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Abstract

One key means of reducing the greenhouse gas (GHG) emissions caused by heating, lighting and ventilating buildings is the use of more efficient low and zero-carbon generating technologies (LZCGTs). In recognition of this, Section 72 of the Climate Change (Scotland) Act 2009, requires Local Development Plans (LDPs) to include policies to ensure 'that all new buildings avoid a specified and rising proportion of the projected greenhouse gas emissions from their use, calculated on the basis of the approved design and plans for the specific development, through the installation and operation of LZCGT's.' This study utilises data collected from 5 Scottish Local Authorities who were early adopters of this policy and examines LZCGT uptake in a randomly selected sample of new domestic buildings and the impact the use of these technologies have on CO_2 emission reduction. Quantitative data extracted from Standard Assessment Procedure reports submitted for Building Warrant was used to assess energy demand, energy consumption and CO_2 emissions and identify trends in LZCGT uptake in the regions studied. This paper provides a number of key insights and recommendations that may foster greater and more impactful use of LZCGTs in Scotland.

Keywords: *Low and Zero Carbon Generating Technology, Microgeneration, Renewable Energy, Low Carbon and Zero Carbon Buildings, Standard Assessment Procedure, Section 3 F Policy.*

Introduction and Background

The construction, operation and maintenance of buildings over their lifespan, consumes large amounts of energy. Globally, this is estimated to account for 40% of the total energy consumed and be responsible for 33% of all CO_2 emissions (UNEP, 2010, p.5). In response, the EU introduced in 2010, the European Union Energy Performance of Buildings Directive 2020 (EPBD) (updated 2016), which requires that member states adopt improved energy performance measures in legislation so that all new buildings comply with the Nearly Zero Energy Building (NZEB) Directive by no later than the end of 2020 (European Commission, 2010). As a result, public policy across Europe is consolidating actions for minimizing the built environment's contribution to greenhouse gas (GHG) emissions by means of a comprehensive shift towards low-energy buildings powered by renewable and low-carbon generating energy sources (Kibbert & Fard, 2012).

In 2015, the final energy consumption of the UK Domestic Sector (space heating, domestic hot water, lighting, household appliances and consumer electricals) was 40046 ktoe (465735 GWh) and represented 29% of total final energy consumption in the UK (HM Government, 2016, p.21-28). With space and water heating accounting for approximately 80% of this total, final domestic energy consumption in the UK is highly susceptible to annual fluctuations in temperature and weather patterns. However, other more tangible factors, such as: the composition and age of the UK housing stock, improvements in fabric energy efficiency of existing as well as new dwellings, the use of low and zero-carbon generating technology and energy efficient appliances, as well as societal changes in population, household characteristics and lifestyles, all have the potential to significantly influence UK domestic energy consumption and GHG emissions.

Scottish GHG Emission Policy and Legislation

The Climate Change (Scotland) Act 2009 requires that Scottish GHG emissions be at least 80% lower than the baseline (1990) by the year 2050, with an interim target of at least 42% lower by 2020. The Scottish Government has also committed to generating an equivalent of 100% of electricity demand from renewable sources by 2020 and at least 11% renewable heat (Scottish Executive, 2011a). In terms of new buildings, Scotland operates a two-stage building consent process: Planning which is concerned mainly with design and appropriateness of development, followed by Building Warrant which ensures that all developments meet Scottish Technical Standards in terms of Structure, Fire, Environment, Safety, Noise, Energy and Sustainability. Both stages play an active role in supporting GHG emission reduction policies. The Town and Country Planning (Scotland) Act 1997 has an insertion, 'Section 3F Greenhouse gas emissions policies', requiring planning authorities to include policies in their Local Development Plans (LDPs):

> *' . . . all new buildings avoid a specified and rising proportion of the projected greenhouse gas emissions from their use, calculated on the basis of the approved design and plans for the specific development, through the installation and operation of low and zero-carbon generating technologies [LZCGT].'*

Section 6: Energy, of the Scottish Technical Standards (Domestic), aims to ensure that effective measures are taken to limit energy demand by addressing the performance of the building fabric and fixed building services in dwellings, and stipulates the CO_2 emissions reductions that must be achieved by new dwellings. The Technical Standards are subject to incrementally more onerous levels of compliance towards 2020. Standard Assessment Procedure (SAP) is the UK Government's standard tool for assessing the energy performance of dwellings and is used to show compliance with CO_2 emissions reductions targets. The current Scottish Technical Standards (2017 Domestic) set this target at 45% fewer CO_2 emissions than the level set by the 2007 Standards. However, the buildings in this study were built at a time when this requirement was set at 30% less. New dwellings must meet the relevant energy performance and CO_2 emission reduction targets to obtain Building Warrant consent. Whilst Section 6: Energy, promotes the use of energy from renewable sources, it does not stipulate that LZCGT must be used to meet these standards. Electricity generated by LZCGTs, as opposed to heat, has no defined end-use, but will inevitably include white goods and other appliances not covered by 'regulated energy'. However, SAP calculations are applied only to 'regulated energy' in Building Standards which excludes significant electrical energy required for additional water heating on white goods and other appliances that tend to have a cold supply in the UK.

Section 7: Sustainability, was introduced to the Scottish Technical Standards (Domestic) to encourage and award buildings that surpassed the minimum standards set out in Sections 1 – 6. Clause 7.1

Statement of Sustainability, defines the building performance criteria required to meet these higher 'Sustainability Levels': Bronze/Bronze Active, Silver/Silver Active and Gold across 8 separate 'Aspects' of sustainability. All new dwellings must display a sustainability label specifying its performance relative to these 8 separate 'Aspects' and at the time of the study, new dwellings would have automatically met the Bronze Level. The Bronze and Silver Sustainability Level can be met without the recourse to LZCGT. The 'Active' delineation was primarily included to signify that LZCGT was employed and thereby assist Local Authorities in meeting their obligations under Section 3F of the Town and Country Planning (Scotland) Act 1997 by identifying their use. In this respect, LZCGTs include: wind turbines, water turbines, heat pumps (all varieties), solar thermal panels, photovoltaic panels, combined heat and power units (fired by low emission sources), fuel cells, biomass boilers/stoves and biogas.

The Scottish Government estimate that building integrated LZCGT or micro-generation could provide 30-40% of Scotland's electricity needs and help to reduce household CO_2 emissions by 15% per year by 2050 (Scottish Executive, 2007, p19). The employment of LZCGT and micro-generation is therefore seen as being central to meeting obligations set under the EPBD 2020 Directive and the aspirations identified in the 2020 Routemap for Renewable Energy in Scotland. Consequently, Section 3F planning policies have the potential to bring GHG emission reduction to the forefront in the planning and development decision making process, potentially providing a step change in LZCGT uptake and facilitating greater building GHG emission reductions.

Previous studies assessing the impact of LZCGT and barriers to uptake in the UK

De-centralised micro-generation has been a cornerstone of UK government policy since the publication of the Micro-Generation Strategy in 2006, which sought to remove barriers to its deployment (DTI, 2006). Micro-generation is defined by the Scottish Government as small-scale production of heat (less than 45kW thermal capacity) and/or electricity (less than 50kW electrical capacity) from LZCGT and includes solar photovoltaics (PV), solar thermal, micro-wind, micro-hydro, heat pumps, biomass, micro-combined heat and power (micro-CHP) and small-scale fuel cells. The definition of micro-renewables excludes those technologies which are not purely from renewable sources (e.g. small scale fuel cells, heat pumps and micro CHP) (Scottish Executive, 2007).

A number of studies into the application and effectiveness of micro-generation technologies and legislation in the UK have been previously undertaken. A survey of the uptake by UK consumers of energy efficiency measures and LZCGT, including micro-wind turbines, solar photovoltaics, solar thermal, and wood burning stoves, was undertaken in an Open University project in 2006 (Caird et. al., 2008). It was shown that while the drivers to adoption were similar, there were different barriers, benefits and problems in actual use. The up-front costs of specific technologies were identified as the major barrier to their adoption; however the hassle and the variability in advice and information available about these technologies were also contributing factors. A number of recommendations to improve uptake were made in relation to the principle stakeholders: Government (standards, incentivisation, regulation); Manufacturers (building integrated systems, smart controls, controllable heat outputs for wood-burning stoves); Energy Suppliers (financial mechanisms to offset up-front costs); Installers (targeted technologies to different market segments).

Watson et al. (2008) and Watson (2004) discuss the economics of different models of energy service co-provision by consumers and energy companies. Specific economic barriers to micro-generation uptake were identified and recommendations made. These included removing discrepancies in the tax rules, the need for new fiscal rules to offset capitalisation costs, reducing technology costs to bring it in line with more passive energy efficiency measures and the development of 'smart' control systems to enable consumers to capitalise on the use of on-site generated energy. Bergman & Eyre (2011) discuss the role of policy in transitioning to a more sustainable low carbon energy economy that incentivises consumer empowerment and engagement in energy provision and consumption. They conclude that new sectoral models are required, supported by long-term planning as a framework for short-term policies to help create and support specific niche applications.

Allen (2008) highlights technical, economic and information related constraints to micro-generation uptake. Financial incentives relative to up-front costs of technologies, monitoring and control of energy output and appropriateness of policy and legislation were considered to be substantial barriers to uptake. The research highlighted a need for greater flexibility in the configuration of installations in respect to context and scale of application i.e. grid-tied (national grid), micro-grid (including islanding capabilities) and off-grid (requiring heat and power storage). Such systems potentially create increased scales of economy, foster energy trading scenarios (external to the micro-grid), empower local community control via energy balancing scenarios (generation, storage and export), encourage behavioural change in relation to energy consumption and contribute to reducing grid transmission constraints.

Research Aim

Based on selected Scottish Local Planning Authorities (LPAs) who were early adopters of Section 3F GHG emissions reduction policies, this paper investigates the application and regional trends in LZCGT uptake in Scotland, quantifying the energy contribution and CO_2 emission reductions that result from employing LZCGTs. The findings presented are based on statistical data taken from a desk-based study commissioned by ClimateXChange for the Scottish Government in 2015; which sought to understand the effectiveness of Section 3F policies, in terms of policy design, practical application and deliverables.

Methods and Data

The research materials discussed in this paper relate to a random sample of new domestic buildings originating from the five LPAs identified above, covering the period since each implemented a GHG emission policy through their LDP. Scottish Planning Policy allows LPAs to tailor policy within their Local Development Plans (LDP) and associated Supplementary Guidance (SG) to their specific regional context. The 5 Scottish LPAs from which data was obtained included a mix of urban, sub-urban, accessible rural and remote rural contexts. Each LDP included reference to the requirements of Section 3F; however the way in which it was presented and the complexity of the compliance procedure differed (Table 1).

Insert table 1 here

Local Planning Authority	Year Policy Adopted	Urban	Suburban	Accessible Rural	Remote Rural	LZCGT	Passive Design Principles	Energy Efficiency	Sustainable Building	Sustainability	Tick Box	Written Statement	Form / Checklist	Calculation / Section 6 / SAP	Sustainability / Section 7
A	2012			■	■	■	■	■				■	■	■	
B	2013	■	■			■						■			
C	2012	■	■	■	■	■	■	■	■	■		■	■	■	■
D	2012				■	■					■				
E	2014	■	■	■	■	■	■	■	■				■	■	■
		Regional Context				Policy Style					Compliance Procedure				

Table 1: Section 3F local policy compliance procedures. LPAs are anonymised.

A range of different approaches to Section 3F policy design were identified within the LDPs and supplementary guidance (Table 2). Authorities B & D included LZCGT requirement as a clearly defined standalone Section 3F policy detailed in their LDPs. Authorities A, C & E promoted a more integrated approach to reducing CO_2 emissions that included improvements in fabric performance, energy efficiency measures and passive design strategies as well as the specification of LZCGT. This is achieved by embedding the LZCGT requirement within an umbrella sustainability policy in their LDPs. To avoid the risk of losing the specific Section 3F policy requirements within a raft of other sustainability measures, Authority E had clearly articulated the policy requirements within the LDP policy statement. Authority A took a different tack and used the LDP to reference a clearly defined standalone policy contained within the supplementary guidance. Authority C, however, despite quoting the requirements of Section 3F, did not articulate a clear Section 3F policy either in the LDP or the Supplementary Guidance.

		Standalone	Umbrella Sustainable	Umbrella Sustainability	None	Energy Efficient	Sustainability in the	Sustainability in the Built Environment: *(Sub-Divided*
A	**2012**			●				●
B	**2013**	●			●			
C	**2012**			●			●	
D	**2012**	●			●			
E	**2014**		●				●	
		LOCAL DEVELOPMENT PLAN			**SUPPLEMENTARY GUIDANCE**			

Table 2: Approaches to Section 3F policy design within the LDPs and Supplementary Guidance

A table of technical abbreviations is contained in Appendix 1. The study focuses on the quantitative analysis of data extracted from SAP calculations submitted as part of the Building Warrant application for the dwellings. Accurate quantitative data relating to the proposed use of LZCGTs in the design of new domestic buildings is typically only available in the form of a SAP calculation, once the building design has been finalised and submitted for Building Warrant. The SAP is primary data source which is governmentally endorsed, is widely explained and applied in a standardised manner to all new domestic buildings (DECC, 2009; DECC, 2012). However in utilising this data, the basic assumption must be made that this predictive data accurately reflects actual energy consumption and CO_2 emissions. There are several factors that might influence the accuracy of these predictions, some of which relate directly to elements of calculation methodology and conversion factors prescribed within SAP which may not accurately reflect reality. Studies also suggest that actual energy consumption and CO_2 emissions vary substantially even between identical properties due to the number of occupants and the way they use the building (Sunikka-Blank & Galvin, 2012). Predictive data can therefore at best provide an approximation of actual energy consumption and CO_2 emissions.

The main limitations encountered undertaking this research were the limited number of domestic new build applications that met our criteria for inclusion and the availability of complete SAP calculations for these. The 5 LPAs studied adopted GHG emissions policies between April 2012 and February 2014. Data was collected between June and September 2015. As SAP calculations are typically submitted at the end of what can be a lengthy Planning and Building Warrant process, the number of applications that met our criteria was limited in some LPAs. Further, at the time of the study, SAP data was not publically available and special dispensation from the Scottish Government had to be obtained to request this information directly from each Building Standards Department. This resulted in a varied response in terms of the amount and quality of SAP data supplied.

Data collection

To provide an in depth understanding of LZCGT specified and installed, overall energy contribution, energy consumption and the CO_2 emissions associated with them; recycled data was extracted from both Planning and Building Warrant submissions for each dwelling sampled. This material was collated for analysis in a database which consisted of separate worksheets designed to capture specific types and sources of information. The Full SAP Calculation submitted with each Building Warrant application was used as the primary source of quantitative data for this study to calculate the Dwelling Emission Rate (DER), Target Emission Rate (TER), Energy Efficiency Rating (EER) and Environmental Impact Rating (EIR) of new domestic buildings. It consists of a number of Worksheets, each subdivided into

Sections with results recorded in numbered Boxes. SAP 2009 was applicable in Scotland during the timeframe in question (DECC, 2009). The Full SAP calculation contains a breakdown of the dwelling, as designed, in terms of its energy demand for space heating, water heating, lighting and ventilation; the type and efficiency of the LZCGT/Fuel used to meet these demands; the energy consumed as a result; and the predicted CO_2 emissions. It also includes the total floor area and assumed occupancy of the dwelling. In the database a SAP worksheet (Figure 1) was devised to capture this information and calculate the Energy Demand, Energy Consumption and CO_2 Emissions for each dwelling. This data was then developed into Energy Maps for each LPA; detailing the frequency with which LZCGT/Fuel sources were specified and the energy contribution, energy consumption and CO_2 emissions associated with each LZCGT Type.

Figure 1: SAP Worksheet

Sample data set (overview of data)

Criteria for inclusion in the sample data set were:

- The proposal was a new domestic building; received after adoption of GHG policies in the LDP.
- The proposal was not exempt from Scottish Technical Standards, Section 6: Energy, 6.1: Carbon Dioxide Emissions [Mandatory Standard].
- The application had obtained Building Warrant Approval and could be expected to furnish relevant SAP Data.

The sample data does not include every relevant New Domestic Building in each of the LPAs included in the study. Most Building Standards Departments were only able to provide Building Warrant data for a limited number of applications and the quality of data in terms of the completeness of SAP data received varied immensely across the LPAs. Therefore, the sample is dominated by Authorities B and E and the contribution made by development in Authority A is particularly under-represented.

The complete sample represents 403 individual dwellings with an aggregate floor area of 50,416 m^2 and an assumed total occupancy of 1054 (Table 3). As all the dwellings had been awarded a Building Warrant, they all complied with the mandatory Carbon Dioxide Emission Reduction requirements set out in the Scottish Technical Standards whether they included LZCGT or not. It should also be noted that the buildings included in this study were at various stages in the construction process at the time of the study.

LOCAL AUTHORITY	DOMESTIC	No of units	% units with LZCGT	MULTI DOMESTIC	No of units	% units with LZCGT	MIXED	No of units	% units with LZCGT	TOTAL	No of units	% units with LZCGT
A		14	100%		25	16%		-	-		**39**	**46%**
B		2	100%		185	34%		-	-		**187**	**34%**
C		22	100%		14	100%		4	100%		**40**	**100%**
D		44	100%		13	100%		-	-		**57**	**100%**
E		30	87%		49	37%		1	100%		**80**	**56%**
TOTAL		**112**	**96%**		**286**	**39%**		**5**	**100%**		**403**	**56%**

Table 3: Summary of sample data by LPA, Development Type and Total.

Results

Energy Demands

The sample data set had an overall Net Energy Demand at Dwellings of 3221.9 MWh/year, which translated to Total CO_2 Emissions of 812.8 tonnes CO_2/year. Over the sample this results in an Average Net Energy Demand at Dwelling of 63.9 kWh/m^2/year (equivalent to 7995 kWh/unit/year) and Average CO_2 Emissions of 16.1kgCO_2/m^2/year (equivalent to 2017 kgCO^2/unit/year).

Heat demand

Every dwelling had a heat demand, with an average of 92% of the total energy demand being attributed to heating - 63% space heating and 23% water heating. The combined Total Heat Demand at Dwelling (Space & Water) was 3161 MWh/year; equivalent to an average of 62.7 kWh/m^2/year or 3000 kWh/occupant/year (Table 4). While all dwellings complied with minimum levels defined in the Scottish Building Standards, differences in space heat demand for dwellings of similar area was evident, which could be attributed to typology; small detached houses having poorer form factors and correspondingly higher heat loss than similarly sized terraced and apartment typologies. Other differences that were apparent are due to increased fabric efficiency specifications (beyond mandatory standards), e.g. a Passivhaus has similar space heat requirements to the smaller dwellings in the sample despite having a floor area equivalent to some of the larger dwellings with the highest space heat demands returned (Figure 2).

LDP	No. of Units	Average Area m^2	Average Occupancy	Average Heat Demands: Space			Water		Total		
				SHD/Unit kWh/year	SHD/m^2 kWh/m^2/year	SHD/occupant kWh/occupant/year	WHD/Unit kWh/year	WHD/occupant kWh/occupant/year	THD/Unit kWh/year	THD/m^2 kWh/m^2/year	THD/occupant kWh/occupant/year
Authority A	39	212	3.02	9911	46.8	3286	2350	779	12261	57.9	4065
Authority B	187	88	2.46	3495	39.8	1422	1806	735	5301	60.4	2157
Authority C	40	123	2.66	6524	53.1	2451	2238	841	8762	71.3	3292
Authority D	57	147	2.73	7488	50.9	2746	2280	836	9768	66.4	3582
Authority E	80	155	2.68	7629	49.1	2843	2179	812	9809	63.1	3655
SAP Data Set	403	125	2.61	5802	46.4	2219	2043	781	7845	62.7	3000

Table 4: Average heat demands by LPA and total.

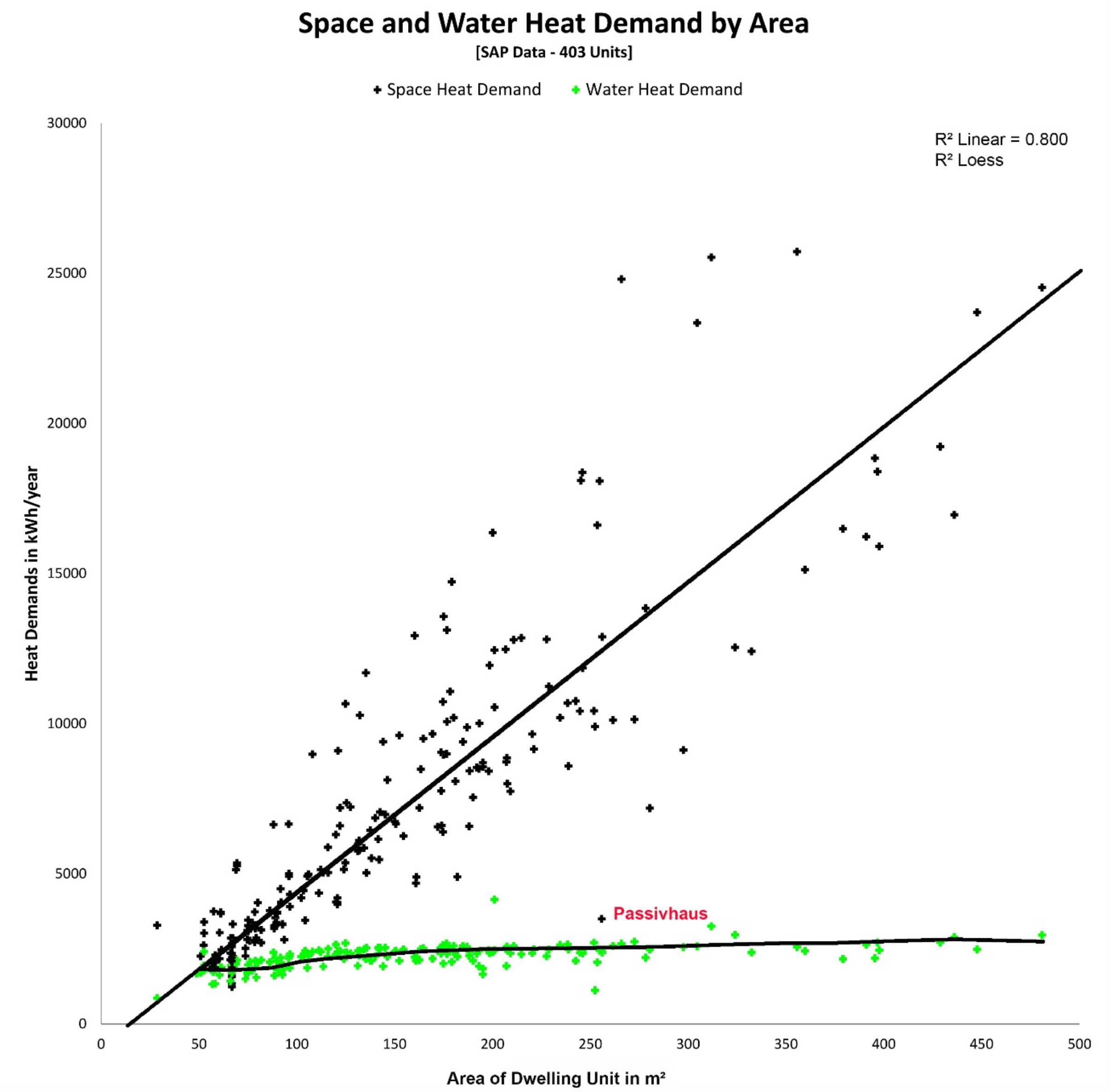

Figure 2: (SAP data: n = 403 units): Scatter Graph of Space and Water Heat Demand relative to Dwelling Size. Note the high correlation between Heat demand per unit area (R^2=0.800; significant at 95% confidence level) meaning that area size explained 80% the value of heat demand. As dwelling size increases the corresponding increase in water heat demand is relatively small. This is because water heat demand is calculated relative to the assumed occupancy of the dwelling not it size.

Water Heat Demand is calculated relative to the assumed occupancy of the dwelling as defined in SAP. However, as dwelling size increases the corresponding increase in Water Heat Demand is relatively slight. As a result, Water Heat Demand is statistically more significant in smaller and/or more energy efficient dwellings. Although still rare, several cases were evident in the sample for Authority B where the Water Heat Demand approached or even surpassed the Space Heat Demand. These were typically one or two bedroom flats or mid-terrace houses in Multi-Domestic developments with an inherently low space heat demand due to their typology and compact size resulting in good form factors. This would suggest that in more modest affordable housing of suitable typology, targeting the Water Heat Demand with LZCGTs such as Solar Thermal, Photovoltaics, Immersion Unit, PFGHR, WWHR could be significant in reducing both CO_2 emissions and fuel poverty because it is a proportionally higher component of total energy demand than in the larger dwellings. Photovoltaics would also be suitable for offsetting lower electrical loads such as lighting and MVHR and would be effective in combination with heat pumps with Coefficients of Performance (COP) much greater than 1.0.

Total heat demand per occupant was found to be statistically significant as the THD/Occupant is substantially higher in large dwellings than in small dwellings (Figure 3). This is a direct result of an increase in Space Heat Demand without a proportional increase in assumed occupancy. Therefore, occupants of large dwellings consume substantially more energy than those accommodated in more modest sized dwellings.

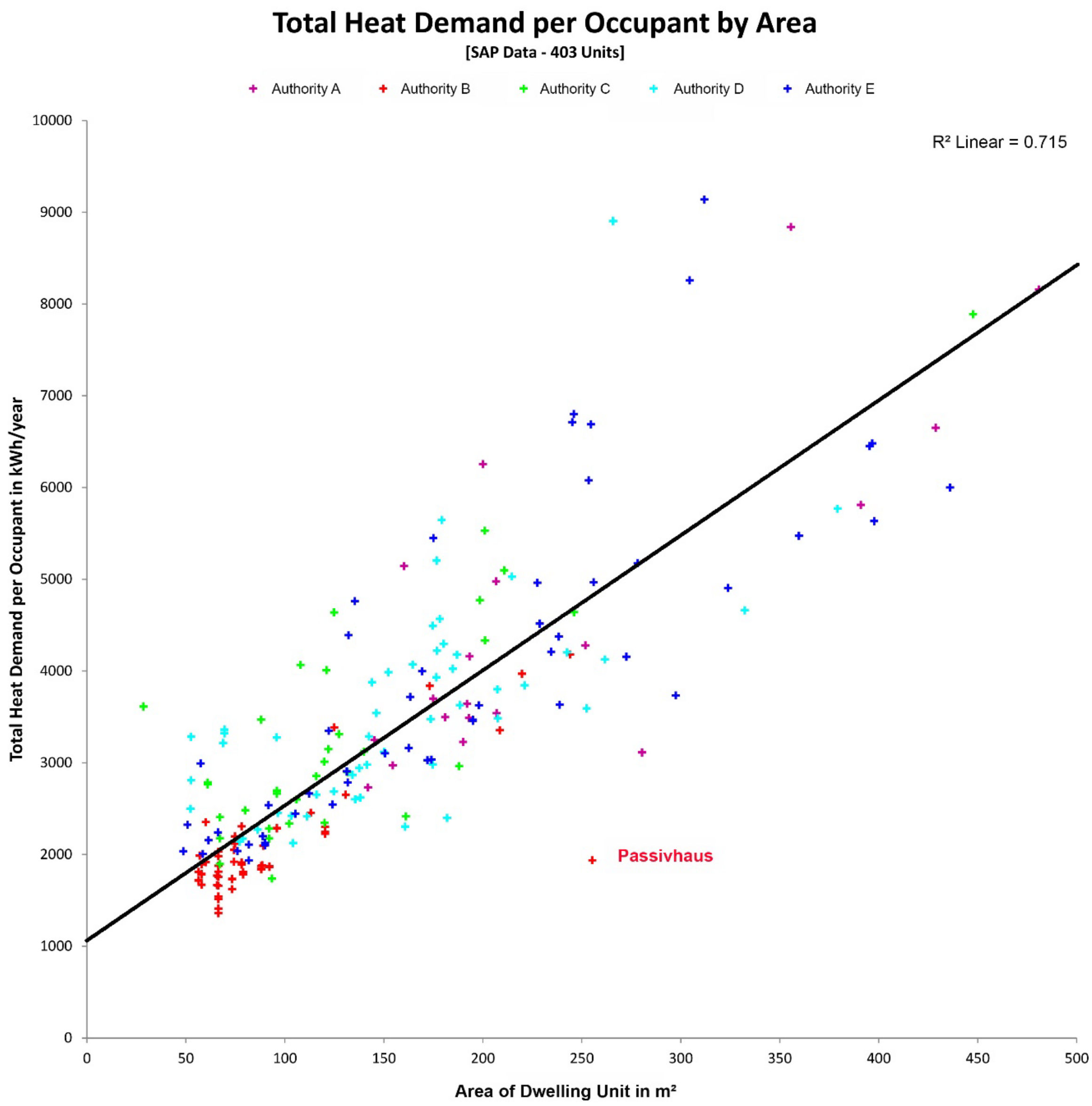

Figure 3: (SAP data: n = 403 units): Scatter Graph of Total Heat Demand/Occupant relative to Dwelling Size. Note the high correlation between Heat demand per unit occupant (R^2=0.715; significant at 95% confidence level) meaning that area size per unit explained 71.5% the observed value of heat demand.

Electricity demand

Every dwelling had an Electricity Demand with the combined Gross Total Electricity Demand at Dwelling of being 599 MWh/year; equivalent to an average of 11.9 kWh/m^2/year or 568 kWh/occupant/year (Table 5). Factoring in the 73 MWh/year electricity generated by LZCGT incorporated in the dwellings (Photovoltaics) this is reduced to a Net Total Electricity Demand at

Dwelling of 526 MWh/year; equivalent to an average of 10.4 kWh/m2/year or 499 kWh/occupant/year.

				Average Electricity Demands								
				Space & Water			Light & Ventilation			Gross Total		
LDP	No. of Units	Average Area m^2	Average Occupancy	S+W/Unit kWh/year	S+W/m^2 kWh/m^2/year	S+W/occupant kWh/occupant/year	L+V/Unit kWh/year	L+V/m^2 kWh/m^2/year	L+V/occupant kWh/occupant/year	TED/Unit kWh/year	TED/m^2 kWh/m^2/year	TED/occupant kWh/occupant/year
Authority A	39	212	3.02	1431	6.8	474	720	3.4	239	2151	10.2	713
Authority B	187	88	2.46	166	1.9	68	433	4.9	176	600	6.8	244
Authority C	40	123	2.66	1666	13.6	626	560	4.6	211	2226	18.1	836
Authority D	57	147	2.73	2381	16.2	873	547	3.7	201	2928	19.9	1074
Authority E	80	155	2.68	1245	8.0	464	589	3.8	220	1834	11.8	684
SAP Data Set	403	125	2.61	965	7.7	369	521	4.2	199	1486	11.9	568

Table 5: Average electricity demands by LPA and total.

65% (388 804 kWh/year) of the Gross Total Electricity Demand is utilised for Space and Water Heating. The wide range of individual values recorded in the sample can be attributed to the differences between dwellings using electricity as a primary fuel source (ASHPs, GSHPs and electric heating systems) and the majority for which electricity is used only to operate pumps and fans associated with the heating system. This leads to two distinct groupings in the graphed results (Figure 4). Data captured by local authority area also clearly indicates that regional context and the resultant choice of heating system is a major factor in determining Electricity Demand (Space & Water). Remote areas with the potential for grid-scale renewable wind and tidal power with inherent problems accessing traditional fuel supplies appear to be specifying more electrical heating systems (ASHPs and GSHPs) than urban areas. As a result Authority D has a significantly higher average Electric Demand (Space & Water) than Authority B where efficient gas boilers are almost universally used for heating as they are the energy system of choice due to existing infrastructure and comparatively inexpensive fuel costs.

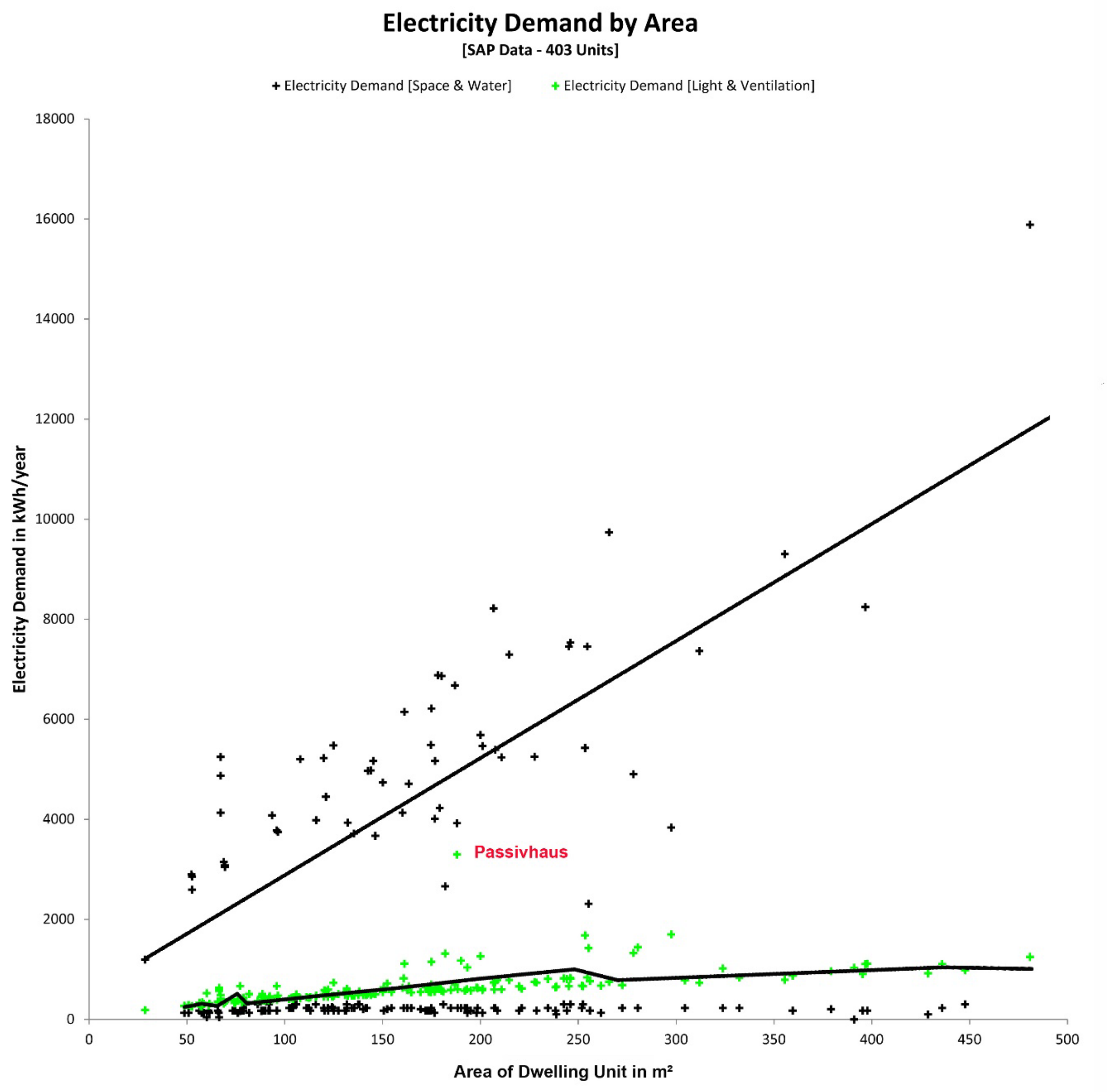

Figure 4: (SAP data: n = 403 units): Scatter Graph of Electrical Demand relative to Dwelling Size. Note the high correlation between Electrical Demand for Space Heat per area of unit (R^2=0.800; significant at 95% confidence level) meaning that area size per unit explained 80% observed Electrical demand, with Light & Ventilation contributing to much less of the Electrical demand.

The remaining 35% (209 857 kWh/year) of the Gross Total Electricity Demand is utilised for Lighting and Ventilation. On average 6% of the total energy demand of the domestic sample was attributed to lighting which translates to 13% of the total CO_2 emissions. There tends to be a gradual increase in Electricity Demand (Lighting & Ventilation) as dwelling size increases most likely due to increased numbers of bathrooms and larger floor areas requiring increased lighting. Specification of Mechanical

Ventilation and Heat Recovery (MVHR) typically doubled the Electricity Demand recorded and appear as slight outliers in the graphed results. In the sample for Authority B Electricity Demand (Lighting & Ventilation) is greater than Electricity Demand (Space & Water) because of the large number of MVHR units in the sample.

LZCGT uptake and contribution to CO_2 emission reduction

The Scottish Technical Handbook: Section 7 Sustainability: Clause 7.1.3: recognises several LZCGT that could be specified to assist Local Authorities to meet their obligations under Section 3F. These include micro hydro, micro wind, photovoltaics, solar thermal, biomass boilers/stoves, biogas, heat pumps and combined heat and power (CHP) fired by low emission sources. Fuel Cells, although an energy storage technology, are also included in this list.

Low versus zero carbon technologies

Whilst the number of occurrences of a LZCGT in the sample may indicate its prevalence in the market, it does little to describe its relative importance within the energy mix or its effectiveness at reducing GHG emissions. To ascertain a technology's impact it is necessary to consider the amount of energy it contributes relative to the amount of energy consumed to make that contribution and the amount of CO_2 emitted as a result. It should be noted that in SAP calculations CO_2 emissions are calculated relative to the theoretical energy consumed or generated, by applying multiplication factors determined in the methodology for each energy type. Energy consumption leads to positive CO_2 emissions being recorded, energy generation to negative CO_2 emissions. It is useful therefore to consider the impact and effectiveness of various LZCGT on CO_2 emissions. Traditional renewable generating technologies - hydro, wind, photovoltaics, solar thermal and some heat recovery devices (PFGHR, WWHR) are true zero carbon technologies. They consume little or no energy in their operation and consequently produce little or no CO_2 emissions. The energy they generate is used to offset the energy requirements of the building so following the SAP methodology their contribution is converted into a negative CO_2 emission. This is an accounting device, as in reality these technologies neither emit nor remove CO_2 from the atmosphere. However, they do displace CO_2 that would have been created had the renewable technology not been used.

Mechanical ventilation heat recovery (MVHR) utilises a moderate amount of energy in its operation and results in some CO_2 emissions. Used in buildings constructed to very good levels of airtightness where infiltration is less than $3m^3/h.m^2$ measured at 50Pa, efficiency gains are as a result of a combination of improved airtightness and heat recovery, which can deliver significant reductions in Space Heat Demand due to the heat recovery system. These cannot be separated as air tightness cannot be improved beyond $3m^3/h/m^2$ without using mechanical ventilation due to air quality issues but without coupling mechanical ventilation to heat recovery it tends the technology tends to be inefficient. While MVHR is considered in the ventilation calculation in SAP, a weighting factor is used but it is unclear from the calculation methodology how this is taken into account in the contribution of the heat recovery element to reducing space heat demand. Therefore, the extent of the energy savings from MVHR, which is fundamental to the Passivhaus concept, is not clearly accounted for in SAP methodology in terms of heat energy savings. However, it is widely accepted that MVHR can reduce Space Heating Demand, with some studies indicating this can be by as much as a third, AECB (2009). A conservative reduction in Space Heat Demand was factored into the calculations in instances where MVHR was present and this was calculated as 0.5 x Space Heat Demand. While there was no direct evidence to substantiate if this disincentives the uptake of MVHR it may be difficult for a building to comply with SAP using this technology particularly where an auxiliary heating system is not needed. It was evident that there were relatively low numbers of instances of the technology being used in the sample.

Biomass, heat pumps and combined heat and power (CHP) are low carbon technologies. They all emit CO_2, but either because of the accounting methods employed or their inherent efficiency they offer varying degrees of carbon saving relative to more traditional fuels and technologies. The SAP methodology uses CO_2 emission factors on figures defined by DEFRA which incentivises specific technology/fuel sources, which it considers sustainable. Biomass could be construed as being particularly controversial because other sources recognise its combustion releases 0.39kgCO_2/kWh9; almost twice as much as natural gas which releases 0.22kgCO_2/kWh. However, the multiplication factors used in SAP to calculate CO_2 emissions are 0.198 for gas and 0.008 for biomass, which implies emissions from biomass are a factor of 100 less than gas. In the sample for 198.4MWh/yr, biomass produced 4.5 tons/yr CO_2 emissions or less than 1% of CO_2 emissions for the sample. In contrast, 134.02 MWh/yr delivered energy from gas produced 315 tons/yr CO_2 emissions or 35% of the total CO_2 emissions. The ability of heat pumps to reduce CO_2 emissions is directly related to how green the electricity source. While they are generally considered more efficient than gas boilers, they are responsible for 20% of the Gross CO_2 emissions in the domestic sample due to the amount of energy they consume. Ground source and water source heat pumps are more efficient than air source heat pumps, but cost more and require more space outside the building envelope.

In SAP the manufacturers' rated efficiency of the heat pump is used to calculate the energy consumption of the unit and this is used to determine CO_2 emissions by applying a multiplication factor of 0.517. In the sample, ground source heat pumps consumed 86.5MWh/yr and produced 246.5MWh/yr of useful energy, resulting in 44.7 tons/yr CO_2 emissions or 5% of total CO_2 emissions. In contrast air source heat pumps consumed 215.7 MWh/yr and produced 483.2MWh/yr useful energy, resulting in 111.6 tons/yr CO_2 emissions or 12% of total CO_2 emissions for the sample. As the conversion factor for GSHP and ASHP is the same, dividing the energy produced by the energy consumed gives the typical efficiency of the technology. Therefore in the total sample ASHP had an efficiency of 224% and GSHP had an efficiency of 285%.

Energy map

The energy map summarizes the number of instances of LZCGT recorded, the energy consumption of the technology, the energy contribution to the building and the associated CO_2 emissions by technology type and places this in the context of end use and the overall energy mix (Figure 5). In the diagram the energy consumption is the total energy used in delivering the heat/electrical demand of the building. Due to the inherent inefficiencies in the combustion process it is typically necessary to consume a larger amount of energy than the heat or electrical demand infers. This is normally due to incomplete combustion and unutilised heat losses. There are exceptions to this rule as electricity is 100% efficient as the energy consumed is the same as the energy contributed. Whereas, heat pump technology consumes less electrical energy than the heat energy delivered. Solar thermal and MVHR contributes more energy than they consume but use relatively small amounts of energy in their operation relative to the energy they contribute. The energy contribution is the amount of useful energy delivered to the building. SAP calculates CO_2 emissions by applying a multiplication factor to the energy consumption which is representative of the fuel type and the efficiency of the technology. These factors are regularly updated therefore the figures used in this report reflect those used at the time of the sample building's construction. In Figure 5, [Technology] represents the different technologies used, these primarily supply heating demand. [Number] refers to the number of instances the technology was recorded.

It should be noted that some electricity is used in the operation of most of these technologies e.g. to run pumps and fans in solar thermal and other technologies. Some buildings within the sample did not include LZCGT while others use more than one fuel source or LZCGT. There were only a few instances of dwellings recorded using electricity directly for heating and this is represented by the [Electricity]. All buildings in the sample had an electricity demand for lighting which is represented in the graphs as [LIGHTS]. In the Electricity category the energy consumption equals the energy contribution. The inefficiencies of grid supplied electricity production is represented in the SAP calculation for the CO_2 emission from this technology type. In SAP, all energy generated by the building is accounted for within the context of the building. Excess energy generated through LZCGT is deducted from the total energy consumed by the building. This either lowers or creates negative energy consumption and CO_2 emission figures. The SAP calculation assumes that all energy produced by the building is consumed within the building. Carbon emission reduction for any subsequent energy exported is already accounted for in the SAP calculation and energy exported is not detailed in the calculation. However, it would be unlikely that all electrical energy generated from LZCGT's would be used within the building directly, but a proportion of the total energy would be exported to the grid and at other times grid energy would be imported to supply the building systems. Contribution of electricity from LZCGT's is deducted from the grid electricity consumption to reduce this figure. Solar Photovoltaics consume no energy therefore all energy produced is presumed to be consumed within the building and is deducted from the electricity demand.

Dual Fuel refers to Solid Fuel Stoves that utilise a variety of low carbon or fossil fuel sources e.g. biomass and coal. These are given a conversion factor in SAP of 0.028 which is lower than biomass but higher than coal. The contribution of MVHR to space heating is shown in the pie charts based on an estimate of its contribution to SHD reduction. As the CO_2 emissions offset by the heat saved from heat recovery is not clearly represented in the SAP data, it should be noted that the CO_2 figures illustrated represents emissions from operating the ventilation component of the technology and NOT the emissions saved from the heat recovery component. Therefore, it would be expected that, the use of MVHR would have a greater impact on CO_2 emission reduction than is represented in the figures illustrated here.

Over the sample ASHP had an efficiency of 224% and GSHP had an efficiency of 285% (60% average difference). Variances across the sample which would contradict this are due to individual assumed efficiencies of devices used within the SAP calculation. The most significant conclusion drawn from the Energy Map is that if the relative efficiencies of different technologies were calculated i.e. energy contribution to CO_2 emission, then it would be possible to determine which technologies would be more efficient at reducing CO_2 emissions if incentivised. In the sample, the relative contribution of LZCGT and non-LZCGT technologies to overall carbon emission reductions can be calculated by comparing total delivered energy contribution against total CO_2 emissions (Table 6).

	Total Energy Contribution MWh/yr	Total CO_2 Emissions Tonnes CO2/yr	CO_2 Emissions / Delivered Energy Tonnes CO2/ MWh	Percentage of Total Energy Contribution %	Percentage of Total CO_2 Emissions %
Non-LZCGT	2385.5	677.7	0.284	68	86
LZCGT	1144.7	113.4	*0.099	32	14
Total (Non-LZCGT + LZCGT)	3530.2	791.1	0.224		

* This figure would reduce if heat recovery component of MVHR is factored into the calculation.

Table 6: Contribution of technology to energy demand and CO_2 emissions.

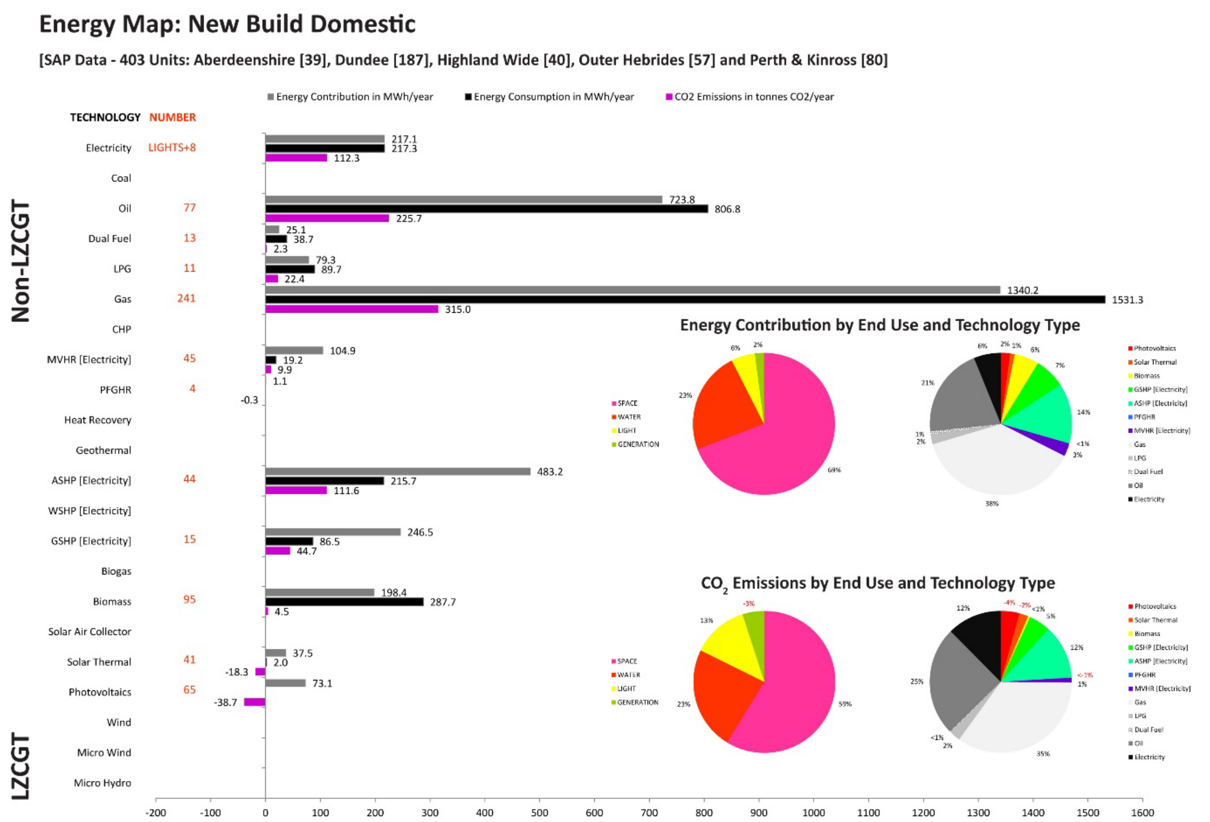

Figure 5: Energy map of all LPAs studied.

Technology trends

The results show that the largest LZCGT energy contributors are all Low Carbon Technologies: biomass boilers, ASHPs and GSHPs are very efficient at producing heat used to provide space and water heating, but these are considered Low Carbon Technologies, and in reality they all emit CO_2 from their operation. However, they are particularly effective where they are used in conjunction with a green grid with evidence pointing to their incentivisation in remote areas such as Local Authority D (Figure 6).

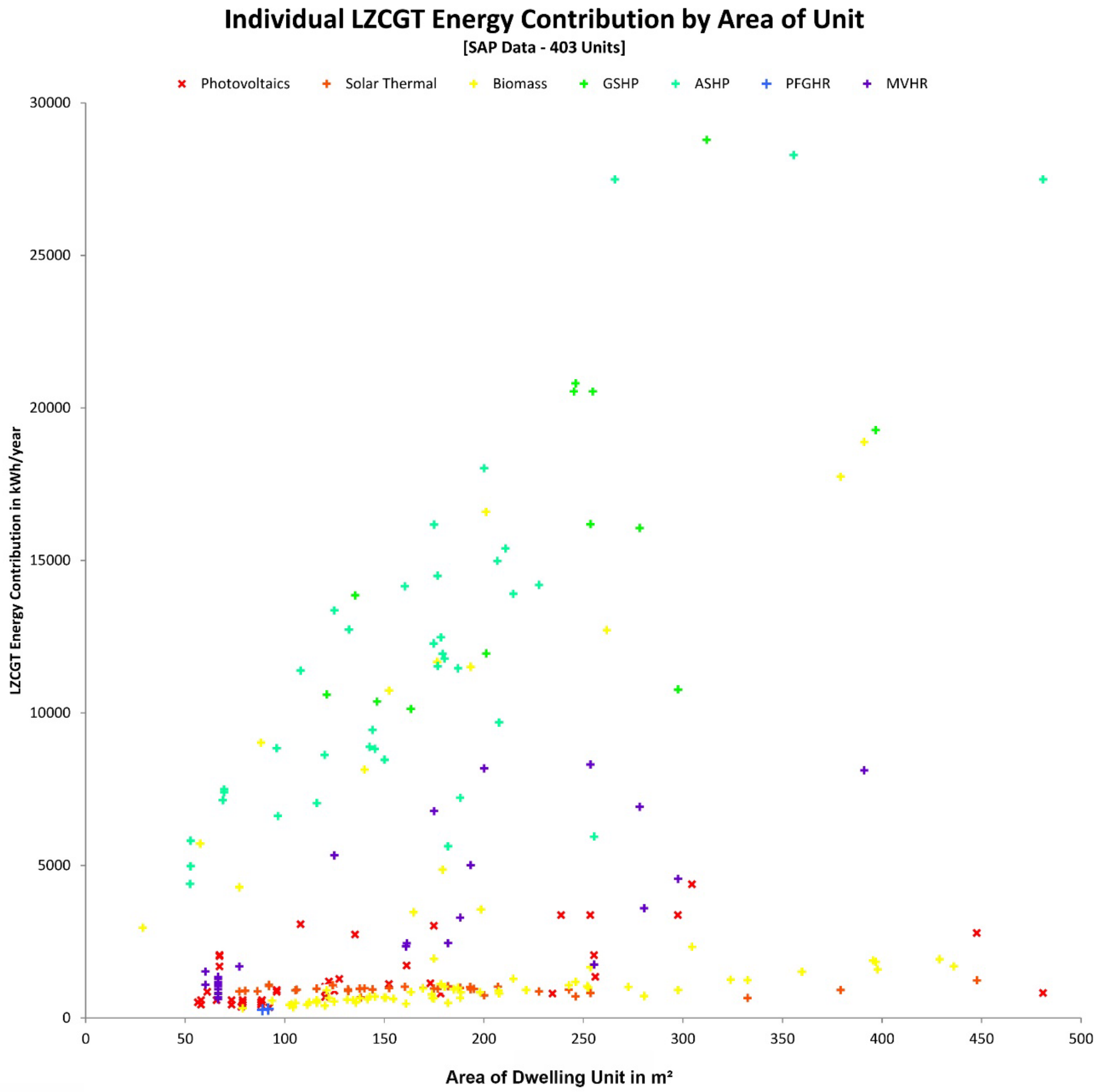

Figure 6: Energy contribution of LZCGT plotted by area of unit.

In a significant number of cases the LZCGT provision is included only to reduce CO_2 emissions to comply with mandatory requirements. In all of the local authorities studied (with the exception of Authority B, which is a smoke free zone), the compliance LZCGT usually takes the form of a biomass stove as these are reasonably inexpensive and provide an autonomous heat source. As a secondary heat source, SAP typically considers that a biomass stove will provide 10% of the Space Heat Demand and because the fuel source CO_2 emissions defined in SAP are low, specifying a biomass stove is an effective way to comply with SAP.

Typically, an economic, PV rooftop installation for a single dwelling would be approximately 3-4kW capacity (KPMG 2015). However, in the sample the majority of PV installations are around 1-1.5kW capacity. In Authority B, small photovoltaic arrays, some with less than 1kW capacity have been employed most likely to gain compliance. PV was installed on 65 dwellings in the sample but it was not possible to calculate an average installed capacity due to the variability of the dataset. Solar thermal makes a relatively small energy contribution and has relatively low operational energy consumption but can typically provide about half of the Water Heat Demand. This is a significant proportion of the energy demand in small and energy efficient dwellings and consideration could be given to incentivising its uptake in the Policy. The conservative estimate of the contribution made by MVHR included in this study clearly indicates that this is a technology that could have greater impact in reducing CO_2 emissions, by facilitating further reductions in space heat demand. However, while PFGHR, WWHR and MVHR all contribute to energy reduction by recovering waste heat in different ways, they are not classified as a LZCGTs as they do not generate energy independently. PFGHR relies on an additional heating system being present and captures heat otherwise wasted through flue gases. WWHR is an emerging technology but no incidences of its application were found in the sample. This distinction may be counter-productive and unhelpful in encouraging uptake of passive energy conservation measures. It should be noted that some authorities permit MVHR as an 'approved' LZCGT. There was little evidencing of energy storage provision, except for hot water storage cylinders for solar thermal, biomass boilers, heat pumps and some heat recovery devices. Grid connections were presumed in all instances of photovoltaics, although none of the applications explicitly stated such.

Regional influences

The distribution of LZCGT by local authority area suggests that regional context is being taken into consideration when specifying LZCGT and is being specified at the discretion of individual applicants (Figure 7 / Table 7). For example, Authority D includes a large proportion of ASHPs in anticipation of locally produced wind and wave power, whilst Authorities B & A with a sunnier east coast climate and the restrictions imposed by urban conditions specify larger proportions of photovoltaics and solar thermal. Biomass boilers and stoves are evidenced in large numbers in all local authority areas that are not smoke free zones. The sample returned very few examples of non-domestic buildings but 9 units in the sample specified biomass as a heating source out of a total of 26 units (35%) a relatively high proportion. Generally, there is a lack of evidence of scaled solutions or significant energy storage technologies (heat or electrical). Regional influences impact not only on the type of LZCGT specified but also the extent of its contribution to the energy mix. In some regions particularly those off the gas grid indicated a higher uptake of LZCGT. This data suggests remote areas currently have a greater proportional uptake of renewable technology than urban areas in terms of number of units specifying LZCGT and its overall contribution to the energy mix. Authorities D and C showed that 100% of the dwellings specified LZCGT in compliance with Section 3F policy and that the LZCGT contributions to the energy mix were the highest at 64.1% and 41.9% respectively. In comparison, the data indicates that Authority B had both the lowest percentage of new builds specifying LZCGT at 34% and by far the lowest LZCGT contribution to the energy mix at just 5.1%, but this evidence is weak due to the reliability of this data and should be read with caution. It should however be noted that the type of LZCGT specified in this sample (mainly photovoltaics and MVHR) showed a high return in terms of energy delivered for energy expended.

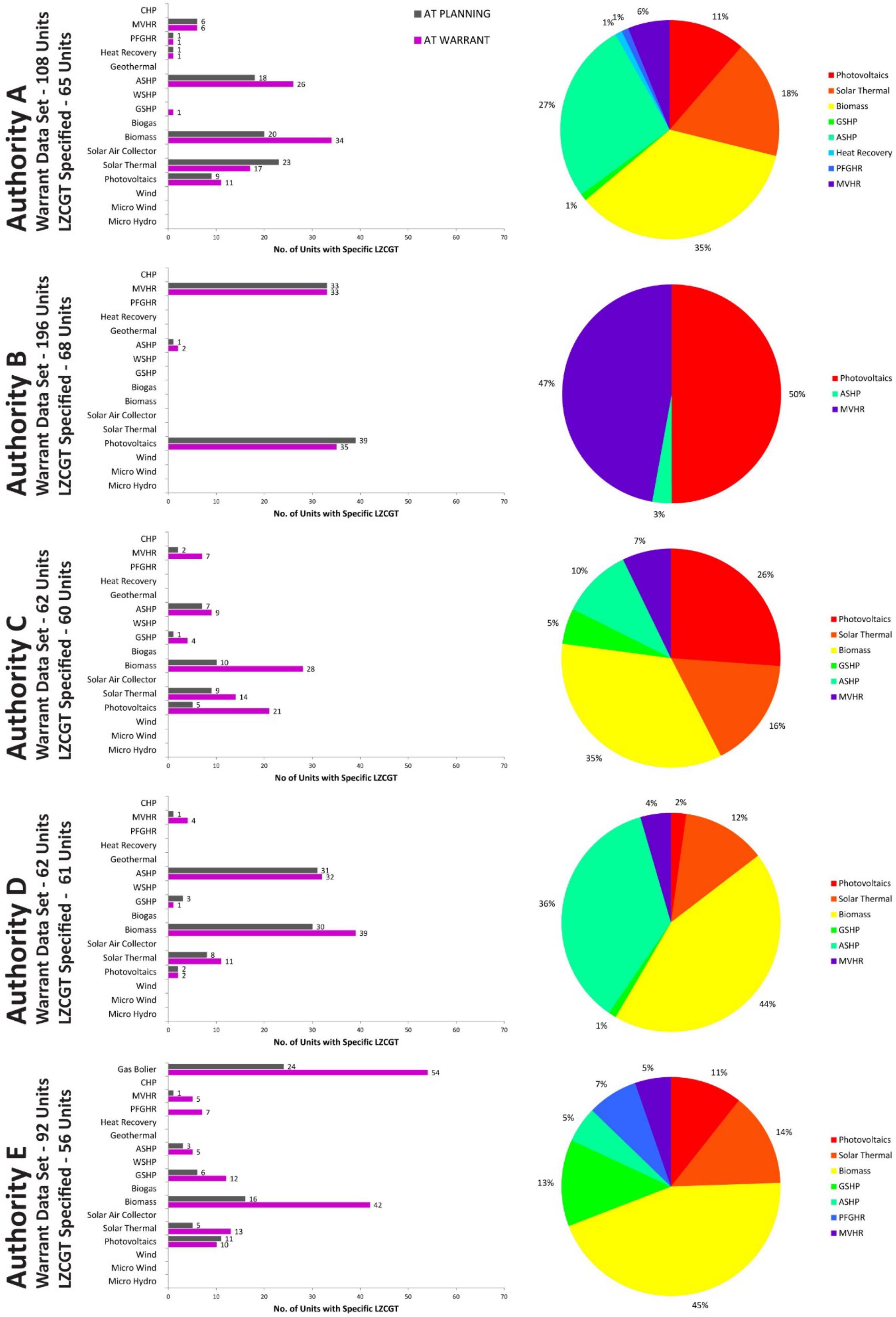

Figure 7: Numbers and relative distribution of LZCGT types by LPA.

				LZCGT Provision											
				No. of Units with LZCGTs						Percentages			Ratios of LZCGT Mix		
LDP	No. of Units	Total Area m^2	Total Occupancy	No LZCGT	1 LZCGT	2 LZCGTs	3 LZCGTs	4 LZCGTs	5 LZCGTs	LZCGT Specified % of Total	Energy Contribution % of Total	Energy Consumption % of Total	Contribution : Consumption kWh/kWh	CO_2 Emissions : Contribution $kgCO_2$/kWh	CO_2 Emissions : Consumption kgCO2/kWh
Authority A	39	8260	118	21	8	8	2	0	0	46	34.5	21.3	1.76	0.120	0.211
Authority B	187	16419	460	123	63	0	1	0	0	34	5.1	1.0	4.90	-0.100	-0.490
Authority C	40	4916	106	0	29	7	3	1	0	100	41.9	28.8	1.60	0.019	0.030
Authority D	57	8389	155	0	36	16	4	1	0	100	64.1	51.7	1.51	0.038	0.057
Authority E	80	12432	215	35	23	15	4	2	1	56	39.9	18.4	2.57	0.085	0.218
SAP Data Set	403	50416	1054	179	159	46	14	4	1	56	32.4	18.5	1.87	0.099	0.186

Table 7: Specification of LZCGT by LPA and total.

Impact of application type (domestic vs multi-domestic)

Differences in the specification of LZCGT are evident between Single Domestic and Multi Domestic Developments, which also might be related to the regions from which the respective developments originate (Figure 8). Larger Multi Domestic developments tend to be in urban areas which could limit certain LZCGT types e.g. biomass in smoke free zones but facilitate others such as district heat networks or solar rooftop installations. It is observed that in Authority A, MVHR and Photovoltaics were the LZCGT of choice for Multi Domestic developments because they are relatively undemanding in terms of space. As urban areas also tend to be smoke free zones, biomass is not an option, which explains the lack of biomass in the Multi Domestic relative to the Single Domestic sample. It is perhaps surprising that the number of ASHPs was not higher in the Multi Domestic group, as this technology does not require much external space, although this probably relates to the fact that urban areas have an established gas supply infrastructure with which new technologies have to compete. It should be noted that the SAP data included no instances of scaled LZCGT in any of the local authority areas. The most significant trend, however, in terms of LZCGT provision relative to building type is that many Multi Domestic developments are failing to comply with Section 3F requirements to specify LZCGT.

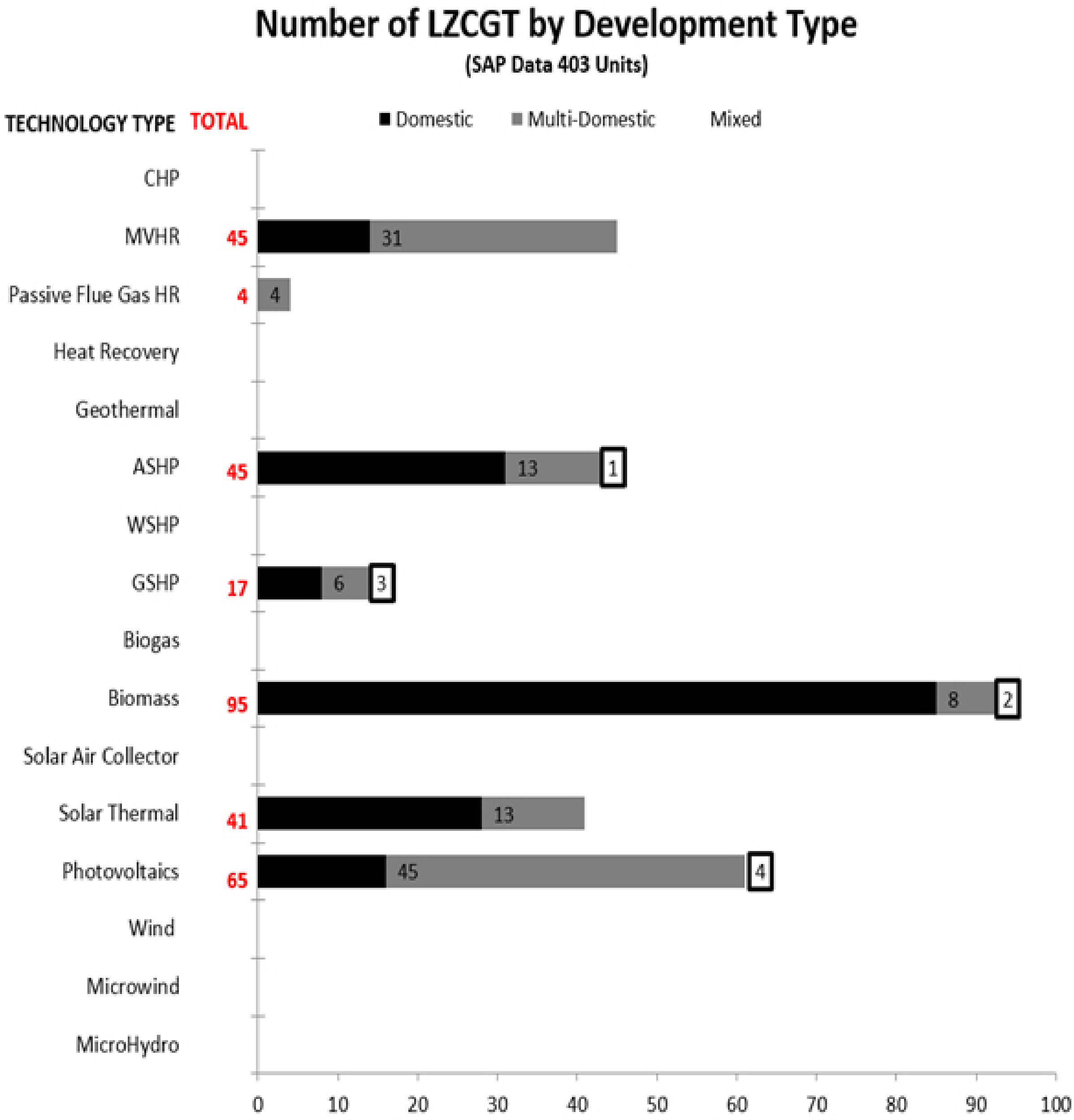

Figure 8: Distribution of LZCGT by application type across building types.

Discussion

Regulating for energy demand, building scale and occupancy

The study confirms that Space Heating remains the single largest contributor to energy demand, energy consumption and CO_2 emissions in domestic buildings, in all but the smallest and most energy efficient dwellings. The data also records a vast range of individual Heat and Electrical Demands (kWh/year) across the sample and demonstrates that these differences relate primarily to variations in dwelling size, where in large dwellings, the total heat demand per occupant can be over six times greater than that in homes of a more modest scale. The evaluation of Space Heat Demand, energy consumption and CO_2 emissions in terms of per m^2 in the calculation methodology masks the realities of building scale. Calculations are based on the assumption that as dwelling size increases the assumed occupancy will increase proportionally, which is generally not the case evidenced by the SAP data. However, the Passivhaus highlighted in the sample for Authority B, has a Total Energy Demand/Occupant in line with the more affordable dwellings, which suggests that it could be beneficial to assess Space Heat Demand and Energy Consumption in terms of kWh/year per occupant and CO_2 emissions in terms of $kgCO_2$/year per occupant. Setting targets relative to these measures could necessitate substantially higher fabric energy efficiencies and /or utilization of increased LZCGT in larger dwellings to compensate for their increased CO_2 emissions, thereby lowering the environmental impact of large scale dwellings, an approach that is already recognised in methodologies such as Passivhaus. Taking this approach could naturally limit excessive individual consumption of energy and materials without actually restricting free choice and favour the development of more modest dwellings and more energy efficient building forms. While low occupancy within larger dwellings signifies relative wealth, high occupancy within very small dwellings is a reflection of relative poverty. Although smaller dwellings are potentially more energy efficient, this potentially hides concomitant problems such as poor indoor air quality and poor health. Higher energy performance approaches such as Passivhaus inherently account for building scale and occupancy through controlled ventilation rates and internal gains with calculations based on a flat rate of $35m^2$ / person. Contrary to accepted practice, recent studies indicate that PH's with small internal footprints (<$50m^2$) and reduced occupant floor areas (>$20m^2$/person) can be designed to comply (Clark et al 2014). In the long term, as building standards improve in all dwellings the underlying issue of scale would resurface and would need to be addressed. Compact building forms with low thermal bridging and higher airtightness levels specifying MVHR would need to be considered in order to make further significant technical improvements.

Improving uptake and effectiveness of LZCGTs

The study has revealed varying uptake in LZCGTs across the authorities studied since Section 3F policies were adopted. Whether this is a direct result of the policies or due to a number of external factors such as improvements in Building Standards legislation, the regional context, market influences and consumer preferences was impossible to determine. However, it is clear that regional differences have a significant impact on the type and extent of LZCGT provision, with remote areas and those without a gas connection demonstrating a relatively greater uptake and overall contribution to the energy mix than urban and grid-connected areas (i.e. gas grid). Significantly, the adoption of a particular LZCGT appears to be driven by individual applicant and not by any specific regional or local policy, which means that the lack of strategic policies in relation to regional and local energy contexts may be limiting greater CO_2 emissions reductions. For example local authorities could legislate and encourage the use of district heating and CHP in fuel poor urban areas or the use of heat pumps and energy storage (batteries and heat) in remote areas with green grids[1] where grid energy balancing are current barriers to grid expansion. However, there was very little evidence in practice for the use of scaled LZCGT (CHP and District Heating) or of energy storage provision with the exception of hot water storage cylinders. There also does not appear to be any evidence that zero carbon as opposed to low carbon technologies are being incentivised and legislated for at local and regional levels.

In most cases biomass stoves and small photovoltaic arrays were observed as compliant LZCGTs across all local authority areas, driven by the requirement to meet baseline building standards, with there

[1] A grid mainly carrying electricity from renewable sources

being little correlation between dwelling energy demand and the appropriateness and scale of the LZCGTs specified. It was also evident that alternative technologies that fall outside Scottish Government's definition for LZCGTs are being approved. While some authorities are including heat recovery devices, MVHR and other innovative technologies which can be operated using non-fossil fuel sources, other authorities, particularly in urban areas are allowing the inclusion of efficient gas boilers and efficient appliances within the definition of LZCGTs. The latter potentially undermines the ethos of the Section 3F policy and may discourage the specification of technologies with greater CO_2 emission reduction impact, while the omission of alternative low and zero-carbon technologies that fall outside the definition for LZCGTs could discourage the use of these technologies potentially limiting the market. Of particular relevance, MVHR (which is considered fundamental to the Passivhaus concept), is currently not sufficiently incentivised within the national calculation methodology, as it difficult for this technology to comply, and yet it is generally accepted that its contribution to space heat reduction is significant.

Accelerating CO_2 emission reduction

All buildings included in the study met the CO_2 emissions reduction set out in Section 6.1 of the building regulations, but only a limited proportion of these (ranged across the authorities from 35% - 98%) complied with Section 3F policy and achieved this reduction through the installation and operation of LZCGT. Only 2 of the 482 dwellings (0.4%) returning building warrant data were carbon negative. The vast majority of dwellings that did not comply were multi-domestic developments (i.e. planning applications for more than one house). Consequently, there appears to be little evidence that higher aspirational CO_2 emissions targets are being met beyond the mandatory Bronze Sustainability Level, which would indicate that the Scottish Building Standards are driving the current reduction in CO_2 emissions, not Section 3F policies (Figure 9).

At present it is not possible to deduce from SAP data submitted for warrant, the percentage CO_2 emissions reduction due specifically to LZCGT. This is because SAP does not distinguish between the electricity produced, which is used within the building (or subsequently exported), but assumes energy produced is used directly to reduce the carbon emissions of the building. To evidence CO_2 reduction contributed by a particular technology, an additional calculation (with and without technology) is required. It was noted that one local authority not included in the survey requests two SAP calculations (with and without LZCGT) in order to calculate energy contribution and percentage CO_2 emission reduction due to LZCGT uptake. If this were adopted local authorities would be able to specify accelerated CO_2 reduction targets and quantifiably assess whether applications deliver these.

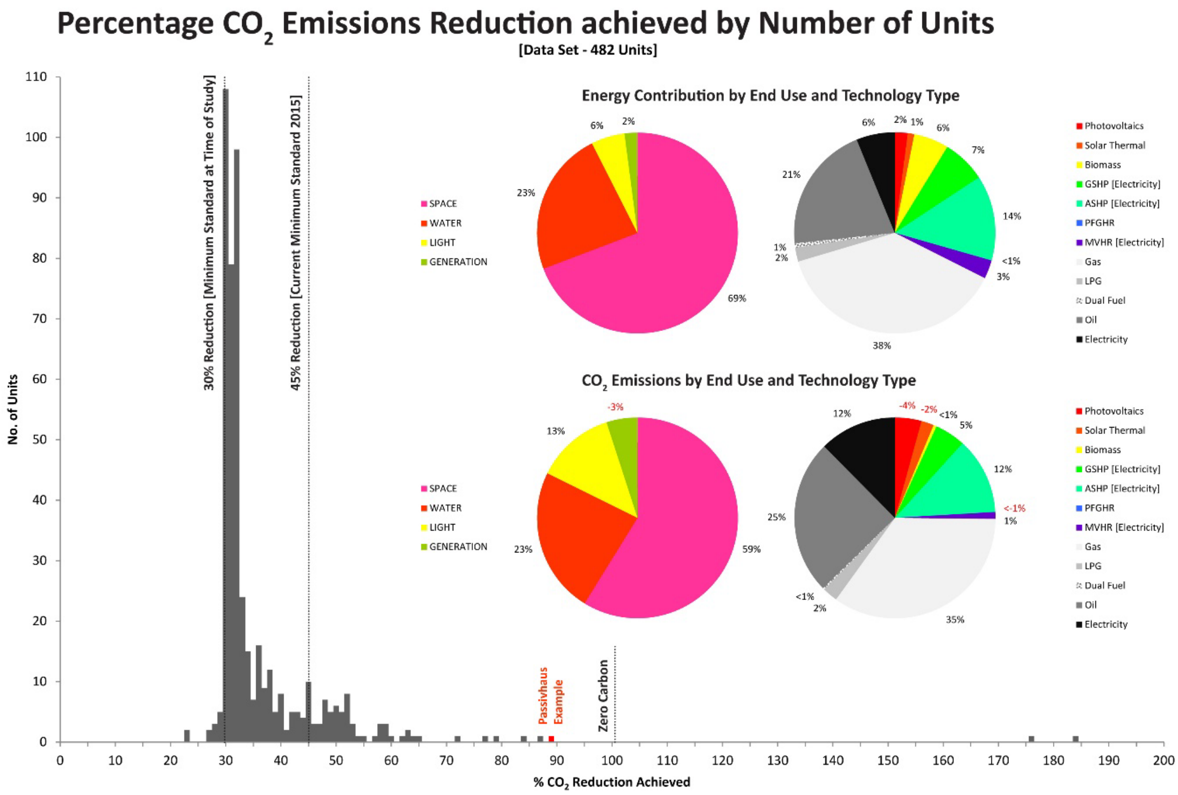

Figure 9: CO_2 emission reductions.

Conclusions and Recommendations

This study has sought to understand trends in LZCGT uptake, energy contribution and CO_2 emission reductions as a result of the technologies employed from a sample of 403 new build domestic planning applications submitted across five local authority planning areas. The study covered a period from 2012 to 2016 during which Section 3F Policies designed to promote and accelerate GHG reduction in new buildings had been introduced in their Local Development Plan (LDP). While all of the buildings in the sample complied with the 2010 energy standards emissions reduction target in the Scottish Government's building regulations Technical Handbooks at the time of study, only a limited proportion achieved this reduction through the installation and operation of LZCGT. A clear trend can be identified in the uptake and implementation of LZCGTs over the review period with the extent and type of the LZCGT provision varying significantly across the regions studied. Remote areas and those without a gas connection demonstrated a relatively greater uptake of LZCGT and a correspondingly higher contribution to the energy mix than urban and grid-connected areas. Low carbon technologies dominate the sample studied as opposed to zero carbon technologies and there was little or no evidence for scaled solutions such as district heat networks or energy storage technologies other than domestic scale hot water cylinders.

Conversely, there is a prevalence for compliant LZCGTs such as biomass stoves and small-scale PV, particularly in urban areas and in multi-domestic applications. High efficiency gas fired combination boilers were more evident in gas grid-connected areas, being 'approved' LZCGTs by some local authorities, potentially diminishing the impact and reach of Section 3F policy. With space heating dominating in terms of energy consumption and CO_2 emissions in all but the smallest and most energy efficient dwellings there is a significant correlation between both heat and electrical demand and dwelling size and occupation which statistically skews emissions counting. The overriding finding is that it is the Scottish building standards that are driving the current reduction in CO_2 emissions, not Section 3F policies, which raises concerns as to the effectiveness of current policies.

Previous studies conducted to assess the uptake of micro generation and LZCGTs have highlighted the lack of effective policy, including the need for: long term planning strategies; short term policies to assist transition to new sustainable technologies, Bergman & Eyre (2011); more strategic policy instruments that support flexibility of installation configurations, Caird et.al (2008); and policies that are representative of different contexts and scales of application (Allen, 2008). This study indicates that improvements to CO2 emission reduction could be obtained if Section 3F policies were more proactive in defining criteria for the relationship between new build developments and regional energy requirements. This might for example define the specific criteria or requirements for particular sites e.g. the need for energy storage or scaled energy systems such as district heat or CHP. It might also limit development scale in relation to energy availability or apply specific increases to energy conservation and/or LZCGT contribution to energy demand in large dwellings. Further consideration could be given to the appropriateness and effectiveness of particular LZCGTs in their ability to meet regional energy conditions e.g. the use of ASHP in areas where there is already a 'green grid'. Concentrating solely on the specification of LZCGT, current Section 3F policies might, arguably, be detrimental to design-led responses to CO2 emissions reduction, which if building scale and occupation were considered appropriately could result in significant reductions in energy demand. Very low energy building design methodologies such as Passivhaus inherently account for building scale and occupation in the calculation methodology defining maximum and minimum floor areas, air quality standards (through controlled ventilation) and the contribution of internal heat gains to energy performance and comfort. Such approaches could find more traction as Building Standards performance criteria improve in the future and where MVHR would need to be considered if airtightness criteria were to increase beyond current standards.

Obtaining basic information on the type of LZCGT proposed early in the planning process is useful, as it offers the opportunity for the LPA to open a dialogue and make strategic energy suggestions. Encouraging a commitment to utilising LZCGT early in the design process would improve the chances of a well thought out energy strategy being incorporated into the building when constructed – even if the type and extent of the LZCGT provision is altered somewhat in the final design. It would also permit conditions pertaining to the proposed LZCGT to be attached to the planning consent. To significantly accelerate emissions reduction would require LPAs to specify additional emissions reductions beyond

2007 regulations that would intrinsically require the specification of LZCGTs. This would normally be evidenced in SAP, but in order to quantify the LZCGT's contribution to CO_2 reduction requires an additional SAP calculation (with and without technology) to confirm if the policy is complied with. The need to correlate the standard of compliance documentation requested with the appropriateness to the design stage is therefore vital. However, SAP calculations tend not to be completed until after the design has been finalised and are simply not available at early planning stages. A staged procedure might be the most suitable approach to promote policy compliance. This might be a simple tick box form to encourage a commitment to using LZCGT early in the design process, followed by a suspensive compliance condition applied to the planning consent, requiring proof at the building warrant stages.

A key lesson from this study is that LZCGTs are recognised as one solution in fulfilling the minimum legislated CO_2 emission reduction as outlined in Section 6 (energy) of the building regulations. The implication of this is that additional energy generation, via LZCGT, is being favoured over energy conservation measures. Although more efficient than traditional fuel sources, many of the commonly specified LZCGTs still emit significant amounts of CO_2 and may consequently have less impact on long-term CO_2 emissions reduction than improvements in fabric energy efficiency and passive design approaches. On this basis, our conclusions indicate that more focused debate is needed on how to formulate, implement, benchmark and monitor performance of future LZCGT policies in order to make a step change in uptake and CO_2 emission reduction.

Embedded in local development plans, Section 3F policies are ideally placed to address some of the more design orientated approaches to reducing greenhouse gas emissions, and could potentially be broadened to achieve greater impact. It is clear that the general consensus among building design professionals is that the most cost effective and long-term approach to reducing CO_2 emissions is to reduce overall energy consumption through improved fabric efficiency and site specific passive design before considering the specification of LZCGT (MacKay, 2009; DECC, 2012). It would therefore be more useful to consider CO_2 emissions from buildings within a wider context, including:

appropriateness of scale; passive design principles; fabric energy efficiency; efficient building systems and efficient appliances; promotion of Zero-Carbon Generating Technologies and scaled systems. Consideration could be given to utilising Section 3F policy to specify application of LZCGT in ways that add-value and go beyond reductions in CO_2 emissions beyond legislated for in Section 6 and improved energy standards. This would ensure that energy conservation is prioritised and the LZCGT is effectively contributing to the smaller energy demand. If this is combined with Section 3F Policies that are more strategic in their response to regional energy context, more significant CO_2 emissions reduction could be achieved as a result.

Finally, whether the 2-phase policy system in Scotland, where planning phase addresses specified building design aspects; and building warrant phase assures and confirms based on set standards, might need review, particularly if it is limited in its efficiency and effectiveness, as shown in this paper.

References

AECB, 2009. Comparing energy use and CO2 emissions from natural ventilation and MVHR in a Passivhaus house. A CarbonLite Information Paper, [online]. Available at: https://www.aecb.net/wp-content/uploads/2013/02/9Jan2009_MVHR_Final-2.pdf. [Accessed 21st December 2018]

Allen S.R., Hammond, G.P. & McManus, M.C., 2008. Prospects and barriers to domestic micro-generation: A United Kingdom perspective, Applied Energy 85 (2008) 528-544, Elsevier Ltd.

Anderson, B., 2006. Energy Performance of Buildings Directive, Building Research Establishment, UK. [online]. Available at: https://www.google.co.uk/search?q=brian+anderson+BRE+Energy+perfromance+of+buildings+directive&ie=utf-8&oe=utf-8&client=firefox-b&gfe_rd=cr&ei=CXE1Wb_bKojSXrPzsZgK [Accessed 5th June 2017].

Bergman, N. & Eyre, N., 2011. What role for microgeneration in a shift to a low carbon domestic energy sector in the UK?, Energy Efficiency (2011)4:335-353, Springer .

Caird, S., Roy, R. & Herring, H., 2008, Improving the energy performance of UK households: Results from surveys of consumer adoption and use of low- and zero-carbon technologies. Energy Efficiency (2008) 1:149-166, Springer Science

Clark, A., Grant, N., 2014, Internal Heat Gain Assumptions in PHPP. Proceedings of the International Passive House Conference Aachen 2014.

Department for Business, Energy & Industrial Strategy, 2017., Greenhouse Gas Emissions, Final Figures [online]. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/604350/2015_Final_Emissions_statistics.pdf, [Accessed 8th April 2017].

Department of Energy and Climate Change (DECC), 2009. *SAP 2009: the government's standard assessment procedure for energy rating of dwellings: 2009 edition* [online]. Available from: https://www.bre.co.uk/filelibrary/SAP/2009/SAP-2009_9-90.pdf [accessed 21/08/2017].

Department of Energy and Climate Change (DECC), 2012. *SAP 2012: the government's standard assessment procedure for energy rating of dwellings: 2012 edition* [online]. Available from: https://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf [accessed 21/08/2017].

Department of Energy and Climate Change (DECC), 2012: The Energy Efficiency Strategy: The Energy Efficiency Opportunity in the UK, Crown copyright, London.

Druckman, A., Jackson,T., 2008., Household energy consumption in the UK: A Highly geographically and social economically disaggregated model, Energy Policy, 36, pp.3177l3192.

Eurostat 2016., Consumption of Energy [online]. Available at: ttp://ec.europa.eu/eurostat/statisticsIexplained/index.php/Consumption_of_energy, [Accessed 6th April, 2017].

European Commission, 2010, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), [online]. Available at: http://eur-lex.europa.eu/legal-content/EN/ALL/;ELX_SESSIONID=FZMjThLLzfxmmMCQGp2Y1s2d3TjwtD8QS3pqdkhXZbwqGwlgY9KN!2064651424?uri=CELEX:32010L0031, [Accessed 2nd June, 2017].

European Commission, 2010, Nearly Zero Energy Buildings. European Union [online]. Available at: ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings, [Accessed 2nd June, 2017].

HM Government 2016, Energy Consumption in the UK, Energy and climate change: evidence and analysis, Chapter 3, pp20-27: Domestic sector energy consumption, Department for Business, Energy & Industrial Strategy, First published: 25 July 2013, Updated: 7 September 2016.

International Energy Agency 2008., Worldwide Trends in Energy Use and Efficiency. OECD/IEA. [online]., Available at: https://www.iea.org/publications/freepublications/publication/Indicators_2008.pdf, [Accessed 6th April 2017].

Kannan. R., 2009. Uncertainties in key low carbon power generation technologies – Implication for UK decentralisation targets. Applied Energy 86 (2009) 1873-1886, Elsevier Ltd.

Kannan, R. & Strachan, N., 2009. Modelling the UK residential energy sector under long-term decarbonisation scenarios: Comparison between energy systems and sectoral modelling approaches. Applied Energy 86 (2009) 416-428, Elsevier Ltd.

Kibert, C., & Fard, M., 2012, Differentiating among low-energy, low-carbon and net-zero-energy building strategies for policy formulation, Building Research and Information (2012) 40(5), pp625-673, Routledge.

KPMG, 2015. UK solar beyond subsidy: the transition, Renewable Energy Association, Avalaible at: www.r-e-a.net/upload/uk-solar-beyond-subsidy-the-transition.pdf [Accessed 25th August 2017].

MacKay,D., 2009. Sustainable Energy Without the Hot Air, UIT Cambridge Ltd.

Peacock, A.D., Owens, E.H., Roaf, S., Corne, D.W., Dissanayake, M., Tuohy, P., Stephen, B. & Galloway, S., 2014. Autarkic Energy Systems: Balancing supply and demand with energy storage and controls in local energy micro-grids, Conf. Proc., Asia-Pacific Solar Research Conference, Sydney, Australia.

Pless, S., & Torcellini, P., 2010, Net-Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options. National Renewable Energy Laboratory report: NREL/TP-5500-44586, June 2010.

Scottish Executive 1997., Section 72 of the Town and Country Planning (Scotland) Act 1997, amended through the Climate Change (Scotland) Act 2009, The Stationary Office Limited, London.

Scottish Executive, 2007, Energy Efficiency & Microgeneration, Achieving a low carbon future: A Strategy for Scotland, Energy Efficiency Unit, Scottish Executive, Edinburgh.

Scottish Executive, 2011(a), 2020 Routemap for Renewable Energy in Scotland, Part 3: Scotland's Renewables Ambitions and Paths to Delivery, Available at: http://www.gov.scot/Publications/2011/08/04110353/3 [Accessed 5th June 2017].

Scottish Executive, 2011(b), Sustainability, Available at: http://www.gov.scot/Topics/Built-Environment/Building/Building-standards/techbooks/Sustainability [Accessed 5th June 2017].

Scottish Executive, 2011(c), Section 6 Software, Available at: http://www.gov.scot/Topics/Built-Environment/Building/Building-standards/techbooks/Sustainability [Accessed 5th June 2017].

Scottish Executive, 2011(d), First Annual Report on the Operation of Section 72 of the Climate Change (Scotland) Act 2009, Part 1, Available at: http://www.gov.scot/Publications/2011/04/13093014/1 [Accessed 5th June 2017].

Scottish Executive, 2016, Technical Handbook – Domestic, Avalaible at: http://www.gov.scot/Topics/Built-Environment/Building/Building-standards/techbooks/techhandbooks/th2016domsustain [Accessed 5th June 2017].

Sunikka-Blank, M., & Galvin, R., 2012. Introducing the prebound effect: the gap between performance and actual energy consumption, Building Research & Information (2012) 40(3), 260–273, Routledge, London.

UNEP 2010, Common Carbon Metric Protocol for Measuring Energy Use and Reporting Greenhouse Gas Emissions from Building Operations, United Nations Environment Programme, Sustainable Buildings and Climate Initiative, P5.

Watson, J., 2004. Co-provision in sustainable energy systems: the case for micro-generation,. Energy Policy 32 (2004) 1981-1990., Elsevier Ltd.

Watson, J., Sauter, R., Bahaj, B., James, P., Myers, L. & Wing R., 2008. Domestic micro-generation: Economic regulatory and policy issues for the UK., Energy Policy 36 (2008) 3085-3106, Elsevier.

1.0 Appendix 1: Abbreviations and definition of terms

ASHP	Air Source Heat Pump
BRE	Building Research Establishment
CHP	Combine Heat and Power
CO_2	Carbon Dioxide, one of the six gasses identified as contributing to climate change
CO_2e	Carbon Dioxide Equivalent, describes GHG emissions associated with fuel use within the NCM which now include carbon dioxide, methane & nitrous oxide.
DER	Dwelling Emission Rate of a proposed new dwelling building
Form Factor	The compactness of a building i.e. the surface area to volume enclosed ratio has significant impact on the rate of heat loss from the building. Passivhaus determines this as the Form Factor; the relationship between the external surface area (A) and the internal Treated Floor Area (TFA). A form factor ≤ 3 is suggested as a benchmark for small Passivhaus buildings.
GHG	Greenhouse Gases, emissions of which are considered to contribute to climate change
Green Grid	A grid mainly carrying electricity from renewable sources.
Gross CO_2 Emissions	The amount of CO_2 emitted as a result of providing the energy demand of a building. This includes all CO_2 emissions from heating, lighting and ventilation. It does not include CO_2 emissions from appliances and household electricals. Typically measured in kg/CO_2/year or tonnes/ CO_2/year.
Gross Energy Demand	The useful energy required to operate a building. This includes all heating, lighting and ventilation. It does not include energy used by appliances and household electricals. Typically measured in kWh/year or MWh/year.
Gross Energy Consumption	The energy consumed in order to provide the Gross Energy Demand. Typically measured in kWh/year or MWh/year.
GSHP	Ground Source Heat Pump
LDP	Local Development Plan
LPA	Local Planning Authority
LPG	Liquefied Petroleum Gas
LZCGT	Low and Zero Carbon Generating Technology: defined in the Scottish Technical Standards 2016 as wind turbines, water turbines, heat pumps (all varieties), solar thermal panels, photovoltaic panels, combined heat and power units (fired by low emission sources), fuel cells, biomass boilers/stoves and biogas.
MVHR	Mechanical Ventilation Heat Recovery. Airtightness is an important factor in reducing uncontrolled ventilation heat losses from buildings, however to maintain internal air quality some form of mechanical ventilation is typically required. MVHR is an energy efficient system that recovers heat from the exhaust air and uses it to heat fresh incoming air. The use of this type of system can reduce the space heat demand of a building by approximately one third, leading to significant savings.
Net CO_2 Emissions	The amount of CO_2 emitted as a result of providing the energy demand of a building balanced against energy generated by the building (Photovoltaics etc.) This includes all CO_2 emissions from heating, lighting, ventilation balanced against generated power. It does not include CO_2 emissions from appliances and household electricals. Typically measured in kg/CO_2/year or tonnes/ CO_2/year.
NCM	National Calculation Methodology
Net Energy Consumption	The energy consumed in order to provide the Gross Energy Demand
Occupancy	The Assumed Occupancy as determined by the SAP Calculation. This represents the typical occupancy patterns observed in the UK and is a function of the Floor Area of the proposed Dwelling.
PFGHR	Passive Flue Gas Heat Recovery.

PV	Photovoltaic
SAP	The Standard Assessment Procedure (SAP) is the methodology determined by the Government to assess and compare the energy and environmental performance of Domestic buildings. Its purpose is to provide the accurate and reliable assessments of energy performance needed to underpin energy and environmental policy initiatives.
SBEM	The Simplified Building Energy Model (SBEM) is the methodology determined by the Government to assess and compare the energy and environmental performance of Non-Domestic buildings. Its purpose is to provide the accurate and reliable assessments of energy performance needed to underpin energy and environmental policy initiatives.
SHD	Space Heat Demand. The useful energy demand for Space Heating.
TER	Target Emission Rate for a proposed new dwelling or non-domestic building
THD	Total Heat Demand. The total useful energy demand for Space and Domestic Water Heating.
U-value	Heat loss through a material or construction (measured in watts per square metre per degree kelvin, W/m·K)
WHD	Water Heat Demand. The useful energy demand for Domestic Water Heating.
WSHP	Water Source Heat Pump
WWHR	Waste Water Heat Recovery.