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D7.3 Operation of the Living Labs – enabling assessment of behaviour change impact from DEHEMS

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1. Executive Summary

Behaviour change impact from DEHEMS was assessed through the Living Lab component of the programme. There were 2 pre-requisites to this assessment process:

- firstly, equipment had to be installed and working
- secondly, a knowledge of householders' existing home energy use had to be established as a baseline against which behaviour change could be monitored

This version of the deliverable has been updated to reflect all activities carried out by WP7 partners (including all Living Labs) to complete Cycles 1, 2 and 3. It has been revised subsequent to completion of Cycle 3 as part of T7.4.1 Living Lab system development feedback loop.

2. Project and Cycle Objectives

The first objective for Work Package 7 (D7.1) was to establish Living Labs and investigate impact on energy usage of the DEHEMS project through the 3 iterative cycles:

- Cycle 1 - established the basis of the service through generating information on requirements and technical delivery capability.
- Cycle 2 - established a beta model with plug level metering and market mechanisms for resource allocation in the SANET.
- Cycle 3 - continued to iterate development of system components and introduced processes to actively drive household behaviour.

3. Activities to achieve the Deliverable (see also D7.5 & D7.6)

Task	Sub tasks	Cycle 1 activities: UK Living Labs only: Bristol, Manchester & Birmingham	Cycle 2 activities: UK & Bulgaria Living Labs: Bristol, Manchester, Birmingham, Plovdiv & Ruse/Ivanovo	Cycle 3 activities: UK & Bulgaria Living Labs: Bristol, Manchester, Birmingham, Plovdiv & Ruse/Ivanovo
T7.1 Third Party agreements to enable Living Lab implementation	None	Agreements put in place between local DEHEMS lead and: - the housing provider; - individual households	As Cycle 1. In addition, the metering/wiring configuration in some households in Bulgaria required agreement with the electricity suppliers	As Cycle 2
T7.2 Living Lab Community engagement	7.2.1 Community Marketing	Awareness raising in the community of the issues addressed by DEHEMS and the opportunities available from participation: - presentations to community organisations and leaders - focus groups with participants	As Cycle 1. In addition, assessment of the readiness of Living Lab users for social networking engagement through DEHEMS	As Cycle 2. In addition the following were introduced: - all users were offered access to energy consumption data via Facebook - Energy Team Challenge: groups of 5 homes competing for monthly inventives for energy saving
	7.2.2 Developing a network of Community Champions	Resident champions established in each location to fulfil both a marketing and support role	Cycle 1 users to assist in engaging / supporting new participants for Cycle 2	Nearly all Cycle 2 users continued to Cycle 3. A few participants dropped out due to changing household circumstances and these were replaced.
	7.2.3 User training needs analysis and preparation	Development work with the local champions and qualitative research with residents specified requirement for training for users	Knowledge of users' training needs gained in Cycle 1 used as the basis for developing briefing/training material for Cycle 2. Some changes resulting from different equipment configuration	As Cycle 2
T7.3 Living Lab	T7.3.1 DEHEMs	• Recruitment	As Cycle 1. Pre-installation survey	As Cycle 2. In addition,

Task	Sub tasks	Cycle 1 activities: UK Living Labs only: Bristol, Manchester & Birmingham	Cycle 2 activities: UK & Bulgaria Living Labs: Bristol, Manchester, Birmingham, Plovdiv & Ruse/Ivanovo	Cycle 3 activities: UK & Bulgaria Living Labs: Bristol, Manchester, Birmingham, Plovdiv & Ruse/Ivanovo
Operation	household implementation	• Pre-installation survey • Equipment testing • Training for installers • Installation • Training for users • Check that Dehems equipment is continuing to transmit and undertake follow-up action	was not carried out in Cycle 2 as a result of understanding gained in Cycle 1	introduction of gas monitoring in some UK homes required survey of gas meters to identify ones compatible with gas monitoring equipment. Installation of gas monitoring required specialist skills provided by Salford University
	T7.3.2 DEHEMs Support	• Establish support procedures (3 levels) • Manage customer support requirements • Record support requests & action taken	As Cycle 1. Considerable support activity required to maintain users online resulting from clamp unit battery fault	As Cycle 2. As most users had been involved with DEHEMS since Cycle 2, the requirement for user support was reduced for Cycle 3
T7.4 Living Lab Analysis	T7.4.1 Living Lab system development feedback loop	• Undertake survey with all users • Undertake initial focus groups – to gather feedback on Cycle 1 • Undertake second focus group – to test use case scenarios for Cycle 2 • Cycle 1 review (D7.5) • Quantitative & qualitative data analysis & report	As Cycle 1 – but in Cycle 2 the user survey was undertaken using an online research tool	As Cycle 2 – online survey (using the same research tool) & focus groups
	T7.4.2 Knowledge base development	Uses information gathered during household survey. Open to academic researchers and other EU projects – via www.dehems.org	As Cycle 1	As Cycle 1/2

4. Updated State of the Art

Research on domestic energy consumerism, focusing on behaviour change and energy awareness dates back to 1970s, mostly carried out in the fields of sociology and psychology. The following conclusions can be drawn from the existing research into domestic energy consumerism:

- A large portion of domestic consumers lack the knowledge on how to decipher their current energy meters and billing calculations. Consumers also lack critical knowledge on the energy consumption of their appliances. Although there are evidences of interest in saving energy, this gap in knowledge is preventing behaviour change.

- There are evidences that energy consumption behaviours can change for the better when consumers are regularly made-aware of the amount of energy they use. In the UK, behaviour change contributes up to 15% reduction in energy consumption for an average consumer that has been given feedback on her energy consumption.

The following details various studies carried out in this field.

4.1 On the awareness of consumers on their energy consumption (see also references)

- A survey carried out by Meyel [1] indicated the lack of knowledge and understanding people have about their energy meters. More than 50% did not know where their gas or electricity meters were and 45% could not read them.

- Dennis et al. [2] argues that feedback in the form of frequent billing or energy audits is inefficient, because consumers do not know the relative energy costs of the various energy using systems in their households.

- Baird and Brier [3] showed that many people assume that the larger the volume of the appliance the more energy it uses per hour.

- Mansouri-Azar et al. [4] tested whether consumers knew which were the first, second and third most energy-consuming electrical appliances within their home. A large majority of respondents chose the washing machine as the first, second or third most energy-consuming appliance, while (if present) the top three consumers in average UK homes are lighting, the freezer and the dishwasher. Some 14% of respondents commented that the cooker was one of the most costly appliances and it is plausible that this indicates a link between power rating and cost, because cooking appliances cause the greatest peak power demands in UK homes. Clearly consumers neither have a clear basis for estimating the energy costs of appliances nor for prioritizing energy-saving actions if feedback of total consumption is provided centrally in the home.

4.2 Behaviour change motivations and techniques

- Kaiser et al. [5] identifies three situation where a person has a positive attitude towards an ecological behaviour but are prevented from carrying out this behaviour:
    a. economic constraints – a person may not be able to afford a new equipment, and have to resort to buying second-hand equipment.
    b. social pressure by family and friends – family and friends may discourage a person from replacing energy inefficient equipment, or making home improvements to improve the energy rating of their property.
    c. lack of opportunity to carry out ecological behaviour-a person may be interested to separate glass bottles or plastics from general waste, but does not have the means to transport or facilities to dispose them.

  Thus the variations in energy saving actions and potentials for a given household make it difficult to predict energy-savings in a particular household and to optimize energy advice.
  On the other hand, over-generalizing and over-prescriptive advice may decrease interest in energy saving among consumers.

- Two techniques for influencing energy consumers:

  a. Antecedent information – general information that describes practical ways to reduce energy consumption. Examples are pamphlets, notices, posters, TV programs and internet sites.

  b. Feedback information – information on the direct consequences of the consumer’s behaviour. Examples are feedback on an individual’s actions or the overall household’s behaviour. Van Houwelingen and Van Raaij [6] outlined three main functions of feedback:
     i. Feedback has a learning function—subjects learn about the connection between the amount of energy they use and energy consuming behaviour.
     ii. Habit formation—subjects put the information they have learnt into practice and may develop a change in a routine habit.
     iii. Internalization of behaviour—when people develop new habits after a while they change their attitudes to suit that new behaviour.

- Ammons [7] and Van Raaij and Verhallen [8] state that the most effective feedback is that which more immediately follows an action.

- Stern [9] argues that it is not the time difference between days, weeks and months that is important, but that the feedback appears immediately after an action, which attempts to save energy.

- Senders and Cruzen [10] showed that feedback is more effective if it relates to individual parts of a control system. Hence, feedback could be given during, or immediately after, the use of an individual appliance or heating system.

- State of the art user studies and experiments performed in the field of domestic energy consumerism

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Technique	Authors	Experiment	Results
Antecedent information	Dennis et al.[2]	Putting up signs near light switches	60% reduction in unnecessary lighting use
	Winnet et al. [11]	20 minute TV program on energy saving	10% reduction in energy consumption
	Hayes and Cone [12]	Posters on energy awareness – include measuring Fallback effect	30% reduction in electricity usage in the 1st week. 9% reduction in the 2nd week.
Feedback information	Selingman and Darley [13] (New Jersey, USA)	Provide daily feedback of percentage of predicted electricity use for that day, on a board outside kitchen window. Predictions were based on one previous month's temperature corrected electricity meter readings. Eg. Prediction is 10 units, while actual consumption is 8 units, display 80%. 29 similar 3-bed houses, 15 houses given feedback, testing period is 1 month.	10.5% average reduction in electricity use in the 15 houses that are given feedback.
	Wilhite and Ling [14] (Oslo, Norway)	Test if informative feedback on actual use energy bills is more effective. Control Group 1 receives average billing (direct debit) as normal. Group 2 receives actual use bills bi-monthly. Group 3 receives graphic bills with this year and last year information bi-monthly. Group 4 receives same as Group 3 plus energy savings tips. 3-year study. Year 1 is normal averaged billing bi-monthly. Year 2 is with the experimental bills for Group 3 and 4. 1386 households.	Year 1 savings: 10% for Group 2,3,4. Year 2 savings: 7.5% for Group 2,3,4. Norwegien Water and Power Authority adopted new billing guidelines that require incorporating graphical **historical feedback plus actual use billing, four times per year.**
	Seaver and Patterson [15]	Test if feedback plus social commendation is more effective. Test that by providing information to consumers specifically about their personal fuel–oil for home heating will lead to lower fuel consumption. The feedback was in the form of a feedback slip, which was issued every time oil was delivered. The commendation was a label with the words "we are saving oil" in red block letters. 122 households in a 4-month study. 42 of which formed the Control Group and received no feedback. 80 were split into two groups; one group (35) with just the feedback and the other (45) with feedback and commendation.	The Control Group used 0.146 gal per day. The Feedback-Only Group showed little reduction in oil usage using 0.143 gal per day, but the Feedback-and-Commendation Group showed a significantly reduced consumption of 0.129 gal per day. Savings are due to the **social recognition** of efforts to save energy.
	Hayes and Cone [12] (West Virginia, USA)	Test which type of feedback is most effective. Experiment tested which would be the most effective method of reducing energy usage; monetary payments (which increased in relation to the proportion saved), energy information, or daily feedback on consumption. 4 units of an 80 person student-housing complex was tested for 90 days. The first 20 days used to generate a comparative baseline. For the rest of the time, payment, feedback and antecedent information was provided, each for period of 1 week.	Payments produced immediate and lasting reductions in consumption. Average reduction of 33%. Feedback produced reduction of 18%. Antecedent information alone produced an initial 30% reduction but fell to a 9% reduction after 2 weeks. **Feedback is more effective than antecedent**

			information alone.
Electronic feedback	McClelland and Cook [16] (North Carolina, USA,)	Employ an electronic device to show consumers electricity information. Monitors placed inside 25 new houses, as they were built, and households observed for 11 months without the knowledge of the owners. Device is Fitch Energy Monitor (FEM) and measured total electricity usage (kWh) from the homes mains supply. Electricity usage was displayed in cents per kWh (where electricity price could be set and reset if needed) and was displayed alternately with the time of day. The display panel was was accessible throughout the day.	12% less electricity usage in households with a FEM compared with the Control Group of 76 houses without the FEM. Participants were not advised or otherwise encouraged to save energy and so the Hawthorne effect was minimized in this study.
	Dobson and Griffin [17] (Canada)	Developed Residential Electricity Cost Speedometer (RECS) software and installed it into the PCs of 25 homes. The RECS system measured household electricity consumption and provided cost and electricity consumption displays for various end uses (cooker, fridge, dishwasher, dryer, lights). The information was displayed on a present end-use cost per hour, which was updated every 0.6 s. The feedback was also presented on an hourly, daily, monthly and annual basis. Electricity consumption was measured for 60 days, and the temperature-corrected results showed that, compared to a Control Group of 75 homes,	Average daily electrical consumption was 12.9% less in the RECS group.
	Brandon and Lewis [18] (Bath, UK)	Use PCs to help homeowners to understand electricity usage. PCs were not automatically updated, but required the user to input meter readings. These readings could then be plotted on a graph and compared to previous consumptions. Also offered a questionnaire and advice on energy saving. 9-month study, 120 houses sub-divided into 7 groups (1) Control Group. (2) PC group, (3) group provided with written information about their electricity expenditures (self-versus-others, (4) self-versus-self, (5) leaflets, (6) money and (7) environment).	80% of the households in the PC group reduced their electricity consumption, with 15% average reduction in consumption, compared to previous year [ ]. Collectively only 55% of the households in the other groups reduced their energy-consumption.

4.3 Feedback via Smart meters

- Brandon and Day [19] and Marvin et al. [20] suggest that smart meter technologies could potentially help consumers to use their energy more effectively.

- The UK Smart Meter Working Group concur that the application of smart metering technologies in-homes has potential to reduce gas and electricity consumption and carbon emissions as well as domestic fuel bills [21].

- The feedback of how much energy is being used whilst operating a domestic appliance is like driving a car with speedometer [02]. Feedback about energy-consumption on an appliance is something a user can employ to regulate their consumption. This form of "appliance-based" feedback would be distinct from previous paper-based feedback studies, as it occurs during and immediately after some energy-consuming action. Also the approach differs from previous electronic indicator studies, as the information would be displayed at the appliance.

Darby [23] concludes that *electronic rather than paper-based feedback is the most promising method of disseminating information about energy usage.*

A comparison is given between DEHEMS system and four other state of the art energy monitoring technologies, as shown in Table 1.

- **Wattson [24]**: designed by DIY KYOTO aims to simplify energy monitoring for users by displaying ambient light to illustrate the energy usage levels of the home; the light changes from blue to purple to red as energy usage increases. The Wattson display unit can be used stand-alone or together with management software called Holmes which can be downloaded and used as an in-home PC-based interface for further analysis and illustration.
- **AlertMe [25]**: a ZigBee based energy monitoring system. It uses Google PowerMeter [26] as its user interface. Google PowerMeter is a web-based user interface for energy providers and energy monitoring technologies to aggregate energy data and display energy feedback information. AlertMe also offers remote control functionalities for home appliances.
- **Plogg [27]**: uses Bluetooth or ZigBee for its networked appliance-level sensors. It is mainly an in-home infrastructure, without server support, but it does provide Internet capability.
- **WattBot [28]**: a research project that provides energy usage feedback to iPhones through a wireless data collection hub. Through its iPhone interface, electricity usage (total and appliances) is shown in horizontal bars and readings. There is no back-end server support.

Features		DEHEMS (C1: Cycle 1, C2: Cycle 2, C3 : Cycle 3)	Wattson	AlertMe	Plogg	WattBot (design-phase)
In-home network	Type of Network	433MHz radio, ZigBee	433MHz radio	ZigBee	ZigBee or Bluetooth	Wi-Fi
	Sensing capability	Electrical sensor at mains (C1,C2,C3) Electrical appliances (C2,C3) Indoor temperature (C1, C2,C3) Gas sensing (C2.C3)	Electricity usage;	Electricity usage; Electrical appliances; Indoor temperature;	Electrical appliances;	Electricity usage; Electrical appliances;
	Update Interval	6 seconds	3 – 20 seconds	15 minutes	1 minute – 45 days	N/A
	Scalability / Expandability	Yes (up to 10 appliances, gateways needed for further extension)	No	Yes (255, repeaters needed for further extension)	Yes	Yes
	Data Collection / Aggregation Method	DEHEMS Gateway	Wattson Display unit	Nano Hub	Plogg Gateway	Data Collection Hub
Internet and Data warehousing	Internet Connectivity	Yes	No	Yes	Yes via Ethernet AP	No
	Server availability	Yes	No	Yes	No	No
	Intelligent reasoning	Yes (energy saving tips)	No	No	No	No
	Back-end DB support	Informix (server side); Historical data up to a year	Historical data for 28 days	N/A	None	None
User interface	UI media	Web interface (C1, C2, C3) Mobile Web Access (C2, C3) In-home display device (C1, C2, C3) IPhone (C2, C3)	In-home PC interface	Web interface (Google PowerMeter)	In-home PC interface Mobile interface	IPhone
	Feedback information	Real-time consumption (C1, C2, C3), Historical consumption (hourly, daily, monthly) (C1, C2, C3), Cost saving (C1), Comparison against DEHEMS average usage (C1, C2, C3) Family member consumption (C2, C3) Goals and target (C2, C3) Comparison against similar households (C2, C3) Context-aware personalised tips and alerts (C2, C3)	Real-time consumption Historical consumption (hourly, daily, weekly, monthly, yearly)	Historical consumption (daily, weekly, monthly). Cost saving, Goals and target	Real-time consumption Historical consumption Cost saving	Historical consumption (daily, weekly, monthly)
	Unit of measurement	Power (C1, C2, C3) CO2 (C1, C2. C3) Cost (C1)	Power, CO2, Cost	Power (kW), Cost	Power, Voltage, Current, Cost	Power
	Data format	Numerical data Speedometer bar Bar charts for monitored appliances Text messages via SMS, email and on web interface Line charts for historical data Thermometers for daily and monthly usage and for each family member usage	Line charts for historical data Text Numerical data Ambient light (blue, purple, red)	Line charts for historical data Text Numerical data	Line charts for historical data Text Numerical data	Line charts for historical data Text Numerical data
	Social media	Yes – Facebook and Twitter adaptors	No	Discussion forum	No	No

Table 1: Domestic Energy Monitoring Systems

The following features can be observed from Table 1, including:-

- All these technologies can examine the total household electricity usage via the electrical mains circuit. DEHEMS (via Plugwise sensors), AlertMe and Plogg provide appliance level electricity usage. WattBot uses a circuit breaker at the fuse box to sense electrical load of each circuit, so that energy consumed by appliances or rooms on each circuit can be displayed. However, this would require pre-configuration as well. DEHEMS and Plogg also provides ambient sensing particularly indoor temperature.
- DEHEMS and Wattson provide the smallest sensing frequency, for frequent updating of electricity usage; every 6 seconds for DEHEMS and every 3 seconds for Wattson respectively.
- AlertMe can support up to 255 appliances, and this number can be further extended if repeaters are attached. DEHEMS supports up to 32 appliances.
- Only DEHEMS and AlertMe have server support for data storage and web user interface via the Internet. Plogg supports Internet access via an Ethernet gateway; however, this is designed to remotely control Plogg devices only.
- History energy usage can be stored either in a local database (Wattson and Plogg) or a networked data warehouse (DEHEMS and AlertMe).
- DEHEMS, Plogg, WattBot and AlertMe provide mobile web access, with IPhone being the common mobile platform for stand-alone applications, while the rest are provided with mobile web-access.
- DEHEMS provides rich feedback information including real-time energy usage, comparison, tips and alerts compared to the rest of the technologies.

Other interesting on-going work which is still in the early design and implementation stages concerns innovative user interfaces such as emotionally engaging narrative using LCD displays to visualize a tree shedding its leaves when energy is being overused [29] and glowing power cords [30], and non-intrusive appliance load monitoring using sophisticated statistical signature inference algorithms to analyze the current and voltage waveforms [31], or solutions that use ambient sensors to detect appliance footprints [32]. However, this work is still at an experimental stage, and yet to be deployed and tested in the real world.

4.4 Future work directions

Early studies in the 1970s concentrated on giving infrequent written feedback that was displayed centrally in the home and was not end-use specific. From the late 1970s onwards a few studies provided continuous electronic displays, but it was not until the 1990s that PCs were used to display continuous energy information that showed the relative consumptions of different end uses. However there is little published research on how best to display continuous electronic information on energy-consumption, especially at the level of an individual activity or appliance. Furthermore, there is still a lack of studies that look into user reactions to feedback from individual, appliance-level metering. Future work in this area can follow the following paths:

- How frequently to feedback the information?
- In what format to present the feedback information (e.g. as numbers, graphics, energy/cost/CO2 data)?
- How effective is the feedback when displayed at the points of end use as opposed to being displayed centrally?
- What is the preferred user interaction techniques?

WP7 will enable the capturing of consumer's learning and awareness process within participating households in 2 ways:

- measuring changes in energy usage through the metering equipment
- assessing attitudinal change through repeated surveys

5. Approach

As the cycles have progressed, feedback has been received on installation and surveying procedures. This feedback has been captured and compared against the definition of user requirements for each cycle. Where feedback identified unforeseen issues, these were logged and passed to the development partner, Hildebrand as change requests, to be actioned before commencement of each cycle. Issues identified included:

- The need for more user guidance on the DEHEMS dashboard
- The need for more comprehensive installation instructions covering all types of household broadband installation

WP7 incorporates the live testing environment and the user facing element of the work and sits between the user-requirement activities of WP2 and the evaluation and reporting technical activities of WP8. The approach taken since this deliverable was first submitted has been to consolidate the establishment of Living Labs and build on existing relationships to create a community of households engaged with DEHEMS. Cycle 2 and 3 participants in Living Labs in the UK & Bulgaria have provided a test-bed for the DEHEMS methodology and an iterative feedback mechanism allowing the system to be improved and refined for subsequent cycles. In addition, data has been collected, both directly and via questionnaires & focus groups, on the usability of all aspects of the project. This extends beyond the technical solution to include the installation of equipment, training and support, communications and research processes. The approach taken has not made any assumptions about usability and users have been encouraged to critically assess their experience.

More details on the research approach are contained in Appendix ll of D7.7.

6. Activities Implemented and Objectives Achieved

Earlier versions of this report included a detailed implementation plan for Cycle 1. This level of detail is no longer necessary as it has been superseded by the end-of-cycle reviews of Cycles 1, 2 and 3 (D7.5, D7.6 and D7.7) – which contain the relevant details. However a summary of activities undertaken by WP7 partners is included in section 3 of this report.

A summary of the achievements of all Cycles are shown below, in terms of participating households:

Living Lab	Number of DEHEMS Cycle 1 installations	Number of DEHEMS Cycle 2 installations	Number of DEHEMS Cycle 3 installations
Manchester	20	59	56
Birmingham	19	46	43
Bristol	19	47	55
Plovdiv	none	50	50
Ivanovo	none	36	50
Others		4	2
Total	**58**	**242**	**256**

As indicated in section 3, collection and analysis of qualitative data forms a significant part of the DEHEMS methodology. Over all cycles this has been undertaken through:

- Pre-installation survey (Cycle 1 only) – to establish householders' current internet connectivity arrangements in order to identify any upgrade requirements
- Household survey (all Cycles) – to establish knowledge of householders' existing home energy use as a baseline against which future behaviour change can be monitored. See D7.6 appendix II for details
- Focus groups (all Cycles) – to investigate attitudes and motivations towards to energy saving and identify where DEHEMS has resulted in behaviour change. See D7.7 appendix lll for example of focus group structure & agenda

7. Next Steps

Cycle 3 is the final operational phase of the project. Lessons learned are set out as Appendix I of D7.7. These will inform D2.15 Future Requirements Evaluation – documentation of future requirements of a DEHEMS type system.

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Appendix 1: Pre-installation Survey

Please check that the following are available:

1. Home Equpiment:
   - PC connected to the internet
   - Broadband Connection
   - Broadband Router
   - Accessible Electricity Junction Box/Meter
   - 2 spare power sockets near (within 2 metre cable distance) to Broad Band Router

2. Green Meter Equipment:
   - Display Unit (A)
   - Transmitter and Sensor Jaw (B)
   - Ethernet to USB cable (C)
   - Display Unit power supply (D)
   - Data Collector (E)
   - Ethernet to Ethernet cable (F)
   - Data Collector power supply (G)