Effectiveness and impacts of community-based action on household energy reduction

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Abstract
This paper investigates the effectiveness and impacts of community-based home energy improvements within six Government-funded low carbon communities (LCCs) in UK as part of a multi-disciplinary research project. The improvements undertaken included physical (fabric) and technical (services and systems, including low-zero carbon technologies) measures as well as behaviour change interventions (from energy display monitors to energy management programmes and workshops). A graduated mixed-method monitoring and evaluation approach is used including: assessment of aggregated and longitudinal domestic energy data (1,000–5,000 households per community over five years), carbon mapping of approximately 1,800 households *before* and *after* implementation of community energy projects, longitudinal meter point gas and electricity data of 88 households over 5 years, qualitative surveys and interviews with 88 households; and thermal imaging and physical monitoring of 60 selected dwellings (of the 88 households).

Whilst the aggregated longitudinal energy data and carbon mapping enable an examination of the *effectiveness* of community-based action, the in-depth case studies provide evidence on the wider *impacts* of home energy improvements and highlight the complexities and limitations of community energy projects in reducing energy use, and sustaining pro-environmental behaviours. Analysis of long term energy use (2008–2012) shows that there is an overall energy reduction trend in these communities, with gas use decreasing significantly in communities where a primary focus was on demand reduction, through physical measures combined with energy management workshops. Interestingly LCCs with a focus on electricity generation (solar PVs) have also seen a higher than national average reduction in electricity use. Yet the household level occupant interviews highlight that whilst the majority are sustaining positive energy behaviours, influential and dominating factors such as cost, lifestyle, health and comfort can impede further change, particularly in relation to one-off purchasing behaviours and heating-related habitual behaviours. Despite this, the LCCs appear to play an important role in increasing individual agency, dispelling myths and mixed messages surrounding 'new' technologies, and providing much needed space for dialogue around demand reduction and local energy generation.

Introduction
With household energy use accounting for 29 % of the UK's total energy consumption (DECC, 2014a), the need for radical change through domestic energy action (energy efficiency, behaviour change and energy generation) is critical, and increasingly necessary for mitigating climate change, reducing national carbon emissions and achieving energy security (UKERC, 2009). Whilst the UK Government has recognised this through incentivisation schemes such as the Feed-in Tariffs and the Green Deal, often they are not as effective in terms of energy reduction as expected and desired (ECCC, 2014 and Galvin, 2014a). In addition, much research (Gupta et al., 2013 and Galvin, 2014b) demonstrates that domestic energy efficiency and generation projects alone do not meet designed energy outcomes, irrespective of the depth and type of physical retrofit, even in well-resourced and funded programmes like 'The Retrofit for

the Future projects' (TSB, 2013). Whilst a variety of reasons for this are known; from incorrect assumptions within modelling tools through to a lack of skilled workmanship and knowledge base within the UK construction sector, research (Gupta & Chandiwala, 2010 and Gupta & Barnfield, 2014) suggests the impact of the occupant can significantly and directly affect the actual energy use of individual dwellings (even in dwellings of similar physical and technical characteristics (Fell & King, 2012) particularly due to their habitual behaviours, thermal comfort expectations and subsequent management and interaction with technologies within the dwelling (Gupta & Kapsali, 2014).

Much research (Heimlich & Ardoin, 2008; Steg & Vlek, 2009 and Stern, 2000) has been undertaken upon the subject of influencing behaviour change and engagement of individuals with energy efficiency and demand reduction measures. A general consensus (Jackson, 2005) pertains that energy-related behaviours are a highly complex intertwining of the individual themselves within a wider socio-psycho-technical framework (Moloney et al. 2010) containing many factors that influence, limit and enable behaviour change but which are not necessarily within the control of the individual. As such, any approach to domestic energy reduction has to address both the individual (in terms of values and attitudes) as well as the wider influencing factors such as social norms, infrastructures and systems of governance.

Subsequently, recent successive UK Governments have recognised the importance of both community (grassroots) actors and local government (Wade et al. 2013) in catalysing and supporting domestic energy reduction activities through multi-disciplinary community-based approaches that do not simply focus on the individual or technical innovations alone (Gupta et al. 2014), but take into account the context (and influences) in which individual behaviours transpire. Practical examples of Government support for this includes a series of national funding programmes, such as the Government's Low Carbon Communities Challenge (LCCC) and the Local Energy Assessment Fund (LEAF), designed to both enable and enhance existing low carbon communities (LCCs) as well as stimulate action in less established communities. Furthermore, the release in 2014 of the UK's first ever Community Energy Strategy highlights the contribution community-led approaches are felt to have on reducing domestic energy use (DECC, 2014b). Despite this, there is relatively little robust evidence and evaluation (DECC, 2013) into such community-led projects, particularly in relation to their actual energy savings (household energy use), their impacts on localised energy behaviours (occupants) and the added value benefits (from better health and comfort through improved indoor environmental conditions to greater social cohesion).

This paper is based on findings from a four-year research programme, EVALOC, and seeks to evaluate six community energy projects in terms of their impacts on individual household energy reductions and localised energy behaviours in a context of 22 low carbon communities (LCCs) across the UK (DECC, 2012). It outlines the effectiveness of community-based energy action approaches in terms of actual energy reductions at a community-scale as well as the impacts of such action on individual household energy use. Furthermore, it discusses the influencing factors (both limiting and enabling) upon both habitual and 'one-off' purchasing energy-related behaviours (POST, 2012). This is followed by a discussion upon the role of LCC organisations in terms of overcoming limiting factors, whilst enabling further and systemic energy-saving behaviours.

Evaluating low carbon communities research

EVALOC is an ongoing interdisciplinary and collaborative research project, funded by the Research Council UK's (RCUK's) Energy and Communities Programme. Its key aims are to assess and evaluate the impacts, role, effects and limitations of low carbon communities (LCCs) in motivating energy reduction and renewable energy investment amongst local residents. The EVALOC project involves active participation from six case study low carbon communities throughout the UK that had energy-related projects funded through the Department of Energy and Climate Change's (DECC) Low Carbon Communities Challenge (LCCC) between 2010 and 2012. The LCCC was a €13.6 million approximately (£10 million) UK Government programme which provided financial support (on average between €550,000 and €680,000 [£400,000–£500,000] per community) to 22 low carbon communities (LCCs) across the UK (DECC, 2012). It was designed to promote and test community-scale delivery of low carbon technologies and measures mainly through integrated approaches involving physical, technical and behavioural interventions.

CASE STUDY LOW CARBON COMMUNITIES

The six case study LCCs are spread geographically across England and Wales (one in North-East England, one in North-West England, one in Yorkshire & Humber, two in South-East England and one in South Wales). The LCCC projects undertaken by the six case study LCCs between 2010-2012 ranged widely in approach and structure; from a community-scale renewables project to household level awareness-raising and energy management programmes with low-medium cost physical and technical measures given to participants as 'rewards' for participation. Other projects concentrated on energy generation at both community and domestic scale through the installation of renewables and LZTs on community buildings and individual households in the area, alongside less intensive behaviour change initiatives such as energy display monitors. As Table 1 demonstrates, all communities except Community A, undertook an integrated approach; combining physical, technical and behavioural interventions as part of their wider energy reduction and low carbon strategy.

MONITORING AND EVALUATION METHODOLOGY

In order to monitor and evaluate the LCC activities, in relation to individual household energy use and behaviours, the research project adopted a graduated mixed-method monitoring and evaluation approach (Figure 1). This included a desk-based assessment of aggregated and longitudinal domestic energy data within the wider geographical area in which LCCs were involved (1,000–5,000 households per community over five years) using DECC's lower level super output area (LLSOA) domestic energy data (gas and electricity only). LLSOA's are areas made up of an average of 400 households with relative social homogeneity. Within the six communities, the geographical reach of the LCCs extends over more than one LLSOA and as such, the findings in this paper present the results of combined LLSOA meter data to suit the potential geographical reach of the LCCs.

Table 1. Type and focus of community projects for reducing household energy use.

		Communities					
		A	B	C	D	E	F
Project delivery type		CL	CF	CL	CF	CF	CL
Focus of community energy project							
Physical (building fabric)	DIY measures (e.g. draught proofing)		✓		✓		
	Wall & loft insulation		✓	✓	✓		
Technical (services and systems)	Improved heating systems. (e.g. new boilers)		✓	✓	✓		
	Household appliances. (e.g. A+ rated refrigerators)		✓		✓		
	Building-level low-zero carbon technologies (e.g. heat pumps, PV)			✓	✓	✓	✓
	Community renewables (e.g. wind turbines, PV)	✓		✓	✓	✓	✓
Behavioural	Community based learning (e.g. eco homes; community events)		✓	✓		✓	✓
	Active individual household education, workshops & training		✓	✓	✓		✓
	Energy feedback to householders		✓	✓		✓	✓

Notes: CL – Community-led (projects led by community groups); CF – Community-focused (partnership projects led by existing agencies (e.g. local authorities, Third Sector organisations) and targeted at communities.

To assess changes in energy use at a more local level, DECoRuM, an energy and carbon modelling and mapping tool (Gupta & Gregg, 2014) was used to evaluate the energy use of approximately 1,800 households *before* and *after* community energy projects (approximately 300 households per community). DECoRuM uses BREDEM-12 (Building Research Establishment's Domestic Energy Model) and SAP 2009 (Standard Assessment Procedure), which are dynamically linked to create an aggregated energy model of the area, which is then displayed as a map, enabling the results to be presented on a street, district and city-level. The data collection involves mainly a desktop-based assessment of a variety of sources including historical and current maps and Energy Performance Certificates (EPCs) as well as household questionnaires and on-site assessment.

Finally, robust monitoring and evaluation of individual case study households within the geographical community was undertaken to provide further in-depth assessment of actual individual household energy use and behaviours. Whilst the total number of households involved from the beginning of the study was 88 across the six communities, this paper concentrates on the findings from 60 households[1] (of the 88), which were involved to some extent in their LCC's energy projects. A wide range of survey techniques, mainly based on Building Performance and Evaluation (BPE) research methods, were used to collect both qualitative and quantitative data from these 60 households, including:

- 5-years (2008–2012) of longitudinal gas and electricity meter data.
- Two rounds of qualitative surveys and interviews (Summer 2012 and Summer 2014).
- Thermal imaging surveys.
- Self-completion questionnaires (heating controls).
- Thermal comfort and activity logging diaries (winter and summer 2013).
- Physical monitoring over a two year period (Summer 2012 to Summer 2014) of:
  - Energy use (gas and electricity use),
  - Long-term performance of low carbon technologies and renewables (LZTs),

1. 11 of which are in Community A which did not involve households directly, due to the main scheme being a larger community-scale generation project.

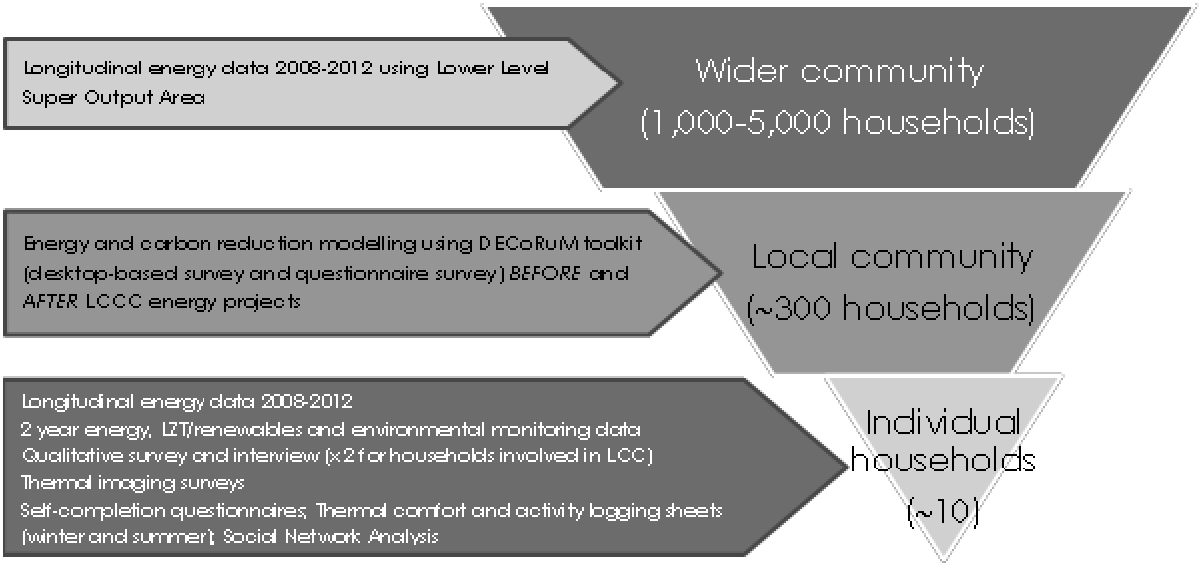

Figure 1. Overall graduated mixed-method monitoring and evaluation approach of the EVALOC project. Note: Numbers are per community.

– Indoor and outdoor environmental conditions (temperature, relative humidity and CO_2 levels),

– Open/closing of windows (assessing user interaction) over a two year period.

Due to quality of data issues and difficulties in retaining all households over a two year period, not all 60 contribute equally to the overall findings and as the analysis probes deeper, subsets of the overall 60 are presented. This paper outlines the findings from all three levels of study in order to draw conclusions relating to the effectiveness of community-led action at reducing energy use at both an individual household level as well as at a wider geographical community scale.

CASE STUDY HOUSEHOLD SAMPLE PROFILE

The 60 case study households were chosen to participate due to their involvement in their LCC's energy projects. However, they also represent, as close as possible, the physical and household characteristics of the dwellings in their wider geographical community, particularly in terms of dwelling age and type. As such, there are a high percentage of detached dwellings and dwellings built pre-1919. Overall, they are mainly owner-occupied dwellings, with the majority occupied by two adults (44 households) between the ages 65–74. Most of the households are occupied 'most of the time'.

In terms of the physical dwellings, 37 are predominantly cavity wall construction (32 with full or partial insulation) and 46 are predominantly solid wall construction (three with partial insulation). On average, the internal floor area is larger than the UK average, at 107.6 m^2. In terms of heating, 39 have gas as the primary fuel, 13 use oil, seven use electricity and one uses coal. Across the households, there are 21 solar PV systems installed, five air source heat pumps and six solar thermal systems.

The type of technical, physical and behavioural interventions within the individual households varies. Figure 2 outlines the number and type of the main interventions within the 60 households. It must be noted that some households received more than one intervention type, and not all were directly through the LCC. An example of this is a household in Community D who attended regular meetings and received a small grant for secondary glazing, but self-funded a solar PV system for their dwelling. Another is a household who attended an energy management programme and received funding towards a solar PV system but self-funded an energy display monitor and installed cavity and loft insulation independently from the LCC.

Physical (fabric) interventions

The majority of the physical interventions were 'standard' retrofit measures installed with the aim of improving the building fabric and reducing heat loss (and thus energy demand). Such measures include cavity wall insulation, loft insulation, draught-proofing strips and double glazing. Only three dwellings have undergone (or undergoing) deep retrofit measures such as solid internal and external wall insulation and these have been included in Figure 2 under 'significant fabric measures'.

Technical (services and systems) interventions

The technical interventions within the dwellings refer to improved systems and services which were installed with the main aim of increasing the energy efficiency of the dwelling, and reducing the household's energy use (e.g. condensing boiler, air source heat pumps, energy efficiency rated appliances and low-cost energy efficient electrical items such as kettles and timer switches) as well as energy generation (solar PV systems).

Behavioural interventions

The behavioural interventions varied between communities from more information-only based interventions such as energy display monitors, through to a structured eight week low carbon living programme, which encouraged participants to set reduction goals in all aspects of their life, not just household energy use. Others attended regular but more informal meetings and presentations hosted by the LCC, with the themes mainly around retrofit and technical improvements that could be made in their homes.

Effectiveness and impacts of community energy action

CHANGES IN ENERGY USE

In order to assess changes in energy use related to community-led energy action, both wider community and individual household energy data are analysed and evaluated across a five year period (2008–2012). Figure 3 demonstrates this graduated approach in Community B – from LLSOA aggregated meter data covering approximately 5,590 households to the monitoring and evaluation of 13 case study households that were involved directly in the LCCC project. Whilst any changes in energy use cannot be fully attributed to LCC energy projects and activities due to the many and varied factors relating to domestic energy use, an assessment of the change in gas and electricity use within the wider communities over a five year period helps provide an overview of energy trends in the six case study communities.

Wider community energy reductions

As Table 2 shows, using relevant LLSOA meter data, all communities (for which data are available) demonstrate an overall reduction trend in average annual total domestic energy use, despite four of the communities having a lower average annual domestic baseline energy use than the UK national average figures (Table 3). What is noticeable is that the community (A) in which the focus was not on individual households, but on a community-scale generation scheme, does not show overall reductions in terms of average domestic electricity and gas use.

There is no *total* energy use data shown for Communities A and D as there is a significant number of households off the mains gas grid in these communities. These households use alternative fuel sources such as oil, coal and biomass for which there is no longitudinal data available and as such average total energy figures cannot be calculated. Despite this, the longitudinal electricity data for these two communities does give possible insights into the impact of technical heating innovations and low-zero carbon technologies such as air source heat pumps; both communities A and D have experienced an increase in the installation of such technologies and both have experienced relatively low (or no) reductions in the average domestic electricity use over the five year period. Whilst this reflects the expected shift in energy vector from fossil fuels to electricity in certain households in the communities, it is not necessarily indicative of increased total energy use in these households.

The potential *ripple* effect of the LCC energy projects across the wider community is further evidenced when the data for

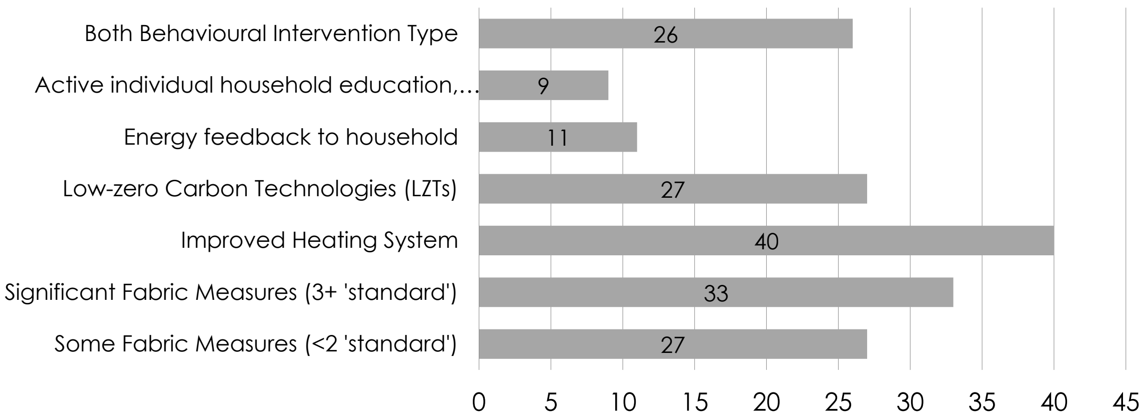

Figure 2. Distribution of physical, technical and behavioural intervention types across the 60 EVALOC case study households described in this paper.

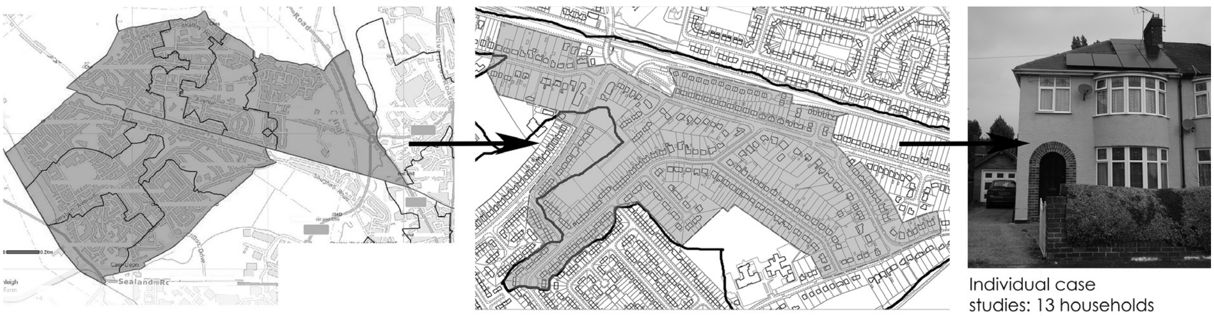

Figure 3. Graduated approach to energy data collection and assessment in Community B.

Table 2. Average annual domestic energy figures across five year period from household meter data covering six case study communities using geographically relevant LLSOA data.

Community	Average domestic (kWh)	2008	2009	2010	2011	2012	Change from 2008 to 2012	Percentage change from 2008 to 2012
A*	Total Energy	–	–	–	–	–	–	–
	Gas	19,114	20,167	20,389	20,161	19,802	688	4 %
	Electricity	4,987	5,095	5,274	4,847	5,011	25	1 %
B	Total Energy	17,378	16,043	15,747	14,398	14,360	-3,018	-17 %
	Gas	13,613	12,308	11,993	10,751	10,747	-2,866	-21 %
	Electricity	3,765	3,735	3,754	3,647	3,613	-152	4 %
C	Total Energy	18,775	17,020	17,292	16,275	16,210	-2,566	-14 %
	Gas	15,407	13,849	14,068	13,114	13,049	-2,358	-15 %
	Electricity	3,368	3,171	3,224	3,161	3,160	-208	-6 %
D*	Total Energy	–	–	–	–	–	–	–
	Gas	18,525	16,616	16,899	16,535	16,517	-2,008	-11 %
	Electricity	6,949	6,792	6,854	6,640	6,761	-188	-3 %
E	Total Energy	19,680	18,236	17,821	16,980	16,471	-3,210	-16 %
	Gas	16,020	14,854	14,478	13,637	13,249	-2,771	-17 %
	Electricity	3,660	3,382	3,344	3,343	3,221	-439	-12 %
F	Total Energy	19,715	18,212	17,861	17,096	17,208	-2,507	-13 %
	Gas	16,057	14,637	14,331	13,570	13,727	-2,330	-15 %
	Electricity	3,658	3,575	3,530	3,527	3,481	-177	-5 %

** Communities with significant additional sources of fuel (other than electricity and gas) such as oil, coal and biomass and higher number of households with primary electric heating. Energy figures are weather-corrected.*

Table 3. National average annual domestic energy figures across five year period from household meter data.

National average domestic (kWh)	2008	2009	2010	2011	2012	Change from 2008 to 2012	Percentage change from 2008 to 2012
Total Energy	21,104	19,535	19,304	18,283	18,094	-3,010	-14 %
Gas	16,906	15,383	15,156	14,205	14,080	-2,826	-17 %
Electricity	4,198	4,152	4,148	4,078	4,014	-184	-4 %

Note: Energy figures are weather corrected.

Table 4. Estimated average annual domestic energy use (kWh) in six case study communities before and after LCCC projects as modelled using DECoRuM mapping tool.

Community	Number of households	Equivalent average end energy use (kWh)		Total reduction from 2008 to 2012 (kWh)	Percentage reduction from 2008 to 2012
		2008	2012		
A	311	25,530	22,890	2,640	11 %
B	373	23,080	19,820	3,260	14 %
C	242	22,080	19,340	2,740	12 %
D	274	27,120	24,100	3,030	11 %
E	184	25,270	21,780	3,500	14 %
F	275	25,650	22,730	2,930	11 %

the other four communities are also broken down into gas and electricity average annual use (Table 2), and compared to the different approaches of the LCCs. Whilst Community B shows the greatest reduction in average domestic gas use (21 %) across all the communities (despite having the lowest 2008 baseline figure), the reduction in average domestic electricity use in this community is less than the three LCCs which included localised and domestic energy generation (solar PVs) as a major part of their energy action during this time period (Communities C, E and F). In contrast, Community B instead concentrated on behaviour change (in terms of energy management) alongside small-scale physical and technical measures mainly focused on reducing heating (gas) demand. The reductions in the communities with domestic energy generation action suggest reduced demand upon the National Grid infrastructure, but as the LLSOA data are only annualised meter readings, they do not necessarily directly infer reductions in *total* electricity use in individual households (the amount of PV generated electricity used in the households is not included in the figures).

Community E provides an interesting case study in terms of gas use; an area of significant deprivation, and with a typical dwelling construction type of solid exposed stone wall it still experienced a 17 % reduction in the average domestic gas use from 2008 to 2012 across the relevant LLSOAs, even though the LCC approach did not include substantial physical and technical measures relating to reduced heating demand. This suggests wider factors influencing the gas reductions seen in this area. Yet, it should be noted that the LCC does hold regular large-scale community events covering a wide range of local services, including energy saving tips and basic energy efficiency measures, which are always very well attended.

Local community energy reductions

The findings from the assessment of the wider community LLSOA data are further corroborated by the findings from DECoRuM energy modelling and mapping of dwellings within a smaller geographical area of the LCCs (Table 4). Whilst not all dwellings in this area will have benefitted directly from LCC energy action, they have been assessed in greater detail in terms of their dwelling and household characteristics and estimated total energy use *before* and *after* the LCCs projects. The DECoRuM modelling, although it cannot account for behavioural interventions, does enable fossil fuels other than gas to be measured and included in the figures, hence total energy results for both Community A and D being provided.

Figure 4 further demonstrates the overall changes in average energy use (kWh) over a five year period in Community E in individual households in the mapped area. Whilst 91 % of the households that benefitted directly from the LCC's LCCC project (which focused on localised energy generation) reduced their energy use, many households that were not directly involved in the LCC's project also reduced their energy use. 159 households reduced their energy use between 2008 and 2012 (86 % of the total households mapped). However, only 30 % of these were households which benefitted directly from the LCC's LCCC project, hinting at significant additional factors contributing to the energy reduction totals within this community.

Case study households: gas use

Longitudinal annual gas meter data are available for 35 case study households (21 households are not on mains gas, and gas data are unavailable/incomplete for four households). Analysis of gas data for individual households indicates that 27 (77 %) of the 35 households show reductions in their gas use over a five year period (2008–2012), with a mean percentage reduction of 11 % (median of 16 %). As nearly all the households had a combination of either physical, technical and/or behavioural interventions relating to gas use and heating since 2008 (through the LCC or otherwise) it is difficult to assess the relative quantitative impact of individual interventions but it does demonstrate overall reduction trends across the households; similar to those at a wider community-scale. Despite this, the variation in percentage reductions across the 35 case study households is significant; ranging from a 94 % increase in gas use to a 55 % decrease.

Furthermore, analysis of monitored gas data (2013–2014) highlights not only the vast range in terms of annual gas use, even when comparing per area, (from 63 kWh/m^2/yr to over 300 kWh/m^2/yr) across the case study households but also the different usage patterns within similar households.

Case study households: electricity use

The longitudinal annual electricity meter data indicates that out of the 54 households for which there are available data, 34 experienced reductions from 2008 to 2012 (63 % of the households), yet with an overall mean percentage change in electricity use of a 13 % *increase*. Furthermore, the median percentage change is a 3 % *reduction*; highlighting the disparity within the electricity use of the case study households. When further investigated, the direct impact of LZTs and renewables is clear; with the electricity use in three of the five households with air source heat pumps (ASHPs) installed increasing by at least 50 %. However, it must be noted that this has not necessarily resulted in an overall increase in total energy use in these households, as all three have switched primary fuels with the installation of the ASHPs (from oil to electricity).

As may be expected in the households with solar PV systems installed (and where longitudinal meter data are available [n=19]), the majority (13) saw reductions in electricity use from the mains grid. However, through the continuous monitoring of the electricity use in a sub-group of the PV households (n=10), it was possible to calculate the comparative *total* annual electricity use (from the mains supply and from the solar PV systems) in 2013 (end of January 2013 to end of January 2014) rather than just the electricity imported from the national mains grid (as shown in the longitudinal data). Whilst not a wholly accurate comparison due to the different data sources, Table 5 shows that most households are using similar or less total electricity as they were prior to the installation of the solar PV systems; only three are using significantly more (figures highlighted in bold ***italics***).

In terms of monitored actual annual electricity use (December 2012 to November 2013), like gas use, there is a wide disparity between the households (households with primary electric heating excluded): from 1,234 kWh/year to 6,623 kWh/year. Whilst full statistical analysis cannot be used due to the sample size, there does not appear to be much correlation between number, age and type of occupants and annual electricity use, which suggests alternative factors are influencing the electricity use in these households.

Electricity end-uses

Further analysis of the electricity end-uses within the case study households was undertaken using DomEARM survey techniques, giving clear insight into the complexities of domestic energy use, particularly in terms of 'high' and 'low' electricity users. DomEARM (Domestic Energy Assessment and Reporting Methodology) is an energy audit methodology developed in 2009 through a collaborative partnership between Arup & Partners Ltd and the Oxford Institute for Sustainable Development, Oxford Brookes University. It provides comparative benchmarks and a clear breakdown of electricity end-uses in the dwelling, such as lighting, appliances, cooking, hot water, space heating and computer electronics. As may be expected, high usage of one end-use type does not necessarily correlate with overall high electricity usage, and vice versa (Figure 5). However, the data suggest that in (relatively) 'higher' electricity users, there are larger percentages of 'non-essential' electrical end-uses (consumer electronics and computer equipment) in contrast to lower electricity use households where higher percentages of 'essential' (always-on) electrical end-uses (refrigeration appliances, cooking and wet appliances) can be seen. This suggests that some households have reached their limit for reducing electricity use, without increased energy efficiency of technological aspects of the dwelling.

INFLUENCING FACTORS ON HOUSEHOLD ENERGY REDUCTIONS

The individual case study households provided not only annual energy data but also enabled detailed investigation of the influencing factors upon household energy reductions, particularly in terms of the occupants, technical and physical aspects of the dwelling, the occupant interactions and control over these as well as wider economic and social factors.

Physical environment and technical innovations

New technologies and the physical characteristics of a dwelling can have a direct effect on energy reductions, as discussed in Gupta et al. 2014 and Gupta & Barnfield, 2014. Practical issues relating to the inappropriateness of certain improvements (both physical and technical) due to the dwelling type, age and orientation can affect the potential for energy reductions. Yet the performance of energy efficiency improvements (once in-

Figure 4. DECoRuM modelling and mapping visualisations of Community E before (left-hand image) and after (right-hand image) the LCC's LCCC energy project.

Table 5. Electricity use over six year period of 10 case study households with solar PV systems installed, highlighting impact of PVs on household use of mains electricity.

Hsd ID	PV system installed (year)	Mains electricity use only (kWh)						Total electricity use (kWh)
		2008	2009	2010	2011	2012	2013	2013
H03	mid 2011	5,680	6,088	6,165	5,382	2,591	3,355	4,722
H04	mid 2012	4,081	3,774	4,629	4,213	3,277	5,722	***6,686***
H38	mid 2011	3,583	3,744	4,053	3,261	3,054	2,150	2,525
H39	mid 2011	3,050	2,802	3,599	2,394	2,933	2,883	3,780
H40	mid 2011	4,140	4,251	3,110	2,500	4,146	4,174	***5,087***
H52	mid 2011	2,665	4,143	3,831	2,652	2,620	2,593	3,018
H72	late 2010	4,068	6,534	3,840	–	3,701	4,423	***5,302***
H75	mid 2011	6,677	6,890	8,598	5,238	5,494	3,764	4,045
H77	mid 2011	7,021	4,315	5,244	2,800	3,696	4,066	4,634
H78	mid 2011	2,999	4,487	4,739	4,047	4,076	3,611	4,655

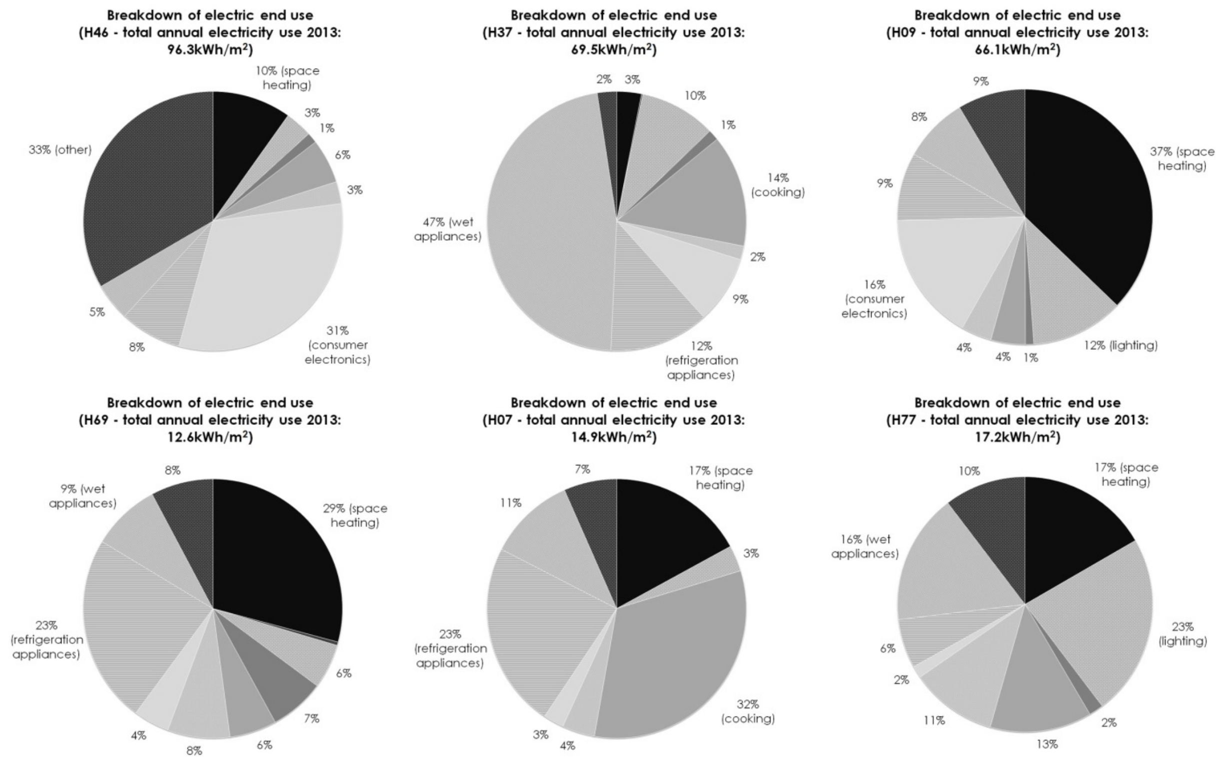

Figure 5. Breakdown of electricity end-uses in the three 'highest' electricity users (top) and the three 'lowest' electricity users (bottom).

stalled) can also impact upon the overall energy reductions in the household. The study uncovered several issues that could lead to the under-performance of both physical (building fabric improvements) and technical interventions (LZTs), particularly in relation to the installation and commissioning of such improvements; thermal imaging surveys highlighted poor installation of cavity wall insulation (Figure 6) and there were several examples of poor installation of air source heat pumps (ASHPs) and solar thermal systems including incorrect glycol ratios (impacting upon the performance of the ASHPs during colder periods) and leakages within the system. Further practical barriers include the physical characteristics of the dwelling, particularly the appropriateness of certain improvements for the dwelling type and age.

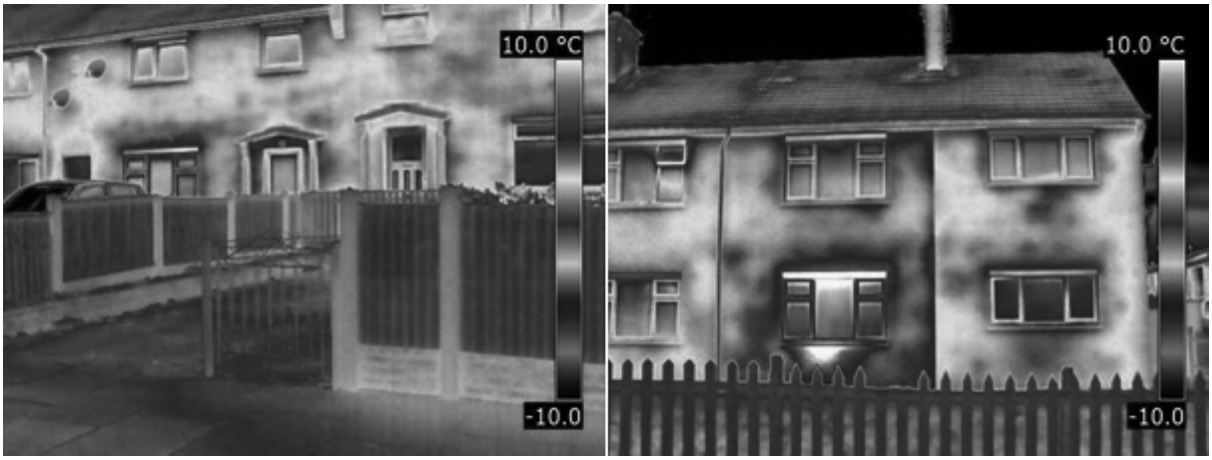

Figure 6. Thermal imaging of dwellings with cavity wall insulation showing the 'patchiness' of the wall insulation.

Control and management of technologies and physical environment

The technologies and physical environment do not only directly affect household energy use; evidence from the study shows that they can also have an indirect effect, through their affordances to the occupants in terms of management and control; in other words, how the technologies enable interaction with the occupants, and vice versa, in order for energy reductions to be maximised. Despite the potential inefficiencies of the technical interventions, the majority of households with LZTs installed reported satisfaction with the management and control of their systems, particularly in terms of ensuring stable and comfortable indoor temperatures. In two households however, additional localised heating (fixed gas fire and fixed wood burner) has either been installed, or is to be installed to provide the occupants with an extra level of localised control. This suggests that potential energy reductions from improved heating systems in these households are being negated by a perceived lack of localised and overall control of 'new' technologies: "I know only how to use the main thermostat and the TRVs", as well as the need for comfortable indoor environmental conditions.

The physical environment, and the occupant's management of this can also hinder energy reductions, when it is at cross-purposes with more important issues such as the control of damp and condensation; a number of households refer to the need for windows to be open all the time for ventilation purposes. Whilst required due to a lack of technical support, such behaviours are counterintuitive when it comes to reducing heat loss and saving energy.

A further lack of control is evident in relation to everyday appliances, even in households who show positive attitudes towards energy-saving behaviours: "I have to leave the TV on standby because I've got a digibox which is set to record." And, "The machine hasn't got a thirty degrees [setting], so it's usually at forty. I think the quick wash is a lower [setting] but you can't put all clothes in." Such examples show the direct influence technologies can have upon household energy behaviours, thus limiting further energy reductions through behaviour change.

There is also evidence of LZTs changing energy-related behaviours, but not necessarily reducing electricity use (increasing electricity use in some cases). Examples of this were predominantly found in relation to the installation of solar PV systems, with many households stating changes in their washing behaviours to suit the 'peak' generation times: "We'll put the washing machine on when it's sunny and try to do things in series." Whilst this does suggest that technical interventions can influence the energy-related awareness and behaviours within individuals and subsequently alter the demand profiles of households it does not appear to have resulted in significant actual energy reductions. Indeed, in more than one household, the installation of solar PVs appears to have increased electricity use, due to negatively changing attitudes and behaviours: "I used to say [I] always [hang clothes out to dry rather than tumble drying] but there are a couple of occasions when I've shoved them in there [the tumble dryer] instead … when it's been sunny."

Occupant-related factors

There is much evidence to suggest that the occupants have both direct and indirect influences upon energy use in the households within the study. The majority of the households were self-selected (both in terms of the research programme and their participation in the LCC activities), which would indicate that the sample is biased towards more motivated and concerned individuals, in terms of energy and/or environmental issues. However, as shown in the wide variation in actual energy data, this does not necessarily translate into energy reductions. As such, the 'agency' afforded to the occupants by other factors, in terms of being *able* to reduce energy use in their home, appears critical, as well as the more intrinsic pro-environmental values and attitudes that enhance motivation. The majority of the households expressed high levels of capability in this respect. However, the results suggest that this feeling of agency has tapered off in recent years; in 2012, 50 of the householders stated that they felt 'capable of reducing energy use in their home', in 2014, this number had dropped to 39. A number of households commented that they felt they had 'done all they could', particularly in terms of habitual behaviours: "we try to be as economical as possible with everything so if we could, we would, but we don't really know that we can do anymore".

Many households stated that they felt that further knowledge and awareness of energy-saving 'one-off' purchasing behaviours, particularly in terms of installing technical innovations, would help increase their motivation and capability, but that a lack of communication networks (particularly in terms of peer-to-peer learning) and sources of reputable and trustworthy information held them back. Furthermore, a number of households commented that the LCC behaviour change programmes (particularly education, training and workshops) provided them with such information, resulting in them undertaking (and self-funding) energy efficient improvements and installing energy generation systems to reduce their energy use: "I think I probably would have done it all anyway but maybe not as quick and maybe not as effectively with the extra things that I learned."

In terms of more direct impacts of the occupants on energy use, important insights are offered from the study of households with solar PV systems installed, and the limitations that habitual behaviours, occupancy patterns and lifestyles can have on the maximising of locally generated electricity, both negatively and positively. Figure 7 shows the weekly electricity profiles of two households with solar PV installed. As the peaks in electricity use demonstrate, there is still a high demand in the late evening (cooking, showers and leisure activities) in the household that is occupied 'most of the time' (and as such potentially more able to reduce and shift mains electricity demand).

Qualitative feedback from the households provides further evidence of the limitations occupancy patterns and lifestyles have on both reducing electricity use and shifting demand; "… if one of us was here all day, we'd probably be able to tailor things…but with the need to go shopping, to work … you can't always". Further findings from the study also emphasise the lack of prioritisation reducing energy use is afforded when it comes to lifestyle choices. Several households also highlight the convenience of more energy-using behaviours and refer to a 'laziness' when it comes to habitual energy-related behaviours; "Occasionally … I find … it's easier, you know lazy really, to chuck them in the dryer". This suggests that even in households with high levels of environmental concern and awareness, the decision-making process and attitude of the individual can lead to energy-using behaviours, rather than energy-saving behaviours.

A further significant limiting factor in terms of reducing energy use in many of the case study households appears to be 'other' occupants (particularly children): "If there was only me on my own I would but because I live with other people it's not so". This highlights the key role of intra-household dynamics in either enabling or limiting household energy reduction.

Thermal comfort and health also appear to be significant factors in terms of potential energy reductions beyond a certain level (even in households with significant fabric improvements) due to their causal effects on energy-related behaviours: "I would feel hesitant about it [changing heating behaviours] … purely from the point of view of X's medical needs". This is corroborated through comparative analysis of heating-related energy use in similar households (and dwelling type) with and without fabric improvements; the household (H20) with significantly more fabric improvements uses 67.8 kWh/m^2 during winter 2013 (December 2012–February 2013) than the household without (H75). It is worth noting that the average (mean) winter living room temperature in H20 is 23.2 °C compared to 15.6 °C in H75, yet both state that they are comfortable overall with the temperatures in their home.

Conversely, much qualitative evidence suggests the perceived benefits of improved thermal comfort and health can be key motivating factors in terms of households installing energy efficient physical and technical improvements within their dwellings: "that little front bedroom was very cold and it was getting mould on the walls…so yes that's what prompted us".

Wider social, economic and practical factors

In terms of more external influencing factors upon one-off purchasing behaviours (such as undergoing further energy efficiency and/or energy generation projects), economic as well as more practical and spatial factors appear to be significant. In terms of economic barriers, both actual cost and the cost-benefit ratio (payback length) of the improvements appear to be blocking further energy reduction: "It is our biggest stumbling block is the cost", and "… really at my age, I'm not going to live long enough to benefit from spending the money".

In terms of practical issues, several households commented on spatial factors such as the impact of LZTs and internal wall insulation on the usable floor area within the dwelling as well

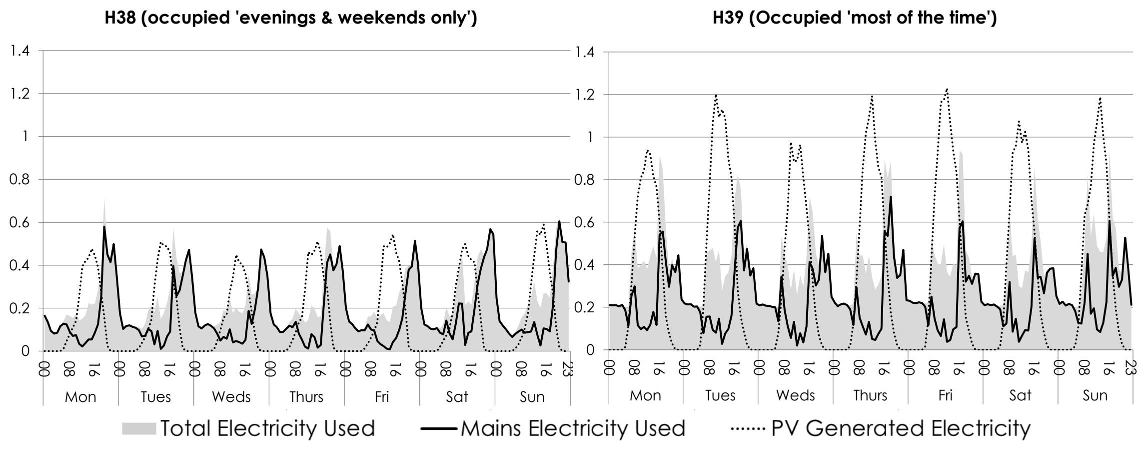

Figure 7. Average weekly summer (June–August 2013) household electricity use and PV generation (kWh).

as the 'hassle' factor of installing both physical and technical improvements: "No, the upheaval would be too much".

Social factors such as social norms and communication networks also appear to both hinder and enable energy-related behaviours that lead to energy reductions. Examples of this have come from social network analysis of the EVALOC households (Hamilton et al, 2014) and suggest that the very topic of energy is rarely discussed outside a small network and as such necessary knowledge and openness relating to energy reduction is not forthcoming.

Discussion: role of low carbon community organisations and household energy reduction

The study highlights the complexities of domestic household energy use, particularly in terms of influencing factors upon energy reductions. However, 33 out of the 60 case study households[2] stated that the LCC had helped them ('*a lot*' or '*it was crucial*') to reduce their household energy use, with a further eight stating it had helped them '*a little*'. LCC action appears to have helped overcome some of the many and varied influencing factors relating to energy reduction; including economic assistance such as part or full funding for energy efficient improvements in households that did not have the financial means available themselves as well as providing practical assistance such as the removal of loft items to enable loft insulation installation.

A major limiting factor within the case study households appears to be knowledge and agency in the face of many mixed messages and increased access to information which is not always trustworthy as well as ever changing technical innovations. Low carbon community organisations appear well placed and trusted to both distil larger messages, and subsequently deliver them in a more meaningful and actionable way: "It's based on a very small scale, you do what you can do…it's about what you can in your house, in your life". The behavioural interventions, in particular, appear to have increased individual agency and motivation. Whilst this has not necessarily led to actual energy reductions, it has enabled the households to make their own informed choices. In addition, the provision of an open and safe space for discussion and dialogue on and around energy-related topics appears critical in 'normalising' energy both in terms of the individual but also their wider social network through peer-to-peer learning; influencing, to some extent, the 'social norms' of the community.

Low carbon community organisations are able to tailor their projects to suit the local context, which in terms of household energy use, is vital due to the highly contextual and individualised nature of household energy use. However, a significant amount of resources (particularly in terms of time and skills) are required and the findings of the study emphasise the need for strong, financially sustained local partnerships and integrated working in order to inform appropriately targeted future activities as well as build wider local support and resources.

In addition, due to most LCCs having wider agendas than just energy, most are able to provide greater integration of energy (and subsequent acceptance) with related areas such as health, environment and social cohesion; which in turn promotes energy within the wider community, again further 'normalising' energy-saving behaviours.

Yet, as this study shows, not all limiting factors can be overcome through community-based localised action, some will require greater infrastructural and even regulatory change; particularly those involving technologies and physical measures. Therefore, whilst the need for focused, informed and contextual approaches to any domestic energy project is clear, it should be complemented by national policy strategies.

Conclusion

The integrated approaches adopted by the majority of the LCCs appear to have both successfully engaged with local residents, as well as help individual households overcome a significant number of influencing barriers to energy reduction. Whilst this may not have resulted in actual energy reductions in all households, the overall trend at both household and community-scale suggests that positive change is happening within these communities in terms of energy reductions.

The EVALOC research project has, by adopting a graduated socio-technical monitoring and evaluation approach been able to investigate the effectiveness and impacts of selected community-based energy projects. The wider community meter data and DECoRuM modelling and mapping enables an examination of community-level longitudinal energy trends, and provides a foundation for the assessment of the effectiveness of community-based energy action. At the smaller-scale, individual case study households have enabled more in-depth analysis and understanding of the wider impacts and contextual influences upon energy reductions within independent households.

By providing learnings on what works, (and what does not work), monitoring and evaluation of community action not only helps with replicating and scaling up community energy action, but also in terms of strengthening the evidence base and informing future national and local policy on domestic energy reduction.

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2. 13 households either did not answer this question or it was felt not applicable; in one community, the focus of the LCCC energy project was not on individual household energy use.

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