduced by about 1%.

Peoples' views on e-services

Investigations show that 39-72% of tenants (depending on country) are interested in monitoring their energy consumption. Such information may be used to get people interested in energy and environment issues. Usage of the Internet varies from 5-75% in the four participating countries. These figures are continuously increasing. For most e-services, the environmental impact is considered to be relatively low but positive. Realistic reductions of CO_2 emissions for the proposed services range from 0.5% to 2%.

2.3.6 WP 6, Economic appraisal of e-services

This WP undertook an economic evaluation for large-scale e-service implementation in order to inform the industry about the scale of the challenge to construct a digital residential community throughout the European Union. Each feasible e-service option to emerge from the market study was appraised in terms of the required capital investment and operation charge to recover this investment. This was achieved by costing the individual components of each e-service. The following example relates to the Scottish 'care for the elderly' e-service, which provides a cold temperature alarm under indoor conditions that might lead to hypothermia. This service was broken down as follows.

- An e-box unit (which could service up to 10 houses) - approximate cost €250.
- Internal wiring per house - approximate cost €100 per sensor loop (usually only one required).
- Sensors to measure temperature and movement and provide an alarm – approximate cost €300.
- A communications line to the house (e.g. BroadbandBT Domestic achieving an ADSL connection via an existing telephone network) - approximately €288:
  - purchase of ADSL modem and filter pack, €136;
  - activation of ADSL connection, €104;
  - monthly rental, €48.
- Inherent cost of the e-service centre - approximately €10 per house.
- Total cost per house - approximately €1,048.

To allow an evaluation of competing investments and ensure that each country used the same assumptions were applicable, a spreadsheet-based economic model was developed. This included consideration of payback, profitability index (PI), net present value (NPV) and internal rate of return (IRR). Each country's e-services were modelled in two stages: a cost breakdown over 10 years and a project investment analysis. The cost breakdown was devised as follows.

1. The individual components were costed as above.
2. A reduction factor was applied to reflect larger production volumes.
3. The predicted number of e-services deployments was obtained from the WP 5 market study.
4. Marketing costs from ScottishPower's Marketing Department were assumed.
5. The cost of delivering the e-service was entered in the income section.
6. A diversity factor was applied to account for the fact that some users will utilise the Internet connection for other purposes.
7. The e-service cost was then varied until an acceptable payback was obtained.

This process gave rise to a first stage cost for the care for the elderly e-service of €375, while the second stage analysis gave the following results.

Profitability index 1.4

Net present value	€22 million
Internal rate of return	43%
Payback period	5 years

Each country produced a cost analysis for a principal e-service using the investment analysis model over a 10 year period. The results, using typical commercial discount rates, for each country are shown in Table 3.

Table 3: Economic analysis for the 'care for the elderly' e-service.

	Sweden: equitable billing	**Czech: district heating**	**Scotland: care for the elderly**	**Greece: cooling control**
Discount rate	5%	5%	8.65%	9%
Service cost	€240	€255	€375	€280
Payback period	3	4	5	7
Profitability index	2.4	1.9	1.4	1.2
Net present value	€35m	€11m	€22m	€0.8m
Internal rate of return	66%	50%	43%	20%

As the market expands, the service cost will reduce as the component costs fall. This has been factored into the model through the reduction factor. Likewise, the model incorporates assumptions on the rate of e-service take-up and installation costs extracted from the WP 5 market study. Note, however, that the analysis did not include the added value of the e-service to the customer, which would act to further improve the costs-effectiveness of the service.

From the results it is clear that an acceptable rate of return can be achieved for most e-services when deployed within each county. The economic appraisal model is available as a project deliverable.

2.3.7 WP 7, Outcome dissemination

The national field trials of WP 4 comprised the main dissemination activities of the project, with participant organisations and the wider community of interests being exposed to the SmartHomes system concept on a daily basis. The primary aim was to demonstrate procedures for the remote activation of e-services. It is expected that some of these field trials will persist beyond the project's end and will therefore form the basis of further demonstrations and future commercial activities.

To further support dissemination, a SOSTAM analysis (**S**ituational analysis, **O**bjectives identification, **S**trategy formulation, **T**actics agreement, **A**ction planning and **M**onitoring) has been undertaken within this WP. This comprises the project's dissemination and exploitation plan that has been agreed by all partners. Details on this activity are given in Appendix 7.

Several outputs have resulted from the project that may by disseminated and exploited:

- information - in the form of sate-of-the-art reviews and market studies;
- know-how - including the experience gained instrumenting buildings, collecting and analysing data, constructing and operating e-services *etc*;
- software - including generic e-box bundles, the analysis pipeline and service delivery components;
- demonstration services - based on the example services developed during the project and hosted on national websites; and
- reference sites demonstrating e-services with commercial potential in the near term.

The e-services that have been demonstrated in the present project are:

- monitoring of the indoor temperature in individual apartments;
- information for occupants on the daily cooling demand;
- information to local authorities on energy consumption at the large scale;
- linking of comfort to energy use;
- prediction of regional cooling energy demand;
- remote actuation and control of appliances;
- monitoring of energy consumption in multi-family houses as an aid to billing;
- monitoring of energy use in support of energy management;
- care for the vulnerable under cold/hot weather conditions;
- monitoring of internal temperatures in cases of fuel poverty; and
- provision of energy consumption data to utilities for demand/supply matching and local load management.

The WP 7 work set out to construct a planning and control instrument for post-project dissemination and exploitation. The resulting plan gives an overview of the project partners, outlining their objectives and infrastructure that can be used for dissemination and exploitation. The products and services that are subject to exploitation are then described, the position of the SmartHomes system in the market is summarised and potential markets identified. Finally, market-related strategies and concrete action plans are elaborated. This dissemination and exploitation plan can therefore be regarded as a basis for a business plan for the future marketing of the developed e-services. The partners have agreed to update the plan as the available technology, legislative context, market conditions and economic viability evolve.

2.3.8 WP 8, Project conclusions
The project has proceeded to plan and has established an operational system, which is capable of supporting the delivery of a range of new energy-related services. The robustness of the SmartHomes system has been proven within laboratory tests before being deployed in the field in order to demonstrate these services and establish their value and commercial potential. Several future benefits are expected to arise from such services:

- running cost reductions;
- management of demand in real time;
- provision of new added-value services to customers;
- optimised operation of supply systems; and
- better management of service quality according to customer requirements.

Because the project included technology partners who are interested in commercialising the outcomes, the future exploitation potential is good.

2.4 Non-paper outputs
In addition to the outputs described in this report, the project generated software for deployment within the e-box to control local data acquisition/actuations and deployment within the e-service centre to co-ordinate the return from distributed e-boxes and extract data to support specific e-services. This software, which is available under an Open Source licence, may be downloaded from http://www.esru.strath.ac.uk.

2.5 Acknowledgements
The project team is indebted to the EESD-Energy Programme of the European Commission for their financial support and to those individuals and organisations, most notably Riverman plc and Gatespace Telematics, who assisted with the establishment of the field trials.

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See also the reference section of Appendices 1 and 2 and the Technology Implementation Plan of Appendix 7.

Note that some of the above reports may be downloaded from www.esru.strath.ac.uk or http://peta-esru.mecheng.strath.ac.uk/smarthomes.

Part 3: Management final report

3.1 List of deliverables

The project deliverables, corresponding to the different work packages, were as follows.

- an extensive technology review;
- an appraisal of possible e-services;
- the SmartHomes system prototype (available under an Open Source licence);
- a check list of actions to be taken in support of e-service deployment;
- results from the field trials of different e-services in 4 EU member states;
- results of the market study;
- an economic appraisal of various e-services; and
- a technology implementation plan.

3.2 Comparison of initially planned activities and work actually accomplished

All initially planned activities were realised although the field study deployments experienced time slippage due to problems with Internet access and sensor procurement (see §3.3). Despite limited resources for sensor fabrication, the project was completed to time and within budget as summarised in Table 4. The latter achievement required the (approved) virement of funds from the dissemination budget to the sensor fabrication budget.

Table 4: SmartHomes project final budget (€).

Partner	Advance	Period 1	Period 2	Total
ERAD	19,462.00	8,786.00	12,912.00	41,160.00
RIT	34,560.00	182.00	11,532.00	46,274.00
GEC	13,246.00	4,728.00	9,539.00	27,513.00
Gävle	6,402.00	1,909.00	3,501.00	11,812.00
USTRAT	71,551.00	26,051.00	33,736.00	131,338.00
SCOTTPO	17,898.00	10,947.00	8,914.00	37,759.00
CLRC	19,422.00	4,687.00	2,597.00	26,706.00
HRC	8,887.00	-	3,081.00	11,968.00
UAT	57,538.00	31,693.00	-	89,231.00
INTRAC	12,077.00	8,917.00	6,359.00	27,353.00
ADWA	3,524.00	2,100.00	2,286.00	7,910.00
CTU	28,223.00	-	-	28,223.00
KMJ	4,706.00	-	4,744.00	9,450.00
MHCC	2,598.00	-	799.00	3,397.00
Total	300,094.00	100,000.00	100,000.00	500,094.00

3.3 Management and co-ordination aspects

As the WP 4 field trials commenced, a critical event occurred: the e-box technology was transferred from Ericsson to Gatespace, who subsequently became bankrupt. Steps were taken to ensure that sufficient numbers of e-boxes were acquired to fulfil the project requirements. To this end, the newly formed company, Gatespace Telematics, were most helpful. Otherwise, the project proceeded to plan, with WP leaders reporting to Ericsson as overall co-ordinator and the University of Strathclyde as technical co-ordinator.

To facilitate the shared exploitation of the project's outcomes, a Technology Implementation Plan was prepared (Appendix 7), which reflects the different intentions of the project partners. These intentions range from specific marketplace opportunities of interest to the industry partners, through downstream research intentions of interest to the academic partners, to actual deployments of interest to the local authority partners. All project outputs, including meeting minutes, are available at http://peta-esru.mecheng.strath.ac.uk/smarthomes.

Appendix 1: Work Package 1, Technology review

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Introduction

Energy management and energy services in the building sector involve a range of actors, with each one having specific objectives. Furthermore, it is important to provide integrated services, in a way that the end-users can benefit without having to be fully familiar with individual systems. It was also recognised that this integration should not affect the individuality, integrity and functionality of the different systems.

A number of services in buildings require integration, but the actual building-related services that attract most attention are fire, security, energy management and maintenance, all joined by information technology and telecommunications. It is necessary to provide an interface between incompatible systems from different manufacturers. Although attempts have been made throughout the world to establish a standard communications protocol, there is no single protocol used by all suppliers of building services. Unification is not an easy task as there are many existing protocols, each a candidate for any standard.

Technology allows systems to become increasingly sophisticated, thereby offering greater functionality to the user. The need for integration is becoming more pressing. Solutions are needed now, as there are strong indications that new energy services provided to citizens are likely to grow significantly over the next years, driven mostly by the deregulation of the energy market. It is likely therefore that energy systems for the 'smart' home of tomorrow will be developed. The aim will be to combine building control and IT technologies in order to meet the needs of building providers, operators, utilities and owners/occupiers. In this context, the gateway concept offers integration to all users of building services by providing the means to exchange data between systems.

The SmartHomes project built on Ericsson's residential gateway, or e-box, technology and aimed to test and prototype new Internet-based energy services for citizens and professionals. The remote monitoring of fuel consumption and environmental conditions, the actuation of domestic appliances and the delivery of interactive information to citizens are examples of possible energy services. Such e-services provide the means to effect an orchestrated energy management system. In order to identify a suitable delivery platform, different topics must be examined.

1. Overview of related projects

In recent years, many pilot projects have been undertaken that relate to aspects of the SmartHomes system such as data acquisition and processing, control strategy implementation and communications. There follows a summary of these projects.

Energy Barometer

This project was developed to measure energy use in relation to internal and external climates in different types of single-family houses.

Radio-Teleswitch

The Radio-Teleswitch System (RTS) was developed for the remote control of storage heating and hot water systems via a 198kHz radio frequency.

Weathercall

The Weathercall (WC) system is used for automatic storage heater charge control and domestic hot water storage.

CELECT

Celect is an extension of the RTS and WC systems that gives more sophisticated local control of heating systems.

Genesys

In the Genesys project the aim was to develop optimum control strategies for HVAC systems, based on multi-criteria analysis and the use of fuzzy controllers to which are applied smart tuning techniques.

SCRATS
In the Smart Controls and Thermal Comfort project, a wide-ranging thermal comfort surveys was carried out in different climate regions of Europe. This led to the development of algorithms for use in control systems for air conditioned and natural ventilated buildings in order to reduce energy use.

Builtech
This project was established to test and document an integrated building energy management system combining intelligent decision-making systems and smart card techniques. The project utilised local network technology, which is suitable for existing buildings equipped with conventional energy facilities.

TeleSurve
This project was a European Commission sponsored programme to develop the Virtual Services Enterprise. This allows teleworkers and business partners to collaborate on a contract-by-contract basis through electronic data exchange or over the Internet. The project modelled business processes and then developed them as workflow steps.

Proflex
This project dealt with the support of highly flexible processes, which are subject to frequent changes. The project encompassed the domains of project management, workflow and groupware systems. Proflex was developed on top of Microsoft's groupware solution and has been successfully introduced in three industrial pilot sites.

W3C-LA
This is a leveraging action funded by ESPRIT to ensure a greater uptake of Web technologies throughout Europe by developing shrink-wrapped demonstrators and encouraging champions to develop demonstrations for their management that show the potential impact of the Web on the company's future business. The belief is that such demonstrations will lead to applications development within companies.

2. Home network communication
This section examines the indoor part of the SmartHomes system. This includes the various sensors for data acquisition and actuators for appliance control.

2.1 Data collection - sensors
In order to proceed from measurement system design to measurement system construction, the first step is to identify the measurement parameters and then select appropriate sensors. In general there are four types of monitored parameters as follows.

Climate parameters
These support the assessment of the indoor and outdoor climate of a building:
- temperature;
- air humidity;
- wind velocity and direction; and
- solar radiation.

Engineering parameters
These characterise the engineering systems of the building:
- mass flow of air and liquids; and
- heat flux.

Chemical parameters
The main issue affecting the operation of the ventilation system of a building is the indoor air quality. This requires the measurement of various contaminants, most notably CO_2 and volatile organic compounds (VOCs) and other particulates.

Occupancy parameters
Occupancy sensors can be used to control lights, windows and doors, while information on the frequency and duration of door/window opening may be used to calculate the ventilation and heat loss rates.

2.1.1 Temperature
Tables 1 through 4 summarise the available sensors.

2.1.1.1 Principles
Thermocouples
A thermocouple is a temperature measurement sensor that consists of two dissimilar metals joined together at one end produce a small thermo-electric voltage when the junction is heated. The change in this voltage is interpreted as a change in temperature. For precise measurements, the reference junctions should be kept at a known temperature (an ice bath is commonly used). The main advantage of thermocouples is their easy construction. They are often used to measure high temperatures (when the measured temperature is close to the reference junction the voltage output is small). Accuracy: up to ±0.1°C, usually ±1°C.

RTD probes
The electrical resistance of various materials changes in a reproducible manner with temperature. This forms the basis of this temperature-sensing method. Resistance temperature detectors (RTD) usually employ a platinum element (wire wound or thin film). To measure the resistance the ohmmeter technique is usually used - the sensor is powered by a constant current source and the voltage signal is an output. Accuracy: up to ±0.03°C, usually ±0.2°C.

Thermistors
Compared with RTD sensors, which have a small positive temperature coefficient, semiconductors have a large negative coefficient and are non-linear. The linear response sensors consist of a thermistor composite for temperature sensing and an external resistor composite for linearising.

Junction semiconductor sensors
These devices employ diodes and transistors as temperature sensors. The main advantage is linearity and good sensitivity. However, their upper range is restricted to about 200°C by the damage limits of silicon transistors.

Infrared temperature measurement
A radiation thermometer consists of an optical system and a detector. The former focuses the energy emitted by an object onto the latter, which is sensitive to radiation. The detector output is proportional to the amount of energy radiated by the object (less the amount absorbed by the optical system), and the response of the detector to the specific radiation wavelengths. This output can be used to infer the object's temperature. The emissivity of the object is an important variable in converting the detector output into an accurate temperature signal. Infrared radiation thermometers/pyrometers, by specifically measuring the energy being radiated from an object in the 0.7 to 20μm wavelength range, are a subset of radiation thermometers. Accuracy (depends on emissivity): up to ±0.5°C, usually ±3°C.

Low cost temperature sensors with digital output
For air temperature measurement, a silicon temperature sensor with an output directly connectable to a microprocessor can be used. The output square wave with a well-defined, temperature-dependent duty cycle is linearly related to temperature and can be read by the microprocessor. Accuracy: varies from ±0.7 to ±2°C. Sensing element price: €10-30.

2.1.1.2 Measured variables
Room air temperature
Air temperature measurement sensors should be shielded to avoid influence by radiation from direct sunlight or from surrounding surfaces. Sensor ranges vary from 0 to 35°C, but it is easy to increase this to -30°C to 120°C. Standard domestic sensors (price depends on accuracy and construction): 20-€80. Digital domestic sensors (price depends on protocol): €120-€180.

Table 1: Internal air temperature sensors.

Producer	Mode	Range	Output	Power	Connection	Assembly	Price
Siemens L+S	QAA64	0, +50°C	Ni1000	No	Doubleline wire	wall	€70
Siemens L+S (duct air)	QAM22	-30, +80°C	Ni1000	No	Doubleline wire	flange	€68
SENZIT	NS100, NS101	-30, +100°C	Ni1000	No	Doubleline wire	wall	€10
SENZIT	PTS300	-30, +130°C	Pt1000	No	Doubleline wire	wall	€11
SENZIT	NS700	Optional	0-10V dc	24V dc	Tripleline wire	wall	€34
SENZIT	NS500	Optional	4-20 mA	24V dc	Doubleline wire	wall	€29
SENZIT (duct air)	NS120, NS121	-30, +150°C	Ni1000	No	Doubleline wire	flange	€23
SENZIT (duct air)	PTS320	-30, +150°C	Pt1000	No	Doubleline wire	flange	€23
SENZIT (duct air)	NS720	Optional	0-10V dc	24V dc	Tripleline wire	flange	€50
SENZIT (duct air)	NS520	Optional	4-20 mA	24V dc	Doubleline wire	flange	€47
Thermocon	WRF02		0-10V				€20
Thermocon	WRF02 LON		LON				€139
Mikroklima	Midam 100		RS485				€117
Sensit	NS760		0-10V				€63

External air temperature
The external temperature sensors should be equipped with sun and rain protection. Sensor range is -30 to 50°C (or -50 to 150°C). Standard sensors (price depends on accuracy and construction): €50-€90. Digital sensors (price depends on protocol): €130-€180.

Table 2: External air temperature sensors.

Producer	Mode	Range	Output	Power	Connection	Assembly	Price
Siemens L+S	QAA24	-35, +50°C	Ni1000	No	Doubleline wire	wall	€50
SENZIT	NS110, NS111	-30, +100°C	Ni1000	No	Doubleline wire	wall	€21
SENZIT	PTS310	-30, +100°C	Pt1000	No	Doubleline wire	wall	€22
SENZIT	NS710	Optional	0-10V dc	24V dc	Doubleline wire	wall	€42
SENZIT	NS510	Optional	4-20mA	24V dc	Doubleline wire	wall	€38
Thermocon	AGS54 Ext		0-10V				€56
Thermocon	AGS54 Ext		LON				€149

	LON						
Mikroklima	Midam 100		Rs485				€128

Surface temperature
For surface temperature measurement, good contact is important. Sensor range is from -30 to 120°C. Standard contact sensors (price depends on accuracy) - €15-€80; digital sensors (price depends on protocol) - €120-€180; standard infrared thermocouple (4-20mA output) - €700-€900; infrared thermocouple - €100-€500; panel meter with thermocouple input and RS232 or 485 communication - €150-€400.

Table 3: Contact temperature sensors.

Producer	Mode	Range	Output	Power	Connection	Assembly	Price
Siemens L+S	QAD22	-30, +130°C	Ni1000	No	Doubleline Wire	Pipe band	€38
Siemens L+S	QAP21.1	-10, +35°C	Ni1000	No	Doubleline Wire	Nalepi se	€100
SENZIT	NS140, NS141	-30, +130°C	Ni1000	No	Doubleline Wire	Pipe band	€35
SENZIT	PTS340	-30, +100°C	Pt1000	No	Doubleline Wire	Pipe band	€35
SENZIT	NS740	Optional	0-10V dc	24V dc	tripleline wire	Pipe band	€50
SENZIT	NS540	Optional	4-20mA	24V dc	Doubleline wire	Pipe band	€48
Thermocon	VFG43		0-10V 4-20mA				€15
Thermocon	VFG43 LON		LON				€135
Mikroklima	Midam140		RS485				€128
Sensit	NS 740		0-10V 4-20mA				€49

Water temperature
When water temperature is measured, the sensors should be protected in the wheel. Screw-in temperature detectors: standard sensors (price depends on accuracy) - €30-€90; digital sensors (price depends on protocol) - €130-€180.

Table 4: Water temperature sensors.

Producer	Mode	Range	Output	Power	Connection	Assembly	Price
Siemens L+S	QAE22	-30, +130°C	Ni1000	No	Doubleline wire	screw	€73
SENZIT	NS130, NS131	-30, +150°C	Ni1000	No	Doubleline wire	screw	€29
SENZIT	PTS330	-30, +150°C	Pt1000	No	Doubleline wire	screw	€29
SENZIT	NS730	Optional	0-10V DC	24V dc	tripleline wire	screw	€56
SENZIT	NS530	Optional	4-20 mA	24V dc	Doubleline wire	screw	€56
Thermocon	SFK02		0-10V 4-20Ma				€41

Thermocon	SF102 LON		LON				€161
Mikroklima	Midam130		RS485				€130
Sensit	NS 730		0-10V 4-20Ma				€56

Operative temperature
For velocities less than 0.4m/s and mean radiant temperatures less then 50°C, the operative temperature is approximately equal to the average of the air and mean radiant temperature. The most common instrument to determine the mean radiant temperature is a black globe thermometer. This comprises a hollow sphere with a flat black paint coating with a thermocouple or thermometer bulb at its centre. Mean radiant temperature is strongly influenced by thermometer position: the black globe thermometer should be at the middle point of the room 1m above the floor. It is difficult to take measurements in a room that is not empty. Black globe thermometer (hollow sphere): €100-€300.

2.1.2 Air humidity measurements
Many instruments are available for measuring the moisture content of the air (Table 5). The sensors used on the instruments respond to different moisture contents. These responses are related to factors such as wet-bulb temperature, relative humidity, humidity mixing ratio, dew point and frost point. For measurement of air humidity in rooms, usually capacity sensors are used. The accuracy of capacitance aluminium oxide sensors is usually ±3%. Standard capacitance sensors (internal wall mounting or to duct): €150-€250. Standard capacitance sensors (external): €220-€300. Laboratory capacitance sensor: €180-€250. Laboratory dew point sensor: €1400-€1600.

Table 5: Humidity sensors.

Producer	Mode	Range	Output	Power	Connection	Assembly	Price
Siemens L+S (internal)	FR-H1	10-95%	0-10V dc	24V ac, dc	24V ac	wall	€188
Siemens L+S (internal)	QFA65	10-90% 0-50^{o}C	1-9/ 0-10V dc	24V ac	Fourline wire	wall	€201
Siemens L+S (internal)	QFA66	0-100% 0-50^{o}C	2X 0-10V dc	24V ac	Fourline wire	wall	€419
Thermocon (internal)	FW 06		0-10V 4-20mA				€184
Thermocon (external)	FA 54		0-10V 4-20mA				€246
Ahloborn (lab Sensor)	FHA646						€235
Ahloborn (lab sensor)	MT 8716						€1498
Omega (industrial)	HW800		4-20mA				€533
Omega (industrial)	HX49		4-20mA				€324
Siemens L+S (H-T air duct sensor)	QFM65	10-90% -35 - 35^{o}C	1-9/ 0-10V DC	24V AC	Fourline wire	flange	€209
Siemens L+S	QFM66	0-100%	1-9/ 0-10V	24V AC	Fourline wire	flange	€421

(H-T air duct sensor)			DC				
Thermocon (H-T air duct sensor)	FK 260		0-10V 4-20ma				€184

2.1.3 Air velocity sensors
Table 6 lists the available sensors.

2.1.3.1 Principles
Vane anemometers
This consists of a light, revolving, wind-driven wheel and the velocity is measured via frequency.

Cup anemometer
This is primarily used to measure outdoor wind speeds. It consists of three or four hemispherical cups mounted radially from a vertical shaft. Cup anemometer for meteorological measurements: €700-€800.

Pitot-static tubes
In conjunction with a suitable differential pressure transducer, this provides a simple method of determining air velocity at a point in a flow field. The accuracy of measurement depends on the manometer minimum velocity (limit around 0.9m/s). Velocities greater than 7.5m/s can be measured with good accuracy.

Hot-wire anemometer
The thermal anemometer consists of a heated RTD, thermocouple junction or thermistor sensor constructed at the end of a probe. The probe is placed into an air stream and the movement of air past the electrically heated velocity sensor tends to cool the sensor in proportion to the speed of the air flow. The principal advantage of thermal anemometers is their wide dynamic range and ability to sense low velocities. Omnidirectional sensing instruments are suitable for thermal comfort measurements. Sensing range 0.005 to 300m/s (but not in a single instrument).

Table 6: Air velocity sensors.

Producer	Mode	Range	Output	Power	Connection	Assembly	Price
Siemens L+S	FKA-V2	0-5 / 0-15m/s	0-10V dc	24V dc	Fourline wire	Pipe catchment	€441
Ahlborn	FD99123						€106
Ahlborn	FD991299						€264
Ahlborn	FVA645						€587
Ahlborn	MT8485						€981
Ahlborn	MT8475						€1,880
Dantech							€1,955
Omega	FMA-900		0-5V				€1,039
Ahlborn	FV915						€587
Ahlborn	FV915						€1,028
Ahlborn	FVA615						€734

2.1.4 Radiation sensors
Table 7 lists the available sensors.

Irradiance
Irradiance is the radiant flux incident on a receiving surface from all directions, per unit area of surface. The properties of the flux depend on the wavelength of the radiation. Spectral irradiance is the irradiance at a given wavelength, per unit wavelength interval. The irradiance within a given

waveband is the integral of spectral irradiance with respect to wavelength.

Solar radiation sensors
Sensors for the measurement of incoming global solar radiation should have a wide spectral range, the wavelengths from 0.3 to 2μm being the most important. The silicon cell photo-diode pyranometer offers an economical solution to the reliable measurement of global solar irradiance from 0.4 to 1.1μm. Silicon cell photo-diode pyranometer sensor: €370. Thermocouple pyranometers are used for the routine measurement of global solar radiation (0.3 to 2.8μm), diffuse sky radiation, and surface reflected solar radiation. Pyranometer sensor (price depended on ISO9060 Class): €500-€2,500.

Table 7: Solar radiation sensors

Producer	Type	Model	Range	Output	Price
Kip Zonen	Lite silicon Pyranometer	SP	0.4-1.1μm	Voltage, 4-20A	€370
Kip Zonen	ISO-9060	CM 3	0.3-2.8μm	Voltage, 4-20A	€510
Kip Zonen	ISO-9060 First Class pyranometer	CM 6	0.3-2.8μm	Voltage, 4-20A	€2203

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2.1.5 Pressure sensors
A wide range of electromechanical transducers exists for pressure measurements (Table 8). For HVAC systems three categories are used:
- absolute pressure measurement of gases (natural gas, air) to calculate density (gauge pressure measurement is often used as a surrogate for absolute pressure, gauge pressure up to 5kPa);
- gauge pressure measurement in HVAC system checks up to 600kPa; and
- differential pressure measurement to determine velocity or air flow rate, up to 300Pa.

Low pressure gauge standard sensors (0-300Pa): €150-€250. Gauge or pressure difference standard sensors: €80-€150. Highly accurate gauge or pressure difference standard sensors: €300-€900. Barometric pressure sensors: €500-€900.

Table 8: Pressure sensors.

Producer	Mode	Range	Output	Power	Connection	Assembly	Price
Siemens L+S (Duct water)	QBE61.1-p	0-0.5bar/ 0-40bar	0-10V dc	24V ac	Tripleline wire	screw	€432
Siemens L+S (Duct air)	QBE620-P	0-1bar/ 0-40bar	0-10V dc	24V ac	Tripleline wire	screw	€258
Siemens L+S Difference sensor (air-n.gas)	QBM62	0-50Pa/ 0-3000Pa	0-10V dc	24V ac	Tripleline wire	Wall, DIN ribband	€153
Siemens L+S Difference sensor (air-gas)	QBM63	0-100Pa/ 0-3000Pa	0-10V dc	24V ac	Tripleline wire	wall, DIN ribband	€311
Siemens L+S Difference	QBM61.2-dP	0-0.5bar/ 0-10bar	0-10V dc	24V ac	Tripleline wire	wall	€561

sensor (air-water)							
Cressto (air)	P	0-100 Pa	0-10V 4-20mA				€175
Cresto (air)	R	0-4 MPa	0-10V 4-20mA				€106
Omega(1)	PX02-BAR		0-5V				€871
Omega(2)	PX2760		0-5V				€459
Omega (air)	PX138		0-5V non-linear				€69
Omega(3)	PX656		4-20mA				€622
Landis (4) & Stefa	QBM65-1	0-100 Pa	0-10V				€251
Landis (5) & Stefa	QBM65-10	0-1,000 Pa	0-10V				€251
Landis (6) & Stefa	QBM63/ 100	0-100 Pa	0-10V				€333
(1): High accuracy electronic barometer. (2): Economical barometric pressure transducer. (3): Low-pressure industrial transmitter, highly accurate. (4), (5), (6): Low pressure sensors.							

2.1.6 Flow rate sensors

There are various means of measuring fluid flow rate as listed in Tables 9 and 10. Positive displacement meters are used to measure water and hot water consumption in flats.

Electromagnetic flow meters

Faraday's law of induction states that a voltage is induced in a conductor moving in a magnetic field. In electromagnetic measuring, the flowing medium corresponds to the moving conductor. The induced voltage is proportional to the flow velocity and is detected by two measuring electrodes and transmitted to an amplifier. Flow volume is computed on the basis of the pipe's diameter. The constant magnetic field is generated by a switched direct current of alternating polarity. Up to DN 25 (RS485 output): €1,300.

Coriolis mass flow meters

A mass flow dependent Coriolis force occurs when a moving mass is subjected to an oscillation perpendicular to the flow direction. The measuring system accurately determines and evaluates the resulting effects on the measuring tubes. Up to DN 25 (RS485 output): €6,000-€8,000.

Ultrasonic flow meters

Prosonic flow operates on the principle of transit time differences. An acoustic signal (ultrasonic) is transmitted from one sensor to another. This can be either in the direction of flow or against this direction. The time that the signal requires to arrive at the receiver is then measured. According to physical principles, the signal sent against the direction of flow requires longer to return than the signal in the direction of flow. The difference in the transit time is directly proportional to the flow velocity. DN more that 50 (RS485 output): €3,500.

Laboratory flow meters

To measure low flow rates laboratory flow meters can be used. Differential pressure measurement across a laminar flow element or a Pelton-type turbine wheel is used to determine the flow rate of a liquid. Low flow meters for laboratory use (analogue output): €200-€900.

Diaphragm gas meter
The measuring unit operates with form-retaining synthetic diaphragms based on the principle of pneumatic control. This results in low noise, long-term stability, high accuracy and the possibility to fit mechanical temperature compensation. A diaphragm gas meter is used for flows up to $100m^3/h$. Standard domestic gas meter for CR (up to $6m^3/h$): €30-€50. Pulse generator (can be installed to existing gas meters type BK): €15-€50. Pulse to M Bus converter: €150-€250.

Rotary-vane water meter
These are used to measure water consumption. Most can be fitted with a pulse generator, which allows electronic measurement. Standard domestic cold water meter + pulse output (up to DN 32): €30-€150. Hot water meter + pulse output (up to DN 32): €130-€180. Pulse to M Bus converter: €150-€250.

Table 9: Flow meters.

Producer	Type	Model	Range	Output	Price
Omega	Electromagnetic Flowmeters	FMG400		0-5V	€2,944
Endress+Ha User	Coriolis mass Flowmeters	Promass I		RS485 4-20mA	€8,181
Endress+Ha User	Ultrasonic Flowmeters			RS485 4-20mA	€3,524
Omega	Multi-liquid Ultrasonic Flowmeters	FD 7000		4-20mA	€7,066
Omega	Volumetric Floemeter	FDP 10	0-500cc/min	Voltage	€389
Omega	Gas/liquid Flowmeter	FLR 1001	0.02,5I/min	0-5V dc	€217
Omega	Teflon liquid Flow sensors	FPR 1500	0.01,2I/min	0-5V dc	€742
Omega	Mass flow meters Gass	FMA 1604	DN15 Class B	0-5V dc	€942
Schlumberger	Rotary-vane Dry-dial Cold watermater	Unimag	DN32 Class B	Pulse	€29
Schlumberger	Rotary-vane Dry-dial Cold watermater	Multimag	DN15 Class C	Pulse	€73
Schlumberger	Rotary-piston Dry-dial Cold watermater	Aquadis	DN15 Class C	Pulse	€66
Schlumberger	Rotary-piston Dry-dial Cold watermater	Aquadis	DN32 Class C	Pulse	€137
Schlumberger	Rotary-piston Dry-dial Hot watermater	MTWH	DN15 Class B	Pulse	€127
Schlumberger	Rotary-piston Dry-dial Hot watermater	MTWH	DN32 Class B	Pulse	€158

Table 10: Gas meters.

Producer	Type	Model	Output	Price
Gas AS	Domestic diaphragm	G1, 8-6		€44

Gas AS	Pulse generator	INZ 31	Pulse	€44
Schlumberger	Domestic diaphragm	G1, 8-6		€41
Schlumberger	Pulse generator		Pulse	€15
Schlumberger	Pulse-Mbus Converter		M-bus	€59

2.1.7 Distribution heat meters

Standard heat meters (Table 11) consist of two temperature sensors, a flow meter and an integration electronic unit. Such meters can be used for houses and flats with horizontal heating devices. Heat meter (up to DN 32, bus output): €300-€500. With vertical devices, temperature sensing and integrating elements on radiators may be used to determine heat consumption. Radiator heat meter (digital output): €30-€50. Central unit for 100 radiators: €1,200.

Table 11: Heat meters.

Producer	Type	Model	Range	Output	Power	Price
RAPP+ KUNDO	Radiator heat meter (temperature integrator)	CH-1800	1 radiator		Battery	€35
RAPP+ KUNDO	Radiator heat meter (remote)	CH-1800 funk	100 radiators		Battery	€1,175
Schlumberger	Compact distribution heat meter	CF Combi	DN 20	M BUS/ pulse		€303
Schlumberger	Distribution heat meter	CF Combi	DN 32	M BUS/ pulse		€483

2.1.8 Water level sensors

Water level sensors (Table 12) are designed to be use in industrial systems and are difficult to use in domestic applications. Sensors for distance measurement are available. On/off water level sensors: €20-€100. Capacitance continuous level transmitter: €180-€700. Ultrasonic continuous level transmitter: 500-€2,500.

Table 12: Water level sensors.

Producer	Mode	Range	Output	Power	Connection	Assembly	Price
SENZIT	SH 1	110°C, 1MPa	contact	24V ac	doubleline wire	screw	€32
SENZIT	SH 2	110°C, 1MPa	contact	24V ac	doubleline wire	screw	€38
Omega	LVU 1100		4-20A				€1,803
Omega	LVU 1000		4-20A				€2,320
Omega	LVU 201		4-20A				€936
Omega	LVU 201		4-20A				€583
Omega	LVCN 70		4-20A				€536
Omega	LV5000		capacity-ance				€183

2.1.9 Water quality

In the present research it was not possible to source standard industrial or domestic sensors for water quality. Economical water pH, ORP, conductivity and TDS testers for field measurements are not equipped with signal outputs (price €25-€70). Labs instruments pH, ORP, conductivity and TDS testers (RS232) are available (Table 13): €350-€1,500.

Table 13: Water quality sensors.

Producer	Mode	Range	Output	Price
Omega [(1)]	PHH 26	Optional	Digital	€548
Omega	PHH 500		RS 232	€1,490
Omega	PHH 830		RS 232	€471
Omega	PHH 820		RS 232	€377
Omega	PHI 359		RS 232	€1,484
Micronix	PH-201	0-14		€42
Micronix	PH-204	0-14		€67

2.1.10 Electricity sensors

Table 14 lists some available sensors.

Ammeters
These are low resistance instruments for measuring current. They should be connected in series with the circuit being measured. Digital busbar ammeter: €80-€100.

Voltmeters
These are high-resistance instruments for measuring voltage. They should be connected across the load (i.e. in parallel). Digital busbar voltmeter: €80-€100.

Watt meters
These are instruments that measure the active power of an ac circuit, which equals the voltage multiplied by that part of the current that is in phase with the voltage. Digital busbar wattmeter: €110-€180.

Electricity meters
Kilowatt-hour (electricity) meters are instruments that measure electricity consumption. Standard electronic kilowatt-hour meters (used by power facilities) are equipped with a pulse generator. Digital meters usually have busbar communication. Digital busbar kilowatt-hour meter: €150-€500. Single phase domestic electronic kilowatt-hour meter (pulse output): €40-€60. Multi phase domestic electronic kilowatt-hour meter (pulse output): €100-€150.

Table 14: Electricity meters.

Producer	Type	Model	Output	Price
Krizik	Single phase (electronic)	ESJ 210	Pulse	€53
Krizik	Multi phase (electronic)	ESJ 320	Pulse	€100
Schlumberger	Single phase (electronic)		Pulse	€41
Schlumberger	Multi phase (electronic)		Pulse	€123
GE	Kilowatt-hour meter (digital, busbar)	V/329-000962	busbar	€188

GE	Voltmeter/ Ammeter (digital, busbar)	V/329-000978	busbar	€121
GE	Ammeter (digital,busbar)	V/329-000979	busbar	€89
GE	Voltmeter (digital,busbar)	V/329-000980	busbar	€88
Continental control system	AC wattmeter with LonWorks	WattNod	LonWorks	€500
GE	Net analyser (digital,485)	V/329-000941	Rs485	€426

2.1.11 Air contaminant measurement

For contaminant measurements relatively costly analytical equipment, which must be calibrated, is required. Some producers offer CO_2/VOC sensors for room measurement (Table 15). Sensors are usually placed in a return air duct. Standard sensors (internal wall mounting or in duct): €400-€600.

Table 15: Air quality sensors.

Producer	Model	Range	Output	Power	Connection	Assembly	Price
Siemens (1) L+S (CO_2 sensor)	QPA63.1, 2	0-2000ppm	0-10V dc	24V ac	Four line Wire	Wall/ Flange	€505
Ahloborn(2) (CO_2 sensor)	FYA600 CO_2						€617
Thermocon(3)	LW02	-30, +150°C	0-10V				€156
Thermocon(4)	LK 260	Optional	0-10V				€227

(1): Air quality sensor CO_2/VOC
(2): CO_2 infrared optical sensor
(3), (4): particles and gases detected: portions of cigarette smoke, hydrogen, carbon monoxide, ethanol, ammonia

2.1.12 Photometry (light) sensors

Photometry refers to the measurement of visible radiation (light) with a sensor having a spectral response curve equal to the average human eye. Table 16 lists some domestic light detectors (0-10V output): €100-€150 (€220-€250 for digital output).

Table 16: Light sensors.

Producer	Type	Model	Range	Output	Price
Thermocon	Outdoor light detector	CM 6		0-10V dc	€121
Thermocon	Outdoor light detector digital	LI 54		LON	€238
Thermocon	Indoor light detector	LI 54 LON		0-10V dc	€123
Thermocon	Indoor light detector digital	LI 02		LON	€238
Micronix	Light meter	LI 02 LON	0-5.104 lux	RS232	€120

2.1.13 Fire detectors

Usually fire protection systems are strictly tested according to local law and it is difficult to combine them with other services. Temperature based fire sensor: €20-€50. Optical local fire sensors (smoke detectors): €40-€100. Infrared beam smoke detectors: €900-€1,200. UV flame sensors: €300-€500.

2.1.14 Security sensors
Motion detectors: €20-€200.

2.1.15 Information from relevant projects
In SmartHomes-related projects various parameters have been measured depending on the precise project objectives and the adopted control strategy.

In the *Energy Barometer* project, three variables are continuously measured: electrical energy use for household appliances, energy use for heating (including domestic hot water) and indoor air temperature. The required weather data (outdoor temperature and solar irradiation) were collected on an hourly basis. A measurement system comprising a maximum of four sensors connected to a logger was employed. Where more than four sensors were required, two loggers were connected in series. The equipment used included the following.

- Energy: Mitec VM23, GEWE 640.
- Temperature: Mitec MATP-1, Mitec GTM20.
- Data logging: Mitec AT 30, Mitec AT 40, Elrapportoren.

In the *Genesys* project, the aim was to experimentally test alternative control scenarios. This required the measurement of indoor, outdoor and HVAC parameters. Tables 17 through 20 list the employed sensors.

Table 17: Indoor sensors (Genesys).

Parameter	Producer	Range	Accuracy	Response
Zone temperature	SIEMENS	0-40°C	±1°C	-
Zone humidity	LANDIS & STAEFA	10-95%	±5%	20s
Occupancy sensor	SIEMENS	-	-	-
Luminance	SIEMENS	0-2000lux	±15%	-
Air quality	LANDIS & STAEFA	0-2000ppm	-	120s

Table 18: HVAC sensors (Genesys).

Parameter	Producer	Range	Accuracy	Response
Duct temperature	LANDIS & STAEFA	-50-100°C	-	-
Duct relative humidity	LANDIS & STAEFA	10-95%	±5%	10s
Water Temperature	LANDIS & STAEFA	-50-120°C	-	-
Duct Pressure	LANDIS & STAEFA	0-3000Pa	±2.5%	10s

Table 19: Outdoor sensors (Genesys).

Parameter	Producer	Range	Accuracy	Response
Ambient temperature	LANDIS & STAEFA	-50-100°C	-	-
Humidity	LANDIS & STAEFA	10-95%	±5%	10s

Table 20: Energy consumption sensor (Genesys).

Parameter	Producer	Range	Accuracy	Response
Active power	MULTITEC	0-30kW	-	-

In the *Builtech* project, indoor and outdoor parameters were measured in order to collect the necessary inputs for a fuzzy controller. Table 21 lists the employed sensors.

Table 21: Indoor and outdoor sensors (Builtech).

Parameter	Product	Range	Output	Interval
Indoor air temperature	SONTAY TT511	-10-40ºC	0-10V DC	5 minutes
Indoor relative humidity	IND/TECHNIK DBUV-01	0-100%	0-10V DC	5 minutes
Mean radiant temperature	LASTEM BST 131	-50-100ºC	0-5V DC	5 minutes
Indoor air velocity	SCHMIDT SS 20.501	0-2.5 m/sec	0-10V DC	5 minutes
Air supply temperature	HT-730-M-L0	-20-60ºC	0-10V DC	5 minutes
Air supply relative humidity	HT-730-M-L0	0-95%	0-10V DC	5 minutes
Indoor CO_2 and VOC	LANDIS & STAEFA GYR QPA62.1	0-2000ppm	0-10V DC	5 minutes
Indoor Illuminace	SONTAY LL- ALS1E	0-2000 lux	0-10V DC	5 minutes
Outdoor air temperature	SONTAY TT531	-10-40ºC	0-10V DC	5 minutes
Outdoor humidity	IND/TECHNIK DBUV-01	0-100%	0-10V DC	5 minutes

In the *Scats* project, the system has been designed based on industrial sensors and instruments. Table 22 lists the employed sensors.

Table 22: Sensor list of the Scats project.

Parameter	Type	Range	Voltage
Carbon dioxide	LSI CO_2 sensor	0-3000ppm	1 - 5
Globe temperature	UNL globe Temperature/power Unit box	0-70^{o}C	0 - 0.7
Air temperature	LSI thermohygrometer	-30 ,+70^{o}C	0 - 5
Relative humidity	LSI thermohygrometer	0-100^{o}C	0 - 5
Illuminance	Megatron Type M Photo cell	0-2500lux	0 - 5
Air velocity	LSI hot wire Anemometer	0-5m/sec	0 - 5
Leq A	01dB sound Level Meter	30-90dBa	-
Leq Lin	01dB sound Level Meter	30-90dBLin	-

Finally, in the *Celect* project, energy use and temperature data were recorded at 10 minutes intervals in a sample of 50 houses.

2.2 Appliances control - actuators

Actuators required for the control of building services must be selected by considering characteristics related to both the control strategy and the controlled devices. These characteristics are:

- thrust - the power of the actuator in operation;
- time response - some building management applications require fast response times, especially in security applications (e.g. fire); and
- system breakdown - some devices must return to a security position in case of system breakdown.

Other criteria that can be used to evaluate actuators are accuracy, compatibility with other hardware, durability and maintenance cost. A large range of motor drives and actuators can be used: electric, hydraulic or pneumatic. Here, the actuators are grouped in three categories: water flow actuators, air flow actuators and electricity switches.

2.2.1 Water flow actuators

Solenoid valve (on/off control, up to DN 25): €100-€200. Control valve with electric motor (up to DN 25): €100-€400. High quality industrial control valve with electric motor (up to DN 25): €400-€800. Table 23 shows some available options.

Table 23: Water flow actuators.

Type	Producer	Model	Range	I/O	Price
Control valve with elect. motor	LDM	RV102	DN15, PN16	3 position	€485
Control valve with elect. motor	LDM	RV102	DN20, PN16	3 position	€499
Control valve with elect. motor	LDM	RV102	DN25, PN16	3 position	€517
Three way control valve with elect. motor	LDM	RV102	DN15, PN16	3 position	€485
Three way control valve with elect. motor	LDM	RV102	DN20, PN16	3 position	€499
Three way control valve with elect. motor	LDM	RV102	DN25, PN16	3 position	€517
Control valve with elect. motor	LDM	RV103	DN15, PN16	3 position	€485
Control valve with elect. motor	LDM	RV103	DN20, PN16	3 position	€499
Control valve with elect. motor	LDM	RV103	DN25, PN16	3 position	€517
Three way control valve with elect. motor	LDM	RV103	DN15, PN16	3 position	€485
Three way control valve with elect. motor	LDM	RV103	DN20, PN16	3 position	€499
Three way	LDM	RV103	DN25, PN16	3 position	€517

control valve with elect. motor					
Four way valve with elect. motor	Siemens-L+S	VCI31	DN20, PN10	3 position	€238
Four way valve with elect. motor	Siemens-L+S	VCI31	DN25, PN10	3 position	€247
Solenoid valve	Danfoss	EVSI T	DN15, 0-6 bar	on/off	€120
Solenoid valve	Danfoss	EVSI T	DN20, 0-6 bar	on/off	€185
Four way valve with elect. motor	Dewe	MIX	DN20, PN10		€100

2.2.2 Air flow actuators

Damper actuator (electrical motor): €100-€200. Table 24 shows some available options.

Table 24: Air flow actuators.

Name	Producer	Model	Range	I/O	Price
Damper actuator (el motor)	BELIMO	LM24, LM230	up to 0.,8m^2	24V ac/dc	€94
Damper actuator (el motor)	BELIMO	LF24, LF230	up to 0.,8m^2	24V ac/dc	€176
Damper actuator (el motor)	BELIMO	min		24V ac/dc	€94
Damper actuator (el motor)	BELIMO	max		24V ac/dc	€249
Damper actuator spring return (el motor)	BELIMO	min		24V ac/dc	€164
Damper actuator spring return (el motor)	BELIMO	max		24V ac/dc	€330

2.2.3 Electricity switches

Relay or contractor (depending on current and type): €10-€100. Multi-relay digital module (RS485): €100. Table 25 shows some available options.

Table 25: Electricity actuators.

Name	Producer	Model	Range	I/O	Price
Contactor 1 pole	SCHRACK		230V	24V	€9
Contactor 3 pole	SCHRACK		400V	24V	€15
Contactor 1 pole	GE		230V	24V	€25
Contactor 3 pole	GE		400V	24V	€86
Relay 1 pole	GE		230V	24V	€13
Relay 4 pole	GE		400V	24V	€65
Relay digital output module	Microclima	Midam 200	600V/10A	RS485	€98

2.2.4 Information from relevant projects

In the *Genesys* project, where a fuzzy HVAC controller was developed, the control parameters were chiller water temperature, air flow supply, fresh air mix, supply air and zone air temperature. The control system allowed for the independent control of window opening, lighting, air temperature, air flow and humidity (Table 26).

Table 26: Actuators used in the *Genesys* project.

Actuator	Number	Type	Response
Water valve open	2	Relay	145s (fully closed to fully open)
Water valve close	2	Relay	145s
Damper	6	Analogue 0-10V	100s (fully closed to fully open)
Blower on-off relay	2	Relay	-
Chiller on-off relay	1	Relay	-
Chiller mode	1	Relay	-

In the *Builtech* project, the fuzzy controller was connected with the actuators listed in Table 27.

Table 27: Actuators used in the *Builtech* project.

Actuator type	Input range/power rating	Position	Function
Modulating damper actuator	0 – 10V dc / 24V ac	Ceiling	Linear
Dimmer for lighting system (fluorescent lamps equipped with electronic ballasts)	0 - 10V dc / 220V ac	Ceiling	Linear
ON/OFF relay output (lights)	Relays	Ceiling	Digital
Actuator for window opening/closing	24V dc	On window	Digital
Relay to control the A/C unit	24V dc	In the unit	Digital

2.3 Local network technologies

As the residential market represents a large opportunity for different technologies, such as computers, audio/video equipment and home automation devices, industry has asserted the need for easy interconnection. As a result, a number of home network standards have emerged and network technologies continue to evolve. In general, the available home network technologies may be grouped as follows.

Wireless LAN technology

This uses radio waves on the unlicensed 2.4Ghz spectrum to connect devices without wires or cables.

Phoneline technology

This utilises existing telephone wiring, operating at frequencies outside the normal telephone range to allow high-speed communications between computers and other information systems. Phoneline, unlike Ethernet, does not require a hub device. Computers can then communicate via the home telephone wiring. The main drawbacks are price and performance as interface cards are still more expensive than Ethernet and performance depends on the quality of the wiring. An additional constraint is that phoneline requires a correctly wired telephone outlet adjacent to each computer.

Powerline technology

This can be used as the medium for transmitting messages between devices within a local electrical network. Such a system takes advantage of the home's electrical power wiring to carry data between devices.

Ethernet

Ethernet is a baseband LAN specification that operates at 10Mbps using CSMA/CD (carrier sense, multiple access, collision detect) run over coaxial cable. Ethernet was designed to serve in networks with sporadic, occasionally heavy traffic requirements. The IEEE 802.3 specification was developed in 1980 based on the original Ethernet technology. Ethernet Version 2.0, which is IEEE 802.3 compatible, was jointly developed by Digital Equipment Corporation, Intel Corporation and Xerox

Corporation.

2.3.1 Local network standards
There follows a review of the technical standards for local network technology, grouped in the above-mentioned categories.

2.3.1.1 Phoneline

HomePNA
The Home Phoneline Networking Alliance is an association of companies working to ensure the adoption of a single, unified phoneline networking standard. The aim is to bring to market a range of interoperable home networking solutions using existing phone wiring. HPNA version 1 enables communications between computers at 1Mbit/s. The newly introduced version 2 increases the speed to 10Mbits/s. Performance is subject to the quality of the home telephone wiring and connected devices, and in some cases special filters may be required to achieve maximum bandwidth. Network adapters (also called network interface cards or NICs) are installed on each computer. These have a standard RJ11 male telephone jack that is plugged into a telephone jack. Software drivers enable applications on the computer to communicate across the phoneline network in the same manner as any LAN. A modem in any of the computers on the LAN may be used by all computers to access the Internet. Although manufacturers are currently introducing high-speed modems that connect to the HPNA standard, most cable and digital subscriber line (DSL) modems in use today require a standard Ethernet network adapter installed in the gateway computer to access the Internet.

2.3.1.2 Wireless

Bluetooth
This is the code name for a technology specification for low-cost, short-range RF (radio frequency) links between mobile PCs, mobile phones and other portable consumer devices. Bluetooth technology is the result of co-operation between leaders in the telecommunication and computer industries. The technology is an open specification for wireless communication, using a 2.4Ghz radio link for sending and receiving voice and data over a maximum communication range of 10 meters. Data can be exchanged at a rate of 1Mbit/s (up to 2Mbits/s in the second generation). Since it uses radio transmission, transfer of both voice and data is in real-time. The mode of transmission provides protection from interference and security of data.

The Bluetooth radio is built into a small microchip and operates in a globally available frequency band ensuring communication compatibility worldwide. The Bluetooth specification offers two power levels: a lower level that covers the shorter personal area within a room, and a higher level that can cover the medium range (e.g. within a home). Software controls and identity coding built into each microchip ensure that only those units pre-set by their owners can communicate. The technology supports both point-to-point and point-to-multipoint connections. With the current specification, up to seven slave devices can be set to communicate with a master radio in one device. Several of these 'piconets' can be established and linked together within *ad hoc* 'scatternets' to allow communication among continually flexible configurations. All devices in the same piconet have priority synchronisation, but other devices can be set to enter at any time. Bluetooth technology, which has gained the support of Nokia, IBM, Toshiba, Intel and other manufacturers, eliminates the need for cables and connectors between phones, modems, headsets, PDAs, computers, printers, projectors and local area networks, and thus paves the way for completely different devices and applications.

HomeRF
The HomeRF Working Group (HRFWG) was formed to develop a single specification for a broad range of interoperable consumer devices. HomeRF is an open industry specification that allows PCs, peripherals, cordless telephones and other electronic devices to share and communicate voice and data in and around the home. It combines the 802.11b and Digital Enhanced Cordless Telecommunication (DECT) portable phone standards into a single system. It operates in the license-free 2.4Ghz frequency band and utilises frequency-hopping spread spectrum RF technology for secure and robust wireless communication. HomeRF 2.0 operates at data rates of up to 10Mbits/s over distances of up to

50m, which is suitable for home applications. It avoids common household interference from microwave ovens, cordless phones, bluetooth devices and neighbouring networks.

IEEE 802.11b

This specifies a Medium Access Control (MAC) and a Physical Layer for wireless connectivity for fixed, portable and moving stations within a local area. It aims to provide wireless connectivity to automatic equipment or stations that require rapid deployment, which may be portable, hand-held and/or mounted on moving vehicles. This standard offers the regulatory bodies a means to regularise access to one or more frequency bands for the purpose of local area communication. Possible target environments include: buildings, financial markets, industry, hospitals and outdoor areas. Vendors' products are emerging, but the specification is still being stabilised. Currently, the IEEE 802.11 standard is having a significant impact on the industry.

HiperLAN

ETSI has created a family of HiperLAN standards that support a wide variety of applications. HiperLAN's intent is to make the physical layer consistent with IEEE, enabling full interoperability and making BRAN a worldwide standard. Using the 5GHz band, HiperLAN operates at 25Mbits/s and supports video, data and voice. Rather than competing, HiperLAN is likely to be a complementary WLAN technology. Users will deploy HiperLAN in a specific area that needs particularly high speed, rather than adopting it in place of 2.4GHz systems.

Table 28 presents a comparison between wireless LANs (WLANs). While installation costs are low relative to wired LANs, WLAN hardware is expensive. Until now, lack of competitive pressures has kept prices inflated, making it difficult for companies to justify deployment. List prices for PC cards have not dropped below $500, prohibiting widespread adoption. With the advent of 802.11 and HiperLAN standards and increased vendor competition, prices are expected to fall and sales volumes increase, justifying further price reductions. The WLAN industry will also be able to take advantage of declining computer hardware prices and the availability of affordable handheld devices.

Table 28: Comparison between wireless WLANs.

	HomeRF	Bluetooth	802.11	802.11a	802.11b	Hiperlan 1	Hiperlan 2
Physical layer	FHSS	FHSS	FHSS, DSSS, IR	FHSS, DSSS, IR	FHSS, DSSS, IR	FHSS, DSSS	FHSS, DSSS
Data rates	1/2 Mbps	1 Mbps	1/2Mbps	6/12/24 Mbps	1/11 Mbps	15 Mbps	25 Mbps
Modulation scheme				PSK, 16QAM, 64QAM			PSK, 16QAM, 64QAM
Multiple-device support	As many as 127 devices in the network	Multiple devices	As many as 26 collocated networks	As many as 26 collocated networks	As many as 26 collocated networks	Multiple devices	Multiple devices
Data security	Blowfish data security	0-, 40-, and 64-bit encryption	40-bit RC4	40-bit RC4	40-bit RC4		Working
Current version	Version 1.0 available	Due to Spring 1999	Version 1.0 available	Due to December 1999	Due to December 1999	Version 1.0 available	First quarter of 2000

The Yankee Group anticipates that PC card prices will drop to within the $300-$350 range over the next 12 months, with the value line dropping to $200. WLAN technology is beginning a transition from a stand-alone niche market to an integral element of enterprise networking that, while still supporting specific application requirements, will also provide an important communications capability in the office or home. This evolution includes a convergence of wireless and wireline, and of local and wide area communications.

2.3.1.3 Powerline

Echelon's LonWorks
LonWorks technology was designed by Echelon Corporation as a universal platform for almost any control system. It is based on an open ANSI standard from the Consumer Electronics Manufacturers Association (CEMA) known as EIA-709. The technology includes all the components necessary to implement interoperable control systems that can be seamlessly integrated within a home and beyond. Based on physical transceivers and application layer software, LonWorks nodes can be connected to multiple media types, with twisted pair and power lines the most common.

CeBus
The CEBus Standard, also known as EIA-600, is a protocol specification developed by the Electronic Industries Association (EIA) to support the interconnection and interoperation of consumer products in a home. The CEBus Standard's Powerline Carrier Technology uses a home's 120V, 60Hz electrical wiring to transport messages between household devices. CEBus Powerline Carrier uses spread spectrum technology to overcome communication impediments found within the home's electrical powerline.

Simple Control Protocol
SCP is a networking technology for devices with limited memory and processing power, and networks with low bandwidth. Devices that would benefit from SCP include lights, home security devices, home automation devices, and small appliances that are unable to support TCP/IP or that connect to a home network through a low speed power line.

The HomePlug Powerline Alliance
This is a non-profit corporation established to provide a forum for the creation of specifications for home powerline networking products and services, and to accelerate the demand for such products and services through sponsorships and user education programmes. HomePlug has announced a powerline technology for home networking that will support a raw data rate of 14Mbits/s.

3. Access network communication

It is important to decide which technology to use for Internet access. The choice depends primarily on cost and the speed required. Currently, customers are not directly connected to high-speed backbone networks, but rather to local access networks, which are then connected to regional networks and national backbone networks. This hierarchical structure allows for better management of the overall communications network and decreases the operational cost. The basic access alternatives are:

- *Telephone Operators* (TOs), who provide the Plain Old Telephone Service (POTS) over a network that is predominately constructed of cabled sets of wire pairs. This construction was designed to support a 4kHz bandwidth for voice frequency telephony.
- *The Integrated Services Digital Network* (ISDN) that is the first evolution of the telephone network.
- *Cable TV Operators* (CTVO), who broadcast analogue video signals over fibre-coax networks.

In addition to these three basic access mechanisms, new alternatives are emerging:

- For the TOs, ADSL technologies offer limited wideband transport capability on the installed base of twisted pair access links. This capability, coupled with MPEG digital video compression and Digital Video Home Terminals (DVHTs) for each video receiver, promises some Switched Digital Video (SDV) connectivity. The architecture consists of ADSL modems at the home and the central office. However, there are severe limitations, such as the inverse relationship between transportable bandwidth and distance, and the penalty paid in upstream bandwidth to implement a significant downstream capability. ADSL allows bit rates ranging from 2Mbits/s for 5 km loops up to 7Mbits/s for shorter loops. In the upstream direction (from customer to the network) the typical capacity ranges up to 640kbits/s.

- Another solution, not suitable for medium range loops, is the VDSL modems. Here, the high bit rate channel may range from 15Mbits/s to 50Mbits/s in the direction towards the customer, depending on the customer distance. The return path is typically in the order of 2Mbits/s.
- For CTVOs, there are two architectures to realise a bi-directional capability. These are the HFC that could be seen as an extension of the installed fibre-coax topology and the SDV that closely resembles the FTTC architecture. In the latter, xDSL modems complement the architecture. Both architectures have relative strengths and weaknesses. The HFC architecture provides significant upstream bandwidth in the 5 to 40MHz range for various communications services (telephony, data services including Internet, switched digital video, broadcast digital video and broadcast AM-VSB cable TV signals) to a fibre node, which typically serves up to 480 homes. In the SDV case, all traffic except analogue broadcast video is carried digitally over point-to-point fibre facilities from the central office to the Optical Network Units (ONUs) located deep in the plant over fibre facilities that serve 4 to 48 homes.
- In principle, a single point-to-point fibre might serve a single ONU and through it a single home/office, i.e. FTTH. Under these circumstances the digital bandwidth available to the home/office, upstream as well as downstream, would be virtually unlimited.
- Passive Optical Networks (PONs) are considered as one of the most promising solutions for the introduction of fibre-based network access. They have been demonstrated in several field trials and have already been installed by some network operators. PONs are optical networks without any additional electronic or opto-electronic devices. They may consist of optical fibre, optical splitters and combiners, directional couplers, lenses, gratings, optical filters *etc.* PONs have several advantages over networks with active components: they do not require an electric power supply and are consequently not sensitive to power failure. PONs are not EMI sensitive, are highly reliable and require no maintenance. The presence of a PON architecture does not necessarily imply that fibre is run to the home/premises: fibre may run only as far as the ONU.
- In the case of broadband wireless, Multichannel Multipoint Distribution Service (MMDS), also known as ‘wireless cable’, is used to carry up to 33 analogue video channels. Broadcast capabilities for carrying as many as 200 digital video signals are expected to be available soon. Local Multipoint Distribution Service (LMDS), known as ‘wireless fibre’, offers greater bandwidth but at the cost of more stringent line-of-sight requirements and smaller coverage patterns than MMDS.

While these technologies do not offer significant point-to-point services or upstream bandwidth capabilities, combining them with other approaches, such as ADSL, offers the opportunity for a complete solution.

Direct Broadcast Satellite (DBS) has recently emerged as a significant contender for providing broadcast broadband services. Broad coverage, ease of adding new subscribers, and a reputation for service quality have enabled a rapid early growth in DBS. Like other wireless technologies, however, it suffers from difficulties with point-to-point services. In addition, because of the large footprint of the satellites, it is difficult to customise services to the locale of the customers, such as offering local programming or local advertising.

Power line access has become interesting only recently, although the concept is not new. Power companies have used this form of relatively low-speed communication for approximately ten years, but only for control and monitoring purposes, which are applications with low bit-rate requirements. To date, there are several companies that produce power line products. However, owing to limited bandwidth and severe line conditions that change rapidly, power line data rates do not exceed 100kbits/s. Efforts are now focused on providing bandwidth-demanding services (of which the most popular seems to be the Internet) using the low-voltage powerline grid. Deregulation of utility companies has boosted these efforts and the first consortium has been formed in the UK.

Where new access systems need to be deployed, or existing plant needs to be upgraded, systems such as SDV or HFC are frequently the choice if near-term growth into broadband services is expected. Where basic dial tone is the primary need, fixed wireless approaches are appropriate. To address targeted needs for interactive broadband services in regions where existing twisted-pair wiring is in place, solutions such as ADSL can be attractive. MMDS/LMDS, or even DBS, built alone or as a complement to ADSL, offers a way to rapidly provide broadcast broadband services without incurring the time and expense of burying cable or stringing aerial lines to end users. As the broadband service penetration increases, these systems can be overbuilt and replaced by fibre systems such as HFC or SDV to economically extend service offerings. Figure 1 shows broadband revenue by technology, while Table 29 summarises the characteristics and the applicability of each service type.

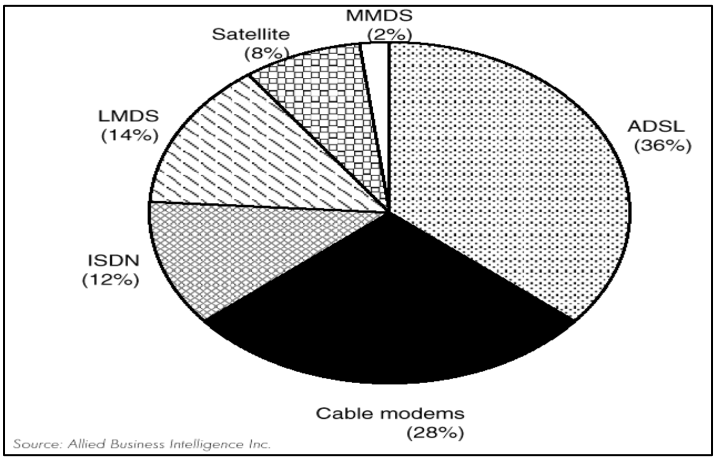

Figure 1: Broadband revenues by technology (US Market, 2004).

Table 29: Characteristics and applicability of emerging access types.

Access	Medium	Typical application	Comment
ADSL	Twisted pair	Telephony, video on demand, broadband data	Good for asymmetric broadband applications using existing twisted-pair plant
HFC	Fibre, coax	Telephony, broadcast video, video on demand, broadband data	Good for new builds and rebuilds
SDV	Fibre, coax, twisted pair	Telephony, broadcast video, video on demand, broadband data	Good for new builds and rebuilds
PON	Fibre	Telephony, broadcast video, video on demand, broadband data	Long-term solution for broadband applications, operations cost savings
MMDS	Air (2-3 GHz)	Broadcast video	Good for rapid deployment of video overlays. Combine with other technologies, such as ADSL, for point -to-point applications
LMDS	Air (28-38 GHz)	Broadcast video, interactive applications	Good for rapid deployment of video overlays. Combine with other technologies, such as ADSL, for point -to-point applications
DBS	Satellite	Broadcast video	Provides broad geographic coverage; difficult to support local programming

Figure 2 shows a cost comparison of the various technologies. To effect a meaningful comparison, the following issues need to be considered:

- fibre is capable of supporting multiple two-way services, whereas analogue MMDS supports only one-way broadcast;
- costs vary with take-up rates and the extend of variation depends on the technology; and

- customer premises equipment costs vary significantly.

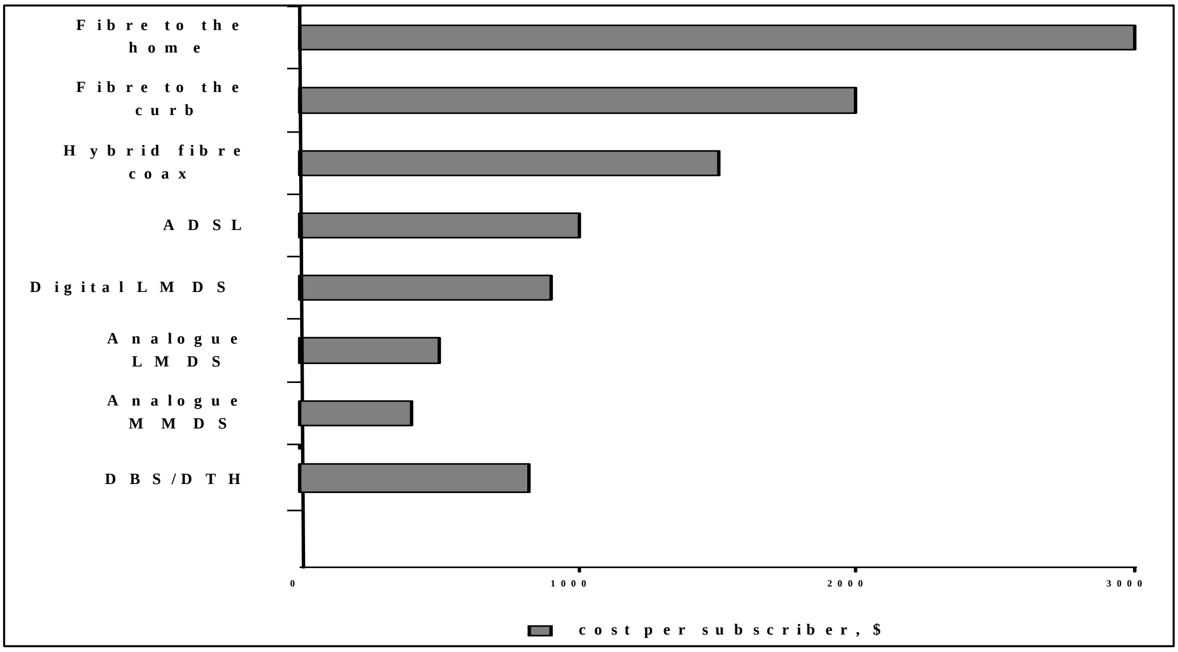

Figure 2: Cost comparison of various technologies.

The cost comparison above indicates that the cost per subscriber in the case of ADSL of up to 8 Mbits/s is not significantly higher (about $1000) than a digital LMDS solution (about $970) or a DTH/DBS solution (about $800). But HFC ($1500) is more expensive than ADSL. As shown in Figure 2, ADSL and LMDS are similar. Therefore, low-end ADSL follows the behaviour of LMDS and is less costly than HFC for low take-up rates. This means that radio is viable for new operators, which may pick up a low market share of customers over a wide area, while ADSL is a viable solution for existing operators.

3.1 Wireless versus wireline

3.1.1 Advantages of wireless over wireline

Installation cost
Once the video head-end and transmitter are in place, receivers in the surrounding area are able to receive a signal if they are in the transmitter's line of sight. MMDS can provide a service up to 40 miles from the transmitter, LMDS up to 6 miles (satellite is a special case). More typically, MMDS and LMDS systems provide a service within 6 miles and 1 mile respectively. Once the fixed cost of the head-end and transmitter has been incurred, incremental costs for each subscriber consist only of equipment at the customer's premises; typically about $300 to $500 per subscriber. Wireline cable systems can cost over $1,200 per subscriber. The return on investment is typically from 7-15 years for wired systems and 3-5 years for wireless.

Maintenance cost
With no physical transmission media between the transmitter and receiver, maintenance of wireless cable systems is limited to tasks such as network monitoring, diagnosis and tuning. Comparable wireline systems require extensive maintenance and rewiring about every 10 years, as well as routine maintenance.

Reliability
With substantial scheduled maintenance and rewiring required, traditional cable systems suffer from inherent service disruptions. According to Link Resources, on any given day a (wireline) cable operator can count on at least 1% of its subscribers losing service because of scheduled maintenance. Unscheduled service outages are an even greater problem. For example, in Time Warner's Manhattan

Cable service, an outage of at least 4 hours involving 4,000 to 5,000 customers happens about once a week. About once every two weeks, an outage will involve up to 20,000 customers. With minimum maintenance required in the case of wireless systems, outages are rare (although with systems operating at high frequencies, such as LMDS, rain can interfere with the short wavelength signals). Customer satisfaction may be improved by:

- lower downtime: 25% of wireline cable subscribers are dissatisfied with their provider; and
- lower cost: with few costs associated with maintenance, providers of wireless service can pass savings to customers; wireless providers generally undercut their wired counterparts by at least $3 per month in the case of cross country, to about 50% in the case of some city subscribers.

Time to market
Once licensed, a provider of wireless services can be on-line in less than 6 months. With faster time to market, a wireless provider can recoup its investment faster than wireline providers.

Quality
Reportedly, the signal quality of even analogue wireless systems is good, while digital systems like LMDS and DBS have extremely high signal quality.

New services

- *Potential telephony transport*: technological advances in the long term will likely enable wireless cable providers to add enough uplink channel capacity to facilitate a wireless telephony service.
- *Internet access and other applications*: with large bandwidth, wireless access has the long-term potential to deliver a wide range of new services including residential video telephony, business video conferencing, wireless remote LAN access, Internet access and an ability to download software.

3.1.2 Advantages of wireline over wireless

Installed base
Currently, wireline providers serve 97% of the paying customer base for video services. There are approximately 120 million wireline cable television subscribers worldwide. Even with the wireless subscribers' base growing, it may be difficult for wireless service providers to entice the 75% of wireline customers to switch.

No line-of-sight requirement
Wireless systems traditionally require an unobstructed straight line between the transmitter and customer receiver. To mitigate this limitation, repeaters or signal benders are placed strategically around areas impeded by buildings, trees or other obstacles. These enable receivers to be placed in areas that are not in line-of-sight of the transmitter. Furthermore, as these signal benders amplify signal strength, noise associated with analogue signals is amplified in the process, distorting signal quality. Wireless cable systems that transmit signals in digital format, and hence have digital repeaters, are able to regenerate signals to their original form and strength and are thus preferred for technical reasons. Additionally, the line-of-sight requirement imposed on wireless cable systems can also be mitigated by deploying shared receivers, which reach individual customer premises via a landline network.

Channel capacity
Wired cable delivery systems have fewer constraints on bandwidth and can deliver about 150 analogue video channels and up to 500 or more with digital encryption.

Delivering interactive services
With numerous video-on-demand trials currently underway, such as those of Time Warner, TCI and US West, wireline providers may have marketing and technical advantages over their wireless counterparts. Additionally, these service providers are forging agreements with video information providers (VIPs) to supply content for their broadband networks. Wireline providers can deploy HFC, SDV and ADSL technologies to deliver interactive services, and in many cases increase network

efficiency. Note that Peoples Choice, a wireless cable provider, currently utilises what it calls impulse pay-per-view remote controls.

3.2 Information from relevant projects

In the Energy Barometer project, data collected from the home network were communicated to the Centre for the Built Environment via a modem. Data were then transferred back to home owners on both an individual and averaged basis. Tests of data collection via radio communication were also performed: communication was established between a GSM-telephone Nokia 2110 with card expander and computer card connected to a computer (side A) and another computer via an Ericsson modem to the telephone switch (side B). Several tests were made where side A worked alternately in originating and answering mode. The established link was used for file transfer (50 to 100 kbytes). Results:

- Both binary and text files were communicated without problems although the communication speed had to be fixed to 9.6kbits/s in all parts of the link.
- The protocol was XON/XOFF.
- The time for establishing contact when calling via a GSM-telephone was long and the carrier was lost if a standard connection protocol was used.
- The set up sequence for the modem was entered with the telephone connected to a computer and saved and used as the start-up sequence.
- Due to the speed, it was possible to use Mitec's AT40 logger, but not the AT30.

Test were also made where side A consisted of a GSM-telephone connected to a Mitec AT40 logger, while the computer on side B used Mitec's Monitor program to collect data from the logger. Results:

- The DTR signal from the logger had to be ignored, and modem 2 chosen in the Mitec setup.
- Data were transferred and the logger displayed the same messages as when the same program collected data via a direct cable connection.

The two-way data communication enabled customers to compare the energy consumption in their home with the general consumption trend in their area. It also provided them with advice on energy saving actions and, where appropriate, initiated such actions on request (e.g. temperature set-point adjustment).

4. E-box technology

Ericsson's solution for home networking provides a link between the broadband network, the Mobile Internet and the home, enabling new services to be developed and distributed. The e-service platform operates via an 'e-box' service gateway, which is a combination of a thin server and a communication gateway. The e-box (Figure 3) is the device that creates the bridge between the broadband network and the home/local network, and between different networking technologies within the home.

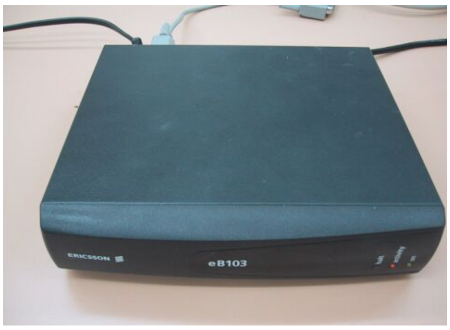

Figure 3: An e-box as deployed in the SmartHomes project.

The e-service system is implemented in two places, locally in every e-service gateway, and centrally in the e-service centre. The e-service gateway is located between the home network and the broadband access network. The access network can be of any type as long as it supports the e-service system requirements concerning IP connectivity. The access network has to be always on, while the need for bandwidth depends on the application.

The e-service centre is the administrative centre of all operation and maintenance activities. The e-service gateways are supported and managed by the e-service centre. The e-service centre is also a place where distributed applications may be implemented. Such applications may be implemented locally in the e-service gateway, centrally in the e-service centre or distributed to both of them. Both the e-service centre and the e-service gateway provide an OSGi (Open Systems Gateway Initiative) compliant application environment, and the e-service system enables the secure and transparent communication between them.

In order to set up the structure required for the SmartHomes project, the e-box system concepts, as well as technical characteristics related to the possibilities for communication with the access network and the home network respectively, must be examined. Figure 4 illustrates a view of the network interfaces, while Figure 5 presents a high-level view of an e-box.

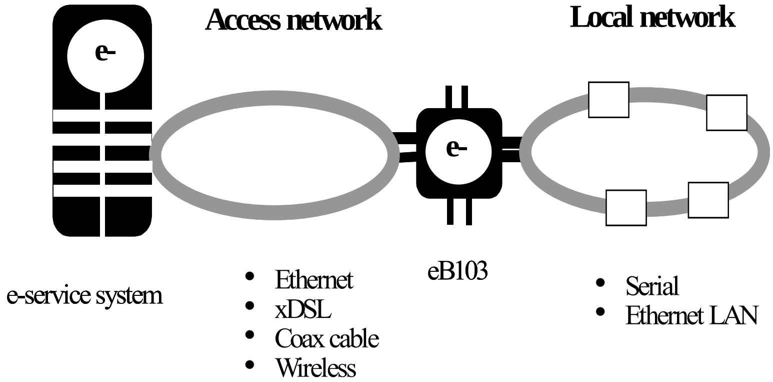

Figure 4: View of the network interfaces.

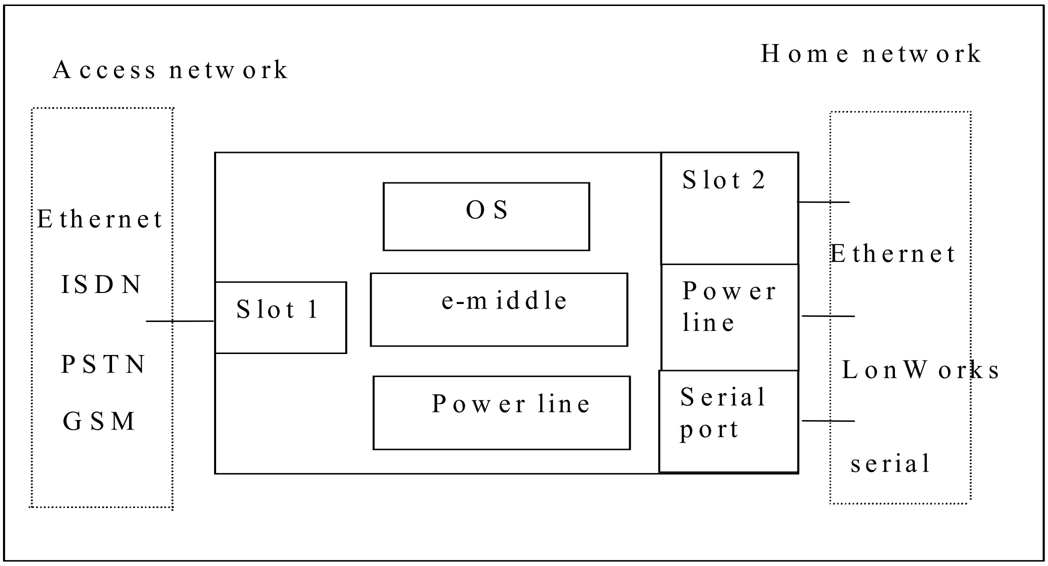

Figure 5: A structural high-level view of an e-box.

The e-box communicates with external systems across two networks, the access network and the home network. To this end, it implements four interfaces. One is towards the access network, used for communication with the e-manager, the main part of the e-service centre. The other three are towards the home network, used for communication with home devices and appliances.

4.1 Access network interfaces

The possible choices for communication are ISDN, PSTN, GSM or Ethernet. The e-boxes can have an ISDN port, a PSTN modem, a GSM modem or an additional Ethernet port for access network purposes equipped with the corresponding daughter board connected to slot 1.

ISDN

The ISDN daughter board is developed in-house and supports one B-channel for data and one D-channel for signalling. The supported protocols are Q.921/Q.931. The maximum speed is 64kbits/s on the B-channel, downstream as well as upstream, and 16kbit/s on the D-channel.

PSTN

The PSTN daughter board is also developed in-house. The supported protocols are V.90 and V.34.

The maximum speed is 56kbit/s downstream and 33.6kbit/s upstream. Note that different countries require different jumper setting on the PSTN-card, which means that there will be different regional versions of the e-box.

GSM
The e-boxes that have a GSM modem are equipped with a PCMCIA connector in slot 1. Ericsson develops the GC25 PCMCIA card; the supported protocol is V.110. The maximum speed is 9.6kbit/s downstream and upstream.

Ethernet
The Ethernet daughter board is developed in-house. The supported protocols are TCP/IP and the maximum speed is 10Mbit/s, both downstream and upstream, in half-duplex.

The public telephony network provides ISDN, PSTN and GSM. No connection between Ethernet and ISDN, PSTN or GSM is possible. Data communication between the ISDN, PSTN and GSM networks is possible according to Table 30.

Table 30: Data communication of the e-box.

e-box/ e-manager	PSTN access via ISDN/BRI	BRI (Basic Rate Interface for ISDN)	PRI (Primary Rate Interface for ISDN)
PSTN	V.90 in both directions	Not possible	Not possible
BRI	Not possible	Communication over one B-channel. D-channel is used for call set-up.	Communication over one B-channel. D-channel is used for call set-up.
GSM	The v.110 GSM e-box modem is working towards a V.90 modem in the e-manager. 1. This requires an IWU interface when data is transferred between GSM and PSTN. 2. Data transfer from PSTN to GSM is possible with a special data subscription within the GSM domain.	Not possible	Not possible

4.2 Home network interfaces

For home network purposes, there are three interfaces: LonWorks, a serial port and Ethernet. The LonWorks port communicates via the power-line cable and is compliant with the European CENELEC C-band regulations. The supported protocol is LonTalk and the maximum speed is about 5kbit/s, downstream and upstream, in half-duplex. To this port, a number of LonWorks compliant devices can be attached as long as they are communicating on the power-line, and using the C-band frequencies (125-140kHz).

Supported devices include actuators (Arigo energy meter switch, current and voltage meter switch, power switch) and S0-counters (Enermet ML10). The serial port connector provides +5V on one of its pins (DTR = pin 4 in DSUB-9) in order to support power to an external serial device. The maximum current allowed is about 100mA. The supported protocol is RS232C and the maximum speed is 115.2kbit/s downstream and upstream. To this port, any serial device can be connected as long as the following criteria are fulfilled:

- there exist a serial device specific driver (or application) that communicates directly with the standard Linux serial port driver; and
- the maximum speed is 115.2kbit/s.

4.3 Other gateway options

Table 31 summarises the results of a survey concerning other gateway options and similar technologies, including Ericsson's e-box service gateway.

4.4 The Gävle experience

E-box trials were carried out during Autumn 2000 and Spring 2001 in Gavle, Sweden. The gateway was an Ericsson e-box eB101, configured with ISDN for communication with homes through regular telephone lines and Ethernet. Private PCs were used as clients and the applications developed monitored electricity consumption and indoor temperatures.

For electricity consumption, an Enermet LM10-LonWorks solution was used in conjunction with the following equipment: IBM Teil, Nr:98f3088, S/N0005001 and a temperature sensor V5.222.4.98. The installation time required was two hours per installation. The conclusion was that the time and cost of installation was high because personnel responsible for installation did not possess both PC and OSGi competence. Also, troubles can arise when combining smart home trials with regular PC usage because different settings are required in each case.

During the planning of the trials, the OSGi standardisation was not fully implemented. The operating system at the e-service centre and at the local gateways had to be written in C++ and not in Java according to the OSGi standard. Early adaptation to OSGi is important because the costs of a later transfer to Java will be high.

5. Procedures for energy control

An integrated energy management and control system must aim at the minimisation of energy consumption as well as the optimisation of the indoor environment. The aim of the SmartHomes project was to prototype and test new Internet-based services for citizens and professionals, such as the remote monitoring of fuel consumption and environmental conditions, and the remote actuation of domestic appliances. As the services are directly related to both energy and indoor conditions, the parameters that must be measured include those relating to:

- thermal comfort, including both global and local parameters;
- indoor air quality as associated with the ventilation system and strongly influenced by thermal comfort and building energy efficiency;
- energy performance; and
- outdoor climate.

Control strategies normally include both indoor comfort parameters (internal temperature, humidity *etc*) to regulate the room conditions, and external climate parameters to regulate central heating and air conditioning plant. Internal control parameters are measured directly by sensors located inside the building, whereas external parameters may be measured in the immediate vicinity or obtained from outside sources such as the Meteorological Office. Because of a limit in the number of control parameters that might be acquired, it is necessary to allow direct regulation of appliances by users in order to accommodate the divergent levels of technical understanding and the different habits that affect energy demand (e.g. the presence of young or old people).

5.1 Thermal comfort

A combination of environmental and personal parameters influence the perceived thermal comfort in an indoor environment. Air temperature is the first criterion to control thermal comfort in a room, indeed this is the parameter used most as a thermal comfort index within control systems. However, control of air temperature alone does not ensure thermal comfort. Theory implies that four physical and two personal parameters are needed to describe an occupant's interaction with the environment:

- air temperature (T_a);
- radiant temperature (T_r);

Table 31: Home gateway survey results.

Product	Hardware	Software	Network Interfaces	Services
Ericsson Radio Systems AB: E-box service gateway. Dimensions (w x d x h): 18.3 x 15.7 x 4.2cm. Standard compliance: HomePNA, LonWorks.	CPU: 486 compatible, 100MHz. EDO-DRAM: 32MB. SRAM: 128 kbyte, battery back-up. Flash memory: 24Mbyte. Real time clock: battery back-up. Two Ethernet ports (RJ-45 connector). RS232C port (9-pin, D-sub, male connector).	OS: Linux, Java. Drivers: external and local network . Server components: Web, WAP and DNS.	LAN interfaces: ethernet 10 Base-T (local and access network), RS232C serial port, LonWorks (via power cable). WAN interfaces: ISDN, PSTN (standards V.90 and V.34), GSM (modem implemented as an Ericsson GC25 PCMCIA card, V.110 standard), ethernet 10 Base-T.	Personal: family calendar, shopping *etc.* Entertainment: TV, video, sports, games, music. Cordless communication: telephone, Webpad. Home automation: control of temperature, appliances *etc.* Monitoring: burglar alarm, smoke detector, camera, damp control *etc.* Internet access and firewalls: privacy protection.
ECHELON i.LON 1000 Internet server, models 72001 and 72002. Dimensions (w x d x h): 21.3 x 20.3 x 4.44 cm. Standard compliance: LonWorks.	32-bit RISC processor, MIPS 3900 core, 50MHz internal speed. FLASH: 4MB. NVRAM: 8kB, battery back-up. RAM: 16MB. Ethernet port: RJ-45. Two serial ports: DB-9. LonWorks TP connector: Weidmuller 2-conductor SLA 2/90.	Password-protected Web server . Includes SNMP (MIB II) support, TCP/IP, UDP, DHCP, ICMP, SNTP, TOS, HTTP and FTP.	Ethernet 10 Base-T. RS-232 serial port. LonWorks twisted pair: TP/FT-10 (model 72001) and TP/XF-1250 (model 72002).	Allows Internet-ready LonWorks devices to be monitored, controlled, or configured over the Internet. Transforms any LAN or WAN) into a pathway for carrying LonWorks control information locally, nationally or internationally.
2wire HomePortal 1500 series residential gateway. Dimensions (w x d x h): 30.48 x 25.4 x 6.35 cm. Standard compliance: HomePNA and HomeRF.		Firewall security, NAT/PAT. Supports TCP/IP, DHCP, DNS, client initiated VPN tunnels with PPTP, L2TP or IPSec, PPP over ATM, PPPoE, RFC 1483. OS compatibility: Windows 95, 98 , 98 SE, NT 4.0, 2000, ME and MAC OS V8 and above (up to but not including MAC OSX).	Supports ADSL full rate G.dmt (ITU G.992.1) and G.Lite (ITU G.992.2), Ethernet 10 Base-T, HomePNA 2.0 (10Mbps) and 1.0 (1Mbps). Wireless through ethernet connection. USB connectivity. Home portal	Share multiple, simultaneous, high-speed network connections throughout the home without additional wiring. Connect an entire home network using wireless, USB, ethernet or existing phone line connections through HPNA technology.

			1500W/1500WC supports wireless through integrated 80211.b access point and HomeRF.	
ShareGate, BSG2000 Broadband Services Gateway Dimensions (w x d x h): 22.86 x 10.16 x 25cm. Standard compliance: HomePNA.		RFC1483 (bridged/routed). PPPoE, PPPoA support. IEEE 802.1d up to 255 MAC address, PAP, CHAP authentication, NAT, PAT. Support for TCP, UDP, ARP; DNS server/relay; DHCP server/client Web-based management and configuration. SNMP-based management through standard ATM, MIB-II, DSL, VoDSL and Ethernet MIBs. Supports ShareGate GateView(tm) management system. Web access to devices and content residing on PCs. ATM PVCs support (CBR, UBR, VBR). Remote software download capability.	ADSL:full rate G.dmt (ITU G.992.1) and G.Lite (ITU G.992.2) lifeline service maintained through POTS service. Distributed voice interface.: Voice-over DSL telephone services for up to 4 derived lines. Micro PBX features with up to 10 independent extensions with fall back to POTS. Extension-to-extension calling. HomePNA. Ethernet 10/100 base-T and USB 1.1.	Security: fully featured BSG that allows the user to remotely access the home network in a secure environment. Additionally, the user is able to implement a secure connection to an outside network. Expanded Phonelines and services: allows users to add up to 4 telephone lines that can be moved to different locations in the premise with the press of a button. Monitoring and management of call activity through secure Web page. Seamless content distribution: enables the user to simultaneously access data, voice and streaming video. Also allows the user to access the data and voice content throughout the premises using existing wiring.
Proxim, Symphony-HRF cordless gateway. Dimensions (w x d x h): 26.92 x 20.57 x 9.65 cm Standard compliance: HomeRF.	Ethernet port (RJ-45 connector).		Ethernet 10 Base-T and HomeRF.	High-speed Internet connection. Users can have access to it from any PC located at home without the need of wires.
Coactive Networks, coactive connector 2000 series. Standard compliance: LonWorks.		Connector access software: CORBA API for Java & C++ with configuration and management utilities. Remote software upgrade download.	Powerline EIA-709 (LonWorks). FT-10 EIA-709 (LonWorks). Ethernet 10 Base-T and serial RS232.	AMR. Home security. Energy management. Home automation.
Broadband Gateways,		Adaptation layers: AAL2 (voice),	ADSL (G.DMT, G. Lite).	Voice services: vice over DSL, top

EVOLVO ADSL base module. Dimensions (w x d x h): 11.43 x 13.97 x 21.59cm. Standard compliance: HomePNA.		AAL5 (data). Encapsulation: RFC 2684 (multi-protocol support on AAL5), RFC 2364 (PPP on AAL5). Data Circuit: multiple AAL5 PVCs Voice QoS: variable bit rate, real-time (VBR-rt), constant bit rate (CBR). Data QoS: unspecified bit rate (UBR), available bit rate (ABR). Bridging: IEEE 802.1d. Security: NAT and port filtering. IP protocols: TCP/IP, DHCP, DNS. Configuration: local Web page. VPN: L2TP, PPTP, PPPoE, IPSEC.	Ethernet 10/100 BaseT. HomePNA 1.0 & 2.0.	20 PBX voice features, 2 wireline extensions. Data services: high speed Internet sharing. 10/100 Base-T Ethernet, Home PNA, firewall and VPN.
3COM, home ethernet gateway Dimensions (w x d x h): 16.3 x 10.2 x 2.8cm.	4 auto sensing 10/100 BASE-TX ports (RJ-45 connector) for modem and/or computers. 1 parallel port for printer. 1 COM port for external ISDN or analogue modem.	Protocols supported: TCP/IP, IPX/SPX, NetBEUI, DHCP, NAT, DNS, IEEE 802.3, IEEE 802.32, PPPoE client, PPTP, HTTP, FTP, SMTP, POP3.	Ethernet 10Base-T/100 and base-TX.	Provides shared Internet access with several desktop or notebook PCs. Users can share personal files and play multiplayer games over Ethernet wiring at office network speeds.

- air velocity (V_a);
- water vapour pressure (P);
- activity level; and
- clothing level.

Conventional comfort theory evaluates the heat exchanges that occur between a person and the thermal environment as well as the physiological conditions that are needed for human comfort. From this analytical method, rationally-based indices of thermal comfort have emerged, such as Fanger's Predicted Mean Vote (PMV) and Gagge's Standard Effective Temperature (SET). Also, a number of field studies have led to the establishment of empirical, statistically-based thermal comfort indices. Differences exist between the various thermal comfort indices. Such discrepancies have led to a view of thermal comfort as part of a self-regulating system (Humphreys and Nicol 1973), an approach generally known as an adaptive model.

In the analytical approach, the environmental parameters are adjusted with regard to air and radiant temperature, humidity and air velocity. This approach treats each component of the interaction separately and thereby gives a complete picture of the various thermal factors involved in an individual's interaction with their environment. PMV is the mean vote obtained by averaging the thermal sensation votes of a large group of people in a given environment. It is a function of the imbalance in the heat equation of the human body under comfort conditions, L (W/m^2), and of the metabolic rate, M (W/m^2), both being related to the area of the human body:

$$PMV = [0.303 \exp(-0.036 M) + 0.0275] L$$

where:

$$L = (M-V)-3.0510^{-3}[5733-6.99(M-W)-P_{air}]-$$
$$-0.42[(M-W)-58.15)]-1.710^{-5}M(5867-P_{air})-0.0014M(34-T_{air})$$
$$-3.9610^{-8}f_{cl}[(T_{cl}+273)^4-(T_{rad}+273)^4]-f_{cl}h_c(T_{cl}-T_{air})$$

where:

$$T_{cl} = 35.7-0.028(M-W)-$$
$$-0.155I_{cl}\ \{3.9610^{-8}f_{cl}[(T_{cl}+273)^4-T_{rad}+273)^4]-f_{cl}h_c)(T_{cl}-T_{air})\}$$

$$h_c = \max[2.38(T_{cl}-T_{air})0.25\ ,\ 12.1(V_{eff})0.25]$$

$$f_{cl} = \begin{cases} 1+0.2I_{cl} \text{ if } & I_{cl} \le 0.5 \\ 1.05+0.1I_{cl} \text{ if } & \text{not} \end{cases}$$

where W is the external work (W/m^2) for the activities, I_{cl} the clothing insulation, f_{cl} the ratio between the clothed body area and the body area, T_{air} the air temperature (^oC), T_{rad} the mean radiant temperature (^oC); V_{eff} the relative air velocity near the external clothing surface (m/s), P_{air} the partial vapour pressure in the air and h_c the convective heat transfer coefficient.

The most commonly used index to express the correspondence between the thermal sensation and the percentage of people expressing discomfort is PPD (Predicted Percentage Dissatisfied), which is directly related to PMV:

$$PPD = 100-95\exp[(-0.03353\ PMV^2 - 0.2179)\ PMV^2]$$

ISO Standard 7730 gives specifications of the conditions for thermal comfort in moderate thermal environments based on the PMV/PPD model. The imbalance of a steady-state, one-node energy balance is related to the PMV index, giving the average response of a population according to the ASHRAE thermal sensation scale, which varies from -3 [cold] to +3 [hot], 0 being neutral. Environmental and personal variables are measured or quantified in order to assess, through the PMV and PPD values, the thermal comfort conditions for the environment. To assess these conditions, environmental variables have to be maintained in a range defined by ISO Standard 7730. This range corresponds to the interval [-0.5 to 0.5] for offices in which a relatively high standard of comfort is required, but in many cases a wider range is acceptable.

In practice, there is a low possibility to base a control strategy on PMV because of the many parameters involved and so control is achieved using a few environmental parameters, mainly temperature. The efficiency of a control strategy for thermal comfort is closely related to the measurement accuracy of the environmental variables, and this accuracy can only be quantified for specific cases. For example, in some room configurations globe temperature gives a reasonable approximation of the mean radiant temperature of the body. If PMV is selected as a control parameter then indoor temperature and humidity must be measured, while the indoor air velocity may be considered constant at 0.1m/s. Also, the mean radiant temperature may be considered equal to the air temperature, with no significant error in the PMV estimation. Finally, typical and constant values may be assumed for the personal parameters.

In the analytical approach, conditions are left to vary and subjects to dress and behave as normal. Then, the measured physical variables are related to the subject's feeling of warmth, which is termed a 'Comfort Vote'. Nicol formed a comfort index, TPV, by using globe temperature, Tg, water vapour pressure, P, and air velocity, V, to calculate a comfort vote regression equation:

$$TPV = 0.186T_g - 0.032P - 0.366V^{1/2} - 0.820$$

Comfort standards based on adaptive assumptions are more than simply a temperature to aim at. The 'comfort temperature' is defined as the temperature at which there is the least probability of discomfort. Its value varies with climate and season.

The results obtained from comfort surveys performed during the SCATS (Smart Controls and Thermal Comfort) project, have been used to develop an algorithm for comfort temperature in terms of outdoor temperature. Researchers from five countries conducted the surveys at two levels differentiated by the detail on the environmental monitoring. The countries were UK, Sweden, Portugal, Greece and France. The study was based on the assumption that the comfort temperature changes with time in a way that is related to the outdoor temperature.

To decide on the appropriate measure of outdoor temperature, the rate at which the comfort temperature changes must be characterised. A common measure of outdoor temperature used as a predictor for indoor comfort temperature is the exponentially weighted running mean of the daily mean outdoor temperature:

$$T_{rm} = (1-a)\ \{T_{od-1} + a\ T_{od-2} + a^2\ T_{od-3} \ldots\}$$

where T_{rm} is the running mean temperature, T_{od} the daily mean outdoor temperature (when T_{rm} is the running mean temperature for a particular day, T_{od-1} the daily mean outdoor temperature for the previous day), 'a' is a constant between 0 and 1, which defines the speed at which the running mean responds to the outdoor temperature and the characteristic time period for the relationship. This equation reduces:

$$T_{rm}{}^{n} = (1-a)\ T_{od}{}^{n-1} + a\ T_{rm}{}^{n-1}$$

where $T_{rm}{}^{n}$ is the running mean temperature for day 'n' and so on. When the running mean has been calculated for one day, it can be calculated for the next day and all follows days from this value and the daily mean outdoor temperature. The best value for the constant 'a' was determined as 0.80. T_{rm80} is then the running mean temperature with a=0.80. Taking account of the above considerations, adaptive algorithms to estimate T_c have been suggested for both levels as given in Table 32.

Table 32: Algorithms for the individual countries.

	Level I		**Level II**	
	T_{r80}<10	T_{r80}>10	T_{r80}<10	T_{r80}>10
France	0.049T+22.58	0.206T+21.42	0.041T+21.59	0.188T+20.10
Greece	Not applicable	0.205T+21.69	Not applicable	0.244T+18.99
Portugal	0.381T + 18.12		0.452T+16.37	

Sweden	0.051T +22.83		0.061T+23.03	0.084T+22.24
UK	0.104T+22.58	0.168T+21.63	0.047T+21.10	0.188T+19.55
All	22.88	0.302T+19.39	21.61	0.267T+18.88

The two surveys gave rise to different recommended temperatures. The Level I results are considered more applicable since the measurements were more accurate. It should be noted that people in different European countries can be expected to have a different concept of thermal comfort, with people at more Northern latitudes feeling comfortable at lower temperatures than those in Mediterranean areas. Note also that the above correlations, based on values of T generally lower than 30^{o}C, cannot be expected to hold for higher values of T and an upper limit to comfort temperature might then be expected. These algorithms can be used to define comfortable indoor conditions and also to control air conditioning systems or assess whether naturally ventilated buildings will provide acceptable indoor temperatures.

5.2 Indoor air quality

Every building has a number of potential contaminant sources. These are related to building materials and furnishing (continuous release), and cooking, smoking, solvents, paints and cleaning products (intermittent release). The most significant pollutants sources are:

- human and animal metabolism;
- occupant activities;
- building materials; and
- equipment.

The main air pollutants are:

- carbon dioxide;
- carbon monoxide;
- tobacco smoke;
- formaldehyde;
- moisture;
- odour;
- ozone;
- particulate matter; and
- volatile organic compounds.

A review of international standards has been undertaken by the International Energy Agency. This included World Health Organisation standards in which three different concentration levels are listed:

- Maximum Allowable Concentration (MAC) at the work space for an eight hour period (occupational health criteria);
- Maximum Environmental (ME) value;
- Acceptable Indoor Concentration (AIC) - for concentrations below the AIC, the negative health effects are either negligible or, if no threshold is known, are at least tolerable.

Tables 33 through 35 list the different national limits for each of the major pollutants found in the indoor environment.

Table 33: International standards for CO_2 concentration level (ppm).

	MAC	Peak limit	ME value	AIC	Remark
Canada	5,000			1000-3500	
Germany	5,000	2 x MAC		1000-1500	
Finland	5,000	5,000		2500	
Italy				1500	
Netherlands	5,000	15000		1000-1500	
Norway	5,000	MAC+25%			
Sweden	5,000	10,000			

Switzerland	5,000			1000-1500	
UK	5,000	15,000			
USA	5,000			1000	

Table 34 International standards for CO concentration level (ppm).

	MAC	**Peak limit**	**ME value**	**AIC**	**Remark**
Canada	50	400		9	
Germany	30	2 x MAC	8-43	1-18	Depends on the duration and type of room
Finland	30	75		8.7-26	Depends on the duration
Italy	30				
Netherlands	25	120		8.7-35	Depends on the duration
Norway	35	+50%			
Sweden	35	100		12	
Switzerland	30		7	1,000-1,500	
UK	50	400			
USA WHO	50	400 9-87		9	Depends on the duration

Table 35: International standards for NO_2 concentration level (ppm).

	MAC	Peak limit	ME value	AIC	Remark
Canada	3	5		0.3 0.052	Offices, homes
Germany	5	2 x MAC	0.05-0.1		
Finland	3	6		0.08 0.16	Daily average, hourly average
Netherlands	2			0.08-0.16	Depends on the duration
Sweden	2	5		0.15-0.2	
Switzerland	3		0.015-0.04	1,000-1,500	
UK	3	5			
USA WHO	3	5 9-87	 0.16	0.3 0.08-0.21	

The measurement of indoor air pollutants in buildings is difficult for technical and financial reasons. However, the following indexes may be considered as representative of the quality of the indoor air.

- CO_2 level may be considered as an indicator of the pollutants directly emitted by occupants in no smoking areas. It is especially useful for variable occupancy zones and is a commonly used index, with concentration values between 500 and 1000ppm.

- CO can be a useful index where tobacco smoke is predominant (or in conjunction with an index such as CO_2). In particular, it can be employed as a security indicator to avoid combustion-related poisoning from heating appliances.
- H_2O, though not exactly an air pollutant, is frequently used to control air flow rates in order to avoid excessive relative humidity levels.
- Occupancy may be employed as an air quality indicator where occupants represent the main source of pollution as it is easier to measure than pollutant concentration.

Ventilation is the process of supplying and removing air to and from a space and can be achieved by natural or mechanical means. Hybrid ventilation combines these two ventilation modes. In a natural ventilation scheme outdoor air moves through building openings, such as doors, windows and cracks. It can be used to provide fresh air for occupants and also to provide cooling when external climate conditions allow it. With mechanical ventilation the air is supplied by electrical fans, which may be part of a HVAC system used to heat, cool and filter the air. There are many techniques for measuring air flows and ventilation rates:

- tracer gas decay;
- tracer gas constant injection;
- tracer gas constant concentration; and
- the multi-tracer gas method.

With these techniques the tracer gas must have the following properties: non-toxic and non-reactive, measurable at low concentrations, not be a normal constituent of ambient air, and have similar molecular weight to the normal constituents of ambient air. SF_6 closely matches these requirements and is the most widely used.

An alternative method is based on occupant-exhaled CO_2. The two most common methods of CO_2 concentration analysis are the decay and constant injection method. The critical parameter in both cases is the CO_2 generation rate because it depends on many characteristics and so cannot be measured accurately. The advantages of this technique are that there is no need to release a tracer gas in the building, and equipment for sampling CO_2 is relatively inexpensive and simple to operate.

It is important to carry out regular air quality monitoring to detect those contaminants that are capable of generating adverse health effects. Monitoring might aim at comparing the indoor and outdoor conditions, and recording gas concentrations over various periods of time. The levels recorded indoors are compared with available national air quality guidelines. Building and room air change rates should be periodically monitored to verify the ventilation effectiveness.

5.3 Lighting

The role of lighting is to produce an adequate visual environment. An environment is adequate if it ensures visual comfort and serves the visual tasks. The following characteristics are generally specified to define an acceptable visual environment:

- average illuminance;
- uniformity;
- ratios of luminances;
- allowable glare level;
- light direction and effect of shadows;
- colour temperature; and
- colour rendering.

The most important issue in visual comfort and quality of illuminance is glare and different indexes have been proposed:

- *Bodmann-Sollner* - for different activities, a minimum viewing angle is defined for light sources in order to avoid glare;
- *Visual Comfort Probability* (VCP) - this represents the percentage of people who probably will not complain about glare. A luminaire-by-luminaire determination of discomfort leads to the calculation of an overall rating, the Discomfort Glare Ratio (DGR). VCP is then evaluated from:

$$\mathrm{VCP} = \frac{100}{\sqrt{2\pi}} \int_0^{6.374-1.3227\ln(\mathrm{DGR})} \exp\left(-t^2/2\right)dt$$

- *Unified Glare Ratio* (UGR) – this is calculated using visual parameters in the field of view, with discomfort evaluated in terms of the position on a scale of discomfort:

$$UGR = 8\frac{0.25}{L_b}\sum\frac{L_s^2\omega}{p^2}$$

where L_b is the background luminance, L_s the luminance of each source, ω the solid angle and p the Guth factor.

Professional associations such as the Illumination Engineering Society of North America and the Association Francais d' Eclairage have provided recommended illuminance categories and illuminance values for lighting design. Tables 36 through 38 give different categories and values corresponding to different activities.

Table 36: Illuminance values for various activities.

Type of activity	Illuminance category	Range of illuminances (lux)
Public spaces with dark surroundings	A	20-50
Simple orientation for a short temporary visit	B	50-100
Working spaces where visual tasks are only occasionally performed	C	100-200
Visual tasks of high contrast or large size	D	200-500
Visual tasks of medium contrast or small size	E	500-100
Visual tasks of low contrast of very small size	F	1000-2000
Visual tasks of low contrast and very small size over a prolonged period	G	2000-5000
Very prolonged and exacting visual tasks	H	5000-10000
Very special visual tasks or extremely low contrast and small size	I	10000-20000

Table 37: Lighting levels for various types of work spaces.

Task group and typical interior	Standard service illuminance(lux)
Minimum for a visual task	200
Rough work, machinery assembly, writing, reading	300
Routine work, offices, control room	500
Drawing office	750
Fine work, machining and inspection	1000
Very fine work	1500
Very demanding task in industry or laboratory	2000

Table 38: Illuminance categories.

Indoor activity	Category
Residences	
General lighting	B
Specific visual tasks	
Dinning	C

Ironing	D
Laundry	D
Reading	
In a chair-books	D
In a chair-poor copies	E

Lighting should not be excluded as a contributor to energy conservation. Lighting controls are used to manage energy use more effectively and more efficiently inside buildings. They can be used to:

- reduce lighting during unoccupied periods;
- switch off or time-set the lights in daylight areas;
- compensate for lumen depreciation;
- adjust light levels according to local tasks; and
- adjust light levels to suit visual adaption.

There are several control types:

- dimmers;
- on/off switching;
- differential switching control;
- photoelectric switching with time delay;
- solar reset;
- photoelectric dimming; and
- manual switching.

The selection of lighting controls may be designated by the factors presented below:

- size of the building;
- lighting system type;
- daylight availability;
- building usage;
- budgetary constraints; and
- dimming requirements.

5.4 Energy performance

The measurement of energy consumption in a building is required to:

- invoice delivered energy;
- reduce peak load;
- analyse system energy behaviour;
- support financial management; and
- optimise the energy tariff.

In order to reach these objectives, different values may be measured:

- delivered thermal and electrical power;
- fossil fuel usage; and
- use duration.

Moreover, power metering may be hierarchically organised per building, per flat and per zone. Analysing as well as controlling energy use has then to take into account energy tariffs. In order to evaluate the energy performance of existing buildings, methods have been developed to assess the total energy consumption, which may be estimated by two distinct approaches as follows.

Black-box

The weather normalised energy performance can be deduced from a statistical analysis of actual energy consumption and a control parameter such as outdoor temperature. Weather normalisation techniques are based on the assumption that the energy consumption is composed of both weather and non-weather-dependent components. The weather dependent component varies linearly with climate (usually expressed as heating/cooling degree-days), while the non-weather component is due to local equipment, lighting *etc.*

Analytical

The energy consumption is calculated by using a building's design data, characteristics of the HVAC systems and standard meteorological conditions. The following brief descriptions are extracted from a survey undertaken within the EuroClass project in which several methods were reviewed, evaluated and classified.

5.4.1 Black-box approaches

PRISM (PRInceton Scorekeeping Method)

This is a weather normalisation technique, which assumes a linear relationship between energy consumption and heating/cooling degree-days. The normalised annual energy consumption is given by the weather-dependent term that is calculated for reference or long term annual average conditions:

$$NAC = a + bf \text{ (climate conditions)}$$

The daily average energy consumption (kWh/m^{2}day) is calculated from:

$$E_i = a + b\, H_i(T_{ref})$$

where E_i is calculated by dividing the total amount entered on the utility bill by the total floor area and by the number of days, 'a' is the non-weather dependent daily energy consumption, 'b' the slope of the weather dependent energy consumption and $H_i(T_{ref})$ the number of degree-days computed for a reference temperature T_{ref}. The following climate data are necessary to apply the method:

- daily average temperatures;
- long term heating degree-days for several reference temperatures; and
- long term average cooling degree-days for several reference temperatures.

If T_{ref} is chosen arbitrarily, 'a' and 'b' must be estimated by using least square techniques. T_{ref} can subsequently be estimated according to the criterion of the highest coefficient R^2. Finally, normalised annual energy consumption, NAC (kWh/m^2), is calculated using the relation:

$$NAC = 365\, a + b\, H_o\, (T_{ref})$$

where H_o is the annual heating degree-days.

Zmeureanu method

This is also a weather normalisation method, with many similarities with the PRISM method, and can be applied to buildings using gas or fuel for heating and electricity for cooling, lighting and equipment. The method uses the term 'building energy signature' to define the linear relation between daily average consumption, E_i (kWh/m^2 year), and the daily average temperature, T_i , for each meter reading interval:

$$Ei = a + b\, T_i$$

where 'a' is the base level of non-weather dependent daily energy consumption and 'b' the slope of the weather-dependent energy consumption corresponding to the ratio between the heat loss rate and the efficiency of the HVAC system. The building consumes energy above the base load only when the outdoor temperature drops below the reference temperature,T_{ref} (heating), or rises above T_{ref} (cooling). The T_{ref} at which the weather dependent curve equals the base load, $E= a + b\, T_{ref} = B_L$, is calculated from the relationship

$$T_{ref}=(B_L - a)/b \; .$$

NAC is then obtained from

$$NAC = 365\, B_L + (Em\text{-}Nm\, B_L)\, C/C_1\, N_{T,15}\, Nm/\, N_T/365 \text{ ; if } T_{DB} < T_{ref} \text{ (heating)}$$
$$NAC = 365\, BL \text{ ; if } T_{DB} \geq T_{ref} \text{ (heating)}$$

$$NAC = 365\ B_L + (Em - Nm\ B_L)\ C/C_1\ N_{T,15}\ Nm/\ N_T/365\ ;\ \text{if}\ T_{DB} > T_{ref}\ (\text{cooliing})$$
$$NAC = 365\ BL\ ;\ \text{if}\ T_{DB} \leq T_{ref}\ (\text{cooling})$$

where Em is the total energy consumption from the utility bills (kWh/m^2 yr), Nm is the total number of days covered by the utility bills; B_L is the base load energy consumption (kWh/m^2 day) and $N_{T,15}$ is the number of hours when $T_{DB} < T_{REF}$ for gas heating or $T_{DB} > T_{REF}$ for electrically cooled buildings. The following relations define the parameters C and C1:

$$C = \frac{1}{15}\sum_{j=1}^{15}\ \sum_{i-1}^{n}\left(a + bT_{DB,i,j} - B_L\right)BIN\left(T_{DB,i,j}\right)\ ;\ \text{if}\ T_{DB} < T_{ref}(\text{heating})\ \text{or}\ T_{DB} > T_{ref}(\text{cooling})$$

$$C=0\ ;\ \text{if}\ T_{DB} \geq T_{ref}(\text{heating})$$

and

$$C_1 = \sum_{i-1}^{n}\left(a + bT_{DB,i,j} - B_L\right)BIN\left(T_{DB,i,j}\right)\ ;\ \text{if}\ T_{DB} < T_{ref}\ (\text{heating})\ \text{or}\ T_{DB} > T_{ref}(\text{cooling})$$

$$C_1=0\ ;\ \text{if}\ T_{DB} \geq T_{ref}\ \ (\text{heating})\ \text{or}\ T_{DB} \leq T_{ref}\ \ (\text{cooling})$$

where BIN (TDB,j) is the number of hours of occurrence of the dry bulb temperature bin having TDB as centre during operation of the HVAC system. For the heating model, the value of b is negative whereas for the cooling model it is positive.

The rating system proposed by Zmeureanu consists of a combination of the following features:
- the index of energy performance is assessed based on the previous history of the building;
- comparison of the energy performance results with those of some reference buildings; and
- information to the house owner on the potential energy savings.

Distinction of energy performance:
- for a new house, evaluation of the energy based on drawings and specifications at the design stage; and
- for an existing house, assessment of the actual energy consumption and parameters such as the thermal performance of the exterior envelope and occupant behaviour.

Two basic approaches exist:
- the absolute approach, which is important for the house owner; and
- a relative approach where potential savings are important.

Two steps are generally followed:
- normalisation of utility bills for weather conditions and size of house (conversion of all energy units to kWh); and
- evaluation of the energy used for heating purposes.

The analysis of utility bills is made using AHEM software in which inputs are year of construction, total heated floor area, location (i.e. climate), energy source used for heating, energy consumption and cost for 12 months at least; outputs are actual energy consumption and cost for each energy source, normalised energy consumption and cost, contribution of each energy source to NAC, and a comparison between the NAC for test and reference houses.

5.4.2 Analytical approaches

Vermont-Hers (Home Energy Rating Systems) method
This characterisation refers to a set of energy rating schemes applied in the USA (also referred to as Home Energy Saver). The home energy rating is a standard measurement of a home's energy efficiency. The implemented HERS may be one of the following:
- the points system, which evaluates the energy performance of a house by awarding performance scores to each subsystem;

- the performance system, which assigns an index of performance in terms of annual heating performance or cost; and
- the awareness system, which recommends the annual total and heating energy consumption, and the corresponding cost, in terms of the year of construction, the climate zone and the energy source.

At first, an on-site inspection of a home is realised by an energy efficiency professional, the home energy rater, aiming to measure energy characteristics such as insulation level, wall-to-window ratios, heating and cooling system efficiency, solar orientation and water heating system type. These data are then input into a computer program and translated to points. The home receives a point score between 1 to 100 according to its relative efficiency. The home's energy performance is then star-rated, ranging from very inefficient to highly efficient (5-star). Finally, the home owner receives a report listing cost-effective options for improving the home's rating. The point score is defined as follows:

$$Point\ score = 100 - 20(ER/EC)$$

where ER is the estimated purchased energy consumption for heating, cooling and hot water for the rated home (Btu), and EC the estimated purchased energy for the same three consumptions for a reference home (Btu). For ER=EC, the points score is 80.

Key Number method
The key number trade name was issued by Norway, although such numbers are used in several countries to compare energy performance between buildings and existing references. Several levels are considered. The lowest level is simply to compare the total yearly energy use of a building of the maximum power demand to references. The energy use must first be normalised. At a second level, the energy use can be graded in various categories: heating, cooling, ventilation, hot water, lighting, appliances and so on and then compared to corresponding references. At a third level, building characteristics can be compared with conventional values.

Energy Barometer for Sweden
This method addresses building performance by the continuous monitoring of energy and climate variables in a random sample of houses with reporting of changes in energy use at the individual building level. According to the measurement protocol, three variables are measured:
- electrical energy use for household appliances;
- energy use for heating, including domestic hot water; and
- indoor temperature.

Weather data are collected from the nearest meteorological station and building technical data are collected either by interviews or by on site inspections. The required weather data includes outdoor temperature and solar irradiation. The required technical data includes
- household size and composition;
- year of construction, house type and heated area;
- construction data;
- service systems information; and
- appliance data.

The measured energy use is standardised with respect to time and climate. This is made by statistically regressing energy data against climate data and by using climate data for a normal or average year with the obtained regression coefficients for determination of average annual energy use. The model used for the regression analysis, called energy-signature, is a three parameter model: the first parameter is the base line energy use when there is no heating; the two others are the intercept and the slope coefficient for the heating regime. This model can be automated and applied to range of buildings. The annual energy use for heating (kWh) during an average year is calculated from:

$$W = cT + bQ + fI + dP$$

where ‘c’ is the average hourly energy use, independent of outdoor temperature and solar irradiation (kW), ‘b’ the heat loss factor expressing how well the building stands the outdoor climate (kW), ‘f’ the solar aperture or window factor (m^2), ‘d’ the average hourly energy use during the period when the house is not heated, W the annual use for heating (kWh), T the length of the heating period, P the length of the period when the house is not heated, I the solar irradiation during the heating season measured as the global radiation on a horizontal surface (kWh/m^2), and Q the number of degree-hours calculated as T times the average indoor-outdoor temperature difference during the heating season (^oCh). The energy parameters c, b, f and d have specific values for each house.

5.4.3 The EuroClass Project

To facilitate the implementation of the proposed European directive on the energy performance of buildings in the residential and tertiary sectors, the EuroClass project set out to develop a European method for the calculation of the energy performance of existing buildings and their classification/rating. Within the project, methods for the analytical and experimental determination of a building’s thermal characteristics were reviewed. In the latter case the emphasis was on the thermal loss coefficient and the gA value related to solar gains. The reviewed methods covered a range of approaches: various university projects, Energy Barometer, House Energy Labeling Procedure, STEM and PSTAR, neural networks and the in-situ evaluation of UA and gA. The focal point of the project was the development of experimental protocols and normalisation procedures.

Experimental protocol

The aim of the experimental protocol is to determine actual energy use and identify its constituents. Two procedures were developed, billed energy protocol (BEP) and monitored energy protocol (MEP). The simpler protocol, BEP, is conducted within four man-hours per residence. The output is the actual and the normalised annual energy use. Normalisation of energy use is only performed with regard to the outdoor climate, for the reason that indoor temperatures are unknown. To decrease costs for the rating process, measurements are not done with the exception of the reading of meters that are already installed in the building. The fact that measurements are not conducted will lead to an increase in result uncertainty. MEP, on the other hand, makes use of bills, but is more flexible since the protocol involves measurements of climate variables and entails sub-metering within the building to enhance data accuracy. MEP is also recommended in the case where BEP criteria prevent application of the simpler protocol. In most cases MEP output will be more reliable than that of BEP. Moreover, normalisation of energy use, taking into consideration reference outdoor climate and indoor climate, is performed. MEP may involve a monitoring scheme lasting for over 10 weeks: the duration time depends on which service, aside from rating, is being purchased. Technical information from MEP is important to document as this information can be used to establish default values for BEP. Example of this is boiler efficiency as a function of fabrication, type and age.

Normalisation

Normalisation takes into account the size of the building, the external climate and the internal climate. Typically the heated floor areas is used to represent building size. This relates energy use to the parts of the residence that are utilised and conditioned. Normalisation by external climate takes into consideration annual variations. By placing the building in reference climate, performance of different buildings may be directly compared. Normalisation for heating is done using the heating degree-days, whereas normalisation for cooling must be done using a more complex climate severity index. Normalisation of the internal climate can be done for a set of predefined conditions. This type of normalisation standardises end-user behaviour and allows a comparison between different occupant types in the same residence.

Rating methodology

A rating procedure is a comparison scheme that associates a score with a specific building. It is based on three issues:

- the performance variable or set of variables to be compared;
- the comparison scenario, i.e. the group of buildings that will provide a distribution of the performance variable thus creating the framework for comparison; and
- the rating score, i.e. the criteria and limits that give the score when the performance variable is compared within the comparison scenario.

The performance variables are the total supplied energy or the total delivered energy, both expressed in kWh/m^2. Both quantities are normalised and attributed to the different energy streams, namely heating, cooling, hot water and lighting. Space heating and cooling require climate normalisation. The score of the rated building allows comparison with other buildings for a given similarity level or normalisation scenario. Several possibilities of expressing the rate exist:

- points on a scale of 0 to 100, based on the percentile that the energy consumption of the building has when compared to the frequency distribution of the energy consumption of the existing building stock;
- star rating whereby the cumulative distribution is divided in a number of sectors and the building is assigned to one sector in terms of its energy consumption; and
- distance to a reference value obtained by dividing the area-related energy to a reference value.

When it is not possible to employ statistics about energy consumption for buildings similar to the rated one, the frequency distribution of the consumption follows an analytical expression inspired from existing distributions in other countries. In all cases, allowance is made for intermittent operation of HVAC systems by means of an intermittency factor, IF, which is used to normalise the actual operation of the building to a standard scenario. The calculation of IF is based on a representative day.

6. Other aspects

6.1 Control strategies

The main aim in building design is the provision of satisfactory comfort conditions for occupants. This requires the maintenance of comfort-related parameters within certain limits. Such parameters must be chosen regarding the control strategy being implemented, the technical feasibility of parameter measurement and economic considerations. Some applicable terms include:

- *controlled parameter* - the parameter that has to be kept constant or within a fixed limit. An example of a controlled parameter is indoor air temperature;
- *control parameter* - the parameter that can be modified by the control system in order to move the controlled parameter close to its set point (e.g. the position of a valve or the status of a pump); and
- *set point* - the value at which the controlled parameter has to be maintained (e.g. 21°C in a zone during winter).

A building control system comprises three elements: sensors to measure the value of the controlled parameters, actuators to modify the equipment according to a control parameter's value, and the controller to set the value of control parameters as a function of controlled parameters. There are two main categories of control techniques:

- *open loop control* – in which the controlled parameter is not explicity taken into account and inputs to the controller are one or more disturbance parameters. The technique is also called feed forward control. A well known example of this technique is the determination of the mixed flow water temperature in a heating system comprising boiler and radiant panels as a function of ambient temperature.
- c*lose loop* control - in which the controlled parameter is an input to the control system and is compared to the set point in order to determine the value to be given to the control parameter. This is also known as feedback control. The most common closed loop control systems are ON-OFF control, proportional (P), proportional-integral (PI) and proportional-integral-differential (PID) control. This last type takes into account the value of the controlled parameter, the difference between the controlled parameter’s value at the current time step and the previous time step, and the previous values of the controlled parameter.
- l*ogic control* - a simple technique based on IF-THEN-ELSE statements, which are easy to program. Used by the first generation of intelligent building energy management systems, which employed hierarchical conditional statements.
- *Time programming* – an important control function implemented in every modern building. The principle is to program the operation of equipment or the value of the controller's parameters (i.e. set-point) as a function of time.

Controllers that implement the above techniques do not assure the optimal control of all controlled variables. To this end, more advanced techniques are being developed:

- *fuzzy logic* - a technique based on the implementation of IF-THEN-ELSE control rules linked to the fuzzy set theory. Such controllers are suitable for the control of imprecise and uncertain parameters (such as comfort indices) and the incorporation of more than one control parameter (multi-criteria control). Genesys and Builtech are projects that have developed and tested fuzzy controllers. The technique requires the setting of a number of parameters and no specific technique has been developed for their *a priori* setting.
- *neural networks* - these have been used for system identification purposes, especially pattern recognition. Their structure corresponds to a simple replication of the human brain. The controller is divided into several layers, the first one being the inputs and the last one being the outputs of the controller. A neural network is therefore a black box, giving no insight into the operation of the system being controlled. While it is well suited to the control of non-linear systems, the method requires time-consuming tuning of the hidden layers and has been rarely implemented in building energy management systems.

6.1.1 Experience from relevant projects

Many control systems have been implemented for heating, cooling, air conditioning, remote energy control and other building services. The Radio-Teleswitch System (RTS) provides remote control of storage heating and hot water systems using a radio frequency of 198kHz (the British Broadcasting Corporation transmits its Radio 4 service via amplitude modulation of the 198kHz carrier broadcast from three transmitters). Digital teleswitching information, under the control of 15 electricity companies, including ScottishPower, is also broadcast using phase modulation of the same carrier. A radio teleswitch, sited in a customer's premises, consists of a 198kHz radio receiver, decoder, memory and four switches. Two switches are rated at 2A and can be used to control the application of different time-of-day registers within the customer's metering. The other two switches are rated at 25A and 80A and are normally used for the control of hot water and space heating respectively. A teleswitch follows its stored program until this is changed, and in this sense it operates as an advanced form of time switch. Radio teleswitches are used to control demand in two distinct ways: the load can be switched ON and OFF by the electricity supplier when the supply cost is low and high respectively. Alternatively, the cost at which electricity is sold can be varied in the expectation that customers will control their demand in response to opportunity. The benefit for the customers is cheaper tariffs, while companies can smooth electricity load demand profiles by remotely controlling a large number of houses.

In the *Celect* project, the implemented control system has distributed intelligence, with each node having built-in processing power and capable of performing in isolation or as part of a network. The system uses Cost Reflective Messages (CRM) and forecast weather data, both broadcast over the RTS, to deliver the comfort level demanded by the user whilst optimising the use of electricity. CRM can include the cost of supply in half hour intervals, and other tariff-related data throughout the following day. Each heater in the system is fitted with its own Optimised Heater Controller (OHC). This can be external or enclosed within the dedicated heater. An algorithm within each OHC optimises the use of electricity to give the user the required comfort settings based on the CRMs and weather data. The OHC algorithm can be used with storage, direct acting or combinational heaters. Each house also has a hot water controller to provide hot water to the requirements of the customer by acting upon CRMs. For home networking Echelon powerline signalling is used. This minimises inconvenience and the cost of system installation in retrofit applications.

In the *Genesys* project, the aim was smart control of a HVAC system. Instead of a classic control strategy, as applied in most HVAC systems and comprising ON-OFF and PID control, the proposed algorithms were based of fuzzy logic techniques. The system allowed the following control actions:

- heat pump switching;
- heat pump mode (heating-cooling) operation and fan switching;
- supply damper position (regulating air flow rate);
- mixing damper position (regulating air mixing); and
- water valve position (regulating water flow rate to the fan-coil).

During the experimental period, two different control strategies were applied in order to regulate indoor temperature and air quality. The first was based on a classic control algorithm, the second on fuzzy logic. In both cases the controlled parameters were PMV, as an index of thermal comfort, and CO_2 concentration, as an index of indoor air quality. The inputs parameters to the fuzzy controller included PMV, PMV derivative, CO_2 concentration, CO_2 concentration derivative, indoor air temperature and supply air temperature. The actuators (outputs) controlled the water valve, the mixer, the blower on-off relay and the chiller on-off relay. The applied strategies were compared via a fitness function (representing PMV, CO_2 concentration, energy consumption and mechanical stability).

6.2 Level of user control

In the controls systems mentioned above, differences exist with regard to the level of user interaction and the service provider control. With a RTS system demand can be controlled in two ways: loads can be switched on and off by the supplier and the cost of electricity to meet the load can be varied in the expectation that the customer will respond. Both strategies can be adopted by suppliers, separately and combined. When a low rate period is offered for the customer's general supply, the customers can schedule their appliances either manually or with time switches. When a separately metered supply is offered for storage space heating, availability may be on the basis of either a fixed duration or a duration that depends on predicted weather for the following day. In either case, the choice of actual timings remains under the control of the supplier.

In the *Celect* system**,** a user interface allows the customer to enter times and temperatures for each day of the week for each heating zone together with hot water requirements. Unlike conventional systems, the user interface is not the controller, merely an interface, and once the customer has defined their requirement the system can operate without the user interface. The system has demonstrated its ability to reach the required temperature levels precisely. The benefit to customers is control over their day-to-day lifestyle requirements, while for the utilities the benefit is that the system allows them to price the availability of electricity in order to minimise supply and distribution costs.

In the *Genesys* project, sensors and actuators are connected via the EIBus. The Instabus allows the control and monitoring of all operating tasks and procedures via a single shared cable. The communication between the Instabus and user is carried out via a PC running SIEMENS visualisation software

In the *Energy Barometer* project, a data analysis and presentation system supports the transference of information back to homes. Community-averaged and individualised data enable citizens to compare their energy consumption to the general consumption trend in their area. In this way, home owners can estimate the energy efficiency of their home and obtain advice on appropriate energy action (e.g. temperature set point adjustment).

6.3 Review of other projects

Several projects have been carried out in Sweden by building and real estate management companies, with a view to explore smart housing solutions. At the present time the first intelligent houses are being built.

Poseidon

A project in Gothenburg carried out by the Poseidon real estate management company. Several smart solutions are evaluated by tenants:

- *electronic lock system* - smart cards or key tags replace metal keys. For insurance reasons, the doors are also equipped with conventional locks. The laundry room can only be booked via the Internet and may only be unlocked by the person who has reserved it.
- *away button* - this function shuts off the water supply, the electricity to some outlets and activates an alarm system. It can be accessed via the Internet or from a WAP mobile phone.
- *broadband* - constant access to the Internet at 10Mbyte/s. Each resident has one portal from where they can control all Internet-based functions. Computer plugs are installed in all rooms except for the bathroom where only a telephone plug is stationed.
- *Intranet* - a local network for communication between the landlord and the tenants. Different issues concerning the house may be discussed allowing direct democracy. An example is the

opening times for the laundry room.
- *individual tap water and space heat metering* - the current consumption is shown directly on a display in the flat or on a Web page and is conveyed both in kWh and in monetary units. Consumption statistics may be obtained for different periods. The tenants pay for their own water consumption and for the indoor climate they choose.
- *information screen* - the notice board is replaced by an information screen where the landlord, the tenants' association, local merchants and tenants can leave messages.
- *weather forecast station on the roof* - the house measures its own weather. Statistics for different intervals may be obtained from the Internet.

Mölndal
In Mölndal outside Gothenburg, the world's first series-manufactured intelligent house has been built. The design has been developed by eHem AB and Lexel Electric AB. All the installations are being supervised by a system based on the EIB protocol. The following 15 services are included:
- lightning scenarios;
- home unit (heating and light from a distance);
- remote unit;
- heating control;
- burglary alarm;
- safety alarm;
- relative's alarm (for elderly people);
- fire alarm;
- status alarm;
- close doors/windows service;
- 'homelog';
- energy metering;
- SMS messages;
- dishwasher and washing machine control; and
- 'lookhomeservice'.

Within the house, all functions can be accessed using a remote control. The price for the 'basic intelligence package' equates to the cost of installing tiles in a normal sized bathroom, i.e. between 50,000 and 60,000 SEK.

Skogsbo
In Skogsbo, outside Gothenburg, a community of intelligent, terraced houses is being built. The participants are Markvärden (client), Frontyard (smart services supplier), and HemEl (energy supplier). At the time of the present review 31 of the 39 houses were sold. The size of the houses varies from 100 to 135m^2 and the prices range from 1.6 to 1.8 million SEK. The cost for the common basic services, which is 60,000 SEK, is included in the price. The basic package contains individual tap water and space heat metering, a web camera in the parking lot, a weather station and broadband. Additional intelligent services are connected to an EIB system. The installation of this system costs 50,000 SEK. Examples of such services include:
- *fire alarm* - fire detector in the hall. Scenario – on alarm stair and hall lights illuminate and a SMS/e-mail messages is sent to the resident, neighbour or real estate administrator.
- *moisture alarm* - moisture sensor under dishwasher and washing machine. Scenario - in case of leakage an alarm is raised, water supply disconnected and an SMS/e-mail sent to HemEl.
- *burglar alarm* - IR sensors and magnetic contacts placed at doors and windows. Scenario - alarm raised, the house is illuminated and an SMS/e-mail is sent to the resident, a neighbour or real estate administrator.
- *look home* - a Web camera takes pictures around the home. Scenario – when the burglar or fire alarm is triggered, the five latest pictures are made available on the Internet.
- *boundary protection* - boundary protection is active between specified times. Scenario - boundary protection is activated automatically or on demand.
- *lock service* - control of windows and doors before leaving home. Scenario - the service is activated by keylock (selected sockets may also be deactivated) and an alarm is activated if any door or window is opened.

- *appliance monitoring* - turn on/off sockets remotely. Scenario - the service makes it possible to disconnect sockets at a distance via the Internet or mobile phone.
- *light control* - lemote light control. Scenario - the service enables the remote control of lamps via the Internet or mobile phone.
- *scenario playing service* - makes the home look inhabited while empty. Scenario - the system manages events in the house (e.g. lighting) to give the appearance of occupancy.
- *individual metering* - of electricity, municipal heating networks, hot and cold water. Scenario - individual metering, charging and statistics for consumed resources are collected and itemised on an invoice from HemEl.
- *Internet link* - with these services, Web pages or local files can be opened. Scenario - when the occupant arrives home and turns on a light, a radio channel is activated.
- *weather station* - local weather information and statistic is available via the Internet.
- *Intranet* - covers the neighbourhood and provides functions such as fire walls, broadband access, digital TV and the possibility to use common disk storage.
- *charging* - HemEl provide residents with an itemised invoice for the services consumed per month.

Furthermore, in the Czech Republic, a project, ‘smart family house’, was built in Karlovy Vary in May 2000. This project applied an industrial controller (TECOMAT TC-500, Teco a.s.) and the know-how of company HEITEC INDUSTRY Plzeň s.r.o. The house has a computer centre, which informs users (via mobile phone) about the house condition. Information is given on room temperatures, energy use and security. The user is able to regulate temperatures, and regulate lights to simulate the presence of people. The computer centre can also monitor and control heating and air conditioning equipment and activate fire alarms.

7. SmartHome system development plan

This section presents a functional overview of the SmartHomes system. The parameters that should be monitored are discussed and the appliances to be controlled identified. Finally, the available options for the home and external network are identified.

7.1. Home data acquisition and appliance control

Thermal comfort

The number of parameters that should be measured in order to evaluate indoor thermal comfort is high and unfortunately the thermal comfort indices depend on the location where the measurements take place (i.e. it is possible to obtain different comfort indices for different locations in the same room). Additionally, the number of required sensors dictates the installation cost and it is important to note that some sensors are sensitive (e.g. air velocity measurement) and require specialist installation approaches. Two solutions are proposed with indoor air temperature and humidity measured in both cases. In the first solution, the comfort index is calculated using default values for the remaining comfort parameters. In the second solution, the thermal comfort is determined according to the national regulation requirements of each country.

An important aspect of the measurement procedure is the sensor location. This aspect is strongly related to the building type. Concerning the measurement of air temperature, the use of the space and its orientation will influence its thermal conditions. Therefore, decisions on sensor location will generally be an installation specific decision.

An alternative approach, that assures more or less the success of the installation, is the fitting of sensors close to the location where the control of the HVAC system is applied. The minimum information to assure thermal comfort is the set point temperature and relative humidity of the HVAC system. The HVAC system type (central or local), as well as its technical characteristics, will determine the actuator types that should be installed. Lastly, system control details are required to determine the actuation approach.

Indoor air quality (IAQ)

To determine level of indoor air pollution, it is necessary to use specialised sensors to measure the concentration of a variety of air pollutants. In order to ensure minimum IAQ only occupant emitted CO_2 need be measured. Also, depending on the use of the indoor space, it may be necessary to install CO sensors. The levels of CO_2 (and possibly CO) characterise IAQ and determine the amount of outdoor air necessary to reduce the pollutant concentration to an acceptable level. Additionally, to take into account the energy required for ventilation, it is necessary to measure the outdoor air. The relevant actuators are dampers to control the percentage of fresh air introduced to the indoor environment. In the cases where no mechanical ventilation system exists, the opening/closing of windows may be realised by an electric motor. In this case it is necessary to take into account the security aspect and occupant annoyance.

Visual comfort
The evaluation of visual comfort in an indoor space is not a straightforward procedure. It depends on the measurement location and the occupant's angle of view. To facilitate the evaluation and also apply energy conservation measures to the artificial lighting system, the measurement of lighting levels only may be sufficient. In this case, the proper positioning of the lighting sensor and its calibration procedure are essentials activities (the position will depend on room geometry and use). Artificial lighting may be controlled by a dimming system along with various modifications to regulate the lighting system (e.g. installation of electronic ballasts for fluorescent lamps). Additionally, the installation of motorised shading devices permits control of incoming sunlight (although the control strategy can be complicated by the need to ensure visual comfort).

Appliance controls
The control of appliances requires the turning on and off of relevant electric sockets. The installation of relays can be effective, as well as the use of commercial electromagnetic switches. Local intelligence is an important issue to ensure that the switching operation is appropriate (e.g. to avoid food spoilage in the case of refrigerator control).

Energy consumption
While total energy consumption can be measured, it is more convenient to monitor the component consumptions (for heating, cooling, lighting, appliances and hot water). This requires a more complicated sensor array but is essential in order to have a clear view of the energy saving potentials. An energy consumption rating method can be effective for the classification of the monitored building.

7.2. Home and access network communication technology

Home network
Several technologies are available to network a home. The most common network approach is Ethernet. However, if Ethernet is selected, new cables must be installed between all device locations. As the installation must ensure low occupant disturbance, rewiring may prove intractable. The phoneline system uses the home's telephone wiring to connect computers and other information gathering devices. This requires that e-service devices must be placed near existing phone jacks. In the case of older homes, this may be an unacceptable limitation. Powerline systems take advantage of the home's electrical wiring and thus share some of the locational restrictions of phoneline systems. The LonWorks powerline networking technology is particularly well suited for utility applications, and is probably a preferred solution for remote energy management and control (Figure 6).

Wireless home networks offer many advantages, both in installation and in flexibility of use. Wireless solutions have no restrictions on device placement. The Ericsson e-box supports wireless solutions via a serial interface as shown in Figure 7. Where it is necessary to link devices without clear line-of-sight transmissions paths, solutions such as Bluetooth may be adopted (although the cost of such implementations is unclear at the present time, as is the extent of the problems associated with interference and equipment compatibility).

Access network
The e-box communicates with an e-service centre (e-sc) via the access network. As different possibilities exist (ISDN, PSTN, GSM and Ethernet), the adopted solution for each country will depend on the available access network connections. For example, a leased line or dial-up connection

(via an Internet Service Provider) might be used to communicate with the e-sc via IP connectivity. A permanent connection is the most suitable option for the SmartHomes project because the provided e-services will typically require the transfer of relatively high frequency data. Of course, this type of connection increases the operation cost. Where the data transfer frequency is low, a dial-up connection (e.g. PSTN, ISDN, DSL) can provide a low cost option.

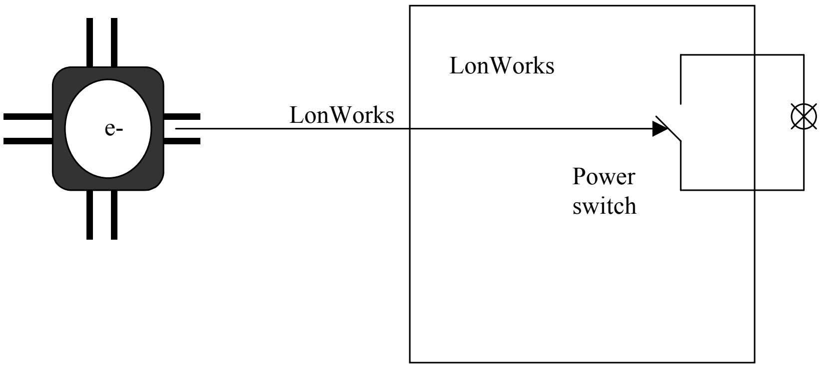

Figure 6: The LonWorks installation.

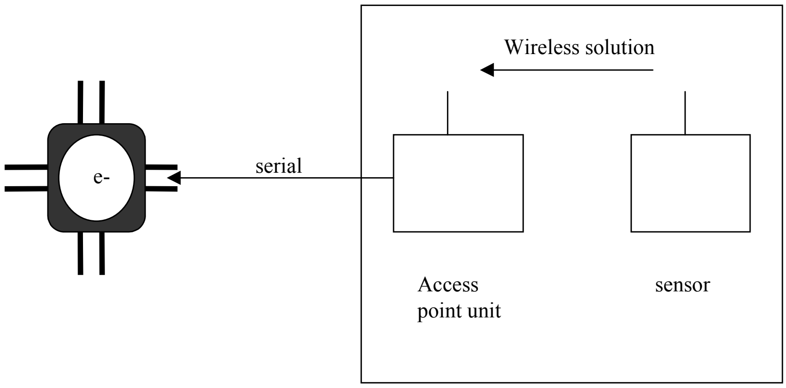

Figure 7: A wireless installation.

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Appendix 2: Work Package 2, Possible energy services

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Introduction

This WP explored future on-line energy services. From the identification of possible actors, systems and service types, including a review of available on-lines services and energy projects, proposals on new on-line energy services are made. The work identified various services that might be delivered via the Internet. These services are grouped in one of five types, and are mainly part of the so-called telemetric group. E-services may also appear together with the other services groups, these being: information, entertainment, e-commerce and communication. The players involved in the chain of services are:

- home owners/occupiers and their organisations;
- property owners/managers/maintenance operators;
- energy supplier and energy distributors;
- local and national authorities;
- service providers; and
- telecommunications operators.

The review addressed three issues within the field of e-services: the benefits obtained from previous projects that focused on energy conservation and thermal comfort; the state-of-the-art in services being provided today to commercial smart homes; and the impact of district load control for efficient energy management. It demonstrated that influencing occupant behaviour corresponds to some 10-20% of the residential energy consumption, with similar figures obtainable by implementing technical improvements. The implementation of energy services through the Internet is expected to give rise to energy conservation by influencing occupants and by operating energy systems more efficiently and effectively. An important issue is to increase energy awareness by providing energy-related information and through measures such as economic inducements and competition. Another conclusion from the review is that little is being done with monitored data other than providing visual feedback of energy use over time to individual occupants.

Important issues are Internet access and usage trends. By reaching out to many residences and organisations simultaneously, impact may be made at the large, aggregate scale. While impacts at the individual scale may be of interest to occupants, the sum of these impacts, applying to the large scale, will be of importance to the wider community of occupants, authorities, energy managers and suppliers. The possible services can be categorised thus:

information, e.g. authorities inform citizens about the energy labelling of domestic appliances and the benefits of low energy purchases;
monitoring with alerts or alarms, e.g. warning that CO levels are excessive in a local area or providing alarms that require immediate action;
monitoring with feedback, e.g. monitored values on energy consumption and indoor conditions are reported to the occupant and the energy supplier;
monitoring with actuation, e.g. for load management where energy suppliers reduce electricity loads for space heating in local areas during critical periods of the day.

The specific services identified include:

environmental monitoring, e.g. detection of gas, smoke, temperature and humidity;
metering, e.g. of gas, electricity and water consumption;
weather-related services, e.g. heating control, night cooling, use of rainwater *etc*;
performance evaluation, e.g. of city energy consumption by fuel type and emission levels;
local appliance control, e.g. of heating, lighting and small power devices;
large scale appliance switching, e.g. for district load manipulation; and
renewable energy trading, e.g. as a function of electricity prices and demand.

Special attention has been given to the remote monitoring of energy use and home conditions, and the remote control of appliances. From the list of potential services, each national partner selected one or two services to implement within the present project. These selections were influenced by the national situation, such as the status of the local IT infrastructure and specific problems being faced by occupants, authorities and energy suppliers. The national service selections were as follows.

Czech Republic - Individual metering of energy use and thermal comfort in multi-family buildings

and remote actuation of set point temperatures of heating systems for entire housing blocks. Data is reported to occupants, the energy supplier and authorities.
Greece - Cooling load predictions based on real time data input to neural networks, with information to occupants on how to reduce space cooling demand.
Scotland - Services targeted social housing (comprising cold conditions and high CO level alarms) and fuel metering, with reporting to occupants, local authorities and utilities.
Sweden - Individual metering of space and water heating and electricity in multi-family buildings. Coupling of metered values to a simulation program to estimate heat exchange between neighbouring apartments, thereby providing information for energy consumption debiting models. Data are reported to occupants, the energy supplier and authorities.

1. Network services

The abundance of technologies that converge within the residence has created a path for the development of the smart home. Integration of telecommunications, information technology, e-commerce, smart appliances, control systems *etc*, results in systems that are categorised under the topic of home automation. The definition of home automation according to Bos and van Leest (2001) is "the combining of appliances, information technology and services inside and outside homes and residential buildings into integrated concepts optimally adjusted to the specific needs and behaviour of users".

Buildings are equipped with appliances, such as climate control systems, and devices for tap water heating, lighting and white goods. These appliances perform one or more specific functions and can be seen as tools for enhancing the quality of modern living. Appliances can be smart, such as a heating system that is equipped with a timer for night setback. Whereas the appliances themselves are increasingly becoming smarter, home automation appliances increase their capabilities by means of intercommunication (Bos and van Leest 2001).

When a set of appliances are interconnected and managed with one or more control units, a system has been created. This leads to the possibility of optimising the function of each appliance, while harmonising sets of functions by means of the controlled intercommunication. An example of this is when the previous heating system, still equipped with the timer, is interconnected to a home/away button of the security system. When the away button is activated during daytime, the security system is alerted and the setback function of the heating system is triggered due to the absence of occupants. Services may be activated from inside or outside the residential envelope.

Among the driving forces of home automation are companies within the telecommunication fields, e-commerce, energy suppliers and domestic appliance manufacturers. This has given rise to a wide range of protocols and standards in the market, of which none have yet dominated in the home automation marketplace. However, it is generally agreed that the Internet is a convenient media to link residences to the outside world and thereby access the service providers.

1.1 Grouping of network services

Network services can be classified into five groups (Aronsson and Tholén 2000):
Information services - such as news, databases, education, errands, citizen networks, online services *etc*;
Entertainment services - such as video-on-demand, music-on-demand, TV-on-demand and online games;
E-commerce services - providing shopping and business transactions;
Communication services - such as IP-telephony (telephony via the Internet), picture telephony, videoconferencing, telecommuting (makes home offices possible) and public electronic notice boards; and
Telemetric services – including the remote control of heating, ventilation and cooling systems, local weather forecasting, safety-related alarms, video surveillance *etc*.

1.2 Energy services

WP 2 focused on energy services that can be introduced within the telemetric group. However, this should not eliminate any of the other groups. For example, energy services provided to and from authorities may merely be informative, such as statistics on the energy consumption of the local building stock, or information on how to perform energy saving retrofits. Another possibility is the e-commerce sector providing new debiting systems in junction with real-time fluctuating energy prices. The link between the entertainment sectors and energy services explored within this project is the least evident. The only common aspect is that these services share the same hardware.

This appendix is structured in the following manner:

- identification of the actors involved and their interests within the smart homes sector;
- review of the state-of-the-art in energy services offered to smart homes;
- identification and quantification of the potentials for beneficial impacts;
- definition of monitored values that can be expected in future services, and the grouping of services on the basis of the actions required;
- suggestions for possible services from the viewpoint of different organisation types and benefits; and
- suggestions for services that may be implemented in the SmartHomes project's national test-beds to capture regional distinctions.

2. Actors involved

The service gateways, combined with new network technologies, creates opportunities for new energy services that will help utilities to load manage and residents to reduce consumption and possibly increase comfort. New energy services that are enabled vary from automated metering and billing, through the remote control of appliances and load management, to indoor climate control. Obviously, there are many opportunities as well as uncertainties here, leading to a clear need for design and analysis. As on-line energy services do not yet exist, their requirements have yet to be elaborated. Also, as services and technology are strongly linked, design decision about energy services and the associated system architecture cannot be decoupled.

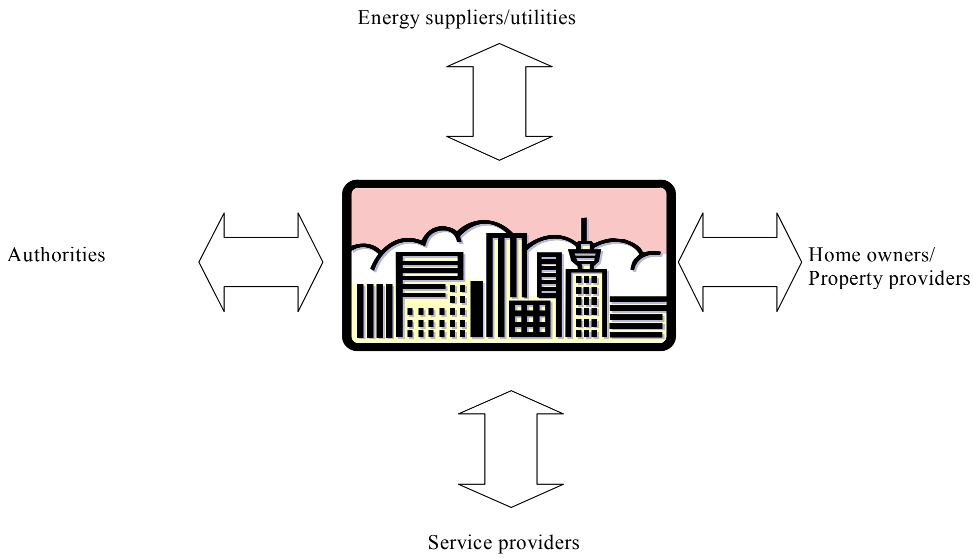

Figure 1: Actors meet at residences; development and use of telecommunications causes barriers between the groups and roles become more difficult to separate.

As summarised in Figure 1, potential energy services involve many different actors: home occupiers, local authorities, utilities, telecommunications companies, and new energy service providers. Consequently, the design of energy services requires a clear understanding of the role of each actor. To keep things simple, new energy services can be assigned to two actor types: service providers, which implicitly could be utilities, private sector companies, local authorities *etc* and customers. In addition, an energy service could be supplied by a utility to private companies, from private companies to local authorities and so on. The delivery of energy services may be expected to involve a wide spectrum of actors; six main groups can be identified:

- home owners/occupiers and their organisations;

- property owners/managers/maintenance operators;
- energy supplier and distribution companies;
- local and national authorities;
- service providers; and
- telecommunications operators.

While these groups are essentially homogeneous, the generalised interests and roles within each group may be both mutual and diverging when it comes to energy services. In the following sections, this issue is elaborated.

2.1 Home owners/tenants

This group is an important target, being end customers of supplied energy services. Research has indicated that this group has a limited awareness of energy issues: each occupant has scant knowledge of the topic and has little understanding about how to reduce consumption. In fact, a substantial part of the consumption is directly related to the habits of the occupants, without them knowing it. A change in the daily behaviour and habits may alone have a greater impact on energy consumption than changing a building's technical aspects through a retrofit. Home owners/occupiers may be members of organisations that capture and promote the common interests of members. These may be powerful organisations that lobby for change, especially to enact legislation. Better awareness of energy issues can be stimulated by several means as follows.

Informative campaigns

Increase home owner/occupier access to fuel consumption data.
Improved information about energy use activities.
Inform, in general terms, how energy consumption may be reduced.

Persuasive campaigns

Inform households about economic and health benefits.
Show the impact of energy consumption on the local and global environment.

Rating campaigns

Compare consumption with national and international benchmarks.
Benchmark comparisons based on consumption impact on the local and global environment.
'Punishment' or 'reward' based on benchmark scores, such as in taxation.

Being the largest target group, the acceptance of smart home concepts by home owners/occupiers is a crucial factor in the development of this market, which in turn will influence the provided services.

2.1.1 Occupant acceptance of smart systems and services in Greece

Homeowners, in general, appear to be attracted to new energy services, because they could pay less by reducing their energy consumption while also facilitating more control over their everyday life. This does not necessarily mean that they are ready to accept services that permit externally activated control actions. Instead, they prefer to retain control, arguing that third party involvement may affect their privacy and convenience. Wired and wireless solutions invoke alternative impressions. The former correspond to images of a home with cables running throughout, while the latter conjure up health concerns associated with radiation. Consequently, the prerequisite of service acceptance is reassurance on issues relating to privacy, security, health and convenience.

2.1.2 Occupant acceptance of smart systems and services in Sweden

Acceptance of home Internet connection is widespread. By governmental decree, the aim is to supply all homes with broadband connections within the next few years. Due to the recent recession in the IT sector and stock market in general, homeowner's demands for broadband have not been met. Even so, the concept of using the Internet is well understood and Swedes are among the global top three Web users. Homeowners, commonly living in single- or multi-family houses, are billed for consumed resources and services. Billing is relatively frequent (usually monthly) and accompanied by itemised breakdowns. Billing and payment via the Internet is becoming popular due to the convenience, speed and reduced cost (extra fees are applied to conventional transactions).

A smart home investigation in the single-family housing sector (Friedman and Malmberg 2001) concluded that security, entertainment and cleaning friendliness were rated higher than energy services. If given €3,000 to spend, the participants' ranked choices would be a balcony, a security system and a room thermostat. Above all, people want help with laundry and cooking, the majority requesting surfaces and layouts that facilitate cleaning robots. Some people identified thermal comfort as a higher priority than energy consumption

In the case of multi-family buildings, there are two occupant types:
- co-operative living societies where the occupant owns a share in the building (but does not own the apartment occupied); and
- tenants who rent the apartment from a property owner (the occupant may be a member of the Swedish Union of Tenants).

The occupants in the building commonly share consumed resource costs, which are included in the rent and determined on the basis of the apartment size relative to the whole building. This implies that individuals cannot affect their rent by consuming less energy for space heating and hot water (electricity for domestic appliances and lighting is often debited individually). For this reason the Swedish Union of Tenants is positively disposed toward the monitoring of individual apartments as a means to effect individualised debiting and communication (Nord 2001 and Berndtsson 1999).

In the public mind a smart home is a luxury since the technology is installed only in a few homes designed for high income customers or as demonstrations at future homes exhibitions. The concept of third party involvement is met with hostility.

2.2 Property owners/managers/maintenance operators

The property owner may or may not be the maintenance operator charged with the responsibility of managing the premises. The common interest is to manage the premises effectively. Though the occupant will pay for the energy consumed, it is in the interest of the property owner and maintenance operator to provide the possibility for the tenants to keep energy consumption low. Moreover, there are synergistic effects:
- minimising energy consumption reduces the tenant's overall costs;
- thermal comfort within the residence may improve;
- the property owner can, by means of benchmark scores, market the property as being more attractive;
- it is in the interest of property owners and operators to make correct choices on energy efficient appliances and gain the knowledge on how to operate these effectively;
- enhancement in the quality and reliability of the energy supply is beneficial to all parties;
- fault detection equipment facilitates maintenance before tenants notice problems;
- facilitated communication between occupants, property owners and maintenance operators is needed to identify problems and to agree solutions; and
- communication with authorities on reporting is facilitated.

2.3 Authorities and energy managers

From an authority's viewpoint, the monitoring of the energy consumption of large populations of buildings in real time becomes possible. Lack of information on energy demand and supply is a major obstacle to the development of a comprehensive regional energy strategy. The difficulty lies with the number of buildings—small gains in energy efficiency over many buildings are required to bring about a significant impact—and embedded generation options may give rise to problems with power quality of supply.

Fortunately, energy monitoring systems now exist that can be used to track performance at the large scale. Unfortunately, the deployment of these systems is problematic because there are no standard procedures for the collection of fuel use and environmental data, and for the analysis of these data in support of local energy action planning. Current methods by which local authorities access energy use data include low resolution information exchange with utilities, simplified modelling (such as normalisation of space heating with regard to climate) and energy audits. While such methods can give crude estimates of energy consumption, they are limited in their ability to support the formulation of local energy action plans and new energy services such as remote appliance control, orchestrated load shedding and property-specific energy advice. The concept of large scale monitoring provides data and statistics that provide a platform for identifying problems, give high resolution databases for analysis to bring forth actions to encounter problems and provide data for evaluation of the actions after implementation. Authorities dealing with social questions are able to initiate rapid actions against reliable information relating to health issues and fuel poverty. From a consumer viewpoint, it is not the statistics that are important but the possibility of raising an alarm.

2.4 Telecommunication operators and e-service providers

In a rapidly changing field, the roles of telecommunication providers and operators may be difficult to capture. The following sub-sections consider how the actors are identified and examines their current roles and how these may develop in future.

2.4.1 Roles in the business model

As shown in Figure 2, the actors can be divided into five groups within a so-called business model.

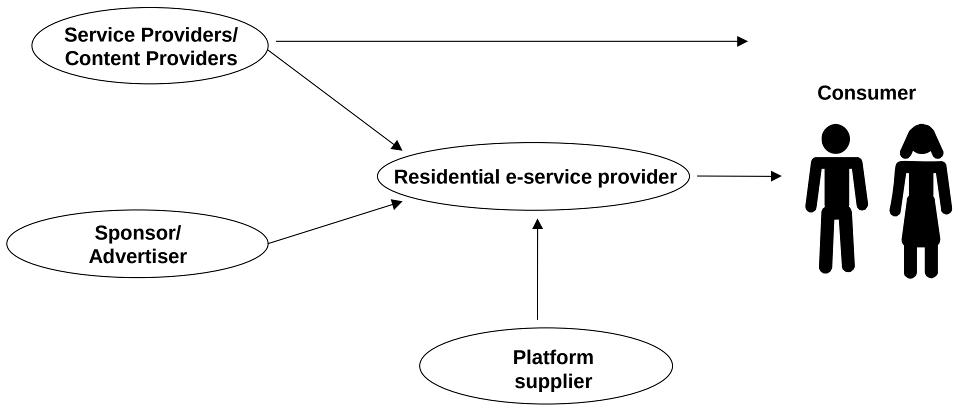

Figure 2: Actors in the chain of services in the business model.

The customer is the target of the service. The residential e-service provider acts as an aggregator of services and sells the residential e-service subscription to the consumer. The service/content provider can be a part of a service delivery from the residential e-service provider, e.g. an insurance company can give a reduction on the home insurance if the consumer subscribes to a security service. The service/content provider could also deliver a service directly to the consumer using the residential e-service provider's delivery system, e.g. a newspaper can transmit personalised information to a dedicated device in the home. The sponsor/advertiser uses the residential e-service provider as a channel for advertisement based on new personalisation capabilities. There are many players that could take on the role as e-service provider: players who will address the market in the short term include fixed access providers, virtual operators and portal/service providers.

2.4.2 Value and revenue flow in the business model

The flow of value and revenue within the business model are idealised in Figure 3 (these flows are quantified in Appendices 5 and 6).

Value proposition to the e-service provider

By providing a completely new set of services, and using the same platform, the e-service provider will be able to increase the attractiveness of the e-service offerings. While there may well be a high degree of service switching in future, once a home has been connected to a given residential e-service provider, and the family has learned to use the service, they will likely be reluctant to change.

Many of the services will generate traffic within the mobile network. For example, in the case of a remote home control service, secure content sharing will generate traffic when information is transferred between the home and mobile. Another important aspect is new service growth whereby the e-service provider is given the possibility to attract partners in order to develop new services for delivery via the residential e-service provider.

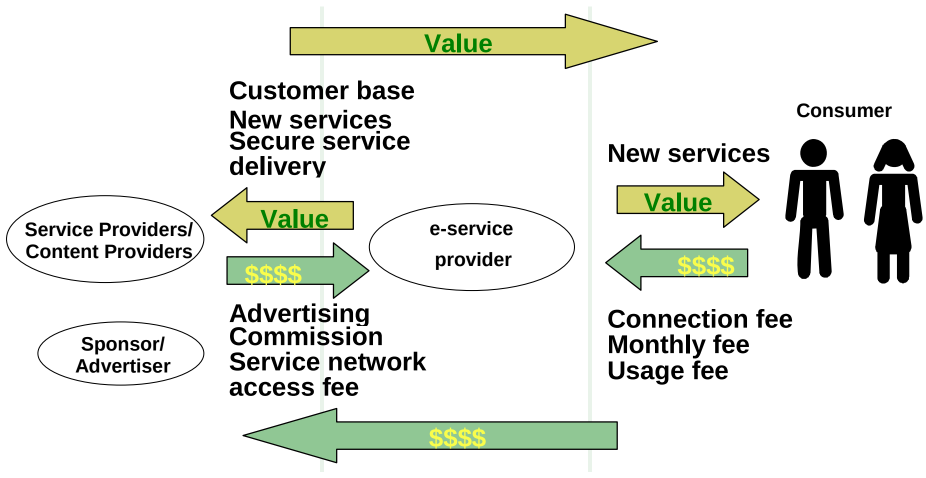

Figure 3: Value and revenue flow in the business model.

Residential e-service provider value proposition to the consumer
The e-service platform addresses the following needs:

- safety - peace of mind, securing the home;
- social - create family, friends and neighbourhood community;
- fun - sharing of music files, photos *etc*;
- time-saving - managing a part of everyday life over time and distance;
- cost saving - energy management and reduced cost for third part services; and
- empowerment - see, hear and act upon things, giving more flexibility and reduced anxiety.

The e-service provider can be compensated from the consumer in a number of ways, e.g. via a connection fee, monthly fee, usage fee or a combination of these. The cost of the hardware and software needed for the service delivery could be paid up front by the consumer, or be totally or partially subsidised by the residential e-service provider in exchange for a commitment from the consumer via a service package subscription.

Residential e-service provider value proposition to service and content providers
Service and content providers will get access to the e-service provider's customer base for service delivery. They will have the possibility to deliver services in a more efficient way and deliver new types of services using the e-service system, e.g. a music distributor can stream music to the consumer in a secure and controlled way, while a security company can provide interactive surveillance services. Furthermore, it is a secure way of delivering services to the consumer, by using the secure point of presence in the home (e-service gateway), thus ensuring that the right persons receive the service and that the service provider is paid by that consumer.

Due to the increased attractiveness and 'stickiness' of the residential e-service providers services as described above, the residential e-service provider portal will be attractive for advertisements and as a distribution channel for services. The partner can pay the residential e-service provider in the form of commission on service sales or a fixed fee for using the network. The consumer interface can be handled both by the partner or the residential e-service provider; the set-up is different between cases.

An access provider will have difficulties in sustaining their future profitability because there is a need for value-added services. Present access providers have significant advantages because the value-added is associated with aspects such as customer interfaces, billing, customer databases *etc*. All major operators have a network part, an access provider part (customer interface) and a portal. Mobile and fixed operations are also likely to merge, both from a service access point of view and from the portal point of view. An access provider could also be a virtual player (e.g. Virgin Mobile). Portals could also be in the form of companies with the sole purpose of providing content and services (e.g. Yahoo). There is also a trend in companies trying to bundle a number of services using their strong brand in order to be the preferred service provider covering all major consumer needs (e.g. communication, entertainment, electricity *etc*). While the access provider could be a telecoms or cable operator, it is important that the services are independent of the access provider to enable service differentiation by geographical region.

Market integration
It is clear that to bring forward viable e-services will require the integration of different markets as depicted in Figure 4.

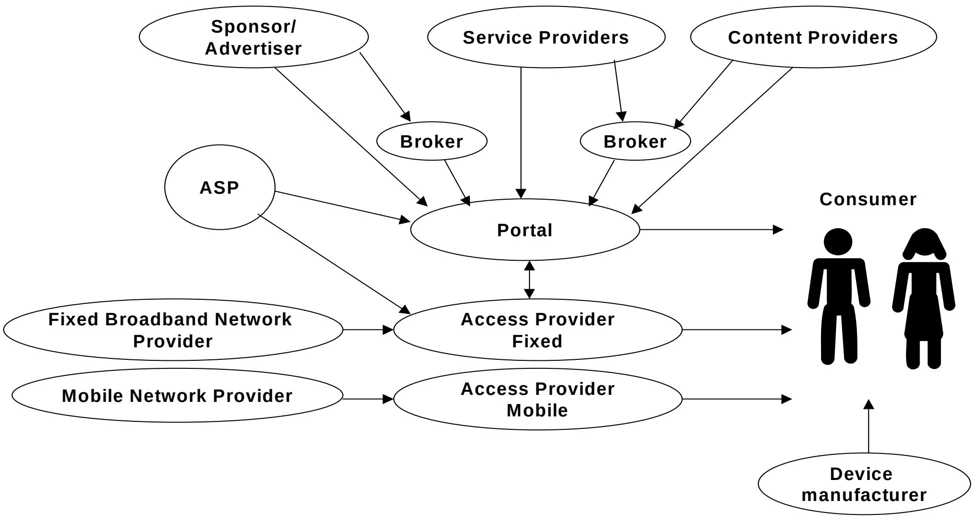

Figure 4: Integration of markets.

3. Energy use: yesterday and today
In order to propose services for tomorrow, it is necessary to undertake a review of the current state-of-the-art and detect which services are in practice today within so-called smart homes. Appendix 1 presents such a review while §5.5 presents the results from a literature review on direct load control. In light of the action plan to improve energy efficiency in the European Community (E.C. 2000), the review focuses on energy savings potentials.

3.1 Studies on energy use in related projects
This section serves to describe energy services that have been introduced and evaluated in full-scale demonstrations or commercial projects. The following questions are pertinent:

- What benefit does monitoring lead to?
- What role does information play?
- Which parts of energy consumption are directly affected by occupant behaviour or technical systems/services?
- The size of the energy saving?

When introducing the term energy use, it is important to identify where in the residence this quantity is utilised. Novem (The Netherlands Agency for Energy and the Environment) compiled a top ten list of domestic energy uses based on the energy use per unit time, time in use and market penetration in the Netherlands. In the following list, descending order means that less energy is used for that appliance (Bos and van Leest 2001):

1. climate control (central heating, boiler and ventilation);
2. hot water supply;
3. tumble dryer;
4. fridge and freezer;
5. lighting in houses and gardens;
6. washing machine;
7. computer and accessories;
8. audio/video;
9. stand-by use and chargers; and
10. portable air-conditioners.

In general, opportunities for energy saving also follow in the same descending rank order.

3.1.1 The energy management Eckernförde Tarif - a field study with real time pricing of electricity (Germany)

A project carried out between August 1994 and December 1996 in the town of Eckernförde in Schleswig-Holstein in the North of Germany studied the effect of informing residents about real-time electricity prices (Nyman 1998). One thousand participating households were equipped with indicators that were plugged into each electric socket in the residence. The current price level was informed by means of three red, three yellow and three green lights on each indicator box, thus dividing the complete price range into nine different bands. As electricity prices varied over time with the electrical power network load, residents were continuously informed to make choices on using domestic appliances.

The results from this study were that 80% of the households obtained reduced electricity costs by using Eckernförde Tarif and that each household reduced the network load by an average of 100W. Since the participants consumed a minor portion (4%) of the electricity supplied to the town, there was no possibility to significantly influence the load and the price. The indicators were well accepted by the users.

3.1.2 Distant reading of heat, electricity, water and gas (Germany)

In Berlin, the companies Doktor Riedel Automatisierungstechnik GmbH and Techem AG, supported by the German Ministry for Science, Research and Technology, evaluated an automation system for heating control. This system also remotely records the hot/cold water and gas consumption (Nyman 1998). The benefits are:

- a real-time measurement of the separate utilities;
- annual energy savings of 20-30kWh/m^2.yr;
- reduced facilities management costs because the system can diagnose problems in the heat supply and inform the facilities manager, leading to rapid remedial response times; and
- an increased attractiveness for the apartments, which attain better comfort levels.

3.1.3 Klockarbacken - experiences after installation of individual metering (Sweden)

Huge Bostäder AB (1998), a Swedish real estate management corporation, has installed individual tap water, electricity and space heat metering in 73 apartments situated in three buildings in the Klockarbacken area. Prior to individual metering, the rent was based on total costs, which were shared by the residents on the basis of apartment floor area. Now, the rent comprises two parts: one that is fixed according to certain marginal costs (such as space heating of corridors), and another that is set in proportion to an apartment’s energy consumption. After 3 years, the energy consumption decreased by 37% relative to the total number of multi-family dwellings within the district managed by Huge Bostäder AB. The average water consumption in Sweden is approximately 500l/day and in an apartment 182.5m^3/yr. In the Klockarbacken area, the average is 170l/day (62m^3/yr by apartment). The three targeted buildings have lower energy consumption than neighbouring buildings, which have more modern installations and are better insulated. The newer buildings still use the old debiting system. The most reasonable explanation for this is that energy consumption is dependent on end-user habits, which are influenced by the debiting form.

3.1.4 Experiences on individual metering (Denmark)

Denmark recently imposed obligatory individual heat metering. Equipment was installed in 25 multi-family buildings (1,551 apartments) during 1995-8. A comparison between energy consumption prior to, and the first year after, installation showed a reduction of 15% (from 152 to 128kWh/m^2.yr). Individual metering of hot water was not implemented although this is included in the total value. In 16 of the buildings, measurements for the second year show a reduction of 20% to 122kWh/m^2.yr. The range was 11-30% (Berndtsson 1999).

In the community Albertslund, the decrease in district heating was approximately 15-17% after implementing individual metering. In some buildings, the decrease was as high as 30%. The rate of decrease seems to depend on the information delivered to occupants: it takes about two years for the effects to come through (Gullev 1999).

3.1.5 Descriptive and informative bills (Norway and Sweden)
In Norway, Wilhite and Ling (1994) investigated the relationship between billing information and household energy consumption. Up to 1,450 households participated at survey commencement (1989), while 1,286 remained at closure (1992). The findings were that more informative bills resulted in a 10% energy saving. Pyrko and Norén (1998) concluded that "feedback during energy efficiency programmes can reduce heating energy demand by approximately 3-9% and electricity consumption by 7-21%".

3.1.6 Potential energy savings on behalf of end-user behaviour (Sweden and The Netherlands)
In Sweden, Louise Gaunt (1985) conducted a study, 'Living habits and energy', concerned with occupants' influence on energy consumption in electrically heated single-family homes. The study showed that energy consumption depends not only on geographical location, orientation, construction and outside temperature, but also the lifestyle of the occupants. The hot water consumption was a large part of the total energy consumption, with showering habits and dishwasher usage contributing most to usage. As an example, Gaunt refers to a difference of 4,500kWh/yr between families who shower the most and the least. The average energy consumption within the study (87 Swedish households) was 20,500kWh/yr. The average water consumption (hot and cold) was 200m^3/yr. The conclusion was that between 10 and 20% of the annual energy consumption could be saved in single-family houses on the basis of changed user behaviour. As much as 80% of the variation in energy use is due to end-user behaviour.

In the multi-family buildings of the co-operative living society Åsagården in Lund, Sweden, a pilot project for individual space heating debiting was performed during 1995-6. Manual readings of radiator meters were undertaken that demonstrated a potential to reduce energy consumption by 10% (Berndtsson 1999) through individual billing and awareness raising.

Research by Novem indicated that an energy saving of 10-20% can be achieved by the adaptation of consumer behaviour (Bos and van Leest 2001).

3.1.7 The Second University Project (Sweden)
At the beginning of the 1980's, the Swedish government commenced the Second University Project (Elmroth *et al* 1989), which aimed to evaluate the efficiency of government loans and subsidises for residence retrofitting. Experimental and theoretical evaluation of energy conservation measures was performed on statistically selected projects that made use of the subsidies. The results were based on measurements before and after retrofitting during the period 1982-6 in approximately 300 single- and multi-family houses in 7 municipalities. The results are displayed in Table 1.

Weekly energy consumption data were used, together with indoor and outdoor temperatures. The static Energy Signature model was used to derive the heat loss coefficient of each apartment. Descriptive technical information was used together with default values to determine a range of energy performance parameters. Energy savings were evaluated as the difference between the energy consumption before and after retrofit as evaluated from the experimental and theoretical approaches.

Table 1: Results obtained from retrofitting actions within the Second University Project.

Retrofit type	Building type	Saving in relation to energy consumption prior to retrofit	
		Measured	Predicted
Triple glazing	Single family	6 %	10 %
Retrofit package	Single family	19 %	25 %
Conversion to electric heating	Single family	22 %	20 %
Triple glazing	Multi family	9 %	10 %
Additional insulation of	Multi family	5 %	6 %

attic			
Regulating package	Multi family	4 %	3 %
Retrofit package	Multi family	14 %	16 %
Conversion to district heating	Multi family	24 %	15 %

Energy savings due to heat pumps in single-family houses were 40-60% in comparison to energy consumption prior to the installation. The results showed that

- energy conservation measures gave statistically significant savings although savings in some cases were small;
- in most cases the measured savings agreed with theoretically predictions; and
- an expected indoor temperature decreases with some retrofits was not observed.

3.2 Energy services in commercial smart home projects

There have been a number of commercial smart homes projects in Sweden. These are described in Appendix 1 and elsewhere (Nord 2001) and are reiterated here with the focus on the energy service provided. All buildings were equipped with broadband access.

Although the energy service listed below in the group ‘lighting scenarios’ is not explicitly an energy service, there may be cases where electricity is saved. Also, lighting scenarios with the purpose of fooling burglars may increase the use of electricity. Another aspect considered is the possibility of accessing external climate data. Though the climate station may not be in use for energy optimisation purposes, its existence opens up possibilities for future energy services. Alarm functions in terms of security are not explicitly considered to be an energy service. However, surveillance systems that recognise that doors or windows are open when the resident has left may be used to avoid increased energy use for space heating or cooling. Other alarms are dedicated to internal climate variables and are considered to directly relate to energy use and thermal comfort.

3.2.1 Poseidon (Sweden)

This is a multi-family complex in Gothenburg, under the supervision of the real estate management company Poseidon. It offers the following energy services (Hagström 2000):

- *Away button* - this shuts off the water supply and the electricity to some sockets, and activates an alarm system. It can be used from the Internet or from a WAP mobile telephone, but only for shutting off.
- *Individual tap water and space heat metering* - consumption is shown directly on a display in the flat or on the Internet and is given both in kWh and in monetary units. Statistics for the consumption can be obtained for different periods. The tenants pay for their own water consumption and for the indoor climate they choose.
- *Weather station* – the local weather is monitored and statistics for different periods can be obtained from the Internet.

3.2.2 Mölndal (Sweden)

In Mölndal outside Gothenburg in Sweden, the world’s first series-manufactured so-called intelligent house has been built. All installations are supervised by a system based on the EIB protocol (Hansson 2000):

- lightning scenarios;
- home unit (heating and lighting control at a distance)
- remote unit;
- heating control;
- safety alarm;
- close doors/windows service; and
- energy metering.

3.2.3 Skogsbo (Sweden)

In the outskirts of Gothenburg, Sweden's first intelligent residential area of 39 terrace houses has been built. The base package contains individual tap water and space heat metering, a Web camera in the parking lot, a weather station, broadband, Intranet *etc*. There are also a number of intelligent services/functions connected to an EIB-bus (Reiland 2001):

- *lock service* - control of windows and doors before leaving home, including the (de)activation of individual lamps and sockets;
- *remote appliance and lighting control* - to turn on/off sockets remotely;
- *individual metering* - of electricity, municipal district heating and hot/cold water;
- *weather station* - to provide information and statistics on the local weather via the Internet; and
- *charging* - the energy supplier Hemel provides the residents with a breakdown of the services on a monthly basis.

3.2.4 The Tango house (Sweden)

The city of Malmö held an exhibition called Bo 01 (May to August 2001) with the focus on buildings of today and tomorrow. The Tango house comprises luxurious apartments with the following energy services:

- *lighting services* - for different fixed lighting scenarios;
- *room thermostats* - to enhance local thermal comfort;
- *an alarm system* – comprising a climate alarm (humidity and temperature), burglar alarm, fire alarm and sabotage alarm (the electronic hardware is protected); the system can be activated, but not deactivated, from the Internet;
- *a log system* - statistics about climate, temperature, door passage and alarms;
- *an away button* - which turns lights and other devices on/off;
- *weather station*; and
- *individual metering* - of cold and hot tap water and space heating.

3.3 Conclusions

The modern smart home projects considered above include buildings that are equipped with on-line capabilities. The collection of data on energy use and climate is not a problem; all cases offer individual metering and have access to weather station data. Furthermore, most cases allow the resident to perform remote actuation of processes, especially that of lighting control, which is mostly used for security reasons. The most substantial energy services that have appeared in the projects are the following:

- individual metering of cold and hot water and space heating;
- individual room thermostats;
- home/away button that includes reduction in set-point temperatures, reduced ventilation rates and automatic shutdown of certain lights and electric sockets (and in some cases water);
- remote actuation of appliances via WAP mobile phones and/or the Internet; and
- display of resources that have been consumed over a selected period of time.

Though the systems can collect immense amounts of data at high frequencies, there is little that is being done with this data other than applications for debiting and displaying of energy consumption. There is no processing of data to provide a value-added service, e.g. offering information on building condition, indoor air quality, or energy use in relation to similar buildings or benchmark values. Nor are there cases where climate stations are actively used for weather forecasting purposes for anticipatory control application. This lack of data processing after collection opens up the possibility of introducing new energy services to residents, local authorities and utilities. Perhaps the best conclusion on the energy services subject is formulated by Bos and van Leest (2001):

> "*As services based on home automation are in their early development stage, there is yet little to say about their positive influence on saving energy. In the Netherlands the main drivers in the domestic service market are housing corporations, power companies and companies that provide e-commerce. The main challenge is to encourage these service providers to develop energy efficient services. Examples of possible services are feedback to households on their*

(present) status of energy use and substitution of existing functionalities by services such as laundry services replacing the domestic use of washing machines or grocery service replacing the daily visit to the supermarket. Finally, consumer behaviour relating to the choice and use of services will determine energy demand."

From an energy conservation viewpoint, the use of smart systems implies savings but it is difficult to distinguish what parameters are influencing the values. On the one hand, the habits and behaviour of the occupants can be affected and consequently have an impact on energy use. On the other hand, technical properties of appliances and systems can also be manipulated and lead to energy saving. In particular, the tuning of appliances during/after systems installation may be a main contributor to energy conservation.

The Second University Project concluded that energy conservation due to retrofitting was not obvious, since this resulted in possibilities to increase comfort by omitting energy savings. This is generally called the 'rebound effect', which can be traced in energy efficient buildings: improved building performance may lead to larger energy consumption than expected. The saving potentials of influencing habits and behaviour of the occupants may give some 10 - 20% in energy saving (see §3.1.6), figures which are of the same magnitude as those of technical retrofits. This aspect should not be forgotten in the light of proposed new energy services.

Bos and van Leest (2001) have identified three levels of home automation that give opportunities for saving energy (Table 2). Energy savings have not been quantified, but the authors show that technical approaches and changing end-user behaviour are key factors for establishing energy saving.

Table 2: Opportunities for saving energy at three levels of home automation.

Level	**Opportunities**
Appliances	Reduce energy use of appliances. Adapt consumer behaviour.
Systems	Reduce energy use of systems. Increase energy efficiency of heating, ventilation and lighting by smart control. Adapt consumer behaviour.
Services	Development of energy efficient services. Substitution of existing functionalities by energy efficient services. Consumer behaviour.

The end-users of energy, in this case occupants, are the main target group. To affect their behaviour, the following points must be considered:

- comprehensive interfaces to ease access of information and controls;
- information to generate energy awareness;
- economic incitements, such as energy savings and energy supply quality;
- environmental incitements, both in the internal and external environment such as thermal comfort, air quality and quality of energy; and
- convenience by providing services that ease daily chores.

4. Relevant variables within energy services

The selection of which parameters are to be monitored is dependent on the nature of the energy service and *vice-versa*. This section presents a list of parameters that influence energy use and introduces some definitions.

4.1 Various energies

Energy is the central consideration in the SmartHomes project. The following sections define various energy entities. The variables chosen for monitoring will depend on the requirements of the service and to whom the service is directed.

4.1.1 Purchased energy
A main purpose of the SmartHomes project is to focus on energy use, especially energy flows that can be monitored. Purchased energy is that supplied to the building in question. However, this is seldom supplied for one function only. Within a building, energy is distributed and allocated to the various groups, the so-called *specific energies*:

- space heating;
- space cooling;
- appliances;
- lighting; and
- tap water heating.

In the case of monitoring supplied energy (fuels), the energy from one source may be distributed among the specific energies mentioned above. The converse also applies where a specific energy may have contributions from various sources. Within a building, it is necessary to distinguish between gross and net energy. Gross energy depicts the quantity prior to being supplied to the energy conversion system. Fuel quantities are examples, where the supplied gross energy corresponds to the equivalent heat content of the fuel. Net energy is the equivalent energy that is delivered from the energy conversion system. Heat delivered from a boiler, via radiators, is an example. The relationship between gross and net energy is the thermal efficiency of the energy conversion system. By paying attention to these two quantities, the overall performance can be monitored over long time periods.

4.1.2 Heat gains
This term refers to the heat supplied into a building from all sources excluding the heating system: occupants, lights, domestic appliances and solar energy. Occupants generate heat depending on metabolism and the temperature of the internal environment. Domestic appliances and lights dissipate heat, though this is not their prime function. Solar energy is transmitted through apertures. Aside from energy for domestic appliances and lighting (usually electrical), all other gains are not purchased. This implies that the solar energy supplied to the building is normally not monitored. While the solar gain through fenestration is regarded as a heat gain, other solar inputs should be regarded as non-purchased supplied energy.

4.1.3 Heat losses
Whereas previous sections have dealt with energy that is supplied to the building, the sum of the net supplied energy, which is not recovered, will leave the building by various routes. Transmission losses denote heat that is transmitted from the internal to the external environment through the envelope of the building. Ventilation losses corresponds to air-borne heat that is transferred from the ventilation system to the external environment. In the case where the ventilation system is mechanical, exfiltrating air (air leakage loss) should be minimised. Waste water loss corresponds to water-borne heat from sanitation systems. Finally there are losses due to energy conversion systems inefficiencies. The sum of transmission and ventilation losses is, for the heating season of a building, proportional to the insulation level and ventilation system efficiency. The heat loss coefficient indicates how large the losses are in relation to the temperature difference between the internal and external environment.

4.1.4 Heat flow rate
Rate of heat flow (power) is of special interest to energy suppliers and distributors. The term is associated with capacity (and hence the capital cost of plant) and is a dominant parameter that affects spot prices. During peak load periods, generation and distribution capacities may set limits to the quantities that are momentarily supplied, with the problem that supplied energy does not meet the demand. In order to avoid unnecessary consumption during these critical periods, load reduction is desired. Two types of strategies are used:

- energy suppliers and distributors remotely limit supplied quantities, or make use of time switches at the supplied site; and
- tariffs are applied that motivate occupants to manually or automatically reduce demand.

4.2 External climate variables

The local micro-climate has a considerable influence on energy consumption. Further, such micro-climates vary over short distances especially in coastal regions. In response, local climate stations may be required in addition to official climate stations: such a decision will depend on judgements about the expected climate deviations and the cost of installing and operating a local weather station. Influential weather variables are

- dry bulb temperature;
- solar radiation (commonly measured as global and diffuse on a horizontal plane);
- wind speed and direction (officially at 10m height above a field);
- air relative humidity;
- long-wave radiation;
- precipitation; and
- snow coverage.

In most applications, the first four variables are considered to be more influential. In northern countries, temperature completely dominates energy use during the heating season. In southern countries, solar radiation plays a central role for most of the year. Air humidity is important during months requiring space cooling.

For some e-services, weather data will be required for a reference or average year. Such data is used to normalise the conditions that the building is subjected to in order to determine an energy consumption figure for use in benchmarking.

Aside from purely weather-related variables, there are other environmental variables that must be monitored. These are often linked to human activity and can be detrimental to living forms at high concentrations. Examples include:

- CO and CO_2;
- NO_X and SO_X;
- smoke; and
- gas leaks.

4.3 Internal climate variables

These dictate the quality of the internal environment in relation to comfort and air quality. Principal variables include:

- dry bulb temperature;
- air relative humidity;
- various comfort temperatures and indexes (e.g. PMV);
- surface temperatures (measured by thermocouples and IR cameras) ;
- air velocity;
- CO_2 concentration;
- VOC and other air contaminants;
- luminance.

The list can be longer. However, it is primarily the first two variables that influence energy use. The other variables require sophisticated monitoring equipment. CO_2 measurements may be required for some e-services since it is an indicator of both occupant presence and indoor air quality.

4.4 Monitoring and actuation

Energy services can be assigned to one of two categories depending on the presence of a home control system. Presuming that the monitoring scheme is the same in both categories, the difference lies in whether or not appliances can be remotely controlled.

4.4.1.Remote monitoring of various resources and other variables

Auto metering, and the remote monitoring of energy use and indoors parameters, enables many e-services:

- real time and time of use pricing of electricity;
- real time and time of use measurement of consumption;
- alarm for malfunctioning equipment;
- alert for adverse indoors conditions;
- display of individual current consumption;
- information and statistics;
- estimation of energy efficiency;
- advice on energy actions, e.g. savings that arise by changing the temperature set point; and
- information on ventilation requirements.

4.4.2 Remote control and actuation of appliances

Home networking, automation and control offers all the aforementioned energy services. Furthermore, it enables more refined e-services. The remote actuation of appliances can be initiated by occupants as well as services providers (Figure 5).

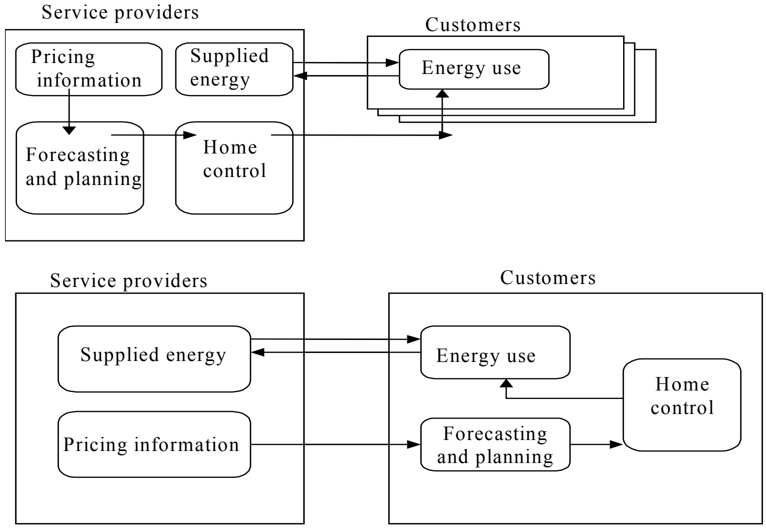

Figure 5. Two different control schemes: remote appliance control performed by a service provider (upper) and appliance control managed within the residence (lower**).**

5. Possible energy services

There are many possible e-services. This section describes these when arranged in four categories: information services, monitoring, services that make use of monitored values, and services that involve actuation.

5.1 On-line information

The simplest energy service that may be provided over the Internet is purely informative. Within this context, there are two ways that information can be obtained:

1. *one-way communication* - the customer seeks information that is available on the Internet, e.g. the Web sites of local authorities and utilities.
2. *two-way communication* - the user can interactively communicate with an authority, organisation or company, e.g. the user poses a specific question that is answered by a specialist; two-way communication also enables the monitoring of process states and consumed resources with feedback and remote actuation.

The role of information in influencing occupant habits has previously been stressed. In addition to this, occupants' and maintenance operators' understanding and interaction with technical appliances are also crucial. The Internet is a tool for accessing information provided by various service centres. Several suggestions follow on how information may be directed to users and how this may be made possible by one-way (1) or two-way (2) communication. The information providers may be a local authority (A), energy supplier or other service provider (E).

- Stimulate users' awareness on energy issues and give reasons why this is important; 1/A.

- Show the links between energy use and the local/global environment; 1/A.
- Give general advice on energy consumption reduction and improved building performance; 1, 2/A, E.
- Provide specific/general solutions on how to obtain and operate energy systems efficiently; 1, 2/A, E.
- Help the user with energy -related appliances choices; 1, 2/A, E.
- Inform customers about energy labelling; 1/A.
- Present statistics, experiences and outcomes from energy-related projects and tests on building products; 1/A, E.
- Present energy efficient and economically beneficial alternatives during planning stages for retrofits; 1, 2/A, E.
- Give feedback on an individual's domestic energy consumption; 2/E.
- Support textual information exchange with utilities; 2/E.
- Present benchmark values for user comparisons; 1/A, E.
- Promote regional and national energy strategies; 1/A, E.
- Allow contact with organisations or companies that are actors within the field of interest; 1/A.
- Provide information on momentary tariffs, fuel availability and quality; 1/E.
- Optimise appliance operation schedules (e.g. washing machine, dishwasher) with respect to the instantaneous price of energy; 2/E.

Such information may be proffered by a vast number of actors. Information, which from the user's point of view is trustworthy, might come from local authorities, tenant and homeowner organisations and national boards for customer policies. This does not eliminate the credibility and role of utilities - on the contrary, within the new deregulated energy market, the quality of customer services becomes more important. The tendency is for utilities to broaden their service range to attract and retain customers. The present problem is to find the right information for the right purpose.

5.2 Monitoring with alerts and alarms

Within any control system, there exists a sensor, the role of which is to capture the state of a process. Furthermore, buildings are equipped with meters of various types. Some buildings already have security systems with alarm functions. By allowing signals from these devices to be transferred on-line, an effective monitoring scene arises. Stand-alone devices and systems can be interconnected via the Internet and services can be provided based on:

- *Monitored values* - to inform on the state of processes or consumed resources. Statistics may also be used for optimising conditions, for forecasting, or merely for timely reporting. Monitoring does not require the system to be connected on-line at all times but only when data transfer is required.
- *Alert functions* - to perform timely actions against malfunctioning conditions or processes. Alerts may not always require immediate actions, which means that the on-line connection is not needed continuously. Nor are delays in Internet data transfer critical.
- *Alarm functions* - to perform immediate actions against malfunctioning conditions or processes. From an analysis of statistics, measures can be taken to minimise the occurrence of critical conditions. A requirement is that the system be connected on-line at all times, or when the function is required. Due to failures in the Internet-based infrastructure (system crashes, delays or power failures), it is likely to at least have a local alarm backup system.

Within the field of home automation, the monitoring aspect becomes a natural ingredient. From the literature, it is clear that the feedback of monitored data is present in most smart home projects. As for alarms, the monitoring phase is also present, since the function of the alarm is to indicate critical performance states.

5.2.1 Services of interest to occupants

Monitoring with feedback to occupants takes two-way communication to a higher level. The effect of information, especially the feedback of information on consumed resources, has been shown to change occupant behaviour and save energy. However, the saving of energy is not the only benefit of this type of service: consideration should also be given to health and safety aspects.

Alarms

- Detection of gas leaks and smoke in sensitive areas (boiler rooms, garages or in buildings situated in the vicinity of industrial areas), or humidity and pollen (important for asthma sufferers).
- Detection of open windows to prevent burglary and air leakage.
- Detection of mains water flow (emergency signal where a water leak is detected).

Alerts

- Checking for appliances and lights that were inadvertently left on.
- Resource targeting to alleviate fuel poverty (monitoring of temperatures and fuel consumption in local authority housing).
- Cold alarm for the elderly to avoid hypothermia.

Statistics

- Indoor/outdoor air quality monitoring.

Optimisations based on statistics

- Counting hours in-use of various appliances with automatic prompting for regular/emergency service.
- Evaluation of heating/cooling energy consumption for different internal temperature set-points as a function of the present external temperature.
- Services and strategies related to weather forecasts (heating, night cooling, grass watering, use of rain water *etc*).
- Operation of the heating or air-conditioning system taking account of the presence/absence of occupants.
- Remote switching of various appliances based on statistics (heating, ventilation *etc*).
- Automatic anti-freezing regimes for heating systems enabled during the long-term absence of occupants (taking into account weather conditions).

5.2.2 Services for maintenance by operators/property managers

Alarms

- Alarm signal for the failure of any devices or systems for quick identification and action.
- Detection of mains water flow in abnormal situations characteristic of a leak.
- Detection of adverse indoor climate including fire.

Statistics

- Instantaneous demand of energy, water, gas *etc*.
- Energy consumption.
- Measurement and control of quantities such as temperature and humidity.
- Automatic reading of delivered energy streams for invoicing.
- Automatic reporting of actual or normalised consumption statistics to authorities.
- Occupant response (after feedback) to operator control interventions.

Optimisation

- Optimisation for remote on-off switching of various appliances.
- Optimisation of heating/cooling system operation with respect to weather forecasts.
- Optimum operation of solar heating systems, PV components, rain water usage *etc*.
- Application of statistics to the prediction of energy demand (different regimes, maximum and minimum demand *etc*).

5.2.3 Services for energy management

Statistics

- Environmental monitoring.
- Planning resources and networks on the basis of energy demand monitoring.
- Short text information exchange with the population.

- Monitoring of building occupancy.
- Services related to weather conditions.
- Energy and water consumption in public buildings.
- Collection of community consumption data for reporting to national authorities.
- Application of statistics in predictions of demands and behaviour of consumers.

5.3 Energy metering

Individual monitoring of energy consumption permits the tracking of consumption per apartment in multi-family buildings serviced by only one meter. Further, it is possible to separate out the energy used for space heating/cooling, domestic appliances/lighting, and hot water. The enhanced resolution can be used to create occupant awareness on energy use by allowing comparisons with benchmark data for the neighbourhood and nationally. Occupant interest may be conveyed through statements such as "why is the billed value for hot water so large?" and "can anything be done to reduce it?". While individual energy monitoring can be considered as a unique service, it is also an important component of other services.

5.3.1 Legislative considerations

EC 93/76/EEG aims to reduce the emission of carbon dioxide to mitigate global warming. Article 3 deals with the sharing of costs for space and water heating and air conditioning in buildings in order to reduce energy consumption and gaseous emissions:

> "*Member States shall draw up and implement programmes on the billing of heating, air-conditioning and hot water costs calculated, in proportion, on the basis of actual consumption. These programmes shall enable the cost of these services to be apportioned among the users of all or of a part of a building on the basis of the specific quantities of heat, of cold water and of hot water consumed by each occupier. This shall apply to buildings or part of buildings supplied by collective heating, air-conditioning or domestic hot water installation. Occupants of such buildings should be enabled to regulate their own consumption of heat, cold or hot water*."

The decree need not become national law but is merely a recommendation to Member States. Other actions can be taken to fulfil the requirements for reduced CO_2 emissions. Any emissions reduction must be evaluated against the costs of any required monitoring installation.

The energy conservation potentials associated with individual metering and debiting have been estimated at 15-20% relative to space heating; for domestic water heating, the savings are larger at 15-30% (Berndtsson 1999). Such predictions imply a vast energy conservation potential at the national level. Though there are few countries where individual metering is legislated, the tendency is in that direction. Germany and Switzerland, for example, have applied individual metering in multi-family buildings for some time and, since 1999, France, Austria, Spain and Denmark have announced similar intentions (Berndtsson 1999).

Since monitoring is the central feature within a smart homes concept, debiting is an important tool for controlling and reducing energy consumption. In this case, the energy service will comprise monitoring integrating with a debiting model. Traditionally, the argument against individual monitoring has been the cost associated with equipment, meter reading, debiting control and documentation distribution. In an era where electronic equipment prices are dropping, and communication capacity inflating, individual energy metering will likely gain ground.

The following two sections present debiting models for space heating. The idea is that the occupants can choose the type they prefer or mix elements of both.

5.3.2 Cost sharing on the basis of heat

Heat that is supplied to an apartment is commonly measured by one of two means:

- The quantity of heat is measured in a legitimate way, e.g. each apartment might have heat supplied to one physical location prior to distribution within the apartment.

- Radiator metering is common in Europe, where electronic sensors are fitted to each radiator to measure the heat dissipation as a function of radiator temperatures. Remote readings can be taken via radio communication.

In an investigation on aspects concerning individual space heat metering, Berndtsson (1999) came to conclusion listed in Table 3.

Table 3: Advantages and disadvantages of individual debiting on basis of supplied energy.

Disadvantages	Advantages
Thermal measurements are due to installation costs and not always economically motivated.	Measurements are made for heat, which is logical if debiting is by heating requirement.
Heat exchange between apartments means that neighbours can ‘steal’ heat, e.g. where indoor temperatures are high for health reasons	Radiator metering is possible in all cases.
Occupants can reduce costs by manipulating ventilation systems and reducing flows. This may cause health problems and damage to the building. Tuned ventilation systems are essential with fair heat metering.	Venting gives larger costs.
Erratic envelope components and air-tightness increase costs for the occupant. Property owner encouragement to repair is decreased.	Insolation, heat from appliances and other internal gains reduce costs.
Correction of monitored values to have a more fair heating cost distribution is difficult to grasp; the occupant’s motive for energy conservation may weaken.	Techniques for heat monitoring with radiator metering are established and there exist DIN and CEN standards for the monitoring equipment.
In mechanically ventilated buildings with pre-heated air, some apartments may receive more free heat than others.	

5.3.3 Cost sharing on the basis of internal temperature

An alternative is to cost share on the basis of the measurement of room temperature (as a proxy for thermal comfort) within the apartment. An evaluation of positive and negative aspects is displayed in Table 4 (Berndtsson 1999).

Table 4. Advantages and disadvantages of individual debiting on basis of indoor temperature.

Advantages	Disadvantages
To share heating costs on basis of internal temperature (thermal comfort) that the occupant chooses may be accepted as a fair method.	Venting has bearing on all occupants with larger costs for those who do not vent.
There are no motives for the occupants to manipulate the ventilation system.	Heat from insolation, appliances and other internal heat sources increase temperature and can raise debited values.
Heat exchange between apartments does not affect debiting.	There are no European standards on requirements of monitoring instruments.
Local erratic envelope components (insulation and air-tightness) do not increase costs from heating point of view. The property owner has an interest in correcting the problems.	In the case where technical systems are required to avoid heat loss by venting, the maintenance cost will rise.

5.3.4 On-line services for individual debiting

These will require the involvement of several actors and the co-ordination of distributed databases, with debiting performed via the Internet. Figure 6 gives an example of the data/resource flows.

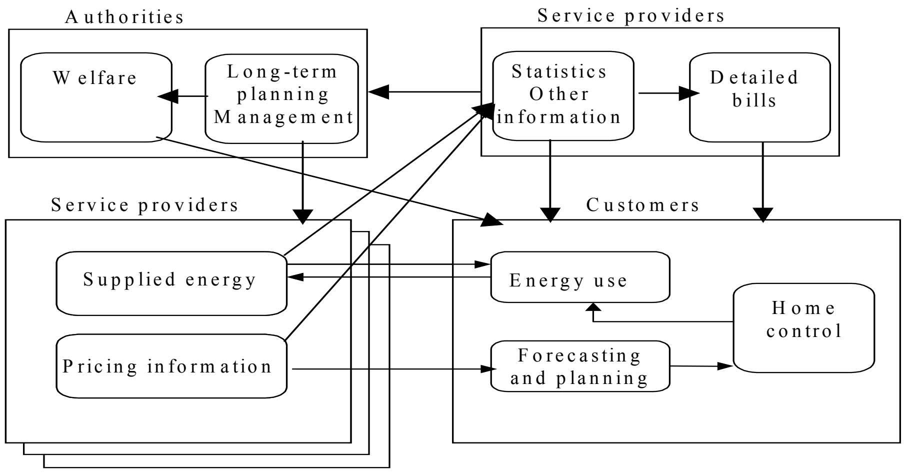

Figure 6. On-line debiting scheme.

5.4 Performance evaluation: benchmarking, rating and certification

Benchmarking is a common way of rating commercial products while certification is where the performance of a product is tested. These principles can be applied to buildings with energy consumption as the comparator. Benchmarking is here illustrated by reference to the SAVE EuroClass procedure.

5.4.1 EuroClass energy rating of residences

Instead of relying on bills to gather information on energy consumption, an on-line connection eases the process and provides better resolution. The service itself is then the rating scheme. In addition to data acquisition, an audit is required to assess the technical aspects of the building (areas, volumes, orientations, shading, efficiency of energy conversion systems *etc*) and occupant habits. This information is needed to normalise the values that have been measured for the actual period. The techniques for deriving normalised data are listed in §5.3.

A special feature of EuroClass is that the residence is rated, i.e. the physical building including appliances and the influence of the occupants. Therefore, the same building with different occupants will likely give different scores. The scores can be used to analyse energy use. Scores are obtained for (Álvarez and Falcon 2000):

- The total performance during a normal year but with actual indoor conditions and household energy use (i.e. the building including effects of occupants). Differences between normalised values can indicate the influence of external climate where the recorded energy consumption gives obscure values. This value can also be put in relation to the building stock that is subjected to the same climate conditions.
- The total performance during a normal year for ‘standard’ occupants (i.e. the building including effects of standard occupants). The real occupants can then be informed about their energy efficiency relative to an idealised case.
- Scores are obtained in the same manner with specific energy consumption.

The service would require service providers with authorisation to perform the audit, the processing of data and certification delivery.

Another application in parallel with this service is the reporting of energy consumption to local authorities. Automatic energy consumption data can be delivered to satisfy statutory reporting requirements and other routine reporting. For example, UK local authorities have a statutory obligation to provide housing sector data to government. In the case where data are to be normalised with regard to external climate, the normalisation procedures of EuroClass are, for milder climates, likely to give more accurate results than traditional degree-day compensation. With on-line concepts, the resolution will contribute to a better normalisation than data based on monthly, seasonal or annual data processing. Moreover, reports will be more timely (e.g. in Sweden data is compiled at the national level one or two years after the consumption).

5.4.2 Encouraging competition

For the case where a home's current energy use is made available on-line, the average consumption of similar homes in the neighbourhood can also be provided to create competition. Scrambling schemes can be deployed to make the presented values anonymous and thereby ensure information confidentiality. Moreover, for the case of individual metering, national/regional benchmark values can also be provided to further stimulate and incentivise the occupant. Climate-dependent entities may be normalised to indicate how weather changes explain variations in household energy consumption.

5.4.3 Detecting trends in energy use

On-line buildings may be few, yet information from these buildings can be applied to the building stock as a whole by means of statistical scaling techniques (Högberg and Norlén 1991, Högberg 1994). If the monitored building types are members of a particular property type then their performance, presuming that numbers are adequately high, represent all properties of this type. What is needed, aside from the sensors and access networks, is an audit that quantifies the numbers and location of each building type. In this way timely energy consumption data and load profiles for vast regions can be obtained and actions executed without delay.

5.4.4 Regional emissions mapping

At the regional scale, the (anonymous) energy consumption of a monitored building can be located on a GIS map, accompanied by information on the fuel types used, estimated emissions *etc*. This will assist local authorities to quantify air pollution and develop local energy action plans. Where only a few buildings are monitored in an area, statistical scaling factors may be applied.

5.5 Information embedded in monitored data

Long term monitoring of a building enables the estimation of the heat loss coefficient. This quantifies the thermal quality of the building envelope and the efficiency of the ventilation system. By separately measuring the ventilation rate, the envelope-only heat loss coefficient (UA-value) can be determined as an input to decisions on fabric upgrading. Given a target heat loss coefficient, predictions can be made of the likely energy savings against reference climate data.

Services to house owners

- Information on the quality of the building envelope and efficiency of the ventilation system.
- Predictions on space heating requirements against different upgrade options.
- Changes in energy use against variations in external climate.
- Heat loss coefficient derived comparisons with benchmark values.

Services to maintenance operators/property owners

- Impact of alternative load control strategies.
- Appraisal of retrofitting plans.

Services to authorities

- Information on buildings with poor thermal performance.
- On-line tools for the appraisal of upgrading options.
- Evaluation tools to consider subsidies for building retrofits.
- Check that new buildings fulfil national building code requirements.

Utilities

- Dynamic load control.

5.5.1 The Energy Signature method

This method has been introduced in many countries and comprises a statistical method for the estimation of the heat loss coefficient. The method is commonly used to estimate energy consumption. Based on energy measurements, the model extrapolates building energy performance over the long term. Measured energy consumption is statistically regressed against climate data (Westergren and Waller 1998, Westergren *et al* 1999):

$$E = (c + b \cdot \Delta\theta) \cdot T + f \cdot I + d \cdot P \qquad (1)$$

where E is the annual total energy use (Wh), T the length of the heating season (h), P the length of the non-heating season (h), c a temperature independent rate of energy consumption (Wh/h) during the heating season, d a temperature independent rate of energy consumption (Wh/h) during the non-heating season, b the gross heat loss factor of the building unit (W/K), f the solar aperture of windows (m^2), $\Delta\theta$ the mean sampled temperature difference between indoors and outdoors (K) and $\bar{I}$ the average sampled solar radiation (Wh/m^2). The terms c, b, f and d are 'energy parameters' and have specific values for each building.

Physical interpretation of the energy parameters

The energy signature method is a black-box approach and gives limited information on how energy is consumed. However, vital information can be gained if the energy parameters are interpreted. The gross heat loss factor of the building (W/K) is

$$b = \frac{\sum_{i=1}^{n} (U_i \cdot A_i + \psi_i \cdot \ell_i) + 0.33(1 - \eta_{vent}) \cdot n \cdot V}{\eta} \qquad (2)$$

where $\sum_{i=1}^{n} (U_i \cdot A_i + \psi_i \cdot \ell_i)$ is the heat loss factor of the building envelope, including the effect of thermal bridges (kW/K), n the average rate of air changes (h^{-1}), V the enclosed volume of the building unit (m^3), η the efficiency of the heating/cooling systems (-) and η_{vent} the efficiency of air handling systems (-).

The winter factor, c, is climate independent and primarily related to the number of occupants and their behaviour:

$$c = \frac{E_{hot\ water} - E_{persons} - E_{domestic}}{\eta \cdot T} \qquad (3)$$

where $E_{hot\ water}$ is the energy required for heating of domestic hot water, $E_{persons}$ the metabolic energy from occupants and $E_{domestic}$ the electricity for domestic appliances.

The summer factor, d, has the same formulation as eqn (3), compensated for the length of the summer season. The solar aperture, f, takes into account solar irradiation within the building energy balance (consideration is in cardinal directions d):

$$f = \frac{\sum_{d=1}^{4} (1 - s_d) \cdot T_d \cdot A_d \cdot I_d}{\eta \cdot I_{ann}} \qquad (4)$$

where s_d is the shading factor of the external environment (-), T_d the transmission factor of the glazed part of the windows (-), A_d the glazed area of the window (m^2), I_d the solar radiation onto the window surface (Wh/m^2) and I_{ann} the average global radiation onto a horizontal surface at the geographical location of the building (Wh).

The gathering and processing of data

Given the solar radiation, I, the length of the heating and non-heating seasons, T and P, and the number of degree hours, $\Delta\theta \cdot T$, the energy parameters can be determined by regressing energy consumption with outdoor climate. The part of eqn (1) that is climate dependent involves the first two terms on the right-hand side. By setting the $d \cdot P$ term aside and dividing the remainder of the expression, a new formulation is obtained which gives the average energy use per unit time, w (kWh/h), during the heating or the cooling season. An error term ε is added such that

$$w = c + b \cdot \Delta\theta + f \cdot s + \varepsilon \ . \tag{5}$$

This is a static model, which is valid provided that the observation period is long enough for the net heat stored in the building to be negligible compared to the total energy supplied during the period. With observed data on energy consumption, w , temperature difference, $\Delta\theta$, and solar irradiation, s , the parameters c , b and f are estimated by linear regression. If the error value, ε , is excessive, more complicated models may be applied.

To estimate the total heating energy use during a normal year, eqn (1) is used with external climate data for a normal year. A confidence interval can be obtained, the width of which depends on the number of observations and on the variability of the data during the observation period. To increase accuracy, the measurement periods should be chosen such that

- the temperature differences and the solar irradiation vary as much as possible; and
- the average temperature difference and average solar irradiation are as close as possible to those of the normalised year.

5.5.2 The UA and gA method

Somogyi (1998) developed a model to estimate the heat loss coefficient for transmission (UA-value) and for solar gains (gA-value). Calculations can thereafter be performed to generate normalised energy consumption. The following excerpts are from a publication by Wouters and Loncour (2000). The following inputs are required over a 20 - 40 day period:

- daily average values of internal and external temperature;
- daily average solar radiation;
- estimation of window shading;
- estimation of the ventilation rate (via the passive tracer gas method or pressurisation method in combination with the LBL model);
- daily energy consumption; and
- estimation of the building heat capacity.

System identification is then performed whereby parameters of a resistance-capacitance (RC) model, as presented in Figure 6, are computed. The output is an estimation of the UA- and gA-values in combination with their confidence interval.

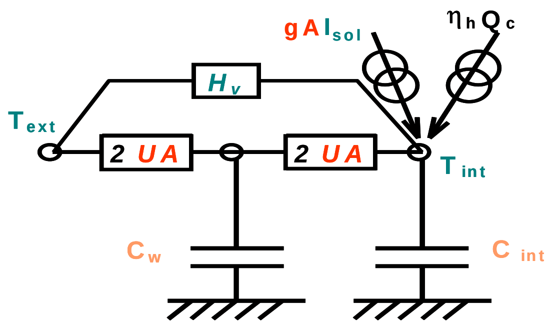

Figure 6: Example of the RC-system used for system identification.

Within the approach, a correct estimation of the confidence intervals is important. A Monte-Carlo approach is applied whereby, for each input variable, a probability function is estimated. Hundreds of data sets are generated (Figure 7) comprising the UA- and gA-values with their respective confidence intervals.

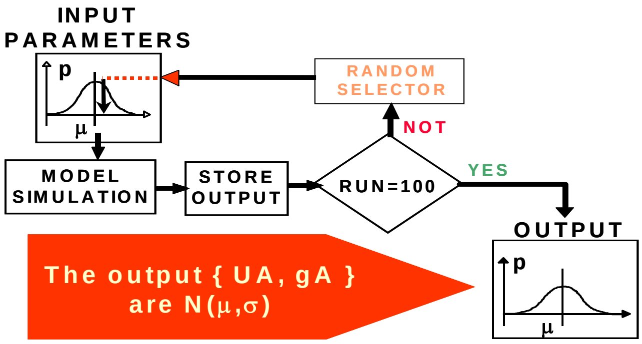

Figure 7: Concept of Monte-Carlo approach for error analysis.

In practice, large confidence intervals and high correlations between the UA- and gA-value sets are observed. The latter indicate that it is not possible to make accurate estimations of individual UA- and gA-values. Instead, a normalised energy consumption is determined, which estimates the annual energy consumption for a standard year and for fixed indoor conditions (Figure 8).

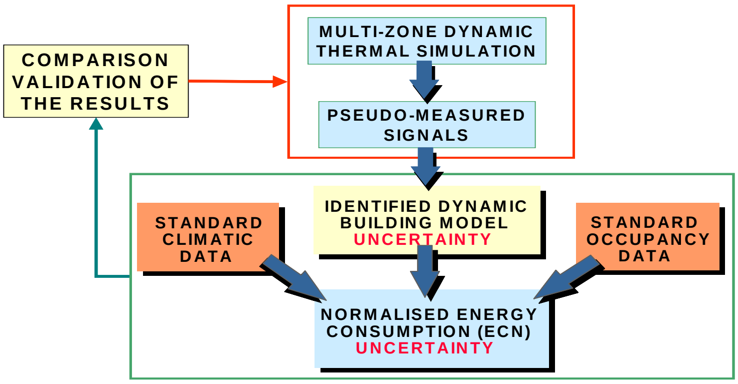

Figure 8: Determining normalised energy consumption and confidence intervals (colour original).

Conclusions

- The on-site measurement of U-values is possible. A European standard (prEN 12494) is available and describes the required procedure.
- A reliable identification of the UA- and gA-value in non-occupied buildings is difficult due to the high correlation between the two parameters. As a result, the confidence intervals on both parameters is often large. Moreover, it is often not possible to estimate ventilation losses with reasonable accuracy.
- Instead of individual UA- and gA-values, it is easier to identify the normalised energy consumption.
- In the case of occupied buildings, there are several additional problems (uncertain internal gains, influence of occupants *etc*), which increases the uncertainty in the identified normalised energy consumption. In occupied buildings, it is not possible to identify the UA- and gA-values with reasonable accuracy.
- The relative accuracy is typically worse in better insulated buildings, worse in warm climates and worse for short measurement durations.

5.5.3 Neural Network method

Being a black box method, neural networks are not designed to give information on physically meaningful parameters. However, research has shown that the heat loss coefficient can be assessed, as demonstrated by Olofsson and Andersson (1999, 2000a) using a backward propagated neural network model for single-family dwellings. The model can capture the change in ventilation rates due to increased buoyancy forces during cold weather periods. This is difficult to achieve using the Energy Signature method.

In terms of energy use prediction, the neural network does not explicitly make use of the heat loss coefficient: it is embedded. This makes it difficult to perform design calculations that aim to study energy conservation measures prior to implementation. A positive aspect is that a new model can be realised after the retrofitting actions. This can be taught on-line when the retrofitted building is again in use. After a short tutoring period, the new model is subjected to reference climate data and a comparison made between the results from the old and the new models to highlight the retrofit impact.

A general drawback with the utilisation of neural networks is the complexity of model training. However, Olofsson and Andersson (2000b) have claimed that once an outline model has been created, arrangements can be made for the network to train itself. With smart homes technology, the possibility exists to achieve this on-line.

5.5.4 Conclusions

The models described above are often utilised in connection with individual buildings. Several support requirements and beneficial application may be identified as follows.

- Collected data can be used to extract an estimated value for the total heat loss coefficient.
- By performing measurements on ventilation flow rates, the heat loss coefficient for transmission can be assessed for use in retrofit planning.
- The overall heat loss coefficient can be used to determine the normalised energy consumption for benchmarking purposes and national statistics.
- Prior to determining the heat loss coefficient, an audit has to be performed to assess building characteristics and appliance efficiencies.

At the larger scale, aggregate information has the potential to contribute significantly to energy management and planning:

- With knowledge of the heat loss coefficient, weather-based energy use forecasting is possible. By co-ordinating the information from different areas, district requirements can be anticipated. This process may be assisted by neural network models, which do not require knowledge about the heat loss coefficient.
- Prediction against forthcoming severe weather allows energy suppliers to better regulate the supply network and target supplies to those consumers with the greatest need.
- Plans for new power generation may be informed by high resolution load data.
- Accurate values on normalised energy use can be reported in real time.
- Retrofitting actions can be targeted to districts with poor energy efficiency.

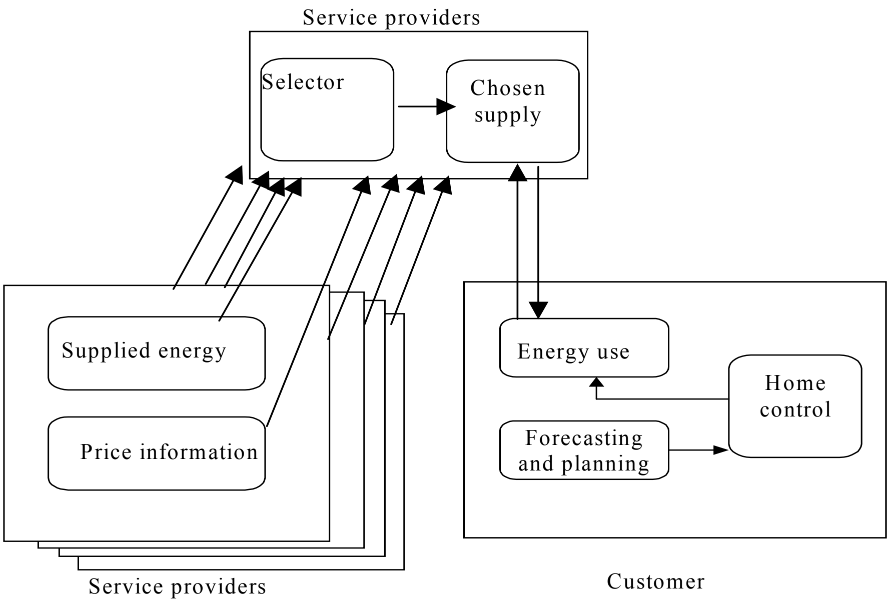

Figure 9: Scheme for selection of the lowest tariff.

5.6 Tariff surveillance

With the deregulation of the electricity supply market, customers are free to choose their supplier. The customer is then committed to the supplier for the contracted period. By means of gateway technology and high frequency data acquisition, the possibility of supplier trading is enabled. For example, a virtual supplier might act as a contract broker, continuously selecting the lowest tariff to provide best value to consumers (Figure 9). Of course, such an approach will give rise to new technical issues. For example, if the power source with the lowest tariff is greater than the instantaneous demand, how will the other sources be handled especially with electricity which cannot be economically stored. Such a structure can also support customers who request low carbon energy sources.

A more modest service is to optimise the operational schedules of domestic appliances with respect to the instantaneous electricity price. Several scenarios are possible:

- Fixed schedules based on constant prices during prescribed periods with appliances manually or automatically controlled.
- Remote control of sockets by suppliers during periods of low supply availability.
- Restriction of appliance usage to periods when prices are less than a contracted maximum.
- Manual operations of appliances on the basis that instantaneous prices are displayed locally.

The use of tariffs is often beneficial for both the end-user and supplier, if operation is optimised. Tariffs are devices to create an inducement for load shedding: energy is cheaper during low load periods and higher during high load periods. For the energy supplier, the largest costs are associated with plant and distribution capacities that must be available to meet peak demands. The benefits of load shedding are not obtained at the small scale but at the large aggregate scale: this renders the smart homes concept a potent idea.

5.7 Direct load control

Direct load control occurs where an energy supplier controls part of a building's heat and electricity use. This may involve space heating systems, domestic water heaters and ventilating systems, as well as selected small power devices. The trend towards energy market deregulation makes load demand more interesting because of the cost reductions that can be realised by the production and distribution companies. In a deregulated market with energy spot prices, direct load control can be justified on purely economical grounds: load reduction is enacted during high price periods and 'pay-back' loads are regained during low price periods. From the supplier's viewpoint, a large number of buildings must be connected to effect significant savings. While infeasible today, the trend is evident (Pyrko and Qvistbäck 1994). Different actuator types are presently marketed, the primary aims being enhanced thermal comfort, reduced energy use and pressure alleviation of the distribution and supply networks. The possibilities of load control depend on occupant acceptance.

5.7.1 Review of direct load control projects

Load control is dependent on a wide range of factors, such as external climate, building characteristics, HVAC system type, set point temperatures and thermal comfort requirements. Experiences on direct load control are recounted below to illustrate the order of magnitude of load reduction that can be achieved. Harrysson (1987) studied the removal of loads in electrically heat single-family house from peak (6 -10 pm) to off-peak (10 pm - 6 am) periods. The results are listed in Table 5, with the recommendation that load reductions should not be greater than 50-75%.

Table 5: Amplitude of indoor temperature for different levels of load reduction (excludes consideration of insolation, external temperature variations and furniture).

Load reduction during peak period	Amplitude of indoor temperature at -15 ºC	at 0 ºC
100%	8	4
75%	6	3
50%	4	2
25%	2	1

In a project conducted by the utility company Vattenfall AB, load actuations were made in 64 electrically heated villas built in the 1970's (Johansson and Ejeklint 1990). The conclusion was made that it is possible to conduct load shedding to achieve a 50% load reduction over 3 hours when the outdoor temperature is -25ºC, without affecting the indoor temperature to the extent that occupants feel discomfort. The largest decay was 2.3ºC and the load reduction was estimated to be 3kW per house. In the same project (Wesslén 1991), two *rundstyrningssystem* were tested in 263 pair and row houses. The results showed a load reduction of 1.6kW per house. For outdoor temperatures down to -5ºC, a three hour shutdown of the heating systems led to a 1ºC drop in the internal air temperature.

Energy supplier Sydkraft AB's investigation of 38 single-family houses showed that the power supply can be reduced over one hour without causing comfort problems. The total power reduction was estimated at 3 - 4kW per house, including tap water heating (SEU 1989).

Result from a load-shedding test in houses with air heating (and day set-back of indoor temperature) showed large temperatures in the morning (up to 26ºC): the occupants were dissatisfied with the resulting thermal comfort. No results were presented on power reduction (Andersson 1991).

Pyrko and Qvistbäck (1994) presented the results from simulations of three single-family buildings:
- When actuating heating systems in single-family houses, an increase/decrease of indoor temperatures of 3-4ºC for 3-4 hours is acceptable to the occupants.
- The maxim reduction in loads that can be obtained due to the actuation of heating systems (1-4 hours and maximum indoor temperature drop of 4ºC) is shown in Table 6.
- The pay-back load is more than twice the size of the ordinary load requirement. After long actuation periods, the heating demand can last for 10 hours, while the air temperature returns to its original state after a few hours.
- Energy conservation varied between 5 and 27kWh per set-back period for different combinations of house heating/ventilation system.
- During set-back periods, temperature differences between zones may reach 3ºC.

Table 6: Computational results for load reduction in three Swedish single-family houses.

1964 house	1983 house	1991 house	Outdoor temp.
~5.5 kW	2.5 - 3.0 kW	~2.5 kW	0 ºC
5.5 - 7.5 kW	2.5 - 4.5 kW	3 - 4 kW	- 10 ºC
5.5 - 10.5 kW	2.5 - 6.5 kW	3 - 5.5 kW	- 20 ºC

ScottishPower is already using power-scheduling strategies via load tele-switching technology. This enables control of electrical storage heaters and wet electric boilers. Two systems are available:
- *Storage heating Comfort Plus* - a weather forecast storage heating system. Charge periods are controlled by means of tele-switching and weather data. The changes are load scheduled and fit into the generation capacity to improve the load curve.
- *Direct heating boilers Economy2000* - an interruptible tariff where supply to an electric boiler is cut over an hour within a 24 hour period (to facilitate generation requirements).

Table 7 summarises the results from the literature review.

Table 7: Summary of the literature review on district load control

Project	Load reduction period (h)	Load reduction (%)	Outdoor temp. (ºC)	Indoor temp. drop (ºC)	Load reduction (kW)	Saving (kWh)
Harrysson*	16	50-75	-15	4-6	n.a.	n.a.
Vattenfall AB	3	50	-25	< 2.3	3	n.a.
Vattenfall AB	3	n.a.	-5	1	1.6	n.a.
Sydkraft AB	1	100	n.a.	n.a.	3-5	n.a.

Pyrko,Qvistbäck*	1-4	100	0, -10, -20	< 3-4	2.5-10.5	5-27 per period

* based on simulations; n.a. = not available

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5.7.2 Possible services

Load control in the building can be exercised either by the occupant or an external party. Who will exercise the control will depend on the customers acceptance of the external influence.

Occupant load control

This service allows the occupant to exercise load control both locally and remotely. Various scenarios can be envisaged, with some already in commercial practice (see §3.2):

- *A home/away button* - upon leaving the residence, space-heating loads are reduced (e.g. by instigating a new set point temperature). Ventilation systems may be shut down completely, or reduced to minimum levels according to national building codes. Domestic water may be shut off, including water heating. Prescribed electrical sockets may be disconnected from the electricity supply.
- *Remote actuation* - the occupant may use the Internet or a WAP mobile telephone for remote actuation. Integration with remote readings of zone temperatures allows load control together with manual control of thermal comfort.
- *Optimisation services* - on the basis of measured temperatures, load profiles and fuel tariffs, a service providers may act to minimise energy use during high load periods. The optimisation criteria will include reduced heating/cooling costs without degrading comfort.

Direct load control by energy suppliers

In the case where load control is automated and remotely actuated by a third party, there must be a contract between the service supplier and the occupant. This might include:

- time schedules where the load reduction duration and time of day are fixed;
- maximum allowable temperature drops/increases;
- tariffs for relevant periods; and
- agreed actions under acute conditions (such as freezing).

On-line capabilities offer new perspectives for direct load control. Communication with appliances is eased and an immediate feedback on building response to control action is enabled.

6. SmartHomes country-specific services

Within the present project, the national test-beds have facilitated the study of energy services that are of particular interest to the four national contexts. These services are listed in the following sections where some background is also given on the national situation.

6.1 The situation in Greece

In Greece, Public Power Corporation is the utility that is predominant in the energy market. It operates almost all power plant and is responsible for the transmission of electricity throughout the country against a growing demand (from 80kWh/person in 1950 to 4,000kWh/person today).

There are two alternatives with regard to pricing: standard pricing throughout the day, or diminished pricing at night. The latter requires the installation of an extra meter and is implemented during eight hours per day, either continuously (23:00-07:00) or segmented (15:30-17:30 and 02:00-08:00), and from November through April only. In either case, pricing is implemented through standard tariffs for the different consumer types.

With the deregulation of the energy market in February 2001, the Regulatory Authority of Energy has begun to issue licenses to other companies. As production prices fluctuate over the day, so the price of the distributed energy fluctuates as well. Hence, financial incentives exist for utilities to compete and add value by, for example, managing the operation of appliances where appropriate. This time-of-use energy load management can realise significant savings for both the utility and customer.

The PETZETAKIS Company, which is the largest manufacturer of plastic pipe systems and flexible hoses in Greece, announced in February 2001 a new product, SmartDom^{TM}. This is an integrated cabling and tubing system for buildings supporting the connection of voice, data, TV, security and control. It has the potential to offer users the followed services:

- Internet and satellite Internet;
- ISDN services;
- TV and satellite TV;
- e-commerce;
- video conference;
- tele-banking;
- security and remote surveillance;
- distributed video and audio; and
- energy management.

Other companies involved in energy management and control, such as building services contractors and building management system suppliers, are potential energy services providers.

E-services
An energy service of particular relevance to Greece is cooling control during summer months. The growth in sales of domestic air conditioning units between 1990 and 1996 is shown in Figure 10. As can be seen, more than 100,000 units per year have been sold, representing an increase of 100MW per year. This is equivalent to a new power station of 300MW capacity every three years. Figure 11 shows the monthly peak electricity consumption profile for Greece: space cooling has an important impact on the peak power demand profile.

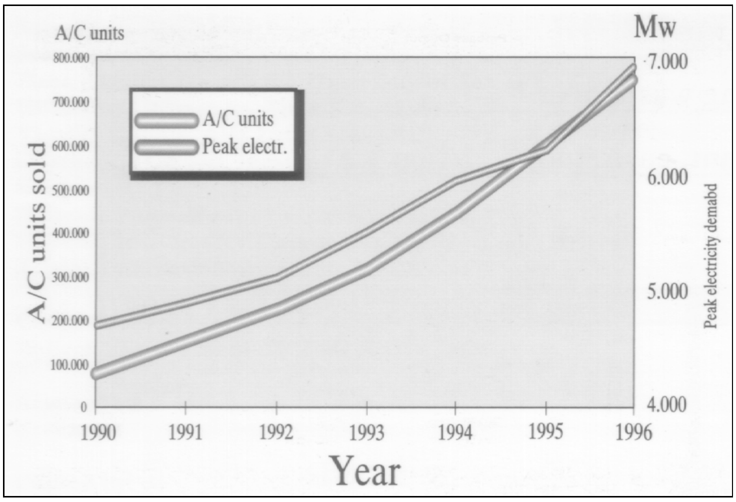

Figure 10: Cumulative number of room A/C units sales in Greece

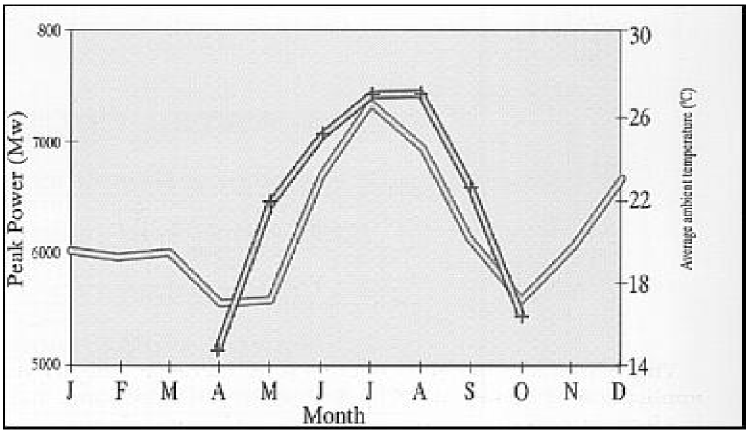

Figure 11: Peak electricity load and average ambient temperature per month in Greece

During the cooling season, the highest peak power demand (July) is approximately 7.3GW, while the lowest peak is 5.5GW during April to May and October when no cooling is in operation. It may be deduced that the increase is due to the operation of cooling units. It is estimated that the impact of cooling is around 1.8GW of peak power demand, representing the necessity to operate an addition six power plants of 300MW each during the cooling season.

The remote control of cooling units at the large scale provides the means to effect orchestrated energy management and load shedding, and thereby minimise the need for new plant and the danger of power cuts.

6.2 The situation in Scotland

There are a number of factors in Scotland, and more generally in the UK, which are driving the greater emphasis on home e-services.

Health-related energy services.

In the UK, there are 30,000 deaths per year from hypothermia and cold-related illnesses. Monitoring the temperature of the internal environment of homes will indicate when room temperatures drop to levels deemed a health hazard. A 'cold alarm' product is promoted by ScottishPower for installation in the homes of elderly people who can suffer from hypothermia if there is a malfunction of the heating system or where the system is not operational for reasons related to fuel poverty. The device monitors room temperature and provides light and acoustic alarms if the temperature drops below pre-defined limits. Such a device could readily be adapted for Internet connection to also raise an alarm with Local Authorities Social Services Departments. An extension to carbon monoxide monitoring, where elderly people use gas appliances, could be a useful related service.

In addition, there is a legacy of poorly maintained local authority housing and there are plans to improve such housing with extensive refurbishment programmes. For example, Glasgow City Council has transferred 80,000 homes to a Housing Association as a means to implement major refurbishment, taking the opportunity, where possible, to gather information on energy consumption and indoor temperatures in order to monitor fuel poverty. Fuel poverty exists in 35% of the Scottish housing stock with 8% (178,000 homes) suffering from extreme cases. Clearly, an alleviation initiative would benefit from automatic data gathering to supply information to health care, social services and housing departments.

Energy services

There is a legal requirement for local authorities to devise and present energy efficiency plans for the houses in their area. A significant problem in complying with this requirement is the difficulty with information collection. Technologies such as SmartHomes could revolutionise monitoring and provide local authorities with the means to routinely develop and appraise their energy and environmental strategies.

Utility services

Utilities are looking for ways to enhance their supply-demand matching capabilities in order to improve their operational efficiency. ScottishPower, for example, have associated significant efficiency and cost benefits with the better matching of supply to demand; a topic that will grow in importance as intermittent renewable energy sources gain more prominence. The information gathering (temperatures, loads) and control possibilities (preferential tariffs for customers allowing utilities to control certain appliances) fostered by smart homes technologies could play an important part in establishing a future supply and distribution network.

6.3 The situation in Sweden

In a series of interviews, Lena Nord (2001) sought to capture the trends within the smart home area. The market is expected to increase within the next five years although some pessimism remains. Prior to the new millennium, optimistic voices predicted an imminent boom. This optimism has now subsided and been replaced by more conservative predictions of up to 20 years before e-services will be commonplace.

While it is agreed that today's technology is capable of delivering e-services, there is a problem of price: systems are considered to be too expensive to install in existent buildings. Costs will be significantly lower in new buildings where systems are implemented during construction. Most commentators agree that the range of available services is limited and offer little value to customers.

The tendency within Sweden is for traditional energy suppliers to expand their activities to become general suppliers. For example, Stockholm's Energi AB has been divided into two sub-companies: one in charge of delivering energy to residences, called Hemel, has already broadened its services to include service provision. An indication of the present low interest in energy services is that Sweden's largest energy supplier, Vattenfall AB, has sold its smart homes division with an intention to review the market in 2004. Another leading company in the smart homes area sold its energy division to a rival company because the market interest was too low. Only pensioners showed an interest in energy conservation issues; families could not afford the systems and had other priorities.

Studies of 'fair' debiting models
In Swedish multi-family houses, energy consumption costs are shared by the occupants on the basis of apartment floor area. Individual metering gives the possibility to implement new debiting systems to fulfil Article 3. However, there has been lively debate on whether or not individual debiting is worthwhile. For the existing stock, installation costs may be greater than €700/apartment (excluding VAT), while the annual administration cost is estimated to be some €30/year. The inducement to install monitoring systems from an economic viewpoint may be weak. For example, the gains for buildings that are newer than 20 years are limited since energy conservation possibilities are limited. For older buildings, which consume more energy, the potentials are larger.

Work is being done to combine heat and temperature debiting by creating a computational model that, on the basis of measured variables, will estimate the heat that is transmitted and shared within the building. Andersson (2002) has performed parametric simulations for three building types to estimate the quantities of energy that are transmitted between apartments. The next step is to apply this model for correcting heat debiting.

6.4 The situation in the Czech Republic
About 60% of dwellings are within apartment buildings and almost 1.4 million flats are located within prefabricated housing blocks. The latter are equipped with hydronic heating systems supplied from centralised systems (hot water, exceptionally steam). The systems are operated by private companies of various size. These operators control the output of the boiler plant: one boiler normally supplies several blocks of flats. Individual users maintain their indoor thermal environment by thermostatic valves located on radiators.

The users obtain information about the heating energy consumption once a year when they receive an annual statement. The operators are informed on-line about energy consumption but do not receive feedback on the level of thermal comfort being attained, i.e. they have no data on the quality of the service they deliver. The consumption of heating energy for individual buildings is normally read once a year and the heating costs are proportionally distributed between occupants using consumption indicators or according to calculation methods based on the floor area and position of individual apartments.

Heating costs are subject of continuous debate as the price of heating energy becomes a more significant part of the occupant's overall budget. The price for heating energy rose by more than 30% over the period 1997-2002. The SmartHomes technology can help occupants to improve their understanding of the relation between their actions and heating energy costs and to assess their performance relative to other consumers. For the system operators it would be interesting to monitor the indoor environment and energy consumption, to obtain data in support of their supply/demand matching procedures and to use on-line fault detection at the level of individual systems. On the other hand some resistance against the introduction of SmartHomes technologies can be expected due to the relatively high installation cost and, perhaps, the perception that on-line monitoring may affect privacy.

Within the national test-bed, the indoor thermal environment and air quality (air temperature, relative humidity, CO_2 concentration) has been monitored together with the presence of occupants in apartments. Through the SmartHomes system occupants receive information about their own indoor environment and about their energy demand compared to other users (i.e. if it is below or above the average). Further, the remote monitoring and control of the heating systems has been performed at the level of individual buildings.

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Appendix 3: Work Package 3, Laboratory prototyping

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1. Introduction

The main aim of this WP was to specify the technology components of the SmartHomes system (sensors, actuators, e-gateway, e-service centre and database) and to test the entire system under laboratory conditions. A second aim was to devise a demonstration system for educational purposes.

2. Sensors and actuators

After a review, sensors and actuators were selected from the Mikroklima company because this offered the required functionality, an acceptable price and good co-operation potential:

Mikroklima s.r.o.
Veverkova 1343
500 02 Hradec Kralove
Czech Republic
tel: +420 49 5500970
fax: +420 49 5500979
email: info@mikroklima.cz
web: www.mikroklima.cz

The laboratory tests aimed to check the integrity, robustness and accuracy of the sensors prior to their later deployment in the national field trials. Miscellaneous accessories (converters, power supplies *etc*) were also tested. Table 1 lists the tested devices.

Table 1 List of tested devices.

Function	Name
Exterior air temperature sensor	MIDAM 110
Interior air temperature sensor	MIDAM 100
Surface temperature sensor	MIDAM 140
Duct temperature sensor	MIDAM 120-120
Humidity sensor	MIDAM 180
Electrical power meter	MIDAM 750
Electrical power meter	MIDAM 750
Gas meter	MIDAM 750
Microwave-based occupancy sensor	MIDAM 800
CO sensor, analogue measurement	MIDAM 170
CO alarm, digital output	MIDAM 420
Pressure difference sensor	MIDAM DPS- 01
Module 4 relay outputs	MIDAM 200
Multi I/O module	MIDAM multi i/o
RS232 to RS485	MIDAM 010

2.1 General properties of MIDAM modules

The module communicates and is controlled solely via the RS485 data bus. Its communication protocol is identical to the ADAM 4000 module series produced by ADVANTECH. The MIDAM 100 sensor operates in the same way as the ADAM 4013 module. This means that a standard actuator used with the ADAM modules can be used to provide control in various programmes. Some of the communication cables used with the RS485 include more line conductor pairs. Therefore, the convertor has been designed to allow that the module power supply can be brought via the free conductors in the cable.

The analogue module is based on a microprocessor controlled A/D converter. The communication inputs are protected against over-voltage. In cases where the module has been installed as a terminal device on the bus, a BUS END terminating resistor may be installed by inducing a short-circuit at the jumpers on the printed circuit board (the SW switch beside the terminals of the communication conductors). The LED flashes whenever the sensor communicates. All adjustments are saved in EEPROM memory. The module is fitted with the WATCHDOG circuit which monitors proper operation of the processor.

2.2 Temperature

Temperature sensor MIDAM 1xx (Figure 1) has several modifications that are applicable to most events.

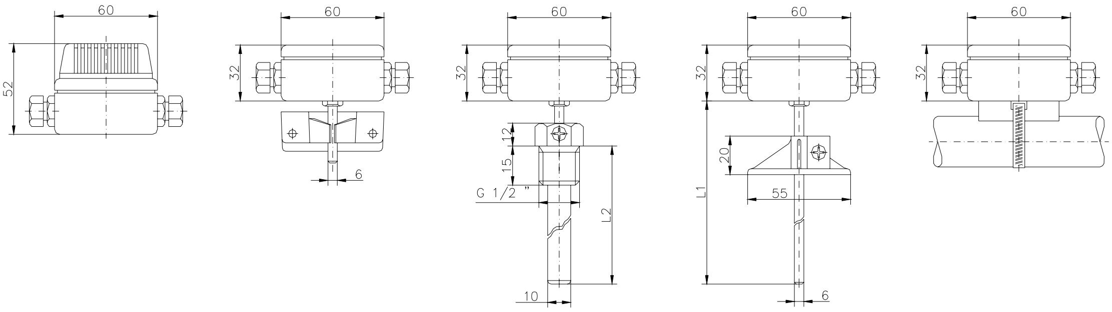

Figure 1: Temperature sensors MIDAM 100 (indoor temperature), MIDAM 110 (outdoor temperature), MIDAM 120-130 (air duct temperature) and MIDAM 140 (surface temperature).

The MIDAM 100 module series is an intelligent microprocessor controlled temperature sensor. The sensor comprises a PT100 measuring element and electronics placed in the sensor casing. The range of measured temperatures is preset to 5 to 250°C and the module is calibrated to this temperature range. This range fits most HVAC applications. The sensors are available in several versions, which are identical with the SENSIT sensor series (various stem and sink dimensions *etc*).

2.3 Relative humidity

Humidity sensing is part of the MIDAM 180 integrated sensor. This sensor behaves like two separate sensors for temperature and relative humidity. The temperature measurement range is preset to –40 to +123.8°C and the module is calibrated to this temperature range. The relative humidity measurement range is preset to 0 to 100% and the module is calibrated to this range.

2.4 Electrical power and gas

Electricity and gas meters comprise any standard meter with pulse output and a Midam digital input module. To calibrate the pulse receiver, the character of the pulse must be defined in terms of parameters such as fmax, th, tl, Vpp and whether the pulses are generated by relay or open collector *etc* (Figure 2).

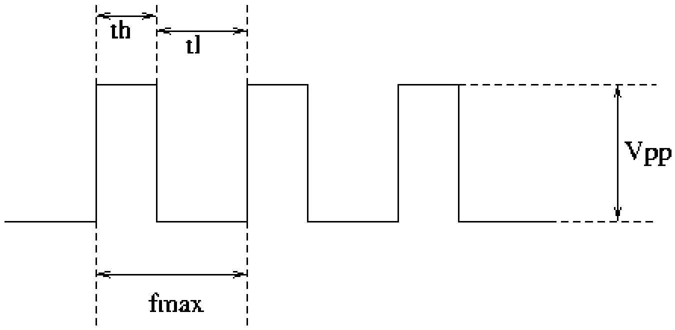

Figure 2: Specification of pulse receiver.

2.5 Occupancy

A microwave-based occupancy sensor, MIDAM 800, has been specially fabricated for the SmartHomes system. This is an infra-passive sensor connected to the RS485 bus. Via control elements at the rear of the sensor is possible to modify its function:

- Sensor sensitivity – maximal distance of motion detection is 8-10m. If the motion is in a direction normal to the sensor's axis, its detection efficiency is higher.
- Closure time – is the hold time since recent activation. The minimal closure time is 5 seconds while the maximum is approximately 10 minutes. Output from the sensor is 1 or 0 (indicating whether movement has been detected or not in the most recent time slot).

2.6 CO and CO_2
Sensors for CO consists of a Midam 100 element (single analogue input) and an ASEKO sensor, GTE CO 0-300ppm. Sensors for CO_2 consists of the same element and Siemens Landis Staefa sensor, QPA63.1.

2.7 Pressure difference
The pressure difference sensor measures air pressure difference in the range 0-6kPa in the temperature range 0-70°C. Output is digital.

2.8 Module 4 relay output
MIDAM 200 is an intelligent module with four relay outputs (four change-over contacts). The relays may switch 380 V ac or 150 V dc, with a maximum switched current of 10A. The status of the outputs may be controlled via the RS485 communication bus. The module, which has to be installed on a DIN strip, communicates and is controlled solely via the RS485 data bus. The communication protocol is identical to the ADAM 4000 module series produced by the ADVANTECH company. The MIDAM 200 sensor operates in the same way as the ADAM 4060 module. This means that a standard actuator used with ADAM modules can be used to provide control in various programmes.

The module wiring to the RS485 bus is provided by two RJ45 connectors arranged in parallel. Thus, it is possible to connect the bus from the module to other modules in the network. Communication inputs are protected against overvoltage. Where the converter has been installed as a terminal device on the bus, a terminating resistor and resistors defining the idle condition on the bus may be installed. This is done by remove the casing cover and connecting the resistors to the line by short-circuiting the contacts on the printed circuit board. There are four LEDs on the top panel of the module indicating the status of each output and two LEDs indicating communication with the module and power supply connection.

2.9 Multi I/O
This module is a combination of several modules in a single box: MIDAM 200 (relay), MIDAM 401/411 (digital input), MIDAM 500 (analogue input) and five MIDAM 600 modules (analog output). This combination provides a cost effective module suited to a wide range of uses. The communication protocol is compatible with the ADAM series 4000 modules from ADVANTECH. A range of analogue inputs can be individually set for each channel. Digital inputs have latch possibility.

When reading current (range 0-20mA), it is necessary to connect 100W/0.1% resistors in parallel with the input terminals so that the input current travels through the resistors. The overall accuracy of input current reading depends on an accurate resistance value.

2.10 Digital input
MIDAM 400 and MIDAM 420 are intelligent modules with eight digital inputs. The inputs are controllable via the RS485 communication bus. The module has to be installed on a DIN strip. It communicates and is controlled solely via the RS485 data bus. Its communication protocol is identical to the ADAM 4000 module series produced by ADVANTECH. The MIDAM 400 and MIDAM 420 sensors operate in the same way as the ADAM 4052 module. This means that a standard actuator used with the ADAM modules can be used for control in various programmes. The module wiring to the RS485 bus is provided by two RJ45 connectors connected in parallel. It is possible to connect this bus to other modules in the network. Communication inputs are protected against overvoltage. Where the converter has been installed as a terminal device on the bus, a terminating resistor may be used by removing the casing cover and connecting the terminal resistor to the line by short-circuiting the contacts on the printed circuit board. The LED arrangement is the same as the Module 4 relay output.

The module outputs are passive (without power supply), so that the reading of the potential-free contacts condition requires an external power supply or power supply voltage from the module (see the examples of wiring). If an alternative voltage supply is used, the terminal polarity is arbitrary.

MIDAM 500 is an intelligent module with eight voltage and current analogue inputs. The inputs are differential and their condition may be controlled via the RS485 communication bus. The module has to be installed on a DIN strip. The module communicates and is controlled solely via the RS485 data bus. Its communication protocol is identical with the ADAM 4000 module series produced by ADVANTECH. The MIDAM 500 sensor operates in the same way as the ADAM 4017 module. This means that a standard actuator used with the ADAM modules can be used for control in various programmes.

2.11 RS232 to RS422/485 converter

MIDAM 010 is a converter between RS232 and RS422 or RS485 buses. It connects RS422/RS485 network devices to devices with a RS232 interface. The converter galvanically separates the buses. The module communication rate is from 1,200 to 19,200baud and has to be installed on a DIN strip. Bus RS485 supports half-duplex communication. An automatic data flow controller processor enables switch data flow direction using hardware control signal CTS or DSR (DSR is implicit). The communication rate of both channels must be equal and may be set by short-circuiting the contacts on the printed circuit board. There are LEDs on the top panel indicating communication direction with the module and power supply connection. The module wiring to the RS485 bus is provided by the RJ45 terminal. Communication inputs are protected against overvoltage.

3. Sensor installation

Connection between e-box and access network - via a standard RJ45 ethernet cable. Note that this is a ‘straight’ cable for connecting to either a router within a LAN or to an ADSL modem.

Power supply for e-box - this requires a mains supply of 100-240V ac. Note that the e-boxes are supplied with a standard European 2 pin mains connector. For the UK this has to be re-terminated with a 3 pin mains plug.

Serial line link to Adam adapter - this link uses 9-pin connectors and cable. Both ends have a female connector (a serial laplink cable).

Power supply for RS232/485 adapter - the Midam 010 data converter takes a supply voltage as 10-35V dc or 14-24V ac. A low cost 12V dc power supply is sufficient. The adapter draws 1W. The total power requirement will depend on the type and number of sensors, assuming all sensors are powered by the RS485 cabling. For example, the Midam 100 temperature sensor draws 300mW. Therefore, for a circuit of 6 temperature sensors plus adapter, the total power requirement is 2.8W, giving a current requirement of 240mA for a 12V dc supply. Allow extra for long cable runs.

Sensor cabling - a screened 4 wire cable is required to provide the power and signal lines. With RS485 digital data transfer, sensors can be linked (i.e. they do not need to be individually cabled). The wire to be used to connect the Midam sensors and the RS232/485 converter should be a 4-core screened cable of type 16/0.2mm, giving each core a cross sectional area of 0.5mm^2, and each core of the cable having a minimum current rating of 1.5A (Figures 3 and 4).

4. Communication protocols

4.1 Data acquisition

The Advantech standard was applied within the SmartHomes system. A table of sensor addresses were agreed according to the sensor type (Table 2). The software bundles installed within the e-boxes were then designed to check for new sensor connections every 10 minutes. The polled sensor data are time stamped and automatically transferred to the central SQL database resident on the e-service centre. A similar protocol was adopted for actuator data handling.

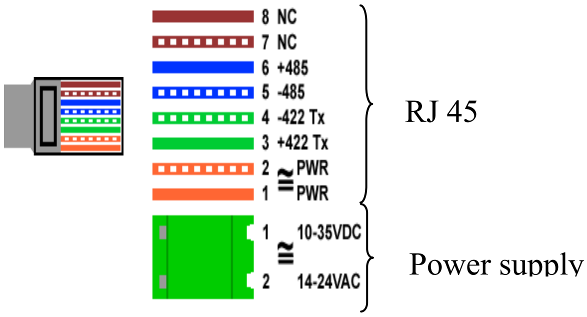

Figure 3: Wiring scheme, 8 core TP cable from RJ45 connector.

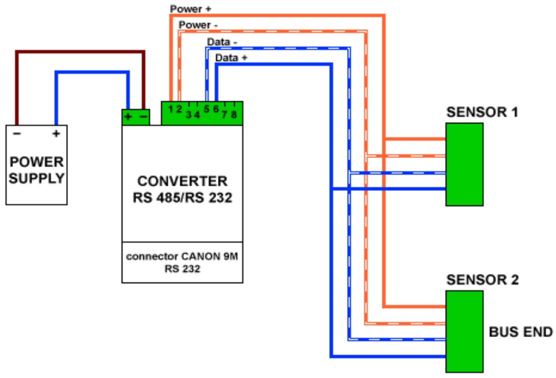

Figure 4: Wiring scheme, MIDAM 010 converter.

Table 2: Sensors addressing.

Midam type	Code	Function	Address	Order ID	Bundle
100/110	4013	Temperature	1-20	MIDAM 100	Yes
180	4113/ 4213	Temperature/humidity	21-60	MIDAM 180	Yes
800	4152	Occupancy	61-70	MIDAM 800	Yes
420	4252	CO alarm	71-75	MIDAM 420	Yes
170	4313	CO concentration analogue.	76-80	MIDAM 170	Yes
DPS-02	4513	Pressure analogue abs.	81-85	MIDAM DPS-02	No
DPS-01	4613	Pressure difference, analogue	86-90	MIDAM DPS 01	Yes
500	4017	Analogue I/P (8 channel)	91-95	MIDAM 500	Yes
300	4050	Digital output	96-100	MIDAM 300	Yes
400	4052	Digital I/P (8 channel)	101-105	MIDAM 400	Yes
750	4180	Pulse counter (1 channel)	106-125	MIDAM 750	Yes
200	4060	Relay output (4 channel)	126-145	MIDAM 200	Yes
171	4413	CO_2 concentration, analogue.	146-160	MIDAM 171	Yes

The communication protocols employed within the SmartHomes system are summarised in Table 3.

Table 3: SmartHomes communication protocols.

ADAM	Communication protocol developed by Advantech used especially for ADAM sensors communication. Sensors are connected by twisted-pair RS485 cable.
TCP/IP	Transmission Control Protocol/Internet Protocol designated for Internet data transfers. It is designed to send, direct and integrity check data packets between computers. Does not guarantee security of transferred data and therefore it is necessary to add another layer (e.g. SSL).
URL	Uniform Resource Locator defining a unique address for each document accessible on the Internet.
HTTP	HyperText Transfer Protocol used for communication between browser and Web servers. Based on a client/server architecture whereby the client (browser) calls the server, sends a request (URL) and the server replies with HTML page.

HTTPS	HyperText Transfer Protocol Secure analogous to HTTP but communication is encrypted (SSL layer)
SSL	Secure Socket Layer between the application protocol (e.g. HTTP) and TCP/IP. Solves data transfer encryption between server and client.
SMTP	Simple Mail Transfer Protocol used for communication between mail servers to transfer electronic mail. This protocol expects permanent accessibility of receiving and sending server. Where receiving server is unavailable, the situation is evaluated as a error and causes message transfer repeats.
NTP	Network Time Protocol used for sever time synchronisation. Required because of time difference between distributed e-boxes and the e-service server.

4.2 Development languages

Table 4 summarises the development languages employed within the SmartHomes system.

Table 4: SmartHomes development languages.

SQL	Structured Query Language used by most database servers. Covers all necessary functions and procedures for database maintenance (search, modify, add, delete, retrieve *etc*).
ODBC	Open Database Connectivity is a standardised database interface that enables communication between Internet-resident databases.
HTML	HyperText Markup Language specified by the W3C consortium for structural text format with links to other documents. Used for Web pages design. Extensions include XHTML (eXtensible HyperText Markup Language) based on the universal markup language XML (eXtensible Markup Language).
PHP, JSP, ASP	Script languages based on classic programming languages (C, java, Visual Basic) used to generate HTML documents and connect these to a database resident on the Internet.

5. Laboratory testing

Typical e-services were tested prior to deployment in the national field trials. For each country a typical set of sensors (depending on the targeted e-services) were configured and tested in relation to operation, data flow, system compatibility and accuracy. Table 5 lists the tested sensors per country.

Table 5: Tested field trial sensor sets.

UK		
2	Interior air temperature sensor	MIDAM 100
1	Microwave-based occupancy sensor	MIDAM 800
1	CO alarm digital output	MIDAM 420
1	Humidity sensor	MIDAM 180
1	RS232 to RS485 converter	MIDAM 010
2	Interior air temperature sensor	MIDAM 100
1	Exterior air temperature sensor	MIDAM 110
2	Electrical power meter	MIDAM 751
2	Microwave-based occupancy sensor	MIDAM 800
1	Gas meter	MIDAM 750
1	RS232 to RS485 converter	MIDAM 010

1	Electrical power meter	MIDAM 751
1	RS232 to RS485 converter	MIDAM 010
Sweden		
2	Exterior air temperature sensor	MIDAM 110
2	Interior air temperature sensor	MIDAM 100
1	Surface temperature sensor	MIDAM 140
1	Duct temperature sensor	MIDAM 120-120
1	Pressure difference sensor	MIDAM DPS - 01
1	Multi I/O module	MIDAM multi i/o
1	Module 4 relay outputs	MIDAM 200
1	RS232 to RS485 converter	MIDAM 010
Greece		
1	Exterior air temperature sensor	MIDAM 110
2	Interior air temperature sensor	MIDAM 100
1	Electrical power meter	MIDAM 750
1	RS232 to RS485 converter	MIDAM 010
1	Exterior air temperature sensor	MIDAM 110
2	Interior air temperature sensor	MIDAM 100
1	Electrical power meter	MIDAM 750
Czech Republic		
1	Exterior air temperature sensor	MIDAM 110
1	Interior air temperature sensor	MIDAM 100
1	RS232 to RS485 converter	MIDAM 010
1	Humidity sensor	MIDAM 180
1	Microwave-based occupancy sensor	MIDAM 800

During testing several sensor problems were detected and corrected. For example, these related to the calibration procedures, which did not take account of the heat effect of the integrated circuitry.

6. MIDAM 180 accuracy testing

The aim of this work was to experimentally establish the temperature error inherent in a MIDAM 180 sensor. Reference measurements were based on values from six calibrated PT100 sensors with a measuring accuracy of ±0.1K.

6.1 Calibration of PT100 temperature sensor

Calibration of the six PT100 temperature sensors was determined for three different temperatures in an insulated calibration chamber under steady-state conditions. The measuring tool used was a mercury calibrated decimal thermometer with the read values adjusted on the bulk mercury column. The measured and corrected values are given in Table 6.

Table 6: Temperature in calibration chamber.

Thermo-meter temp. (K)	Air temp. (K)	Mercury column height over calibration chamber edge (cm)	Correction on bulk column (K)	Calibration correction (K)	Corrected temperature (K)	Table
20.0	19.1	-2.4	0.00	0.03	20.0	1
49.1	18.0	4.4	0.01	-0.14	49.0	2
0.6	0.6	0.0	0.00	-0.02	0.6	3

Measured values of sensors resistance and calibration temperatures are shown in Table 7.

Table 7: Temperature sensor resistance.

PT-1 (ohm)	PT-2 (ohm)	PT-3 (ohm)	PT-4 (ohm)	PT-5 (ohm)	PT-6 (ohm)	Teplota (K)
108.535	108.545	108.545	108.535	108.485	108.545	20.0
119.875	119.875	119.865	119.845	119.805	119.865	49.0
100.95	100.94	100.96	100.92	100.87	100.94	0.6

The temperature/resistance relation is output from the calibration evaluation of the PT100 sensors, with the accuracy of the linear regression evaluation being adequate in this case. Graphs 1 to 6 in Figure 5 give the relation expressed in equation form.

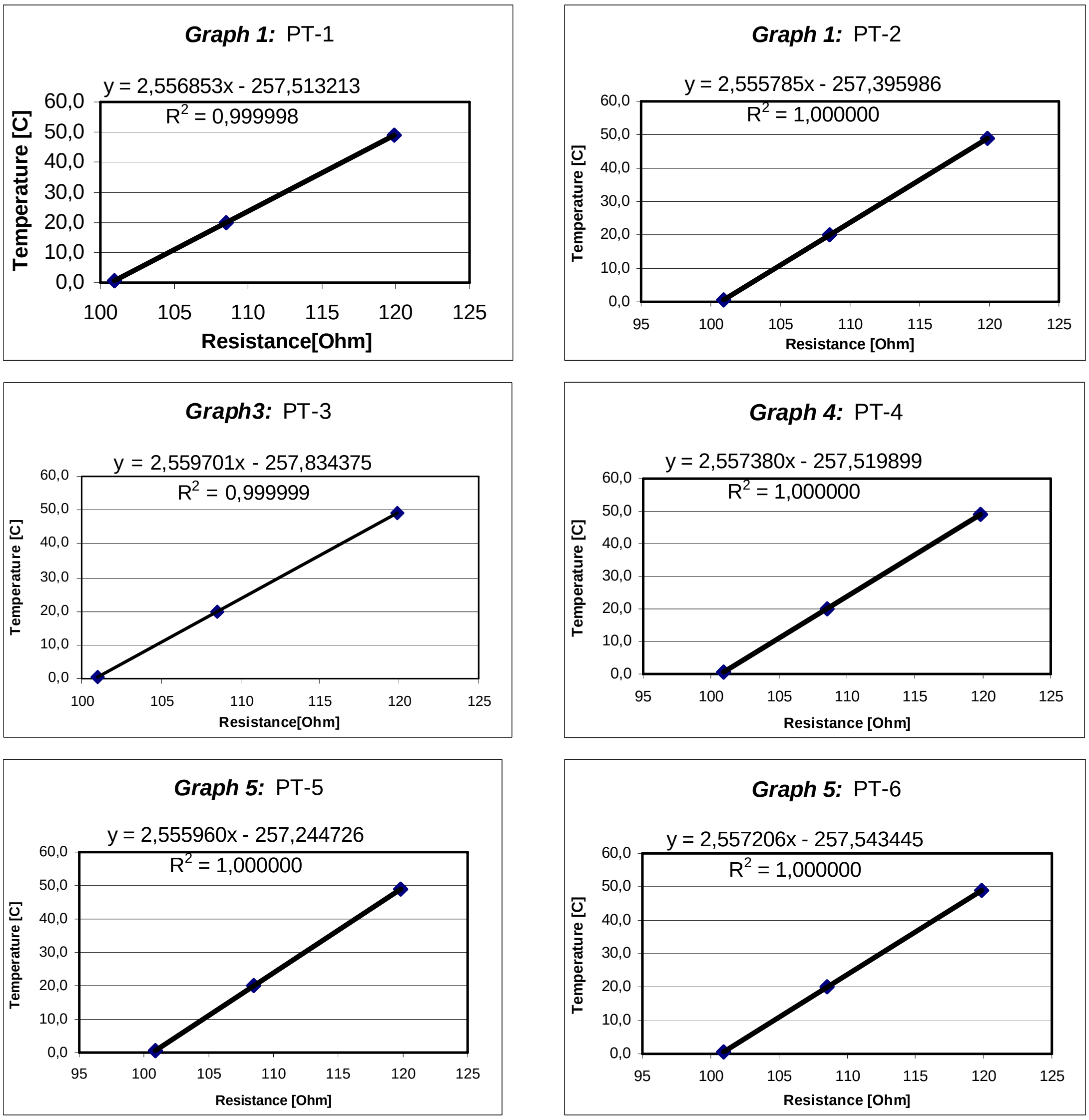

Figure 5: PT 100 calibration.

6.2 Calibration of SHT15 chip

The SHT15 chip is part of the MIDAM 180 sensor. This sensor embodies temperature and moisture sensors and an A to D converter. The chip is located in the sensor shank. The accuracy of the chip measurement according to manufacturer documentation is ±0.5K in the range 5 to 40°C. Two SHT15 chips, extracted from MIDAM 180 sensors, were calibrated in the insulated calibration chamber The chips were connected with sensors by extended power and communication cable. Inside the calibration chamber were located only chips, with the body of the sensor (equipped with electronics) located outside the chamber to avoid thermal interference. The calibration results under steady-state conditions are given in Table 8.

Table 8: Calibration of SHT15 chips.

Sensor address	Thermometer temperature (K)	Sensor temperature (K)	Chip error (K)
01	19.2	20.87	+1,7
03	21.0	22.71	+1,7

6.3 Measurement of MIDAM 180 sensors

Four MIDAM 180 sensors were measured in a closed insulated measuring chamber, separated from the laboratory space by an external chamber to prevent thermal radiation interactions. Sensors were fitted to a common board, enabling a 90° stepped rotation. The board was located at a chamber wall 1.6m above the floor level. Two layouts of the sensor shank were tested - horizontal and vertical. The measurement schemes for both MIDAM and calibrated PT100 sensors are shown in Figures 6 and 7.

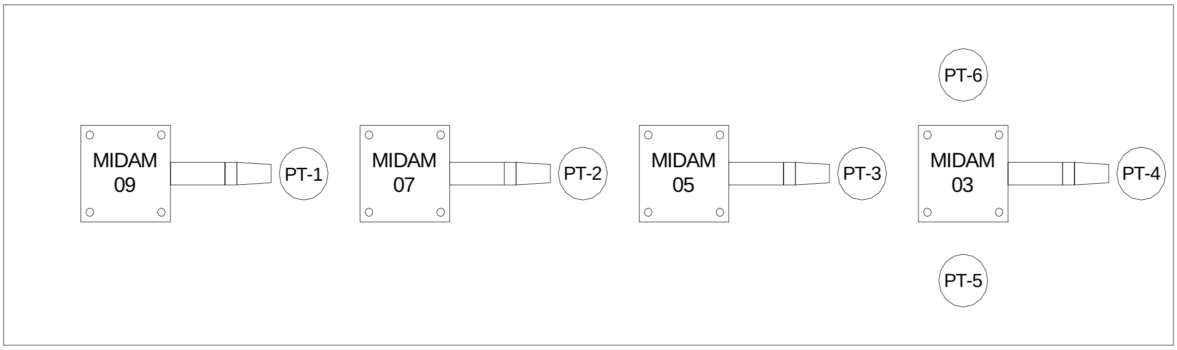

Figure 6: Horizontal sensors measurement.

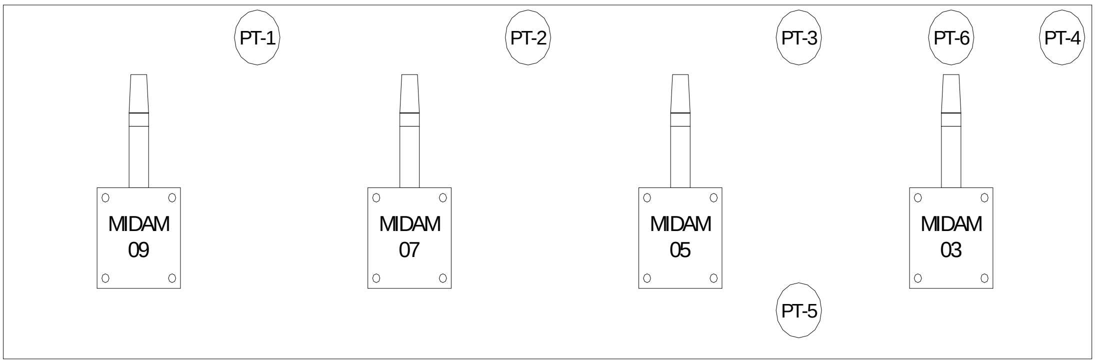

Figure 7: Vertical sensors measurement.

In both cases the measurements were made under steady-state conditions after a 12 hour start-up period to achieve constant temperature conditions in the chamber. The measurements corresponding to the horizontal position were used to check if the heat produced by the sensor electronics affects the chip by conduction through the sensor shank. From the measured values, presented in Table 9, it is evident that the electronics of the sensor does not affect the measured value. The error for the MIDAM 180 sensor is equal to that for the SHT 15 chip. From the comparison of values from the PT5 and PT6 sensors it was deduced that the sensor electronics affects the immediate surroundings. Around the sensor body there is a convective stream, which increases the temperature by 0.9K in the location of the PT6 sensor.

Measurement of the convective stream effect (and sensor shank position) on the accuracy of the temperature measurement was now examined and Table 10 gives the results. The measurement error for a vertical shank position increases to 0.5 - 0.7K. Comparing the value measured by the MIDAM 03 and PT-6 sensors, the measurement error is 1.6K.

Table 9: Horizontal sensor measurements.

PH-1 (K)	PH-2 (K)	PH-3 (K)	PH-4 (K)	PH-5 (K)	PH-6 (K)
20.3	20.3	20.3	20.2	20.3	21.2
MIDAM 09 (K)	MIDAM 07 (K)	MIDAM 05 (K)	MIDAM 03 (K)		
21.9	21.8	22.0	21.8		
+1,6	+1,5	+1,7	+1,6	Sensor error (K)	

Table 10: Vertical sensor measurements.

PH-1 [C]	PH-2 [C]	PH-3 [C]	PH-4 [C]	PH-5 [C]	PH-6 [C]
20.8	20.9	20.9	20.8	20.8	21.5
MIDAM 09 [C]	MIDAM 07 [C]	MIDAM 05 [C]	MIDAM 03 [C]		
23.1	23.0	23.3	23.1		
+2,3	+2,2	+2,4	+2,2	Sensor error [K]	

6.4 Project software

Within the project software packages were developed for data communication between sensors, e-boxes, the e-service centre, the central EnTrak system database, and the energy service providers. The project software was implemented using Java technology. An OSGi bundle, a software package deployable over a network running within an OSGi framework, was developed to handle the transmission of data between the e-box and the e-service centre. Control algorithms may be encapsulated within a bundle, resident on the e-service centre, or applied by the service provider.

Communication between the e-boxes and the e-service centre is established via the encrypted messenger service based on a bespoke protocol. A OSGi bundle deployed in the e-service centre controls the data transaction between the e-boxes and the EnTrak database. This bundle receives data from the e-boxes and passes it to EnTrak using a SQL protocol. On receiving a control command from EnTrak through a socket stream, the bundle passes the command to a specific e-box. The role of EnTrak is to supply a service-specific data aspect model to the energy service providers and to manage any transaction request that may be sent back.

6.5 Conclusions

The measuring error of the MIDAM 180 sensor was +2.5 K. Two basic influences give rise to this error. First, the manufacturer does not specify a correct positioning of the sensor. If this error is omitted, then the MIDAM 180 error reduces to +1.7K. The cause of this error lies in the SHT15 chip. The effect of the heat produced by the sensor electronics was not measured by the manufacturer when the sensor is located in the correct position as shown in Figure 8. Assuming that the SHT15 chip error of +1.7K is systematic, it is possible to set the accuracy of the chip at ±0.5 K (according to the chip documentation). The measured error was in the range –0.3 to +0.1K.

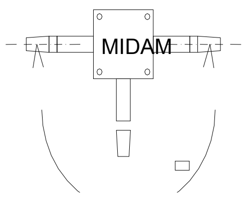

Figure 8: Correct sensor position.

7. Laboratory scale demonstrations

Laboratory scale demonstrations of the SmartHome system were installed at the Czech Technical University and the University of Strathclyde and a demonstration panel and explanatory poster were created. The complete system was then tested by sending control signals from the e-service centre to the e-box to enact load switching. This resulted in enhancements being made to the e-box resident software to improve the polling of sensors and the efficiency of data handling. Improvements were also made to the software at the e-service centre to handle high frequency acquisition from multiple sites, and to customise the dispatch of information to service providers via dedicated Web sites.

These software agents are available for download from http://www.esru.strath.ac.uk under an Open Source licence.

Finally an A0 poster was developed to explain the project concept and assist with the project's dissemination activities (Figure 10).

7.1 Demonstration panel

This is designed to show the end-user part of the SmartHome system and support sensor testing. The panel is sized (800x550mm) to be it readily transportable; the weight is approximately 10kg. It incorporates the following components (Figure 9):

- e-service gateway (e-box eB103);
- Internet connection;
- converter (RS485/RS232);
- interior temperature sensor (MIDAM 100);
- interior temperature/humidity sensor (MIDAM 180);
- CO_2 analogue sensor (MIDAM 170);
- microwave-based occupancy sensor (MIDAM 800);
- surface temperature sensor (MIDAM 140); and
- power supply.

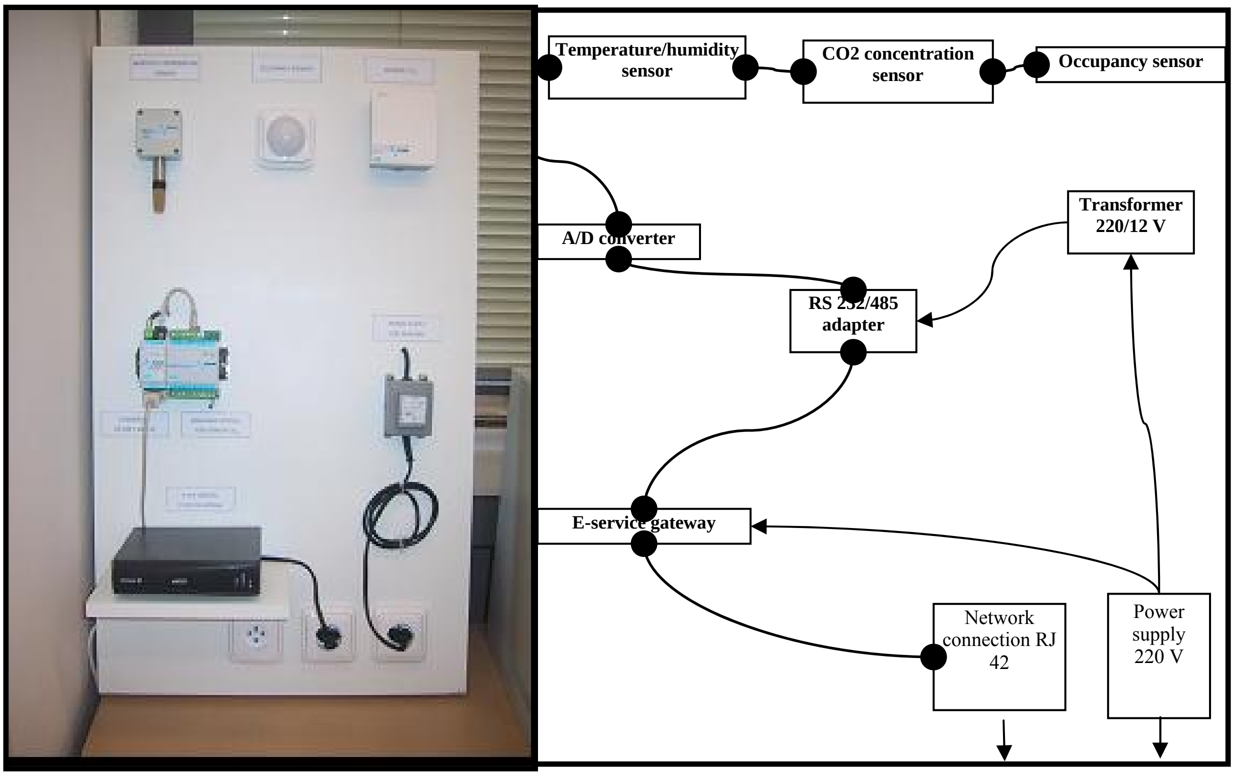

Figure 9: Schematic layout of the demonstration board.

When connected to an Internet access point sensor data is automatically transferred to the e-service centre where an e-service is enacted and the result transmitted back to the demonstration panel as an actuation request (e.g. higher panel illumination would cause a lamp to turn off). The demonstration board is fully functional and runs on-line from a Web interface accessible from an adjacent computer via http://tzb.fsv.cvut.cz/smarthomes/service/demolab/.

7.2 Explanation poster

Figure 10 shows the poster, which is designed to illustrate the data path from the e-service gateways to the e-service centre and to the SmartHomes database. The size of the poster is 800x1000mm, available for downloaded from http://tzb.fsv.cvut.cz/smarthomes/.

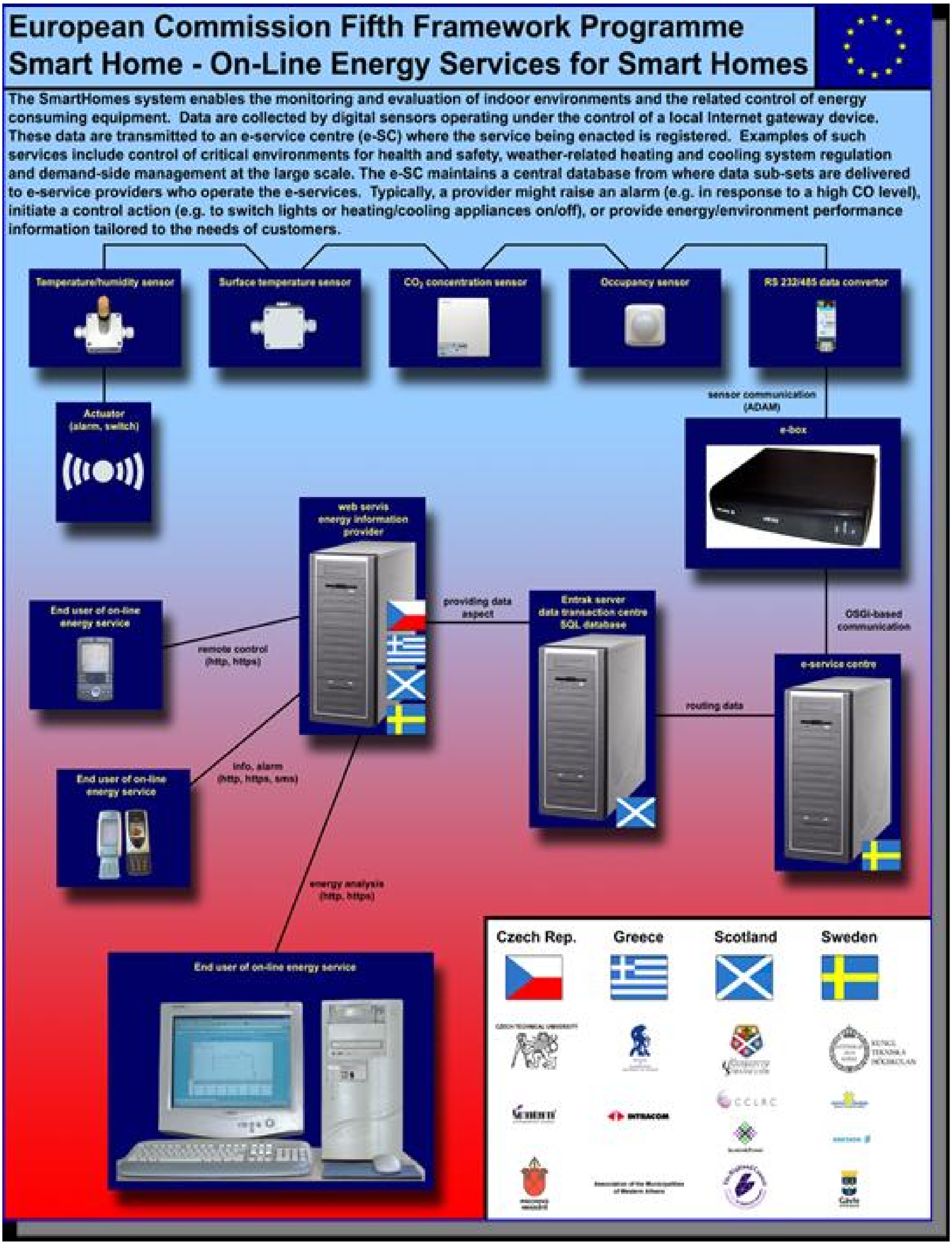

Figure 10: The SmartHomes poster (original in colour).

Appendix 4: Work Package 4, Field trials

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1. Deployed e-boxes

Table 1 lists the e-box deployments by country as at April 2004. The indicated serial number is required by the generic Web interface in order to call up individual e-boxes and interrogate their real-time sensor returns. For reasons of information confidentiality, the list does not identify the specific location of each e-box.

Table 1: Deployed e-boxes.

Location	Serial no.	Location	Serial no.
Greece			
GSKAND, Athens	A062177111	PBAK, Athens	A062172023
KTHOD, Athens	A062111091	VVAG, Athens	A062175563
EPAP, Athens	A062177110	TSIK, Athens	A062175581
GSKOUR, Athens	A062170700	LARVA, Athens	A062174932
VSAK, Athens	A062171585	GREN, Athens	A062175561
MMANO, Athens	A062165240	APAP, Athens	A062175566
LMAND, Athens	A062165751	EMOUR, Athens	A062175560
ADIM, Athens	A062177108	GCHRIS, Athens	A062175575
PDIM, Athens	A062175558	VKEF, Athens	A062175582
GHAL, Athens	A062170514	GPAPA, Athens	A062175572
PALEX, Athens	A062177106	NMOUT, Athens	A062167475
ATHEO, Athens	A062170717	NKOTS, Athens	A062469412
GPAP, Athens	A062170512	DZON, Athens	A062469409
ESPAR, Athens	A062164579	PARAT, Athens	A062475350
GBAT, Athens	A062173462	BES, Athens	A062467209
AFAS, Athens	A062174552	MMAK, Athens	A062475314
PZITOU, Athens	A062172026	ROOT, 65 Ethinis Antistaseos, Athens	A062447481
DMAK, Athens	A062171779	AS1F, 65 Ethinis Antistaseos, Athens	A062447484
PELEF, Athens	A062172152	ASPRE, 65 Ethinis Antistaseos, Athens	A062451162
EPSAR, Athens	A062172184	YKASTRIT, 45 Agias Varbaras, Athens	A062451164
8ROUT, Athens	A062172192	AZIRIN, 4 Veaki , Athens	A062447489
GVLAX, Athens	A062171784	PDOUKAS, Athens	A062462363
LGER, Athens	A062171794	LTSINTSEL, 20 Thiseos, Athens	A062444926
Czech Republic			
A429 – Hájek, Prague	A061895309	A027a - Kounovská, Prague	A062175573
1140 ul.CSA -1, Mnichovo Hradište	A062165333	1140 ul.CSA-11, Mnichovo Hradište	A062175574
A121 - Dvoráková, Prague	A062166070	1140 ul.CSA-12, Mnichovo Hradište	A062175580
1140 ul.CSA-2, Mnichovo Hradište	A062170515	B410 - Demel, Prague	A062175583
1140 ul.CSA -3, Mnichovo Hradište	A062170672	A028 - Vyoralová, Prague	A062175585
B327 - Kurfürstová, Kolárová, Prague	A062171796	1140 ul.CSA-13, Mnichovo Hradište	A062177104
B405 - Vytlacil, Prague	A062172015	A121 - Dvoráková, Prague	A062177105
B109 - Šibrava, Prague	A062172030	1140 ul.CSA-14, Mnichovo Hradište	A062177107
B529 - Pospíchal, Prague	A062172142	A031 - Dole□ílková, Prague	A062177109
A028 - Vyoralová, Prague	A062172144	Jirí Král, Prague	A062444929
A026 - Adamovský, Prague	A062172162	2 Základní škola MH, Mnichovo Hradište	A062447501
B728 - Vašková, Prague	A062172164	1140 ul.CSA-15, Mnichovo Hradište	A062467170
A028a - Kotek, Prague	A062172714	A030 - Reinberk, Prague	A062467173
A146 - Hulka, Prague	A062172740	Strojní - Lain, Prague	A062467182
1140 ul.CSA-4, Mnichovo Hradište	A062174485	2 Základní škola MH, Mnichovo Hradište	A062467184
1140 ul.CSA-5, Mnichovo Hradište	A062174487	Strojní - Lain, Prague	A062467195
1140 ul.CSA-6, Mnichovo Hradište	A062174501	2 Základní škola MH, Mnichovo Hradište	A062467215
A028a - Kotek, Prague	A062174566	2 Základní škola MH, Mnichovo Hradište	A062469377
1140 ul.CSA-7, Mnichovo Hradište	A062174933	1140 ul.CSA-16, Mnichovo Hradište	A062469400
A031 - Dole□ílková, Prague	A062175557	2 Základní škola MH, Mnichovo Hradište	A062469424
1140 ul.CSA-8, Mnichovo Hradište	A062175559	1140 ul.CSA-17, Mnichovo Hradište	A062470946
A026 - Adamovský, Prague	A062175564	A122 – Kabele, Prague	A062470953
1140 ul.CSA-9, Mnichovo Hradište	A062175565	A233 - Demolab, Prague	A062475339
A227a – Pape□, Prague	A062175567	Strojní - Lain, Prague	A062475347
1140 ul.CSA-10, Mnichovo Hradište	A062175571		
Scotland			
M322A, 75 Montrose St, Glasgow	A061728882	D131 Andrew Ure Hall, Glasgow	A062166081
M6CR, 75 Montrose St, Glasgow	A061728954	D143 Andrew Ure Hall, Glasgow	A062166082
M6CS, 75 Montrose St, Glasgow	A061737265	101 St James' Road, Glasgow	A062166092
James Blyth, Glasgow	A061745616	B23 Andrew Ure Hall, Glasgow	A062166093

14 Walmer Crescent, Glasgow	A061814130	621, 107 Rottenrow East, Glasgow	A062166104
123 Hairmyers Road, Glasgow	A061814926	M313, 75 Montrose St, Glasgow	A062166112
M327, 75 Montrose St, Glasgow	A062136817	212 Patrick Thomas Hall, Glasgow	A062167471
Maitos Ltd, Glasgow	A062136820	ScottishPower HQ, Glasgow	A062306530
M333A, 75 Montrose St, Glasgow	A062164584	85 Birnie Terrace, Inverness	A062418466
M612, 75 Montrose St, Glasgow	A062164586	M333E, 75 Montrose St, Glasgow	A062567810
M333B, 75 Montrose St, Glasgow	A062164618	Lighthouse Building, Glasgow	A062567818
M313, 75 Montrose St, Glasgow	A062173458	Partnersoft, Glasgow	A062567824
Dr Hwang, KICT, Seoul, Korea	A062164846	M104, 75 Montrose St, Glasgow	A062567836
3/4 Patrick Thomas Hall, Glasgow	A062164847	M333, 75 Montrose St, Glasgow	A062567840
C11-4 Andrew Ure Hall, Glasgow	A062164855	345 Great Western Road, Glasgow	A062569857
704A, 48 North Portland St, Glasgow	A062164865	HQ Highland Council, Inverness	A062569859
M322 C, 75 Montrose St, Glasgow	A062165017	M409, 75 Montrose St, Glasgow	A062569860
A-25 Andrew Ure Hall, Glasgow	A062165084	131 Rottenrow, Glasgow	A062175569
D141 Andrew Ure Hall, Glasgow	A062165087	181 St James' Rd, Glasgow	A062164676
704B, 48 North Portland St, Glasgow	A062165108	ITS, 101 St James' Road, Glasgow	A062171598
726, 48 North Portland St, Glasgow	A062165136	Studio West, 131 Rottenrow, Glasgow	A062170509
M322, 75 Montrose St, Glasgow	A062165171	L5, 101 St James' Road, Glasgow	A062165088
A136 Andrew Ure Hall, Glasgow	A062165189	K326, 107 Rottenrow East, Glasgow	A062171785
M6STR, 75 Montrose St, Glasgow	A062165214	27 Taylor St, Glasgow	A062167515
M616, 75 Montrose St, Glasgow	A062165215	22 Richmond St, Glasgow	A062172019
M324, 75 Montrose St, Glasgow	A062165941	K412, 107 Rottenrow, Glasgow	A062172013
M333B, 75 Montrose St, Glasgow	A062165946	PR, 101 St James' Road, Glasgow	A062172158
Sweden			
Hillmansgatan, Gävle	A062567811	Vallgossen, Stockholm	V61
Hillmansgatan, Gävle	A062567823	Vallgossen, Stockholm	V62
Hillmansgatan, Gävle	A062567832	Vallgossen, Stockholm	V63
Hillmansgatan, Gävle	A062420133	Vallgossen, Stockholm	V64
Farsta, Stockholm	A062567841	Vallgossen, Stockholm	V65
Tilskogen, Sigtuna	A062164863	Vallgossen, Stockholm	V66
Tilskogen, Sigtuna	A062164587	Vallgossen, Stockholm	V67
Vallgossen, Stockholm	V1	Vallgossen, Stockholm	V68
Vallgossen, Stockholm	V2	Vallgossen, Stockholm	V69
Vallgossen, Stockholm	V3	Vallgossen, Stockholm	V70
Vallgossen, Stockholm	V4	Vallgossen, Stockholm	V71
Vallgossen, Stockholm	V5	Vallgossen, Stockholm	V72
Vallgossen, Stockholm	V6	Vallgossen, Stockholm	V73
Vallgossen, Stockholm	V7	Vallgossen, Stockholm	V74
Vallgossen, Stockholm	V8	Vallgossen, Stockholm	V75
Vallgossen, Stockholm	V9	Vallgossen, Stockholm	V76
Vallgossen, Stockholm	V10	Vallgossen, Stockholm	V77
Vallgossen, Stockholm	V11	Vallgossen, Stockholm	V78
Vallgossen, Stockholm	V12	Vallgossen, Stockholm	V79
Vallgossen, Stockholm	V13	Vallgossen, Stockholm	V80
Vallgossen, Stockholm	V14	Vallgossen, Stockholm	V81
Vallgossen, Stockholm	V15	Vallgossen, Stockholm	V82
Vallgossen, Stockholm	V16	Vallgossen, Stockholm	V83
Vallgossen, Stockholm	V17	Vallgossen, Stockholm	V84
Vallgossen, Stockholm	V18	Vallgossen, Stockholm	V85
Vallgossen, Stockholm	V19	Vallgossen, Stockholm	V86
Vallgossen, Stockholm	V20	Vallgossen, Stockholm	V87
Vallgossen, Stockholm	V21	Vallgossen, Stockholm	V88
Vallgossen, Stockholm	V22	Vallgossen, Stockholm	V89
Vallgossen, Stockholm	V23	Vallgossen, Stockholm	V90
Vallgossen, Stockholm	V24	Vallgossen, Stockholm	V91
Vallgossen, Stockholm	V25	Vallgossen, Stockholm	V92
Vallgossen, Stockholm	V26	Vallgossen, Stockholm	V93
Vallgossen, Stockholm	V27	Vallgossen, Stockholm	V94
Vallgossen, Stockholm	V28	Vallgossen, Stockholm	V95
Vallgossen, Stockholm	V29	Vallgossen, Stockholm	V96
Vallgossen, Stockholm	V30	Vallgossen, Stockholm	V97
Vallgossen, Stockholm	V31	Vallgossen, Stockholm	V98
Vallgossen, Stockholm	V32	Vallgossen, Stockholm	V99
Vallgossen, Stockholm	V33	Vallgossen, Stockholm	V100
Vallgossen, Stockholm	V34	Vallgossen, Stockholm	V101
Vallgossen, Stockholm	V35	Vallgossen, Stockholm	V102
Vallgossen, Stockholm	V36	Vallgossen, Stockholm	V103
Vallgossen, Stockholm	V37	Vallgossen, Stockholm	V104

Vallgossen, Stockholm	V38	Vallgossen, Stockholm	V105
Vallgossen, Stockholm	V39	Vallgossen, Stockholm	V106
Vallgossen, Stockholm	V40	Vallgossen, Stockholm	V107
Vallgossen, Stockholm	V41	Vallgossen, Stockholm	V108
Vallgossen, Stockholm	V42	Vallgossen, Stockholm	V109
Vallgossen, Stockholm	V43	Vallgossen, Stockholm	V110
Vallgossen, Stockholm	V44	Vallgossen, Stockholm	V111
Vallgossen, Stockholm	V45	Vallgossen, Stockholm	V112
Vallgossen, Stockholm	V46	Vallgossen, Stockholm	V113
Vallgossen, Stockholm	V47	Vallgossen, Stockholm	V114
Vallgossen, Stockholm	V48	Vallgossen, Stockholm	V115
Vallgossen, Stockholm	V49	Vallgossen, Stockholm	V116
Vallgossen, Stockholm	V50	Vallgossen, Stockholm	V117
Vallgossen, Stockholm	V51	Vallgossen, Stockholm	V118
Vallgossen, Stockholm	V52	Vallgossen, Stockholm	V119
Vallgossen, Stockholm	V53	Vallgossen, Stockholm	V120
Vallgossen, Stockholm	V54	Vallgossen, Stockholm	V121
Vallgossen, Stockholm	V55	Vallgossen, Stockholm	V122
Vallgossen, Stockholm	V56	Vallgossen, Stockholm	V123
Vallgossen, Stockholm	V57	Vallgossen, Stockholm	V124
Vallgossen, Stockholm	V58	Vallgossen, Stockholm	V125
Vallgossen, Stockholm	V59	Vallgossen, Stockholm	V126
Vallgossen, Stockholm	V60	Vallgossen, Stockholm	V127

2. Installation procedure

The following instructions indicate the steps necessary to introduce a new e-service and deploy the required equipment in the field (i.e. install eB103 e-boxes, connect sensors using the Adam system and actuate related control software).

2.1 Define the e-service

The first step is to specify the envisaged e-service in terms of the following parameters. At this stage the specification is generic with no specific installation in mind.

General
- purpose of the e-service;
- location details, including a map;
- target for information delivery; and
- specification of actions to be initiated.

Interfaces
- user-oriented Web pages; and
- service provider Web pages.

Network
- LAN;
- Internet access;
- availability and reliability requirements;
- network interruption handling; and
- firewalls.

E-boxes
- numbers and their location.

Sensors/actuators
- sensor types and positions;
- actuator types and positions; and
- accuracy and validation checks.

Data handling
- user authentication;
- security and privacy;
- e-service aspect model definition;
- analysis requirements;
- measurement frequencies; and

- actuation requests.

Software
- algorithm location (e-service centre, e-box, other); and
- authentication of users.

2.2. Site survey

The requirement here is to visit a specific site in order to confirm or vary the installation parameters as a function of local conditions. During the survey, cabling requirements are determined and installation routes identified. Figure 1 shows the hardware targets of an e-service installation.

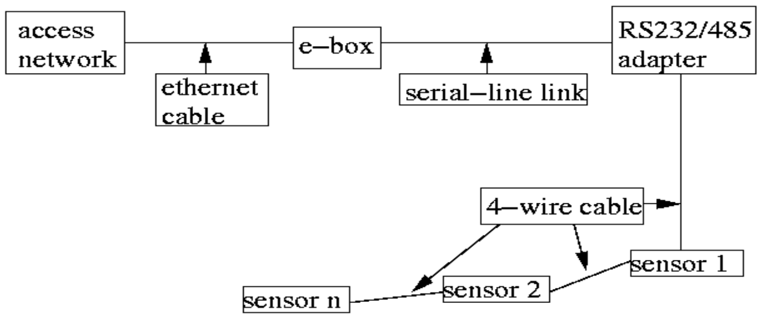

Figure 1: E-service hardware.

Access network

The requirement is for a permanent Internet connection that allows the remotely located e-service centre to interact with the e-box. Two-way communication must be possible at any time. The connection possibilities are:
- connecting to an existing LAN with Internet access;
- using an ADSL line; and
- using a GPRS router.

Either dynamic or static IP addresses can be used with the e-box. However, the preferred method is a dynamic address provided by a DHCP server (provided by the Access Network Provider (ANP) or Internet Service Provider (ISP)). The static address option has been provided within the SmartHomes project as a temporary measure only. Other technical requirements include:
- No proxies must be present.
- Reverse lookup of the fully qualified domain name (FQDN) must be possible (when the e-box receives its IP address it tries to make a reverse lookup for the domain name associated with it).
- The Domain Name Server (DNS), HyperText Transfer Protocol Secure (HTTPS), Simple Mail Transfer Protocol (SMTP) and Network Time Protocol (NTP) services must be enabled. The required ports (both directions) are 2303, 2304 and 2305 respectively.
- Where a firewall is in place, Internet access for the e-box IP address must be enabled.
- In organisations that have a strict security policy, and where static addresses are used, the DNS must be able to resolve the URL of the e-service centre (*.sh.rivermen.se).
- The e-box ethernet interface to the access network is 10Mbit/s half-duplex. For the case of LAN connection, the switch router must be configured for this transfer rate (note that auto-set may not work).

Connection between e-box and access network

This requires a standard RJ45 ethernet cable. Note that this is a ‘straight’ cable for connecting to either a router within a LAN or to an ADSL modem.

Power supply for e-box

This requires a mains supply at 100-240V ac. Note that the e-boxes are supplied with a standard European 2 pin mains connector. In the UK, this has to be re-terminated with a 3 pin mains plug.

Serial line link to the Adam adapter
This uses 9-pin connectors and cable. Both ends have a female connector (i.e. a serial laplink cable).

Power supply for RS232/485 adapter
The Midam 010 data converter takes a supply voltage of 10-35V dc or 14-24V ac. A low cost 12V dc power supply is sufficient. The adapter draws 1W. The total power requirement will depend on the type and number of sensors, assuming all sensors are powered by the RS485 cabling. For example, the Midam 100 temperature sensor draws 300mW. Therefore, for a circuit of 6 temperature sensors plus adapter, the total power requirement is 2.8W, giving a current requirement of 240mA for a 12V dc supply. Allow extra for long cable runs.

Sensor cabling
To provide the power and signal lines, a 4-core, screened cable is required. With RS485 digital data transfer, sensors can be linked one to the other (i.e. they do not need to be cabled individually). The wire to be used to connect the Midam sensors and the RS232/485 converter should be a 4-core, screened cable of type 16/0.2mm, giving each core a cross-sectional area of 0.5mm^2, with each core having a minimum current rating of 1.5A.

Sensors
Information on Midam sensors can be obtained from http://tzb2.fsv.cvut.cz/smarthomes/midam.

Home network
Although not employed in this project, the e-box can be made part of a home network as it provides DHCP/NAT 172.24.85.1-99, DNS and NTP support for PCs and other components on a local ethernet network. The RJ45 cable between the e-box and the PC must be a 'cross-over' type.

2.3 Steps prior to installation

Ordering sensors
Sensors may be ordered from Mikroklima:

Mikroklima s.r.o.	Tel: +420 49 5500970
Veverkova 1343	Fax: +420 49 5500979
500 02 Hradec Kralove	Email: info@mikroklima.cz
Czech Republic	Web: www.mikroklima.cz.

For example, the order for the SmartHomes 'care for the elderly' e-service comprised:
- 2 Midam 100 interior air temperature sensors
- 1 Midam 170 CO analogue sensor
- 2 Midam 800 microwave-based occupancy sensors
- 1 Midam 010 RS232 to RS485 converter.

Cable lengths may be added to the order and, in the case of pulse sensors, additional information is required to allow them to be factory configured: fmax, th, tl, Vpp as depicted in Figure 2, and whether the pulses are generated by solid state relay, open collector or other means.

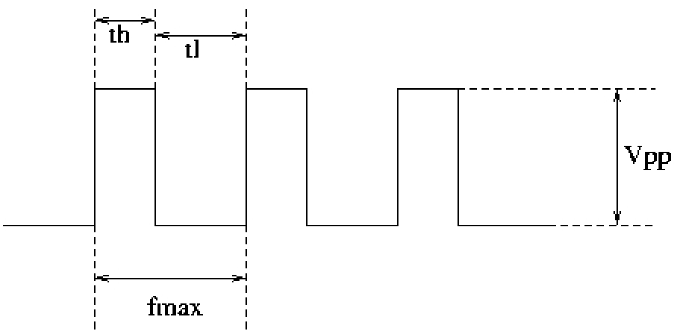

Figure 2: Pulse sensor information requirements.

Each sensor has an address in the range 1 to 255 within the RS485 network (only about 200 are available as some are used for communication handshaking). These need to be set as defined in Table 2 (for other sensors see Table 1).

Table 2: Sensor addresses for the care for the elderly example order.

Number	Sensor	Addresses
2	Midam 100 interior air temperature	1 and 2
1	Midam 170 CO, analogue	76
2	Midam 800 microwave-based occupancy	61 and 62

Define the data/processing requirements
The following information will typically be required.

- name of e-service;
- installation location;
- e-box serial number(s); and
- sensor list (including MIDAM numbers, units of measurement, sampling intervals and identification tags).

This information is required to configure the central SmartHomes database, which resides within the e-service centre. A matched, service-specific software bundle is then installed on the e-service centre ready for downloading to the locations at which the service is being enacted.

Register the e-box
This is achieved by email the following information to the e-service centre.

- Serial number of the e-box. This is located on the bottom of the e-box and starts with 'A0'.
- Information to identify the e-box installer: name, address, telephone and e-mail.

The IP address of the e-service centre and a user name and password is then sent in reply. Alternatively, where helpdesk access is available, it is possible to self-register. From any Internet-connected computer:

- login to https://admin.sh.rivermen.se:446;
- select the desired language;
- enter the username and password as issued by the e-service centre for helpdesk access;
- choose 'register owner';
- complete the form, including the e-box serial number; and
- retain the resulting registration information.

Plan field deployment
Obtain access consent from the service recipient and building owner if different. Arrange dates for e-box/sensors delivery and agree access times.

Activate e-box
Activation may be done on site or from any convenient Internet access point prior to the installation. The activation procedure is as follows.

- Connect the e-box to the Internet using slot 2.
- Plug in the power cable.
- Wait for the e-box to boot - this may take a few minutes.
- Connect a computer to the local network via slot 1 of the e-box.
- The computer should use DHCP to receive its IP address from the e-box:
  - go to TCP/IP properties (available via the 'TCP/IP protocol' found at 'start>settings>control panels>network> protocols' under MS Windows);
  - select the DHCP ON option (under MS Windows select 'Obtain an IP address automatically' and select the 'Obtain DNS address automatically' option);
  - reboot to refresh the IP address or use the 'ipconfig' command (i.e. at the DOS prompt

type ‘ipconfig /release’ followed by ‘ipconfig /renew’; confirm IP assignment by typing ‘ipconfig’, an e-box issued IP will commence with ‘172’).

- Using the computer and Internet Explorer 5.5 or later, connect to http://ebox.homenet:8080. This should result in the screen image shown in Figure 3. Where the local network uses a proxy server, this should be deactivated (go to ’tools>internet options>connections>LAN setting’ and uncheck all options regarding proxy configuration; for Netscape go to ‘edit>preference>advanced>proxies’ and check ‘direct connection to the Internet’).

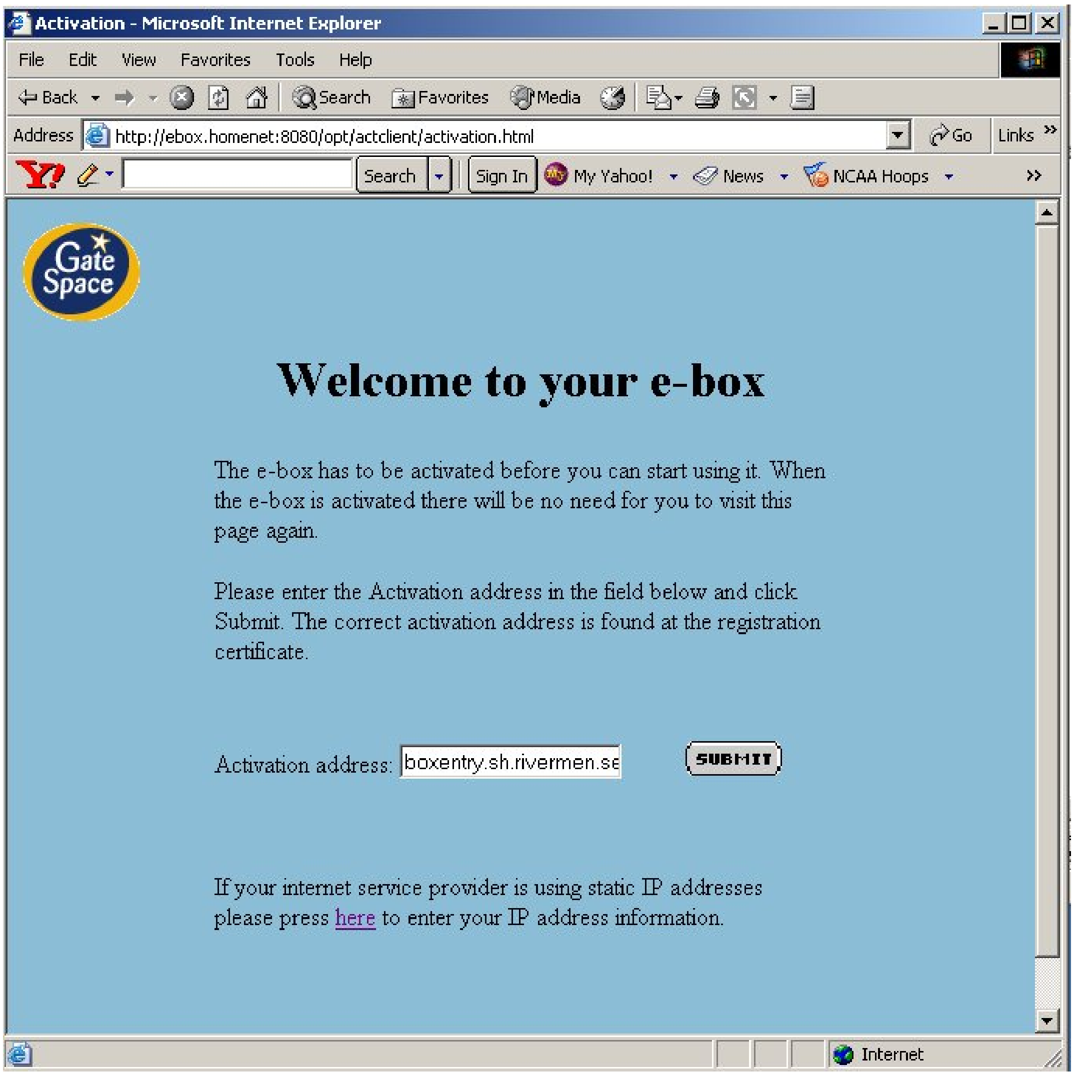

Figure 3: E-box registration screen (colour original).

- Where dynamic addressing is used (the normal case), enter the domain name address of the (boxentry.sh.rivermen.se) in the field ‘activation address’.
- Where a static IP address has been assigned to the e-box, the connection configuration needs to be set up. After entering the configuration information, click the ‘update’ button; the e-box will reboot. Then select the ‘activate’ button and enter the e-service centre address as in the preceding step. The new e-box connection configuration will be updates as shown in Figure 4.
- The e-box is now connected to the e-service centre. Note that the procedure can take up to 20 minutes depending on network performance. To check if the activation went well, log in to the e-service centre (https://www.sh.rivermen.se). As shown in Figure 5, this requires the user name and password issued earlier. Note that the e-service centre Web site employs secured HTTP (https) and therefore the local computer must have this capability as well as 128-bit encryption.
- If the e-box has not been activated, the error message shown in Figure 6 will be displayed.

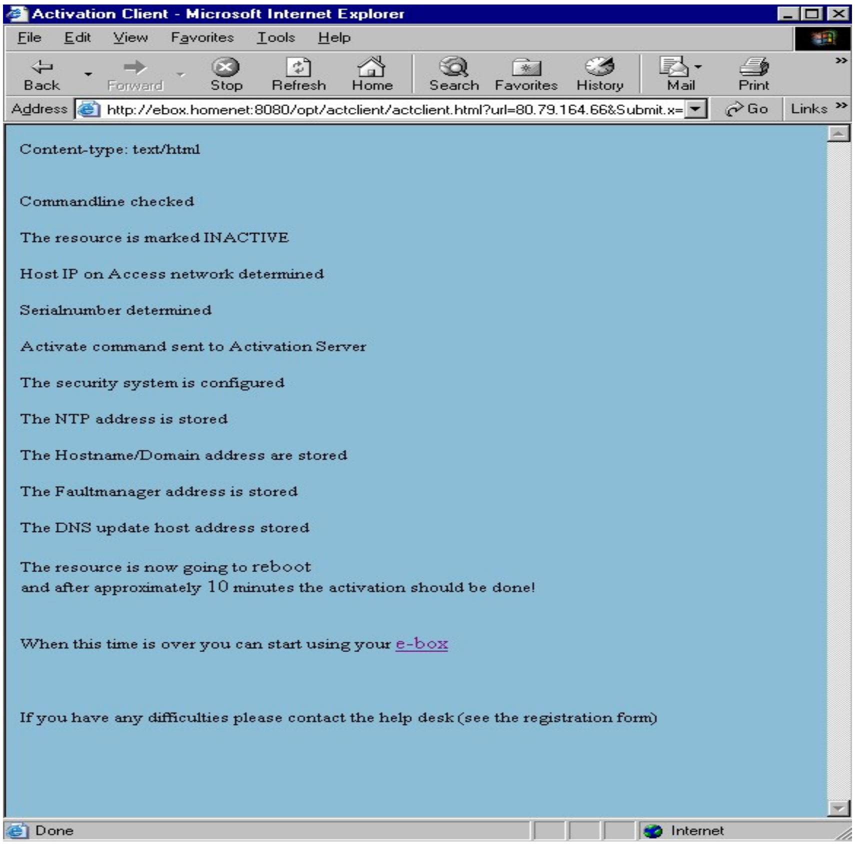

Figure 4: E-box activation (colour original).

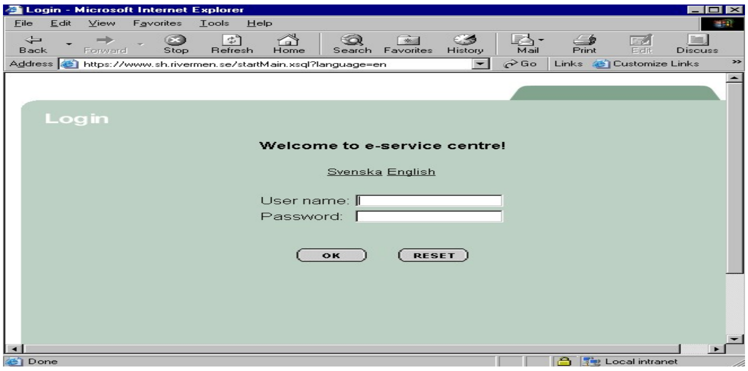

Figure 5: E-service centre log in (original in colour).

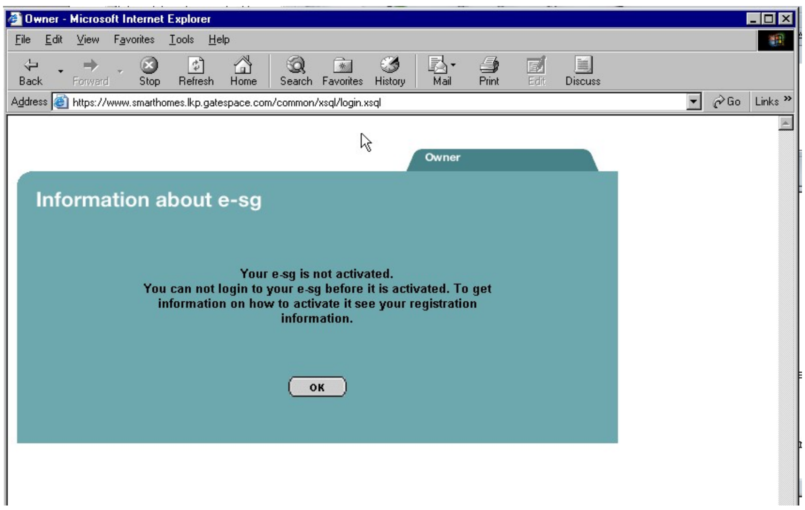

Figure 6: e-box activation error message.

Download a software bundle to the e-box

The procedure to download a software bundle (e-service software) to the e-box is as follows.

- Point the Web browser to https://www.sh.rivermen.se; entering the username and password provided by the e-service centre should result in the screen shown in Figure 7.

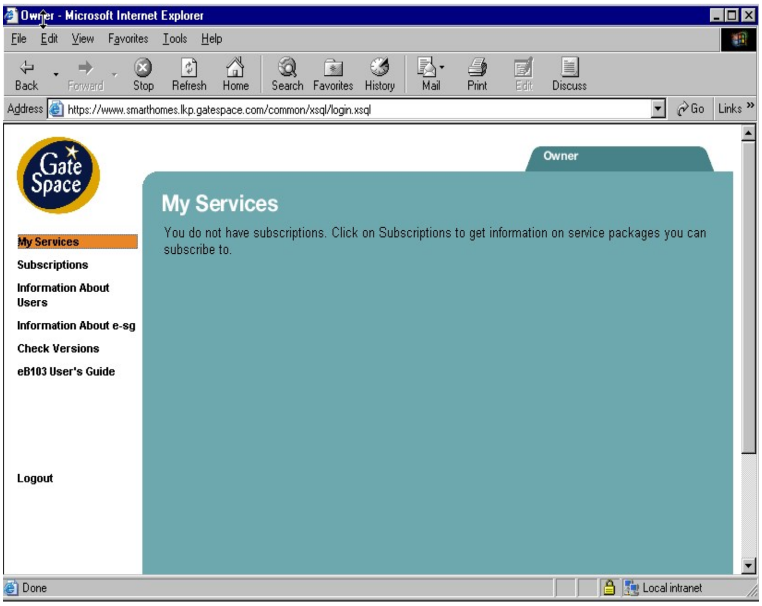

Figure 7: The 'My Services' screen (colour original).

- Select the subscriptions option to obtain the screen shown in Figure 8.

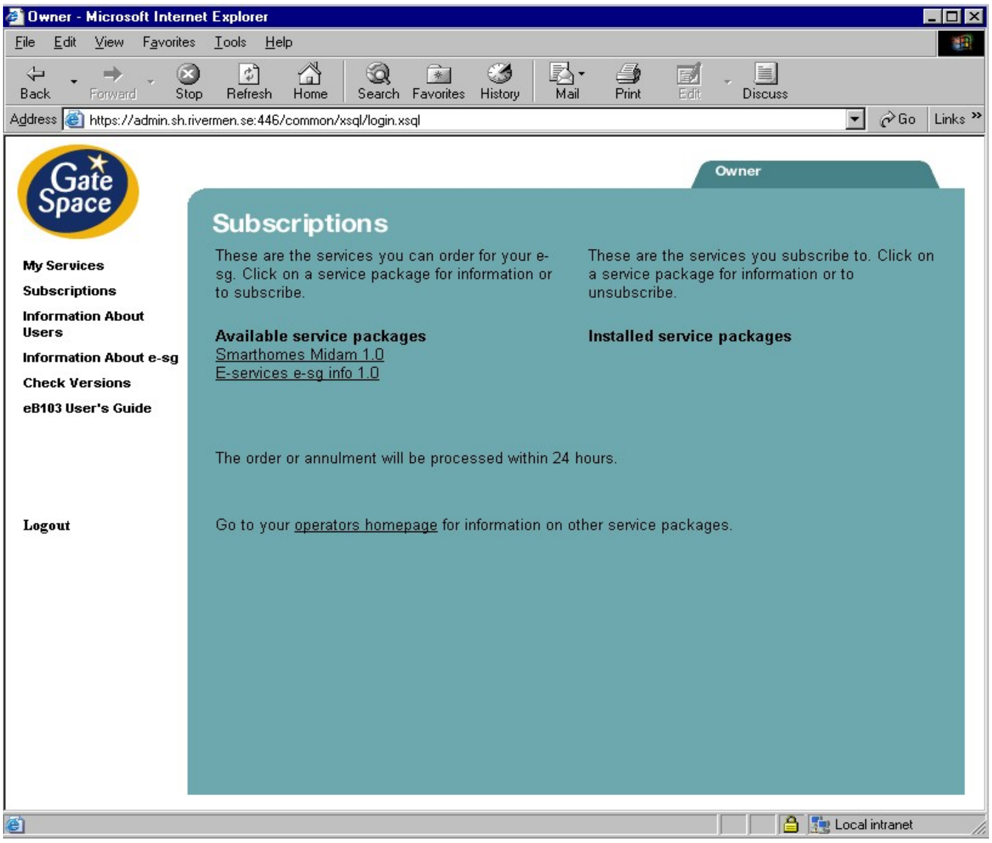

Figure 8: The 'Subscriptions' screen (colour original).

- Select the appropriate bundle for download ('Smarthomes Midam 1.0' in the current example). Then select 'subscribe' to initiate the subscription process (Figure 9).

Figure 9: Initiating bundle downloading.

- To check progress, select ‘My Services’ to obtain the screen shown in Figure 10, which in the present example indicates a successful service subscription (note that this may take some time and require persistent page reloads).

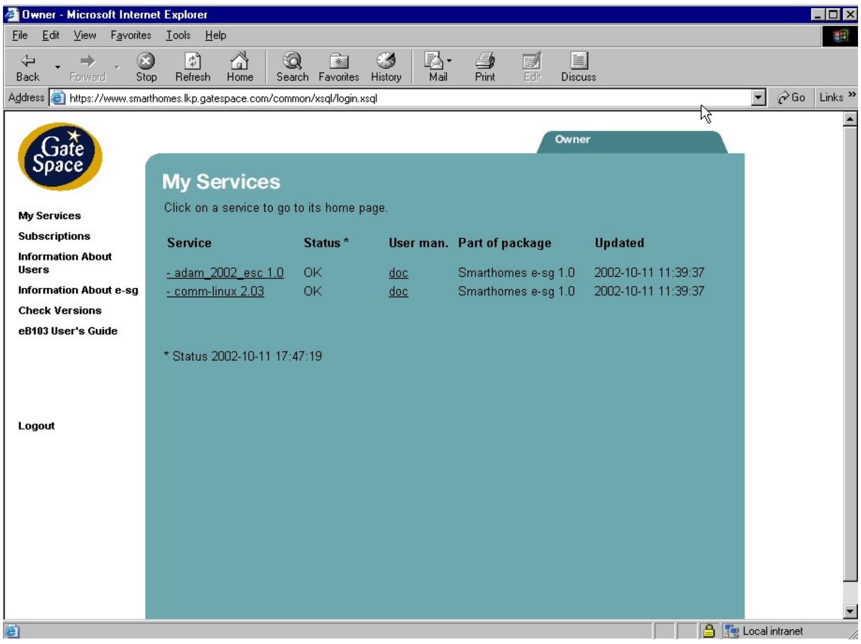

Figure 10: Revisiting the ‘My Services’ screen (original in colour).

2.4 Field installation

Prepare equipment
The following is required: e-box including its ethernet address, RS232/485 adapter, sensors, cabling (RS232 link, RJ45 ethernet link, 4 wire cable for sensors), power supply for RS232/485 adapter/sensors, cable fixing ties, sensor fixing tape and toolkit.

Connect sensors
The sensors required to support the e-service should be connected together along the lines implied by the example of Table 4, noting their assigned addresses.

Table 4: Sensors connected within the SmartHomes generic bundle.

Midam Type	ID	Sensor	Address	Order ID	Bundle OK
100/110	4013	Temperature (indoor/outdoor)	1-20	MIDAM 100 or 110	Yes
180	4113/4213	Temperature/humidity	21-60	MIDAM 180	Yes
800	4152	Occupancy	61-70	MIDAM 800	Yes
420	4252	CO alarm	71-75	MIDAM 420	
170	4313	CO concentration, analogue	76-80	MIDAM 170	Yes
DPS-02	4513	Pressure analogue, absolute	81-85	MIDAM DPS-02	
DPS-01	4613	Pressure difference, analogue	86-90	MIDAM DPS 01	
500	4017	Analogue input (8 channel)	91-95	MIDAM 500	Yes
300	4050	Digital output (8 channel, open collector)	96-100	MIDAM 300	
400	4052	Digital input (8 channel)	101-105	MIDAM 400	Yes
750	4180	Pulse counter (1 channel)	106-125	MIDAM 750	Yes
200	4060	Relay output (4 channel)	126-145	MIDAM 200	
171	4413	CO_2 concentration, analogue	146-160	MIDAM 171	

Notes:

- An-box with MIDAM sensors must use one MIDAM 010 RS232 to RS485 converter.
- There are a large number of humidity sensors because these sensors are combined temperature and humidity probes that require consecutive addresses.
- Sensor addresses are pre-set by Mikrolima as specified in the order. They may be reset as follows:
    - open the sensor and set the jumper to 'init';
    - connect the sensor to the RS232/485 adapter and to the computer serial port;
    - run the program available from Komterm to reset the address; and
    - reset the jumper to its former setting.
- For the 8 channel analogue and digital inputs, the driver in the bundle will send additional addressing information to identify the particular channel. Each channel is polled by the generic bundle.
- The driver for pulses must be pre-set by Mikroklima.
- Note that the last sensor in the chain has to have a terminator jumper connected, but only if the total segment length is 50m or greater. Again, these jumpers are in the sensor casing and are set to 'off' by default.

Connecting sensors to the e-box

Figure 11 shows the wiring used to connect the Adam system to the e-box.

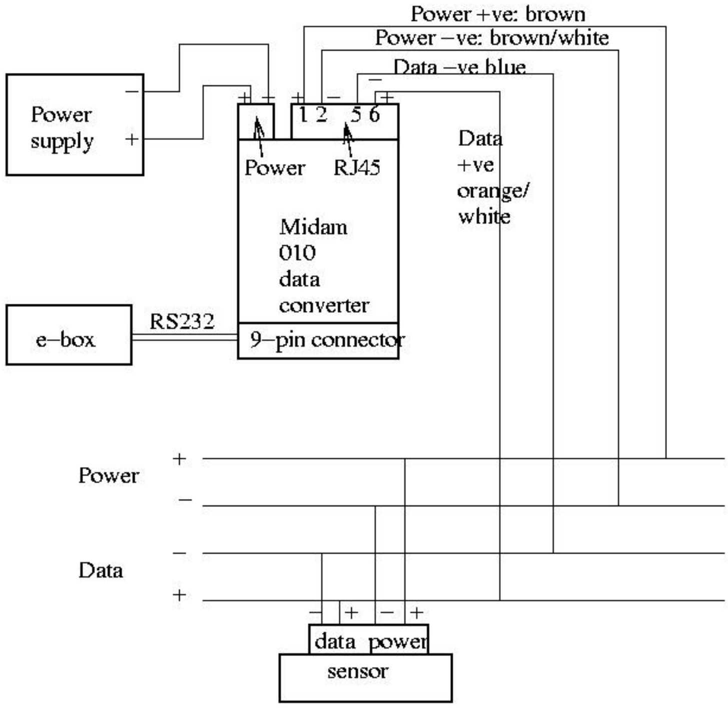

Figure 11. Connecting sensors to the e-box.

Notes:

- 4-core cable is used to connect the sensors to the RS232/485 converter. Two of the cores carry the positive and negative voltage supply, while the other two carry the positive and negative signal from the sensor back to the RS232/483 converter.
- The connection of multiple sensors should be undertaken using parallel connections at the 4 terminal connection block within the sensor casing (as shown in Figure 10).
- There does not seem to be a standard wiring colour configuration for RJ45. It is important therefore to identify the wiring at terminals 1 and 2 for supplying power and terminals 5 and 6 for the data signal. When identifying terminals, the RJ45 connector should have the side containing the bayonet connector facing the floor, with the copper terminals pointing upwards and terminal numbers 1-8 reading from right to left.

Initiate data collection

If the bundles are downloaded in advance of field installation, the e-box should automatically start sending data as soon as it is booted (see next section). If not, revisit the ‘My Services’ Web page as above. Note that all parts of the Smarthomes system, including the e-service centre, adhere to GMT.

Check installed e-service

A generic SmartHomes Web site is available at http://peta-sru.mecheng.strath.ac.uk/smarthomes, which includes a link to the database server at http://peta-esru.mecheng.strath.ac.uk:8000/eeis. When prompted, enter the username and password. The data from an e-box can then be interrogated by entering the e-box serial number followed by the required sensor code as indicated in Table 5.

Table 5: Data used to interrogate e-box data returns.

Sensor type	**Code**	**Examples**
Temperature	tmp+SENSOR_NUMBER	tmp1…tmp20, tmp21, tmp23…tmp59
Humidity	hmd+SENSOR_NUMBER	hmd22...hmd60
Occupancy	occ+SENSOR_NUMBER	occ61...occ70
CO alarm	coa+SENSOR_NUMBER	coa71...coa75

CO concentration	coc+SENSOR_NUMBER	coc76...coc80
Analogue input	anlg+CHANNEL_NUMBER+SENSOR_NUMBER	anlg091, anlg192...anlg795
Digital input	dgt+CHANNEL_NUMBER+SENSOR_NUMBER	dgt0101...dgt7105
Pulse counter	cnt+SENSOR_NUMBER	cnt106...cnt125

Troubleshooting
In case of difficulty, the following checks/actions should be initiated.

- Check the requirements of the access network.
- Check the cable connections (in particular that there is a straight RJ45 cable between the e-box and the access network and a cross over RJ45 cable between the e-box and the local PC).
- Use the 'ping' or 'pathping' command to check the physical connection.
- Ensure that the ethernet interface of any router connected to the e-box is configured at 10Mbits/s.
- When installing the e-box in an organisation with a static IP address, ensure that the DNS server can resolve the e-service centre alias.

3. Generic data interrogation procedure
To support all e-box deployments, a generic Web site was created as illustrated in Figure 11. Via this tool, users can view the list of currently installed e-boxes as registered with the EnTrak database. The obtained list contains basic e-box information including locations and the serial number. Details on the sensor set connected to a given e-box may then be accessed via the e-box serial number. The result for e-box AO62166112 is shown in Figure 12.

The historical profiles for the monitored parameters (e.g. temperatures, humidity, occupancy, CO, electrical power *etc*) may now be accessed. Figure 13, for example, shows the temperature profile monitored by e-box A062166112. The output period and time resolution of the graph is user-defined (since the monitoring frequency is 30 seconds, the time resolution can vary from minutes to months). Hourly profiles of CO and occupancy are displayed in Figures 14 and 15 respectively.

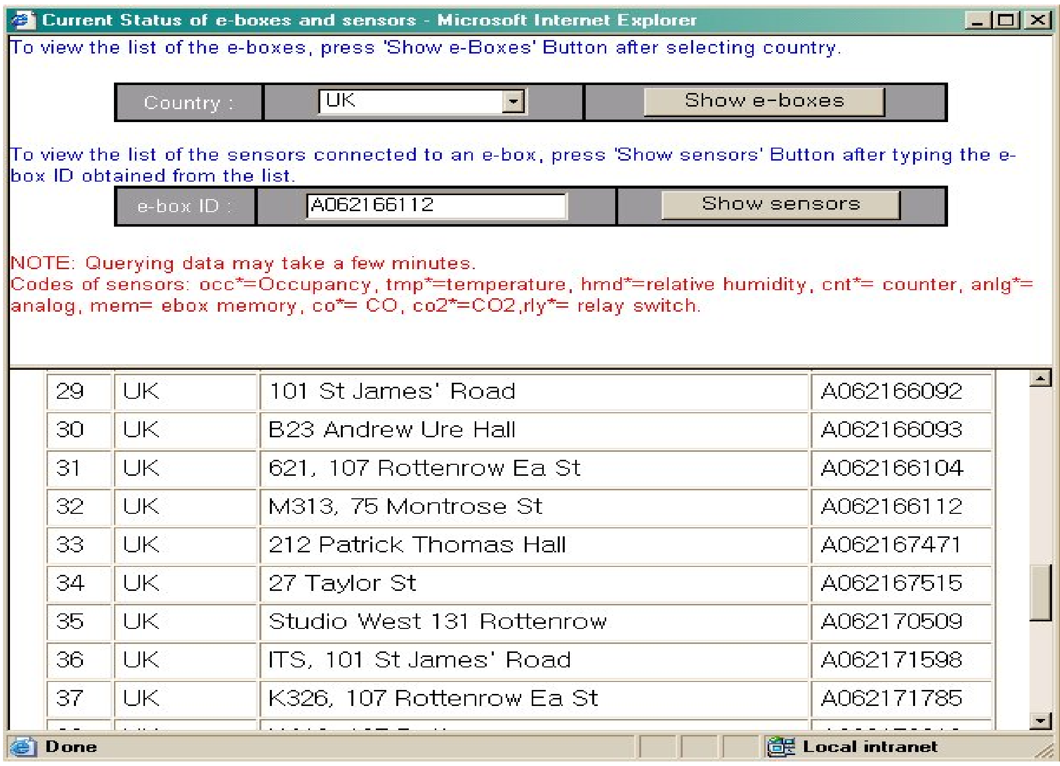

Figure 11: Querying deployed e-boxes (colour original).

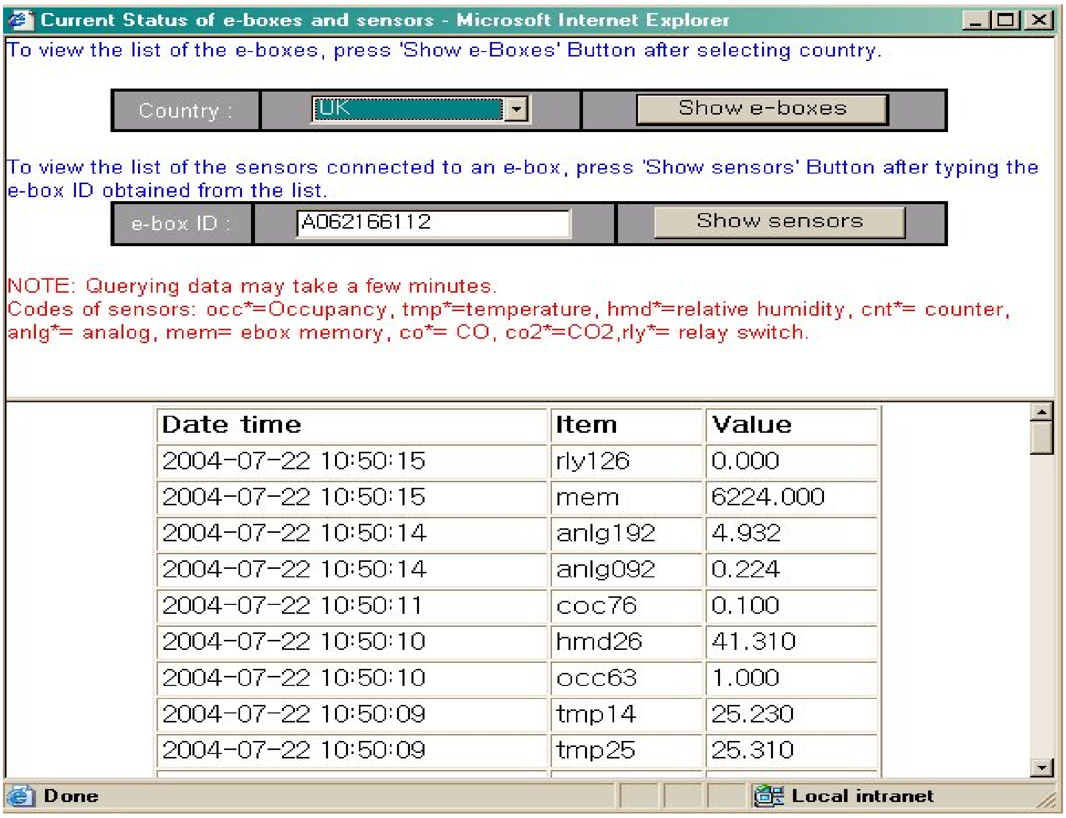

Figure 22: Querying the sensors connected to a specified e-box (colour original).

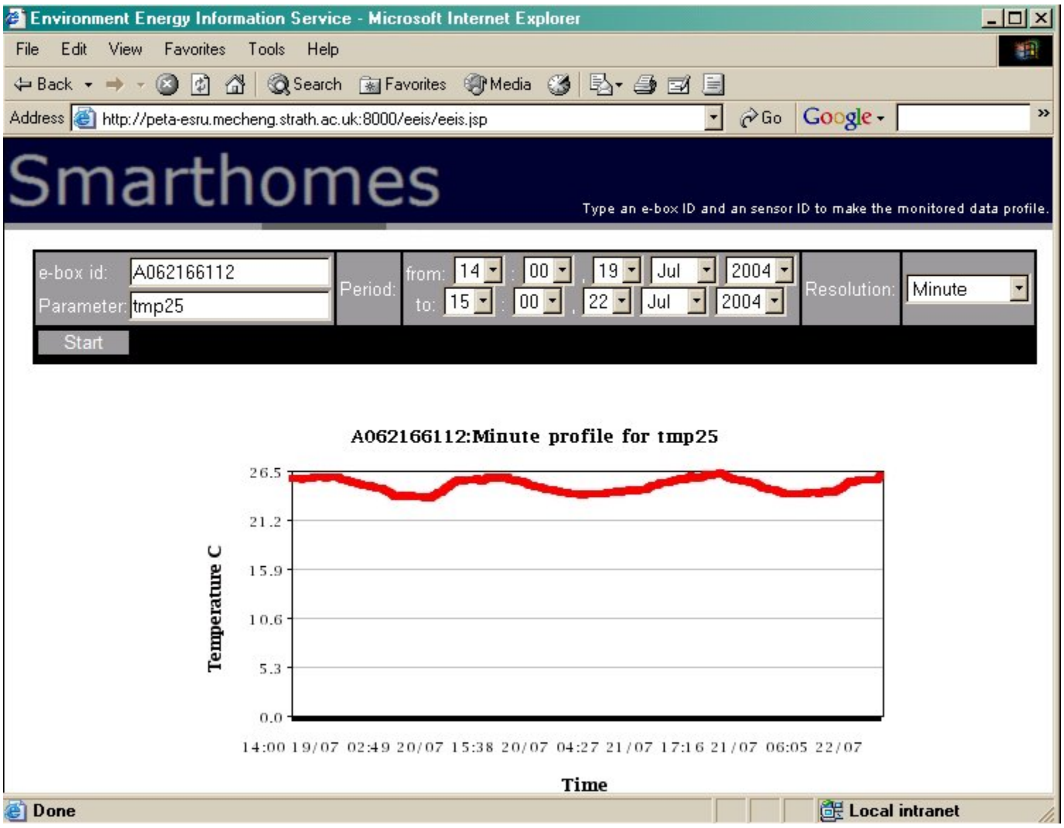

Figure 13: A monitored temperature profile (colour original).

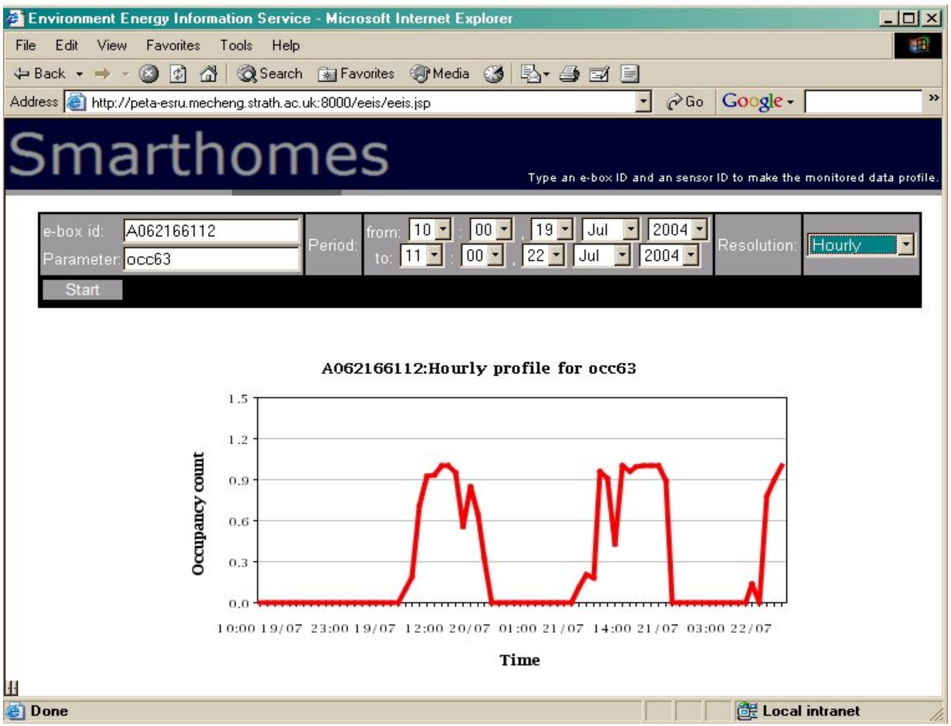

Figure 14: A monitored occupancy profile (colour original).

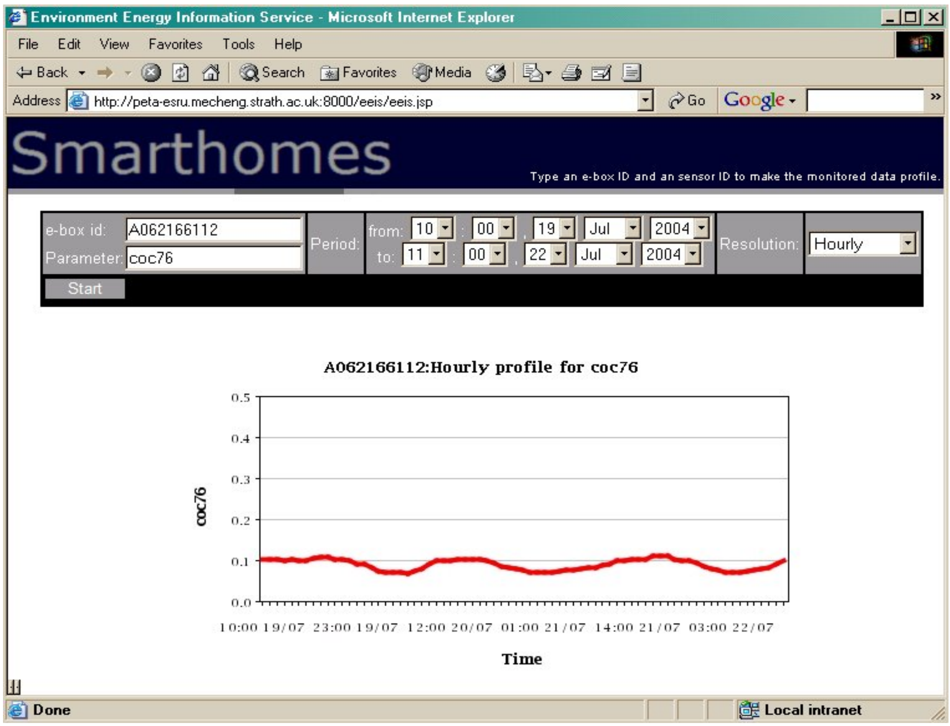

Figure 15: A monitored CO profile (colour original).

4. Service-specific Web sites

4.1 Sweden

The ‘thermal justice’ energy service has been developed through deployment of 57 e-boxes in a multi-family dwelling in Gävle, with a total of 74 sensors measuring apartment temperature, humidity and electricity consumption, and external temperature, global solar radiation and wind speed, all at 30 second intervals. In one case, 48 sensors have been connected to a single e-box, which then operated reliably. Deployments were also made in multi-family and single-family houses in Stockholm, and an experimental house in Sigtuna. In the multi-family house, e-boxes are installed in each of 126 flats with the monitored data used to deliver an e-service to the tenants. In the single-family house, the efficiency of a heat recovery and cooling system was addressed, while the experimental house deployment set out to monitor and prove the efficiency of low-exergy prototypes.

The results from the Swedish trials demonstrated that the SmartHomes system can handle various scales and types of services and that a single e-box can serve several users and handle a high number of sensors. Figures 16 through 22 give examples of the Swedish e-services.

Figure 16: Top page of the Swedish SmartHomes project.

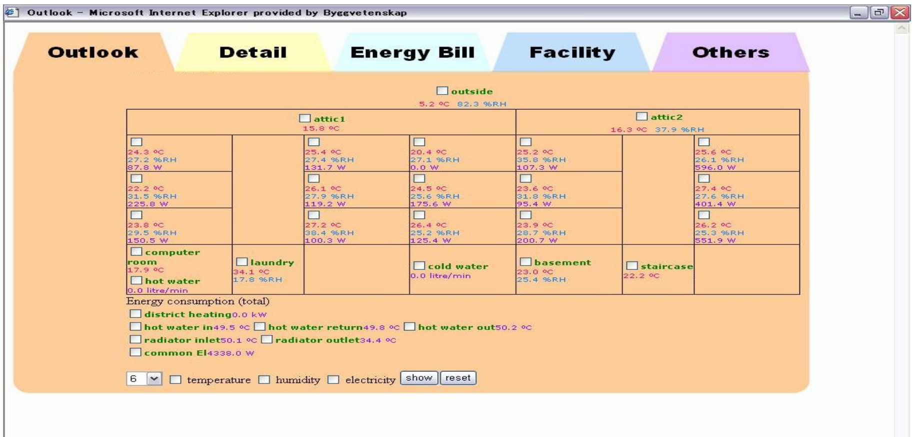

Figure 17: Energy consumption in a multi-family house.

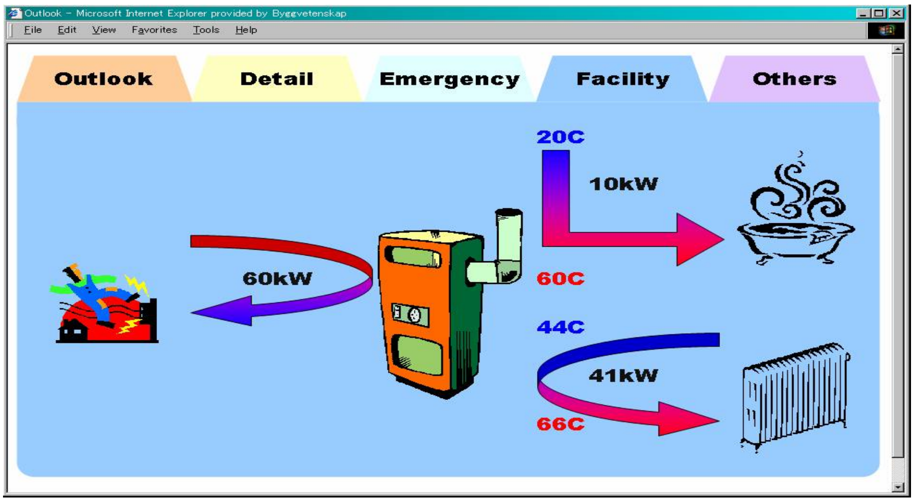

Figure 18: Heat exchanger efficiency (left - energy from district heating; top right - energy consumed for water heating; bottom right - energy consumed for space heating).

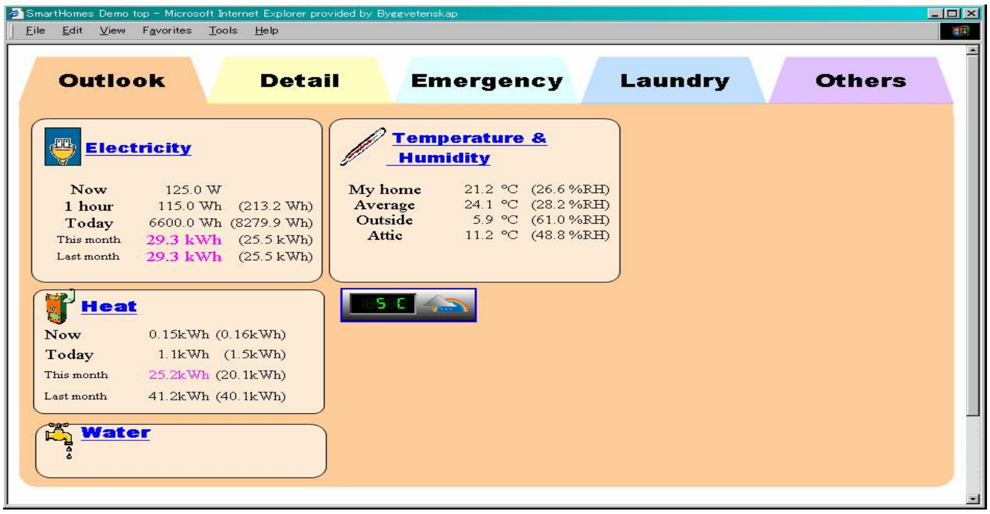

Figure 19: Apartment energy consumption and comparison with average values.

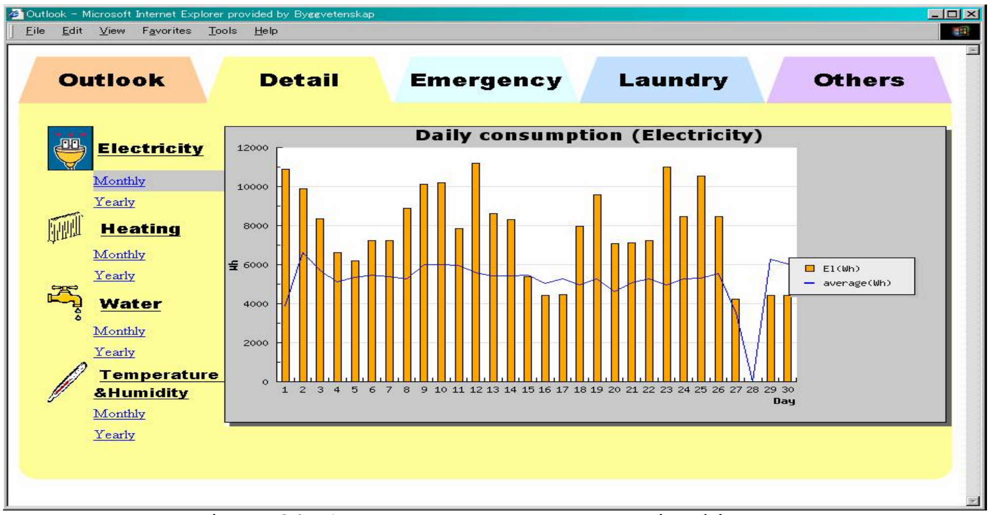

Figure 20: Apartment energy consumption history.

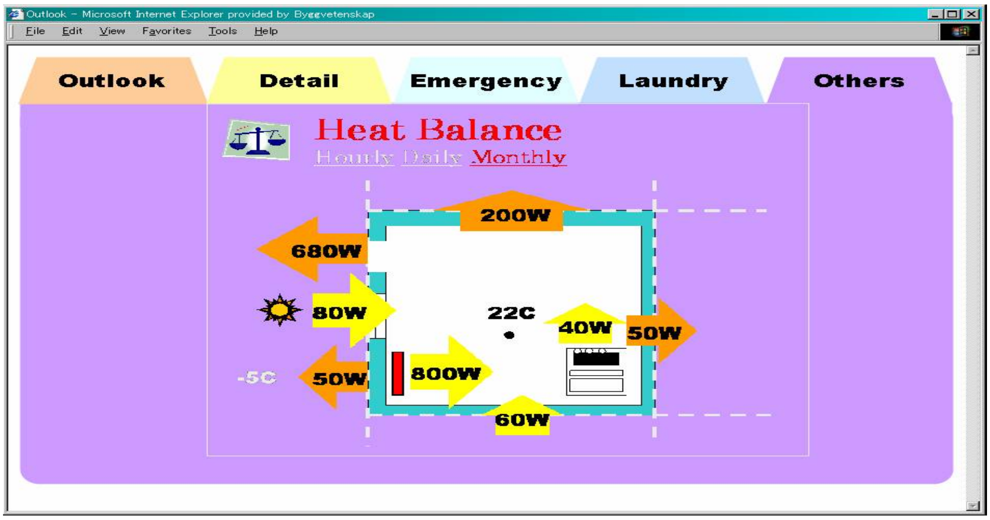

Figure 21: Apartment energy balance.

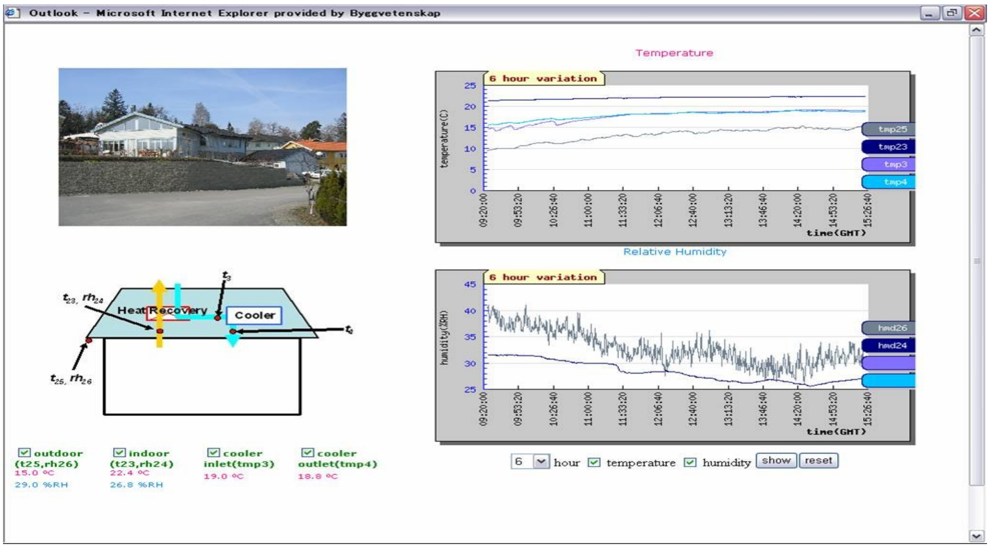

Figure 22: Heat recovery and cooling system monitoring.

4.2 Greece

Some 47 e-boxes were deployed in Greece to support 7 e-services grouped in 6 categories: prediction of cooling energy consumption, control of cooling equipment, indoor temperature alarm, energy rating for cooling, ambient temperature prediction and indoor/outdoor temperature and cooling consumption monitoring. Figure 23 shows the main Web page that presents these services.

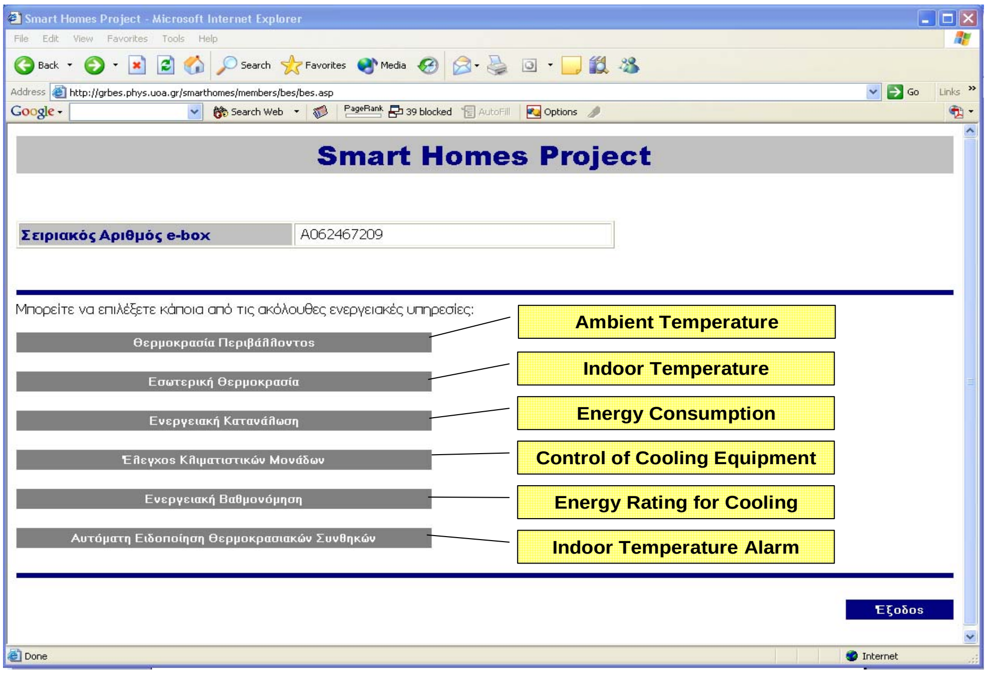

Figure 23. The SmartHomes main Web page in Greece.

4.2.1 Prediction of cooling energy consumption

This is based on an artificial neural network model (ANN) that executes online and estimates the cooling energy consumption for the next 24 hours. The input requirements are the cooling consumption measurements for the preceding 5 days and the ambient temperature the previous day.

The model accuracy is close to 7% (Figure 24), giving a useful tool to utility companies to effect regional demand management. Where the schedule of use of the cooling equipment is repeated daily (a common situation in office buildings) the accuracy increases to about 4%.

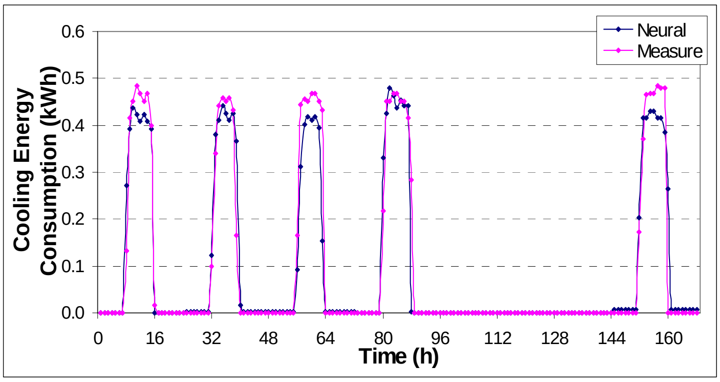

Figure 24. Accuracy of the ANN approach.

The aspect model for this e-service is depicted in Figure 25, while the instrumentation required for its implementation is 1 e-box, 1 RS232 to 422/485 converter (Midam 010 module), 1 cooling energy consumption sensor (Hager EC120 electrical meter, 1 pulse per 100Wh), 1 pulse counter (Midam 750) and 1 ambient temperature sensor (Midam 11).

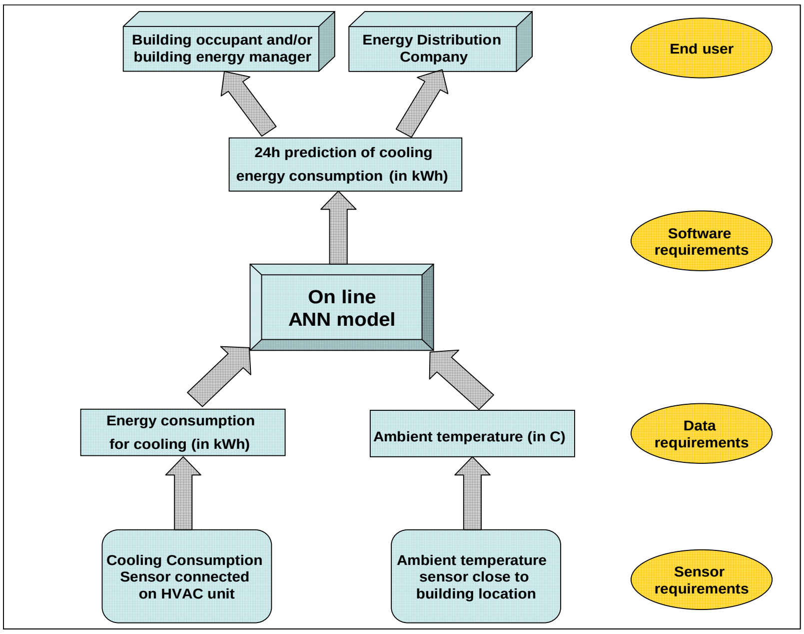

Figure 25: Aspect model for the cooling energy prediction service.

The cooling energy as predicted by the ANN model is as illustrated in Figure 26.

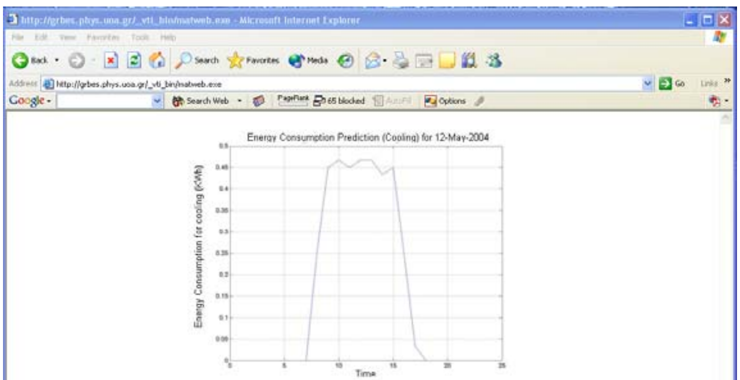

Figure 26: Predicted cooling energy consumption as presented to the end user.

4.2.2 Control of cooling equipment

Two strategies have been implemented: scheduled control and intermittent control. The first allows the user to define a weekly schedule of operation on an hourly basis (Figure 27).

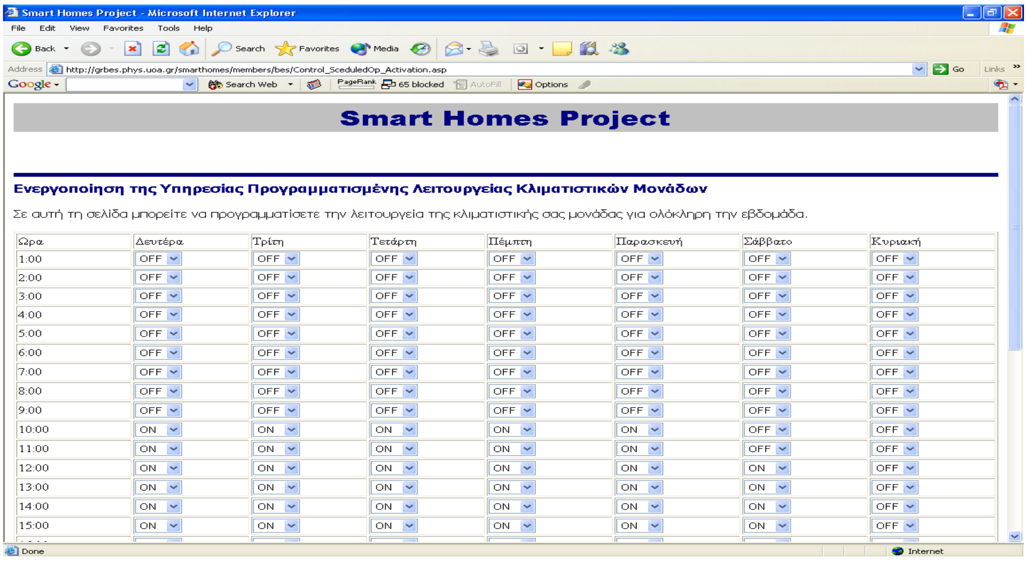

Figure 27: Web interface for the scheduled control e-service.

After activation, operation of the A/C unit follows the defined schedule. In order to avoid intervention with the unit's electronics, a programmable controller is connected to a relay actuator (Figure 28). This relay is part of the local SmartHomes sensor network and is managed through the e-service centre with control performed by sending commands via the e-service centre. This allows service recipients to remotely operate their cooling unit. The instrumentation required for the implementation of the service is 1 e-box, 1 RS232 to RS422/485 converter (Midam 010), 1 programmable remote control and 1 relay switch (Midam 200).

Figure 28: Components used to control cooling equipment.

The second control strategy enables the intermittent operation of the controlled cooling equipment; an approach that leads to energy conservation (with reductions up to 17%) and improves energy management. This strategy requires the definition of a threshold value of the indoor temperature under which the cooling unit operates intermittently. The e-service then checks every 15 minutes if the indoor temperature is lower than the threshold value. If so, the unit is turned off for 5 minutes (but not more than two times per hour or less than 20 minutes between off actuations).

4.2.3 Indoor temperature alarm

This service provides notification of the indoor thermal conditions at specific building locations as part of a health care e-service. The service monitors hourly indoor air temperatures and compares these with a threshold value defined by the user via the service Web page. When the indoor temperature is higher than the threshold value, an alert is raised with an appropriate authority. The required instrumentation includes 1 e-box, 1 RS232 to RS422/485 converter (Midam 010) and 1 indoor temperature sensor (Midam 100).

4.2.4 Energy rating for cooling

Greece has prepared new energy certification regulations in response to the requirements of the EU directive for the Energy Performance of Buildings. As a function of annual energy consumption (kWh/m^2) for heating and cooling, the building category (residence, office, school, hotel *etc*) and the climate zone (4 in Greece), an e-service has been devised to classify a building from A to E. Figure 29 shows the corresponding aspect model.

The required instrumentation includes 1 e-box, 1 RS232 to RS422/485 converter (Midam 010), 1 cooling energy consumption meter (Hager EC120 electrical meter, 1 pulse per 100Wh) and 1 pulse counter (Midam 750, frequency module).

Figure 30 shows the result as presented to the service recipient (building owner/occupier, energy manager, performance inspectorate *etc*).

4.2.5 Ambient temperature prediction

This deployment measures ambient temperature as an input to the abovementioned ANN model to forecast temperatures over the next 24 hour period with accuracy close to 6% as shown in Figure 31.

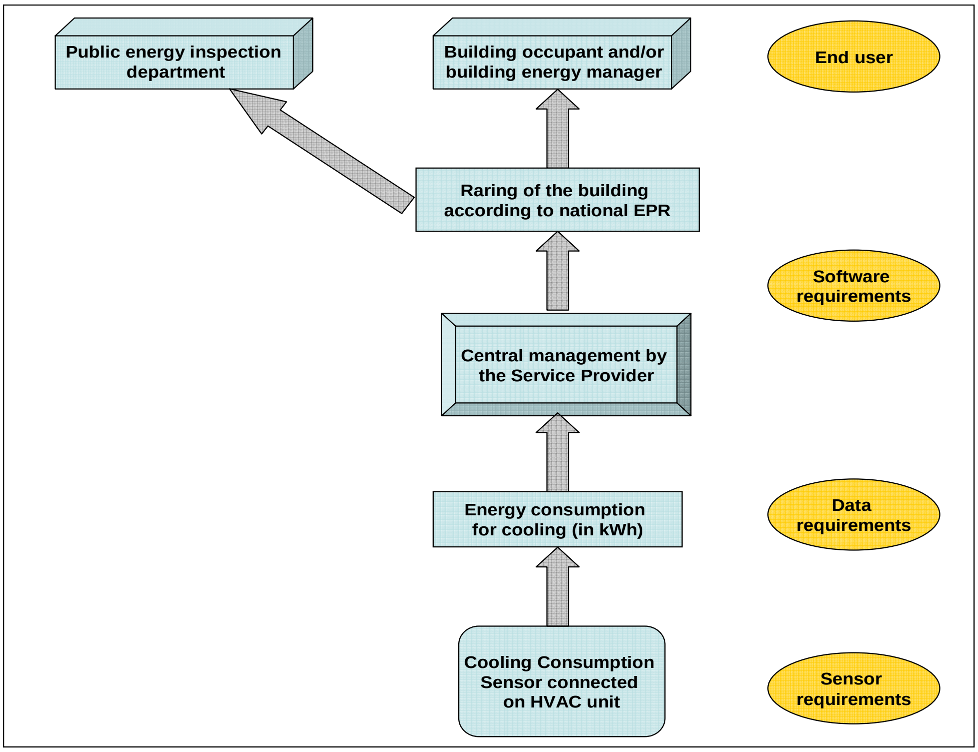

Figure 29: Aspect model for the cooling energy rating e-service.

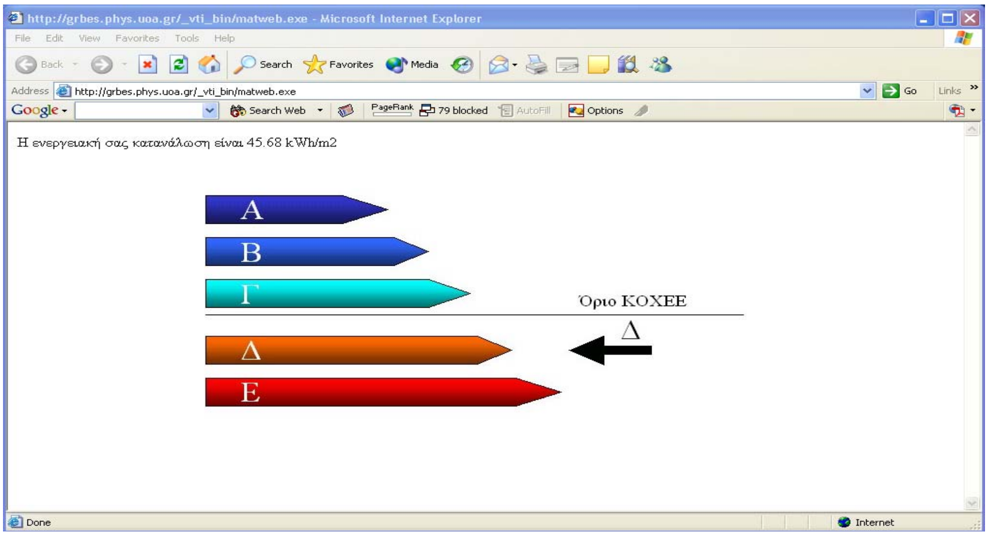

Figure 30: A building cooling energy rating.

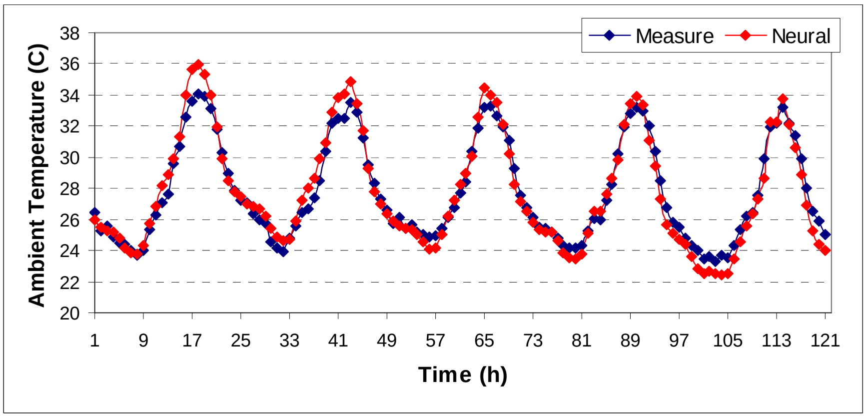

Figure 31: Comparison between measured and predicted ambient temperature.

4.2.6 Indoor/outdoor and cooling consumption monitoring

This e-service provides information on the above over any selected time period. The required instrumentation includes 1 e-box, 1 RS232 to RS422/485 converter (Midam 010), 1 indoor temperature sensor (Midam 100, digital), 1 ambient temperature sensor (Midam 110, digital), 1 cooling energy consumption meter (Hager EC120 electrical meter, 1 pulse per 100Wh) and 1 pulse counter (Midam 750, frequency module). Figure 32 shows the location of the ambient temperature sensor in the Aigaleo field trial.


Figure 32: Ambient temperature monitoring.

4.3 Scotland

4.3.1 Regional energy management

Figure 33 shows an e-service for energy management support. At the core of the service lies the SmartHomes database served by e-boxes distributed throughout the estate being managed (Highland Region within the present field trials). The collected data is analysed in order to provide relevant and up-to-the-minute information to a range of possible recipients, from policy makers, through planners and designers, to citizens.

To assist with interpretation, a Geographical Information System may be employed to overlay the energy and environment information on conventional types of information such as street layouts or power cable routings. To assist with policy formulation, an energy simulation model is included in the e-service to enable an appraisal of options for change. Where an option proves beneficial, its predicted fuel use may be returned to the database to be held alongside the present fuel use data. This enables the side-by-side display of information relating to present and future states in support of extensive inter-comparisons before deployment decisions are taken.

By modelling proposed measures prior to their deployment, alternative options may be compared in terms of relevant criteria, including the impact on the energy supply system and the mitigation of greenhouse gas emissions. Furthermore, the impact of previous actions is implicit within the monitoring process so that schemes with a poor return can be quickly discarded and those with a high return retained.

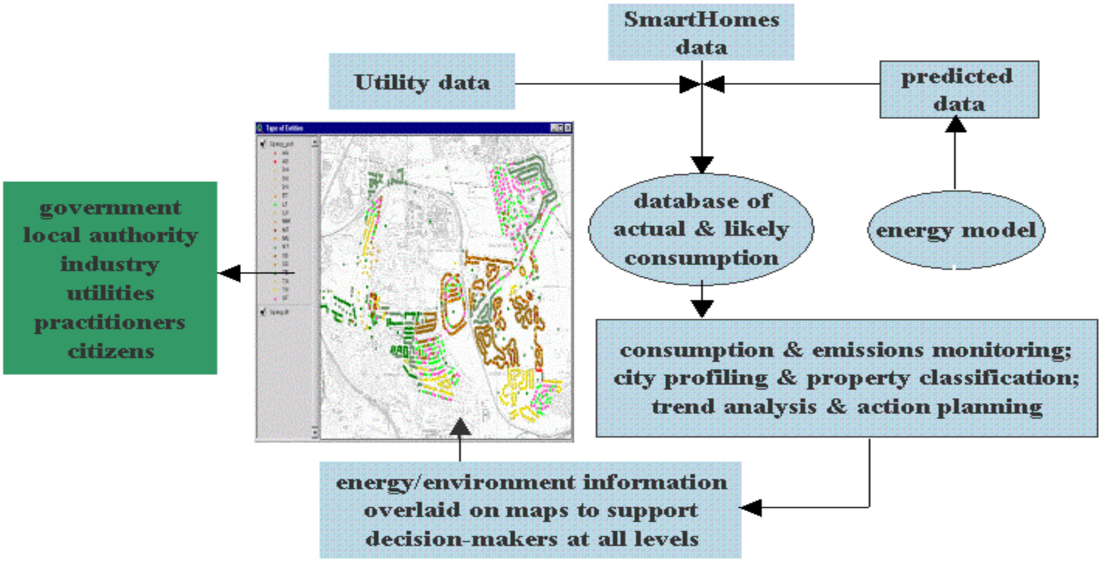

Figure 33: The energy management e-service.

4.3.2 Demand-supply matching

Current energy policy promotes the increasing use of renewable technologies for electricity generation. The technologies being deployed to satisfy this are inherently stochastic in operation, e.g. wind and hydro power. The use of high levels of renewable energy can result in perceptible variations in the quantities of power delivered. If the electrical supply system integrity is to be maintained during these variations, a greater level of control over both the supply and demand side will be required. Such control can be:

- demand-side focused, so that a proportion of the demand load can be shed as the supply availability falls and recovered as output from the supply increases; or
- supply-side focused, so that supply output can be restricted when there is insufficient demand to absorb the excess power supplied.

The embedding of simulation tools within an e-service allows prediction of:

- the magnitude and rate of change in demand, based on trend and climate analyses; and
- the magnitude of the power supply from renewable generation plant based on weather trends.

A prototype algorithm termed REDMan (Real-time Embedded Dispatch Manager) was developed (Conner 2003) to enable the predictive control required for the integration of small heterogeneous renewable supply technologies. On the basis of the returns from e-boxes embedded throughout small communities, the REDMan controller prioritises supply-load matching as follows.

A source (generator) must first advertise the maximum amount of power it can supply, and its per-unit price. The source will then be informed of the amount of power required of it, and must then supply that amount. The amount of power required may change at any time and may be any amount between zero and the advertised maximum. In advance of switching on, a demand (load) must state the amount of power required and the maximum per-unit price it is prepared to pay for fulfilment. The demand will then be informed as to whether or not it can be fulfilled at that price. If so, it may proceed; if not, it must remain off, or resubmit at a different price. This information is supplied to a dispatching algorithm whose goal is to buy energy from sources and sell it to demands in an optimal manner, or as close to optimal as possible.

The algorithm used is a simple rule-based one, which strikes a compromise between complexity and degree of optimisation. The price that the demand submits to the dispatcher is the price it must pay, irrespective of how much the dispatcher paid for the electricity in the first place. The REDMan algorithm is summarised in Figure 34.

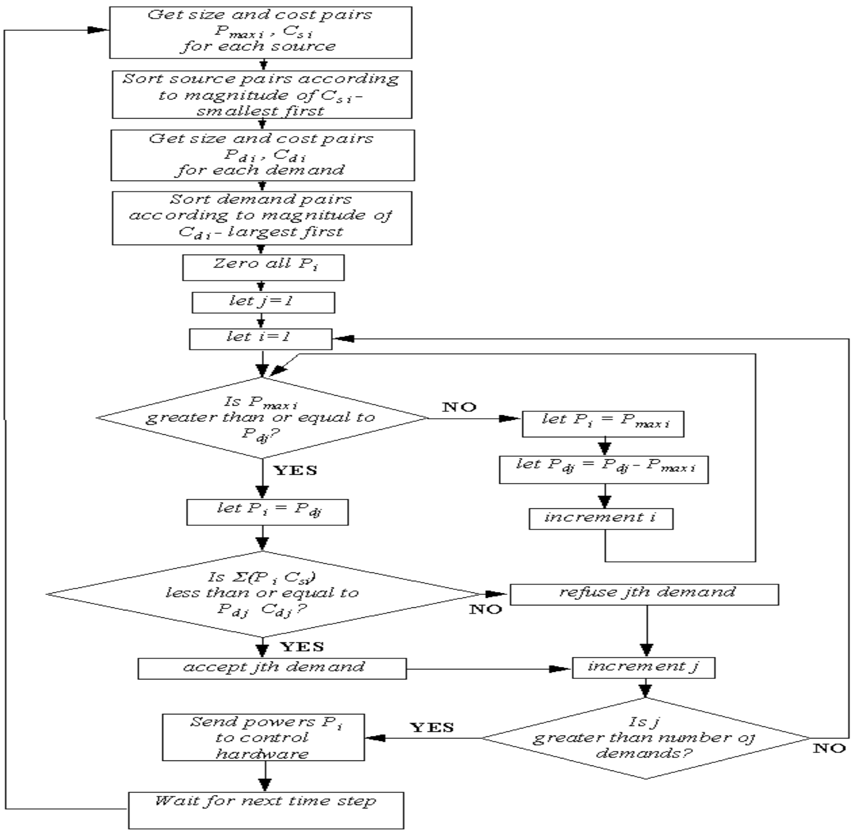

Figure 34: REDMan logic for demand- supply prioritisation and matching.

4.3.3 Care for the elderly

An e-service was developed corresponding to care for the elderly. The service provides health risk advice associated with indoor climate conditions and activates a cold alarm when necessary. Figure 35 shows the service home page, while Figure 36 shows the real-time temperature and humidity monitoring, which serves a cold detection process running on the EnTrak server. The cold alarm is activated when the temperature remains below a specified value over a given period of time. Via the Web site, the service recipient can influence the arrangements to be followed under an alarm condition. The service has been extended to include the monitoring of the health risk associated with mould growth. The underlying analysis module relates the monitored temperature and humidity to the growth limits for several mould categories. Figure 37 gives an example outcome for the situation where the indoor temperature is 25°C and 78% relative humidity.

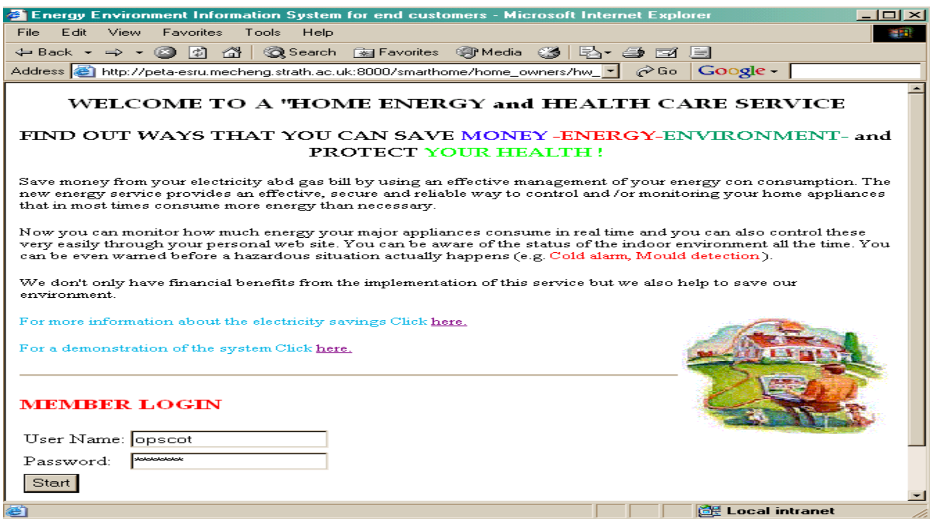

Figure 35: The care for the elderly e-service.

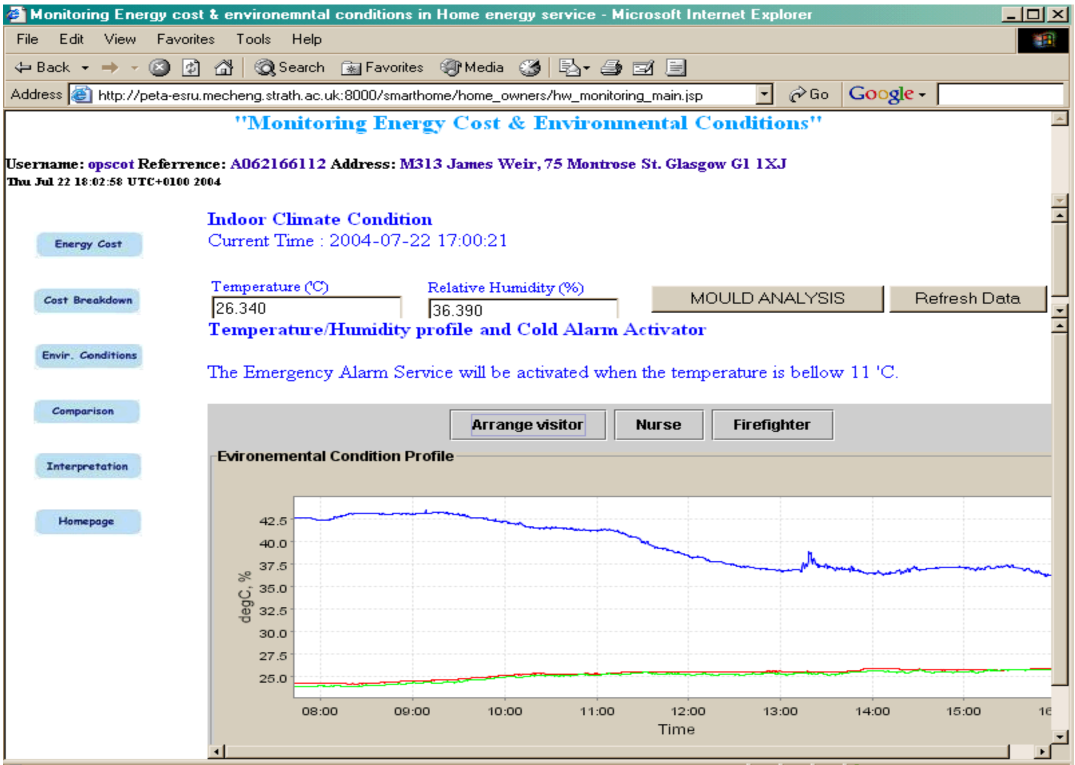

Figure 36: Indoor climate profiler and cold alarm activator.

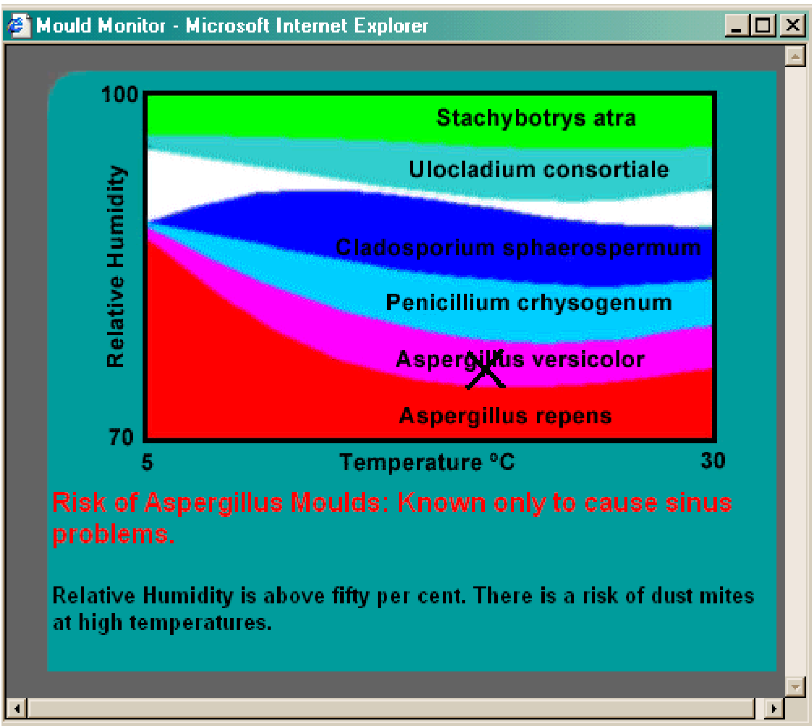

Figure 37: Detection of potential mould occurrence.

4.4 Czech Republic

Four test bed types were targeted in the Czech Republic:

- comfort control in a primary school in Mnichovo Hradiště;
- temperature, humidity, occupancy and CO_2 monitoring in offices at the Czech Technical University;
- temperature and humidity control at the Czech National Library; and
- temperature/energy consumption monitoring within multi-family flats in Mnichovo Hradiště.

4.4.1 Comfort control in a primary school

As depicted in Figure 38, the envisaged e-service involved comfort evaluation with adaptive control by the energy supplier and feedback to the user.

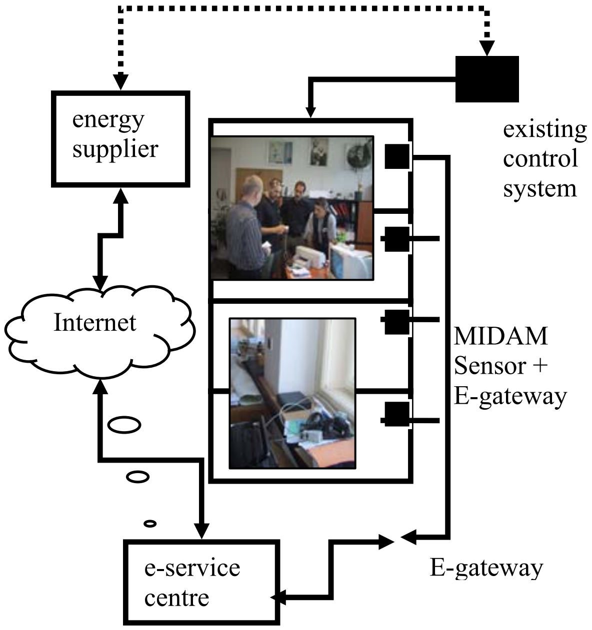

Figure 38: School comfort control.

The required hardware included 5 e-boxes and a temperature sensor located in each space.

4.4.2 Office comfort and air quality

As depicted in Figure 39, this e-service comprised the reporting to occupants of indoor conditions relating to comfort and air quality.

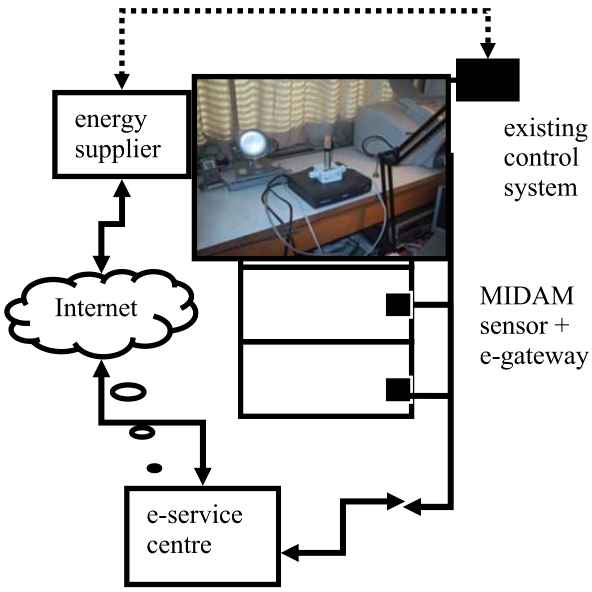

Figure 39: Office comfort and air quality.

The hardware deployed including 6 e-boxes, each equipped with temperature, humidity, occupancy and CO_2 sensors.

4.4.3 Conditions monitoring within the National

As depicted in Figure 40, this e-service entailed the monitoring of indoor conditions from the viewpoint of artwork protection. The hardware comprises one e-box to which was connected multiple sensors for temperature and humidity.

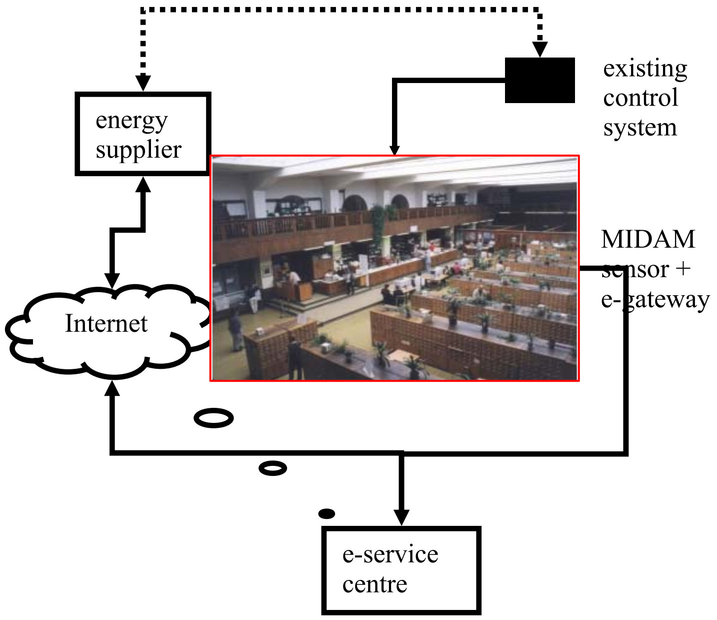

Figure 40: Artwork protection.

4.4.4 Energy use monitoring in multi-family flats

As depicted in Figure 41, this e-service entailed the monitoring of apartment energy use along with internal and external temperatures as an input to equitable billing and feedback to encourage energy savings through temperature reduction.

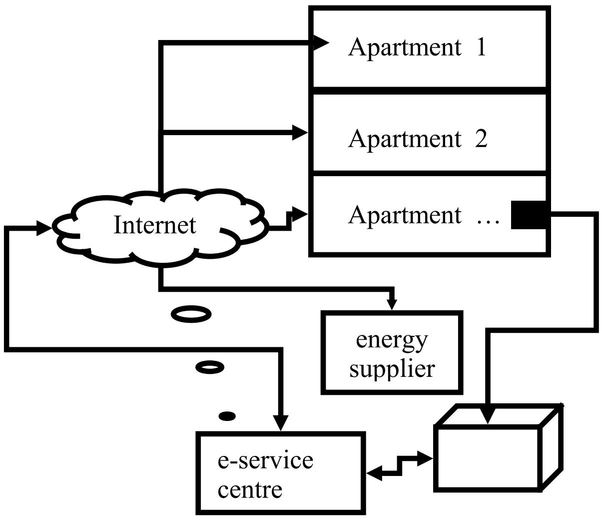

Figure 41: Energy monitoring and control in multi-family flats.

The deployed hardware included an e-box per apartment with connected sensors for temperature, electricity/heat use and heating system actuation.

4.4.5 E-service Web sites

Figures 42 through 45 show a selection of annotated Web pages as established to support the above e-services.

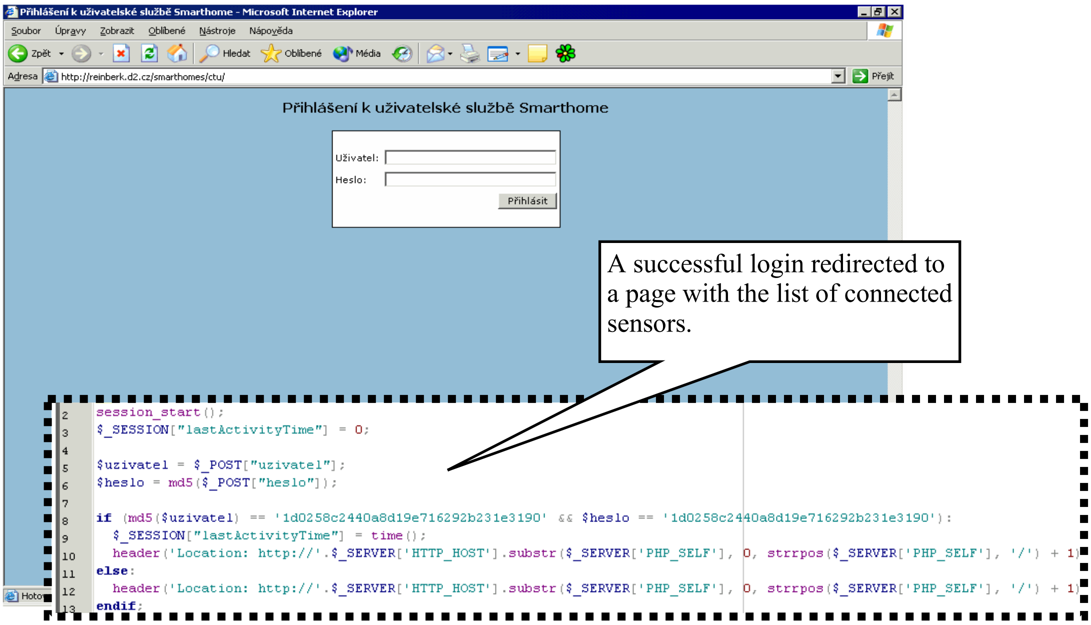

Figure 42.

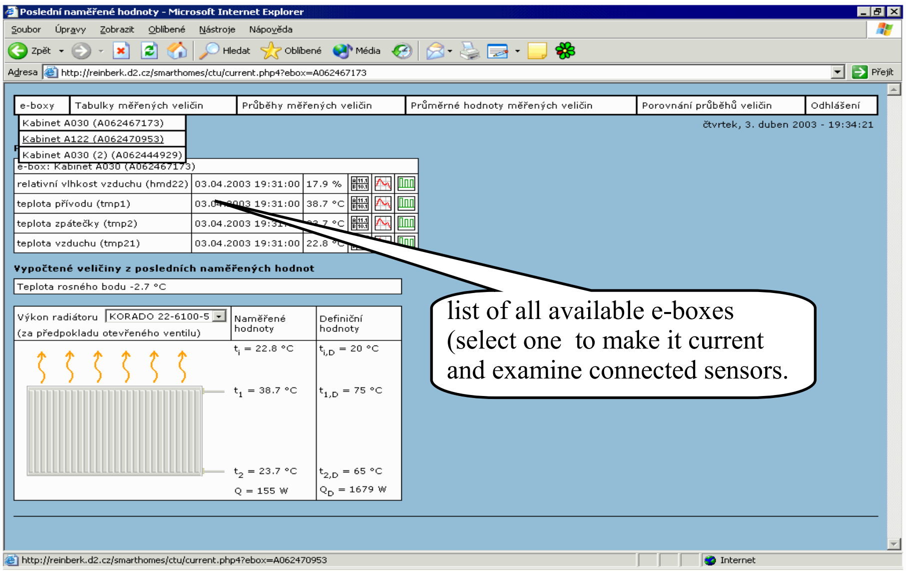

Figure 43: E-box interrogation.

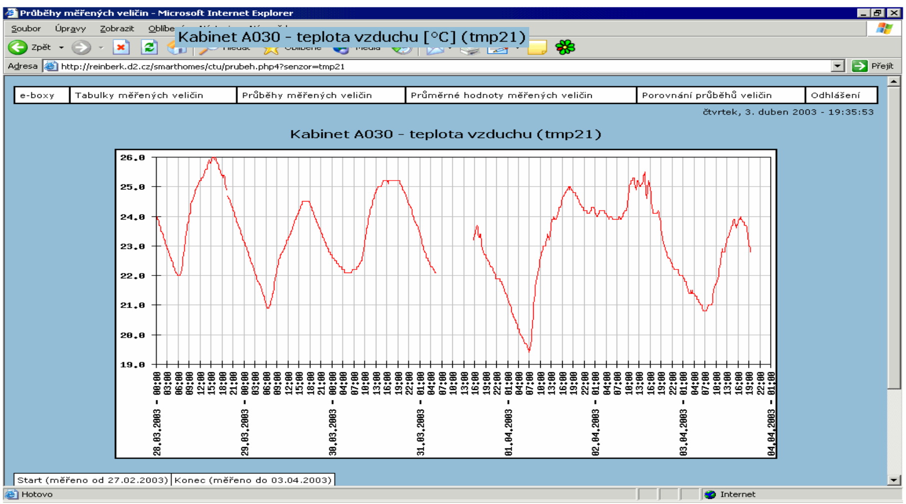

Figure 44: Apartment temperature response.

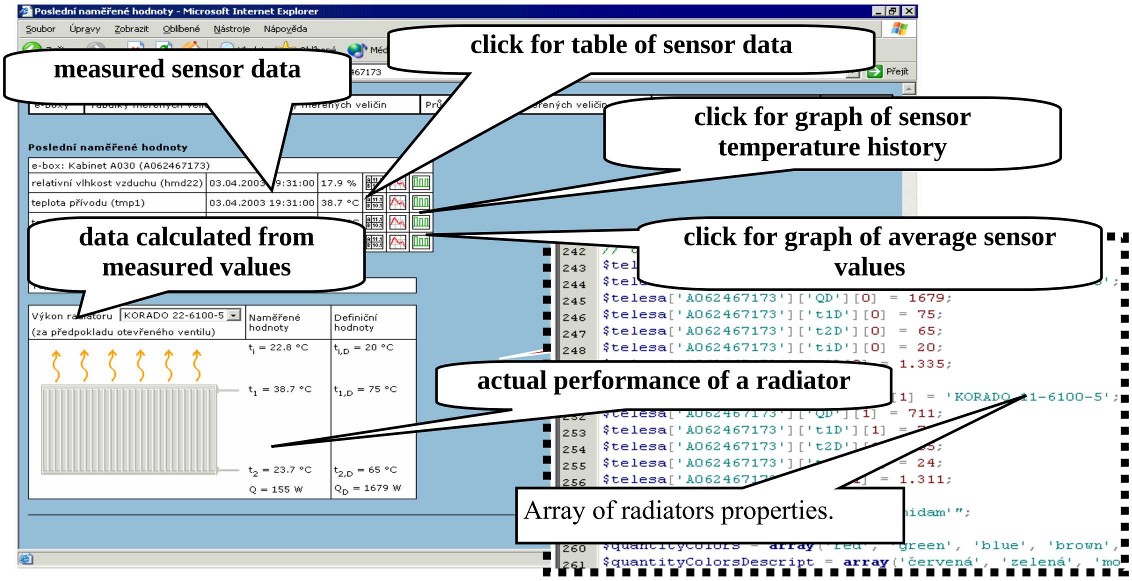

Figure 45: Heating system performance.

Appendix 5: Work Package 5, Market study

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1. Introduction

Four market studies have been performed corresponding to each of the participating countries. Since both the targeted e-services and market conditions in each country are different, the scope for a detailed inter-comparison is limited. Instead, the study set out to quantify public acceptability of e-services, estimate the value of these services to users, and elaborate the required changes to current work practices within provider organisations. The services investigated included:

Czech Republic

- Linking comfort to energy with individual apartment feed-back on energy use extracted from whole building metering.
- Remote systems control (e.g. whole block temperature set-point adjustment as a function of weather conditions).
- Information to local authorities on energy consumption.

Greece

- Prediction of regional cooling energy demand based on the knowledge of a building’s balance point temperature as a function of predicted ambient temperatures.
- Information to building occupants on cooling demand and appropriate measures to reduce this demand.
- Monitoring of the indoor temperature to guard against overheating.

Scotland

- Regional level energy management support to local authorities and utilities with the emphasis on energy action plan formulation.
- Care for the vulnerable in relation to fuel poverty and hypothermia.

Sweden

- Equitable billing in multi-family buildings based on centrally metered data pro rated by monitored energy-related parameters.
- Information systems based on monitored data compared with benchmarks.

2. Survey results

This section presents the results of investigations performed both within the present project and by external organisations. The results are used to estimate the market potential for each e-service

2.1 Energy and the Internet

The Czech team interviewed 250 people in Mnichovo Hradiste. Of people living in rented flats, 39% were interested in the regular monitoring of energy consumption, while 49% had no view. Regarding the possibility to regulate energy consumption, 69% were positive. While 60% were planning an Internet connection, only 8% of respondents were actually connected.

The Greek team surveyed 120 tenants in the city of Athens. 72% of respondents raised concerns about energy monitoring for economic reasons. The service of most interest was the provision of an alarm under threatening conditions (e.g. overheating). More than 20% of Greeks above the age of 15 years are PC users while 13% are Internet connected.

In Sweden, the TEMO company performed a telephone investigation. Tenants were asked general questions about the monitoring of energy consumption and their Internet usage. The result showed that about 50% regarded individual energy measurement as an effective way to influence running costs, but that only one in three would accept lower indoor temperatures if suggested as an energy saving measure. A recurring finding from several projects addressing individual metering was that the administration costs of data management can be high and must be taken into account at the project planning stage. In a 2002 investigation performed by Sweden Statistics, 8,000 people were asked about their PC and Internet usage. About 80% of respondents had access to a home PC, while about 75% in the age range 16-64 years access the Internet on a regular basis.

In the UK, some 47% (11.7 million) of homes accessed the Internet via a fixed telephone line in 2003. Some 67% of UK consumers are within an area covered by a DSL-enabled exchange (i.e. a potential coverage of 16.5 million homes). The actual number of subscribers was 1,180,000 and rising rapidly. In addition, the number of users of cable modem services had increased to 1,141,000. The July 2003 Oftel Broadband and Internet Brief (www.oftel.gov.uk/publications/internet/internet-brief/broad) indicated a significant growth in the take-up of broadband. The 2001 census showed that 52% of Internet-connected homes had used the Internet to purchase tickets, goods or services. This indicates a growing confidence in e-services in the UK.

2.2 Market potential for the SmartHomes system

The question addressed here is "what is the number of required e-boxes and sensors if all possible consumers in any given category subscribed to an e-service?". Table 1 summarises the results as extracted from the data gathered for each country.

Table 1: Equipment required per national e-service.

	Czech Rep.	**Sweden**	**Sweden**	**Sweden**
	Energy management	Energy management	Care for the elderly	Cooling energy
e-box	75,000	230,000	50,000	50,000
Pulse counter	75,000	2,600,000		
Humidity sensor	75,000	2,600,000		
Temperature sensor			50,000	50,000
CO + smoke sensor			50,000	
	UK	**UK**	**UK**	**Total**
	Energy management	Care for the elderly	Utility load management	
e-box	240,000	160,000	6,000	811,000
Pulse counter				2,675,000
Humidity sensor				2,675,000
Temperature sensor	720,000	160,000		980,000
CO + smoke sensor		160,000		210,000
Current Sensor			1,000	1,000
High voltage sensor			1,000	1,000
Low voltage sensor			5,000	5,000

Note that Table 1 has certain omissions as follows:

- While Greece has estimated that 16,000 e-boxes will be installed in the coming 8 years, the uncertainties were such that it was not possible to estimated the total potentials.
- While the 'care for the elderly' service is not of present interest in Sweden, its potential has nevertheless been estimated. At the present time, Sweden has about 800,000 people older than 75 years and in 2020 that figure is expected to rise to about 1,000,000. Assuming that 50% of these people live alone and 50% are married, the total potential is about 530,000 service recipients today and 670,000 in 2020. If one e-box can service 10-20 apartments, and assuming that some elderly people live in their own house, some 50,000 e-boxes would be required.
- There is no official figure for the cooling demand in Sweden, but the Swedish Society of Refrigeration has estimated a demand of about 30TWh over 500,000 cooling units. Most of these units are already connected to computerised systems for maintenance and supervision and it is anticipated that about 10% could be connected to an e-box system.

3. Laws and legislation

The Czech Republic has no legislation that would act to restrict the services targeted in this project. All services are possible on the basis of mutually signed contracts.

Likewise, in Greece there are no specific legislative constraints.

According to Swedish law, heating must be included in the rent. In some cases this requirement has been varied by agreement between the Swedish Union of Tenants and the estate owners. The Swedish Housing Act is unclear on this issue.

In the UK, the domestic sector is covered by legislation and initiatives aimed at meeting Kyoto targets. There is a requirement on each local authority to report on energy consumption as an indicator of CO_2 emission. Furthermore, an annual report must be produced that identifies improvement targets and shows how these will be met.

4. Impact on the energy system and environment

Clearly, the environmental impact will depend on the nature of the displaced fuel stream. As the energy supply system shifts towards low carbon technologies, so the ability of an e-service to reduce the environmental impact will fall. In addition, not all e-services have an energy saving component.

Czech Republic
The reduction of CO_2 by decreasing heat production is not included in legislation. The Czech Republic is signatory to the Kyoto Protocol and, in the context of entering the EU, has accepted directive 2001/77/EU, which requires the contribution of renewable sources to electricity production to rise to 8% by 2010. This will reduce CO_2 emissions by 2,200 tonnes relative to the 2000 level.

Greece
The energy consumption for cooling in residential buildings represents about 3% of the total. Of the total electricity supply, about 10% is produced from renewable sources of energy. Thus, the reduction of CO_2 emissions will be about 0.45% where the cooling energy reduction is 20%.

UK
Individual energy measurement is a way for Local Authority Energy Managers to comply with the Home Energy Conservation Act. In addition, the domestic sector is covered by other legislation and initiatives aimed at meeting Kyoto targets. For example, all fuel suppliers with over 15,000 customers have an energy reduction target imposed by the regulator OFGEM under an Energy Efficiency Commitment. This totals 62TWh over the period 2002-5 with a further reduction likely for the period up to 2010. The saving by improved control of heating systems is estimated at 10%.

Sweden
The environmental impact of reducing heating energy requirements in apartments is low. The reason is that the energy system in Sweden is relatively environment friendly and will become more so when the number of co-generation plants operating on biomass or natural gas is increased. The amount of waste heat will then be larger than the demands placed on district heating schemes. Many experts believe that this will lead to the scenario where the electricity demand increases and eventually the nuclear plants in Sweden will close. If all apartments in Sweden had individual energy measurement, the CO_2 emissions could possibly be reduced by about 1%.

5. Conclusions

Peoples' views on e-services
The investigations show that 39-72% of tenants are interested in monitoring energy consumption depending on the national context. Further education will be required to significantly increase this value.

The Internet
Peoples' usage of the Internet varies form 5-75% throughout the four countries. In most sectors, these figures are inflating.

Environmental impact
This is relatively low but positive. Realistic CO_2 emission reduction levels vary from 0.5% to 10%.

Legislation

The Czech Republic and Greece have no legislative barriers that would restrict the deployment of the envisaged e-services, while the UK has legislation in place that would directly benefit from Internet-based data collection. Sweden has legislation that requires the inclusion of heat in the rent in the case of multi-family housing while the Swedish Housing Act is ambiguous in relation the gathering of apartment-specific information in support of individualised debiting.

Appendix 6: Work Package 6, Economic appraisal

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1. Introduction

An economic evaluation of the targeted e-services was undertaken in order to inform the industry about the scale of the challenge to construct a digital residential community throughout the EU. The main task was to cost each feasible e-service option to emerge from the WP 5 market study in terms of the required capital investment and operation charges to recover this investment. The evaluated services are therefore as listed in Appendix 5.

2. Breakdown of energy service costs

Each e-service was broken down into the following components:

- e-box units;
- sensors (temperature, movement, CO, meter reading, gas leak detector, humidity or smoke detector) and actuators for appliance control;
- installation;
- house wiring or the additional cost for sensor/actuators to operate via remote control, wireless control or power line signalling;
- rental of communications line (ISDN or broadband) and modem;
- e-service centre shared cost (depends on the number of e-service deployments); and
- computer equipment to view the e-service results.

Example cost breakdown

The Scottish 'care for the elderly' service offers a cold temperature alarm to prevent hypothermia under conditions of extreme cold weather. This service has been broken down as follows.

- E-box unit (which could service up to ten houses although one e-box per house is assumed here): €250.
- Wiring the e-box to the sensors: €100.
- The cold alarm comprising an internal temperature sensor, a movement detector and an alarm: €300.
- A Broadband BT Domestic connection via an existing telephone line (including a modem and filter pack, €136, activation, €104, and monthly rental, €48): €288.
- E-service centre charge (depends on number of e-service customers): €10 (estimated by Rivermen, who operated the SmartHomes e-service centre).

The total cost per house for this e-service is therefore approximately €1,048. Note that a significant cost reduction is possible where the e-service is added to an existing broadband service.

Using the data collected in the WP 5 market study (Table 1, Appendix 5), an economic evaluation was performed for the different national e-services using a specially constructed economic evaluation model.

3. Economic evaluation model

This model examines competing investments using payback, profitability index (PI), net present value (NPV) and internal rate of return (IRR). The definition of these terms are as follows.

Payback

This compares the cost of the investment with the time that it would take for the investment to pay for itself. The investment return is measured in terms of the net cash flow, which is the difference between the total amount of cash received during a particular period and the total amount of cash paid out during the same period.

Profitability index

This is a measurement of the total cash returned as compared to the total investment. The higher the value, the better the investment. It assesses project profitability by relating the average net profit of the project to the cost of the original investment.

Discounted cash flow

This is a common method of project appraisal. There are two approaches to using discounted cash flow in a project appraisal: the net present value and the internal rate of return.

Net present value (NPV)
This recognises that the cash received today might be worth more than cash received in the future. Thus if €90.91 is available now, and it can be invested at a rate of interest of 10% per annum, it will be worth €100 after one year (€90.91+€ 9.09). Clearly, in these circumstances, it is preferable to have €90.91 now rather than, say, €99 in a year's time. This is known as the time value of money, and can be incorporated into any project appraisal. Since cash received in the future might be worth less than its value now, it is fairer if returns are compared in terms of their present value. This method involves the use of discounting, which requires the selection of an appropriate rate of interest to bring the future net cash flows to their present value. The rate of interest chosen might be similar to that which can be obtained by opting for an alternative investment. It should be noted that future net cash flows are not necessarily worth less because of inflation (although the declining purchasing power of the monetary unit will be taken into account in assessing future net cash flows). The point is that in a discounted cash flow calculations, cash receivable in the future is considered to be worth less than cash received now because cash that is available at present may be used, i.e. invested. By adopting the NPV method, alternative projects can be fairly assessed since the total of their respective net present values can be compared. The project with the highest NPV is likely to be the most profitable, although there are other factors to be taken into account, such as projects that are necessary for safety reasons.

Internal rate of return (IRR)
This method requires the calculation of a rate of return, which would discount the future net cash flows back to a net present value equal to the original cost of the project. A project would be acceptable if the IRR produced a total net present value, which was equal to, or in excess of, the cost of the project. The project would not be acceptable, however, if it produced a negative rate of return.

4. Economic evaluation results

Each e-service has been modelled in two parts:
- a ten year cost breakdown; and
- a project investment analysis.

The cost breakdown model consists of a spreadsheet-based procedure:
- the individual e-service components are detailed;
- a cost reduction factor is applied to reflect volume manufacture;
- the predicted number of services is entered for each year (as determined from the market study);
- the marketing costs are estimated based on data from ScottishPower's marketing department;
- a guesstimated service cost is entered;
- an Internet line rental discount is applied to take account of the fact that the line is utilised for traffic other than that underpinning the e-service; and
- the service cost is then manipulated until an acceptable payback is obtained.

The outcome is therefore the lowest possible cost that will generate a profit, while maximising the service take-up rate. In this way, the outlay and income over a ten year period was established and used as input to the investment analysis model. As an example, consider again the 'care for the elderly' e-service. The analysis for this service produced the following result:

Service cost:	€375
Payback period:	5 years
Profitability index	1.4
Net present value	€22 million
Internal rate of return	43%

Figure 1 shows the NPV variation over a ten year period. Note that payback commences after all investments have been made and the NPV is positive.

Each country produced a cost analysis for a principal e-service using the investment analysis model over a 10 year period. The principal e-services for each country are as follows.
- Scotland - care for the elderly comprising a cold temperature alarm.

- Sweden – equitable billing in multi-family blocks with central metering.
- Czech Republic - district heating energy supplier feedback in multi-family blocks.
- Greece – cooling unit control in homes.

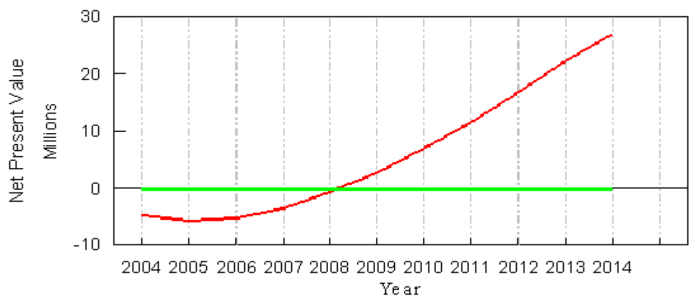

Figure 1: NPV variation for the 'care for the elderly' service.

The results, using typical commercial discount rates, for each country are shown in Table 1.

Table 1: Appraisal of principal e-services by country.

	Sweden: equitable billing	**Czech: district heating**	**Scotland: care for the elderly**	**Greece: cooling control**
Discount rate	5%	5%	8.65%	9%
Service cost	€240	€255	€375	€280
Payback period	3	4	5	7
Profitability index	2.4	1.9	1.4	1.2
Net present value	€35m	€11m	€22m	€0.8m
Internal rate of return	66%	50%	43%	20%

From the data of Table 1 it is clear that an acceptable rate of return can be achieved for most e-services when deployed within each county. The table shows the most profitable service to the left and the least profitable to the right. The profitability balance point is achieved when the highest service cost can be achieved with a good take-up rate. The lowest service cost was associated with the Swedish service because this has the lowest installation cost as only one e-box is required to serve 40 houses. The Scottish service corresponded to the highest service cost because one e-box is required per home and sensor costs are high. Greece has the lowest profitability because the service cost was set at a low rate to reflect the market condition.

5. Conclusions

With the bulk purchase of components, the cost of each e-service may be expected to reduce. This has been factored into the economic model over a ten year period to produce cash flows for each year. The prediction of market take-up has been extracted from the market study results and labour and logistics costs have been incorporated in the model. From the results, it is apparent that all services have a good rate of return in each country. Once the equipment is installed, the costs of additional service deployment may be expected to reduce significantly. While the above analysis addresses the commercial value of the service, it does not include customer and environmental added value, which may be substantial.

The economic appraisal model is available as a project deliverable.

Appendix 7: Work Package 7, Technology Implementation Plan

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1. Summary

"The technological implementation plan shall include a summary of the project and a forecast of the intentions of the contractors, as well as a description of their achievements regarding the use of the knowledge."

The SmartHomes project is part of the EU EESD-Energy Programme (1998-2002). The aim of the project is to implement and test a range of new energy services that are suitable for widespread delivery using the emerging electronic gateway technologies being developed by the telecommunications industry.

The project set out to demonstrate that homes using modern communication technologies could be adapted to acquire and transfer high frequency fuel, power, appliance operation and space temperature data in support of a range of new energy services of benefit to home owners/occupiers, utilities and local authorities. Examples of such services include:

- the real-time monitoring of homes to enable better care for the elderly and other vulnerable groups;
- the management of electrical loads as a mechanism to improved the efficiency of supply;
- the attainment of a better match between local demands and renewable energy supplies as a means to reinforce power quality of supply in areas where the electricity supply network is fragile;
- the development of partnerships between local authority, utilities and telecommunications companies as an apt response to the challenges of an integrated energy market;
- the construction of city-scale databases for use in local authority and utility service planning; and
- the development of procedures for prioritising home improvements based on detailed consumption data.

Such services require the development of data acquisition and remote actuation protocols that can offer service value at appropriate cost.

To demonstrate the above, the project has carried out state-of-the-art and market surveys, developed a prototype system and run full scale field trials in 4 locations:

- Sweden – in an urban context with extensive existing IT infrastructure;
- Scotland – in a rural context with geographically dispersed homes;
- Czech Republic – in a legacy context comprising eastern block social housing; and
- Greece – in an urban context with weak existing IT infrastructure

In each location, a consortium of technology, utility, local authority and academic partners was established. In addition to running the field trials, these partners provided an economic assessment of the trialed services and provide a marketing focus for further exploitation.

Several outputs have arisen that may be disseminated and exploited:

- *information* - in the form of sate-of-the-art reviews and market studies;
- *know-how* - including the experience gained in instrumenting buildings, collecting and analysing data, constructing and operating e-services *etc*;
- *software* - including generic e-box bundles, the analysis pipeline and service delivery components;
- *demonstration services* - based on the example services developed during the project and hosted on national Web sites; and
- *reference sites*.

The e-services that have been demonstrated are:

- monitoring of the indoor temperature in individual apartments;

- information for occupants on the daily cooling demand;
- information to local authorities on energy consumption at the large scale;
- linking of comfort to energy use;
- prediction of regional cooling energy demand;
- remote actuation and control of appliances;
- monitoring of energy consumption in multi-family houses as an aid to equitable billing;
- monitoring of energy use in support of energy management and action planning;
- care for the vulnerable under cold/hot weather conditions;
- monitoring of internal temperatures in cases of fuel poverty; and
- provision of energy consumption data to utilities for local load management.

This Appendix has been constructed as a planning and control instrument for post-project dissemination and exploitation. First, the plan gives an overview of the organisations, outlining the objectives and infrastructure that can be used for dissemination and exploitation. Second, the products and services that are subject to exploitation are described. Third, the position of the SmartHomes system in the market is summarised and its potential customer markets identified. Finally, market related strategies and concrete action plans are developed. This dissemination and exploitation plan can therefore be regarded as a basis for a business plan for the future marketing of the developed e-services. It will be updated as the available technology, legislative context, market conditions and economic viability evolve.

2. Structure of the dissemination and exploitation plan

The plan is divided into sections covering the following principal topics:

- *Objectives and infrastructure* - the objectives of the consortium and the participating organisations are described. The infrastructure that is available at the individual organisation level in respect to planning and co-ordination of exploitation is described.
- *Products and services* - that are subject to dissemination and exploitation are described. Also, planned enhancements, resulting from the requirements defined by the user organisations and the marketing specialists, are laid down and updated.
- *Marketing method* – is elaborated by following the SOSTAM method that comprises six stages: **S**ituation analysis, **O**bjectives, **S**trategy, **T**actics, **A**ction plan and **M**onitoring.
- *Dissemination strategies* - covering both the exploitation and dissemination strategy. While the previous topics cover exploitation of the SmartHomes services, this topic outlines the strategy for disseminating both the theory and field trial content, with the intention of educating the market for the product.

3. Objectives and infrastructure

Results dissemination and exploitation is based on three pillars: the overall consortium, the national sub-consortia and the individual partners.

The overall consortium's approach is to market the services and delivery tools developed during the project and to market the knowledge and the experience gained. This marketing will be carried out at national level, but with support from the whole consortium where appropriate. In particular, the whole consortium will be concerned to ensure lessons learned in one market are disseminated to others. This approach has the following advantages:

- it has a European-wide perspective;
- it can bring experiences from other countries to bear on specific national problems;
- the European dimension adds credibility to national activities; and
- it can act as a lobbyist at the European level.

The national consortia bring the following additional advantages:

- knowledge of the local environment and an ability to identify opportunities to build on existing or planned infrastructure;
- an understanding of the economic viability of the different services;

- the ability, through the local technology partner, to tailor the services offered to the local IT infrastructure;
- an understanding of end-user needs since the local utility and local government partners represent two major end-user classes;
- experience of setting up and running services as part of the field trials; and
- a running pilot system to act as a showcase for demonstration.

Finally, individual partners can try to secure the company backing necessary to initiate a commercial venture.

The consortium has discussed its approach to dissemination and exploitation and agreed on the following actions:
- running the pilot services and producing user acceptance and operational data;
- updating the service and infrastructure definitions to take advantage of recent technological and infrastructural improvements;
- developing marketing strategies and materials; and
- carrying out dissemination and marketing activities.

The future co-operation of the partners is based on a *Memorandum of Understanding*, which has been signed by all partners. The consortium approach to exploitation and dissemination will be carried out under the guidance of the national academic partners and adhere to the recommendations contained in this report. In parallel, each country will initiate its own dissemination and exploitation plan. These naturally fall into similar patterns: the academic partner focusing on dissemination activities and maintaining the demonstration services, the technology providers concentrating on building a market, and the utilities/local authorities looking for internal opportunities to exploit the existing (or re-engineered) field trials.

4. Products and services

Installation know-how
During the field trials, expertise in installation of sensor networks was accumulated. This has been recorded in an additional deliverable contained in Appendix 4. Together with the local knowledge of the communications infrastructure in the locations monitored, this would be of significant value to others involved in the smart buildings field.

Ebox bundles
Each target space is monitored by a set of sensors attached to an e-box. While the e-box operating system and communications software is provided by the e-box provider, significant additional software has to be placed in the e-box to record and package the sensed data for transmission. The know-how and tools developed to create these software 'bundles' could be exploited to tailor monitoring of sensor networks and other devices to exact service requirements.

Data handling pipeline
The data collected by the e-box is transmitted to the e-service centre and then to the database server. Access to the data is via a Web server. Specific e-services access this Web server to request the raw data, which are then processed to deliver the requested service. Each part of this pipeline has been designed to be as generic as possible, and reuse for other purposes would be straightforward.

Service delivery software
Each specific service has bespoke software running at the service provider's location. This consists of a data manipulation phase, possibly a decision phase and an information delivery phase. The last is normally a Web site, though it could just be commands delivered back to actuators at the monitored site. Parts of this software could be used elsewhere, e.g. in local energy management systems.

Services
A wide range of possible services could be supported using the technology developed and piloted

within the project. These include: monitoring and alarms, individual energy metering, benchmarking/rating/certification, embedded control, tariff surveillance, and direct load control. A significant number of these services have been demonstrated in the field trials carried out during the project, and many of these will be continued in the near future, either as part of further projects or as a resource for teaching and market education. The national services currently available to act as demonstrators are:

Greece
The target was the summer cooling period and involved demonstrating a cooling load prediction capability in 3 apartments. Further deployments have been made in buildings within the University of Athens campus and several apartments in the Athens area.

Czech Republic
Field trials measured temperatures in flats, comfort control in schools and measurements of temperature, relative humidity and occupancy in accommodation within the Czech Technical University in Prague.

Sweden
A 'thermal justice' energy service was developed for multi-family dwellings in Gävle and Stockholm, with sensors measuring temperature, humidity and electricity consumption in support of equitable billing.

Scotland
The field trials measured temperature, occupancy and electricity consumption in support of regional scale energy management and demand/supply matching; and temperatures, occupancy and CO_2 levels in support of hypothermia alerts.

5 Marketing method
This adopted the SOSTAM method that follows five distinct stages as follows.

5.1 Situation analysis
The captures seven issues: structure of the market, trend analysis, economic factors, competition, technology, social and cultural issues and the political environment.

Structure of the market
In this field, the European market is fragmented, with large differences in regulations, social attitudes, energy needs and costs between and within countries. As a result, four independent market studies were carried out. The main conclusions were that there is significant interest in energy services across Europe but that Internet access is a problem (either its non-existence or the impact of e-service traffic on other services) and environmental impact will be low. The most marketable services would seem to be those generating alerts – such as the care for the elderly or remote breakdown monitoring. While interest from utilities and government was not fully explored, the impression is that there is a lack of sufficient economic drivers to encourage adoption (though new legislation, especially in the UK and Sweden could change this situation).

Internet access and sensor installation costs are major obstacles to the provision of reasonably priced e-services. There are a number of other established players in related areas with whom a symbiotic relationship could be established, such as broadband providers, entertainment suppliers, utility companies, property management companies and local authorities.

In summary, energy services are not currently offered in any of the countries covered, but there is clearly an interest by potential customers and a number of players are well positioned to provide or exploit this interest.

Trend analysis
The major stumbling block identified during the field trials is broadband access. Even where this was available, the bandwidth used by the monitoring traffic was deemed to be unacceptable. This,

however, is only a near term issue, as broadband (and high capacity broadband) is increasing rapidly in all countries. In addition, other service providers will be contributing to the spread of Internet access into homes.

More significant was the cost of, and resistance to, sensor installation. Relying on new build or refurbishment to provide suitably wired buildings is unrealistic, so cheap wireless sensors designed for modern homes are essential. These will appear fairly quickly once a demand is shown to exist, but their absence will make it harder to develop the market.

Economic factors
The main factors influencing energy service uptake will be its cost, the control over energy costs provided to the home owner and the value of the aggregate data to utilities and others. Appendix 6 provides a breakdown of the cost involved in providing an e-service, while Appendix 5 provides estimates of the market size. What is missing is an estimation of the value to end-users of the e-services. Unfortunately, evaluating what end-users might be prepared to pay for products and services of which they have no direct experience is so error-prone as to be worthless. However, corporate or government uptake, particularly where pricing for existing or proposed alternatives can be obtained, is a different matter. One estimate is that the current cost of providing the required statutory oversight of elderly people in the UK via fixed alarms and personal visits is about twice the estimated price of a home alarm system based on the SmartHomes technology. This encourages the Consortium to believing that specific niche markets could be found.

Competition
At the moment there is little or no competition. The main potential competitors are:

- services offered by existing players;
- utilities building a remote monitoring infrastructure; and
- broadband providers wishing to offer more attractive packages (this would be as much an opportunity as a threat).

Technology
Impact of sensors (and wires) on the home environment: most sensors are designed for an industrial environment and so look unsightly in a domestic context. This is exacerbated by the need to place sensors in a technically relevant location, again regardless of the decorative impact. Finally, unsightly wires running around living spaces (or penetrating walls) is a major barrier to uptake.
Heterogeneity of platforms: the staggering growth of the Web and Java technologies are partly due to their platform independence. The standard protocols of the Web provide a technology by which energy services could be delivered to heterogeneous client systems.
Internet connectivity: the biggest potential weakness for the SmartHomes system is the need for an always-on connection to the e-service centre. This imposes a high fixed charge on the home owner, which, if not shared with other services such as entertainment, could make energy services uneconomic. A further technology-based risk (due to dependency on third party network providers) is security of personal data – or to be more accurate, the perceived security of the data. The technologies employed in by SmartHomes system provide a high level of security with regard to the collection and transport of personal data. The risk, however, comes with the service providers who actually store data, analyse it and disseminate derivative data to customers. This issue can best be addressed by the service providers themselves.

Social and cultural issues
The SmartHomes project covered a wide range of different social and cultural environments, as the field trials demonstrate. Sweden and the Czech Republic share significant use of district heating, Swedish and UK legislation sets increasingly strict energy performance targets, care for the elderly is a particular concern in the UK, and so on. However, in spite of this diversity, it is clear that there is a reasonable level of interest in energy services from the general public in each country. The main social and cultural issues that need to be addressed at some level are security of personal data, economic benefits directly accruing from the services and the level of environmental impact mitigation.

Political environment
The legal and political environment in all countries is neutral or positive in regard to energy services. In Sweden and the UK, some statutory obligations could be more easily met via energy services, such as those piloted, than via the current methods of provision. For example, equitable allocation of heating costs in Swedish multi-family buildings, or monitoring of dwelling temperatures in accommodation for the elderly in the UK, are both difficult to achieve without installing real-time sensors, and the technologies developed in this project provide a cost-effective approach.

5.2 Objectives
The objectives of the consortium and individual partners has been described in §2. It is believed that in the near term there will only be a few niche markets for smart homes technologies (the care for the elderly service is an example). However, with the increasing penetration of broadband and the emergence of other services targeted at the general public, it is believed that other country-specific services will become viable in the medium term (2-5 years). With the experience gained in the field trials, the consortium members will be well placed to capitalise on such opportunities.

The consortium's primary objective is therefore to build a market for energy services by disseminating the project's results. A second objective is to ensure that technological developments are tracked and folded into the overall consortium consciousness. This will be achieved by targeting new R&D projects and disseminating the results from these to consortium members. Finally, individual opportunities in niche markets will be actively pursued. These will probably be via direct spin-outs of the field trials and will be best served by the utility and local government partners.

5.3 Strategy
Externally, the consortium will focus on dissemination and market building activities. Internally, it will seek to convince one or more of the utility/local government partners to ramp up one of the field trials into a full service. The findings of the market study and economic assessment will provide the basis for a refined business plan. Finally, the consortium will pursue opportunities to carry on further R&D in this area, in order to be ready when broadband Internet access and market acceptance make energy services commercially viable.

5.4 Tactics

Promotion
For promoting SmartHomes energy services to potential customers and partners, the main avenues are:
- Web site;
- newsgroups and mailing lists; and
- presentations at conferences/tradeshows.

An effective Web site will reach a large number of people – eventually. The main drawback is that it is passive, i.e. it will only reach people who are actively monitoring the Web for 'energy service' sites. These are much more likely to be competitors than customers. Further, unless the site is well designed and populated, the overall impression could do more harm than good to the perception of the SmartHomes system. Developing a full marketing site is probably too large an investment, but a small site describing the main features and benefits of energy services and soliciting suitable partners and end-users would be useful. This is being developed.

Posting articles on newsgroups has the advantage that the mechanism is active – SmartHomes can be described briefly to potential partners and their involvement solicited. The need to keep the postings short is another advantage, as interested parties will have to contact the consortium for further details. This avenue is being pursued.

Presentations at conferences/tradeshows are an ideal opportunity to talk directly to potential customers and partners. The consortium is making a point of presenting at conferences where there are significant numbers of energy suppliers present.

Once the initial contact with a potential partner/customer has been made, either directly or via one of the mechanisms above, further material will have to be in place to capitalise on any initial interest. The first item provided will be a flyer – a single page highlighting the main benefits to be obtained from energy services. The purpose of this is to convince the potential customer that the SmartHomes services are valuable (or marketable in the case of potential partners). This will be followed by a demonstration of the system, as this is the quickest and easiest way to show users what the SmartHomes system can do for them. Following that, a more detailed description of the system will be given from both technical and end-user viewpoints.

Resources
There are two main resources for dissemination and exploitation. First, the academic partners will maintain the Web site and continue the field trials as part of their on-going research programmes. They will also naturally disseminate information about the technology through publications and presentations. Second, industrial partners will, as part of their normal operations, monitor the market and attempt to build market awareness, so as to be able to exploit their IP when the opportunity arises.

One final source of resources that the consortium will pursue is national or European R&D funding to support a special interest group or research network tasked with tracking technological developments in this rapidly changing field and building awareness in utility and local government circles of the potential of the new services they could be offering to the public.

5.5 Action plan
To date, the consortium has published a number of papers about the project, its technologies and applications and further publications are planned. A common project Web site has been created to act as a focus for promotion activities: www.bitd.clrc.ac.uk/Activity/ACTIVITY=SmartHomes.

A demonstration board, containing an e-box and a connected set of sensors, has been produced. This, together with a laptop, can be used to show the technology in action. In conjunction with the live data from the field trial Web sites, this can provide a powerful demonstration of the technologies underlying the SmartHomes system and its potential for supporting energy services.

Each National node has undertaken to develop one workshop targeted at building market awareness. These workshops will, if possible, be offered at a major national/international event.

Finally, the consortium (and individual partners) will look for ways of ensuring that the momentum built up during the project is carried forward into further research and development projects. In addition, funding will be sought for a research network to track technological developments in this rapidly changing field, proactively encourage further R&D in areas the network considers key to the adoption of energy services, and build awareness in utilities/local government of the potential offered by this technology.

5.6 Monitoring
The partners have agreed to monitor the further emergence of e-services in order to identify opportunities for the application and exploitation of the deliverables from the present project.

6. Dissemination strategy and activities
The following options exist.

Web site: This is under development. Ultimately, this will have to handle all categories of people interested in SmartHomes (potential customers, new partners, decision makers, IT staff *etc*) so it has to concentrate on general descriptions and examples. It needs to cover the main concepts and focus on the benefits to home owners, utilities and governments. Examples that are not specific to any particular environment will be used, though some specific examples will be given of the services that are already activated within the field trials. It can include a canned demonstration or screen dumps, but it is not realistic to provide a demo version on a Web site, unless one of the pilot projects is providing service data that can be made publicly available and does not violate the data protection act. A way for the reader to register interest and receive more information will be provided.

Newsletter articles and press releases: Articles will be prepared for trade and IT newsletters to introduce SmartHomes to a wider market. Most activities in this category will be driven and/or co-ordinated by the individual consortium members.

Conference presentations and demonstrations: Descriptions of the SmartHomes system, the lessons learned during the project and the experiences of deploying energy services within different environments will be presented at appropriate conferences. The emphasis will be on raising awareness of the benefits of the approach and on technology transfer.

Workshops: One of the best methods of disseminating information about the SmartHomes technologies is to arrange a half-day workshop in conjunction with a major national or international conference. The workshop should be an appropriate mix of technical presentations and case study material. Posters, the demonstration board (an e-box and set of sensors connected so that it provides a portable test-bed) and on-line access to the field test Web sites will provide an excellent basis for the workshop. Combined with 2-3 directed presentations, this should have a significant impact on potential service providers and consumers.

Scientific journal articles: Articles in the technical press will complement conference publications, providing more technical depth and analysis than possible in a conference paper.