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User learning and emerging practices in relation to innovative technologies: a case study of domestic photovoltaic systems in the UK.

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ABSTRACT

Due to the rapid growth of the domestic photovoltaic (PV) sector in the UK all involved are at an early learning stage in terms of implementation. Investors typically rely on national standards and guidance when developing specifications that define PV system components. However, PV technology performance is promoted and reported solely in terms of cost and energy efficiency goals without holistic consideration of other contributing factors such occupants' ability to effectively manage PV systems to reduce the current peak demand issue linked with PV systems in the UK. This paper examines policy, design, installation, handover and use of domestic PV systems and how this impacts on the occupant. An in-depth case study of 20 households in a new-build UK development demonstrates the challenges and opportunities related to introducing PV systems in UK housing. Key findings identify the need for complete rather than partial design team involvement and capacity building for inexperienced residents. PV systems are perceived by policy makers and industry as requiring very limited occupant interaction with limited potential to impact on energy use practices - thus an integrated industry PV system learning process incorporating occupant feedback is disregarded. Poor individual occupant learning support and PV system feedback onsite makes this learning even more difficult. If shifting electricity load to off-peak is to be embedded in PV system policy, design and guidance need to support its development based on understanding of occupant needs and practices.

KEYWORDS: occupants learning practices domestic photovoltaic systems

INTRODUCTION

The aim of this article is to identify whether or not households' energy consumption practices adapt effectively in relation to having a PV system in their new homes and the reasons behind this. The following sections in this introduction justify the significance of this key research question in terms of policy, technology and research needs.

Policy: PV domestic installations have grown rapidly in the UK due to the EU Zero Energy Building Concept which encourages micro generation (Seyfang et al., 2013, Hammond et al., 2012) as part of reducing the EU's overall carbon emissions and peak load energy demands. Since 2010 until June 2015 more than 650 thousand homes have been equipped with solar Photovoltaic panels, making housing the largest subsector of UK solar PV market in terms of number of installations and installed capacity (DECC, 2015). In 2014 UK had the highest annual increase of the installed PV systems capacity among all European countries (Chadbourne, 2014). The current renewable energy generation target ratio is set for each country in EU Directive 2009/28/EC (European Parliment, 2009). The UK Photovoltaic systems (PV systems) targets, however, refer only to PV peak power installed, and not to the interaction of the technologies with each other and with humans (Sarrica *et al.*, 2016) Domestic UK PV policy tends to transfer the installation tariff benefits to individual households. For UK domestic grid connected installations, occupants can take advantage of the generous financial terms of the Feed-in Tariff (FIT) incentive from the government to encourage these installations. Even though the FIT has become less attractive, the snowball effect is expected to play a role in ensuring on-going installations (Noll. et al., 2014). There has been an unfortunate history in the UK of sudden changes in the level of FIT intended by government to suddenly accelerate and then slow down the increase in PV installations, whereas industry needs consistency in policy in order to develop effectively. Despite this inconsistency, the stable domestic Energy Performance (EPC) rating based on the Standard Assessment Procedure (SAP) model has encouraged PV installations for top band EPC categories with a correlation between higher EPC ratings and increased house prices in the UK (DECC, 2012). Equally, there is generally a high acceptance of PV technology on an individual level (Allen *et al.*, 2008) – as long as there are clear benefits.

UK policy is not only to produce renewable energy but to tackle peak electricity demand (Ali *et al.*, 2012; Beckmann, 2013) and increasing the on-site consumption and decreasing export to grid is a paramount challenge. On-site consumption is assumed to be 50% of PV generation by the UK government (Sunnika-Blank and Galvin, 2012), but clearly a higher level is desirable, with 100% as optimal. Current UK dissemination strategies for PV systems are beginning to acknowledge a need for some learning on the occupants' part in relation to PV systems (Energy Saving Trust, 2014). However, there is no indication of the need for feedback from occupants to inform PV system design itself in terms of its usability and hence efficiency, the importance of which is suggested by (Hondo and Baba, 2010). The promotion of occupant interaction and education in order to increase on-site rather than grid consumption is also neglected at a wider policy level (Palmer *et al.*, 2012) despite research indicating the benefit of this (Dobbyn and Thomas, 2005; Hondo and Baba, 2010). There is also no indication, however, in recent government studies on Smart Metering of how this might link to education about using PV generation effectively (DECC, 2015) despite EU studies indicating how this can be done (Energy Saving Trust, 2013).

Technology: From a technical point of view, intermittent solar PV electricity generation in the UK climate increases the peak demand problem once the grid connected PV generation exceeds 10GW, unless storage facilities are provided (DECC, 2012). This is due to the diurnal peak PV generation overlapping with a minimum demand for electricity. For domestic grid-connected PV systems, time-shift demand through the addition of batteries has been found to bring environmental and financial disadvantages (McKenna *et al.*, 2013) and some new products are tackling this. Significantly, however, there is no automated procurement and specification process as yet to solve this PV related peak demand issue in the UK, although grid systems are developing in the Netherlands which can match energy demand and supply from a variety of sources, including PV systems, to help offset peak demand (Kok *et al.*, 2012). Varied levels of user engagement exist ranging from investing in smart appliances to changing energy consumption practices (Roaf, 2013). Behaviour change to support time shifting to reduce peak demand as the most efficient strategy (Stern, 2005) is unlikely to occur unless technology is available which positively supports changes in households' practices (Stevenson *et al*., 2013; Stern, 2014).

Research: There is thus a pressing need for research *combining* building science and engineering with social science to explore the potential for integrating PV systems as 'smart' home' technologies into daily practices and facilitating behavioural change to shift loads (Lomas, 2009; Guy and Shove, 2000; Sovacool, 2015). Synergy between these two areas of research occurs when technology is developed and deployed with feedback to support behavioural change (Goulden, 2014). Feedback can help answer questions such as whether such technology actually matches specific user group needs and whether the inhabitants are willing to make the intended use of them in their own homes (Stern, 2013; Maréchal and Holzemer, 2015). The need for occupant engagement in monitoring PV systems in domestic context has been suggested in several studies (Firth *et al.*, 2010, Bahaj and James, 2007). To have further impact on occupant practices, this engagement would also benefit from wider mutually supported social learning between residents as exemplified in a Social Learning Framework developed by (Baborska *et al.,* 2014).

The paper is divided into the following sections: case study presentation, theoretical background, methods, discussion and analysis followed by conclusions. The single case study presented below is used to provide in-depth and data-rich analysis in order to provide new insights that would not be derived from a purely quantitative field study (Yin 2013).

CASE STUDY PRESENTATION

There is a growing interest in collaborative forms of energy efficient housing in the UK (Chatterton, 2013) and in Europe (Droste, 2015; Bresson and Denefle, 2015; Ache and Fedrowitz, 2012; Tummers, 2015). The Low Impact Living Affordable Community (LILAC) in Leeds, England was selected as a case study of a community faced with a challenge of living in recently built low energy co-housing development. LILAC's 35 adult members with 9 children moved into the innovative housing development of 20 dwellings in spring 2013. The community's concern for the environment led to the novel selection of prefabricated straw and timber technology (Wall *et al.*, 2012), and other systems intended to reduce the carbon footprint, including PV systems (Fig.1). The residents all signed a 'low impact living' agreement including common core values such as environmental sustainability and self-reliance (Chatterton, 2015). This made LILAC an ideal comparator against the UK carbon cutting policy for housing (HM Government, 2011) with all residents committed to reducing carbon emissions. All 20 households agreed to participate in the study. This ensured that the context of group activities, information flow within community, social learning and decision making process could be adequately mapped (Baborska-Narozny and Stevenson, 2014).

Figure 1. Case study development with PV panels on the roofs (photo MBN).

The case study chosen exhibits demographics broadly in line with the UK (Table 1) as well as broad income, skills and housing experience (Chatterton, 2015). The wide range of dwelling types are broadly comparable to minimum space standards set by Greater London Authority in 2013 (Table 2) (Robert-Hughes, 2011), illustrating sufficient diversity. Co-housing governance of the case study means that the community acted as a client throughout procurement and then was responsible for the maintenance during occupancy. In the UK this is unusual compared to the mainstream developer led process in the residential sector. In terms of PV installations it allows better tracing the whole sequence of initial motivations, followed by procurement and emerging practices during occupancy.

	LILAC				UK profile
Age structure	male	female	all	%	%
0-14	5	5	10	23	17.3
15-24	0	0	0	0	12.6
25-54	13	14	27	61	41
55-64	0	3	3	7	11.5
65 and over	1	3	4	9	17.5
Total	19	25	44	100	100

Table 1. Demographic profile of LILAC against UK average.

		Min. UK space requirement (GLA) [m^2]	LILAC [m^2]	% difference
Flat	1p	37	46.6	126
	1b2p	50	46.6	93
	2b3p	61	70.35	115
	2b4p	70	70.35	101
Two storey house	3b4p	87	93.3	107
	4b5p	100	111.14	111

Table 2. Dwelling sizes in LILAC against UK min guidance (1b2p = 1 bedroom, 2 people)

THEORETICAL BACKGROUND

Three key theories can be interrelated in terms of understanding how occupants engage with PV systems and learn about them: Affordance theory, Practice theory and the theory of Planned Behaviour (Table 3).

Affordance theory: Gibson defines affordance in terms of what a physical environment offers to a human and uses this to explain the sense in which values and meanings are external to the perceiver (Gibson, 1979). Affordance exists in the environment through size, shape, weight etc. (Chemero, 2003) attributes the perception of affordance to the relation of an agent-environment system and Ingold further defines affordances as "properties of the real environment as directly perceived by an agent in a context of practical action" (Ingold, 1992:46). The theory of Affordance helps to understand how occupants interact through their perception of elements of PV systems.

Behaviours and Practice: A number of authors underline different features of practices that help to locate the behaviours of individuals within broader material and social frameworks (see Schatzki, 2010; Reckwitz, 2002a; Shove et al., 2012). In this study, we will focus on three key concepts employed here to understand the occupant behaviour in relation to PV technologies. First, practice theory as "knowing from activity" (Blackler and Regan, 2009) where knowledge is a practical and collective activity, which is acquired through thought, body, sensory and aesthetic knowledge (Ingold, 2000, Strati, 2007). Second, the non-linearity of end-directed actions (Nicolini *et al.*, 2003) which have the potential to change in every use where "Every engagement with technology is temporally and contextually provisional, and thus there is, in every use, always the possibility of a different structure being enacted" (Orlikowski, 2000: 412). Finally, practices are internally differentiated, providing room for diversity within a particular practice every time it is enacted (Warde, 2005). An empirical study of PV systems by Santin et al. (2009) demonstrated that occupants' characteristics and behaviour significantly influence energy consumption (by 4.2%) for the same building characteristics and conditions. Practice theory can help unpack what occupants are really *doing* with their PV systems and can be linked with their perceptions via affordance theory. The paper doesn't focus on what people do but on the underlying constrains and meanings of their actions: what is their approach, intentions, what are the constraints and how do they build up, what is the meaning of PV system for residents. How social norms in co-housing lower the need for own discoveries in some areas, how policy and industry needs to nurture the potential for change of behaviour and development of new practices. For understanding the procurement stage when PV installation is first envisioned and then given technical specifications the factors introduced by theory of planned behaviour (TPB) are considered. TBP explains how individuals' attitudes and behavioural intentions are depending on norms, expectations and perceived control (Ajzen, 1991). These lens help to focus on what were the expectations towards the PV installations, what norms guided selecting them and whether load shifting was considered as a goal at all. Understanding people's rational behaviour alongside the technical approach in technological development process represents a major concern of the recent social learning studies (Ingold, 2000) and this study attempts to link the understanding of people's perceptions and practices relating to their PV systems with their planned behaviour. The study also relates these social theories directly to building performance, building on previous work by Hansen (Gram-Hanssen, 2010, 2011) and others (O'Callaghan *et al.*, 2012, Gill *et al.*, 2010) through addition of affordance considerations.

Theory	quantitative/qualitative factors	Research Methods
	PV system	
TPB (environmental attitudes)	Client environmental attitudes and PV related expectations at individual and community level - design goals	Interview with design team, Environmental ratings achieved + Energy strategy check Handover shadowing + HUG and manuals, General and PV focused interviews
TPB (Social pressure)	PV policy context/social norms	CfSH Level 4, SAP check, FIT, PV certificates, PV focused interviews
Affordance **TPB (Self-efficacy)**	PV systems design process (architect, design team members and client roles, procurement process, PV power installed)	PV focused interviews
Affordance	Intended user control & feedback on system's operation (design and location of PV controls), guidance provided	Walk through, Usability survey, PV focused interviews + photographic survey
	Inhabitant	
Practices	Prevailing household specific occupancy patterns (electricity loads distribution)	Interview & DomEARM
Practices	Previous experience with PV systems and solar thermal	Interviews
Perceived behavioural control (TPB)	Initial awareness of PV installation - Engagement in design/ procurement, system visibility	Interviews, walk-through
Intention to engage (TPB)	Expectations (of control, of benefits, of need to adapt practices) and perceived benefits at individual, community and society level	Interviews – three sets, PV meter readings, FIT benefits, electricity meter readings, on-site observations
Perceived behavioural control (TPB)	Understanding & skills to interact with PV controls	Usability survey
Practices	PV related home use learning: individual and collective	Home handover tour shadowing, Home User Guide and other PV related info check, interviews and on-site visits, Usability survey
Practices	Household specific electricity consumption & practices, behavioural change observed to adapt to PV generation Individual electricity consumption against benchmarks vs. adding to peak load through PV generation at individual and community level	Walk through, Electricity meter readings + PV meter readings, DomEARM + all 3 interviews, BUS survey

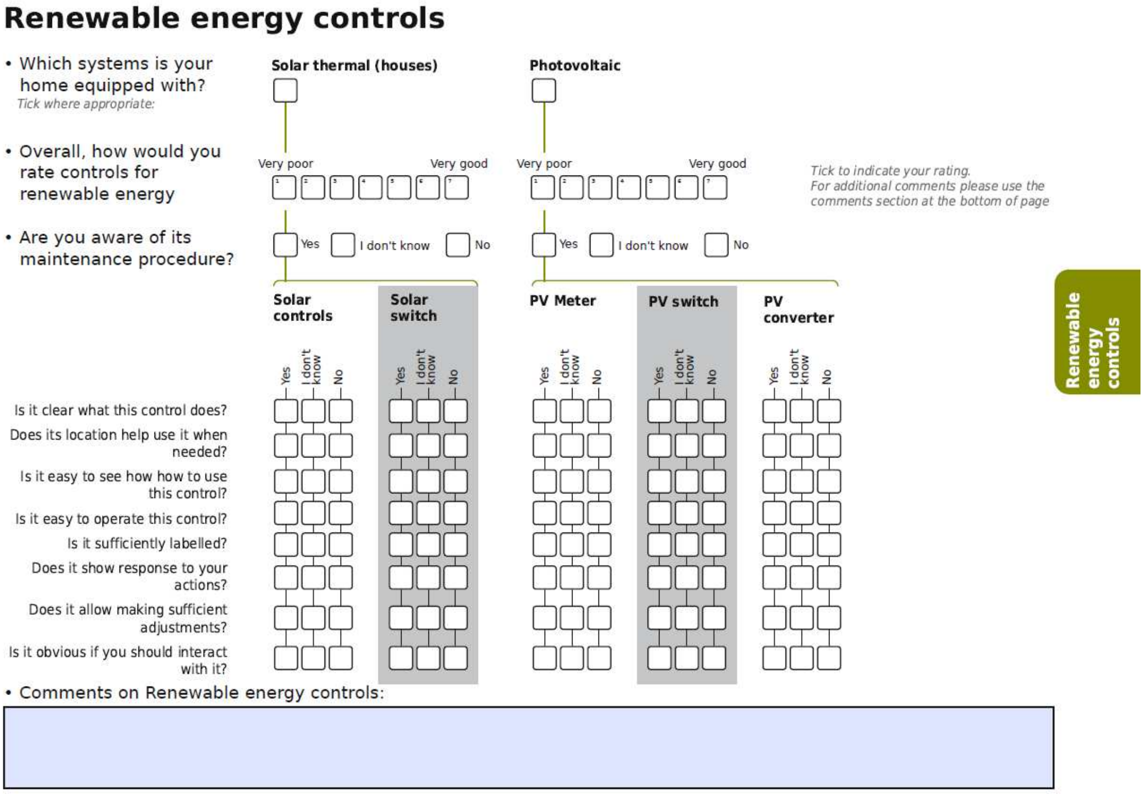
Table 3. Theories guiding factors considered and methods used.

AIMS AND METHODS

Table 3 outlines the methods applied that are described below. A mixed methods empirical case study approach (Yin, 2013) was adopted to build an in depth understanding of domestic PV installation and its policy context, client's environmental goals, design, procurement, in-use phase and consequent benefits at individual, community and society (grid) level, in order to understand factors that enhance or hinder change of electricity use practises to adjust to PV generation in terms of the theories described above. Semi-structured interviews with the Design Team, an evaluation of UK standards applied (Standard Assessment Procedure, Code for Sustainable Homes Level 4, Feed-in Tariffs (FIT) for PV systems) as well an evaluation of Handover procedures and Home User Guides at completion stage, all helped to establish the contextual pressures and responses in relation to the PV systems deployment.

A comprehensive Building Performance Evaluation (BPE) methodology (Mallory Hill et al., 2012) was adopted in this study, with energy, temperature, humidity monitoring carried out in all twenty homes over one year from July 2013 - July 2014. In addition, three different sets of one hour semi-structured interviews, together with Building Use Studies questionnaires (Leaman *et al.*, 2010), walkthroughs and observation methods were used with occupants in all homes to understand the consequences of the relationship between occupants and their

PV systems, based on their intentions and practices. These methods also revealed what and how people know about the PV systems and their context, and were used to identify and interpret any changes that people made (Pink, 2007). An evaluative usability methodology as originally developed by (Stevenson *et al.*, 2013) was further developed by the authors into an interview-based multiple choice user questionnaire with comment boxes (Fig.2). The survey was deployed across all 20 households to indicate the impact that PV system design affordances have on occupants' opportunities to perform actions related to these systems. The 20 minute survey was conducted in January 2014, between seven and nine months after the residents moved in to allow time for residents to familiarise themselves with using the controls in different seasons. It covered all environmental home controls – or 'touchpoints' of interaction between the user and environmental technologies.



Renewable energy controls

- Which systems is your home equipped with?
  Tick where appropriate:
  Solar thermal (houses) ☐ **Photovoltaic** ☐
- Overall, how would you rate controls for renewable energy
  Solar thermal: Very poor ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 Very good
  Photovoltaic: Very poor ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 Very good
  Tick to indicate your rating.
  For additional comments please use the comments section at the bottom of page
- Are you aware of its maintenance procedure?
  Solar thermal: ☐ Yes ☐ I don't know ☐ No
  Photovoltaic: ☐ Yes ☐ I don't know ☐ No

	Solar controls			**Solar switch**			**PV Meter**			**PV switch**			**PV converter**		
	Yes	I don't know	No	Yes	I don't know	No	Yes	I don't know	No	Yes	I don't know	No	Yes	I don't know	No
Is it clear what this control does?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Does its location help use it when needed?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Is it easy to see how how to use this control?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Is it easy to operate this control?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Is it sufficiently labelled?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Does it show response to your actions?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Does it allow making sufficient adjustments?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Is it obvious if you should interact with it?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

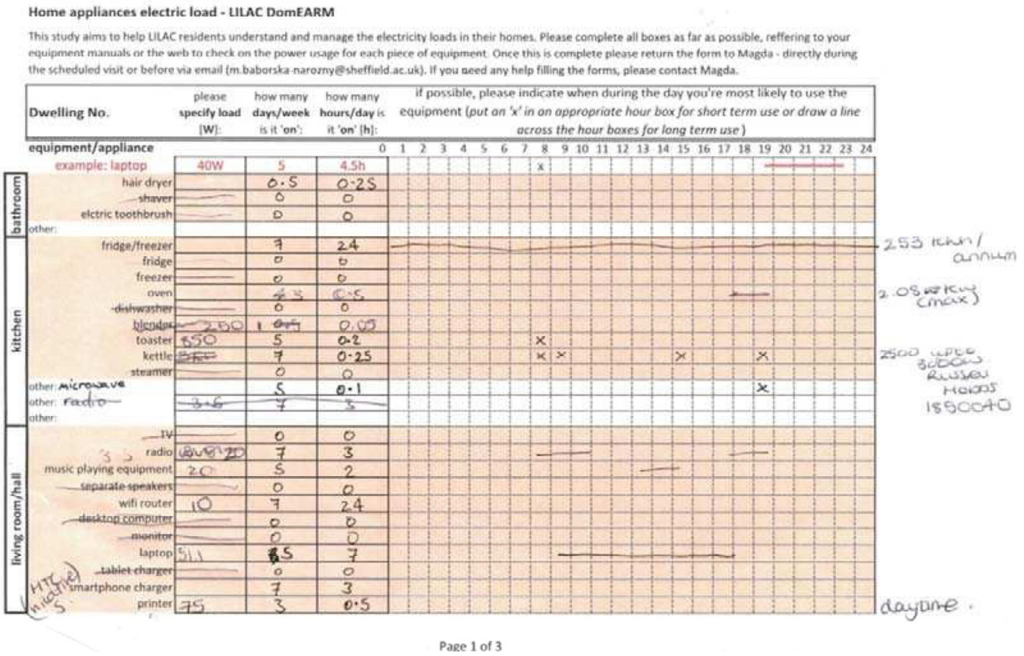
- Comments on Renewable energy controls:

Renewable energy controls

Figure 2. Usability survey Renewable energy controls page.

Residents were asked to evaluate each control against 8 usability criteria derived from Norman's cognitive alignment theory (Norman, 1998).

The use of a proprietary domestic energy auditing tool DomEARM (Mawditt, 2012), based on Energy Assessment and Reporting Methodology developed by Chartered Institution of Building Services Engineers CIBSE TM22 tool (CIBSE, 2006), revealed more detail about exactly what electrical equipment residents were using in the home and how much power each item was using. The prime purpose of applying this method was to understand the actual household electricity consumption (including non-regulated energy) for five households, including the on-site use of PV generation and also the diurnal match between PV generation and household energy load. In order to achieve this the DomEARM method was extended. Questionnaires were developed for different dwelling sizes, which asked for detailed information about all base loads and plug in electrical appliances residents use at home (Fig.3). Heating, lighting and ventilation load constituted base load and were analysed at a weekly and seasonal basis, while other appliances were considered at a weekly and diurnal basis. The validity of information on appliances possessed and wattage given by the residents was checked during the energy audit walkthrough. The collected data was processed with the DomEARM spreadsheet giving results for different categories of energy loads against benchmark values. Additional Excel analysis indicated average match between PV between electricity consumption and PV generation. Domestic energy audit DomEARM covered 5 households (Table 4).



Home appliances electric load - LILAC DomEARM

This study aims to help LILAC residents understand and manage the electricity loads in their homes. Please complete all boxes as far as possible, reffering to your equipment manuals or the web to check on the power usage for each piece of equipment. Once this is complete please return the form to Magda - directly during the scheduled visit or before via email (m.baborska-narozny@sheffield.ac.uk). If you need any help filling the forms, please contact Magda.

Dwelling No.	please specify load [W]:	how many days/week is it 'on':	how many hours/day is it 'on' [h]:	if possible, please indicate when during the day you're most likely to use the equipment (*put an 'x' in an appropriate hour box for short term use or draw a line across the hour boxes for long term use*)
equipment/appliance				0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
example: laptop	40W	5	4.5h	x
bathroom: hair dryer		0.5	0.25	
~~shaver~~		0	0	
elctric toothbrush		0	0	
other:				
kitchen: fridge/freezer		7	24	253 kWh / annum
fridge		0	0	
freezer		0	0	
oven		4.5	0.5	2.05 kW (max)
~~dishwasher~~		0	0	
~~blender~~	~~250~~	1 ~~[illegible]~~	0.05	
toaster	850	5	0.2	x
kettle	[illegible]	7	0.25	x x x x
~~steamer~~		0	0	
other: microwave		5	0.1	x
~~other: radio~~	~~3-6~~	~~7~~	~~3~~	
other:				
living room/hall: ~~TV~~		0	0	
3.5 radio	[illegible] 20	7	3	
music playing equipment	20	5	2	
~~separate speakers~~		0	0	
wifi router	10	7	24	
~~desktop computer~~		0	0	
~~monitor~~		0	0	
laptop	5[illegible]	5	7	
~~tablet charger~~		0	0	
HTC (wildfire) 5 smartphone charger		7	3	
printer	75	3	0.5	daytime.

2500 upto 3000W Russell Hobbs 1850040

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Figure 3. Example page appliance load questionnaire.

Household	Dwelling type	Size [m^2]	Occupancy	Annual PV electricity generation end June 2013 - end June 2014 (kWh)
A	1-bed flat	46.6	1 working adult - no homeworking	987
B	1-bed flat	46.6	1 retired adult	932
C	2-bed flat	73.3	2 working adults – one homeworking	953
D	3-bed house	94.66	2+2 with two working adults – one part time - no homeworking	917
E	3-bed house	93.3	2 working adults – one part time - homeworking occasionally	970

Table 4. DomEARM case study characteristic.

Three sets of interviews were triangulated in order to deepen understanding of energy related behaviour, practices and home use learning. The first set combined with the DomEARM energy audit, covered five residents (25% stratified sample of households) in order to understand resident's perception of PV systems in relation to household electricity consumption. The results informed questions for the second more general interviews covering all households, which established the context of the PV process. The third interview sample of five residents and the Design Team focused specifically on the PV procurement process and actual interaction with the system.

The participatory action research (William, 1991) element which developed incidentally during this project went well beyond the anticipated researcher activity of simply gathering data. This allowed the researchers to follow major unforeseen issues discovered when applying the planned methods (see Table 1) through additional checks as well as shadowing occupant and client interventions related to fabric and systems. Such interventions were initiated and organised by the community in response to interim research findings. This approach, though time consuming for the researchers, had dual benefits for the research quality. First its application encouraged an excellent 100% involvement and cooperation of all the households throughout the duration of the project that required prolonged data collection in people's homes and numerous direct engagements of the residents in research activities. Secondly it allowed the researchers to better understand the underlying causes of issues experienced by the community.

ANALYSIS AND DISCUSSION

PLANNING STAGE AND POLICY CONTEXT

It was agreed by LILAC members to go well beyond Building Regulations requirements and towards a landmark project with ambitions to promote green building technologies (Chatterton, 2015). Code for Sustainable Homes, an environmental standard for sustainability in housing in the UK in the years 2007-2015, became a critical reference point at an early planning stage (DCLG, 2015). PV systems were considered very early on due to their strong 'image' associated with green architecture. PV systems provided an opportunity to make the green agenda visible. Another resident recalls: '*Well, we joined the community, which was going to be ecologically oriented. Therefore, it would be very odd if we did not have solar panels on the roof.'* Social norm clearly linked PV systems with a visible green ethos. The Feed-in Tariff (FIT) was also early on considered as a valuable stream of income for the community. Social norms supported *having* the PV system but it gave no hints about embedding its generation into daily practices of electricity use. As there were no previous experiences the expectations towards PV installations were built upon the message disseminated by the policy and industry.

An Energy Strategy report was commissioned based on compliance with CfSH4 and modelled building characteristics. 4 outline energy strategies were considered in the report, 2 of which included PV systems (Style, 2011). In the report, the compulsory SAP 2009 model demonstrated negative dwelling CO_2 emissions from electricity consumption due to PV generation – a crucial message given LILAC's core goals. Thus PV systems were adopted in preference to other renewable technologies.

The SAP model does not cover electricity consumption from appliances and in the spreadsheet 100% of predicted PV generation is erroneously subtracted from the electricity load, as if it was all consumed on-site. This effectively concealed the grid peak load problem that PV systems actually add to by intermittent generation with peak not overlapping with peak demand in the UK context (Energy Saving Trust, 2014; Nesta, 2015). It also failed to highlight the need for user interaction with PV systems to maximise individual and environmental benefit. This can seriously distort residents' expectations of PV systems in reducing their electricity bills. The SAP results clearly favour PV systems without explaining the critical assumptions behind them and how they relate to reality. The domestic energy audit (DomEARM) illustrated a wide diversity of on-site consumption of PV generated electricity. SAP's simplified message is particularly worrying where those involved with it lack experience and where models and predictions are thus the main reference point for expectations. SAP only considers the level of peak power installed and this is perhaps why the design of a PV system only considers electrical engineering and financial aspects, leaving out the affordance of controls, user guidance and practices.

AFFORDANCE

In LILAC, the project manager, developer, quantity surveyor and LILAC's representative constituted the design team involved in the PV system design process, without the architect's involvement. The LILAC representative made decisions based on information received from the project manager and recalls the main issue being to balance future loan payments with future FIT income: how much could be spent on the PV system's capital cost to maximise the future FIT income. The UK FIT tariffs change dynamically, but at LILAC's design stage they consisted of two payments: one for generation and one for export, with the latter one ca. six times lower; the export was paid ca. three times less per kW and was assumed to be at the level of 50% of the generation. This indicates that the major factor FIT promoted was how much power would be installed. How much would be consumed on site was deemed irrelevant. The PV panels were installed by a roofing subcontractor and all the controls were specified and installed by electrical engineers, with no meaningful interaction with the occupants or architect, which proved to be problematic.

Figure 4. PV converter as installed in LILAC houses and catalogue image.

Figure 5. PV meter and switch installed in LILAC (photo MBN).

The LILAC PV systems have a separate string of 5 panels per each dwelling (1.25kWp) expected to deliver an annual generation of 1073kWh. The panels are located on flat roofs but no maintenance access was provided for any of the roofs other than by an expensive cherry picker. This was a result of the architect’s lack of awareness of the plans to cover the roofs with technology that needs access on a regular basis. Each dwelling is equipped with its own PV switch, PV meter (Fig.5) and converter (Fig.4). The switch and meter are in an easily accessible location in the hallway but the converter is located in a relatively hidden location under the stairs in a storage space in the houses and in a closed cupboard adjacent to small communal guest bedrooms accessible from staircases for the flats. The converter dissipates heat which is perceived by those who use guest bedroom as an issue for that room in a heatwave. On the other hand some residents noticed that the converter causes noise, and are happy to have it in an isolated location. As one LILAC representative (resident A) in the PV design team recalls in the focused interview: *‘…Actually when I walked into my house, I was surprised with the location of some of the things. We were never talked about the location of the PV parts through the design stage until I saw them. I would have liked to have influence over where they would be placed. It was too late. They never told us, they have never been a part of the design process of PV system.’* The same resident was unclear about the need for designed affordance to be taken into account during his involvement with the procurement process. He claimed he was interested in PV converter readings at the early occupancy stage and was aware that ‘*there might be some interesting information about the generated electricity at a specific moment’* but soon gave up. He then advised others not to interact with PV controls other than to take meter readings and at the same time he blamed the inaccessible location and a small display for the lack of residents’ interaction with the converter. Assuming that *‘people in LILAC are already low consumers’* he did not see much potential for behavioural change, which was perhaps a missed opportunity despite conforming to social norms. The perception by LILAC households of being 'low consumers' derives from the community's energy strategy development. (Style, 2011:28). Total electricity use was considered and assumed to be low across LILAC, based on occupant data from their original homes, but the peak demand issue and load shift potential were never examined until the researchers raised the issue.

The manufacturer claims that the converter (Mastervolt, Sunmaster XS series) features *'accessible monitoring functions that offer a complete overview of performance… with LCD read-out that further optimises the user-friendliness'* (Mastervolt, 2008, p.7). However, these features were impeded by an inaccessible location.

INTERACTION WITH PV CONTROLS

The analysis quickly identified those users who had no basic understanding of the purpose of a control or their own role in using it (Fig. 6) given that without such basic understanding, users could not meaningfully rate the quality of interaction with a control. The analysis further identified whether a control had been tested and used, on the assumption that without actual experience of using a control, neither its design nor interaction affordance could be meaningfully rated. For increased validity at this stage, interview and BUS survey comments were evaluated to further assess understanding of a control and its location in a dwelling. Only those responses that claimed understanding and indicated actual use of a control provided insight into experienced design issues or lack of skills.

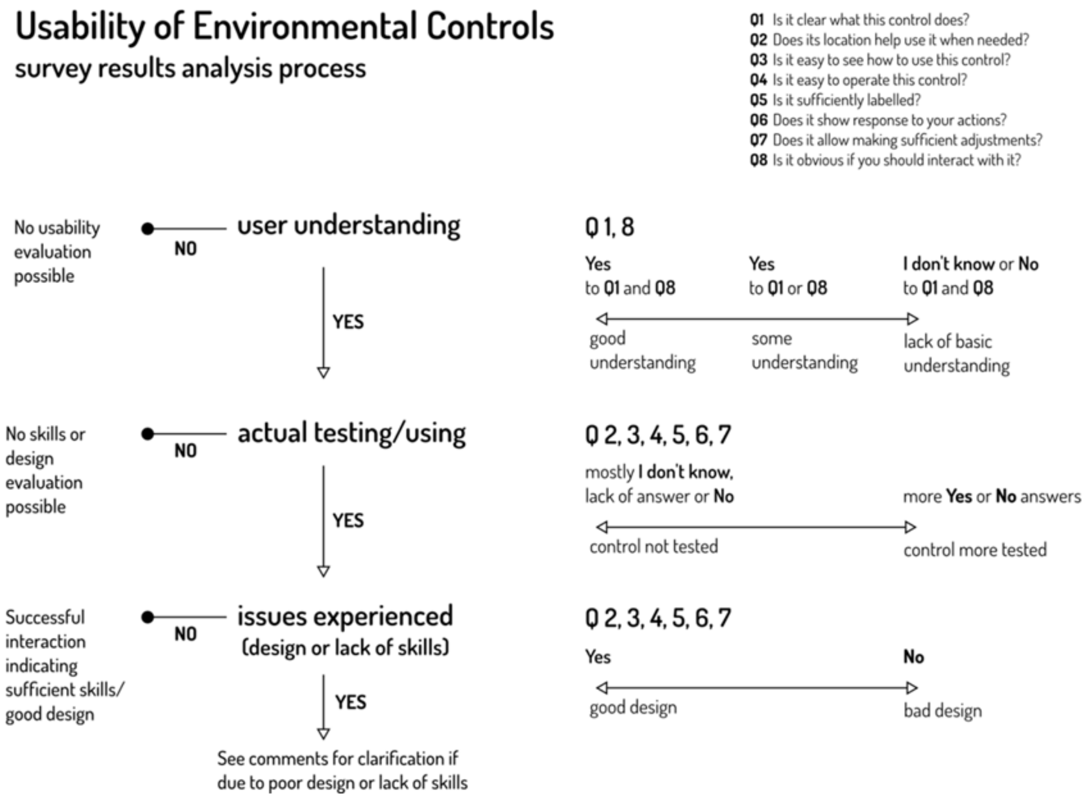


Fig. 6. Usability survey analysis process

For the PV controls 'I don't know' was the predominant answer on average across all of the usability questions (50-63%). Residents' comments often revealed a complete lack of awareness of a PV control, or that they were not sure whether the question was relevant. Feedback and fine-tuning issues among those who understood the PV meters, resulted in a twice as high number of 'I don't know' answers to these two questions compared to the other 6 questions for this control (see Fig. 7). Resident A explained his lack of awareness of the PV converter and switch location in terms of '*I learn things on a need to know basis and will ask advice from someone if/when I* *need to know.'* Clearly for this resident there had never been a need to know about the converter during the 8 months of occupancy. Comments from four other residents pointed towards an important learning point during the early occupancy stage, when trusted advice was given not to interact with PV system. Resident A confessed: *'I don't know what 'PV switch and PV converter' are. I've been told never to touch the PV stuff, just leave it alone, so I have no interaction with these at all.'* Despite this advice, three other residents used the comment box to reveal their wish to learn more in case there was anything they should know about PV systems.

The best perceived understanding for PV controls related to the PV meter (over 30% of residents surveyed) as this is the only control most inhabitants need to interact with to take readings required for the FIT purposes. Resident B admitted a lack of skills to take the readings and expressed an eagerness to learn: '*I do not understand how the PV controls work - or how can I read them. Information needed please.'* Three out of 14 households who did take manual meter readings made comments on PV meter design issues such as a small display and/or numbers flashing for unknown reasons. Importantly, this lack of affordance makes a simple task a nuisance. On-site visits, conversations and interviews, confirmed that taking a PV reading once every 3 months (as required by the utility company) did not help residents to understand the PV generation or to see any link with their own energy consumption. Electricity monitors were initially installed but due to technical problems for each dwelling they aggregated electricity flows both coming from the grid (consumption) and exported to the grid (surplus PV generation) and thus proved to be useless and were soon removed. Electricity bills covering irregular time spans and not linked with FIT did not help to build resident understanding either, despite a single energy company managing both grid electricity and feeding PV generated energy into it.

The worst resident understanding related to the PV converter was 7%. This score reflects a predominant lack of understanding of the purpose of the converter and a lack of interest or even awareness of this control, hidden away from sight. Only one resident commented on design issues linked with the converter, i.e. an inconvenient location that makes attempts of interaction difficult, in a dim under stairs storage space at low level, which is particularly unfortunate in terms of trying read the display unit, given that the visual display is positioned at the bottom end of the device (Fig.3). All other inhabitants never understood the point of looking at the convertor display even though it presented the percentage of instantaneous power generated against peak power. Importantly, for such information to become useful it needs to be readily available and to be understood in relation to residents own electricity consumption practices. Only then can the convertor become an essential support for managing efficient domestic load shifting in order to use PV electricity while it is generated and thus lessen impact on the grid in peak demand period as well as saving financially from this practice. Despite having a 'Low Impact Living' policy, the housing community in this study had never explored the load shifting challenge as it was never identified as one. This correlates with the way PV systems are advertised to the public as generically free green electricity *'Solar electricity is green renewable energy and doesn't release any harmful carbon dioxide or other pollutants'* (Energy Saving Trust, 2015) '*By installing a solar PV system on your business premises or your residential home you are reducing your carbon footprint.'* (Green Team Partnership, 2015). There is no hint included that residents could maximise their individual and grid benefits by load shifting, or that the environmental benefits can disappear if a rebound effect described below takes place.

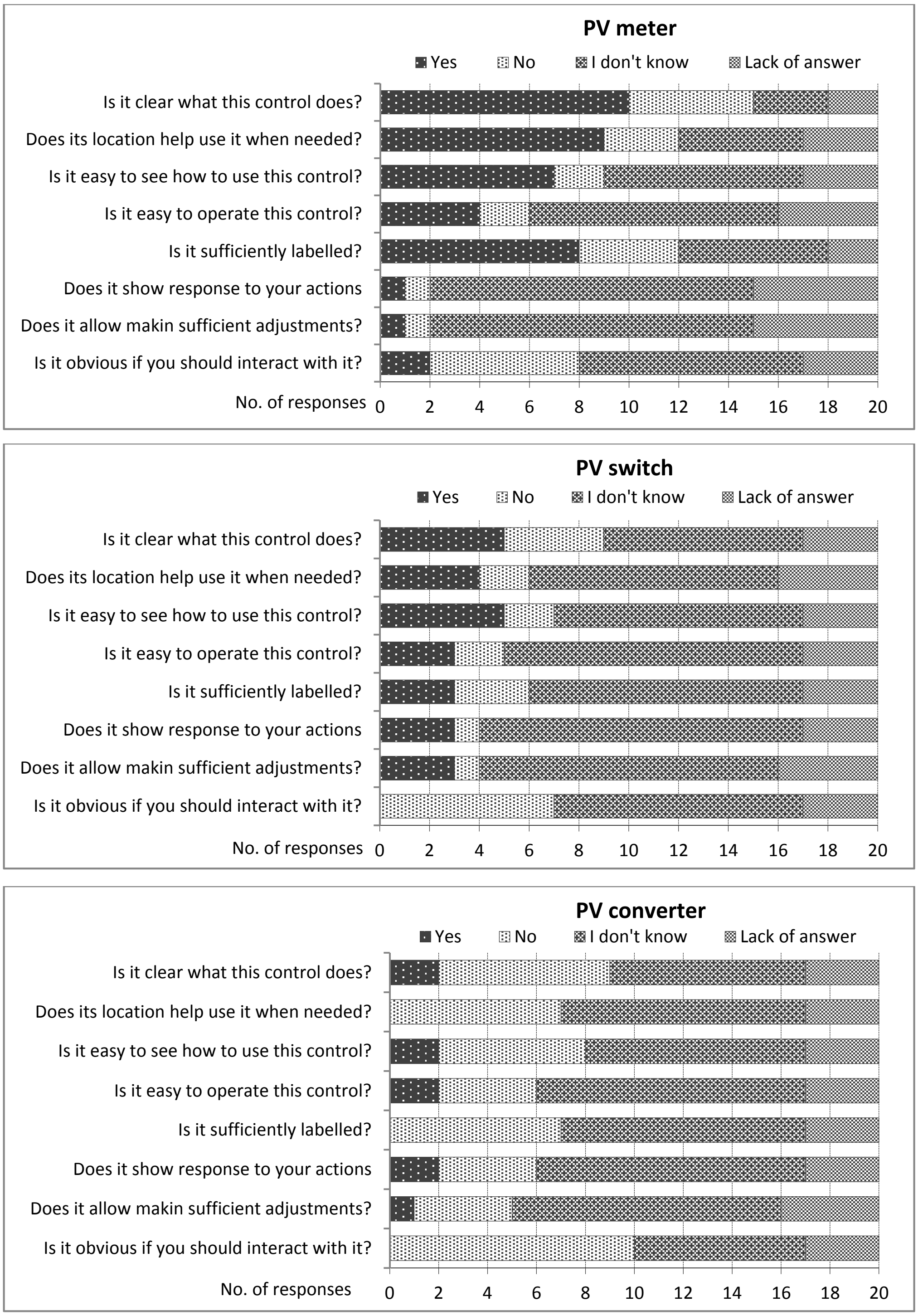
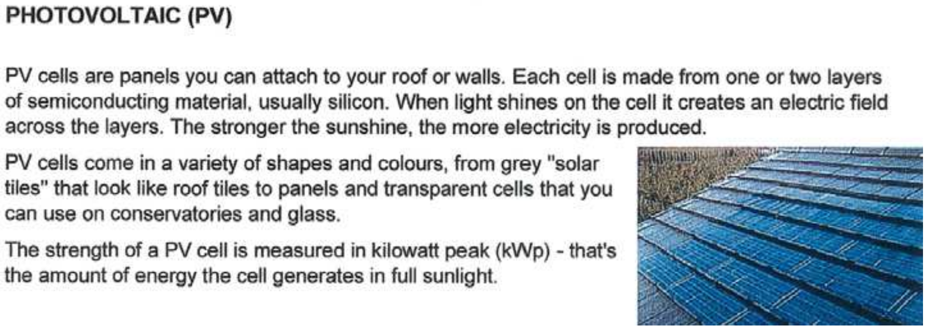


Figure 7. Usability survey responses for PV controls.

PV RELATED LEARNING AND PRACTICES

LILAC did not commission a bespoke professional home handover procedure for its members, which is typically delivered by larger developers. Instead it invented a pioneering handover procedure to suit its particular circumstances. This involved the subcontractor instructing selected LILAC members on the skills and understanding needed to make use of the systems installed as intended (Norman, 1998). The plan was for these LILAC members to then pass on their knowledge to all other members in a subsequent tour. As a result cost savings would be made compared to a typical handover procedure while the skills and understanding of home use would be shared within the community. However as the residents moved in in stages the tour was actually organised only for one group of six households. Given that one resident participated in both demonstrations, altogether representatives of 8 out of 20 LILAC households participated in one of the two home demonstration tours. Both tours were shadowed by the researcher, recorded and transcribed. The first one, led by the subcontractor responsible for installing all mechanical and electrical systems, including the PV systems, was given to 3 LILAC representatives. This one hour tour only gave a brisk mention of the PV controls located in the hallway (PV switch and meter) without showing the converter. The converter was referred to once when the demonstrator said: *'the rest of the equipment is under your stairs…'* When a resident asked how he could check if the PV was generating power he was instructed *'you just press the button on the equipment under your stairs…',* without any demonstration. During a subsequent tour lead by a LILAC member for 7 other LILAC members the converter was shown, and the manual for it was mentioned but as the demonstrator confessed *'…I didn't look at it yet'* and '*all I know is that if you push the right hand button twice it tells you how much you're generating at the moment with PV panels '*. Crucially, no information was provided as to why this reading might be of interest in terms of FIT and energy load matching. User and installation manuals were perceived as too technical by 18/20 households in the Usability survey and interviews. The section on PV in the Home User Guide provided by the contractor gave only generic information about PV cells, and was not specific to the system installed in LILAC (Fig.8). The manufacturer's on-line brochure, not given to the residents, clearly shows much richer functionality of converter display than mentioned during the tour (Mastervolt, 2008). Despite the on-line accessibility of this resource, the converter remained a completely unknown control for a vast majority of residents (Fig. 6) throughout the project duration, which points towards a crucial lack of awareness of any reason to engage in PV related learning.



PHOTOVOLTAIC (PV)

PV cells are panels you can attach to your roof or walls. Each cell is made from one or two layers of semiconducting material, usually silicon. When light shines on the cell it creates an electric field across the layers. The stronger the sunshine, the more electricity is produced.

PV cells come in a variety of shapes and colours, from grey "solar tiles" that look like roof tiles to panels and transparent cells that you can use on conservatories and glass.

The strength of a PV cell is measured in kilowatt peak (kWp) - that's the amount of energy the cell generates in full sunlight.

Figure 8. The only PV related information in the LILAC Home User Guide.

INTERVIEWS

From the triangulation of the interview results with other results, four types of 'learning' residents emerged (Table 5):

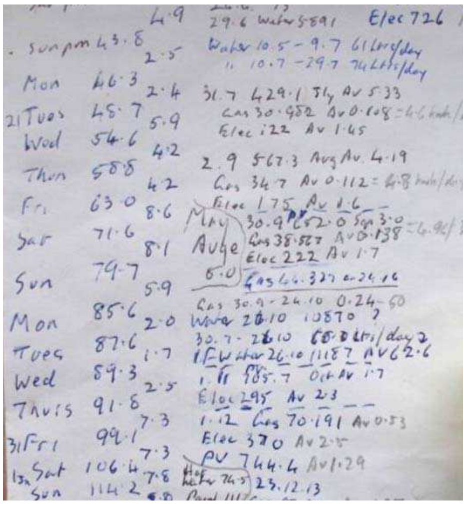
Residents' learning type	PV generation vs. own consumption perceived understanding after one year of occupancy	PV related learning process/potential	No. of households
Type 1	None or very little	Not yet or very limited and no need for	9
Type 2	None or very little	Not yet or very limited but willingness to engage	8
Type 3	Perception of limited understanding	Did happen but ceased due to lack of progress	1
Type 4	Confidence in sufficient understanding	Did happen but ceased due to lack of need	2

Table 5. Types of residents in relation to PV understanding and learning.

The PV system was one that none of the residents had previous experience with. It was perceived mainly in the context of 'free' energy, securing FIT income. Expected financial gains were foregrounded by occupants when PV systems were discussed. For Type 1 and Type 2 households (17 out of 20) these expectations were not backed by efforts to gain understanding of the actual intermittent level of PV generation in relation to their own consumption. As one resident confessed: *'I don't know about the solar panels but I don't need to know about them'*. The **Type 1** approach reveals lack of intention to learn about the PV system which clearly reflects the PV marketing strategy described above strengthened with trusted advice **'not to touch'** in relation to PV controls. Another resident classified in this group explained: '*I believe that PV are making a difference but not enough that I noticed without counting it up and you know keeping a tally for a year which I haven't been because the bill isn't enough to make me worry that much about reducing it...'* Electricity bills were not perceived as helpful in understanding consumption compared to the first year of occupancy, as for the majority of households, they were based on estimations and not on meter readings. Further to this they included a high standing charge which made it difficult for occupants to see the impact of lower consumption within a lower bill. Bills were also issued irregularly.

Type 2 residents realised their own lack of understanding and were eager to learn more in order to maximise the financial and environmental benefits of having PV systems. In this group there is a strong appreciation of information received as a part of the building performance evaluation process and high expectations of feedback meetings regarded as important learning points. However in this group the learning process was not proactive. They would have liked to **learn more from others**, but were not prompted to find out by themselves. One resident explained their own attitude in terms of diffused responsibility specific to communal living: '*…because there were other people using the same system, I do not have to worry about it because I have always got somebody I can go and ask. So from that point of view, I suppose if I was in my own home or just had one neighbour, I have to find out and understand everything about my system. I'm a bit lazy now'.* There was trust that one would be informed if need be. A self-managing community has so many issues that need constant attention and residents were used to delegating tasks that not everyone needed to be involved in. PV learning subconsciously fell into this latter category.

There was only one **Type 3** resident in the sample. This resident with a strong environmental agenda was **eager to learn all** about low carbon features of the house, even though PV was at the bottom of the 'need to know' list on assumption that '*PV just does what it does, and even I do not know how to do better'*. He found the lack of any introduction given at the start of occupancy justified due to the premise of no interaction possible with the PV system *'…because there is nothing particularly to switch'*. From the very beginning he took daily PV meter readings along with readings from other appliances (Fig.10). He made this effort even though for almost a year into occupancy he was unaware that he individually could benefit from using PV generated electricity – he thought all the generation went to the community just like the FIT income. He only learned this was not the case by talking to a technician who came to assess a potential electric car charging point. This is a particularly surprising finding given that most of the other residents knew about FIT income generation. It indicates a serious pitfall of unstructured home use learning based on responding to questions raised; 'unknown unknowns' cannot be efficiently tackled this way and new technologies in a domestic environment are particularly vulnerable. After almost a year and a half since moving in the resident was still unaware of how many PV panels he had on his roof – the technical side of the system remained a mystery. In the interview he confessed: '*I'm vaguely conscious… And I'm conscious that I feel a bit pathetic anyway because one of the facts and figures that I've found was that through July 1st year which was the best month ever, it generated the average of about 5.33kWh a day. So that was less than a kilowatt-hour per hour.'* This was assumed to be insufficient to justify substantial behavioural change especially given the variability of generation *'…it would be very difficult, very complex to work it out hour by hour what you were getting free and what you weren't. But I'm aware that when the sun is shining you should be able to use low power electricity, electrical equipment. I have it at the back of my mind. How much did I apply it in practice? It's hard to say.'* The converter function that could help overcome this problem was never used due to lack of user awareness. Type 3 resident did not become a source of information for others, because despite some learning effort (daily PV meter readings), his findings in relation to PV did not take him much further than others' intuitive behaviour. His self-efficacy in relation to adapting daily practices to PV generated electricity remained low.



4.9 29.6 Water 5891 Elec 726
Sun pm 43.8 2.5 Water 10.5 – 9.7 61 Ltrs/day
" 10.7 – 29.7 74 Ltrs/day
Mon 46.3 2.4 31.7 429.1 July Av 5.33
21 Tues 48.7 5.9 Gas 30.482 Av 0.108 = 4.6 kwh/
Wed 54.6 4.2 Elec 122 Av 1.45
Thurs 58.8 4.2 2.9 567.3 Aug Av. 4.19
Gas 34.7 Av 0.112 = 4.8 kwh/day
Fri 63.0 8.6 Elec 175 Av 1.6
May 30.9 PV 652.0 Sep 3.0
Sat 71.6 8.1 Auge Gas 38.527 Av 0.138 = 4.96/
Elec 222 Av 1.7
Sun 79.7 5.9 6.0 Gas 44.327 [illegible] 24.10
Gas 30.9 – 24.10 0.24 – 60
Mon 85.6 2.0 Water 26.10 10870 ?
Tues 87.6 1.7 30.7 – 26.10 68.0 Ltrs/day
1 F Water 26.10 11187 AV 62.6
Wed 89.3 2.5 1.11 PV 885.7 Oct Av 1.7
Thurs 91.8 7.3 Elec 295 Av 2.3
1.12 Gas 70.191 Av 0.53
31 Fri 99.1 7.3 Elec 370 Av 2.5
PV 744.4 Av 1.29
1st Sat 106.4 7.8 Hot water 74.5 23.12.13
Sun 114.2

Figure 9. Daily meter readings for gas, grid electricity and PV generation.

There were two **Type 4** households where a resident was confident he understood enough about PV as a result of previous learning and **did not see the need to explore further** the potential for behavioural change. Residents from these households are of particular importance given the ‘task delegation’ approach prevailing within the community and trust that one would be informed in case there was something worth knowing. One of them came to the conclusion that no further adjustments in behaviour could be made due to prevailing household occupancy patterns: both adults working, one full time. The assumption was that if there was no one home, the PV generation could not be consumed. The issue was not explored any further. This household was covered by the energy audit reported below (household D) that confirmed a low ratio of on-site consumption to PV generated electricity. An interview with the other resident revealed a significant error in his justification of no need to explore further the opportunity that PV systems create for further reducing energy use as illustrated by this exchange during his interview:

> *‘Are you happy with your energy consumption in relation to your energy generation from your PV system and why?’*
> *‘Yes. Absolutely yes, because each house generates just a little bit less than it uses. It is pretty good actually as expected. I have got the figures in my house.’*

In practice when the PV systems were installed, the household electricity consumption was no longer equal to the metered electricity taken from the grid. The resident compared figures for household annual metered PV generation with the annual metered consumption from the grid. He missed the fact that there is a hidden ratio of on-site consumption of PV generated electricity that none of these meters captures. As a result the metered consumption may be 50% lower than actual use (see Fig.10, household ‘C’). This finding was captured through the DomEARM energy audit. Such a categorical error strongly supports the presumption of belonging to the ‘low consumers’ category which lowers motivation for any learning. When asked about PV related social learning and its impact on behaviour change the resident confesses: *‘Actually, just now there is a desire to have a meeting to look at our energy use and discuss ideas about how we could reduce it further. I think it is useful for sharing ideas. But I mean because we are low energy occupants anyway, I think we have understood how much energy we have used and how much energy we have generated.’* The need for such a meeting expressed by Type 2 residents was questioned here by the Type 4 resident convinced there is ‘not much more to learn’. The resident himself reveals not having adapted his electricity use to the PV systems, other than using the communal laundry during daytime hours. He explains *‘I’m quite a low-user of energy but also I’m aware that I’m generating a lot of energy. I’m happy to still use the energy as well. I feel less guilty about using energy because I’m already generating it.’* This statement point towards an important electricity specific ‘rebound effect’ (Sunikka-Blank, 2012) related to introducing PV systems to households used to conscious electricity consumption. As another resident (household E in the energy audit below) asserts: *‘You’ve got to change your relationship to electricity use, which is ‘electricity is expensive, try not to use much’, but actually when we’re generating it, it benefits us to use it so it’s really interesting having to re-think’.* Importantly, with this type of ‘rebound’ approach, additional appliances that would otherwise be regarded as unnecessary, like an ice cream maker, become the desired 'solar-powered gadgets' that help consume more of the 'free' electricity. Yet another resident revealed a similar attitude when describing her experience with PV systems: *'When we first moved in, on the day I thought 'ooh, this is free!' and plugged loads of things in, but now I don't really think about it.'* This household used 98% of PV generated electricity according to the energy audit (household C), thus almost twice as much as the FIT assumption. This energy hungry side effect of introducing individual PV systems could have significant implications for the current government estimates of energy saving predicted by transferring to PV systems, particularly as these new gadgets will also have to draw on grid electricity in the winter.

In terms of actual adaptation of electricity consumption practices to PV, no systematic behaviour was reported by the vast majority of residents other than doing laundry during daylight hours. 3 households used an electric kettle in daylight. Two of these stored hot water in flasks, which is an excellent attempt to shift load. The third one switched to a gas kettle when dark outside. Two households tried to charge laptops and phones in daylight. None of these practices were grounded in any calculations or checked against their real impact on electricity consumption and remained on a random, intuitive level.

ENERGY CONSUMPTION

Results for the domestic energy assessment of household electricity consumption in detail indicate that on-site consumption of PV generated electricity varied for different households between 40-98%, depending on occupancy pattern and electricity load (size of household). It was the lowest for those who spent less time at home during the day. The single retired person in a one bed flat (B), despite being at home a lot, did not consume enough electricity to use half of what was generated by his PV system (Fig.11). The biggest beneficiaries of PV installations were those who consume more electricity and are at home during the day - homeworking. The sample of audited dwellings was small and further research would be needed but both high on-site consuming households revealed 'rebound' behaviours in relation to PV generation in the interviews.

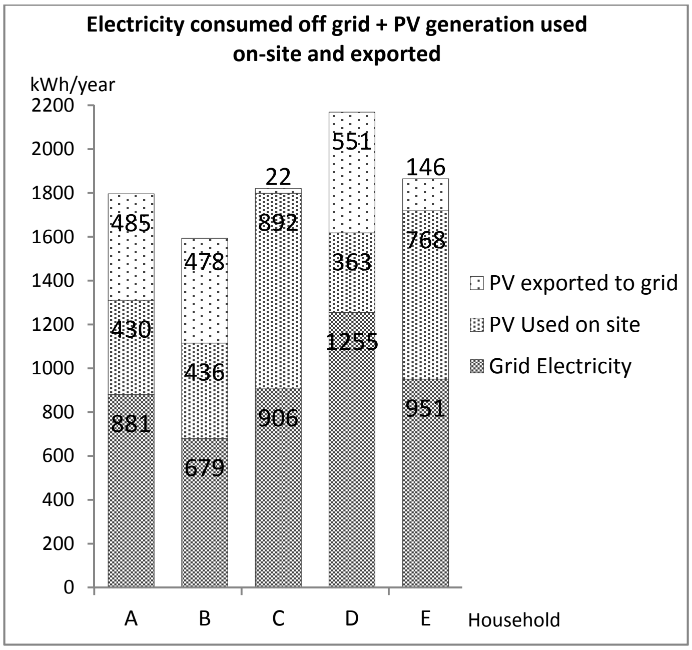


Figure 10. DomEARM results: electricity consumption: off grid and PV generated.

The varied match between PV generation and domestic electricity consumption was illustrated more starkly with summer conditions for households A and E (Fig.11). In household A the single working adult was away most of the day and the majority of electricity use was concentrated in the evening with a clear peak demand. Also the base loads from the refrigerator or whole house ventilation was lower. In household E the work pattern of one of two working adults was varied; usually there was someone at home and electricity consuming activities like cooking were more spread across the day. Base loads were also higher and more appliances used. The yellow rectangle below is a robust representation of diurnal summer PV generation based on seasonal average PV meter reading.

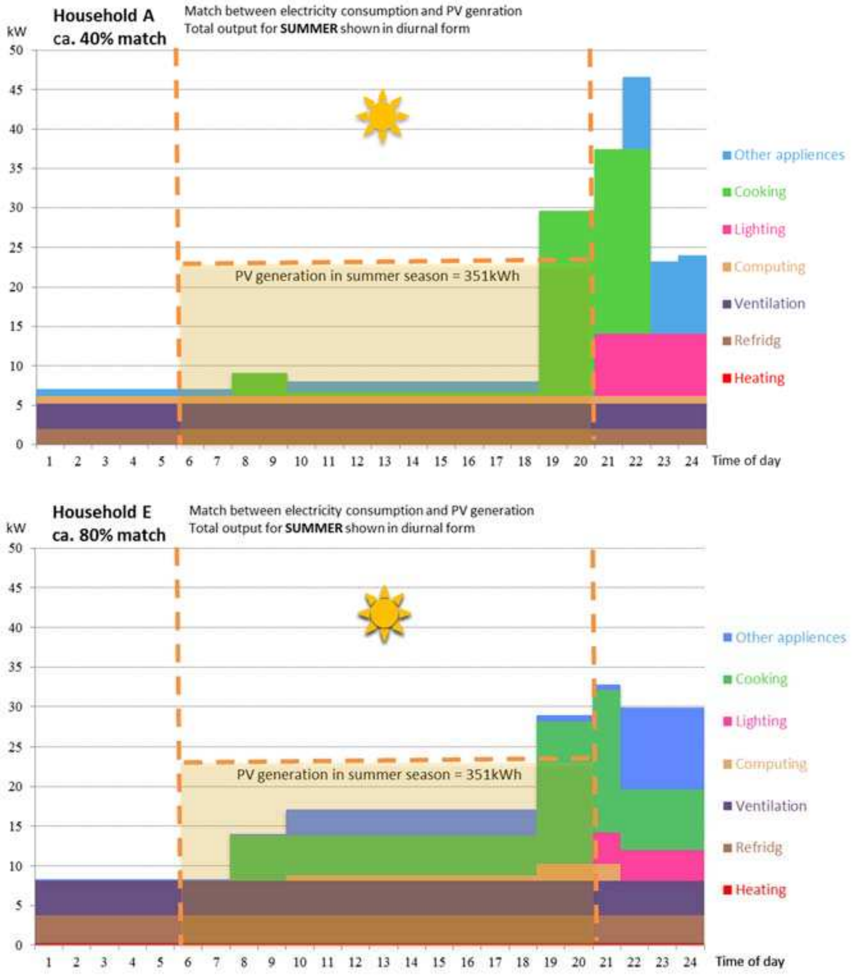


Figure 11. Summer match between PV generation and consumption for households A and E.

CONCLUSIONS

In this case study, households generally perceived themselves as sensitive to a ‘low impact’ agenda that drives the transition of the residential sector towards low energy goals. They wanted to be at the forefront of the change towards sustainability. The question was: how did they incorporate PV technology into their electricity use practices and what role does affordance play? The fieldwork analysis has revealed some significant barriers and pitfalls of the process of adopting PV systems in new housing, even among pioneering eco-residents, for whom the actual goal should have been not only to install a certain amount of PV peak power but also to lower peak demand on grid by introduction of load shifting. The achievement of the later goal has not been envisioned by the community at procurement stage as neither social norms nor FIT policy or industry advice supported it. As a result, it is clear that any aspirations of residents to be able to fully and properly engage with the PV systems has been thwarted through a combination of incorrect design assumptions, poor installation, poor handover, poor affordances resulting in poor understanding and practices on behalf of households with this system in place.

The need to lower energy consumption was accepted from the start by the people in this study based on LILAC’s carbon emissions and financial criteria. However, the PV technology was marketed and generally introduced and perceived as ‘free and green electricity’ which clearly undermined the motivational attitude towards electricity consumption, causing an unintended ‘rebound’ effect even among careful energy consumers which actually promoted energy use per se. Gradual shift of attitude from very careful electricity use towards a more relaxed or even encouraged one was expressed by the residents: plugging more equipment in was reported compared to previous accommodation or leaving it on standby was no longer perceived as expensive or harmful to the environment. PV electricity generation inspired plans to buy appliances that would not be considered otherwise like ice-cream makers. Further research involving a bigger sample would be needed to fully understand the impact of this finding. However, given the increasing development and supply of potentially programmable 'solar-powered gadgets' which will use more energy the need for such research is urgent to avoid excessive use of FIT at the level of 50%, subsidised with public money.

The peak demand issue and load shifting opportunity linked with PV generation has been identified as one hidden from residents. Adaptive electricity use behaviour to improve the match with PV generation was only promoted by government campaigns and industry to residents in terms of financial motivation. This was not the only motivation in the studied community when other factors such as choosing the electricity supplier based on their environmental agenda were put ahead of the price criterion. Policy and practice which puts PV systems only into a monetary context of FIT and maximises the use of 'free' electricity suggests lack of awareness of other energy factors which need examining. The way new technology is presented to the public, from national policy level down to suppliers' marketing strategy and professional advice, has complex 're-bound' consequences at different stages: planning, procurement, in-use and providing feedback to the next occupants. Policymakers and the housing industry need to take this into account when developing renewable energy strategies. The UK Standard Assessment Procedure results clearly favour PV systems without explaining the hidden assumptions made which generates design team and occupant unrealistic expectations about the direct impact of the system on the energy and environmental savings.

These unintended consequences are particularly important in the transition period when the actors involved have no previous experience. Domestic PV systems are likely to be discussed and perceived by those with no experience only in terms of the installed power of the panels and without reference to occupants' specific electricity consumption and practices and households' occupancy patterns. As a result PV systems are then considered at the planning stage as a system that needs no interaction affordances. The architect's and installer's role in offering appropriate affordances for successful user interaction needs to be more carefully considered, alongside the development of effective user guidance which promotes intention to engage with the PV system controls in order to develop appropriate practices in relation to the use of PV generated energy. Even if a control does provide affordances for user interaction, it may still never be tried out because of being out of the user's 'radar' both physically and mentally. The erroneous practice of non-interaction can be passed on to wider networks, further reinforcing through subjective norm the original erroneous perceptions, causing a vicious circle of lack of intention and ability to engage in efficient PV related learning. Without efficient learning, any practice adaptations to PV systems remain intuitive and all actors remain unclear about their impact. Technology design that provides occupants with integrated feedback on the results of their own behaviours, practices as evidenced through consumption and generation in an accessible way is essential to overcome this problem. This will only happen if the need to invest in such feedback solutions and to learn how to use them is promoted to all communities and individual residents. Meters of energy exported to grid not usually present in domestic PV installations in the UK could be a useful feedback tool if they provided information in an accessible way.

In the energy transition period (Sarrica *et al.,* 2016), when new technologies like PV are introduced into housing, not only the occupants need the feedback on the performance from PV system but the design team, manufacturers and installers need feedback from the occupancy stage in order to avoid repeating the same mistakes. BPE studies can close this feedback loop (Mallory Hill *et al.*, 2012) but their implementation on a wider scale requires policy changes at national level. A way forward currently developed in the UK is Soft Landings for housing with Quality Assurance systems to ensure that BPE study findings are automatically fed back into Design Team process and procurement strategies (https://www.bsria.co.uk/services/design/soft-landings/).

Occupancy stage feedback to improve systems design can also be achieved by strategically using a Show Home ahead of the final build process to check installation processes with occupants on larger developments. Such a step was taken on Hanham Hall by Barrett Housing (Pearson, 2014). Show Homes could also be used for co-creation of a new technology's presence in a home by engaging the occupants in fine tuning the controls' specification or design and identifying their optimum location within a dwelling from user's perspective. For individual home installation, it is important that the PV systems industry takes occupant feedback more seriously and develops the use of focus groups with home owners to understand how their systems perform in practice.

To achieve such a wholesale transformation and avoid future renewable energy 'rebound' effects relating to user understanding, policy makers, manufacturers and the construction industry needs to develop and communicate a more holistic understanding of PV technologies in the context of the wider energy challenges and opportunities they bring. PV marketing strategies for the public should be more fine-tuned for different audiences to promote genuine energy saving behaviours and practices, not just financial juggling of energy. In the UK context this means ensuring that load shifting as an actual 'win-win' situation for both user and environment must be positively presented, instead of limiting the promoting PV installations as suppliers of 'green and free' electricity.

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