Research Project:

Developing a Scotland wide Section 3F Planning Policy

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Introduction

This report was commissioned to help develop a Scotland wide Section 3F planning policy, by proposing reasonable levels of CO_2 (Carbon dioxide) emissions reduction that can be expected from use of low and zero carbon generating technologies (LZCGTs) in new buildings. The research also draws attention to methods by which planning officers can ascertain that the reductions have been met. Section 3F of the Town and Country Planning (Scotland) Act 1997, as amended through Section 72 of the Climate Change (Scotland) Act 2009 states that:

> ‘A planning authority, in any local development plan prepared by them, must include policies requiring all developments in the local development plan area to be designed so as 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 low and zero carbon generating technologies.’
>
> (Scottish Parliament, 2019b).

As a consequence, planning authorities across Scotland have had relative autonomy in determining the contribution LZCGT should make to the CO_2 emission reductions of new buildings. This has led to duplication of effort in determining appropriate policies; inconsistences in terms of the LZCGT contribution sought, compliance procedures and calculation methodologies; and a general lack of clarity for all stakeholders. In response, the Scottish Government is using the preparation of the next National Planning Framework to further explore how the legislative requirements could be met, with a particular focus on the level of emission savings from the use of LZCGTs.

Objectives

The objectives of this study were to support the Scottish Government’s aim in this respect in three ways:

i. Propose a methodology to identify the level of CO_2 emission savings that would be reasonable to expect from the use of LZCGT in new buildings.
ii. Recommend the proportion of CO_2 emission savings which could be reasonably sought as a result of the use of LZCGT in new buildings over the next 10 year period.
iii. Propose a calculation methodology for use by development management officers to understand whether the specified LZCGT contribution has been met.

Methodology

The research was primarily desk-based. Literature was reviewed relating to current best practice approaches to CO_2 emission reduction in buildings, the principles underpinning robust energy policy design, the regulatory framework within which Section 3F policy operates, and the calculation methods embedded in the Standard Assessment Procedure (SAP) used to calculate CO_2 emission from new buildings. A survey was undertaken to learn from the experiences planning authorities have gained as a result of administrating current Section 3F policies (Appendix A). The aim was to benchmark current policy and procedures, and reveal where practical issues or concerns were being raised.

Literature Review

The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019, amended the Climate Change (Scotland) Act 2009, advancing the timeframe for reducing GHG (Greenhouse Gas) emissions in Scotland to net-zero by 2045 at the latest. Interim targets for reductions of at least 56% by 2020, 75% by 2030 and 90% by 2040 were also set (Scottish Parliament, 2019a). Further, the revised Climate Change Plan sets specific targets requiring 35% of the heating demand in new domestic buildings to be provided by low-carbon technologies by 2032. In non-domestic buildings this target will be 70% (Scottish Government, 2018a).

Decarbonising heat is seen as the single biggest challenge in decarbonising Scottish buildings. New targets introduced in 2019 legislate for ultra-energy efficient dwellings from 2025 which utilise low-carbon heating thereby reducing the reliance on the gas grid. Further, impending restrictions limiting the use of biomass expected in the near future means that heat pumps are widely viewed as the most affordable and proven immediate solution to domestic low-carbon heating. With the electricity grid currently at near-capacity, grid constraints are a major barrier in moving to the electrification of building heating. Overcoming intermittency issues and reducing peak demands, which are more likely in moving to heat pump technology, will be the critical limiting factors in protecting the security of the electricity supply. Energy balancing generating technologies at the building may be needed to offset all or a significant proportion of the regulated power and heat requirements. This still assumes that the grid has the capacity to supply peak demand and it does not take into account intermittency inherent in the generation of renewable energy, which will need additional considerations such as energy storage to overcome.

A holistic approach is generally considered the best long-term strategy to reduce CO_2 emissions in buildings. This approach could be characterised as three stages:

i. Reduce energy demand
ii. Increase energy efficiency
iii. Increase use of renewable energy to cover remaining energy demand.

A substantial reduction in energy demand is crucial to this strategy. Without it the ability to meet the remaining demand through the use of renewables and LZCGT is diminished and less cost effective.

Prioritising a fabric first approach is advised in the majority of the literature. This approach has numerous benefits. Increased fabric energy efficiency reduces energy demand and therefore directly reduces CO_2 emissions. Reducing energy demand protects national energy security by reducing the need for extra generating capacity in the network. This is of particular importance when bearing in mind expected growth in electrical needs due to proposed switch to electrical vehicles and the anticipated increase in electrical demand from heat pumps. Getting the fabric right from the outset effectively locks in carbon savings for the lifetime of the building, whereas the benefits of LZCGT only last the lifetime of the equipment which is usually only 15 to 20 years. It is also more difficult and expensive to upgrade fabric energy efficiency at a later date than at the construction stage. Increased fabric energy efficiency also reduces energy poverty and has positive effects on the comfort, health and well-being of occupants.

At very high fabric energy efficiency standards e.g. Passivhaus, the demand on the heating system is significantly reduced and the cost savings made help balance out the cost of improving the fabric. However, there is a balance to be made between reduced operational energy use and the increased embodied energy of the construction materials if going beyond this point.

In Scotland, limiting energy consumption and CO_2 emissions from new buildings is primarily legislated for through Section 6 of the Scottish Building Standards. Section 6 takes a holistic whole building approach; allowing architects to meet the emission reduction targets calculated through SAP/SBEM (Simplified Building Energy Model) by any means they deem suitable, subject to meeting robust fabric energy efficiency and equipment efficiency backstops. Under the current building standards the use of LZCGT is not mandatory. Conversely, Section 3F Planning Policy is a single-issue policy which makes the use of LZCGT mandatory in new buildings. Section 3F policy does not seek to increase CO_2 emission reductions beyond that set by Scottish Building Standard 6.1; it simply defines the proportion of those emission reductions that should be achieved through the deployment of LZCGT.

Section 3F Survey

It is expected that the development of a Scotland-wide Section 3F policy will improve policy awareness and provide greater clarity and consistency for design practitioners, which in turn should improve the standard of compliance information submitted to Planning. Greater clarity in terms policy aims, LZCGT contribution target, evidence requirements and calculation methodology, as well as guidance on implementation procedures and enforcement is essential moving forward. The current standard of compliance evidence submitted to planning authorities is extremely variable. The main issue for both implementation and enforcement is attempting to apply a policy at the planning stage, when the information that is required to confirm compliance with the specified LZCGT contribution target is typically not available until later in the design process. The use of suspensive conditions to enable detailed technical information to be submitted later in the design process, prior to works commencing on site, is widespread, but not without difficulties. Almost half of survey respondents had concerns about the strength of suspensive conditions and the subsequent ability to enforce compliance.

In the long-term there is a need to address the underlying conflict between Planning and Building Standards over the mandatory use of LZCGT, convey a clear and consistent message, and generally develop collaborative working practices on the issue of climate change and CO_2 emissions reduction. It is beyond the legal remit of Building Standard officers to play an active role in enforcing planning policy, and they will not delay granting building warrant consent or issuing a completion certificate on the basis that an application does not comply with a planning condition (Scottish Government, 2019e).

The majority of survey respondents felt that quantitatively assessing the contribution of LZCGT to CO_2 emissions reduction would be an issue better dealt with and enforced through Building Standards. It was suggested that a new mandatory standard within the Scottish Building Standards that meets the minimum LZCGT contribution target set by Section 3F policy could remove many of the existing difficulties currently encountered by planning officers, and give Building Standards an active role in enforcement. This would not negate the major role that Planning would still play in prioritising, discussing, advising and influencing action on climate change, the reduction of CO_2 emissions and Section 3F policy at an early stage in the design process. Planning has a large sphere of influence and the potential to reduce CO_2 emission in many different arenas beyond the single issue confines of Section 3F policy. Regular feedback on outcomes, to judge successes and failures within the system, and how collaboration between planning and building standards officers could be improved, would benefit the process.

Proposals

In response to the brief we have included two separate proposals:

- **Proposal 1:** Is a minimum LZCGT contribution standard, which simply fulfils the objectives of the brief as stated.
- **Proposal 2:** Is a whole building approach, which re-envisions Section 3F policy in line with the more holistic approach taken by Building Standards. This is as a result of the researchers' own further reflection while undertaking the study. Focussed on the domestic sector and centred on the idea of a maximum acceptable annual energy demand per occupant; it seeks to promote a more equitable use of resources, address fundamental design issues such as dwelling scale, prioritise fabric energy efficiency and promote the use of LZCGT.

Proposal 1: A minimum LZCGT Contribution Standard

Proposed Methodology to identify a reasonable level of LZCGT contribution to CO_2 emission reduction

The proposed methodology is pragmatic in approach, envisioning what would be an appropriate LZCGT contribution to the annual energy demand in new domestic buildings under different CO_2 emission reduction standards. The purpose is to identify a reasonable level of LZCGT contribution to CO_2 emission reduction in new buildings. It does this by gauging the practical impact on annual energy demand of utilising LZCGT in new buildings to either replace a proportion of the annual energy demand or generate electricity to offset that demand, and what real-world practical limitations might be encountered in doing so.

The data used in these deliberations was based on the predicted energy demand for dwellings ranging in size from 25m^2 to 300m^2 calculated using formulae prescribed in the Standard Assessment Procedure (SAP) 2012 (BRE, 2014). Three different scenarios were developed representing three different fabric energy efficiency standards: 45kWh/m^2.annum, 30kWh/m^2.annum and 15kWh/m^2.annum. These scenarios were developed to provide a reasonable approximation of past, present/near future and future fabric energy efficiency contexts.

Modelling was based on the domestic sector for several reasons:

i. Domestic buildings are the most frequent building type encountered by planning authorities.
ii. The domestic sector consumes a much larger proportion of energy for space heating, hot water and lighting than other sectors.
iii. It is vital that Section 3F policy does not adversely impact on the ability to deliver essential domestic infrastructure such as affordable and social housing in a cost effective way.
iv. Non-domestic buildings have fairly diverse energy consumption patterns contingent to their functional needs. It was therefore considered more reliable to determine a reasonable LZCGT contribution for the domestic sector and extrapolate to the non-domestic, rather than vice versa.

This judgement as to what would be a reasonable LZCGT contribution to annual energy demand in new buildings was made with respect to the following criteria:

i. It should be a reasonable minimum expectation, in respect to the overall level of CO_2 emission reduction new buildings are expected to achieve due to the changing regulatory climate.
ii. It should be readily achievable by all buildings whether in an urban or rural context.
iii. It should be low enough not to undermine or dis-incentivise a fabric first approach or other innovative passive design responses to CO_2 emission reduction.
iv. It should not be too onerous in terms of cost, and should offer long-term value for money for stakeholders.
v. It should not restrict the architect to only one viable option in choice of LZCGT, either directly or indirectly.
vi. It should not interfere with the ability to deliver wider sociological goals or essential infrastructure. In this respect the delivery of affordable and social housing was defined as a significant parameter. Consequently, final assessments were focussed on the impact the LZCGT contribution level would have on this critical context, specifically dwellings ranging in size from 45m^2 to 100 m^2.

Taking these factors into consideration the level of LZCGT contribution to CO_2 emission reduction that could be reasonably sought by Section 3F policy must by necessity be a minimum standard rather than an aspirational one.

Recommendations

Having determined what would be a reasonable LZCGT contribution as a percentage of annual energy demand under different CO_2 emission reduction standards, it was necessary to express this in terms of CO_2 emissions. This refers to levels of CO_2 emission saving which could be reasonably sought as a result of the use of LZCGT in new buildings over the next 10 year period. Three alternative ways of defining LZCGT contribution relative to CO_2 emissions were identified in current Section 3F policy (Scottish Government, 2019b). We designated these metrics, A%, C% and E%:

- **A%** An absolute percentage CO_2 emission reduction relative to the 2007 baseline established by Scottish Building Standard 6.1.
- **C%** A percentage of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1 relative to the 2007 baseline.
- **E%** An avoidance of a percentage of the building projected CO_2 emissions as calculated by SAP/SBEM (Simplified Building Energy Model).

The final metric (E%) most closely aligns to the definition included in Section 3F policy, and equates reasonably well, although not exactly, to the LZCGT contribution defined as a percentage of annual energy demand. From a practical standpoint it is the most useful to architects and developers because it relates directly to real world variables they can understand and manipulate in the design process.

However, on balance, we recommend that in Section 3F policy the minimum LZCGT contribution be defined in terms of a percentage of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1 for several reasons:

i. Linking Section 3F policy directly to Building Standard 6.1 avoids potential conflict.
ii. It simplifies Section 3F policy, by allowing the LZCGT contribution to be defined as a constant and perpetual percentage that will automatically deliver increases in real terms with every improvement of Standard 6.1 (Table 1).
iii. It provides regulatory certainty going forward.
iv. It ensures changes that occur in Building Standards 6.1 are reflected immediately, proportionately and automatically in Planning.
v. It allows differences in the CO_2 emission reduction sought for domestic and non-domestic buildings at building standards, to be simply and automatically reflected in the LZCGT contribution sought at Planning.

It is vital that it is understood that any attempt to increase the level of LZCGT contribution either disproportionately or at more frequent intervals than the changes to overall CO_2 emission reduction sought by Building Standard 6.1, will undermine the fabric first approach. It should therefore be avoided. However this is a minimum standard and does not preclude designers of new buildings from deciding not to take the recommended fabric first approach and using a higher percentage of LZCGT to meet their Target Emission Rate (TER) if they wish to do so.

We recommend that the LZCGT contribution to CO_2 emission reductions be defined as a constant and perpetual 12% of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1.

R%	A %	C %	E %
0% CO_2 Reduction Standard	0 %	12.0 %	0 %
30% CO_2 Reduction Standard	3.6 %	12.0 %	4.9 %
45% CO_2 Reduction Standard	5.4 %	12.0 %	8.9 %
60% CO_2 Reduction Standard	7.2 %	12.0 %	15.3 %
75% CO_2 Reduction Standard	9.0 %	12.0 %	26.5 %
90% CO_2 Reduction Standard	10.8 %	12.0 %	51.9 %
100% CO_2 Reduction Standard	12.0 %	12.0 %	100 %

Table 1: The same minimum LZCGT Contribution target calculated relative to each metric under different Standard 6.1 CO_2 emission reduction contexts.

It is expected that once the carbon factors used in the SAP/SBEM methodology are updated with the introduction of SAP10, that there will be a dramatic increase in the use of heat pumps. We would suggest that the CO_2 emission standard and building insulation envelope backstops (Standards 6.1 and 6.2) need to be improved accordingly at this stage. Otherwise there may be a tendency among developers to achieve their CO_2 emission reduction targets mainly through the use of LZCGT and the positive gains made as a result of increased fabric energy efficiency might be lost with long-term negative consequences.

Proposed Calculation Methodology

Not all LZCGT have zero carbon emissions. Therefore the simplest way to accurately calculate if the specified LZCGT contribution has been met is to run two separate SAP/SBEM calculations; one for the building as designed with the proposed LZCGT and another with the proposed LZCGT removed and replaced with pre-defined conventional systems. We would recommend that the presumption of what replaces the LZCGT in this second SAP/SBEM calculation is consistent for all buildings; although the appropriateness of this needs further consideration by Building Standards. The CO_2 emission rates generated by these two SAP/SBEM calculations are then substituted into a formula to calculate the LZCGT contribution. If the value calculated is greater than or equal to the relevant figure given in Table 1 the proposed building has complied with Section 3F requirements.

The formula to calculate LZCGT contribution defined as an absolute percentage CO_2 emission reduction relative to the 2007 baseline is given by:

$$\textbf{A\%} \quad = \quad (\mathbf{100} - \mathbf{R}\%)\left(\frac{\mathbf{DERNT} - \mathbf{DER}}{\mathbf{TER}}\right)$$

The formula to calculate the LZCGT contribution defined as a percentage of the percentage CO_2 emission reduction sought by Scottish Building Standard 6.1 is given by:

$$\textbf{C\%} \quad = \quad \left(\frac{100\,(100-\mathrm{R\%})}{\mathrm{R\%}}\right)\left(\frac{\mathrm{DERNT}-\mathrm{DER}}{\mathrm{TER}}\right)$$

The formula to calculate the LZCGT contribution defined as an avoidance of a percentage of projected CO_2 emissions as calculated by SAP/SBEM:

$$\textbf{E\%} \quad = \quad 100\left(\frac{\mathrm{DERNT}-\mathrm{DER}}{\mathrm{DERNT}}\right)$$

Where:

DER	=	Dwelling Emission Rate
DERNT	=	Dwelling Emission Rate calculated with no LZCGT
TER	=	Target Emission Rate
R%	=	Statutory required CO_2 emission reduction sought by Scottish Building Standard 6.1 defined as a percentage relative to the 2007 baseline.

Proposal 2: A Whole Building Approach

Overview

This proposal takes a whole building approach to CO_2 emission reduction and diverges significantly from current Section 3F Policy, which it reinvents in a way that plays to the strengths and skillsets of Planning, whilst complementing and aligning constructively with the holistic approach taken by Building Standards. Focussed on the domestic sector; the proposal centres on the idea of limiting annual energy demand (AED) in new dwellings to an acceptable per capita level; and through this mechanism it aims to leverage better design solutions, prioritise fabric energy efficiency, promote the use of LZCGT and address fundamental issues not tackled by the current system.

This acceptable annual energy demand (AAED) will be defined on a per capita basis, calculated with respect to the predicted occupancy and annual energy demand (AED) of a modest-sized energy-efficient dwelling. A modest-sized dwelling has been defined as between 45m^2 and 100m^2 (Appendix E). This measure should allow the target rate to be set at an ambitious but achievable level, whilst ensuring that it does not impact adversely on the ability to deliver essential domestic infrastructure such as affordable housing.

The objective of this mechanism is to:

i. Realise in practice the recommended 3-step holistic approach to reducing CO_2 emission from buildings:
    - Reduce energy demand

- Increase efficiency of energy use
- Increase the use of zero-carbon renewable energy

ii. Focus on those issues that ideally need to be addressed early in the design process and that planning can positively influence.
iii. Recognise that architectural design plays a significant role in reducing energy demand, and incentivise good design, passive design responses and innovative approaches.
iv. Prioritise fabric energy efficiency as a means of reducing energy demand.
v. Promote the use of high quality zero-carbon renewable energy sources (LZCGT).
vi. Address the finite nature of resources, issues of personal choice and responsibility, and determine a fair and equitable share of resources for everyone.
vii. Directly address the energy and material consumption issues related to scale and excessive per capita heated living space in large domestic buildings (Burford et al., 2019).

Compliance with the proposal will be allowed through any combination of design, fabric energy efficiency, equipment efficiency or LZCGT. Applicants will be actively encouraged to meet the acceptable annual energy demand (AAED) calculated for their proposed dwelling through good design and fabric energy efficiency measures alone, if that is feasible and cost effective. However if a dwelling does not manage to achieve this, then all remaining energy demand in excess of the acceptable level must be met by zero-carbon renewable energy sources.

As the focus of the proposal is on reducing the annual energy demand of dwellings and increasing the use of zero-carbon renewable energy, it was decided that the metrics used should reflect this. The metric used throughout will therefore be kWh/annum. There are several reasons for this:

i. It keeps the focus on energy, and emphasises the need to first and foremost reduce energy demand, both to ensure long-term energy security and reduce CO_2 emissions.
ii. It is a tangible and easy to comprehend metric with real world meaning for all stakeholders which allows the impact of design changes to be easily quantified and understood.
iii. It allows the contribution of LZCGT to the annual energy demand to be clearly and easily quantified.
iv. It is the base metric used in SAP calculations, and data extracted from this document will be expressed in kWh/annum
v. It is the obvious metric to link LZCGT contribution, annual energy demand, and regional or national energy networks. It is therefore much more useful in ongoing reporting and the development of future regional or national energy strategy than a carbon metric.
vi. By avoiding a carbon metric it circumvents any potential conflict with Scottish Building Standard 6.1.

Compliance Target

The acceptable annual energy demand per capita (AAED/Capita) for new dwellings was determined using the same data stream as Proposal 1. This involved modelling the annual energy demand of dwellings ranging in size from $25m^2$ to $300m^2$ using formula prescribed in SAP 2012 (BRE, 2014). To effectively assess how the target level might potentially shift over time, two different scenarios were developed to represent evolving fabric energy efficiency standards. These were based on space heat demands of $30kWh/m^2$.annum and $15kWh/m^2$.annum respectively to represent present/near future (2020-2021) and future (2024-2050) contexts.

As there are issues with excess per capita energy consumption in large dwellings because of their inherent scale and relatively low average occupancy rates (BRE, 2008); the AAED/Capita level was established with respect to the predicted annual energy demand of modest-sized dwellings between $45m^2$ and $100m^2$. This acceptable level will apply to all dwellings regardless of size, and it is recognised that it will be potentially more challenging for large dwellings as a result. However with considered design it is still readily achievable (Appendix C: Worked Examples) It should also be remembered that it is not the intention of this proposal that dwellings should meet the AAED/Capita target purely by dint of increased fabric energy efficiency. It is accepted in the compliance methodology that some of the annual energy demand can be effectively offset through the use of zero-carbon energy sources. By whatever means it is achieved, reducing the per capita annual energy demand of large dwellings to bring them in line with more modest dwellings, could deliver truly substantial CO_2 emission reductions in this sector (Appendix E).

We recommend AAED/Capita targets levels are set at:

2021 AAED/Capita	**=**	**1910**	**kWh/annum**
2024 AAED/Capita	**=**	**1500**	**kWh/annum**

As the country evolves towards 2050 and net-zero carbon buildings, it is envisaged that the AAED/Capita would be progressively reduced until it reaches zero. At this point all remaining regulated energy demands from new dwellings would have to be met by zero-carbon renewable energy sources.

Documenting Compliance

Compliance is basically determined by comparing three values calculated for the proposed dwelling:

Acceptable Annual Energy Demand	**AAED**
Annual Energy Demand	**AED**
Zero-Carbon Adjusted Annual Energy Demand	**ZCAED**

Compliance is achieved if either of the following hold true:

Compliance Method 1: (With or Without LZCGT)	**AED ≤ AAED**
Compliance Method 2: (With LZCGT)	**ZCAED ≤ AAED**

The compliance documentation was designed with the objective of making the entire process as easy as possible for all stakeholders, whilst taking the opportunity to collect useful data for research and future energy planning purposes. It comprises of a standardised Excel spreadsheet, split into two sections; Section 1 is to be completed for dwellings that have individual energy systems and micro-CHP (Appendix C: Figures C.3 and C.4), Section 2 for those with community heating systems (Appendix C: Figures C.5 and C.6). Each Section is sub-divided into a Data Input worksheet and a Compliance Calculation worksheet.

To use the spreadsheet, the applicant simply extracts the relevant data from the SAP document submitted to Building Standards for the proposed dwelling and inputs this into the appropriate Data Input worksheet. There is no need to have knowledge of the workings of SAP calculations to complete the spreadsheet as all required data is referenced by its SAP box number. The whole process should take no more than 10 minutes. Excel then performs all the necessary calculations automatically and the results are displayed on the Compliance Calculation worksheet.

Through the use of this spreadsheet the compliance procedure is simplified as much as possible. The Compliance Calculation worksheet provides both a clear statement of policy compliance/non-compliance and a quantified breakdown of the contribution of individual energy systems, fuels and LZCGT. These are characterised as zero-carbon, low-carbon, grid electricity, bio-carbon or fossil fuel, and colour coded to indicate preferable choices. To incentivise best practice, only zero-carbon energy sources are used to calculate the zero-carbon adjusted energy demand (ZCAED).

The compliance procedure is quite flexible and there are several ways that a designer can bring a non-compliant building into compliance, either by reducing the annual energy demand (i. – iv.) or employing additional zero-carbon renewable energy systems (iv. – vii.). Used alongside SAP, the compliance spreadsheet can be exploited as a design tool for architects, developers and planners to objectively explore these different options. These measures might include:

i. Revising the building design by considering scale, built form, solar orientation, and other passive design measures to reduce overall energy demand.
ii. Increasing fabric energy efficiency.
iii. Increasing air tightness and employing MVHR.
iv. Considering solar thermal or waste water heat recovery (WWHR).
v. Considering zero-carbon electricity generation such as PV, wind, water etc.
vi. Considering zero-carbon heat generation including all types of heat pumps. Be aware however that in calculating the zero-carbon contribution, the electrical input will be subtracted from the output.
vii. Considering a community heating scheme. Typically numerous different energy sources may be employed within a single district heating scheme, some of which would not be feasible at the individual building scale. In the compliance calculation methodology each of these will be considered proportionally and on their individual merits. Scaled zero-carbon renewable energy sources might include PV, wind, water, tidal or geothermal energy, waste heat recovery from power stations, or waste heat recovery from industrial or agricultural processes.

Conclusion

This report has been informed by relevant considerations from academic and grey literature in relation to reducing CO_2 emissions from buildings, and the issues raised by planning officers in local authorities across Scotland who are administrating current Section 3F policies. As a result, two distinct proposals that might be appropriate for the Scottish Government to consider at this juncture, are developed and presented. However, the strengths and weaknesses of each proposal, and the limitations of some of the assumptions made in formulating these approaches, target levels, and workflows for demonstrating compliance, are worth highlighting.

Both proposals took an essentially pragmatic approach to determining target levels, guided by relevant Scottish government policy pronouncements and aspirations; and deliberations were based on the predicted energy demand of dwellings ranging in size from $25m^2$ to $300m^2$ calculated using formulae prescribed in the Standard Assessment Procedure SAP 2012 (BRE, 2014). Particular attention was paid to dwellings between $45m^2$ and $100m^2$ as it was felt this size range would include the majority of social and affordable housing.

Three scenarios were developed to provide a better appreciation of how improvements in fabric energy efficiency could potentially impact on annual energy demand and the viability of certain LZCGT solutions. In the absence of a firm timetable of commitment to improving CO_2 emission reduction in new buildings, a future scenario based on a space heat demand of $15kWh/m^2$.annum was developed. This is in line with the recommendation by the Committee on Climate Change that by 2025, at the latest, all new buildings should be built to an ultra-high fabric energy efficiency standard commensurate with a space heat demand of 15 – 20 kWh/m^2.annum and be designed to use low carbon heat (CCC, 2019b, p66; CCC, 2019d, pp 14-15).

Modelling was based on domestic buildings because these are the most frequent building type encountered by planning authorities; they consume a much larger proportion of energy for space heating, hot water and lighting than other sectors; and avoiding any unintended impact on the ability to deliver affordable housing was considered of paramount importance (BEIS, 2019a).

Proposal 1 satisfies the research objectives as stated in the brief relative to Section 3F Policy as enacted in current legislation. It acknowledges that other factors also contribute to reducing emissions from buildings, and defines a realistic minimum LZCGT contribution to CO_2 emission reduction in new buildings that could be sought by Section 3F policy without undermining the viability of a fabric first approach or the development of innovative passive design solutions. This approach does not preclude architects and developers from using a higher proportion of LZCGT to meet their Target Emission Rate (TER) if they so desire.

Although target levels were determined with respect to empirical quantitative data, the methodology used to determine what would be ‘reasonable’ under different CO_2 emission reduction standards was essentially a qualitative judgement. The levels calculated by this method were subsequently evaluated with respect to interim targets and aspirations set by the Scottish Government (Scottish Government, 2018a, pp. 87-89; CCC, 2019b, p66; Scottish Parliament, 2019a), and found to be in general accord.

Having determined what would be a reasonable LZCGT contribution as a percentage of annual energy demand under different emission reduction standards, it was necessary to express this in terms of a percentage CO_2 emission reduction to comply with the requirements of Section 3F policy. Although three alternative ways of defining LZCGT contribution relative to CO_2 emissions were identified in current Section 3F policies; presenting it as "A percentage of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1 relative to the 2007 baseline" was most appropriate.

It effectively links Section 3F policy directly to whatever is the CO_2 emission reduction required by the current Scottish Building Standard 6.1. However, we note that this metric is problematic from a practical design standpoint. Consequently there is a need to ensure that stakeholders can understand the practical implications of this metric in terms of the LZCGT contribution to annual energy demand that would be required to meet this target under different emission reduction standards. This could be achieved through reference to Figure 8, Table 9 and/or the type of graphical data developed for each scenario (Appendix B).

Showing compliance is relatively straightforward and a standard excel spreadsheet has been developed for this purpose (Appendix C: Proposal 1). The compliance calculation utilizes the emissions rates (DER and TER) calculated for the dwelling by the SAP methodology. However it also requires a second SAP calculation to be conducted to determine the dwelling emission rate with the LZCGT removed and replaced with pre-defined conventional system (DERNT). What these replacement systems will consist of needs to be clearly defined. The final compliance calculation is then a simple matter of substituting these factors and the required emission reduction standard (R%) into the formula and if the result is greater than or equal to the target percentage the building is in compliance. This has been calculated as 12% for both domestic and non-domestic buildings under all emission reduction standards. This level of LZCGT contribution is in general accord with interim targets set by the Scottish Government in order to achieve net-zero emissions by 2045, without onerous burdens to the public and without being too high as to undermine the fabric first approach.

Proposal 2 takes a whole building approach to CO_2 emission reduction which diverges significantly from the enacted Section 3F policy and would therefore require new legislation. It was not part of the brief but we arrived at it based on our own insights from undertaking the study.

This proposal re-invents policy in a way that focuses on the strengths, skillsets and wider objectives of Planning, whilst complementing the whole building approach taken by Building Standards. It concentrates solely on domestic buildings, and centres on the idea of limiting annual energy demand (AED) in new dwellings to an acceptable per capita level. Through this mechanism, it aims to leverage better design solutions, prioritise fabric energy efficiency, promote the use of LZCGT, and address fundamental issues not tackled by the current system.

Policy compliance will be established by completing a simple standardised spreadsheet with data taken directly from the building's SAP document. Applicants will be actively encouraged to meet the acceptable annual energy demand (AAED) calculated for their proposed building through good design and fabric energy efficiency measures alone, if that is feasible and cost effective. However, if a dwelling does not manage to achieve this, then all remaining energy demand in excess of the acceptable level must be met by zero-carbon renewable energy sources.

The methodology used to determine an acceptable annual energy demand per capita (AAED/Capita) is based on a simple calculation; with the judgement of what is reasonable primarily embedded in the space heat demand deemed appropriate to the timeframe in question and the range of dwelling sizes taken under consideration. It should be noted that if either of these variables is changed the resultant AAED/Capita would be substantially different (Appendix E)

The AAED/Capita was established with respect to the predicted annual energy demand (AED) and assumed occupancy (N) of modest-sized dwellings of between 45m^2 and 100m^2. This allows the target rate to be set at an ambitious but achievable level, whilst ensuring that it does not impact adversely on the ability to deliver essential domestic infrastructure such as affordable housing. The target AAED/Capita will apply to all dwellings regardless of size. It is recognised that it will be potentially more challenging for large dwellings, but it is still readily achievable (Appendix C).

As the country evolves towards 2045 and net-zero carbon buildings, it is envisaged that that the AAED/Capita could be progressively reduced until it reaches zero. At this point any remaining regulated energy demands in new dwellings would have to be met by zero-carbon renewable energy sources.

The proposal takes a more broad brush approach to CO2 emission reduction certain in the knowledge that reducing annual energy demand and/or replacing a proportion of that demand with zero-carbon renewable energy sources will inevitably have a positive impact. It does not apply carbon factors, compare the proposed building to a notionally similar one, or require a second SAP calculation to be performed. Rather than attempting to quantify CO_2 emissions; the methodology remains firmly focussed on the annual energy demand and annual energy consumption and the contribution made by zero-carbon renewable energy sources as calculated for the proposed building. The aim in this approach is to keep the focus on variables that architects, developers and planners can easily identify with and manipulate by taking good decisions in these early stages of the design process.

Compliance is evidenced by completing a standard excel spreadsheet using data extracted from the SAP calculation (Appendix C: Proposal 2). Although more complex than proposal 1, the spreadsheet should take no more than 10 minutes to complete and excel performs all necessary calculations automatically. Used alongside SAP data, the compliance spreadsheet can be exploited as a design tool for architects, developers and planners to objectively explore these different options.

Overall, both proposals actively consider protecting the ability to deliver essential domestic infrastructure such as social and affordable housing as a critical parameter. This is achieved by focussing on the impact of the proposals on the sub-group of dwellings in the 45m^2 to 100m^2 size range (Appendix E). However, the use of SAP data to quantify LZCGT contributions does mean that neither proposal truly addresses the intransigent issue of the stage in the design process at which this data becomes available and the implications this has in terms of enforcement and delivering better built outcomes.

1. Introduction

1.1 Introduction

Section 3F of the Town and Country Planning (Scotland) Act 1997, as amended through Section 72 of the Climate Change (Scotland) Act 2009 states that:

> 'A planning authority, in any local development plan prepared by them, must include policies requiring all developments in the local development plan area to be designed so as 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 low and zero carbon generating technologies.'
>
> (Scottish Parliament, 2019b).

As a consequence, planning authorities across Scotland have had relative autonomy in determining the contribution low and zero-carbon generating technologies (LZCGT) should make to the CO_2 (Carbon dioxide) emission reductions of new buildings. This has led to duplication of effort in determining appropriate policies; inconsistences in terms of the LZCGT contribution sought, compliance procedures and calculation methodologies; and a general lack of clarity for all stakeholders. In response, the Scottish Government is using the preparation of the next National Planning Framework to further explore how the legislative requirements could be met, with a particular focus on the level of emission savings from the use of LZCGT.

1.2 Aims and Objectives

The aim of this study is to determine the proportion of in-use building emissions that could be reasonably saved as a result of using LZCGT, how this may change over the next 10 years, and what information is needed to demonstrate building level compliance at Planning.

Objectives

1. Identify an appropriate methodology for identifying the level of emissions savings which may be reasonably expected to be gained from LZCGT.
2. Recommend at least two levels of proportions of emissions savings which may reasonably be achieved when applied to new buildings over the next 10 years, one of which could be applied from 2021 and another greater proportion which could be applied from a later date, which may be 2024.
3. Identify an appropriate methodology which could be used by development management officers to understand whether the specified proportion of emissions savings has been reached.

1.3 Methodology

The research was primarily desk-based to provide relevant data, context and insight, and the scope went beyond Scotland. Literature was reviewed relating to current best practice approaches to CO_2 emission reduction in buildings, the principles underpinning robust energy policy design, the regulatory framework within which Section 3F policy operates, and the calculation methods embedded in the Standard Assessment Procedure (SAP) used to calculate CO_2 emission from new buildings.

Because existing Section 3F policy had attracted generally negative comments during the public consultation that took place as part of the recent Scottish Planning Review (86% of respondents from the 'Policy and Planning' and 'Development Industry' sectors called for its removal), it was felt further investigation was also needed to determine the exact nature of the problems that exist in current Section 3F policy so they could be avoided in any new policy. A survey was therefore undertaken that sought to learn from the experiences planning authorities have gained as a result of administrating current Section 3F policies (Appendix A). The aim was to benchmark current policy and procedures, and reveal where practical issues or concerns were being raised.

The outcome of this research has been formulated as two separate proposals. Proposal 1 simply satisfies the research objectives as stated in the brief. It defines a reasonable minimum LZCGT contribution to CO_2 emission reduction in new buildings that could be sought by Section 3F policy and the method by which this contribution could be calculated to establish policy compliance. This is achieved through a simple and pragmatic approach that models predicted energy demand in dwellings of various sizes and fabric energy efficiency. The outcome of this process was subsequently evaluated with respect to both implied and explicit governmental expectations of the rate of CO_2 emission reduction in buildings. The results are applicable to both domestic and non-domestic buildings.

Proposal 2 is a whole building approach which diverges significantly from the existing Section 3F policy and would therefore require new legislation. It is a result of the researchers' insight and reflections while undertaking this study. It re-imagines Section 3F policy in a way that plays to the strengths and skillsets of planning whilst complementing and supporting the existing whole-building approach to CO_2 emission reduction taken by building standards. It is anticipated that this proposed approach will add leverage to the type of sustainable and passive design solutions many planning authorities currently advocate, and address fundamental societal issues of consumption and the equitable use of resources; whilst simultaneously reducing energy demand, increasing fabric energy efficiency and incentivising the use of LZCGT. It is only intended to be applicable to domestic buildings.

2. Literature Review

2.1 GHG Emission Reduction

2.1.1 Action on Global GHG Emissions

It is widely acknowledged that substantial and sustained action to reduce global greenhouse gas (GHG) emissions is required to prevent damaging climate change (IPCC, 2014). There are signs that efforts made in this respect are slowly beginning to stabilise global GHG emissions, albeit at a level that is 60% greater than in 1990 (Jackson et al., 2017; Ritchie and Roser, 2019). However, it has been calculated that global GHG emissions would need to fall by 7.6% every year over the next decade simply to limit global warming to a 1.5°C rise (Evans, 2020). Based on currently implemented climate policies a projected warming of 3.1 to 3.7°C is likely by 2100 (Ritchie and Roser, 2019). Accelerating action to reduce GHG emissions is therefore essential.

With growing recognition that urgent action is needed; over two thirds of District, County, Unitary & Metropolitan Councils in the UK have declared a climate and ecological emergency, and the UK as a whole has legally committed to achieving net-zero emissions by 2050 (BEIS, 2019b; Climate Emergency UK, 2020). In line with recommendations from the Committee for Climate Change (CCC) which highlighted that Scotland had a greater potential capacity to remove GHG emissions from the atmosphere than the rest of the UK through a program of reforestation; the Scottish Government has gone further and set a target of reaching net-zero emissions by 2045 (CCC, 2019a, p15; Institute for Government, 2020). These more ambitious targets necessitate a steeper rate of reduction in emissions than has been previously achieved. The Committee on Climate Change advise that to meet this target UK emissions will need to fall by 15 $MtCO_2e$ every year. To put this in perspective, this is equivalent to 3% of all UK GHG emissions in 2018 (CCC, 2019c, pp 17-18).

The UK GHG emissions for 2018 were 491 $MtCO_2e$. This represents an overall emission reduction of 40% since 1990 (CCC, 2019c, p19). The four highest emitting sectors were respectively surface transportation (115 $MtCO_2e$), industry (104 $MtCO_2e$), buildings (88 $MtCO_2e$) and power (65 $MtCO_2e$). In 2018 these accounted for approximately 76% of all UK GHG emissions (CCC, 2019c, pp 24-27). Progress in reducing UK GHG emissions in the five years between 2013 and 2018 has been primarily driven by the power sector, with emissions from this sector 68% below 1990 levels (CCC, 2019c, p27). However, to achieve net-zero targets progress needs to be made consistently across all sectors of the UK economy.

2.1.2 Impact of the Built Environment on GHG Emissions

In 2016, buildings were on average accountable for 41% of the final energy consumption and 60% of the electricity consumption in EU-28 countries; Residential buildings accounting for two thirds of this consumption (458 Mtoe) (Rousselot, 2018).

Reducing CO_2 emissions from the building sector is therefore crucial, and it is recognised as one of the most cost-effective ways to mitigate climate change (Grove-Smith et al., 2018).

In acknowledgement of the impact buildings have on GHG emissions, the European Parliament passed European Directive 2002/91/EC which was subsequently recast as European Directive 2010/31/EU on the Energy Performance of Buildings (EPBD). Article 9 of this legislation requires that all new public buildings must be nearly zero-energy by the end of 2018, and all other new buildings be nearly zero-energy by the end of 2020 (EC, 2018). Article 2 describes nearly zero-energy buildings as having a very high energy performance, with the remaining nearly zero or very low amount of energy still required being supplied to a very significant extent by energy from renewable sources, produced on-site or nearby (EC, 2018). The exact definition of a nearly zero-energy building has been determined independently by each EU member state and varies widely across EU-28 countries (EC, 2013). There is concern that some national building codes across member states do not comply with the sentiments expressed in the EPBD (Groezinger et al., 2014; Erhorn and Erhorn-Kluttig, 2018). Nevertheless, the design principles and technologies requisite to achieving this level of performance in new buildings are relatively well-established and readily accessible to the construction industry.

With the Paris Agreement on Climate Change in 2016 demanding a more ambitious built environment strategy, initiatives have been growing worldwide to accelerate the transition towards a fully decarbonised building stock (UNFCCC, 2020). Encouraging major and deep renovations as well as new construction to strive for a nearly zero-energy level of performance will be crucial in achieving this aim. However to minimise our environmental footprint, and create ecological and sustainable places for future generations, a significant and fundamental change is needed in the way we design, build, inhabit, maintain and deconstruct our built environment. The need for change is now accepted by most stakeholders and there is general agreement on the benchmarks for reducing both operational and embodied energy in buildings that will take the construction industry on the steep decent towards net-zero emissions by 2050 (RIBA, 2019a; UK Green Building Council, 2019).

2.1.3 GHG Emission Reduction in Scotland

The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019, amended the existing Climate Change (Scotland) Act 2009, and revised the year by which Scotland aims to reach net-zero emissions, i.e. 100% emission reduction relative to the baseline level of 1990, to 2045. The act also set more ambitious interim emission reduction targets of at least 56% lower than the baseline by 2020, 75% by 2030 and 90% by 2040 (Scottish Parliament, 2019a).

The development of renewable energy resources is seen as critical to achieving these aims. In the 2020 Routemap for Renewable Energy in Scotland, published in 2011, the Scottish Government committed to generating an equivalent of 100% of Scotland's gross electricity consumption from renewable sources by 2020, and achieving targets of 11% renewable heat and 10% renewable transport (Scottish Government, 2011). In 2017, the Scottish Energy Strategy extended and strengthened these ambitions, with plans to almost completely decarbonise the Scottish energy system by 2050 through the large scale transition to low carbon and renewable transport and further expansion of renewable energy generation (Scottish Government, 2017a).

Progress in achieving these objectives has been steady. The Committee for Climate Change recently reported that in 2019 the GHG emissions in Scotland were 47% lower than the 1990 baseline set by the Climate Change (Scotland) Act 2009. The majority of this reduction has been driven by reforming the power sector (CCC, 2019b, p11). In 2019 Scotland generated 30,521 GWh of electricity from renewable energy sources; this represents 90.1% of gross electricity consumption in Scotland (Scottish Energy Statistics Hub, 2020d).

However it should be noted that across all sectors, more than 80% of total energy consumption in Scotland is still attributable to the burning of fossil fuels, with renewables supplying just 17.8% of overall demand (Royal Society of Edinburgh, 2019). Further, the Royal Society of Edinburgh's (2019) Enquiry into Scotland's Energy Future identified the need to improve energy security by increasing capacity, diversifying the range of energy storage options, developing a clearly articulated position on security of supply and deciding whether domestic energy-generating capacity should be increased.

2.1.4 Reducing Emissions from Buildings in Scotland

With respect to reducing GHG emissions from buildings, progress has been more protracted; with Sullivan's instructive report (Sullivan, 2007, 2013) providing recommendations for improving the energy performance of buildings in Scotland in order to reduce CO_2 emissions. It advocated a staged approach to delivery, with progressive tightening of energy standards and the adoption of backstop levels for U-values and airtightness in building fabric equating to those of Nordic countries. The primary objective was to deliver net zero carbon buildings (i.e. space and water heating, lighting and ventilation) by 2016/2017, if practical (Sullivan, 2007). This broadly aligned with the UK Government strategy for delivering Zero Carbon Homes by 2016 (Ares, 2016). There was also a long-term ambition to achieve total-life zero carbon buildings by 2030 i.e. all new buildings should be responsible for net zero emissions over their entire life including construction, use, maintenance and demolition (Sullivan, 2007).

The update of the Sullivan Report (2013) recognised the impact of the 2008 Financial Crisis and the additional challenges this imposed on the construction industry. Although the need to mitigate climate change was still considered pressing, the timescale of regulatory change was revised to provide a longer lead-in time for improving building energy standards and the programming of these to align with commitments set out in Article 9 of the recast Energy Performance of Buildings Directive (2010/31/EU) which required all new buildings to be nearly zero energy by the end of 2020 (Scottish Government, 2013; EC, 2018). Following the withdrawal of the UK's ambitious building emission reduction targets in 2016, progress in implementing more onerous standards for full decarbonisation of regulated energy use in buildings has been relatively slow.

Both the original and updated Sullivan Reports perceived decarbonising the UK energy supply and increasing the energy efficiency of buildings as more reliable long-term strategies for reducing CO_2 emissions from new buildings, than the use of building-integrated LZCGT (Sullivan, 2007, 2013). This view was formed due to the relative immaturity of the technologies involved, their associated cost and the limited knowledge and skills base present in the industry at that time. There was concern that mandating the use of LZCGT in new buildings would discourage development and be particularly detrimental to the provision of affordable housing (Sullivan, 2007). The Sullivan Reports also raised the issue of potential conflict between Planning (Section 3F Policy) and Building Standards over this issue (Sullivan, 2007, p26-27; 2013, p11).

However other research at that time contended that if the technical barriers to adopting microgeneration were addressed, then the widespread installation of LZCGT could potentially provide 30 to 40% of Scotland's electricity needs by 2050; effectively reducing annual household CO_2 emissions by 15% (Scottish Executive, 2007, p19). Promoting the microgeneration of heat and/or electricity from LZCGT was therefore seen as central to meeting Scotland's long-term obligations and aspirations in relation to GHG emission reduction (Scottish Executive, 2007; Scottish Government, 2009).

Published in 2009, the Renewable Heat Action Plan for Scotland promoted the use of renewable heat technologies ranging in scale from individual building systems to district heating schemes (Scottish Government, 2009). This was supported in 2014 by the UK wide Renewable Heat Incentive which offered financial incentives to householders, communities and businesses to encourage uptake of renewable heat technologies (Energy Saving Trust, 2020). Microgeneration of electricity from renewables was also encouraged and financially supported through Feed-in Tariffs (FIT) (Ofgem, 2020).

Whilst not all targets have yet been fully realised, Scottish government policies and improved building standards have delivered substantial GHG emission reduction in this sector. Direct emissions from Scotland's buildings in 2017 amounted to 8.3 $MtCO_2e$, or 20% of Scotland's total GHG emissions. This represents an overall fall in GHG emissions from buildings of 24% relative to 1990 levels (CCC, 2019b, p67). It should be noted that there are year on year fluctuations in this figure due to prevailing weather conditions. Improvements in Building Standards have had a particularly significant effect, with CO_2 emissions from new domestic buildings now typically 75% lower than they would have been if built to the construction standards applicable in 1990 (Scottish Government, 2018a, p85).

2.1.5 Future GHG Emission Reduction Targets

In addition to the aforementioned intention of Scotland to reach net-zero emissions by 2045, the Scottish Government has established other targets in relation to future energy generation and GHG emission reduction (Scottish Parliament, 2019a). In 2017, the Scottish Energy Strategy: the future of energy in Scotland set a new policy target for 2030, requiring the equivalent of 50% of all energy consumption for heat, electricity and transport to be supplied from renewable energy sources (Scottish Government, 2017a).

The following year, Scotland's revised Climate Change Plan set out policies for the period between 2018 and 2032 (Scottish Government, 2018a, pp 80-101). These include an ambition to supply 35% of heat for domestic buildings using low carbon technologies where technically feasible by 2032. In non-domestic buildings the equivalent ambition is 70% of heating and cooling demand. There is also an intention to insulate buildings to the maximum appropriate level; with improvements in fabric energy efficiency anticipated to deliver 15% and 20% reductions in heat demand in domestic and non-domestic buildings respectively by 2032.

The Climate Change Plan also highlights that overall electricity consumption is expected to increase because of efforts to decarbonise heat and transport, and this will place additional burdens on the electricity sector and the supply network (Scottish Government, 2018a). Whilst renewable electricity generation is expected to expand to meet this demand; it is also recognised that policies that aim to reduce energy demand, increase in-use energy efficiency and promote the appropriate deployment of small scale renewable energy generation are also requisite to reduce pressure on the centrally generated electricity supply and ensuring long-term energy security.

2.2 Key Factors Determining GHG Emissions from Buildings

There are a number of factors that affect the level of GHG emission from buildings. The impact of some are relatively simple to identify, quantify and take appropriate action on e.g. fabric energy efficiency, equipment efficiency, LZCGT, and the use of renewable energy in national energy networks. Other factors require deeper deliberation to appreciate and understand their impact e.g. passive architectural design and changes in societal demands, expectations and aspirations. How these factors interact is not always obvious at the outset, and the results of actions taken are not always exactly as expected (Copiello, 2017).

2.2.1 Societal Demands, Expectations and Aspirations

Many of the societal changes that are currently happening on a global scale effectively increase energy demand and counteract efforts to reduce global GHG emissions. Societal factors that have a negative impact on energy used in buildings include increased urbanisation, population growth, a decrease in size but an accompanying increase in the number of households, increases in per capita heated living space, enhanced expectations of thermal comfort, increased reliance on technological devices, greater consumerism and general aspirations for a more affluent western lifestyle (Urge-Vorsatz et al., 2013; Grove-Smith et al., 2018). Many of these factors have an obvious impact on the regulated energy consumption of buildings i.e. energy used for space heating, hot water, lighting and ventilation. However aspirations for a more affluent lifestyle, consumerism and the ubiquitous use of technology can also result in substantial increases in the currently unregulated operational and embodied energy demand of buildings.

An example of the influence societal aspirations have on energy use can be seen in the changes in energy consumption patterns in the UK. In 2018, 5,360 ktoe (12.8%) of energy consumption in domestic buildings was attributed to household electrical appliances. Palmer and Cooper (2014) suggest that this amount has roughly tripled over the past 40 years in the UK. The main factors contributing to this increase in unregulated electricity use are: the proliferation in the number and type of home electrical appliances (e.g. washing machines, tumble dryers, dish washers, TVs and entertainment consoles, computers, personal electronics, chargers etc.); the larger size and much greater use of cold appliances to store food (large 'American style' fridges and freezers); and the increased use of all these items (actual use and standby electricity) (Palmer and Cooper, 2014, p38-39).

Of course societal influences can equally have a positive impact and encourage change that will be beneficial to the environment. For example the concept of a 2000 Watt Society developed in 1998 by the Swiss Federal Institute of Technology recognised that the current level of consumption in developed countries is unsustainable and that we each need to take more responsibility for our choices, and use only what is a fair and equitable share of the world's resources (Morosini, 2008; Stulz et al., 2011). It envisaged an 'energy-sober society' where total primary energy use per capita is limited to the global average of 17,520kWh/annum without any attendant loss in the quality of life (Morosini, 2010). Whilst various critics have argued that the metric does not take into account the quality of the energy consumed, others argue that setting an aspirational limit to overall energy consumption would avoid potential rebound effects and incentivise individuals to re-examine their relationship with energy across all aspects of their lives and hopefully make appropriate changes to their lifestyles. At the very least it opens a discussion about unfettered energy consumption.

It should also be recognised that measures taken to reduce GHG emissions may not deliver as extensive an impact as might be expected because of the interplay of sociological factors in the real world. For example, studies have looked at the impact of improving fabric energy efficiency on overall GHG gas emissions. In these circumstances, increased fabric energy efficiency has a positive impact peoples' lives, initially reducing energy consumption, energy bills and fuel poverty, whilst simultaneously improving health, comfort and well-being. However, lower energy bills eventually result in increased disposable income, which in turns leads to greater consumerism and energy consumption in other areas of life. This is known as a rebound effect or Jevon's Paradox, and can result in actions taken to reduce GHG emissions failing to reach their expected potential (Copiello, 2017).

2.2.2 Passive Design

DeKay and Brown (2014), have been long-standing proponents of reducing energy consumption and emissions from buildings using passive architectural design strategies. In their seminal book 'Sun, Wind and Light' they suggest a hierarchy of strategies for attaining net-zero energy buildings that prioritises actions that are low technology and low cost, and which substitutes the ‘embodied intelligence in architectural form for hardware’ (DeKay and Brown, 2014) (Figure 1). This pyramidal diagram is not intended to infer a strict sequence of decision making, but rather imply that each higher level depends on decisions made at lower levels. For example, it is considered better to use site design to create a favourable microclimate and reduce environmental stresses on a building, before trying to use building design or technologies to solve problems that the building need not actually face. This passive design approach aligns with prevailing wisdom that to achieve net-zero energy buildings it is necessary to first reduce energy demand and increase energy efficiency to enable the cost-effective use of renewable technologies (Urge-Vorsatz et al., 2013; Grove-Smith et al., 2018). Where it might diverge from some of that literature is in identifying architectural design as the critical component that is too often absent in achieving this aim.

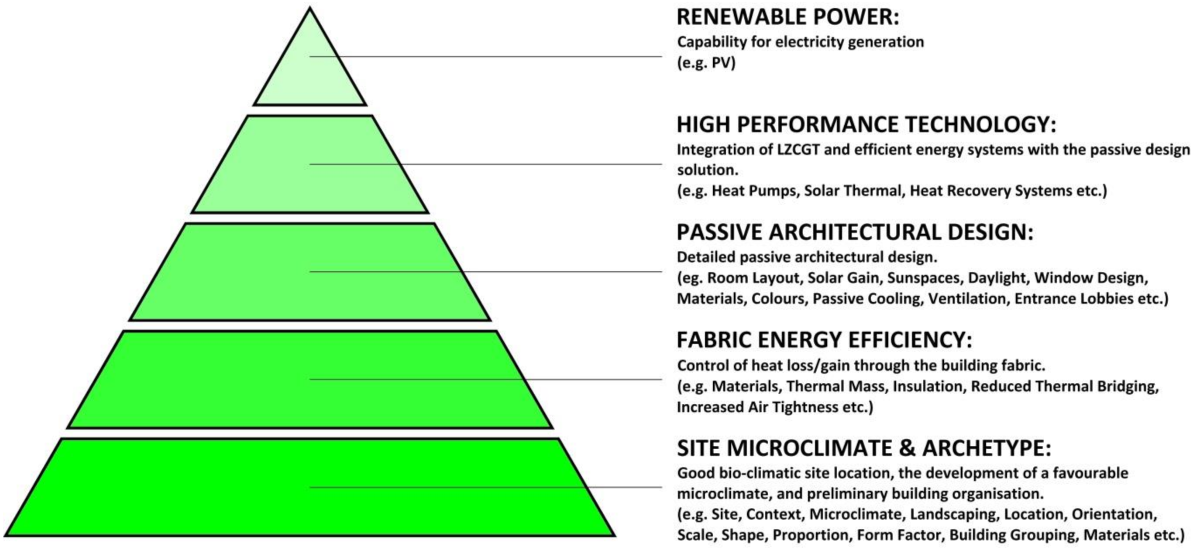


Figure 1: Hierarchy of Strategies (adapted from DeKay and Brown, 2014).

Passive design measures are not complicated or difficult to incorporate into the built environment, but they do need to be considered early in the design process. They might require that the appropriateness of the scale, form factor or solar access of the proposed building be reassessed (Cotterell and Dadeby, 2013; DeKay and Brown, 2014; Burford et al., 2019). Alternatively they might involve re-evaluating the site layout and incorporating landscape elements into the design to create a more favourable microclimate. Trees or other vegetation might be used to create shelter and shade while simultaneously reducing sound propagation, improving air quality, sequestering carbon and creating pleasant outdoor spaces (Harris and Borer, 1998). The thermal mass of building materials might be employed to effectively store heat, moderate temperature fluctuations or induce air movement. Orientating a building and most of its windows towards the south maximises the potential for solar gain and daylighting, but the architectural detailing of the windows and their surrounds can also have a significant impact on how well this is controlled (DeKay and Brown, 2014). Thoughtful forward planning might also be applied by orientating roof surfaces towards the south to accommodate future solar thermal or PV panels, enabling the building to be retrofitted to higher standards later in its life.

Unfortunately the potential of architectural design to make a meaningful contribution to emission reduction is not currently being given the priority and level of consideration it deserves. Most planning authorities do recognise the impact that these types of measures can have on energy consumption and GHG emissions, and actively promote sustainable and passive design approaches alongside Section 3F policy within their local development plans. However there appears to be little change in general building practices that would suggest that these measures are actually systematically employed.

The issue may simply be that the impact of passive design measures requires a more nuanced and deeper understanding of architectural design, the interactions between a building and its immediate environment, and the extent to which that environment can be manipulated to create more favourable microclimatic conditions. It is therefore not as easy and straightforward for policymakers to quantify and legislate for, in comparison to the technological efficiencies of the building fabric or equipment. Furthermore there are no mandatory standards setting a limit to either space heat demand or building energy demand in the UK. The Standard Assessment Procedure (SAP) used to determine whether a proposed dwelling has achieved the required CO_2 emission reductions, does so by comparison to a 'notional dwelling' built to specified technical standards. This notional building is described as having the same size, shape and living area fraction as the proposed dwelling (Scottish Government, 2019a). This not only fails to incentivise the use of passive architectural design as a critical and cost-effective means of achieving net-zero energy building, it effectively removes it from the calculation.

2.2.3 Fabric Energy Efficiency (FEE)

In the UK in 2018, energy consumed for space heating in the domestic, industrial and services sectors was 38,547 ktoe, or 46.6% of their total energy consumption (BEIS, 2019a, Table U1). The majority of this, 27,144 ktoe, was consumed in domestic buildings and represents 64.8% of their total energy consumption (BEIS, 2019a, Table U3). Given these proportions it is evident that to make a significant impact on reducing CO_2 emissions from buildings it is essential to reduce and/or decarbonise the energy used for space heating (Palmer and Cooper, 2014, p.35-36).

Increasing the fabric energy efficiency of a building by improving insulation, minimising thermal bridging and increasing air-tightness is therefore an obvious action to take to reduce CO_2 emissions from buildings. This is easier to accomplish during the initial construction of the building, with the cost being only about one-fifth of that incurred by retrofitting to the same quality and standard at a later date (CCC, 2019d, p14). Furthermore, failure to take action now risks constructing buildings that, without costly retrofitting, will underperform throughout their entire life and effectively lock a certain level of CO_2 emission into the built infrastructure for decades to come. Numerous scenarios predicting global energy use and CO_2 emissions have documented this carbon lock-in effect, and initially it was thought that Western Europe would mostly avoid it because of rapid moves to decarbonise (Urge-Vorsatz et al., 2013; Berardi, 2016; Grove-Smith et al., 2018). However progress has been slower than predicted because many proposed policies were either withdrawn before implementation or their ambitions curtailed in the aftermath of the global financial crisis of 2008 (Erhorn and Erhorn-Kluttig, 2018).

It is therefore essential that all new buildings are designed to the highest fabric energy efficiency standards, so that their environmental impact in the long-term is as small as possible (Willmott Dixon, 2020). Acknowledging this the Committee for Climate Change recently advised that all new homes should deliver ultra-high levels of energy efficiency as soon as possible and by 2025 at the latest. This proposed ultra-high level of energy efficiency was considered consistent with a space heat demand of 15 to 20kWh/m^2.annum (CCC, 2019d, p14).

However, the larger challenge that needs to be addressed in order to achieve net-zero emissions is not predicated on the energy standards in new buildings, but on how to bring the existing building stock up to a similar level of energy efficiency. In Scotland, new buildings have had to comply with minimum standards for energy efficiency and airtightness since 1982, and in the intervening decades these building standards have been regularly improved (Scottish Government, 2017b; Scottish Government, 2019a; Scottish Government, 2019b). However, 75% of Scotland's occupied dwellings were built before 1982, and 20% were built before 1919 (Scottish Government, 2017b). This ageing and varied building stock presents a significant challenge because of the scale of investment required and the physical and technical difficulties involved in bringing them in line with contemporary expectations (Royal Society of Edinburgh, 2019).

In response, Scotland designated energy efficiency as a national infrastructure priority in 2015 and has made clear progress with the Energy Efficient Scotland programme in setting targets and proposing financial support packages (Scottish Government, 2018b; CCC, 2019b). The objective is for all Scottish homes to achieve an Energy Performance Certificate (EPC) band C or better by 2040 where technically feasible and cost effective (Scottish Government, 2018b). The current programme has so far focused on social housing and the private rented sector and has made a greater per household investment in energy efficiency schemes than the UK average, however further measures for owner occupied homes are not anticipated until after 2021 (CCC, 2019b).

2.2.4 Low and Zero Carbon Generating Technology (LZCGT)

In its definition of nearly zero-energy buildings the Energy Performance of Buildings Directive (EPBD) clearly envisions that these buildings will have a very high energy performance with any remaining energy demand being very small and met substantially by energy from renewable sources, produced on-site or nearby (EC, 2018, Article 2). To enable this, the on-going development and maturation of small scale renewable energy technologies has been supported by successive governmental policies through Feed-in Tariffs (FIT) and the Renewable Heat Incentives (RHI) (Energy Saving Trust, 2020; Ofgem, 2020). These have sought to create cost effective renewable energy solutions and promote the normalisation of their use within the building sector. Section 3F also supports this objective, requiring planning authorities to include policies within their local development plans, which ask all new buildings to install and operate LZCGT. Further it states that the use of these LZCGT should be responsible for avoiding a specified proportion of the buildings predicted GHG emissions. This proportion is to increase over time (Scottish Parliament, 2019b).

Building Integrated Solutions

From the perspective of electricity generation potential renewable energy technologies include photovoltaics (PV), wind, hydro and biomass combined heat and power (CHP). PV is seen as being the most practical and cost-effective building-integrated solution, with the ability to simultaneously contribute to the decarbonisation of the national grid and reduce grid demand from buildings (BRE, 2016b; Osseweijer et al., 2018).

From the perspective of heat generation potential renewable technologies include solar thermal, heat pumps, deep geothermal , biomass primary combustion, biomass combined heat and power (CHP), biomass fuel cells, energy from waste (EfW) which includes advanced conversion technologies (bio-methane to grid, anaerobic digestion CHP and anaerobic digestion heat production) incineration and landfill gas (Grillanda and Khanal, 2019). There are currently no recorded incidences of biomass fuel cell and deep geothermal in Scotland. Grillanda and Khanal (2019) also note that passive renewable heating i.e. solar gain should be considered a renewable energy heat source, but because of the difficulty in assessing its contribution to heating demand it is not currently captured in the Renewable Heat Database.

In 2018, Scotland generated an estimated 6.3% of its non-electrical heat demand from renewable sources (Grillanda and Khanal, 2019). The aim is to achieve 11% by 2020 (Scottish Government, 2011; CCC, 2019b). The majority of this was generated through biomass primary combustion and biomass combined heat and power (CHP). Together, these two technologies account for 3,850 GWh (73%) of all renewable heat output and 1.66 GW (83%) of capacity (Grillanda and Khanal, 2019, p7). These figures include large installations (> 1MW), small to medium installations (between 45kW and 1MW) and micro installations (≤ 45kW). Building integrated systems will tend to fall within the micro category; district heating systems within the small to medium.

In 2018, micro-renewable heat generation accounted for just 18% of Scotland’s total renewable heat capacity and 12% of annual output, but a total of 85% of all installations (Grillanda and Khanal, 2019, p24). The discrepancy between capacity and output is attributed to the fact that many micro-renewable heat installations are used more intermittently than larger commercial or industrial systems. In 2018 micro-renewable heat generation in Scotland provided an annual output of 634 GWh, which comprised of approximately 326 GWh (51%) from biomass primary combustion, 292 GWh (46%) from heat pumps and 16 GWh (3%) from solar thermal (Grillanda and Khanal, 2019).

Distribution and technological trends have been observed within the micro-renewable heat generation data. Of the heat installation accredited under the Domestic Renewable Heat Incentive in Scotland from April 2014 to December 2019, 89% of biomass, 89.6% of air source heat pumps (ASHP), 88% of ground source heat pumps (GSHP) and 64.6% of solar thermal installations were located in off gas grid locations (Scottish Energy Statistics Hub, 2020e). Further in the period between June 2019 and June 2020 the trends observed in the type of technologies being deployed in Scotland by the number of accredited applications under the Domestic Renewable Heat Incentive were; Air Source Heat Pumps (ASHP) increased by 23.5% (from 7,356 to 9,083 accredited applications), Ground Source Heat Pumps (GSHP) increased by 9.4% (from 1,328 to 1,453), Solar Thermal increased by 3.4% (from 1,192 to 1,232) and biomass decreased by 1.8% (from 3,825 to 3,758) (Scottish Energy Statistics Hub, 2020e). The rapid increase in the uptake of heat pumps is also borne out in the anecdotal data collected within the survey carried out for this research (Appendix A, Questions 15, 16 & 17).

Pertinent to the discussion of micro-renewable heat generation is that the Committee on Climate Change (2018) has recently concluded that the current uses of biomass need to change to increase carbon sequestration and storage. This will entail a transition towards biomass being used in construction and bioenergy with carbon capture and storage (BECCS) and away from biomass for heating buildings or biomass for generating power without carbon capture and storage. They have therefore recommended that the UK should limit future support for bioenergy use in buildings to bio-methane from anaerobic digestion (CCC, 2019b).

Local Energy Networks

The Scottish Government aspires to a smarter and more coordinated approach to planning and meeting local energy needs. To facilitate this, it has developed a Local Heat & Energy Efficiency Strategies (LHEES) framework. The aim of which is to have local authorities work closely with their communities to set out a long-term prospectus for investment in new energy efficiency, district heating (heat networks), and other heat decarbonisation programmes at a local level (Scottish Government, 2017a).

The advantage heat networks offer over building integrated systems is that they are dynamic entities, not completely tied to any single energy generating source. This flexibility allows them to grow and change in relation to shifts in energy needs or the development of new technologies (Royal Society of Edinburgh, 2019; District Heating Scotland, 2020). By aggregating heating and cooling demands across multiple buildings heat networks can also make the most efficient use of locally available renewable and waste energy resources, and employ renewable technologies which would not be viable options for individual buildings. Heat networks also have the potential to temper the peak winter demands on the national electricity grid which would be exacerbated by the mass uptake of individual heat pumps (Royal Society of Edinburgh, 2019).

Renewable heat technologies that could realistically contribute to district heating systems might include: air source heat pumps (ASHP), ground source heat pumps (GSHP), water source heat pumps (WSHP), biomass combined heat and power (CHP), solar thermal with seasonal thermal energy storage (STES), energy from waste (EfW), hydrogen, geothermal (disused mines, sedimentary aquifers and granite), waste heat from industrial or commercial processes, waste water heat recovery (WWHR), and utilizing surplus electricity from intermittent renewables (Royal Society of Edinburgh, 2019; District Heating Scotland 2020).

The economic viability and carbon saving potential of district heat networks will ultimately depend on locally available energy resources and the density and diversity of heat demand (Royal Society of Edinburgh, 2019). They are particularly suited to dense urban areas, but can also provide solutions in some rural contexts by enabling the development of local renewable heat sources. Whilst the implementation of district heating might be limited by context, it is envisaged that it will meet at least 10% of residential and service sector demand in the future (Royal Society of Edinburgh, 2019). There are however a number of financial and regulatory constraints that would need to be addressed to facilitate their wide-scale uptake (Appendix A: Questions 18-20).

2.2.5 National Energy Networks

In 2016 almost 50% of all energy consumed in Scotland was supplied via the national gas and electricity networks. This includes 86% of domestic energy consumption. Ensuring these networks can continue to supply affordable energy on demand to everyone across Scotland while the energy they supply is gradually decarbonised is essential to Scotland's future energy security (Scottish Government, 2019d).

The Gas Network

Gas networks in Scotland currently connect to approximately 80% of households and deliver a secure and comparatively low cost energy supply. These extensive networks effectively provide an energy storage capacity several hundred times greater than anything that could be developed in relation to the electricity grid (Scottish Government, 2019d). The inherent storage capacity of the gas network allows it to easily absorb large swings in daily demand and in doing so it supports the wider energy system.

The UK is currently investigating the possibility of decarbonising the gas supply and how this might be safely achieved. At present this work is exploring the technical implications of incrementally blending low carbon gases (bio-methane and bioSNG) and hydrogen with the natural gas within the existing network (Carbon Connect, 2017). 15 bio-methane sites are already connected to the gas grid in Scotland (Scottish Government, 2019d).

Other work is also examining the technical feasibility and potential cost implications of converting natural gas networks to 100% hydrogen after 2030, in line with the hydrogen based future energy scenario identified as one potential path to achieving the 2045 net-zero emission target (Scottish Government, 2017a; Scottish Government, 2019d). A 100% hydrogen grid is unprecedented. This would therefore be a more radical solution which would require all pipes to be converted to polyethylene (this is on-going and due to be completed by 2032) and the replacement of consumer gas appliances with hydrogen compatible ones (Carbon Connect, 2017).

To what extent the gas grid could be successfully decarbonised is still debateable. The carbon intensity of low carbon gases and hydrogen vary depending on their feedstock, production method, energy used in the production process and the effectiveness of carbon capture (Carbon Connect, 2018). For example producing bio-methane from food waste has lower emissions than producing it from energy crops, as well as avoiding potential conflict over the use of land that could be used for food production. Many of the processes for producing low carbon gases and hydrogen are still in their development stages and the carbon intensity of these processes is as yet uncertain (Policy Connect, 2018).

The Electricity Grid

In the 12 months to June 2020, 86.5% of the electricity consumed in Scotland was generated from low carbon sources - 56% from renewables and 30.5% from nuclear (Scottish Energy Statistics Hub, 2020a). For the UK as a whole the carbon intensity of the electricity grid in 2018 was calculated as 200.7 gCO_2e/kWh. In Scotland the carbon intensity in 2018 was 44.6 gCO_2e/kWh; a rise from the 24.0 gCO2e/kWh recorded in 2017; due to the prolonged power outages associated with Hunterston B nuclear power station (Scottish Energy Statistics Hub, 2020b).

In 2019, 30,521 GWh of electricity was generated from renewable energy sources in Scotland (Scottish Energy Statistics Hub, 2020d). In order of prominence this was comprised of: 19,143 GWh from onshore wind; 5,362 GWh from hydro; 3,182 GWh from offshore wind; 2,031 GWh from biomass (including co-firing); 412 GWh from landfill gas; 347 GWh from solar PV; 29 GWh from sewage sludge digestion; and 14 GWh from wave/tidal (Scottish Energy Statistics Hub, 2020c). Although only the first quarterly figure for renewable electricity production in 2020 is available, this saw an increase of 28% relative to the same quarterly period in 2019 (Scottish Energy Statistics Hub, 2020c).

Notwithstanding these achievements, realising net-zero emissions by 2050 will have a profound effect on the UK's electricity grid. The drive to decarbonise transport and heat will almost certainly result in a precipitous rise in the use of electric vehicles and heat pump technology, and a rapid increase in electricity demand. As a result it is expected that UK electricity generation will need to double from 300 TWh to around 600 TWh by 2050 (CCC, 2019b, p95). Without a corresponding increase in low carbon generation there is every possibility that these demands would have to be met by gas-fired generation. To ensure that this does not happen and that the anticipated increase in electricity demand can be met without increasing emissions the Committee for Climate Change has recommended that the UK electricity network as a whole should aspire to a maximum emission intensity of 50g CO_2e/kWh by 2030. To achieve this target will require a substantial increase in new renewables as well as technologies such as nuclear and carbon capture and storage (CCS) (CCC, 2019b, pp. 42-43).

Higher electricity demands coupled with the increased use of intermittent renewable energy sources will necessitate improvements in system flexibility and widespread upgrades in terms of capacity and transmission networks. To enable Scotland to realise its renewable energy potential large scale investment is currently being delivered by a series of network development and reinforcement projects (CCC, 2019b, p96).

The management of energy flows and reducing demand side requirements are recognised as critical to maintaining the affordability and security of the electricity supply whilst the grid is decarbonised. To achieve greater flexibility, manage increasing peak demands, tighten capacity margins and overcome the intermittency issues associated with renewable generation the development of energy storage capacity is critical (Millar, 2015). This could be integral to the electricity grid or incorporated into local energy networks or buildings, and could be either in the form of electricity or heat (Abegg, 2011).

This also raises questions concerning the design of building energy systems and the appropriateness of different technology types in supplying the different building energy requirements. In the raft of the many available building energy policies, Hermelink et al. (2013) highlights a lack of attention to and a mismatch in the design and energy demand of new buildings and their interaction with the energy grid; with Hogeling (2012) stating the assumed infinite capacity and storage in the grid was a failure to account for timing of electricity generation and use.

2.3 Priorities in New Buildings

The primary objective of this research is to ascertain what would be a reasonable level of emission reduction that could be sought by Section 3F Policy through the use of LZCGT in new buildings within the Scottish context. As we have seen there are several factors that actively contribute to the level of GHG emission from buildings. These include societal influences, passive design solutions, fabric energy efficiency, building services equipment efficiency, building integrated LZCGT and the prevalence of renewable energy within local and national energy networks. Determining which factors should be prioritised and in what proportion to attain both a rapid and continuing long-term decarbonisation of the building sector without stifling potential architectural innovation is a more complex matter.

2.3.1 Architectural Innovation

The difficulty of assigning a numerical value to the contribution LZCGT should make to GHG emission reduction is that every building is different, and if this level is set too high there is the potential to stifle architectural innovation that may result in more cost effective long-term solutions. This is perhaps best illustrated by considering two buildings: the R128 House and the 22-26 Building (Blaser and Heinlein, 2002; Eberle and Aicher, 2016). While both concepts are at the cutting edge of ultra-low emission building design, and each delivers a sustainable and nearly zero-energy outcome, they start from very different philosophical positions and take vastly different approaches (Figure 2).

Figure 2: a) R128 House, Werner Sobek, Stuttgart, Germany 2002 & b) 22-26 Building, Baumchlager & Eberle, Lustenau, Austria, 2013. (Source: Blaser and Heinlein, 2002; Eberle and Aicher, 2016).

The R128 house (Germany, completed 2002) is an emission free highly automated house requiring no energy input for heating and is completely recyclable. The all-glass facade which provides complete transparency has a comparatively poor U-value compared to conventional building facades that aim to conserve energy through using high-performance thermal envelopes. Instead R128 relies on renewable power generating systems, mechanical ventilation and a heat store to manage the comparatively large diurnal and seasonal fluctuations in temperature to ensure constant indoor climatic conditions. The electricity grid is used as an energy store by feeding in surplus energy from the solar panels and tapping it when there is a shortfall – this assumes that any carbon intensive energy drawn from the grid is replaced by renewable energy generated at the building. The PV generating system produces surplus energy over the lifetime of the building which is sufficient to cover the operational energy and embodied energy costs of the prefabricated, demountable construction system and its recycling.

By contrast, the 22-26 Building (Austria, completed 2013) is notable in its apparent simplicity as there are no mechanical environmental systems and no active heating equipment. Instead, it relies on a very high thermal mass and sensor operated windows to control indoor temperature and ventilation, with heating coming from solar gain, equipment and occupants. The dynamic behaviour of the solid exterior wall construction combines high heat flow resistance and high thermal capacity to manage indoor climatic conditions and control heat loss. Most of the construction materials were sourced locally and chosen because of their minimal need for processing from their natural state, thereby reducing their embodied impact. While the 22-26 Building does not attempt to employ LZCGTs to cover other energy uses such as lighting and plug load it is clearly a very low-impact, low-emission form of construction. The approach taken by the 22-26 Building is further justified by its notably low construction costs of about 1200 €/m^2 as a result of its simplicity and lack of applied technology. In comparison R128 is technically sophisticated and the building services are likely to prove costly both in initial outlay and in their on-going maintenance and eventual upgrade.

2.3.2 Holistic Approach with Hierarchy of Actions

The consensus among academics and construction industry figures is that the most effective way to reduce GHG emissions from buildings is to tackle the problem from a holistic perspective rather than fixate on any single contributing factor (Sullivan, 2007; Urge-Vorsatz et al., 2013; Beradi, 2016; Grove-Smith et al., 2018; Scottish Government, 2019a). This approach perceives buildings as systems that can be optimised with respect to design, efficiency, economy and contextual opportunities and constraints, in order to deliver the most appropriate emission reduction strategy. This does not preclude certain factors in general being strategically prioritised.

Governments however also need to take into consideration the wider interactions of buildings with the existing energy infrastructure, how these relationships and infrastructures are changing due to ongoing decarbonisation and the projected increase in energy demand from other sources such as electrical vehicles. Seen from this perspective the government needs to develop logical strategies in relation to energy use in buildings that will maintain energy security whilst simultaneously taking the country on the rapid decent to net-zero emissions by 2045.

Urge-Vorsatz et al. (2013) submit that strategically the best long-term solutions to reducing GHG emissions from buildings should include the following hierarchy of actions:

i. **Reduce energy demand:**
   From a sociological viewpoint, this might involve supporting positive lifestyle or behavioural changes. From the perspective of building design it might include the consideration of passive design solutions or increasing building fabric energy efficiency.
ii. **Increase efficiency of energy use:**
   All aspect of the design, construction, and occupational phases should be considered. This might include investigating the embodied energy of building materials, more efficient construction methods, ways to minimise building energy losses or utilise heat recovery, the efficiencies of specific equipment and technologies, and the optimization and maintenance of building systems once occupied.
iii. **Increase the use of renewable energy:**
   To maximise sustainability and reduce the impact on national energy infrastructures, these energy sources should preferably be generated locally.

The reasoning behind this approach is that to achieve ultra-low energy, net-zero energy or eventually positive energy buildings in a cost-effective way, it is first necessary to reduce the energy requirement of the building to the point that the remaining energy demands can be practically and economically met by renewable energy sources. This basic 3-point strategy underpins the approach taken by most governments and internationally recognised standards such as Passivhaus. In developed countries where demand for energy is very high and already exceeds globally sustainable levels, it is also suggested that further measures might be necessary to change attitudes and behaviours at a societal level; for example by developing policies that actively discourage wasteful excesses or cap individual energy usage (Morosini, 2010; Ettlin, 2013; Urge-Vorsatz et al., 2013).

In terms of specific actions that architects and building owners should focus on, the UK government has identified two priorities: increasing fabric energy efficiency and decarbonising heat (CCC, 2019b, d). Both these priorities can be seen to relate directly to the fact that in the UK in 2018, 56.7% (46,936 ktoe) of the total energy consumption in the domestic, industrial and service sectors (excluding agriculture and transport) was due to space and water heating. In the domestic sector this proportion rose to 81.7% (34,184 ktoe) of total energy consumption (BEIS, 2019a, Table U1).

2.3.3 Prioritising Fabric Energy Efficiency

Whilst supporting an integrated design approach which promotes GHG emission reduction through improvements in building design, fabric and services; most of the literature also advises prioritising the issue of fabric energy efficiency (Urge-Vorsatz et al., 2013). There are several reasons for this.

In our cold northern climate, the need for space heating tends to dominate energy demand. In 2018, it represented 64.8% (27,144 ktoe) of the total annual energy demand in the domestic sector in the UK (BEIS, 2019a, Table U3). Enhancing fabric energy efficiency; by improving insulation levels, minimising thermal bridging and increasing airtightness; is therefore the most obvious and cost-effective way to cut energy demand and CO_2 emissions in new buildings (Beradi, 2016).

It should be noted that at very high fabric energy efficiency levels there are balances to be made between the initial construction costs versus operational costs, and the embodied energy of the building materials versus the operational energy demand of the building. However the optimum point overall for both cost and energy appears to fall within the general descriptor of Passivhaus i.e. at an annual space heat demand of about 15kWh/m^2.annum (Copiello, 2017; Grove-Smith et al., 2018). This is primarily because of a shift in technologies at this point. At this very high level of fabric energy efficiency the use of mechanical ventilation becomes necessary to maintain indoor air quality during the heating season. However, if an efficient mechanical ventilation heat recovery (MVHR) system is employed the size of the heating system can be significantly reduced. This associated cost saving tends to largely offset the cost of improving the building fabric (Cotterell and Dadeby, 2013; Copiello, 2017; Currie and Brown, 2019).

On a national scale, taking a fabric first approach reduces the peak energy demand of the building, minimising the additional capacity that needs to be built into the national energy networks to meet peak winter demands and thereby supports long-term energy security (Currie and Brown, 2019). This matters, because in the absence of long-term storage options, the on-going decarbonisation of the national grid requires increased capacity to cope with the intermittency of renewable energy sources. Yet changing lifestyles, the switch to electric vehicles, and the increased use of heat pumps, will see electricity demands grow.

The timeframe over which emission savings can be reasonably expected to be made also needs to be considered. Increasing fabric energy efficiency effectively reduces operational energy demand and GHG emission over the entire lifetime of the building (>100 years), whilst the effect of specifying LZCGT will be limited to the equipment's operational lifespan (15 - 20 years). Furthermore poor fabric energy efficiency is much more difficult and costly to remedy at a later date than during the initial construction phase (CCC, 2019d, p14). This can lead to buildings that have failed to take a fabric first approach underperforming over their entire life and a certain level of carbon emissions being effectively locked-in to the built infrastructure (Urge-Vorsatz et al., 2013; Beradi, 2016).

On a purely practical level the substantial reduction in energy demand that can be achieved through improved fabric energy efficiency has an impact on the size and cost of energy systems required to meet this demand and can make the use of renewable energy systems more practical and affordable. For building occupants, increased fabric energy efficiency also reduces energy bills, increases disposable income and a positive impact on occupants' comfort, health and well-being (Payne et al., 2015; Copiello, 2017; IEA, 2019).

2.3.4 Decarbonising Heat

Different challenges exist for decarbonising heat in domestic and non-domestic buildings in Scotland. EPC data suggests that 50% of non-domestic buildings use electricity as their primary source of heat and only 42% use natural gas. Conversely in domestic buildings only 12% use electricity, whilst 79% use natural gas (CCC, 2019b). The use of natural gas in domestic building for space heating and hot water is almost ubiquitous if a connection to the gas grid is available. The development of a national strategy to decarbonise heat is considered essential if the UK is to meet the 2050 net-zero emission target (CCC, 2019b,d). This challenge can be approached from many different angles and several tactics have been developed that can be employed in different contexts.

At a national level:

i. Continue support for decarbonising the gas network through bio-methane injection.
ii. Support research into the possibility of repurposing the gas network for hydrogen.
iii. Continue to decarbonise and increase the capacity of the national electricity grid. This is essential to obtain the largest benefit from the deployment of technologies such as heat pumps, which typically consume one unit of electricity for every three units of heat they produce.

At a local level:

iv. Invest in building or extending low-carbon heat networks particularly in heat dense urban areas, large-scale new developments and some rural locations; assess prospective network location taking into consideration the available renewable energy opportunities, heat demand, capital costs and the level of householder engagement. The aim is to have approximately 1.5 million homes across the UK connected to heat networks by 2030 (CCC, 2019d).

v. Instigate a shift to bioenergy with carbon capture and storage (BECCS) for all medium to large scale biomass energy generation.

At a building level:

vi. Limit the support for bioenergy use in buildings to bio-methane produced from anaerobic digestion. The widespread use of solid biomass boilers is not consistent with the long-term decarbonisation of heat.

vii. During the 2020s; retrofit at-scale existing buildings on the gas grid with hybrid heat pumps (HHP). Hybrid heat pumps are capable of switching between electricity and a variety of other heat sources, and have the advantage that they can be retrofitted into an existing heating system without changing radiators and with the existing boiler acting as the supplementary heat source. As such they are considered a low regret choice. The householder could switch to a hydrogen boiler if the gas network is converted and this will continue to work with the hybrid heat pump, or if the gas network is decommissioned they could be run completely on electricity.

viii. During the 2020s; increase heat pump uptake in homes not on the gas grid, with particular focus on those homes that would otherwise use high carbon fossil fuels.

ix. During the 2020s; all new homes should be future proofed for low carbon heating systems with appropriately sized radiator and low temperature compatible thermal stores. It is estimated that these measures could save householders between £1,500 and £5,500 compared to having to retrofit low carbon heat from scratch (Currie and Brown, 2019).

x. By 2025 at the latest no new homes should connect to the gas grid. Instead they should be designed to either use low-carbon heating systems such as heat pumps or be connected to low-carbon heat networks.

With biomass being discouraged, the technological constraints of decarbonising the gas grid, and the long-term policy and planning decisions needed for district heating schemes still being explored, it is expected that heat pumps may well become the most prevalent mainstream solution for supplying renewable heat to buildings in the immediate future. This increased uptake in the use of ASHPs and GSHPs has already been observed, and the technology is widely viewed as the most affordable and proven solution to low-carbon domestic heat, especially if the electricity consumed by their operation is also generated from renewable energy sources (Scottish Energy Statistics Hub, 2020e).

2.3.5 Achieving Balance

As the UK moves towards the net-zero emissions target there are considerable challenges to be addressed that will require a level of joined-up thinking and appreciation of the wider impacts decisions can have. The national electricity grid in particular will face difficulties maintaining rapid decarbonisation whilst responding to an unprecedented increase in demand from both the building and transport sectors. It is therefore more important than ever that architects take a holistic approach to reducing emissions and consider the wider impact of their design decisions, including the potential of a building to change and evolve in the future to achieve an even higher level of emission reductions.

In their recent cost and benefit analysis, Currie and Brown (2019) concluded that significant long-term carbon saving could be made by switching from natural gas to low-carbon heat in both domestic and non-domestic contexts. Their analysis found that the regulated operational carbon emissions of a home built in 2020 using a heat pump for space heating and hot water would, over a 60 year period, be 90% lower than the equivalent building heated with natural gas. Further they identified a significant carbon penalty and substantial cost implications in delaying adoption of low carbon heat technologies and retro-fitting them at a later date.

However they also recognised that combining a low-carbon heat source, such as an ASHP, with ultra-high fabric energy efficiency ultimately offered even greater overall benefits than either used alone (Currie and Brown, 2019). There are two main reasons for this. Firstly the reduction in heat loss that results from improving fabric energy efficiency to 15kWh/m^2.annum and operating a mechanical ventilation heat recovery (MVHR) system substantially reduce the building's annual and peak energy demands. This minimises the impact the building and the uptake of low-carbon heat has on the national electricity grid, and its ability to maintain both security of supply and continued decarbonisation. Secondly, there are both capital and operational cost savings at the building level because a much reduced energy demand can be satisfied with a smaller ASHP, a more compact heat distribution system and less radiators. Significantly analysis of these benefits determined that it would be more cost-effective to move rapidly to an ultra-high fabric energy efficiency combined with low-carbon heat, rather than take a more measured incremental approach to improving fabric energy efficiency (Currie and Brown, 2019).

The study further suggests that the adoption of low-carbon heat technologies such as ASHPs is cost-effective in the domestic arena from 2021; however Currie and Brown advise a more phased approach to manage transitional risks. The aim is therefore to have all new homes adopt an ultra-high level of fabric energy efficiency and low carbon heat from 2025 (CCC, 2019b, d; Currie and Brown, 2019). There is some caution required in transposing this cost analysis and timescale for adoption directly to the Scottish context. This is primarily because the modelling was based on a cavity wall construction rather than the timber frame construction methods more prevalent in Scotland. However, it is expected that an ultra-high fabric energy efficiency standard would be more readily achievable with a timber kit and potentially less expensive than achieving this level of fabric energy efficiency with a cavity wall construction. There are numerous examples of social and affordable housing built to Passivhaus standards using timber kit construction (Kinghorn Housing Association, 2010; Paul Heat Recovery Scotland, 2020a).

Rapid movement in tandem to both an ultra-high fabric energy efficiency and low-carbon heat is a very sensible course of action if this is sustainable in terms of grid capacity. Otherwise there may be a tendency among some developers to achieve their requisite CO_2 emission reductions mainly through the use of LZCGT and the positive gains made as a result of increased fabric energy efficiency might be lost with long-term negative consequences for both built and energy infrastructures.

2.3.6 Beyond Reducing Energy Demand

The Energy Performance of Buildings Directive (European Community Directive 2002 & European Community Directive 2010) introduced the term nearly zero-energy building (nZEB) (EC, 2018). Subsequently, a significant amount of research has been undertaken around the definitions of the term, the metrics used to account for energy and carbon emissions and the strategies needed for cost effective implementation of low carbon generating technologies in buildings, including Mussal and Voss (2012), Marszal and Heiselberg, (2010), Kibbert and Fard (2012), Hernandez and Kenny (2010) and Pless and Torcellini (2010). Various factors were highlighted in relation to energy balancing concepts including the indicators used, unit of balance (final/delivered energy; primary energy; exergy; energy costs or CO_2 emissions) and the type of energy used (operational energy; embodied energy and/or unregulated energy). They also showed that the boundaries for energy use need to be accounted for, including definitions for regulated energy, whether other end-uses not directly associated with the operation of the building, such as plug loads, are included and consideration given to how and the extent to which on-site LZCGT's offset both energy demand and emissions. They also show that understanding the different impacts and interactions between energy and carbon are important in designing appropriate integrated energy systems and that accounting for the 'quality' of the energy used is also important in accounting for emissions reductions. Time dependency between demand and generation is also highlighted as a significant barrier to further deployment of renewable technologies. In order to meet peak demand periods and reduce the impacts on an increasingly decarbonised grid, balancing energy supply and demand with storage (both short-term and seasonal) and controls will be needed in the future (Peacock et al., 2014).

2.4 Levels of Ambition

2.4.1 Passivhaus Standard

The aspirational Passivhaus standard is generally considered to set the international benchmark for achieving ultra-low energy building performance. Developed in Germany by Wolfgang Feist and Bo Adamson in 1988, the Passivhaus concept utilises knowledge of building physics to enable architects to systematically evaluate and fine tune building designs. Because of its clear scientific evaluation method and adoption of Mechanical Ventilation and Heat Recovery (MVHR) systems, Passivhaus is often wrongly perceived as an inherently technological and expensive way of building. In actuality its core principles are a holistic attitude to building design, a fabric first approach, excellent thermal detailing and exceptional care in construction (Cotterell and Dadeby, 2013).

Fundamental to a Passivhaus achieving an extremely low operational energy demand is a fabric first approach; combining high levels of insulation with an airtight and thermal bridge free construction. Sealing a building tight enough to effectively control heat loss necessitates a mechanical ventilation strategy to maintain indoor air quality during the heating season. The Passivhaus concept turns this necessity to its advantage by employing very low energy Mechanical Ventilation and Heat Recovery (MVHR) systems. Such systems typically employ a counter flow heat exchanger with an efficiency of between 80% and 93% to recover the heat from stale extract air and transfer it to the fresh supply air (Passive House Institute, 2020; Paul Heat Recovery Scotland, 2020b). In warmer weather this system can be simply bypassed and replaced with a natural ventilation strategy instead.

At this level of energy conservation it becomes possible to utilise incidental heat gains from passive solar, household activities, electronic equipment and the occupants themselves to help maintain an internal temperature of 20°C and effectively minimise the size of any heating system required (IBO, 2009; Cotterell and Dadeby, 2013; Paul Heat Recovery Scotland, 2020b). This represents a significant financial saving that partially compensates for the overall increase in cost due to increasing the efficiency of the building fabric. This combination of high fabric energy efficiency and heat recovery enables Passivhaus buildings to come close to the nearly zero-energy building definition without recourse to significant additional renewable energy input.

The Passive House Institute currently promotes three different aspirational standards: Passivhaus Classic, Passivhaus Plus and Passivhaus Premium (Table 2). These roughly equate to the definitions of an ultra-low energy building, a net zero energy building, and a plus energy building respectively (Paul Heat Recovery Scotland, 2020b). To attain any of these standards the annual space heat demand of the building required to provide an internal temperature of 20°C must be no more than 15kWh/m^2.annum; or, the specific heat load, i.e. the peak power needed to maintain 20°C internally when it is -10°C outside, must be no more than 10W/m^2 (Cotterell and Dadeby, 2013; Passive House Institute, 2016).

	Passivhaus Classic	**Passivhaus Plus**	**Passivhaus Premium**
Space Heat Demand	Maximum Annual Space Heat Demand of 15kWh/m^2.annum . . . or . . . Maximum Space Heat Load of 10W/m^2		
Airtightness	Less than 0.6 air changes per hour @ 50 Pa		
MVHR	Minimum 75% efficiency		
Renewable Primary Energy (PER)	Maximum 60kWh/m^2.annum	Maximum 45kWh/m^2.annum	Maximum 30kWh/m^2.annum
Renewable Energy Generation	Not Required	Minimum 60kWh/m^2.annum	Minimum 120kWh/m^2.annum

Table 2: Summary of Passivhaus Standards (Paul Heat Recovery Scotland, 2020b).The Renewable Primary Energy criteria replaced that of a maximum Primary Energy Demand in 2016. This value includes energy used for space heating, hot water, lighting, ventilation and all appliances and takes into consideration short-term and seasonal storage losses from renewable energy sources (Passipedia, 2017). These are not mandatory standards.

How this level of fabric energy efficiency is achieved is at the discretion of the designer, however climatic conditions and the design of the building e.g. orientation, solar gain, form factor etc. will all contribute to determining what level of insulation is required. The form factor is essentially the ratio of the external surface area to the internal usable floor area. It is easier and cheaper to achieve a Passivhaus standard of construction with a more compact design (Cotterell and Dadeby, 2013). Table 3 outlines the impact of the form factor on typical u-values need to achieve the Passivhaus standard in the UK.

Form Factor	Type of dwelling this might represent	U-value range of external envelope to achieve a space heat demand ≤ $15kWh/m^2$.annum in the UK
<2	Apartment block or terrace	0.15 W/m^2K
2 -3	2 or 3 storey semi-detached or compact detached house	0.10 - 0.15 W/m^2K
3-4	Less compact detached house or bungalow	0.10 W/m^2K
>4	Very spread-out bungalow	0.05 - 0.10 W/m^2K

Table 3: How form factor affects U-value requirements (Cotterell and Dadeby, 2013).

2.4.2 UK and Scottish Aspirations

At the moment there is no mandatory maximum annual space heat demand set for either domestic or non-domestic buildings within the Scottish Building Standards (Scottish Government, 2019a; Scottish Government, 2019b). There are robust backstops set in relation to the performance of the building insulation envelope (Standard 6.2) and building services (Standards 6.3 – 6.7); and it is fully expected that these will have to be improved upon to enable a building to comply with its CO_2 emission reduction target (Standard 6.1). Different maximum area weighted u-values are set for domestic and non-domestic buildings, and these diverge further with respect to whether the works are new buildings, extensions, conversions or alterations. Building extensions have the most onerous requirements in this respect, to compensate for poorer levels of fabric energy efficiency in the existing building.

Data from a study in 2015, which considered the approved SAP data of 402 randomly selected new dwellings in Scotland, recorded an average annual space heat demand of $46.3kWh/m^2$.annum, with actual values ranging from $13.7kWh/m^2$.annum to $93.4kWh/m^2$.annum (Appendix E; Onyango et al., 2016; Burford et al., 2019). All of these dwellings were designed between 2012 and 2014, were either under construction or completed at the time of the study, and met the minimum 30% reduction in CO_2 emissions (relative to the 2007 standard) legislated for in Scottish Building Standard 6.1 at that time. Energy standards for domestic buildings have since been revised so it is likely that the average annual space heat demand in new dwellings is now lower (Scottish Government, 2019a).

Aspirational sustainability standards have been set by the Scottish Government within Section 7 of the Scottish Building Standard (Table 4). These include at Silver/Silver Active Level, Aspect 2: a maximum annual space heat demand [SAP Box 99] of $40kWh/m^2$.annum for houses and $30kWh/m^2$.annum for flats and maisonettes. At Gold level this is improved to $30kWh/m^2$.annum for houses and

20kWh/m^2.annum for flats and maisonettes (Scottish Government, 2019a). Attaining these levels is not mandatory.

New Domestic Buildings	Scottish Building Standards: 2019 **Section 7 Silver/Silver Active**	Scottish Building Standards: 2019 **Section 7 Gold/Gold Active**	Committee for Climate Change: 2019 **UK Aspirations for 2025 at the latest**
CO_2 Emission Reduction (relative to 2007) (S7: Aspect 1)	45% (Mandatory)	60%	Unspecified
Annual Energy Demand for Space Heating (S7: Aspect 2)	Maximum Houses: **40kWh/m^2.annum** Flats/Maisonettes: **30kWh/m^2.annum**	Maximum Houses: **30kWh/m^2.annum** Flats/Maisonettes: **20kWh/m^2.annum**	Maximum All new homes: **15 - 20kWh/m^2.annum**
Space Cooling			All new homes should consider passive cooling measures to avoid overheating
Annual Energy Demand for Water Heating (S7: Aspect 3)	Minimum 5% from heat recovery or renewables	Minimum 50% from heat recovery or renewables	
LZCGT (S7: Active)	Mandatory LZCGT contribution defined by individual planning authorities in local development plans. The use of LZCGT is promoted at building standards, but there is no mandatory requirement to use.		All new homes to be made ready for low carbon heating. No new homes to be connected to the gas grid by 2025 at latest. All new homes to use low carbon heat sources by 2025 at latest.
Whole Life Carbon Impact			Recommend shift to timber construction due to low embodied energy and high carbon storage potential
End of Life Strategy (S7: Aspect 8)		Design for Deconstruction	

Table 4: Summary of current aspirations for Scottish and UK standards compiled from the Scottish Building Standards Technical Handbook 2019: Domestic (Scottish Government 2019a), Reducing Emissions in Scotland: 2019 Progress Report to Parliament (Committee on Climate Change, 2019b) and UK housing: Fit for the future? (Committee on Climate Change, 2019d). These are not current mandatory standards, although the aspirations for 2025 are intended to be mandatory when adopted.

The Committee for Climate Change has also recently highlighted the aspirations that will need to be made concrete by 2025 at the latest to enable the UK achieve its net-zero emissions target (Table 4) (CCC, 2019b, p66; 2019d, pp 14-15). They counsel that all new homes in the UK should be designed to deliver ultra-high levels of energy efficiency as soon as possible, and by 2025 at the latest. This proposed ultra-high level of energy efficiency was considered consistent with an annual space heat demand of 15 to 20kWh/m^2.annum (CCC, 2019d, p14). They also recommend that all new homes be made suitable for low carbon heat now; and by 2025 at the latest no new homes should connect to the gas grid but should instead use low-carbon heating systems such as heat pumps and low-carbon heat networks. There are also recommendations that there should be a refocussing of efforts on the whole-life carbon impact of new homes. In particular they advise a shift towards timber frame construction because of its lower embodied energy and ability to act as a long-term sequestrated carbon store. This is, of course, already the standard construction method in Scotland.

2.5 Effective Policy Design

2.5.1 Overview

There is a considerable body of academic literature devoted to GHG emission reduction and renewable energy policies. However most is based on empirical work undertaken across the globe in contexts that are climatologically, environmentally, politically, socially and economically diverse. These contextual differences along with divergences in aspirations, concepts and calculation methodologies relating to nearly zero-energy buildings effectively hamper accurate benchmarking of the performance of these different approaches and largely constrain direct comparison and cross-context learning (Pan and Li, 2016).

There is a general consensus that reducing GHG emissions from buildings is best tackled by taking a multifaceted approach (Urge-Vorsatz et al., 2013; Beradi, 2016; Grove-Smith et al., 2018). However, improving building energy efficiency is repeatedly highlighted as the most significant and cost effect means of reducing energy demand and GHG emissions, and ultimately protecting the environment. This finding is supported by numerous and comprehensive reviews of building energy consumption data from the UK, USA, EU and China (Xing et al., 2011; Annunziata et al., 2013; Urge-Vorsatz et al., 2013; Pan, 2014; Cole and Fedoruk, 2015; Beradi, 2016; Grove-Smith et al., 2018). A full analysis of the academic literature is contained in Appendix D.

2.5.2 Design and Application of Robust Energy Policies

Empirical analysis of policy instruments in the building sector clearly shows that governmental intervention is fundamental in reducing GHG emissions from buildings (Ürge-Vorsatz et al., 2008; Boza-Kiss et al. 2013; Levinson, 2014; Lemprière, 2016; Gürtler et al., 2019; Schwarz et al., 2020). However, it is also true that in many countries these changes in building regulations are often subject to debate and review as conflicting goals become evident between minimising regulatory and administrative burden on citizens and businesses, and addressing socio-economic and environmental concerns (Gürtler et al., 2019; Schwarz et al., 2020).

Gürtler et al. (2019) sought to understand the mechanisms, factors and actors that led to certain government policies succeeding whilst others ultimately collapsed; by considering the dismantling of renewable energy policies in Spain and the Czech Republic. Policy design was obviously a major factor in the robustness of a policy. The outcome was also determined by other wider societal factors e.g. interplay between policy design, the political economy of the policy field, macro level external factors, and institutional constraints and opportunities that could either reinforce or weaken a policy (Figure 3). Their preliminary findings determined that with some forethought many of these factors could be effectively managed and mitigated for. The primary lessons learnt were to:

i. **Recognise fiscal feedback can strongly influence policy durability:** It is important that the societal cost of the policy is effectively controlled. Costs incurred must not be seen as damaging by stakeholders, politicians or the general public and should be fairly distributed. The perception that the policy provides excess benefits to a small group of stakeholders, or equally adversely affects others, should be avoided.
ii. **Develop an explicit strategy for managing the political economy:** This entails gaining an in-depth understanding of the political economy of the field and addressing the concerns of the primary stakeholders with either policy changes or other interventions to mitigate any transitional periods.
iii. **Maintain ambition and the ability to adapt:** Policy collapse can often occur prematurely if it is perceived that targets and objectives have been met. If further improvements are possible and desirable, there is a need in this context to keep momentum going through the use of adaptive frameworks which can respond effectively to innovation and change, and prevent stagnation of ambition.

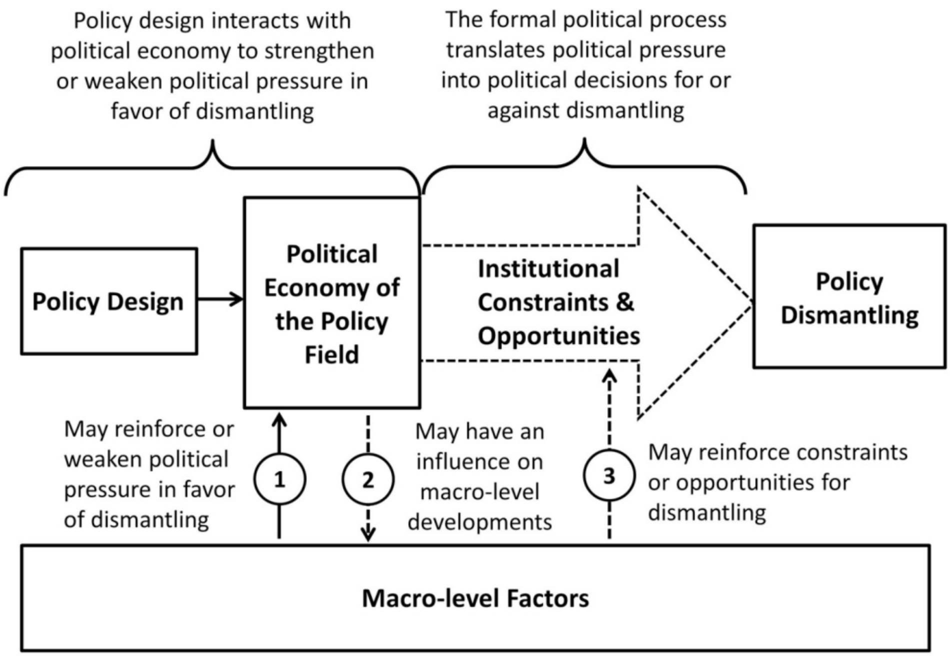


Figure 3: Analytical framework for the analysis of policy dismantling (Gurtler et al. 2019; based on Bauer and Knill (2014)).

In another recent study, Schwarz et al. (2020) identified five case studies where innovative approaches to building energy policy design had been taken by Denmark, France, Sweden, Switzerland and the UK. By exploring the effectiveness and challenges experienced in implementing these energy policies, they identified six policy design principles:

i. **Keep additional burdens for building owners light.**
Building energy policy should only require cost-effective measures that are economically beneficial to the consumer.
ii. **Create long-term regulatory certainty.**
This allows time for forward planning, investment and innovation to develop whether industrial or architectural. There is however a need to build in a degree of flexibility to enable effective response to developing knowledge, opinion, innovations and societal expectations.
iii. **Beware technologically specific requirements.**
It is recommended that there are multiple technological options available to choose from, for the most appropriate and cost-effective technology for any given context.
iv. **Anticipate the impact of new regulations on small actors.**
The cost impact of increasingly complex environmental legislation may be much more onerous for small firms and planning authorities, than large firms because of economies of scale. This should be borne in mind and expensive and time consuming compliance and evidencing procedures reduced as much as possible. Necessary information and means of evidencing compliance should be made free and publically available.
v. **Promote knowledge of innovative policy designs.**
Ensure that all stakeholders have sufficient knowledge about new policies well in advance of implementation. This can be achieved by pre-announcing upcoming changes to legislation, conducting pilots, building on voluntary schemes or learning from front-runner legislation enacted elsewhere.
vi. **Integrate building energy policy in the local context.**
It is important to adapt policies to the local context by leveraging existing energy infrastructures and locally available renewable energy resources.

3. The Scottish Development and Consent Process

3.1 Overview

All European countries operate building regulatory systems which legislate for planning demands and building technical standards which may be carried out in separate or combined procedures. Scotland operates a two-stage building consent process:

i. Planning which is governed by the National Planning Framework (NPF) and enforced through local planning policies set out by individual local authorities is concerned mainly with design, appropriateness, use and location of development.
ii. Building Warrant ensures that all developments meet Scottish Technical Standards in terms of Structure, Fire, Environment, Safety, Noise, Energy and Sustainability. These technical standards are defined in separate Technical Handbooks for Domestic and Non-Domestic Construction.

Both Planning and Building Warrant play an active role in supporting GHG emission reduction policies.

In relation to Planning; the Scottish Government is currently undertaking a review of National Planning Framework 3 (NPF3) and Scottish Planning Policy (SPP) and is exploring the option of bringing both documents together to form a single National Planning Framework 4 (NPF4). Under the 2019 Planning (Scotland) Act, the National Planning Framework will become part of the Development Plan with the idea that it will contain policies which could be applied across Scotland for day to day decision making. It is anticipated that NPF4 would be in place for 10 years once adopted.

3.2 Scottish Building Standards

3.2.1 Section 6: Energy

Section 6: Energy of the Scottish Building Standards aims to ensure that effective measures are taken to limit energy demand by addressing the performance of the building fabric and fixed building services and stipulates the CO_2 emissions reductions that must be achieved by new buildings. Building Standards have taken a staged approach to reducing emissions, the current CO_2 emissions reduction targets for new buildings are:

Domestic Buildings: 45% CO_2 emission reduction relative to 2007 Standard
(Scottish Government, 2019a)

Non-Domestic Buildings: 60% CO_2 emission reduction relative to 2007 Standard
(Scottish Government, 2019b)

The primary intent of Section 6 is to ensure that buildings incorporate effective measures for the conservation of fuel and power, and define the minimum standards deemed acceptable in this respect. The Building Standards clearly promote the belief that this aim is best achieved through a balanced and holistic approach to building design, in which energy demand is limited by addressing both the performance of the building fabric and fixed building services. Compliance is primarily determined by meeting the CO_2 emission reduction target calculated for the proposed building (Standard 6.1) and complying with the robust performance backstops set in relation to the performance of the building fabric (Standard 6.2) and building services (Standards 6.3 – 6.7). Whilst reducing CO_2 emissions is the primary focus and metric in determining compliance with Section 6; the measures defined are designed to reduce the energy demand of new buildings, minimising energy use and associated fuel cost over the lifetime of the building.

Whilst Section 6 promotes the use of energy from renewable sources, it does not stipulate that LZCGT must be used to meet these standards. This offers a degree of flexibility for architects and developers in determining the appropriate balance between design, fabric efficiency and LZCGT in any given context. However it is expected that with the continued improvement in standards, the need to use low carbon equipment to satisfy the energy demand remaining after savings have been made through fabric energy efficiency will increase.

3.2.2 SAP and SBEM

The Standard Assessment Procedure (SAP) used for domestic buildings, and the Simplified Building Energy Model (SBEM) used for non-domestic buildings, are the UK's National Calculation Methodologies and standard tools for assessing the energy performance of buildings. These tools predict the energy use in buildings and provide a quantifiable mechanism to show compliance with the CO_2 emissions reductions targets defined in Section 6 and legislated for in the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019.

Calculation Methodologies: Domestic Buildings

There are two potential methods for domestic buildings to show compliance with Standard 6.1:

1 **Standard Assessment Procedure (SAP)**
The benefit of this methodology is that designers are not constrained in their design response; and subject to meeting the benchmarks and backstops set out in Standards 6.2 – 6.6, are free to develop their own cost-effective solutions to meeting the TER.
   i. **Establish Target Emission Rate (TER)**
   The Target Emission Rate (TER) is established for the 'notional dwelling' (a dwelling of the same size, shape and living area fraction as

the proposed dwelling) by inputting into BRE approved SAP software the package of measures detailed in Tables 6.1 & 6.2 of Clause 6.1.2 for the fuel chosen for the main space heating (Gas, LPG, Oil, Electricity, Biomass). These measures are designed to achieve the required CO_2 emissions reduction standard and represent a 'whole dwelling approach'. Each includes some level of LZCGT in achieving this. These tables give designers a clear concept of the type of measures and standards that need to be adopted to achieve the required emission reductions.

ii. **Establish Dwelling Emission Rate (DER)**
A second calculation is then carried out using the actual design values for the proposed dwelling.

iii. **Compare DER to TER**
If the DER is less than or equal to the TER the proposed dwelling is in compliance to Standard 6.1

2 A Simplified Approach
The alternative to using SAP is to simply design to one of the five packages of measures used to determine the Target Emission Rate (TER) set out in Table 6.1 & 6.2 of Clause 6.1.2. This method can still be used even when there are minor deviations from the measures outlined as long as these deviations achieve the same or better emissions reductions. It cannot be used if deviations produce higher CO_2 emissions. Clause 6.1.6 sets out example deviations and when this approach cannot be used.

Calculation Methodologies: Non-Domestic Buildings

The equivalent non-domestic calculation methodology typically uses the Simplified Building Energy Model (SBEM). Other tools may be used, such as dynamic simulation modelling, particularly where the building is considered to be a complex design. The methodology for calculating the CO_2 emissions reduction is similar to that outlined above for the Standard Assessment Procedure (SAP). To comply with Standard 6.1, the calculated CO_2 emissions rate for the 'actual' building (Building Emissions Rate or BER) must be less than or equal to that calculated for a 'notional' building (Target Emissions Rate or TER).

3.2.3 Section 7: Sustainability

Section 7: Sustainability of the Scottish Building Standards was introduced in 2011 to both recognise the level of sustainability already embedded within Sections 1 to 6 (Bronze Level), and encourage architects and developers to achieve higher standards (Silver, Gold and Platinum Levels) through a sustainability labelling system. All new buildings must display a Sustainability Label detailing the buildings performance in relation to these sustainability targets.

Domestic Buildings

Standard 7.1 defines the optional higher levels of sustainability that new domestic buildings can aspire to. The four general levels of attainment are set: Bronze, Silver, Gold and Platinum. Within each level, target measures relating to different aspects of sustainability are defined. For domestic buildings these aspects are:

Aspect 1: CO_2 Emissions
Aspect 2: Energy for Space Heating
Aspect 3: Energy for Water Heating
Aspect 4: Water Use Efficiency
Aspect 5: Optimising Performance
Aspect 6: Flexibility and Adaptability
Aspect 7: Well-Being and Security
Aspect 8: Material Use and Waste

Whilst the sustainability label recognises the level of achievement in all aspects; for a building to achieve a higher overall award all aspects within that level must be achieved. All new domestic buildings currently automatically meet Silver Level Aspect 1 in respect of CO_2 emissions, because of improvements in Standard 6.1. In addition to these 8 aspects; Bronze Active and Silver Active delineations are included to recognise the use of LZCGT in achieving these targets. These are primarily included to assist local authorities in meeting their obligations under Section 3F of the Town and Country Planning (Scotland) Act 1997 by identifying the use of LZCGT. In this respect, the definition of LZCGT 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 contribution of the LZCGT is not quantified.

Non-Domestic Buildings

For all non-domestic building (except schools containing classrooms), Standard 7.1 only defines sustainability targets relative to Aspect 1: CO_2 emissions. All new non-domestic buildings currently automatically meet Silver Level Aspect 1 in respect of CO_2 emissions, because of improvements in Standard 6.1. The non-domestic standards also include the Bronze Active and Silver Active delineations to help local authorities identify the use of LZCGT.

3.3 Section 3F Policy

Section 3F of the Town and Country Planning (Scotland) Act 1997, as amended through Section 72 of the Climate Change (Scotland) Act 2009 requires planning authorities to make the following policy provision in terms of greenhouse gas (GHG) emissions.

> ‘A planning authority, in any local development plan prepared by them, must include policies requiring all developments in the local development plan area to be designed so as 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 low and zero-carbon generating technologies.’ (Scottish Parliament, 2019b).

As part of the Scottish Planning Review undertaken between 2015 and 2019, a public consultation invited views on the removal of Section 3F policy (Scottish Government, 2019c). Of all comments received on the subject, 60% thought Section 3F policy should be removed. Amongst those in 'Policy and Planning' and 'Development Industry' respondent sub-categories this rose to 86% in favour of removal. However the 'Civil Society' sub-category was slightly in favour of retaining the policy, with only 45% favouring removal (Kevin Murray Associates/University of Dundee, 2017).

It should be noted that those who called for policy removal did not seek to undermine the objectives of the Climate Change Act. Rather it was based on the view that Section 3F Policy was not really progressing CO_2 emission reduction since this was being led by Building Standards; and there were other more effective ways that planning could contribute to the delivery of low carbon development, especially on a macro-scale. Respondents also argued that the policy created additional burdens, duplicated effort and added a layer of complexity to the planning system for no additional benefit (Kevin Murray Associates/University of Dundee, 2017). However, on deliberation, the Scottish Government decided to retain Section 3F policy, as it was felt that removing it would be inconsistent with the emerging Climate Change Plan (Scottish Government, 2019c).

To better understand the issues surrounding Section 3F policy, we sought the views of planning authorities across Scotland to learn from their experiences administrating current Section 3F policies. The aim of this survey was to benchmark current policy and procedures; identify practical issues or concerns; and gain an insight into how these might be practically addressed. The survey was conducted using an online questionnaire. The opinions expressed by respondents are summarised below. For a full analysis of responses see Appendix A.

3.3.1 Existing LZCGT Target Contribution

As Section 3F does not stipulate the contribution LZCGT should make to the emission reductions of new buildings, planning authorities across Scotland have had relative autonomy in determining the minimum LZCGT target contribution to include in their LDP (Figure 4). In determining an appropriate LZCGT target, the survey data suggests that many planning authorities felt they had not received enough guidance from the Scottish Government on this matter, and lacked the resources, expertise and understanding of the issues in-house to assess what would be an appropriate level. Other respondents reported that they had simply adopted the Section 3F policy wording that Scottish Ministers had suggested that they or other planning authorities include in their LDP.

Approximately a third of survey respondents indicated that they had deliberately taken a balanced and restrained approach to setting their minimum LZCGT target contribution; deciding to keep the percentage low so as not to be overly onerous, deter development or interfere with a fabric first approach. In their guidance, they had tried to be clear with applicants that they were seeking to reduce CO_2 emissions through the provision of highly efficient buildings and the better the insulation and fabric of the building the lower the amount of LZCGT would be required.

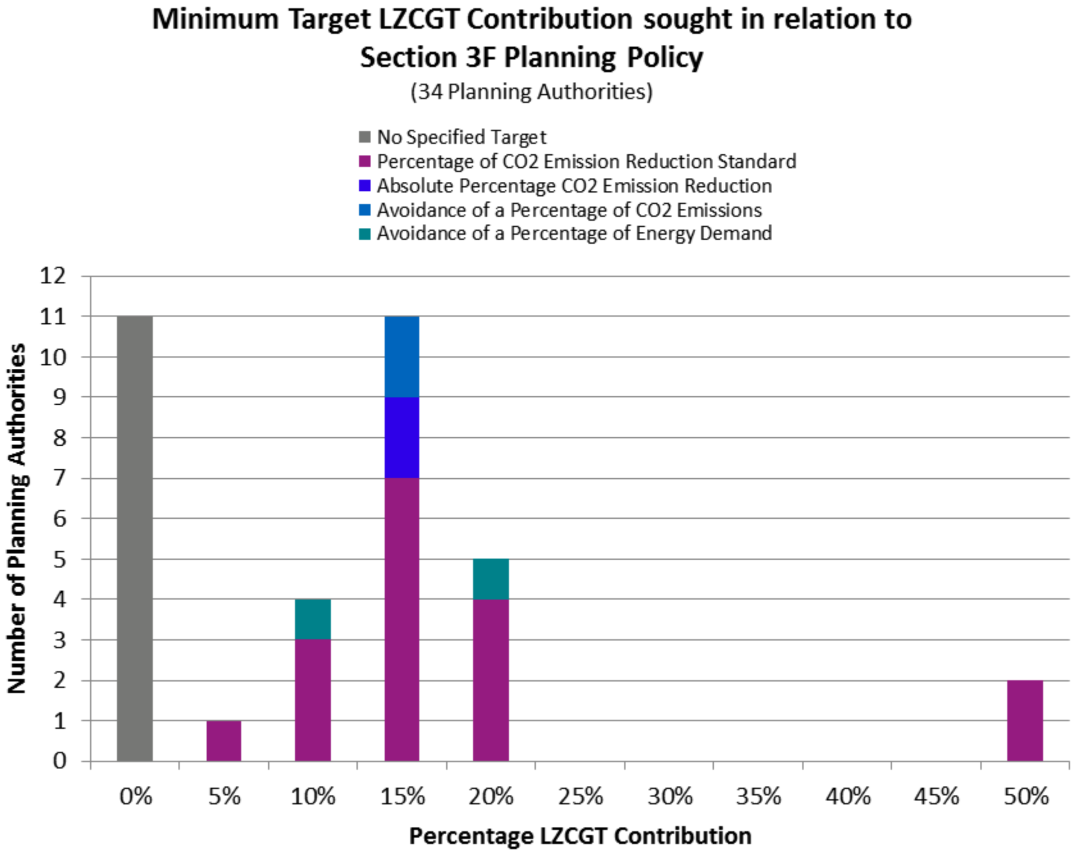


Figure 4: The range of LZCGT contributions sought by planning authorities across Scotland compiled from Survey Data and the Ninth Annual Report on the Operation of Section 72 of the Climate Change (Scotland) Act (Appendix A; Scottish Government, 2019e). It should be noted that the wording of some of the target definitions are confusing and it was not totally clear to what metric they referred. A number of policies also refer to LZCGT targets set within supplementary guidance that on closer investigation did not appear to have been adopted. Further with reference to Figure 7 the metric 'avoidance of a percentage of CO_2 emissions' and 'avoidance of a percentage of energy demand' are analogous and it is expected they would be calculated by the same formula.

Of those planning authorities that have set a specified minimum LZCGT target contribution, most have defined it in terms of a percentage of the percentage CO_2 emissions reductions sought through Scottish Building Standard 6.1: carbon dioxide emissions and the most frequent LZCGT target is 15% of this value (Figure 4). Typically Section 3F policy is applied to all new development with certain exceptions, and in general these mirror the exceptions made to Scottish Building Standard 6.1. Meeting the LZCGT target does not appear to be a major issue for applicants (Appendix A: Question 4; Figure A.2); the difficulty arises in demonstrating compliance at the planning application stage. This is an issue of timing and the lack of availability of accurate SAP/SBEM data this early in the design process.

3.3.2 Evidence and Procedures

The majority of survey respondents reported that their planning authority did not have defined standard assessment procedures and calculation methodologies for determining whether applications comply with Section 3F Policy (Appendix A: Question 7; Figure A.3).

Compliance is most commonly evidenced through a process of self-certification; typically through the submission of a statement containing detailed information about the proposed LZCGT. The type of information requested typically includes: the type of LZCGTs proposed; the scale, location and visual impact of the installation; ongoing operation and maintenance issues; SAP/SBEM calculations; and a calculation to show compliance with the minimum LZCGT target contribution. Survey respondents reported that the standard of compliance evidence received by planning authorities is very variable in terms of format and content, even where planning guidance has been given and compliance procedures and calculations have been defined.

Where calculation methodologies have been defined these usually require two separate SAP/SBEM calculations; one for the building as designed with the proposed LZCGT and another with the proposed LZCGT removed and replaced with pre-defined conventional systems. This second SAP/SBEM calculation is not currently required for Building Standards purposes. The CO_2 emission rates generated by these two SAP/SBEM calculations are then substituted into a formula to calculate the LZCGT contribution. Of the formula defined by survey respondents; none accurately defined the LZCGT target in terms of a percentage of the percentage reduction in CO_2 emissions sought by Scottish Building Standard 6.1.

Although many planning authorities have not defined standard assessment procedures in relation to Section 3F, a general work pattern did emerge from the survey responses. Initially planning officers use the opportunities afforded by pre-application meetings and the application determination process to highlight to applicants the general importance attached to sustainable design and CO_2 emission reduction, and the specific requirements of Section 3F policy.

Approximately half of survey respondents aim for evidence of compliance to be submitted at the planning stage; however the majority of respondents accept that this is not practically feasible in many circumstances. This is because the detailed SAP/SBEM information needed to quantify the amount LZCGT contributes to overall CO_2 emissions reduction is usually not available at the planning stage. Normally building design and technical details are refined and finalised in the period between obtaining planning and building warrant consent. Compliance with Building Standard 6.1 is determined during this period through the submission of finalised SAP/SBEM calculations to Building Standards and it is information contained within these calculations that is used to quantify LZCGT contribution to CO_2 emission reduction and determining compliance with Section 3F policy.

Accepting that this level of information is not typically available at the planning stage at the present time, the most common response of planning authorities is to apply a suspensive condition to the planning consent decision notice requiring that compliance documentation be submitted to planning prior to commencement on site. Many applicants prefer to take this route and submit Section 3F compliance documents at this later stage because it fits better with their workflow practices. It also reduces duplication of effort and the confusion of having to resubmit revised documents should further design development take a different path.

3.3.3 Implementation Issues

Virtually all survey respondents reported that they had experienced some difficulties in applying their current Section 3F policy and procedures.

Over half of survey respondents reported they had struggled to implement their Section 3F policy in a consistent and systematic way. Some reported they were currently working with development management teams to raise awareness and provide guidance on how to apply the policy in practice. The development of a Scotland-wide Section 3F policy, guidance and procedures would ameliorate this situation.

The inherent contradiction with Scottish Building Standards over the mandatory use of LZCGT and the lack of a homogenous Scotland-wide Section 3F policy with a single clearly defined minimum LZCGT target contribution, has caused confusion and resulted in a lack of developer cooperation with Section 3F policy. Further, the lack of clearly defined compliance requirements, standard evidencing procedures and calculation methodologies, has resulted in the submitted compliance evidence varying widely and being of a general poor quality.

Survey respondents reported that with the current standard of evidence it was often difficult for planning officers to ascertain if a development had actually met the minimum LZCGT target contribution. Almost half of survey respondents considered that in the absence of clear guidance they simply did not have sufficient knowledge and experience to make informed judgements on these issues. Further, they were unfamiliar with the type of technical information and SAP data submitted as proof of compliance, and felt ill equipped to interpret this information or use it calculate the LZCGT target themselves. Officer training and up-to-date Scotland-wide guidance with clearly defined LZCGT target, evidencing procedures and calculation methodologies would improve this situation.

Two thirds of survey respondents reported that the main issue for them was attempting to implement a policy at the planning stage, when the information that was required to confirm compliance was typically not available until later in the design process. Receiving good quality data at the planning stage places planning officers in a strong position; because if sufficient information is available to conclude that an application will not comply, they have the power to withhold planning consent and leverage a better solution from the applicant. This can have a significant positive impact on the built outcome.

The use of suspensive conditions to circumvent this issue has engendered its own complications. Whilst considered a reasonable practical workaround, it has resulted in planning officers having to monitor the progress of developments in an attempt to obtain evidence of compliance when it becomes available. This has time and resource implications. It also leaves Planning in a weaker position with little or no means to force applicants to improve proposals. Almost half of survey respondents had concerns about the strength of suspensive conditions and the subsequent ability to enforce compliance.

The underlying issue here is the disconnection between Planning and Building Standards over the issue of LZCGT. Scottish Building Standards do not include a mandatory minimum LZCGT contribution to CO_2 emission reduction, so it is beyond their remit to play an active role in enforcing a minimum LZCGT target. Further Building Standards will not delay granting building warrant consent or issuing a completion certificate on the basis that an application does not comply with a planning condition (Scottish Government, 2019e). Half of survey respondents concluded they would like to see improved inter-departmental working between Planning and Building Standards on this issue.

3.3.4 Going Forward - LZCGT Trends

According to survey respondents, the most commonly encountered LZCGT were Photovoltaics, Air Source Heat Pumps (ASHP), Ground Source Heat Pumps (GSHP), Mechanical Ventilation Heat Recovery (MVHR), Biomass and Solar Thermal. Photovoltaics were the most frequently specified LZCGT; however ASHPs had seen the greatest increase in uptake over the past 5 years (Appendix A: Questions 15 & 16; Figures A.5 & A.6). One respondent reported that ASHP had really begun to take off over the last year in the non-domestic sector, particularly in hotel and large-scale office developments. The same planning authority has become aware of cases where the benefits from PV had accrued to the landlord and not the tenant. The same respondent also considered Waste Water Heat Recovery (WWHR) an as yet untapped resource with great potential.

The majority of survey respondents felt it was important that planning authorities should be able to promote their preferred regional, local or site specific solutions to CO_2 emissions reductions (Appendix A: Question 18; Figure A.7). Approximately three quarters of survey respondents also felt that planning authorities should be able to compel new developments to link to existing local large scale LZCGT initiatives or heat networks, where appropriate, in order to support such schemes (Appendix A: Questions 19; Figure A.8) However this was not without serious reservations about how these energy infrastructures would work in practice.

The local context was identified as a potential barrier to the development of large scale LZCGT and heat networks and it was felt that planning authorities needed a degree of autonomy to develop schemes that are appropriate to their unique context. It was also recognised by survey respondents that large scale LZCGT and heat networks would need to be delivered upfront so that developers can be confident they will be in place from the first day of occupation. This raised questions about who would be responsible for the planning, financing, delivery and ongoing maintenance of these energy infrastructures.

Liberalisation of the energy market means that the choice of energy provider is up to the developer or occupant, and there is no legal means for planning authorities to compel connection to or delivery of specific energy services. Monitoring and enforcement would require additional capacity and resources. There was also concern that this type of policy would restrict developers and future occupants to one energy provider with no choice to change to a cheaper supplier or a less carbon intensive system in the future. This called into question the whole premise that it would be reasonable to insist that new developments link to local large scale LZCGT and heat networks; especially if developers could provide their customers with cheaper building scale alternatives.

One respondent noted that the Danish schemes which are often cited as exemplars for Scotland to follow are all municipally owned and run on a not for profit basis. This raises the question of how the government would ensure the best value for money for citizens locked into such schemes, if they were not in public ownership. Further, if there was a proliferation of small private sector energy companies, how would the government ensure the integrity of these energy networks, and who would become the owner of last resort if these companies were to fail.

Over a third of survey respondents felt that planning professionals currently lacked the technical knowledge, skillset and expertise to make sensible joined-up decisions about large scale LZCGT and heat networks. This would require building technical knowledge and expertise within planning departments which would have a resource implication.

3.3.5 Going Forward - LZCGT Target Contribution

One respondent emphasised that their interpretation of Section 3F policy was that it does not seek to increase CO_2 emission reductions overall, it just seeks to define the proportion of those CO_2 emission reductions that are achieved through the deployment of LZCGT. Whilst not rejecting the important role LZCGT can play in reducing CO_2 emissions; several respondents also advocated strongly for prioritising fabric energy efficiency as a means of reducing CO_2 emissions. They emphasised the need for any future LZCGT target to be a minimum standard rather than an aspirational one, so that it would not interfere with a fabric first approach.

There was a fairly even split between those survey respondents who thought it was important to quantify a target LZCGT contribution at Planning and those who did not (Appendix A: Question 21; Figure A.9). Reflecting on the respective roles and skillsets of planning and building standards officers, approximately half of survey respondents questioned the positioning of Section 3F policy within the remit of Planning. Further, in light of the practical difficulties planning authorities have experienced in implementing Section 3F policy, and considering that the calculation needed to quantify the contribution of LZCGT relies on information submitted to Building Standards; several respondents concluded the LZCGT target would be better suited for inclusion within Building Standards than Planning.

It was suggested by one respondent that the easy way out of this difficult situation would be to simply include a new mandatory standard within the Scottish Building Standards that meets the requirements of Section 3F policy. Planning could then simply highlight and reference this standard as a requirement, only one calculation would be necessary and it would be effectively enforced by Building Standards.

A majority of survey respondents also concluded there was no case to be made for planning policies that attempt to accelerate the reduction in CO_2 emissions beyond the current Scottish Building Standards, because it would be unhelpful to have Planning and Building Standards set different targets in this respect (Appendix A: Question 22; Figure A.10). Although respondents felt there was a need to accelerate CO_2 emission reduction, they considered that the most logical and straightforward way to do so is to simply increase the CO_2 emission reduction required by Scottish Building Standard 6.1. It was considered essential for successful and productive engagement with stakeholders that Planning and Building Standards have a clear and consistent message to avoid contradiction and confusion.

A clearly defined minimum LZCGT contribution target, evidencing procedures and calculation methodology, together with quality supplementary guidance to raise awareness of the policy aims and compliance procedures, was therefore considered essential to provide clarity for architects and developers and improve the quality of submitted information. In this respect, a Scotland-wide policy, whether set through Planning or Building Standards, was considered preferable to the current situation where different planning authorities have different expectations.

3.3.6 Going Forward – Roles of Planning and Building Standards

The need for better collaboration between Planning and Building Standards on policies relating to CO_2 emission reduction was highlighted by several respondents, recognising that Planning and Building Standards are complementary to each other in their approach, skillsets and outlook. Several respondents expressed the view that Planning was more aligned to delivering CO_2 emission reduction through strategic large scale planning, place-making and appropriate design; and this approach complemented Building Standards with its more technical regulations that ensure buildings meet minimum acceptable standards including those for fabric energy efficiency, equipment efficiency and CO_2 emissions reduction.

When asked to consider where Planning should concentrate their efforts in reducing greenhouse gas emissions and mitigating climate change, most survey respondents considered their focus should be on: Landscape Scale Planning; Sustainable Planning; Large Scale LZCGT; Architectural Design; Architectural Design Details; Building Scale LZCGT; and Assessing Sustainability (Appendix A: Question 24; Figure A.11).

When asked the same question in relation to Building Standards, the majority of survey respondents thought that they should concentrate their main efforts on Architectural Design Details; Fabric Energy Efficiency; Building Scale LZCGT; Assessing Energy Consumption; Assessing CO_2 Emission Reductions; Assessing the Contribution of LZCGT; and Assessing Sustainability (Appendix A: Question 24; Figure A.11). Survey responses suggest a joint responsibility for Assessing Sustainability and a less evenly divided joint responsibility for Large Scale LZCGT; Building Scale LZCGT; Architectural Design; and Architectural Design Detailing.

Approximately a third of survey respondents highlighted that Planning could influence CO_2 emission reduction through supporting practical passive architectural design responses that utilise the topographical, micro-climatic, and environmental features of a site to minimise energy consumption. Many planning authorities already provide basic supplementary guidance relating to this approach (location, site, landscape, shelter, shade, solar orientation, built form, scale, design details, material choice etc.) alongside existing section 3F policy in an attempt to promote better design decisions. This is a sphere of influence that has been largely ignored in the discussion of CO_2 emission reduction, but with the right guidance could be expanded and is ideally suited to inclusion within the skillset of Planning.

In general Planning was seen as well-placed to prioritise action on climate change and the reduction of CO_2 emissions at an early stage in the design process. Early engagement with applicants, either through pre-application advice or during the process of determining planning applications, can be used to advise applicants of their responsibilities in relation reducing energy consumption and CO_2 emissions at a stage where it could positively influence design responses. Effective engagement with applicants or developers and obtaining their commitment to these aspirations is fundamental to achieving success in this.

During this engagement process planners can facilitate discussions that promote practical means of achieving reductions in energy consumption and CO_2 emissions from either a design or technical perspective; address the feasibility of adopting alternative energy solutions; and influence the choice developers make with respect to different types of LZCGT and other carbon mitigation measures. Survey respondents considered it important that the planning implications of LZCGT are captured during the planning permission process and not applied retrospectively. Planning officers could potentially flag any building standard requirements for specified LZCGT during the engagement process as a way of front-loading the system and avoiding retrospective changes.

3.3.7 Going Forward – Scottish Government Support

If Planning and Building Standards officers are to play an active role in shaping responses to climate change they need proper training with regards to these issues to enable them to offer better informed advice to applicants and developers. Virtually all respondents thought the development of Scotland-wide sustainable design guidelines and simple assessment procedures would be useful for both planning officers and applicants to clarify expectations (Appendix A: Question 26; Figure A.12). Scotland-wide Design Guidelines were welcomed by the majority of survey respondents in all subject categories suggested. These included Sustainable Urban Planning; Sustainable Rural Planning; Sustainable Building Design; Large Scale LZCGT; Energy Efficient Architectural Design; Sustainable Construction, Materials and Embodied Energy; Fabric Energy Efficiency; and Small Scale LZCGT (Appendix A: Question 27; Figure A.13).

3.4 Interactions between Consent Process, Design & Construction Workflows

Scotland's two-stage consent process broadly reflects the timeline and workflow of most developments. Applicants seek planning consent once the major design decisions have been made, but before many of the technical decisions are taken. Once the technical design has been finalised building consent is sought and if awarded construction can commence. At the end of the construction phase compliance with any suspensive planning conditions must be verified and a completion certificate sought from Building Standards before the building can be occupied. This process is reflected in the RIBA Plan of Work (Table 5) (RIBA, 2020).

	RIBA Plan of Work Stage	Consent Stage
Stage 0	Strategic Definition	
Stage 1	Preparation and Briefing	
Stage 2	Concept Design	
Stage 3	Spatial Coordination	Planning Consent
Stage 4	Technical Design	Building Consent
Stage 5	Manufacturing and Construction	
Stage 6	Handover	Completion Certificate
Stage 7	Use	

Table 5: The relationship between the RIBA Plan of Work and key Consent Stages.

The fundamental paradox and unfortunate commercial reality is that this two-stage consent process and the design and development timeline are not conducive to encouraging architects and developers to expend energy and expense in defining and calculating the technical and performance outcomes of a project during the early design stages. On one hand, applicants want certainty that a development will gain planning consent before they are willing to invest further in a projects development. On the other hand, leaving the quantifiable assessment of the sustainable performance of a building until later in the design process negates the major savings in resources and efficiencies that can be gained at early stages.

A key change in emphasis in the updated RIBA Plan of Work 2020 is to challenge architects and design teams to design with a focus on sustainable outcomes from the outset of the project (RIBA, 2020). The approach requires sustainability outcomes and associated targets to be defined and agreed at the start of the project, reality-checked throughout the design and construction process and verified through post occupancy evaluation (Sinclaire, 2019). This objective is supported by the RIBA’s Sustainable Outcomes Guide which provides guidance on targeting, designing and evaluating sustainable outcomes for buildings of all scales and includes measures among others for designing to net-zero operational carbon, net-zero embodied carbon and sustainable lifecycle cost (RIBA, 2019b). This outcomes-based design approach addresses the acknowledged gaps between design intent and in-use performance across a range of metrics by reinforcing the feedback loop between briefing and realisation.

This new approach could also provide a vehicle to reinforce section 3F Policy and engage clients, professionals and planners in early discussions. It may also help alleviate current issues with the standard of compliance information provided in relation to Section 3F policy.

4. Proposal Overview

4.1 Introduction

In responding to the aim of the Scottish Government to develop a Scotland wide Section 3F development plan policy, we have considered both the established literature in relation to the most efficient, cost-effective and future-proof means of reducing CO_2 emissions from buildings, and the issues raised by planning professionals administrating current Section 3F planning policies in Scotland. This research resulted in the development of two distinct responses that might be appropriate for the Scottish Government to consider at this juncture.

In respect to calculating an appropriate level for LZCGT contribution, both proposals utilise predicted energy consumption data, modelled for domestic buildings ranging in size from $25m^2$ to $300m^2$ using formulae prescribed by SAP 2012 (BRE, 2014). In this respect three scenarios were developed to better represent the impact of expected improvements in fabric energy efficiency (Appendix B).

4.2 Proposal 1: A Minimum LZCGT Contribution Standard

The first proposal simply satisfies the research objectives as stated in the brief relative to Section 3F Policy as currently enacted. Section 3F policy does not seek to reduce the CO_2 emissions from new buildings beyond what is already legislated for at Building Standards; it simply defines the proportion of that reduction that should be achieved through the use of LZCGT.

The proposal defines a realistic minimum LZCGT contribution to CO_2 emission reduction in new buildings that could be sought by Section 3F policy and the method by which this contribution could be calculated to establish policy compliance. This is achieved through a simple and pragmatic approach which models the potential impact of utilizing LZCGT to replace a proportion of heat or electrical demand in domestic buildings on overall energy consumption; and interpreting the resultant graphical data in relation to what might be a reasonable minimum expectation of LZCGT use under different CO_2 emission reduction standards. The resultant LZCGT contribution level and compliance methodology can be applied to both domestic and non-domestic buildings.

In pursuing this methodology it is recognised that setting a minimum level of LZCGT contribution that is too high might have adverse consequences on long-term goals for CO_2 emission reduction, energy security and the ability to achieve wider societal goals. In particular it was concluded that the contribution level should not preclude architects from taking a fabric first approach or developing innovative passive design solutions, and should not restrict the ability to deliver affordable housing in a cost-effective way. It is also acknowledged that what is ‘reasonable’ is open to interpretation. As a consequence the level of LZCGT contribution calculated by this method was subsequently evaluated with respect to both implied and explicit expectations set out in current Scottish Government legislation i.e. Section 7 of the

Scottish Technical Standards (Domestic Buildings), the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019, and the Climate Change Plan.

4.3 Proposal 2: A Whole Building Approach

The second proposal takes a whole building approach which diverges significantly from the existing Section 3F policy and would therefore require new legislation. It re-invents this policy in a way that plays to the strengths and skillsets of planning whilst complementing and supporting the existing whole building approach to CO_2 emission reduction taken by building standards. It is anticipated that this proposed approach will add leverage to the type of sustainable and passive design solutions many planning authorities currently advocate, and address fundamental societal issues of consumption and the equitable use of resources; whilst simultaneously reducing energy demand, increasing fabric energy efficiency and incentivising the use of LZCGT.

This proposal is solely focussed on the domestic sector, and in essence seeks to cap annual energy demand in new dwellings to an ‘acceptable’ per capita level. This level will be calculated with reference to the predicted per capita energy consumption of modestly-sized energy efficient dwellings (45m^2 to 100m^2). As a consequence this policy will have a greater impact on dwellings with larger per capita heated living spaces.

Architects and developers will have the option of meeting the acceptable annual energy demand (AAED) calculated for their proposed building through any combination of design, fabric energy efficiency, equipment efficiency or LZCGT. Applicants will be encouraged to meet this target as far as possible through good design and fabric energy efficiency measures alone to avoid potential carbon lock-in. However if this is not feasible any remaining demand above the acceptable level will have to be met through the use of zero-carbon renewable energy resources. Policy compliance will be established by completing a simple standardised spreadsheet with data taken directly from the building’s SAP document.

5. Proposal 1: A Minimum LZCGT Contribution Standard

5.1 Key Points

Proposed methodology to identify the level of CO_2 emission savings that would be reasonable to expect from the use of LZCGT in new buildings.

- The methodology is based on the consideration of what would be an appropriate LZCGT contribution to the energy demand in new domestic buildings under different CO_2 emission reduction standards.
- The data used in these deliberations was based on the predicted energy demand for dwellings ranging in size from $25m^2$ to $300m^2$ calculated using formula prescribed in SAP 2012 (BRE, 2014).
- Three different scenarios were developed representing three different fabric energy efficiency standards: $45kWh/m^2$.annum, $30kWh/m^2$.annum and $15kWh/m^2$.annum. These scenarios provided a reasonable approximation of past, present/near future and future fabric energy efficiency contexts.
- Modelling was based on the domestic sector.
- It is important to recognise that what is judged reasonable, must be considered within the broader context of achieving CO_2 emission reductions in the most impactful, efficient and cost-effective way.
    1. It should not undermine a fabric first approach. This approach seeks to reduce CO_2 emissions by reducing overall energy demand and has numerous long-term economic, social and environmental benefits (IEA, 2019).
    2. It should not inhibit the potential to develop innovative passive design approaches.
    3. It should not restrict the ability to deliver essential infrastructure such as affordable and social housing in a cost effective way.
- Taking these factors into consideration the level of LZCGT contribution to CO_2 emission reduction that could be reasonably sought by the current Section 3F policy must by necessity be a minimum standard rather than an aspirational one.

Recommendation of the proportions of emission savings which may reasonably be achieved through the use of LZCGT applied to new buildings over the next 10 year period.

- Four different metrics are currently used to define the contribution of LZCGT to CO_2 emission reduction in Section 3F policies (Scottish Government, 2019c).

i. An absolute percentage CO_2 emission reduction relative to the 2007 baseline established by Scottish Building Standard 6.1.
ii. A percentage of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1 relative to the 2007 baseline.
iii. Avoidance of a percentage of projected CO_2 emissions as calculated by SAP/SBEM.
iv. Avoidance of a percentage of projected energy consumption as calculated by SAP/SBEM.

- Each metric has its own merits.
    i. Metric ii. is most frequently used
    ii. Metrics i. and ii. are quite abstract and difficult for architects to relate to in terms of the design process, but relate directly to governmental CO_2 emission reduction targets.
    iii. Metrics iii. and iv. are roughly analogous, relate more directly to the Section 3F policy definition, and are more meaningful and tangible from a designer's perspective.
    iv. It is useful for all stakeholders to be able to calculate each of these metrics and understand the relationship between them.
- On balance, we recommend that in Section 3F policy the minimum LZCGT contribution be defined in terms of a percentage of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1. because:
    i. It avoids potential conflict between Planning and Building Standards.
    ii. It simplifies Section 3F policy, by allowing the LZCGT contribution to be defined as a constant and perpetual percentage that will automatically deliver increases in real terms with every improvement of Standard 6.1 (Table 6).
    iii. It provides regulatory certainty going forward (Schwartz et al., 2020)
    iv. It ensures changes that occur in Building Standards 6.1 are reflected immediately, proportionately and automatically in Planning.
    v. It allows differences in the CO_2 emission reduction sought for domestic and non-domestic buildings at building standards, to be simply and automatically reflected in the LZCGT contribution sought at Planning.
- It is vital that it is understood that any attempt to increase the level of LZCGT contribution either disproportionately or at more frequent intervals than the changes to overall CO_2 emission reduction sought by Building Standard 6.1, will undermine a fabric first approach and the potential to develop innovative passive design approaches. It should therefore be avoided.
- We recommend that the LZCGT contribution to CO_2 emission reductions be defined as 12% of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1 (Table 6).

- This is a minimum standard and does not preclude designers of new buildings from using a higher percentage of LZCGT to meet their Target Emission Rate (TER) if they wish to do so.

R%	A %	C %	E %
0% CO_2 Reduction	0 %	12.0 %	0 %
30% CO_2 Reduction	3.6 %	12.0 %	4.9 %
45% CO_2 Reduction	5.4 %	12.0 %	8.9 %
60% CO_2 Reduction	7.2 %	12.0 %	15.3 %
75% CO_2 Reduction	9.0 %	12.0 %	26.5 %
90% CO_2 Reduction	10.8 %	12.0 %	51.9 %
100% CO_2 Reduction	12.0 %	12.0 %	100 %

Where:

R% = The percentage CO_2 emission reduction sought by Scottish Building Standard 6.1 relative to the 2007 baseline.

A% = The percentage LZCGT contribution defined as an absolute percentage CO_2 emission reduction relative to the 2007 baseline.

C% = The percentage LZCGT contribution defined as a percentage of the percentage CO_2 emission reduction sought by Scottish Building Standard 6.1.

E% = The percentage LZCGT contribution defined as avoidance of a percentage of projected CO_2 emissions as calculated by SAP/SBEM.

Table 6: Minimum LZCGT Contribution under different Scottish Building Standard 6.1 contexts.

Proposed calculation methodology for use by development management officers to understand whether the specified LZCGT contribution has been reached

- Not all LZCGT have zero carbon emissions. Therefore the simplest way to accurately calculate if the specified LZCGT contribution has been met is to run two separate SAP/SBEM calculations; one for the building as designed with the proposed LZCGT and another with the proposed LZCGT removed and replaced with pre-defined conventional systems. The CO_2 emission rates generated by these two SAP/SBEM calculations are then substituted into a formula to calculate the LZCGT contribution.
- We would recommend that the presumption of what replaces the LZCGT in this second SAP/SBEM calculation is consistent for all buildings; although the appropriateness of this needs further consideration by Building Standards.

- The formula to calculate the LZCGT contribution as a percentage of the percentage CO_2 emission reduction sought by Scottish Building Standard 6.1 is given by:

$$\mathbf{C\%} = \left(\frac{\mathbf{100\ (100 - R\%)}}{\mathbf{R\%}}\right)\left(\frac{\mathbf{DERNT - DER}}{\mathbf{TER}}\right) \geq \mathbf{12\%}$$

Where:

R% = Percentage CO_2 emission reduction sought by Standard 6.1
TER = Target Emission Rate
DER = Dwelling Emission Rate with LZCGT
DERNT = Dwelling Emission Rate with no LZCGT

Other Recommendations

- It is essential that going forward planning and building standards work in collaboration to manage issues related to climate change mitigation and CO_2 emission reduction. In respect to Section 3F policy:
  i. Conflict between planning and building standard approaches and legislation need to be resolved to provide clarity of intent and prevent confusion amongst applicants.
  ii. The current implementation and enforcement issues identified by planning authorities in relation to Section 3F policy need to be addressed.
  iii. It was strongly suggested by survey respondents that the LZCGT target contribution be written into Building Standards to resolve i) and ii).
  iv. Inter-departmental working practices at the level of local government need to be developed to support shared objectives, with feedforward and feedback mechanisms to monitor and improve collaborative practices.

5.2 Approach Rationale

5.2.1 What is Reasonable?

It is important to recognise that what is judged a reasonable LZCGT contribution to CO_2 emission reduction, must be considered within the broader context of achieving CO_2 emission reductions in the most impactful, efficient and cost-effective way, whilst simultaneously minimising adverse effects on other wider societal goals. Of particular concern is the potential negative impact on:

i. Fabric First Approaches:
The level of LZCGT contribution should not be so onerous that it undermines the ability of architects to adopt the high fabric energy efficiency standards of

a fabric first approach. This approach seeks to reduce CO_2 emissions by reducing overall energy demand and is considered by most of the literature to be the most cost-effective long-term strategy to reduce CO_2 emissions and has numerous other economic, social and environmental benefits (Payne et al., 2015; Grove-Smith et al., 2018; IEA, 2019).

ii. **Innovative Passive Design Approaches:**
The level should similarly not inhibit established passive design approaches such as Passivhaus, nor should it unduly inhibit the potential to develop further innovative passive design responses (IBO, 2009; Cotterell and Dadeby, 2013; Eberle and Aicher, 2016).

iii. **Developer Costs:**
As most LZCGTs currently have additional cost implications beyond those that would be incurred to achieve the same CO_2 emission reduction through energy efficiency measures; the level of contribution should not be so onerous that developers might be prompted to take legal action against planning decisions made on this issue.

iv. **Tackling the Housing Crisis:**
The level of LZCGT contribution should not be so high that it restricts the ability to deliver essential infrastructure such as affordable and social housing in a cost effective way.

v. **Tackling Energy Poverty:**
The financial benefits of reduced energy consumption due to increased fabric energy efficiency are felt directly by the occupant through reduced energy bills; but financial benefits related to LZCGT may accrue to landlords and are not always passed on to tenants.

That the determined level of LZCGT contribution to CO_2 emission reduction policy must by necessity be a minimum standard rather than an aspirational one, is not to suggest that the proportion should not be meaningful. A minimum standard can still be impactful. It has been shown that by making a small amount of LZCGT mandatory, architects and developers may be prompted to add additional capacity or adopt other technologies they had not previously considered.

This has been the experience in Switzerland where legislation requiring only $10W/m^2$ on-site renewable energy generation in new buildings has had a much larger impact because architects have generally avoided the tokenism of one PV panel and have instead provided substantial PV arrays (Schwarz et al., 2020). However there is also a note of caution in relation to this policy. Using PV is the most cost effective way to meet this target, therefore this policy has become by default technologically specific. It is considered preferable for policy robustness, that targets are neither too onerous nor written in a way that limits technological choice either directly or indirectly (Schwarz et al., 2020). These are fundamental principles that should be borne in mind when determining the level at which to set the LZCGT contribution.

It is also recognised that the relationship between Section 3F Policy and the Scottish Building Standards needs to be carefully defined and managed so that existing legislative conflicts are not exacerbated by setting a mandatory level of LZCGT contribution to CO_2 emission reduction that undermines the established whole building approach taken by Building Standards. This would also suggest that a minimum standard rather than an aspirational one is the most appropriate approach.

Whilst accepting that LZCGT have a role to play in reducing CO_2 emissions; Section 6: Energy of the Scottish Building Standards clearly promotes the view that the emphasis should be on reducing the overall energy consumption of buildings, and that this is best achieved through a balanced and holistic approach to building design, in which energy demand is limited by addressing both the performance of the building fabric and fixed building services (Scottish Government, 2019a). Exactly how a designer meets the Target Emission Rate (TER) set by the Standard Assessment Procedure (SAP) is completely at their discretion. There is a requirement to assess the feasibility of using LZCGT and the use of renewables is encouraged for both domestic and non-domestic buildings, but there is no compulsion to employ them. Indeed it is explicitly stated that in respect to high-efficiency alternative systems:

> ‘Whilst new buildings do not have to incorporate such technologies, the challenging standards set under Standard 6.1 (carbon dioxide emissions) do mean that they are a more common part of design solutions in energy efficient, low carbon buildings.’
>
> (Annex 6.C.1: Scottish Government, 2019a).

At the same time, we also recognised that Section 7: Sustainability of the Scottish Building Standards does include optional higher Sustainability Levels ‘Bronze Active’ and ‘Silver Active’ which accredit the use of LZCGT, but do not stipulate a specific contribution level (Scottish Government, 2019a; Scottish Government, 2019b). Although these are not mandatory requirements the intent to support Section 3F is clearly stated:

> ‘This level is primarily to assist local authorities to meet their obligations under Section 72 of the Climate Change (Scotland) Act 2009 by identifying the use of LZCGT. 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.’
>
> (7.1.3 and 7.1.5: Scottish Government, 2019a).

The only place in the Scottish Building Standards where the contribution of LZCGT is quantified is in optional higher Sustainability Level Aspect 3 in relation to Energy for Water Heating; where it is stated that a proportion of the annual energy demand for water heating should be from heat recovery and/or renewable sources with little or no associated fuel costs (e.g. solar thermal water heating and associated storage or heat recovery from greywater). The LZCGT contributions are defined respectively as:

Domestic Buildings:
Silver Aspect 3: 5% of the dwelling’s annual energy demand for water heating
Gold Aspect 3: 50% of the dwelling’s annual energy demand for water heating

(7.1.4 and 7.1.6: Scottish Government, 2019a)

Non-Domestic Buildings: (school buildings containing classrooms only)
Silver Aspect 3: 10% of the building's annual energy demand for water heating
Gold Aspect 3: 50% of the building's annual energy demand for water heating
(7.1.5 and 7.1.8: Scottish Government, 2019b)

It should also be noted that in dwellings, energy for water heating is currently calculated relative to occupancy and because many large dwellings have a relative small occupancy and large space heat demand, the hot water demand is proportionally less significant (Burford et al., 2019). The way energy for water heating is calculated is currently being reviewed in the proposed SAP 10. These measures do however give some indication of what is considered a reasonable LZCGT contribution to CO_2 emission reduction from the perspective of building standards, because each Sustainability Level is a package of measures and also includes under Aspect 1 the envisaged corresponding CO_2 emission reduction standard.

Domestic Buildings:
Silver: Aspect 1: 45% CO_2 emission reduction relative to 2007 Standard (Current)
Gold: Aspect 1: 60% CO_2 emission reduction relative to 2007 Standard
(7.1.4 and 7.1.6: Scottish Government, 2019a)
Non-Domestic Buildings: (school buildings containing classrooms only)
Silver: Aspect 1: 60% CO_2 emission reduction relative to 2007 Standard (Current)
Gold: Aspect 1: 75% CO_2 emission reduction relative to 2007 Standard
(7.1.5 and 7.1.8: Scottish Government, 2019b)

In conclusion, we consider a reasonable and appropriate level of LZCGT contribution to CO_2 emission reduction should reflect the following:

i. It should be a reasonable minimum expectation in respect to changing overall CO_2 emission reduction standards.
ii. It should be readily achievable by all buildings whether in an urban or rural context.
iii. The cost implications should not be overly onerous and should represent long-term value for money for stakeholders (Gürtler et al., 2019; Schwarz et al., 2020).
iv. The level should be low enough that is does not dis-incentivise a fabric first approach or innovative passive design responses to CO_2 emission reduction.
v. It should not restrict the designer to only one viable option in choice of LZCGT, either directly or indirectly (Schwarz et al., 2020).
vi. It should not interfere in the ability to deliver wider sociological goals or the ability to provide essential infrastructure such as affordable housing in a cost effective way.

5.2.2 Methodological Approach

To calculate what would represent a reasonable contribution LZCGT could be expected to deliver in respect to CO_2 emission reduction, one must first quantify the impact the use of LZCGT has on energy consumption in the context of new domestic buildings. This approach took into account an appreciation of the real-world limitations that might be encountered, and assumptions of the extent to which LZCGTs might be reasonably expected to deliver a rising proportion of the annual energy demand under tightening CO_2 emission reduction standards. The choice to base modelling on the domestic sector was taken for several reasons:

i. Domestic buildings are the most numerous building type dealt with by planning authorities.
ii. The domestic sector consumes a much larger proportion of energy for space heating, hot water and lighting than other sectors. According to UK national statistics; in 2018 the domestic sector consumed 35,399ktoe (thousand tonnes of oil equivalent) for space heating, hot water and lighting; whilst the industrial and service sectors only used 2,104ktoe and 12,692ktoe respectively (BEIS, 2019a).
iii. When compared to domestic buildings, non-domestic buildings have a fairly diverse range of energy consumption patterns contingent to their functional needs. It was therefore considered more reliable to determine a reasonable LZCGT contribution for the domestic sector and extrapolate to the non-domestic, rather than vice versa.
iv. The conviction that the LZCGT contribution level recommended should not impact negatively on the ability to deliver essential domestic infrastructure such as affordable or social housing in a cost effective way, established this as a context that was essential to model.

To determine a reasonable level of LZCGT contribution the predicted energy demand for new dwellings ranging in size from 25m^2 to 300m^2 was calculated using formulae prescribed in the Standard Assessment Procedure (SAP 2012) and three different fabric energy efficiency scenarios (BRE, 2014). These scenarios were developed to provide a reasonable approximation of past (2012), present/near future (2020-2021) and future (2024-2050) fabric energy efficiency contexts, and allow a better understanding of how tightening CO_2 emission reduction standards could potentially impact on the contribution and cost-effectiveness of LZCGT. The fabric energy efficiency standards chosen were 45kWh/m^2.annum, 30kWh/m^2.annum and 15kWh/m^2.annum respectively. Although theoretically fabric energy efficiencies greater than 15kWh/m^2.annum are possible; on balance this was considered a practical upper limit in respect to future scenarios. This is the level of fabric energy efficiency prescribed for Passivhaus and given the right impetus it is readily achievable using prefabricated timber frame construction in Scotland (Kinghorn Housing Association, 2010; Paul Heat Recovery Scotland, 2020a).

The data generated by this means was used to calculate and graph the potential impact of using LZCGT to either replace specific proportions of space and/or water heating demand or to generate electricity to offset demand. The implications of these measures were considered both in terms of the energy generated (kWh/annum) and the proportion of the overall annual energy demand this represented. By considering the variety of measures that might be capable of delivering these results and bearing in mind real world limitations it was possible to determine what might be a reasonable LZCGT contribution to include in Section 3F policy. Whilst making this determination particular emphasis was placed on ensuring that potential LZCGT contribution levels would not be overly onerous for dwellings within the size range of

45m^2 to 100m^2, which was identified as the critical range likely to contain the majority of social and affordable housing (Appendix E; Joyce, 2011; Onyango et al., 2016; Scottish Government, 2017b, pp. 18-19). This critical sub-group of dwellings became our limiting context against which final judgements of reasonableness were primarily made.

This LZCGT contribution was subsequently calculated and expressed in three ways (Table 6):

i. An absolute percentage CO_2 emission reduction relative to the 2007 baseline established by Scottish Building Standard 6.1.
ii. A percentage of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1 relative to the 2007 baseline.
iii. Avoidance of a percentage of projected CO_2 emissions as calculated by SAP/SBEM. This is roughly analogous to avoidance of a percentage of projected energy consumption.

The third metric is roughly analogous to the one used throughout this methodology, is the most meaningful and tangible from a designer's perspective, and relates directly to the Section 3F policy definition. However it is recognised that the second metric has distinct advantages in terms of policy definition because:

i. It avoids potential conflict between Planning and Building Standards.
ii. It simplifies Section 3F policy, by allowing the LZCGT contribution to be defined as a single constant percentage applied to both domestic and non-domestic buildings that will automatically deliver increases in real terms with every improvement of Building Standard 6.1 (Table 6).
iii. It provides regulatory certainty moving forwards.
iv. It ensures changes that occur in Building Standards 6.1 are reflected immediately, proportionately and automatically in Planning.
v. It allows differences in the CO_2 emission reduction sought for domestic and non-domestic buildings at building standards, to be simply and automatically reflected in the LZCGT contribution sought at Planning (Scottish Government, 2019a; Scottish Government, 2019b).

5.3 Proposed Methodology: Identifying a reasonable level for LZCGT contribution to CO_2 emission reduction in new buildings

5.3.1 Methodological Steps

1 Calculate and graph the annual energy demand of dwellings sized 25m^2 to 300m^2, under three different fabric energy efficiency scenarios, using:
   i. Space heat demands
      Scenario 1: 45kWh/m^2.annum (Past 2012),
      Scenario 2: 30kWh/m^2.annum (Present/Near Future 2020 to 2021)
      Scenario 3: 15kWh/m^2.annum (Future 2024 to 2050)

ii. The hot water demand calculation method outlined in SAP 2012 (BRE, 2014).
iii. The electricity for lighting demand calculation method outlined in SAP 2012 (BRE, 2014). Assuming 75% fixed low energy lighting outlets (Scottish Government, 2015, p85).
iv. Electricity consumed by pumps and fans associated with building services.
Scenarios 1 & 2: 75kWh/annum for general building services.
Scenario 3: 75kWh/annum plus electricity to operate an MVHR unit. This was calculated using the method outlined in SAP 2012 (BRE, 2014).

2 With respect to each scenario; calculate and graph relative to dwelling size, the potential contribution to annual energy demand represented by:
   i. Replacing different proportions of the space heat demand and/or hot water demand with LZCGT
   ii. Generating electricity with LZCGT (PV panels) to offset annual energy demand.

3 With respect to each scenario; calculate and graph relative to dwelling size, each of these strategies as a percentage of the annual energy demand.

4 Recognise that energy use and CO_2 emissions in buildings are analogous systems, and mathematically define the relationship between these elements, so that the percentage LZCGT contributes to annual energy demand can be expressed in terms of CO_2 emission reduction. Potential CO_2 metrics definitions to include:
   i. An absolute percentage CO_2 emission reduction relative to the 2007 baseline established by Scottish Building Standard 6.1.
   ii. A percentage of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1 relative to the 2007 baseline.
   iii. Avoidance of a percentage of projected CO_2 emissions as calculated by SAP/SBEM.

5 Utilizing the information modelled for each scenario; determine what would represent a reasonable minimum LZCGT contribution to annual energy demand under different CO_2 emission reduction standards. Criteria for judging a reasonable LZCGT level include:
   i. It is readily achievable by all buildings whether in an urban or rural context.
   ii. It is low enough that is does not dis-incentivise a fabric first approach.
   iii. The cost implications should not be overly onerous and should represent long-term value for money.
   iv. It does not restrict the designer to only one viable option in choice of LZCGT, either directly or indirectly.
   v. It should not interfere in the ability deliver wider sociological goals or provide essential infrastructure such as affordable housing in a cost effective way. Dwellings between $45m^2$ – $100m^2$ were used as the critical limiting context.

5.3.2 STEP 1: Calculate Annual Energy Demand

Calculate and graph the annual energy demand of dwellings sized 25m^2 to 300m^2, under three different fabric energy efficiency scenarios.

Occupancy: N

In domestic buildings, occupancy is fundamental to the calculation of the heat demand for domestic hot water [SAP Box No. 64] and the electric demand for lighting [SAP box No. 232]. For dwellings the UK Government's Standard Assessment Procedure SAP 2012 calculates an assumed occupancy, N [SAP Box No. 42] for a proposed dwelling relative to its total floor area TFA [SAP Box No. 4] by the formula:

If TFA > 13.9,

$$N = 1 + 1.76 \times [1 - \exp(-0.000349 \times (TFA - 13.9)^2)] + 0.0013 \times (TFA - 13.9)$$

If TFA < 13.9,

$$N = 1$$

Formula 1 (BRE, 2014)

This formula is based on empirical evidence of average occupancy of dwellings in England (BRE, 2008). Figure 5 illustrates this relationship and indicates that from approximately 90m^2 the average occupancy pattern of dwellings begins to change and eventually saturates at close to 3 occupants in larger homes.

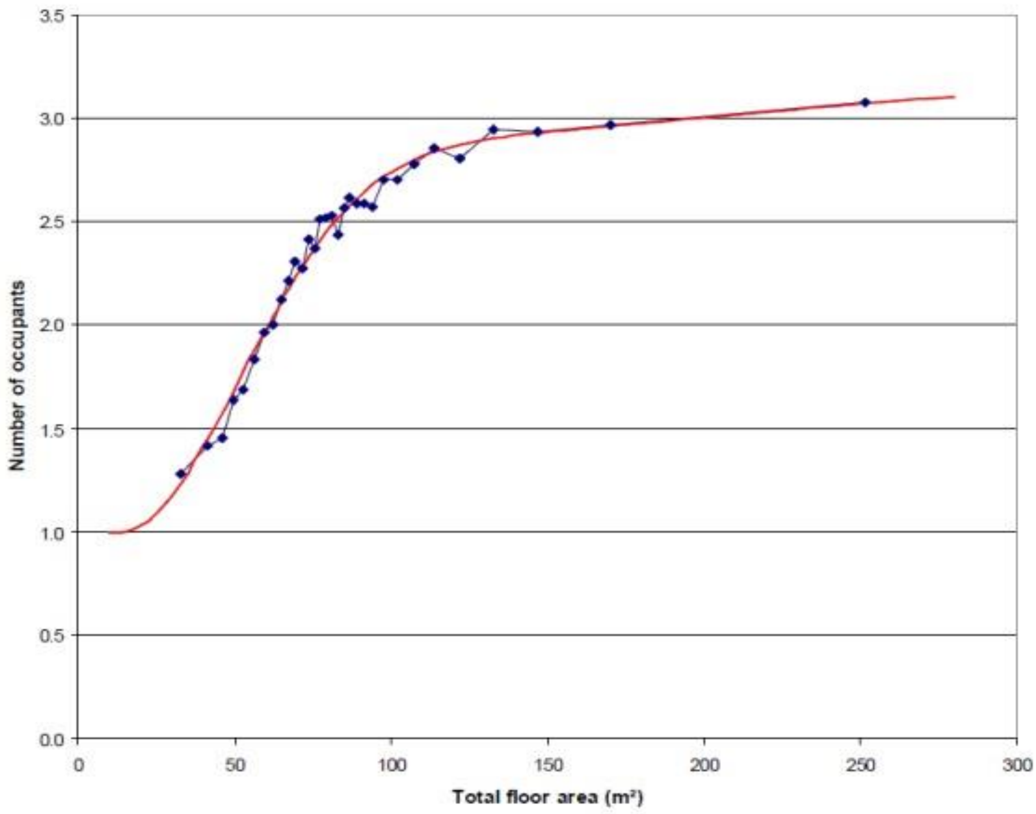


Figure 5: The relationship between floor area and occupancy in SAP 2012 calculations (blue = average data points, red = predictive formula (BRE, 2008).

Annual Space Heating & Space Cooling Demand: SHD

Three scenarios were developed for this study, each representing a level of fabric energy efficiency that might be reasonably expected and achievable by a moderate sized dwelling built under the Scottish Building Standards. These scenarios were developed to provide a better appreciation of past (2012), present (2020 to 2021) and future (2024 to 2050) fabric energy efficiency contexts, and allow a more accurate model of how tightening CO_2 emission reduction standards could potentially impact on the contribution and cost-effectiveness of LZCGT (Appendix E). The annual space heating & space cooling demands suggested for each scenario are:

Scenario 1:	**45kWh/m^2.annum**	Past	2012
Scenario 2:	**30kWh/m^2.annum**	Present/Near Future	2020 - 2021
Scenario 3:	**15kWh/m^2.annum**	Future	2024 - 2050

Using these values for each scenario, the annual space heating & space cooling demand (kWh/annum) was calculated for dwellings ranging in size from 25m^2 to 300m^2 using Formula 2. These are graphically represented in Appendix B: Figures S1.1, S2.1 and S3.1. Most domestic buildings do not require space cooling.

$$\text{SHD} = \text{TFA (m}^2\text{) x Annual Space Heating/Cooling Demand (kWh/m}^2\text{.annum)}$$

Formula 2

Annual Hot Water Demand: HWD

In SAP 2012 annual average hot water usage in litres per day [SAP box No. 43] is calculated relative to assumed occupancy N [SAP Box No. 42] using the formula:

Daily domestic hot water usage (litres) $V_{d,average} = (25 \times N) + 36$

Formula 3 (BRE, 2014)

Over the course of the year the energy content of the hot water used [SAP Box No. 45] can be calculated in kWh/annum using the formula:

$$\text{Annual energy content of domestic hot water} = \frac{4.18 \times V_{daverage} \times n_{annual} \times \Delta T_{annual}}{3600}$$

Formula 4 (BRE, 2014)

Where:

n_{annual} = number of days in a year
= 365

ΔT_{annual} = annual average temperature rise of hot water drawn off
= 37.0

In reality the energy consumed heating domestic hot water will be greater than this, due to specific equipment efficiencies, transmission losses or storage heat losses. SAP 2012 calculates these losses and apportions a proportion of them to dwelling heat gains. For the purposes of this calculation we will consider the annual energy content of domestic hot water a fair approximation of the annual hot water demand. For each scenario, the annual hot water demand (kWh/annum) was calculated for dwellings ranging in size from 25m^2 to 300m^2 using Formulae 3 and 4. These are graphically represented in Appendix B: Figures S1.1, S2.1 and S3.1.

Annual Lighting Demand: LD

SAP 2012 calculates the annual energy use for lighting in a dwelling using the formula:

$$E_L = E_B \times C_1 \times C_2$$

Formula 5 (BRE, 2014)

Where:

E_B	=	Average annual energy consumption for lighting if no low-energy lighting
	=	$59.73(TFA \times N)^{0.4714}$
C_1	=	Correction for fixed lighting outlets with low-energy lamps
	=	$1 - 0.5\left(\frac{L_{LE}}{L}\right)$
C_2	=	Correction for daylighting
TFA	=	Total floor area
N	=	Occupancy
L_{LE}	=	Number of fixed low energy lighting outlets
L	=	Number of fixed lighting outlets

Assuming $C_1 = 0.625$ (75% low energy lighting outlets) and $C_2 = 0.96$; for each scenario, the annual energy demand for lighting (kWh/annum) was calculated for dwellings ranging in size from 25m^2 to 300m^2 using Formula 5. These are graphically represented in Appendix B: Figures S1.1, S2.1 and S3.1.

Annual Electricity Demand for Pumps and Fans: P&F

The annual electricity demand for pumps and fans (P&F) has been assumed to be 75kWh/annum in Scenarios 1 and 2, no matter the size of dwelling. In SAP 2012, this represents 45kWh/annum for a gas boiler flue fan and 30kWh/annum for a central heating pump for radiators or underfloor heating (BRE, 2014).

However, Scenario 3 has been defined with a very high fabric energy efficiency and air-tightness on a par with a Passivhaus, it is therefore expected that an MVHR unit will be necessary to maintain good indoor air quality. Consequently, in addition to the 75kWh/annum assumed for Scenario 1 and 2; Scenario 3 also includes an allowance for electricity consumed by an MVHR unit.

With reference to SAP 2012, the electricity used to operate an MVHR unit is given by Formula 6.

$$E_{MVHR} = IUF \times SFP \times 2.44 \times n_{mech} \times V$$

Formula 6 (BRE, 2014)

Where:

IUF	=	Applicable in-use factor
SFP	=	Specific fan power
n_{mech}	=	Throughput of the MVHR system
	=	0.5 air changes per hour (ach)
V	=	Volume of the building (m^3)
	=	TFA x H
TFA	=	Total floor area [SAP box No. 4]
H	=	Room height (assumed as 2.4m)

To provide a realistic estimate of the actual electricity consumed in operating an MVHR unit in various sized dwellings, data was drawn from the product characterisation database with respect to a Paul Novus 300 (BRE, 2016a). This is the type of highly-efficient MVHR unit that would be specified in a Passivhaus context. The assumptions made in the calculation of Formula 6 for Scenario 3 are set out in Table 7. Realistically these will vary in different dwellings.

Dwelling Size	Description	SFP	IUF (Rigid Duct)
TFA ≤ 100m^2	Kitchen + 2 Wet Rooms	0.66	1.4
100m^2 < TFA ≤ 200m^2	Kitchen + 3 Wet Rooms	0.73	1.4
TFA > 200m^2	Kitchen + 4 Wet Rooms	0.83	1.4

Table 7: Specific fan power (SFP) and in-use factors (IUF) for a Paul Novus 300 MVHR unit, with respect to different built contexts (Scenario 3) (BRE, 2016a).

The values calculated for each Scenario are graphically represented in Appendix B: Figures S1.1, S2.1 and S3.1.

Annual Energy Demand: AED

Combining these four elements, the total annual energy demand (for space heating, space cooling, hot water, lighting and attendant pumps and fans) was calculated for dwellings ranging in size from 25m^2 to 300m^2 in each scenario, using Formula 7. These are graphically represented in Appendix B: Figures S1.1, S2.1 and S3.1.

AED = SHD + HWD + LD + P&F

Formula 7

In relation to the SAP 2012 document this would be represented by:

AED = [SAP Box 98] + [SAP Box 107] + [SAP Box 64] + [SAP Box 232] + [SAP Box 231]

Formula 8

Figure 6 depicts the changes in the annual energy demand relative to dwelling size under each fabric efficiency scenario. This graph aptly illustrates the impact tackling fabric efficiency has on reducing the annual energy demand and CO_2 emissions from a building. This in turn reduces the scale and cost of the heating plant or LZCGT required to meet this annual energy demand.

It should also be noted that whilst LZCGT may last for 15 – 20 years before needing replacement, the fabric will perform throughout the lifetime of the building and is much more expensive to upgrade at a later date than during the construction phase (CCC, 2019d, p14). If the fabric is not to a good standard from the start, the building will tend to underperform throughout its life (Urge-Vorsatz et al., 2013; Beradi, 2016).

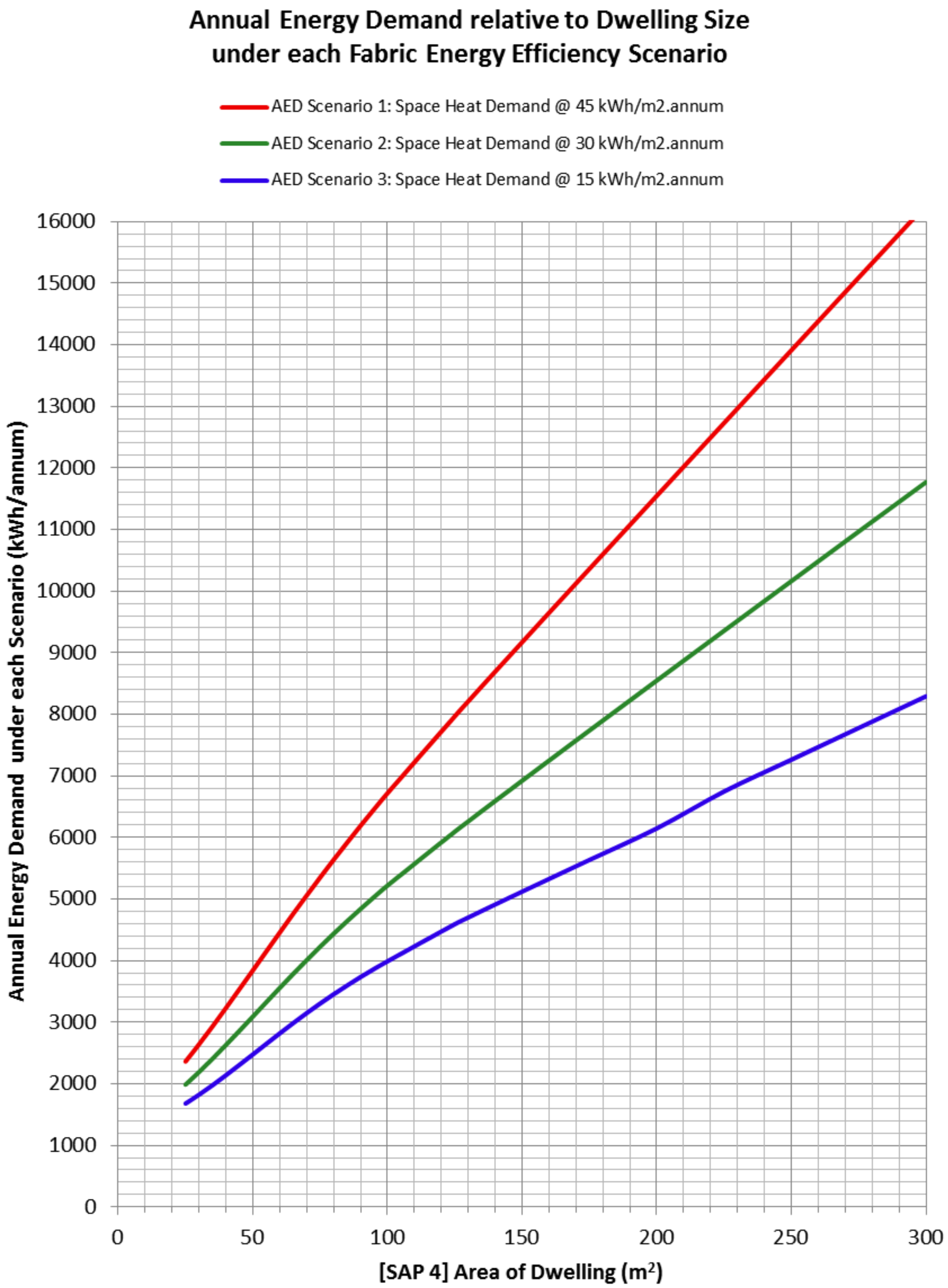


Figure 6: Annual energy demand relative to dwelling size under each of the three fabric efficiency scenarios.

5.3.3 STEP 2: Calculate Potential LZCGT Contributions to Annual Energy Demand.

With respect to each scenario; calculate and graph relative to dwelling size, the potential contribution to annual energy demand represented by:

i. Replacing different proportions of the space heat demand and/or hot water demand with LZCGT; and
ii. Generating electricity with LZCGT (PV panels) to offset annual energy demand.

Replacing a Proportion of Space Heat Demand and/or Hot Water Demand with LZCGT

For each scenario, the potential contribution of LZCGT in kWh/annum was calculated for each of the following intervention strategies for dwellings ranging in size from $25m^2$ to $300m^2$. Single system intervention strategies are graphically represented in Appendix B: Figures S1.2, S2.2 and S3.2; Dual system intervention strategies in Appendix B: Figures S1.3, S2.3 and S3.3.

Single System Intervention Strategy:

i. 10% of the hot water demand
ii. 20% of the hot water demand
iii. 50% of the hot water demand
iv. 66.6% of the hot water demand
v. 10% of the space heat demand
vi. 20% of the space heat demand
vii. 50% of the space heat demand
viii. 66.6% of the space heat demand

Dual System Intervention Strategy:

i. 10% of the hot water demand + 10% of space heat demand
ii. 10% of the hot water demand + 20% of space heat demand
iii. 10% of the hot water demand + 50% of space heat demand
iv. 20% of the hot water demand + 10% of space heat demand
v. 20% of the hot water demand + 20% of space heat demand
vi. 20% of the hot water demand + 50% of space heat demand
vii. 50% of the hot water demand + 10% of space heat demand
viii. 50% of the hot water demand + 20% of space heat demand
ix. 50% of the hot water demand + 50% of space heat demand
x. 66.6% of the hot water demand + 66.6% of space heat demand

Generating Electricity with LZCGT (PV panels) to Offset AED

In the UK, 1 kWp of PV will typically produce 720 to 940kWh/annum, depending on factors such as the latitude and prevailing microclimate of the site, as well as the orientation, inclination and over shading of the installation (BRE, 2014). SAP 2012 calculates the electricity produced by a PV module in kWh/year using the formula:

$$E_{PV} = 0.8 \times kWp \times S \times Z_{PV}$$

Formula 9 (BRE, 2014)

Where:

kWp	=		Installed peak power of the PV units
Z_{PV}	=		Over shading factor (none or very little = 1.0)
S	=		Annual solar radiation (kWh/m²) on a surface of any orientation and tilt
	=		$0.024 \sum_{m=1}^{12} n_m \times S(\mathrm{orient}, p, m)$
n_m	=		Number of days in month m
S(orient, p, m)	=		Solar radiation for any orientation and tilt (W/m²)
	=		$S_{h,m} \times R_{h\text{-}inc}(\mathrm{orient}, p, m)$
$S_{h,m}$	=		Horizontal solar flux for applicable month (W/m²) (BRE, 2014)
$R_{h\text{-}inc}$(orient, p, m)	=	*	Factor for converting from horizontal to vertical or inclined solar flux in month m for a given orientation and tilt
	=		$A \times \cos^2(\phi - \delta) + B \times \cos(\phi - \delta) + C$
ϕ	=	*	Latitude (UK average = 53.5°)
δ	=	*	Solar declination for the applicable month (BRE, 2014)
A	=	*	$k_1 \times \sin^3\left(\frac{p}{2}\right) + k_2 \times \sin^2\left(\frac{p}{2}\right) + k_3 \times \sin\left(\frac{p}{2}\right)$
B	=	*	$K_4 \times \sin^3\left(\frac{p}{2}\right) + k_5 \times \sin^2\left(\frac{p}{2}\right) + k_6 \times \sin\left(\frac{p}{2}\right)$
C	=	*	$K_7 \times \sin^3\left(\frac{p}{2}\right) + k_8 \times \sin^2\left(\frac{p}{2}\right) + k_9 \times \sin\left(\frac{p}{2}\right) + 1$
p	=	*	The tilt of the surface in degrees from horizontal (Pitch = 30°)
k_1	=		Orientation SW = -2.95
K_2	=		Orientation SW = 2.89
K_3	=		Orientation SW = 1.17
K_4	=		Orientation SW = 5.67
K_5	=		Orientation SW = -3.54
K_6	=		Orientation SW = -4.28
K_7	=		Orientation SW = -2.72
K_8	=		Orientation SW = -0.25
K_9	=		Orientation SW = 3.07
		*	All angles must be converted to radians for calculation purposes

For the purpose of this study, we will presume the modelled PV units benefit from the same conditions used to calculate the contribution of PV units to the Target Emission Rate (TER) in SAP calculations. This is defined as: the region is 'UK average', orientation 'SW', pitch '30°' and over shading 'none or very little' (Scottish Government, 2019a). Using these assumptions, Formula 9 calculated the electricity produced by 1kWp of PV as 823kWh/annum.

The use of photovoltaics has several physical limitations. In the UK, the optimum panel performance is achieved when they are installed at an angle of 30 to 40 degrees, orientated towards the south and not over shadowed. Installation on a south-facing roof is therefore ideal. The size and weight of the PV array and the availability of appropriate roof space are the prime limiting factors in their use. PV panels can be installed at less than optimum angles and orientations but their performance will suffer. Installed horizontally they will still deliver approximately 90% of the optimum performance, but as they will not be able to self-clean efficiently at this angle the output will drop further if they are allowed to become dirty (Free Solar Panels, 2011; Eco Home Essentials, 2020).

Four differently sized PV arrays were modelled for this study (Table 8) and the potential contribution in KWh/annum of each graphically represented in Appendix B: Figures S1.4, S2.4 and S3.4. It should be noted that because of the practical limitations of PV their use should be considered early in the design process. Even with good design orientation, larger systems might not be appropriate for small dwellings and flats because of physical size limitations.

Modelled PV Arrays:

System Rating	kWp	1	2	3	4
Number of Panels (approx.)		4	8	12	16
Area of Array (approx.)	m^2	8	16	24	32
Output	kWh/annum	823	1646	2469	3292

Table 8: Modelled PV arrays, expected size constraints and output in kWh calculated from formula 9 using assumptions outlined above (Clissitt, 2020).

5.3.4 STEP 3: Calculate Potential LZCGT Contributions as a Percentage of Annual Energy Demand.

For each scenario the potential contributions of LZCGT in each intervention strategy identified in Step 2 was calculated as a percentage of the annual energy demand for dwellings ranging in size from $25m^2$ to $300m^2$. Single system intervention strategies are graphically represented relative to dwelling size in Appendix B: Figures S1.5, S2.5 and S3.5; Dual system intervention strategies in Appendix B: Figures S1.6, S2.6 and S3.6; and PV intervention strategies in Appendix B: Figures S1.7, S2.7 and S3.7.

For each scenario the percentages calculated for dwellings of a size critical for affordable housing i.e. between $45m^2$ and 100 m^2 are tabulated for clearer understanding. These are found in Appendix B: Table S1.1, S2.1 and S3.1.

5.3.5 STEP 4: Define the mathematical relationship between Energy Use and CO_2 Emissions in buildings

Mathematically define the relationship between energy use and CO_2 emissions in buildings so that the percentage LZCGT contributes to annual energy demand can be expressed in terms of a CO_2 emission reduction.

Analogous Systems

To facilitate a better understanding of the relationship between energy use in buildings and CO_2 emissions, and a familiarity with the terms used when calculating CO_2 emissions using the UK's Standard Assessment Procedure (SAP) these have been expressed diagrammatically in Figure 7. With reference to this figure; if we assume that the LZCGT contribution on the Energy side of the diagram has little or no associated operational CO_2 emissions (most renewables and heat recovery systems), or if there are sizable CO_2 emissions associated with the LZCGT (e.g. from the electricity consumed in operating a heat pump) this quantity is adjusted appropriately to take this into account; then we could consider Energy and CO_2 Emissions as analogous.

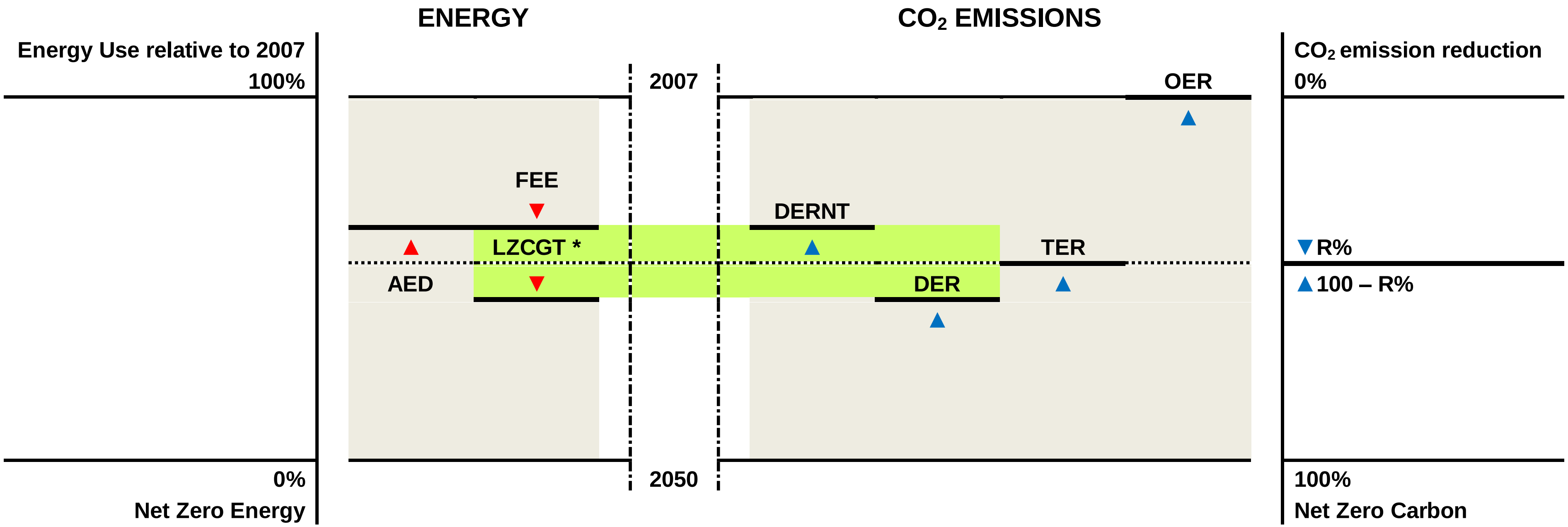
From that we can deduce that:

$$\frac{\mathrm{LZCGT}}{\mathrm{AED}} \equiv \frac{\mathrm{DERNT}-\mathrm{DER}}{\mathrm{DERNT}}$$

Formula 10

Where, and in relation to further discussions:

AED	=	Annual Energy Demand
LZCGT	=	LZCGT Energy Contribution
OER	=	Original Emission Rate (0% reduction relative to 2007 Baseline)
TER	=	Target Emission Rate (calculated by SAP 2012)
DER	=	Dwelling Emission Rate of the building as designed (calculated by SAP 2012). Fabric energy efficiency (FEE), equipment efficiency (EE) & LZCGT are all used to achieve this DER
DERNT	=	Dwelling Emission Rate calculated with LZCGT removed and replaced with predefined conventional energy systems (calculated by SAP 2012)
R%	=	Statutory required CO_2 emission reduction sought by Building Standard 6.1 defined as a percentage relative to the 2007 baseline standard. This is currently: A 45% CO_2 emission reduction for Domestic Buildings A 60% CO_2 emission reduction for Non-Domestic Buildings



Analogous Systems:

Notes: * Assuming that the LZCGT Contribution has little or no associated CO_2 emissions (most renewables and heat recovery systems) or if there are substantial CO_2 emissions associated with the LZCGT (most heat pumps) this quantity is adjusted appropriately to take this into account.

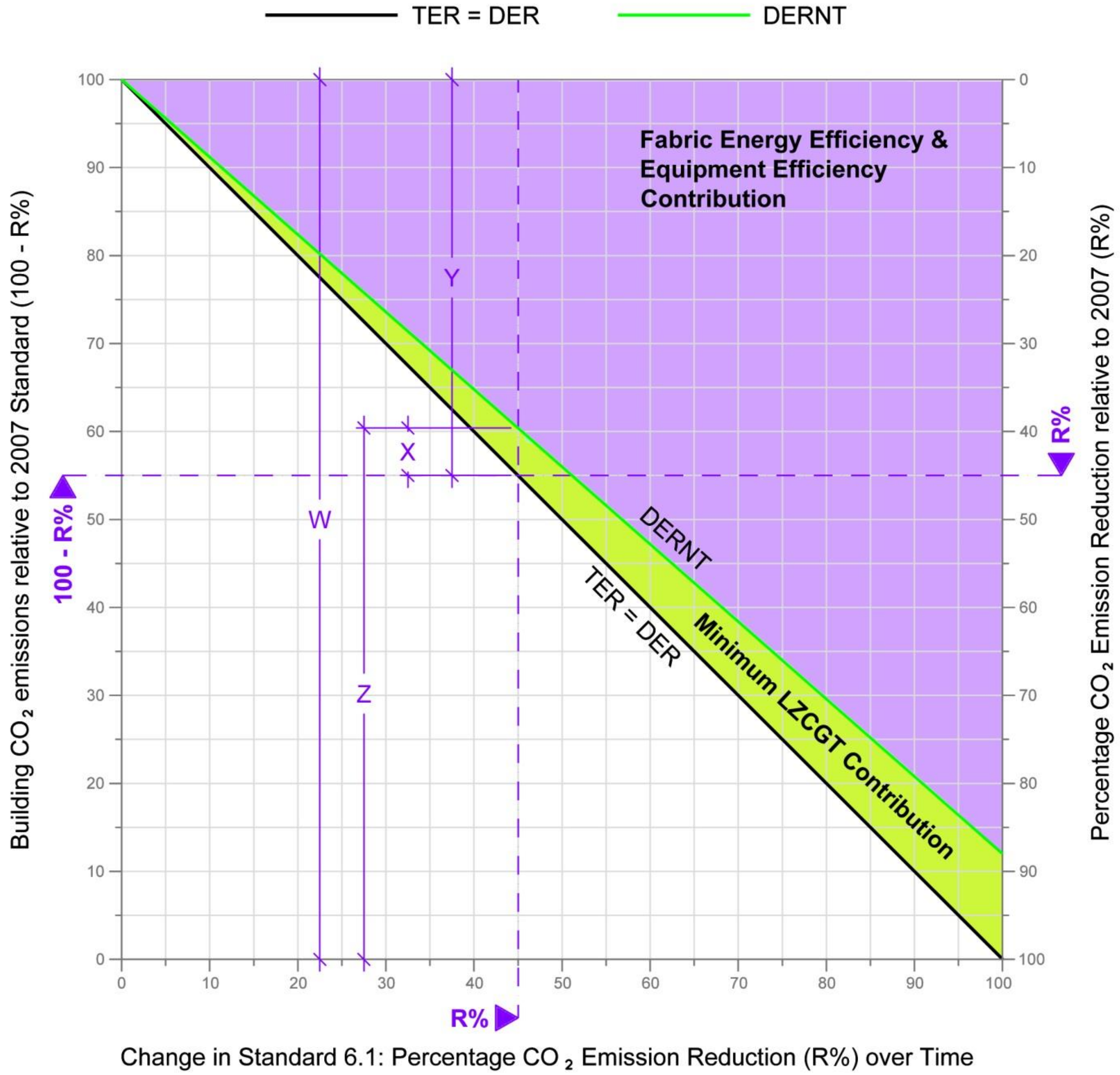
It should also be noted that CO_2 emissions from the use of biomass and biogas are not accurately represented in the current regulatory system.

Key:

AED	Annual Energy Demand
FEE	Fabric Energy Efficiency
LZCGT	LZCGT Contribution to the Energy Mix
OER	Original Emission Rate (0% reduction – 2007 Baseline)
TER	Target Emission Rate (calculated by SAP 2012)
DER	Dwelling Emission Rate (calculated by SAP 2012)
DERNT	Dwelling Emission Rate calculated with LZCGT removed and replaced with predefined conventional energy systems (calculated by SAP 2012)
R%	Percentage CO_2 emission reduction sought by Standard 6.1 relative to 2007.

Figure 7: Energy Use and CO_2 Emissions from buildings seen as analogous systems

The Relationship between the Minimum LZCGT Contribution and Scottish Building Standard 6.1: CO_2 Emissions



For ANY Percentage CO_2 Emission Reduction Standard = R%

$$A\% = \frac{X}{W} \times 100 \qquad C\% = \frac{X}{Y} \times 100 \qquad E\% = \frac{X}{Z} \times 100$$

Figure 8: The changing relationship between Minimum LZCGT Contribution and Scottish Building Standard 6.1: CO_2 Emissions over time, including graphical representation of the three potential metrics and how these are calculated. The graph depicts a LZCGT contribution of C% = 12%, and illustrates the measurement required for the current domestic CO_2 emission reduction standard of 45% relative to the 2007 standard. However, this graph can be used to calculate a value for any of the metrics for any emission reduction standard. Simply draw a vertical line up from the required CO_2 emission reduction standard (x-axis), measure the values for W, X, Y or Z at that point on the graph and perform the relevant highlighted calculation. It should be borne in mind that this is a minimum LZCGT contribution. A designer might elect to use more than the minimum LZCGT. In this circumstance if the DER = TER then the DERNT would plot in the purple zone.

Figure 8 expands on the analogous relationship defined in Figure 7, and depicts in the form of a straight line graph the potential change in the relationship between these elements as the country moves in time from the baseline of the 2007 standard (100% emissions / 0% reduction) towards zero carbon buildings (0% emissions / 100% reduction). In Figures 7 and 8 the space between the lines representing DER and DERNT denotes the contribution made to CO_2 emission reduction by LZCGT. In both diagrams this is shaded green.

In relation to Figure 8; if we presume that the building meets CO_2 emission standard 6.1, but does not go beyond it, i.e. the Dwelling Emission Rate equates to the Target Emission Rate (DER = TER), and the minimum acceptable amount of LZCGT was used to achieve the Target Emission Rate, then the line denoting DERNT would define the minimum acceptable amount of LZCGT as defined under Section 3F planning policy.

Envisioned as a straight line dissecting the upper portion of Figure 8; this implies that the minimum LZCGT contribution required by Section 3F policy could be written in terms of a fixed proportion of the percentage CO_2 emission reduction required by Scottish Building Standard 6.1. Practically this would have a number of advantages in terms of simplifying Section 3F Policy. Although this proportion would remain unaltered; because the Scottish Building Standards are regularly improved, this would 'ensure that all new buildings avoid a specified and rising proportion of the projected greenhouse gas emissions' in real terms, as required by Section 3F Policy (Scottish Parliament, 2019b).

Three ways of measuring LZCGT contribution to CO_2 emission reduction in buildings have been identified in current Section 3F policies (Scottish Government, 2019c). For clarity we have designated these as A%, C% and E% respectively:

- A% An absolute percentage CO_2 emission reduction relative to the 2007 baseline established by Scottish Building Standard 6.1.
- C% A percentage of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1 relative to the 2007 baseline.
- E% Avoidance of a percentage of projected CO_2 emissions as calculated by SAP/SBEM.

How these metrics are calculated and their relationship to each other is expressed in Figure 8, and defined mathematically below:

An absolute percentage CO_2 emission reduction relative to the 2007 Standard: A%

With reference to Figures 7 and 8; for any CO_2 emission reduction standard (R%), the absolute percentage LZCGT contributes to CO_2 emission reduction is defined by Formula 11.

$$\mathbf{A\%} = \left(\frac{\mathbf{DERNT - DER}}{\mathbf{OER}}\right) \mathbf{x\ 100}$$

Formula 11

To visualise how this proportion increases with changes to building standards over time refer to Figure 8.

A percentage of the percentage CO_2 emission reduction sought by Building Standard 6.1: C%

The percentage CO_2 emission reduction sought by Building Standard 6.1 is defined relative to the 2007 Standard. It is different for domestic and non-domestic buildings. The LZCGT contribution as a percentage of this percentage CO_2 emission reduction is defined by Formula 12.

$$\mathbf{C\% \quad = \quad \left(\frac{A\%}{R\%}\right) x\ 100}$$

Formula 12

Figure 8 clearly illustrates the possibility that by using this metric, the LZCGT contribution could be defined as a constant percentage yet still deliver increasing CO_2 emission reductions with every improvement in building standards.

Avoidance of a percentage of projected CO_2 emissions as calculated by SAP/SBEM: E%

This metric is the one most closely aligned to the definition included in Section 3F policy. With reference to Figures 7 and 8, it is defined by Formula 13.

$$\mathbf{E\% \quad = \quad \left(\frac{DERNT-DER}{DERNT}\right) x\ 100}$$

Formula 13

With reference to the analogies drawn between energy use and CO_2 emissions from buildings explored in Figure 7 and Formula 10, and taking into consideration the assumptions we made in drawing those analogies; we can conclude that this metric will deliver a broadly similar percentage to defining the LZCGT contribution as a percentage of annual energy demand. This is not exact. However if an awareness of any associated CO_2 emissions and the carbon factors SAP applies to different fuels and technologies are borne in mind, and some of the LZCGT contribution discounted proportionately, it provides a good approximation. For designers it is the most useful metric because it relates directly to real world variables they can understand and manipulate in the design process.

5.3.6 STEP 5: Determine a Reasonable Minimum LZCGT Contribution.

Overview

This methodology approached identifying what would be a reasonable minimum level of LZCGT contribution to CO_2 emission reduction in new buildings from a pragmatic and practical standpoint. It sought to understand what might be the impact on annual energy demand of utilising LZCGT in new buildings to either replace a proportion of the annual energy demand or generate electricity to offset that demand, and what real-world limitations might be encountered in doing so.

In order to achieve this objective the predicted annual energy demands for dwellings ranging in size from 25m^2 to 300m^2 were modelled in respect to three different fabric energy efficiency scenarios to represent tightening CO_2 emission reduction standards. Whilst these scenarios might be characterised as representing past, present/near future and future contexts, this is not strictly true. Although fabric energy efficiency standards are increasing in response to improved CO_2 emission reduction standards, not all buildings are advancing at the same pace in this respect. When comparing the same graphs developed for different scenarios it is obvious that buildings with lower fabric energy efficiencies must provide proportionately larger scaled LZCGT equipment to offset their larger annual energy demands. This has cost implications, and in some cases limit the technological options available. All the fabric energy efficiency levels modelled are currently achievable within the Scottish context of prefabricated timber frame construction (Kinghorn Housing Association, 2010; Paul Heat Recovery Scotland, 2020a). Further they are considered cost effective by the mid-2020s for brick and block cavity wall construction methods used in other parts of the UK (Currie and Brown, 2019).

When making these judgements as to what level of LZCGT contribution could be reasonably expected in new buildings in different CO_2 emission reduction contexts, the following criteria were considered:

i. It should be a reasonable minimum expectation, in respect to the overall level of CO_2 emission reduction new buildings are expected to achieve due to the changing regulatory climate.
ii. It should be readily achievable by all buildings whether in an urban or rural context.
iii. It should be low enough not to undermine or dis-incentivise a fabric first approach or other innovative passive design responses to CO_2 emission reduction.
iv. It should not be too onerous in terms of cost, and should offer long-term value for money for stakeholders (Gürtler et al., 2019).
v. It should not restrict the architect to only one viable option in choice of LZCGT, either directly or indirectly (Schwarz et al., 2020).
vi. It should not interfere with the ability to deliver wider sociological goals or provide essential infrastructure such as affordable housing in a cost effective way. The delivery of affordable housing was defined as a critical consideration and all judgements focussed on the impact the contribution level would have on this context, specifically dwellings within the size range of 45m^2 to 100m^2 (Appendix E).

An initial quantification of what would be a reasonable minimum LZCGT contribution to annual energy demand was achieved by focussing on the timeframe at each end of the path to zero carbon buildings, and considering what would be a reasonable expectation of the role of LZCGT in each of these extremes of circumstance. Then, assuming that the required LZCGT contribution would increase gradually and proportionately to improvements to Building Standard 6.1, as depicted by Figure 8; the LZCGT contribution at intermediary CO_2 emission reduction standards were calculated and explored to ascertain whether these too would be a reasonable ask in those circumstances. Finally it was considered how a 100% emissions reduction standard could be met. Once we were satisfied that our criteria were broadly met at each stage of the journey to zero-carbon buildings, Formulae 11, 12 and 13 were used to calculate and express the LZCGT contribution determined with respect to annual energy demand in terms of CO_2 emission reduction.

To conclude this calculated minimum LZCGT contribution was compared with specific targets and timeframes for CO_2 emission reduction set by the Scottish Government to ascertain whether the target value was consistent with these aspirations (Scottish Government, 2018a, pp. 87-89; Scottish Parliament, 2019a).

Historic Context: 30% CO2 Emissions Reduction Standard

When Section 3F planning policy was first introduced, most early adopters of the policy did not stipulate a specific contribution to be made by the LZCGT. As a result many architects and developers took the easiest and least expensive way to meet this obligation and pass the SAP/SBEM test. Although in some regions where wind power was prevalent dwellings were already moving towards air source heat pumps (ASHP) as the main heating system; in most other areas small PV arrays were incorporated into designs or biomass stoves were employed as secondary heating systems (Onyango et al., 2016). It is a convention in SAP that most secondary heating systems are designated to supply 10% of the space heat demand, irrespective of their frequency of use (BRE, 2014). This was therefore an easy way to improve SAP scores and simultaneously meet Section 3F obligations.

Modelled under Scenario 1; 10% of the space heat demand represents 5.7% to 6.7% of the annual energy demand of dwellings in the critical 45m^2 to 100m^2 size range (Appendix B: Table S1.1 and/or Figure S1.5). Modelled with respect to the improved fabric energy efficiency of Scenario 2; the equivalent figures are 4.7% to 5.7% of the annual energy demand of dwellings in this critical range (Appendix B: Table S2.1 and/or Figure S2.5). This suggests that a minimum LZCGT contribution of approximately 5% of annual energy demand was typically being achieved with this strategy.

To determine what other strategies could meet this LZCGT contribution level in the context of Scenario 1, a horizontal line is drawn across Appendix B: Figures S1.5, S1.6, and S1.7 at 5% and the proportion of the curves that lie above this line represent options that would deliver an equal or greater contribution. As these curves are plotted relative to dwelling sizes in the range of 25m^2 to 300m^2, it is possible to determine what LZCGT options might be suitable for a dwelling of a specific size (Appendix B: Figure B.1 for further explanation of how to interpret the graphs). This information is also tabulated for the critical 45m^2 to 100m^2 dwelling size range (Appendix B: Table S1.1). The process can be repeated for Scenario 2, using Appendix B: Figures S2.5, S2.6, S2.7 and/or Table S2.1.

As it is clear that there were many technological options available to meet this contribution level within the critical dwelling size range; 5% of the annual energy demand was considered a reasonable minimum LZCGT contribution in the historic context of the 30% CO_2 emissions reduction standard.

Future Context: 90% CO_2 Emissions Reduction Standard.

At the opposite end of the spectrum on the journey to zero carbon building at 90% CO_2 emission reduction standard; it is likely that high fabric energy efficiency will be essential and that the main space heat and hot water demands will have to be met by LZCGT.

Let us assume that 100% of the space heat and hot water demands are met by a 300% efficient air source heat pump (ASHP). At this level of efficiency for every 1kWh of electricity the heat pump consumes, it produces 3kWh of heat energy. Or seen from an alternative perspective it could be considered that the ASHP is producing 66.6% of the space heat and hot water demands with little or no associated CO_2 emissions. With reference to Scenario 3, 66.6% of the space heat and hot water demands represent 53.3% to 52.4% of the annual energy demand of dwellings in the critical size range of 45m^2 to 100 m^2 (Appendix B: Figure S3.6 and/or Table S3.1).

Whilst at this level of LZCGT contribution the number of technological options becomes limited; by following the procedure described above but using Appendix B: Figures S3.5, S3.6, S3.7 and/or Table S3.1 and drawing a horizontal line across at approximately 52% of annual energy demand some options become apparent (See Appendix B: Figure B.1 for further explanation of how to interpret the graphs). For dwellings within the critical 45m^2 to 100 m^2 size range this contribution could be met completely with a 2kWp or 3kWp PV array, or a combination of PV, Solar Thermal or Waste Water Heat Recovery (WWHR). Alternatively, because SAP offers very low carbon factors for biomass and biogas these too could be considered available, if not preferred, options.

Intermediary Contexts: 45%, 60% & 75% CO_2 Emission Reduction Standards.

Having previously determined that the LZCGT contribution as a percentage of annual energy demand is roughly analogous to the LZCGT contribution to CO_2 emission defined by E% (Figure 7, Formulae 10 and 13); we utilized this knowledge to create a straight line graph using the origin point (0% LZCGT contribution), and the two LZCGT contribution levels suggested for 30% CO_2 emission reduction (approx. 5% LZCGT contribution) and 90% CO_2 emission reduction (approx. 52% LZCGT contribution). This is the graph depicted in Figure 8. The values used result in a LZCGT contribution defined as a percentage of the percentage CO_2 emission reduction sought by Scottish Building Standard 6.1, i.e. C% equal to 12%.

Using this graph (Figure 8), LZCGT contributions for 45%, 60% and 75% CO_2 emission reduction standards were calculated (Table 9) and considered as to their appropriateness. All allowed various different LZCGT solutions, and did not appear to be overtly onerous with respect to the CO_2 emission reduction standard to which they were linked.

Final Context: Net Zero Carbon - 100% Emission Reduction Standard.

Moving forward towards 100% CO_2 emission reduction; the combination of using a ASHP to provide the majority of the space heat and hot water demand coupled with a photovoltaic array to offset the electricity used to operate the heat pump, lights and other pumps and fans was considered, and appears to be a viable and achievable option. The practical limitations to this approach is the size of the PV array needed to offset the electricity demand and the availability of sufficient roof space orientated in the correct southerly direction to meet these requirements. If this approach is to be taken, or maintained as a future upgrade option, these limiting factors need to be addressed at the design stage and could be highlighted by planning officers.

Considered in respect to Scenario 3; a 45m^2 dwelling using a 300% efficient ASHP would have an annual energy consumption of 1077 kWh/annum (Appendix B: Table S3.1). If this was coupled with a PV array to offset the remaining energy demands, this array would need to be approximately 1.5kWp or 12m^2 in size (Table 8). Given the right orientation this is probably achievable for small individual dwellings but may be more problematic in flats. Considering a 100m^2 dwelling in the same context, to offset remaining energy demands the PV array would have to deliver 1897 kWh/annum, and therefore would need to be sized at approximately 2.5kWp or 20m^2. Again this is probably achievable given the right building orientation.

Undertaking the same calculations for the other scenarios shows that this option might still be available at the fabric energy efficiency standard depicted by Scenario 2, but becomes increasingly difficult at lower fabric energy standards. This is because the size of the PV array required to offset a larger remaining energy demand might exceed the available roof space.

Comparison with Scottish Government Targets and Timeframes for CO_2 Emission Reduction

The Climate Change Plan (Third Report) sets out several ambitions related to energy efficiency and CO_2 emission reduction in buildings; including the target of 35% of heat in domestic buildings being supplied by low carbon technologies by 2032 (Scottish Government, 2018a, pp. 87-89). Further the Committee on Climate Change recommend that by 2025 at the latest there should be a joint move to both an ultra-high fabric energy efficiency (considered consistent with an annual space heat demand of 15 to 20kWh/m^2.annum) and low carbon heating (CCC, 2019b, p66; 2019d, pp 14-15).

To determine to what extent the minimum LZCGT contribution calculated through this methodology reflects this aspiration; Scenario 3 was used to calculate 35% of heat demand (SHD + HWD) for dwellings ranging in size from 25m^2 to 300m^2, as a percentage of the annual energy demand (AED). The results ranged from 28.5% to 26.6% of AED respectively, and are graphically represented in Figure 9. If we assume, as we did previously, that the LZCGT contribution as a percentage of annual energy demand is analogous to E%; then with reference to Figure 8, if the minimum LZCGT contribution is defined as 12% of the percentage CO_2 emission reduction sought by Standard 6.1 (R%), we can state that for any CO_2 emission reduction sought:

$$A\% = \frac{12}{100} R\% = 0.12\,R\%$$

(Formula 14)

$$\text{DERNT} = (100 - R\%) + A\% = 100 - 0.88\,R\%$$

(Formula 15)

$$E\% = \left(\frac{A\%}{\text{DERNT}}\right) 100$$

(Formula 16)

Substituting for A% (Formula 14) and DERNT (Formula 15) in Formula 16; and rearranging gives Formula 17.

$$\mathbf{R\%} = \frac{\mathbf{100\ E\%}}{\mathbf{12 + 0.88\ E\%}}$$

(Formula 17)

This can be used to calculate the CO_2 emission reduction standard (R%) that would need to be sought to meet the 35% of heat demand target if the minimum LZCGT contribution is defined as 12% of that standard. The results for dwellings sized between 25m^2 and 300m^2 ranged from 76.8% to 75.1% respectively, and are graphically represented in Figure 9.

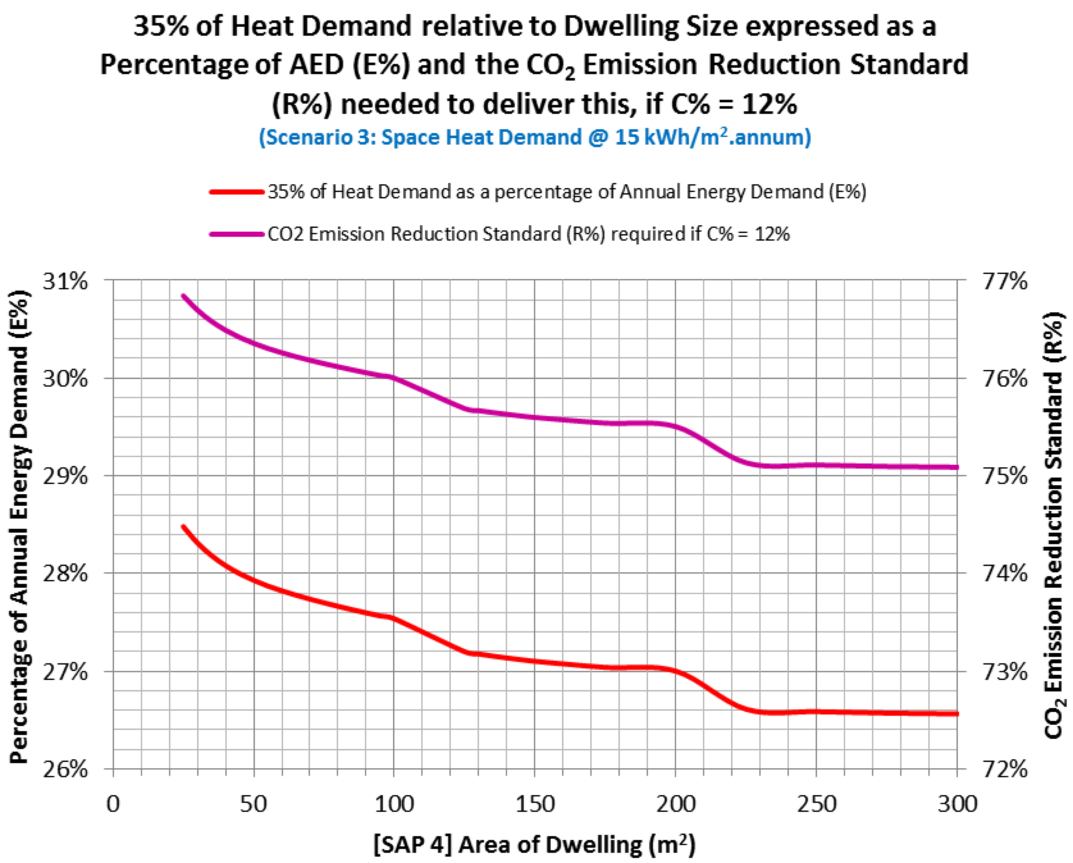


Figure 9: 35% of heat demand expressed as a percentage of annual energy demand (analogous to E%) and the CO_2 emission reduction standard (R%) that would be needed to deliver this if the LZCGT contribution is defined as 12% of that Standard. The bumpy nature of this graph is due to the abrupt changes in the variables used to define the energy consumed by the MVHR unit in Scenario 3.

These values were also compared to the interim targets and timeframe set out in the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 for reducing GHG emissions in Scotland (Scottish Parliament, 2019a). These targets and timeframe are graphically represented in Figure 10. Extrapolating from this graph, in 2032 a projected interim target of 78% GHG reduction appears to be anticipated. This corresponds closely to our calculated values of 76.8% to 75.1%. We can therefore conclude that a minimum LZCGT contribution of 12% of the percentage CO_2 emission reduction sought by Standard 6.1 is likely to deliver the target of 35% of heat demand in new domestic buildings by 2032. The timeframe for delivering this target in new building could be accelerated by advancing the CO_2 emission reductions sought by Scottish Building Standard 6.1. Currie and Brown (2019) consider these levels could be achieved easily and cost effectively by employing heat pumps, high levels of fabric energy efficiency and MVHR by the mid 2020's.

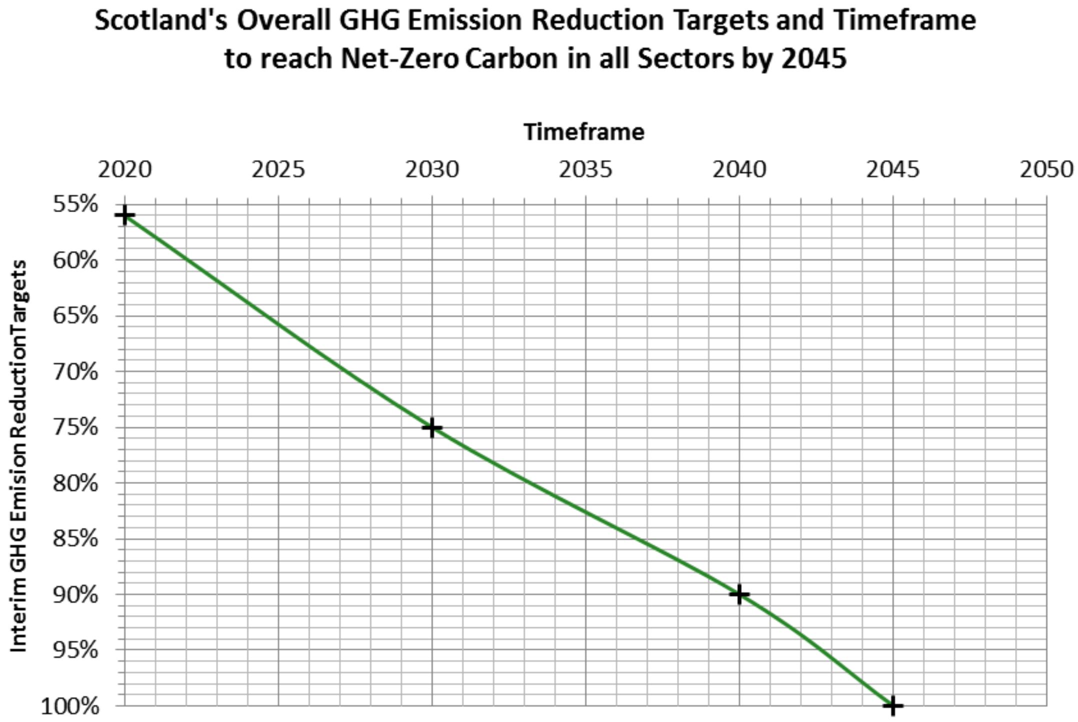


Figure 10: Scotland's GHG emission reduction targets and timeframe from 2020 to 2045 (Scottish Parliament, 2019a).

5.4 Recommendations and Compliance Targets

Through the methodology described above a reasonable minimum level of LZCGT contribution to CO_2 emission reduction for new buildings was determined. We recommend that this level is set at a universal and perpetual 12% of the percentage of CO_2 emission reduction required by Scottish Building Standard 6.1 relative to the 2007 baseline (Scottish Government, 2019a; Scottish Government, 2019b). This judgement was reached by considering what would be a reasonable LZCGT contribution to annual energy demand in new buildings, against a changing regulatory framework that would tend to simultaneously increase fabric energy efficiency. Taking inspiration from the principles identified by Schwartz et al (2020) in relation to innovative and robust energy policy design; care was taken in making this judgement that certain criteria were met. These were:

i. It should be a reasonable minimum expectation, in respect to the overall level of CO_2 emission reduction new buildings are expected to achieve due to the changing regulatory climate.
ii. It should be readily achievable by all buildings whether in an urban or rural context.
iii. It should be low enough not to undermine or dis-incentivise a fabric first approach or other innovative passive design responses to CO_2 emission reduction.
iv. It should not be too onerous in terms of cost, and should offer long-term value for money for stakeholders.
v. It should not restrict the architect to only one viable option in choice of LZCGT, either directly or indirectly.
vi. It should not interfere with the ability to deliver wider sociological goals or essential infrastructure.

With respect to the final criteria the delivery of affordable and social housing was defined as a critical consideration and limiting parameter. Final judgement was therefore focussed on the impact the contribution level would have on this critical context of dwellings within the size range of $45m^2$ to $100\ m^2$ (Appendix E).

Having determined a reasonable LZCGT contribution as a percentage of annual energy demand, it was necessary to express this in terms of CO_2 emissions. Three alternative ways of defining LZCGT contribution relative to CO_2 emissions were identified in current Section 3F policy (Scottish Government, 2019c). These were defined as A%, C% and E% respectively.

A% An absolute percentage CO_2 emission reduction relative to the 2007 baseline established by Scottish Building Standard 6.1.

C% A percentage of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1 relative to the 2007 baseline.

E% An avoidance of a percentage of projected CO_2 emissions as calculated by SAP/SBEM.

The final metric (E%) most closely aligns to the definition included in Section 3F policy, and equates reasonably well, although not exactly, to the LZCGT contribution defined as a percentage of annual energy demand. Using the formulae developed to define the relationship between these metrics (Formulae 11, 12 and 13), it was possible to express the LZCGT contribution determined as a percentage of annual energy demand in terms of each. These values were calculated for specific CO_2 emission reduction standards and the results set out in Table 9. The recommended LZCGT contributions can also be calculated graphically by reference to Figure 8.

R%	A % Formula 11	C % Formula 12	E % Formula 13
0% CO_2 Reduction	0 %	12 %	0 %
30% CO_2 Reduction	3.6 %	12 %	4.9 %
45% CO_2 Reduction	5.4 %	12 %	8.9 %
60% CO_2 Reduction	7.2 %	12 %	15.3 %
75% CO_2 Reduction	9.0 %	12 %	26.5 %
90% CO_2 Reduction	10.8 %	12 %	51.9 %
100% CO_2 Reduction	12.0 %	12 %	100 %

Table 9: Recommended minimum LZCGT Contributions under different Scottish Building Standard 6.1 carbon dioxide emissions contexts.

R% = the CO_2 emissions reduction sought by Standard 6.1

A% = an absolute percentage CO_2 emissions reduction relative to the 2007 baseline

C% = a percentage of the percentage CO_2 emissions reduction sought by Standard 6.1

E% = Avoidance of a percentage of CO_2 emissions

It is useful for architects and planners to understand the relationship between these metrics. The first two (A% and C%) are quite abstract concepts but useful in government reporting. The final metric (E%) equates reasonably well to the LZCGT contribution defined as a percentage of annual energy demand so is a lot more meaningful and tangible from an architect's or developer's perspective, as it is a real-world meaningful target that can be directly used in planning a building's energy response.

However, on balance we recommend that in Section 3F policy the minimum LZCGT contribution be defined in terms of a percentage of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1 for several reasons:

i. By linking directly to the Building Standard 6.1, it avoids potential conflict between Planning and Building Standards.
ii. It simplifies Section 3F policy, by allowing the LZCGT contribution to be defined as a constant and perpetual percentage that will automatically deliver increases in real terms with every improvement of Standard 6.1 (Table 9, Figure 8).
iii. It provides regulatory certainty going forward (Schwartz et al, 2020)
iv. It ensures changes that occur in Building Standards 6.1 are reflected immediately, proportionately and automatically in Planning.
v. It allows differences in the CO_2 emission reduction sought for domestic and non-domestic buildings at building standards, to be simply and automatically

reflected in the LZCGT contribution sought at Planning (Scottish Government, 2019a,b).

Going forward the extent of the LZCGT contributions in real terms will be determined relative to the CO_2 emission reduction set by Scottish Building Standard 6.1 at that time. Defined as a percentage of the percentage CO_2 emission reduction sought by Standard 6.1, the LZCGT contribution will remain constant at 12%. In real terms this will be a specified and rising proportion of the projected CO_2 emissions as required by Section 3F planning policy. It is vital to understand that any attempt to raise the minimum LZCGT contribution either disproportionately or at more frequent intervals than the changes to the overall CO_2 emission reduction sought by Building Standard 6.1, would be counter-productive and to the detriment of fabric energy efficiency (Figure 8). Such a situation should therefore be avoided.

5.5 Proposed Calculation Methodology

5.5.1 Compliance Formulae

The following formulae can be used to ascertain whether the specified LZCGT contribution has been met by a particular planning application. These formulae have be calculated as set out in Section 5.5.3.

- The formula to calculate LZCGT contribution defined as an absolute percentage CO_2 emission reduction relative to the 2007 baseline is given by:

$$\mathbf{A\%} \quad = \quad (\mathbf{100} - \mathbf{R}\%)\left(\frac{\mathbf{DERNT}-\mathbf{DER}}{\mathbf{TER}}\right)$$

- The formula to calculate the LZCGT contribution defined as a percentage of the percentage CO_2 emission reduction sought by Scottish Building Standard 6.1 is given by:

$$\mathbf{C\%} \quad = \quad \left(\frac{\mathbf{100}\ (\mathbf{100}-\mathbf{R}\%)}{\mathbf{R}\%}\right)\left(\frac{\mathbf{DERNT}-\mathbf{DER}}{\mathbf{TER}}\right)$$

- The formula to calculate the LZCGT contribution defined as an avoidance of a percentage of projected CO_2 emissions as calculated by SAP/SBEM:

$$\mathbf{E\%} \quad = \quad \left(\frac{\mathbf{DERNT}-\mathbf{DER}}{\mathbf{DERNT}}\right) \mathbf{x\ 100}$$

5.5.2 LZCGT Contribution Based on CO_2 Emission Rates ($kgCO_2/m^2$)

Not all LZCGT have zero carbon emissions. Therefore the simplest way to accurately calculate if the specified LZCGT contribution to CO_2 emission reduction has been met by the proposed building is to run two separate SAP/SBEM calculations; one for the building as designed with the proposed LZCGT and another with the proposed LZCGT removed and replaced with pre-defined conventional systems. The CO_2 emission rates generated by these two separate SAP/SBEM calculations are then substituted into a formula to calculate the LZCGT contribution. This second SAP/SBEM calculation is not currently required for Building Standards purposes.

We would recommend that the presumption of what replaces the LZCGT in this second SAP/SBEM calculation is consistent for all buildings; although the appropriateness of this needs further consideration by Building Standards. Reasonable assumptions might be:

i. Renewable heat energy is displacing natural gas.
ii. Renewable electrical energy is displacing grid electricity

Three alternative ways of defining and calculating LZCGT contribution relative to CO_2 emissions are set out below. Each delivers the same result in real terms, and they all comply with the intention of Section 3F policy, i.e.

> ' . . . 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 low and zero-carbon generating technologies.'
>
> Section 72 of the Climate Change (Scotland) Act, 2009 (Scottish Parliament, 2019b).

Although on balance our recommendation is to define the LZCGT contribution in terms of a percentage of the percentage CO_2 emission reduction sought by Standard 6.1; it will be for the Scottish Government to choose which one will be most useful in their ongoing reporting. As the LZCGT contribution percentages differ greatly between these definitions the need to avoid any ambiguity in use or reporting from various actors is paramount. Absolute clarity as to the definition and calculation methodology is therefore essential.

5.5.3 Compliance Calculations

In determining the compliance formulae the following abbreviations are used:

OER = Original Emission Rate (0% reduction relative to 2007 Baseline)
TER = Target Emission Rate (calculated by SAP 2012)
DER = Dwelling Emission Rate (calculated by SAP 2012)
As designed FEE, EE & LZCGT used to achieve DER

DERNT	=	Dwelling Emission Rate calculated with no LZCGT (calculated by SAP 2012) As designed FEE & EE with LZCGT replaced with predefined conventional energy systems

All the above are specific to the particular building and are measured in $kgCO_2/m^2$

R%	=	Statutory required CO_2 emission reduction sought by Scottish Building Standard 6.1 defined as a percentage relative to the 2007 baseline. This is currently: A 45% CO_2 emission reduction for Domestic Buildings A 60% CO_2 emission reduction for Non-Domestic Buildings

The inter-relationships between these elements were defined previously with reference to Figures 7 and 8, and from these definitions we can state:

Reduction in CO_2 Emission Rate due to LZCGT contribution = **DERNT - DER**

Formula 18

Given that the relationship between OER and TER can be defined as:

$$\frac{\mathrm{TER}}{\mathrm{OER}} = \frac{100 - \mathrm{R}\%}{100} \qquad \mathbf{OER} = \left(\frac{\mathbf{100}}{\mathbf{100 - R\%}}\right)\mathbf{TER}$$

Formula 19

LZCGT contribution defined as an absolute percentage CO_2 emission reduction, relative to 2007 baseline.

The percentage of CO_2 emission reductions that can be attributed to the use of LZCGT, calculated relative to a notionally similar dwelling built to the 2007 baseline standard (0% emission reduction) was defined previously as A%:

$$\mathrm{A}\% = \left(\frac{\mathrm{DERNT - DER}}{\mathrm{OER}}\right) \times 100$$

Formula 11

As the original state is not defined during the SAP/SBEM calculation process, we need to substitute for OER from Formula 19 and simplify:

$$\mathbf{A\%} = (\mathbf{100 - R}\%)\left(\frac{\mathbf{DERNT - DER}}{\mathbf{TER}}\right)$$

Formula 20

For domestic buildings; the current CO_2 emissions reduction sought by Standard 6.1 relative to the 2007 standard is 45%. The LZCGT contribution defined as an absolute percentage of CO_2 emission reduction would therefore be defined as:

$$A\%_{45} = 55\left(\frac{\text{DERNT}-\text{DER}}{\text{TER}}\right) \geq 5.4\ \%$$

For non-domestic buildings; the current CO_2 emissions reduction sought by Standard 6.1 relative to the 2007 standard is 60%. The LZCGT contribution defined as an absolute percentage of CO_2 emission reduction would therefore be defined as:

$$A\%_{60} = 40\left(\frac{\text{DERNT}-\text{DER}}{\text{TER}}\right) \geq 7.2\ \%$$

LZCGT contribution defined as a percentage of the percentage CO_2 emission reduction sought by Building Standard 6.1

With reference to Figures 7 and 8, the LZCGT contribution calculated as a percentage of the percentage CO_2 emission reduction sought by Scottish Building Standard 6.1 relative to the 2007 standard (C%) is given by:

$$C\% = \left(\frac{\text{DERNT} - \text{DER}}{\text{OER} - \text{TER}}\right) \times 100$$

Formula 21

Substituting for OER from Formula 19, and simplifying:

$$\mathbf{C\%} = \left(\frac{\mathbf{100\ (100-R\%)}}{\mathbf{R\%}}\right)\left(\frac{\mathbf{DERNT-DER}}{\mathbf{TER}}\right)$$

Formula 22

Or as defined previously:

$$\mathbf{C\%} = \left(\frac{\mathbf{A\%}}{\mathbf{R\%}}\right) \times 100$$

Formula 12

For domestic buildings; the current CO_2 emissions reduction sought by Standard 6.1 relative to the 2007 standard is 45%. The LZCGT contribution defined as a percentage of this CO_2 emission reduction standard would therefore be defined as:

$$C\%_{45} = \left(\frac{5500}{45}\right)\left(\frac{\text{DERNT}-\text{DER}}{\text{TER}}\right) \geq 12\ \%$$

For non-domestic buildings; the current CO_2 emissions reduction sought by Standard 6.1 relative to the 2007 standard is 60%. The LZCGT contribution defined as a percentage of this CO_2 emission reduction standard would therefore be defined as:

$$C\%_{60} = \left(\frac{4000}{60}\right)\left(\frac{\text{DERNT}-\text{DER}}{\text{TER}}\right) \geq 12\ \%$$

LZCGT contribution defined as avoidance of a percentage of projected CO_2 emissions as calculated by SAP/SBEM

This metric is the one most closely aligned to the definition included in Section 3F policy. It was previously defined as E%.

$$\textbf{E\% =} \left(\frac{\textbf{DERNT}-\textbf{DER}}{\textbf{DERNT}}\right) \textbf{x 100}$$

Formula 13

5.5.4 Compliance Procedure

Ascertaining whether the specified LZCGT contribution has been met by the proposed building is simply a matter of substituting the relevant information from the two SAP/SBEM calculations into the appropriate formula and comparing the result to the target percentages set out in Table 9 for the relevant regulatory requirement. If the value calculated is greater than or equal to the relevant figure given in Table 9 the proposed building has complied with Section 3F requirements.

A standard Compliance Calculation Spreadsheet which calculates the LZCGT contribution defined as a percentage of the percentage CO_2 emission reduction sought by Building Standard 6.1 is included in Appendix C (Figures C.1 and C.2).

6. Proposal 2: A Whole Building Approach

6.1 Key Points

Policy Overview

- This proposal takes a whole building approach to CO_2 emission reduction and diverges significantly from current single issue Section 3F Policy.
- It reinvents this policy in a way that plays to the strengths and skillsets of Planning, whilst complementing and aligning constructively with the whole-building approach taken by Building Standards.
- It focuses on the domestic sector
- The overarching intention is to limit the annual energy demand (AED) in new buildings to an acceptable level:
    - i. This acceptable annual energy demand (AAED) will be calculated on a per capita basis.
    - ii. It will be based on the predicted AED of a modest-sized energy-efficient dwelling, to avoid adverse impact on the ability to deliver essential domestic infrastructure such as affordable housing.
    - iii. A modest-sized dwelling will be defined as between $45m^2$ and $100m^2$ (Appendix E)
- The objective of this mechanism is to:
    - i. Realise the recommended 3-step holistic approach to reducing CO_2 emission from buildings: reduce energy demand, increase efficiency of energy use, and increase the use of zero-carbon renewable energy.
    - ii. Recognise that design plays a significant role in reducing energy demand, and incentivise good design, passive design responses and innovative approaches.
    - iii. Prioritise fabric energy efficiency as a means of reducing energy demand.
    - iv. Promote the use of zero-carbon renewable energy sources (LZCGT).
    - v. Address the finite nature of resources, issues of personal responsibility and determine a more fair and equitable share of resources for everyone.
    - vi. Directly address the energy consumption issues related to scale and excessive per capita heated living space in large domestic buildings.

- Compliance with the policy will be allowed through any combination of design, fabric energy efficiency, equipment efficiency or LZCGT:
    i. The use of LZCGT will not be mandatory but it is expected this will be needed to meet the target levels. As emissions reductions targets from buildings get closer to 100% net-zero emissions, then by default LZCGT would need to be employed to offset the remaining energy demand after other passive measures have been adopted.
    ii. Applicants will be encouraged to meet the acceptable annual energy demand (AAED) calculated for their proposed dwelling through good design and fabric energy efficiency measures alone if possible.
    iii. If a building does not initially meet the acceptable annual energy demand (AAED), then any remaining energy demand above the acceptable level must be met by zero-carbon renewable energy sources.
- It is recognised that this policy will impact far greater on large dwellings than more modest ones, due to the small average occupancy rates of large dwellings (BRE, 2008).
- The metric used will be kWh/annum rather than a carbon metric, because:
    i. Data extracted from SAP will be expressed thus.
    ii. It emphasises the need to first and foremost reduce energy demand.
    iii. It is a tangible and easy to understand metric with real world meaning for all stakeholders. As such it is easier to directly manipulate and comprehend the impact of specific changes during the design process.
    iv. It allows the contribution of LZCGT to the annual energy demand to be clearly and easily quantified.
    v. It is the obvious metric to link LZCGT contribution, annual energy demand, and other regional or national energy networks. It is therefore extremely useful for ongoing reporting and in the development of future regional or national energy policy.

Compliance Targets

- The acceptable annual energy demand per capita (AAED/Capita) was calculated by modelling the predicted annual energy demand for dwellings ranging in size from $25m^2$ to $300m^2$ using formula prescribed in SAP 2012 (BRE, 2014).
- Two different scenarios were developed to represent evolving fabric energy efficiency standards. These were based on space heat demands of $30kWh/m^2$.annum (Present and Near Future 2020-2021) and $15kWh/m^2$.annum (Future 2024 - 2050).

- The AAED/Capita level determined through this process is based on the predicted annual energy demand of a modest-sized energy-efficient dwelling between 45m^2 and 100m^2. It will be applied to all dwellings regardless of size.
- The recommended AAED/Capita targets levels are:

2021 AAED/Capita	**=**	**1910**	**kWh/annum**
2024 AAED/Capita	**=**	**1500**	**kWh/annum**

- As the country evolves towards 2045 and net-zero carbon buildings, if the annual energy demand/capita of the proposed dwelling exceeds this acceptable level, the surplus demand must be met through zero-carbon renewable energy sources.

Compliance Documentation

- Compliance is basically determined by comparing three values calculated for the proposed dwelling.

Acceptable Annual Energy Demand	**AAED**
Annual Energy Demand	**AED**
Zero-Carbon Adjusted Annual Energy Demand	**ZCAED**

- Compliance is achieved if either of the following hold true:

Compliance Method 1: (With / Without LZCGT)	**AED ≤ AAED**
Compliance Method 2: (With LZCGT)	**ZCAED≤ AAED**

- The compliance documentation was designed with the objective of making the entire process as easy as possible for all stakeholders, whilst taking the opportunity to collect useful data for research and planning purposes.
- It comprises of a standardised Excel spreadsheet, which should take no more than 10 minutes to complete (Appendix C); data used is extracted from the DER worksheet of the SAP document submitted to Building Standards; there is no need to have knowledge of SAP calculations to complete the spreadsheet; Excel will perform all necessary calculations automatically.
- The calculation process is simplified as much as possible and remains focussed on the annual energy demand of the proposed dwelling and the contribution of the different systems, fuels and LZCGT.
    i. The metric used throughout is kWh/m^2.
    ii. The contributions of different systems, fuels and LZCGT are defined as zero-carbon, low-carbon, grid electricity, bio-carbon or fossil fuels.
    iii. These are colour coded to indicate preferable choices.
    iv. Only zero-carbon energy sources are used to calculate the zero-carbon adjusted energy demand (ZCAED)

- The compliance procedure is quite flexible and there are several ways that a designer can bring a non-compliant building into compliance, either by reducing the annual energy demand (i. – iv.) or employing additional zero-carbon renewable energy systems (iv. – vii.). The compliance spreadsheet used alongside SAP can be exploited as a design tool to explore these options:
    i. Revise the Building Design: consider scale, built form, solar orientation, and other passive design measures to reduce overall heat demand.
    ii. Increase fabric energy efficiency.
    iii. Increase air tightness and employ MVHR.
    iv. Consider Solar Thermal or Waste Water Heat Recovery (WWHR).
    v. Consider Zero Carbon Electricity Generation: PV, Wind, Water etc.
    vi. Consider Zero Carbon Heat Generation: All types of Heat Pumps: GSHP, GWSHP, SWSHP, ASHP, EASHP, and SASHP. Be aware that in calculating the zero-carbon contribution, the electrical input will be subtracted from the output.
    vii. Community Heating: Numerous different energy sources may be employed within district heating schemes; these will be considered on their individual merits. Scaled zero-carbon renewable energy systems might include PV, Wind, Water, Tidal or Geothermal Energy, Waste Heat Recovery from Power Stations, or Waste Heat Recovery from Industrial or Agricultural processes.
- Only zero-carbon energy sources are used to calculate the zero-carbon adjusted energy demand (ZCAED). These do not include:
    i. Combined Heat and Power (CHP) that are based on fossil fuels or biomass. These are designated either low-carbon or bio-carbon depending on their fuel source.
    ii. Biomass and Biogas. These are designated bio-carbon. Both emit substantial amounts of CO_2 when burnt.

6.2 Approach Rationale

By embracing a more holistic approach to CO_2 emission reduction, this proposal re-envisions Section 3F policy as an ambitious standard that complements and aligns constructively with the whole building approach taken by Scottish Building Standards. Focussed on the domestic sector; the proposed policy centres on the idea of capping annual energy demand in new dwellings at an acceptable level per capita; and through this mechanism leverages better design solutions that address fundamental issues not tackled by the current system, prioritises fabric energy efficiency and simultaneously promotes the appropriate and responsible use of LZCGT.

6.2.1 A holistic Approach to CO_2 Emission Reduction.

Population growth, increased urbanisation and the pursuit of affluent modern lifestyles have relentlessly increased energy demand across the globe, despite attempts to reduce consumption and CO_2 emissions. In many developed countries, sociological shifts have led to the decrease in the size of households but a corresponding growth in their number, increases in per capita living space, higher expectations of thermal comfort, and ever expanding demands on electricity grids to satisfy highly technological lifestyles (Urge-Vorsatz et al., 2013; Beradi, 2016; Grove-Smith et al., 2018).

With respect to reducing CO_2 emissions in the built environment; the consensus among academics and industry professionals is that the most effective long-term strategy is to tackle the problem in a holistic manner (Urge-Vorsatz et al., 2013; Beradi, 2016; Grove-Smith et al., 2018). Typically by following three fundamental steps:

i. **Reduce energy demand:**
From a sociological viewpoint, this might involve questioning unsustainable expectations or taking measures to prompt lifestyle or behavioural change at either an individual or a societal level. From the perspective of building design it might involve greater reflection on the appropriateness, scale and sustainability of design proposals, consideration of passive design solutions, or increasing building fabric energy efficiency.

ii. **Increase efficiency of energy use:**
This should take into consideration all aspects of the design and construction process and might involve taking a systems approach to architectural design to optimize efficiency at a building level. Key areas for examination might include the embodied energy of building materials; judicious consideration of different materials, components and technologies; reducing energy losses and the reuse of energy through cascading energy systems or heat recovery; technological efficiencies of equipment and systems; and the optimization and maintenance of building systems.

iii. **Increase the use of renewable energy:**
The intention of the first two actions in this strategic approach is to reduce the energy requirements of the building by such an extent that the remaining energy demands can be practically and economically met by zero-carbon renewable energy sources. To maximise sustainability and reduce reliance and impact on centrally generated grid electricity these energy sources should preferably be generated locally.

In developed countries where demand for energy is very high and already far exceeds long-term sustainable levels, Urge-Vorsatz et al. (2013) suggest further measures might be necessary to change attitudes and behaviours at a societal level, including:

iv. **Capping energy demand:**
The concept of a ‘2000 Watt Society’ developed in 1998 by the Swiss Federal Institute of Technology is an example of this type of tactic. It envisages an

energy-sober society where total primary energy use per capita is limited to the global average of 17,520kWh/annum without any attendant loss in the quality of life (Morosini, 2010). This level of sustainability is achievable; however it requires commitment to a more frugal lifestyle that avoids excess particularly in relation to limiting heated living space and transport use, and avoiding excessive consumption of goods and services (Ettlin, 2013).

6.2.2 Prioritising Fabric Energy Efficiency.

Whilst supporting this holistic, integrated design approach which relies first and foremost on demand reduction through improvements in building design, fabric and services and also challenging individual behaviour and consumption of energy; most of the literature also advises prioritising fabric energy efficiency (Urge-Vorsatz et al., 2013). There are numerous reasons for this.

In our cold northern climate, the need for space heating tends to dominate energy demand. In 2018, it represented 64.8% of the total annual energy demand in the domestic sector in the UK (BEIS, 2019a). Improving fabric energy efficiency, by increasing insulation levels and airtightness, is therefore the most obvious and cost-effective way to cut energy demand and CO_2 emissions in new buildings (Beradi, 2016). At very high fabric energy efficiency levels there are balances to be made between embodied and operational energy, and initial investment and operational costs (Copiello, 2017; Grove-Smith et al., 2018). The optimum point for both appears to fall within the general region of the Passivhaus standard (Space Heat Demand ≤ 15kWh/m^2.annum). At this high level of fabric energy efficiency the size of heating system is reduced significantly and the associated cost savings tend to largely offset the cost of improving the fabric (Cotterell and Dadeby, 2013; Copiello, 2017; Currie and Brown, 2019).

On a macro scale, taking a fabric first approach reduces peak energy demand, and minimises the impact the building has on the national energy infrastructure and the ability to meet future energy demands (Currie and Brown, 2019). This is particularly important because the on-going decarbonisation of the national grid has already resulted in the need for increased capacity to cope with intermittent renewable energy sources, and electricity demands are only expected grow due to changing lifestyles, the switch to electrical vehicles and the increased use of heat pumps. Reducing energy demand where possible is vital for maintaining energy security in the long-term.

The timeframe over which CO_2 emission savings can be reasonably expected to be made also needs to be considered. Increasing fabric energy efficiency effectively reduces operational energy demand and CO_2 emission over the entire lifetime of the building (>100 years), whilst the effect of specifying LZCGT will be limited to the equipment's operational lifespan (15 - 20 years). Furthermore, because poor fabric energy efficiency is more difficult and costly to remedy at a later date than during initial construction; buildings that don't take a fabric first approach will tend to underperform over their entire lifespan. This leads to a certain level of CO_2 emissions being effectively locked-in to the built infrastructure (Urge-Vorsatz et al., 2013; Beradi, 2016).

Obviously for building occupants increased fabric energy efficiency also has many practical benefits including reduced energy bills, increased disposable income and a positive impact on their comfort, health and well-being (Payne et al., 2015; Copiello, 2017; IEA, 2019).

6.2.3 Promoting Design Solutions.

Tackling climate change is the fundamental issue of our time. Planning, with its wide sphere of influence, has the opportunity to mitigate the effects of climate change and reduce greenhouse gas emissions in many contexts and at a variety of scales (Appendix A). These include taking strategic macro-scale decisions related to Landscape Scale Planning, Sustainable Place-making and Large Scale LZCGT as well as offering individual micro-scale guidance in relation to Architectural Design, Architectural Design Details, and Building Scale LZCGT.

Focussing on the issue of reducing CO_2 emissions from buildings; Planning and Building Standards could be considered complementary to each other in terms of outlook. Planning approaches the issue from the perspective of exploring the appropriateness and sustainability of design proposals, and the interaction of the building as a whole with its environment. Whereas, Building Standards is focussed on technical regulations that ensure buildings meet minimum acceptable standards including those for fabric energy efficiency, equipment efficiency and CO_2 emissions reduction. Collaboration between Planning and Building Standards is essential if we are to develop effective joined-up policies to address climate change.

In Scotland, limiting energy consumption and CO_2 emissions from new buildings is primarily legislated for through Section 6 of the Scottish Building Standards. Building Standards take a whole building approach based on reducing energy demand, increasing energy efficiency and the judicious use of LZCGT. They sanction meeting the mandatory CO_2 emission reduction target by whatever means Architects and Developers deem suitable, subject to the design meeting robust fabric energy efficiency and equipment efficiency backstops. The use of LZCGT is not mandatory (Scottish Government, 2019a). This holistic approach allows architectural designers the valuable freedom to innovate and find new and cost effective solutions.

However, the UK government's SAP used by Section 6 to determine CO_2 emissions from buildings is not without a few fundamental flaws (BRE, 2014). It is not clear which of the national policy aims: reducing fuel poverty, increasing energy efficiency decreasing overall energy use, or reducing carbon emissions is being captured by the various performance measures contained in SAP. It has been shown that this can lead to confusion and disconnect between performance measures, policy instruments and policy objectives and which of the policy aims is being improved by a particular strategy which can result in perverse incentives (Kelly et al., 2012). Prime among these flaws is that the calculation methodology is based on comparing the proposed building to a notionally similar building to adjudicate the level of CO_2 emission reduction. This removes any semblance of an absolute CO_2 emissions target, effectively ignores much of the impact architectural design can have on overall CO_2 emissions, and fails to incentivise sensible design solutions.

In contrast, most planning authorities rightly recognise the potential of sustainable design approaches and actively promote simple passive design responses in their planning guidance. These design measures might include consideration of site microclimate, topography and natural environment on the general positioning of development as well as the impact of landscape design, shelter, shade, solar orientation, scale, built form, fenestration, solar gain, natural daylight, sunspaces, protected entrances, material choices etc. These types of design choices can contribute significantly to reducing energy demand and CO_2 emissions from buildings and sit well with other sustainability measures addressed through planning policy, but they need to be incorporated and incentivised early in the design process. Planning is ideally-placed to undertake this task.

Early engagement with applicants, either through pre-application discussions or during the process of determining planning applications can be used to advise applicants about their responsibilities at a stage when it could positively influence design responses. During this engagement process planners can address the long-term need to reduce energy demand; facilitate discussions about the pros and cons of specific design and technological solutions; and influence choices made with respect to design, energy efficiency and the use of LZCGT.

6.2.4 Determining a Fair and Equitable Share of Resources for Everyone.

In advancing the concept of a 2000 Watt Society, the Swiss recognised that the current level of consumption in developed countries is unsustainable and that we each need to take responsibility for our choices, and use only what is a fair and equitable share of the world's resources (Morosini, 2008; Stulz et al., 2011).

An example of this type of unsustainable level of energy consumption was evident in the SAP data collected for an earlier study into LZCGT use in new domestic buildings in Scotland (Onyango et al., 2016; Burford et al., 2019). This study clearly recorded excessively large annual energy demands relating directly to the size of the per capita heated living space observed in large dwellings because of their low average occupancy rates (BRE, 2008; Ettlin, 2013). The data captured during this study in relation to size, occupancy and space heat demand suggests that the 50% of occupants who live in dwellings less than $100m^2$ were responsible for only 36% of annual energy demand (Appendix E: Table E.1). These figures suggest that bringing the per capita annual energy demand in buildings greater than $100m^2$ in line with more modest dwellings could have a significant impact on overall energy consumption and CO_2 emissions.

This inequitable division of resources is currently obscured by the convention of defining metrics in terms of per m^2, because this effectively disguises the real magnitude of annual energy demand and CO_2 emissions in large dwellings. In a domestic setting an absolute target defined in terms of per capita is potentially more useful, because it could be used to leverage either higher fabric efficiency standards or increased LZCGT provision in large dwellings to bring excess consumption down to acceptable levels. It should be noted that the sole Passivhaus example recorded in the above study; whilst representing a vast improvement over many other houses of a similar scale, still only equalled the energy consumption per capita readily achieved by more modest dwellings because of their compact design and built form (Appendix C: Worked Example 1).

6.2.5 A Whole Building Standard.

This proposal is substantially different to the current 3F Policy. Although it takes a holistic approach, its underlying aim of reducing CO_2 emissions and ultimately promoting the use of LZCGT, remains unchanged.

By adhering to the recommended 3-step strategy for reducing CO_2 emissions; the proposal aims to avoid conflict with the approach taken by Scottish Building Standards which allows architect and developers the freedom to innovate and choose the most appropriate and cost effective approach to CO_2 emission reduction for any given site. It achieves this primarily by allowing compliance through any combination of design, fabric efficiency and LZCGT. If a dwelling can meet the acceptable annual energy demand (AAED) calculated for it through good design and fabric energy efficiency measures alone, this should be encouraged. However, if it does not, then any remaining energy demand above the acceptable level must be met through zero-carbon renewable energy sources.

The use of LZCGT is not compulsory under this proposal; but by setting the acceptable annual energy demand per capita (AAED/Capita) at a level that is ambitious but achievable by most modest sized dwellings, it should force larger dwellings to either substantially cut energy demand through good design and fabric energy efficiency and/or markedly increase their use of LZCGT. It is expected that overall the use of LZCGT will be higher than with the minimum standard approach previously discussed. Furthermore, by making LZCGT non-compulsory the proposal should not interfere with the cost effective delivery of essential domestic infrastructure such as social or affordable housing. With increased CO_2 emissions reduction requirements anticipated in future Section 6 standards it is inevitable that the proportion of LZCGT needed to satisfy remaining energy demand will automatically increase.

6.2.6 An Acceptable Annual Energy Demand Per Capita: (AAED/Capita)

Framing the standard in terms of an acceptable annual energy demand per capita (AAED/Capita), and basing that level on the annual energy demand of a modestly-sized energy-efficient dwelling, has several positive inferences:

i. It emphasises the fact that resources are finite and individuals need to take responsibility for their lifestyle choices and the impact these will have on CO_2 emissions and ultimately climate change. This focus on individual energy consumption echoes the Swiss concept of a 2000-Watt Society.
ii. It acknowledges that the surest way to reduce CO_2 emissions from buildings is to simply reduce energy demand, and that this is the vital first step in achieving net zero-carbon buildings. Reducing energy demand is also vital for maintaining energy security in the long-term.

iii. By setting an absolute target, it recognises that the design of a building has a significant impact on energy demand and CO_2 emissions, and incentivises innovative approaches and passive design solutions.
iv. For modest dwellings it allows architects and developers to take a purely fabric first approach if they wish to do so, without incurring additional costs providing LZCGT. This reduces the risk of higher levels of CO_2 emissions being effectively locked-in to the built infrastructure over the long-term because a certain amount of LZCGT is mandatory.
v. It clearly recognises that dwelling scale has a huge impact on per capita operational and embodied energy demand, consumption levels and CO_2 emissions (Appendix E; Burford et al., 2019). This is because the average occupancy rate in large dwellings in the UK is small relative to more modest dwellings and saturates at around 3 in buildings over $90m^2$ (BRE, 2008). This can result in very large per capita heated living spaces.
vi. It countenances a more equitable and fair division of resources in the future and incentivises more sensible levels of consumption. While the policy will be effective universally, its impact will be much greater on larger dwellings. The design proposals for very large dwellings may need to be re-evaluated, the performance of the building fabric improved dramatically and zero-carbon renewable energy invested in heavily to bring the per capita annual energy demand down to acceptable levels. Conversely, as most modest dwellings are inherently energy efficient because of their scale and built form, the policy will have a lot less impact.

6.2.7 Target Level

We consider that the acceptable annual energy demand per capita (AAED/Capita) should be set at an ambitious but readily achievable level based on the predicted annual energy demand (AED) of a modestly sized energy-efficient dwelling built to Scottish Building Standards. It is extremely important that the level should not interfere with the ability to deliver essential domestic infrastructure such as affordable housing in a cost effective way. To determine the appropriate target level, the predicted annual energy demand of dwellings ranging in size from $25m^2$ to $300m^2$ will be modelled using the same methodology adopted in Proposal 1.

We propose that initially the target level, AAED/Capita 2020-2021, should be achievable without the use of LZCGT for modest dwellings. This will offer architects and developers a wide range of options as to how to achieve compliance and should allow familiarity with the policy and compliance procedures to develop without any major discontent settling in before the target is tightened. We therefore suggest that the AAED/Capita 2020-2021 be calculated relative to the predicted annual energy demand of a modestly-sized energy-efficient dwelling with a space heat demand of $30kWh/m^2$.annum (Proposal 1: Scenario 2). A modestly-sized dwelling will be defined as between $45m^2$ and $100m^2$ (Appendix E).

The subsequent target level, AAED/Capita 2024-2050 should likewise reflect expected advances in Scottish Building Standards. A recent cost-analysis suggests that it will be more cost effective to aim for very high fabric efficiency comparable to Passivhaus by the mid-2020s, than take a slower step by step approach which would result in further infrastructural carbon lock-in (Currie and Brown, 2019). We therefore suggest that the AAED/Capita 2024-2050 be calculated relative to the predicted annual energy demand of a modestly-sized energy-efficient dwelling with a space heat demand of 15kWh/m^2.annum (Proposal 1: Scenario 3). This will be significantly more challenging for large buildings to achieve through fabric energy efficiency alone (Appendix C: Worked Examples 1 & 3).

As the country evolves towards 2050 and net-zero carbon buildings, the AAED/capita could be progressively reduced until it reaches zero. At this point all remaining energy demands will have to be met by zero-carbon renewable energy sources.

6.2.8 Compliance

The policy design takes in consideration the need for a standard compliance procedure that presents information to planning authorities in a clear, comprehensible and useful format, but does not place overly onerous demands on architects and developers. For this reason we suggest that the data used as evidence be extracted from the building's SAP document and a standardised excel spreadsheet developed for the compliance calculation (Appendix C).

This spreadsheet is seen as more than a simple means of showing policy compliance; it is envisaged as a potential tool through which planners, architects and developers can explore and discuss the impact of different options. It is also seen as a potential means of accurately recording information in a simple format that could be fed forward for reporting and future regional or national energy planning purposes.

Unlike the comparative procedure used to determine compliance with Building Standard 6.1; this policy will use the absolute values calculated by SAP for the building as designed. There is no need to refer to values calculated for the notionally similar building and there is no need for a second SAP calculation as required by Proposal 1. This simplifies the compliance procedure. With its emphasis on the overall annual energy demand of a building and factors that can be best addressed through the design process at the planning stage, this policy is seen as complementary to the existing more technical focussed building standards. The metric used throughout will be kWh/annum for several reasons:

i. It is a tangible and easy to understand metric with real world meaning for all stakeholders. As such it is easy to directly manipulate in the design process.
ii. It emphasises the need to first and foremost reduce energy demand.
iii. It is the principal metric used in SAP calculations.
iv. It allows the contribution of LZCGT to the annual energy demand to be clearly and easily quantified.
v. It is the obvious metric to link the building's annual energy demand, LZCGT contribution and other regional or national energy networks. It is therefore extremely useful for ongoing reporting and in the development of future regional or national energy policy.

vi. It avoids conflict with Building Standards as they do not seek to quantify or limit the annual energy demand of a building.
vii. It promotes transparency, by making clear and apparent the true extent of annual energy consumption in individual buildings.

6.3 Proposed Methodology: Identifying an Acceptable Annual Energy Demand per Capita in new buildings

6.3.1 Methodological Steps

1 Calculate and graph the predicted annual energy demand (AED) of dwellings sized 25m^2 to 300m^2, under two different fabric energy efficiency scenarios: (These scenarios have already been used for Proposal 1, so for clarity and consistency we will apply the same nomenclature)
   i. Space heat demand
   Scenario 2: 30kWh/m^2.annum (Present/Near Future 2020 to 2021)
   Scenario 3: 15kWh/m^2.annum (Future 2024 to 2050)
   ii. The hot water demand calculation method outlined in SAP 2012 (BRE, 2014).
   iii. The electricity for lighting demand calculation method outlined in SAP 2012 (BRE, 2014). Assuming 75% fixed low energy lighting outlets (Scottish Government, 2015).
   iv. Electricity consumed by pumps and fans associated with building services.
   Scenario 2: 75kWh/annum for general building services.
   Scenario 3: 75kWh/annum plus electricity to operate an MVHR unit. This was calculated using the method outlined in SAP 2012 (BRE, 2014).
2 With respect to each scenario; calculate and graph the annual energy demand per capita (AED/Capita) relative to dwelling size.
3 Utilizing the information modelled for each scenario; determine what would represent an acceptable annual energy demand per capita. This judgement was based on the predicted annual energy demand of a modestly-sized energy-efficient dwelling. This was defined as a dwelling between 45m^2 and 100m^2 because:
   i. The average size of a new dwelling in the UK is just 76m^2 (Joyce, 2011).
   ii. In Scotland the average size of a dwelling built post 1982 is 101m^2 (Scottish Government, 2017b)
   iii. Average occupancy patterns begin to change at around 90m^2 and thereafter soon saturate at close to 3 occupants in larger homes (BRE, 2008).
   iv. In Scotland, approximately half of all new dwellings fall in the 45m^2 to 100m^2 size category (Appendix E; Onyango et al., 2016).
   v. It is considered vital that the level set should not interfere with the ability to deliver essential housing needs in a cost-effective way, and this definition will include most social and affordable housing.

6.3.2 STEP 1: Calculate the Annual Energy Demand (AED) of Dwellings.

To represent the change expected as CO_2 emission reduction standards tighten over time; the AEDs were modelled with respect to two different fabric energy efficiency scenarios. The first scenario, with a space heating & space cooling demand of 30kWh/m^2.annum, represents the level of fabric energy efficiency that could be reasonably expected of an energy efficient dwelling in the present or near future. The second scenario, with a space heating & space cooling demand of 15kWh/m^2.annum, represents the future normalisation of very highly energy efficient dwellings, possibly as early as the mid-2020s (Currie and Brown, 2019). As these scenarios have previously been defined for Proposal 1, we will for clarity and consistency retain that nomenclature and colour coding.

Scenario 2:	**30kWh/m^2.annum**	Present/Near Future	2020 - 2021
Scenario 3:	**15kWh/m^2.annum**	Future	2024 - 2050

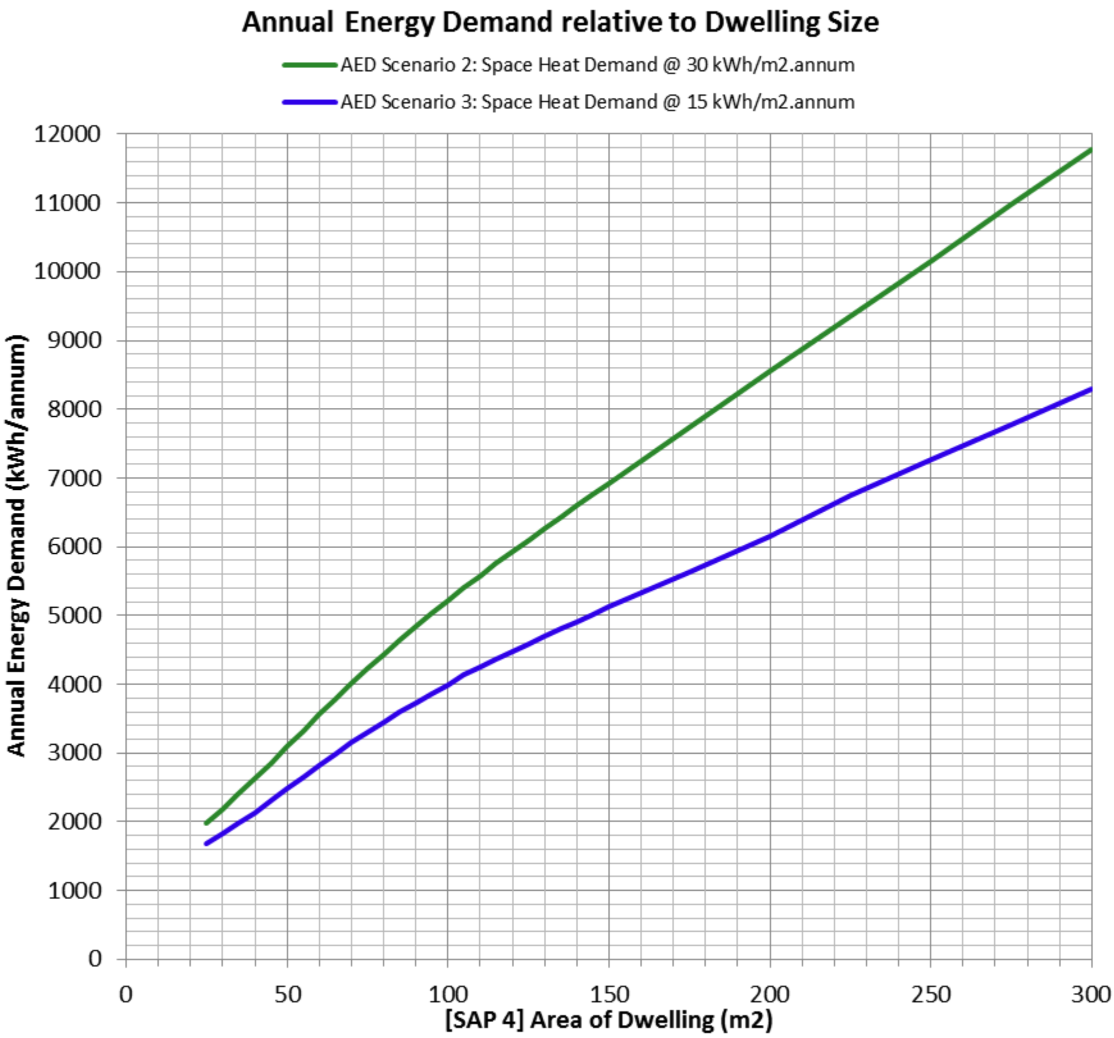


Figure 11: Predicted annual energy demand relative to dwelling size under scenario 2 and 3.

The annual energy demands (AED) for dwellings sized 25m^2 to 300m^2 were calculated as set out in detail in Proposal 1. The results are graphically represented in Figure 11. This graph clearly illustrates the impact tackling fabric energy efficiency has on reducing the annual energy demand and by extension CO_2 emissions from a building. This in turn reduces the scale and cost of the heating plant or LZCGT required to satisfy this demand.

6.3.3 STEP 2: Calculate the Annual Energy Demand Per Capita of Dwelling

With respect to each scenario, the predicted annual energy demand per capita (AED/Capita) was calculated for dwellings sized 25m^2 to 300m^2 using Formula 23. Occupancy (N) is defined by Formula 1 (BRE, 2014). The results are represented graphically in Figure 12.

$$\textbf{AED/Capita} = \frac{\textbf{Annual Energy Demand}}{\textbf{Occupancy}} = \frac{\textbf{AED}}{\textbf{N}}$$

Formula 23

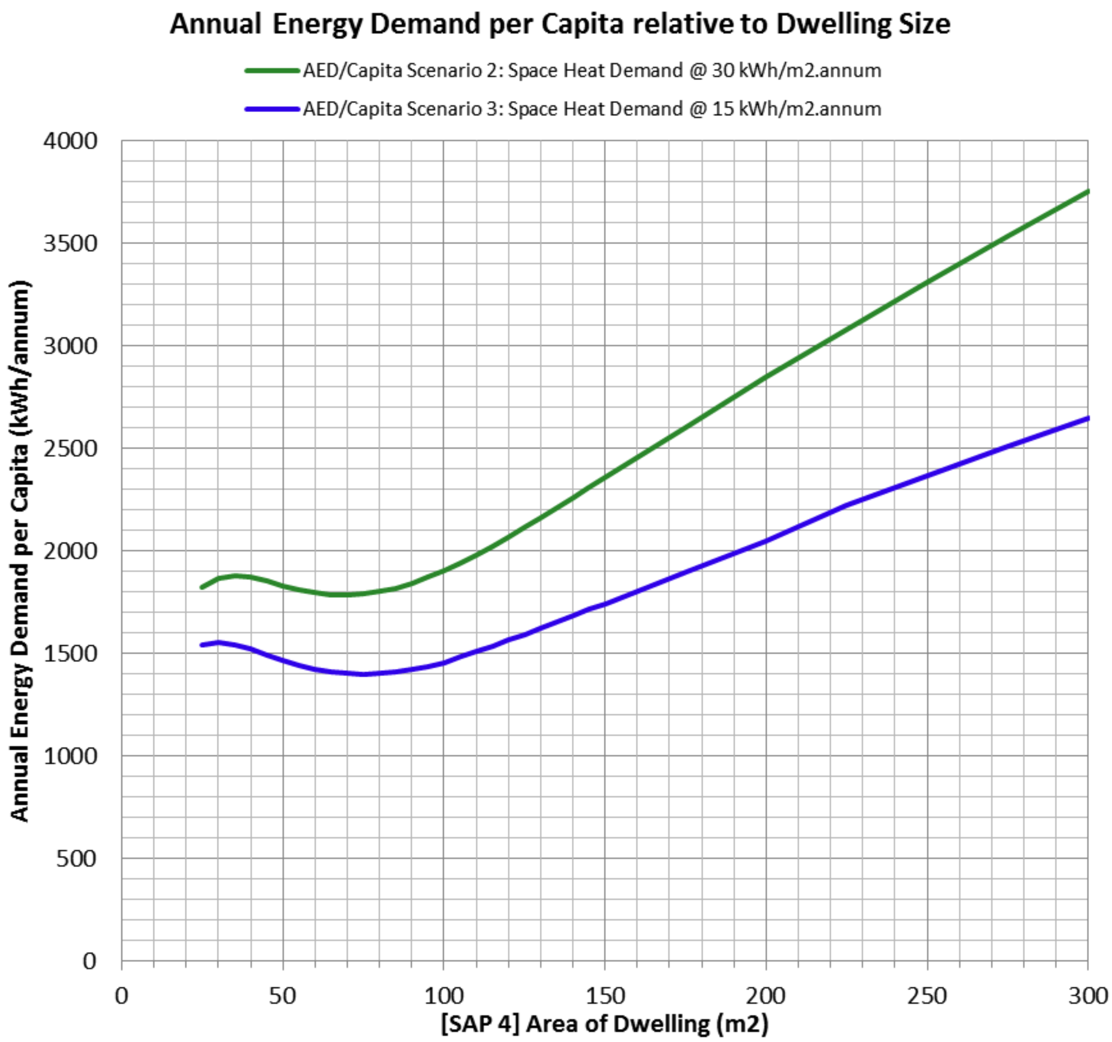


Figure 12: Predicted annual energy demand per capita (AED/Capita) calculated using Formula 23, relative to dwelling size.

6.3.4 STEP 3: Determine an Acceptable Annual Energy Demand Per Capita.

It was determined that the acceptable annual energy demand per capita (AAED/Capita) in all new dwellings would be calculated in kWh/annum and be based on the annual energy demand (AED) of a modestly-sized energy-efficient dwelling because it was considered vital that the level deemed acceptable should not interfere with the ability to deliver essential infrastructure such as social and affordable housing in a cost-effective way.

For the purposes of this study a modestly-sized dwelling was defined as falling in the 45m^2 to 100m^2 size range. In making this judgement we considered:

i. The average size of a new dwelling in the UK is just 76m^2 (Joyce, 2011).
ii. In Scotland the average size of a dwelling built post 1982 is 101m^2; the average urban dwelling being 93m^2 and the average rural dwelling was 47% larger at 137m^2 (Scottish Government, 2017b, pp. 18-19).
iii. Average occupancy patterns begin to change at around 90m^2 and thereafter soon saturate at close to 3 occupants in larger homes (BRE, 2008).
iv. SAP data was collected from an earlier study containing 402 randomly selected dwellings built in Scotland between 2012 and 2014. These dwellings ranged in size from 49m^2 to 481m^2 (Onyango et al., 2016). When analysed with respect to average expected occupancy and dwelling size, it became clear that 50% of all occupants lived in dwellings with a total floor area of between 45m^2 and 100m^2, and this size range represented 56% of the total sample (Appendix E: Table E.1).
v. It was considered highly likely that the vast majority of social and affordable housing would fall within this range.

The AAED/Capita for each scenario was determined with reference to Figure 12; by reading the peak value for each curve respectively for dwellings within the 45m^2 to 100m^2 size range. With slight rounding up this gives the following values for acceptable annual energy demands:

2021 AAED/Capita	**=**	**1910**	**kWh/annum**	(Scenario 2)
2024 AAED/Capita	**=**	**1500**	**kWh/annum**	(Scenario 3)

This AAED/Capita is applied to all dwellings regardless of size. If the annual energy demand of the proposed dwelling exceeds this acceptable level, the surplus demand must be met through zero-carbon renewable energy sources.

6.4 Compliance Targets

Essentially, compliance with this policy will be determined by comparing three values calculated for the proposed dwelling:

Acceptable Annual Energy Demand	**AAED**
Annual Energy Demand	**AED**
Zero-Carbon Adjusted Annual Energy Demand	**ZCAED**

Each will be calculated automatically in the proposed compliance spreadsheet from data extracted from the building's SAP document. The formula used to do this are set out below:

6.4.1 The Acceptable Annual Energy Demand of the Proposed Dwelling: AAED

Calculating the acceptable annual energy demand (AAED) for a proposed dwelling is simply a matter of multiplying the relevant acceptable annual energy demand per capita (AAED/Capita), by the occupancy (N) of the proposed dwelling (Formula 24). Occupancy (N) is calculated by Formula 1 and is contained within the SAP document as [SAP box No. 42].

$$\text{AAED} = \text{AAED/Capita} \times \text{N}$$

Formula 24

Using the values determined previously from Figure 12,

2021 AAED	**=**	**1910 N**	kWh/annum	(Scenario 2)
2024 AAED	**=**	**1500 N**	kWh/annum	(Scenario 3)

Using Formula 24, the acceptable annual energy demand (AAED) was calculated for dwellings ranging in size from 25m^2 to 300m^2 for both scenarios. These values are graphically represented in Figure 13. This curve clearly mirrors Figure 5.

To illustrate the extent of potential energy savings that capping annual energy demand relative to occupancy might achieve, Figure 13 also includes, for reference as dotted lines, the uncapped predicted annual energy demand for dwellings sized between 25m^2 and 300m^2 calculated under the same fabric energy efficiency scenario. It is apparent that the potential savings in respect to large dwellings are substantial.

With reference to Figure 13; for both scenarios the two lines representing predicted and acceptable annual energy demand intersect at around 100m^2. This means that dwellings between 45m^2 and 100m^2 and built to achieve a space heating and space cooling demand of less than or equal to 30 or 15 kWh/m^2.annum respectively, should not have to use LZCGT under this policy, unless they elect to do so to achieve the CO_2 emissions reductions target set by Scottish Building Standard 6.1. This ensures that the cost of social and affordable housing is not adversely affected by the insistence on the use of LZCGT. Expanding this simple analysis for Scenario 2 to include the predicted annual energy demand of dwellings built to achieve a space heating and space cooling demand of less than or equal to 15 kWh/m^2.annum (Scenario 3); it is clear that dwellings of up to approximately 175m^2 could also comply with this policy without recourse to LZCGT if they chose to build to this higher fabric energy efficiency standard.

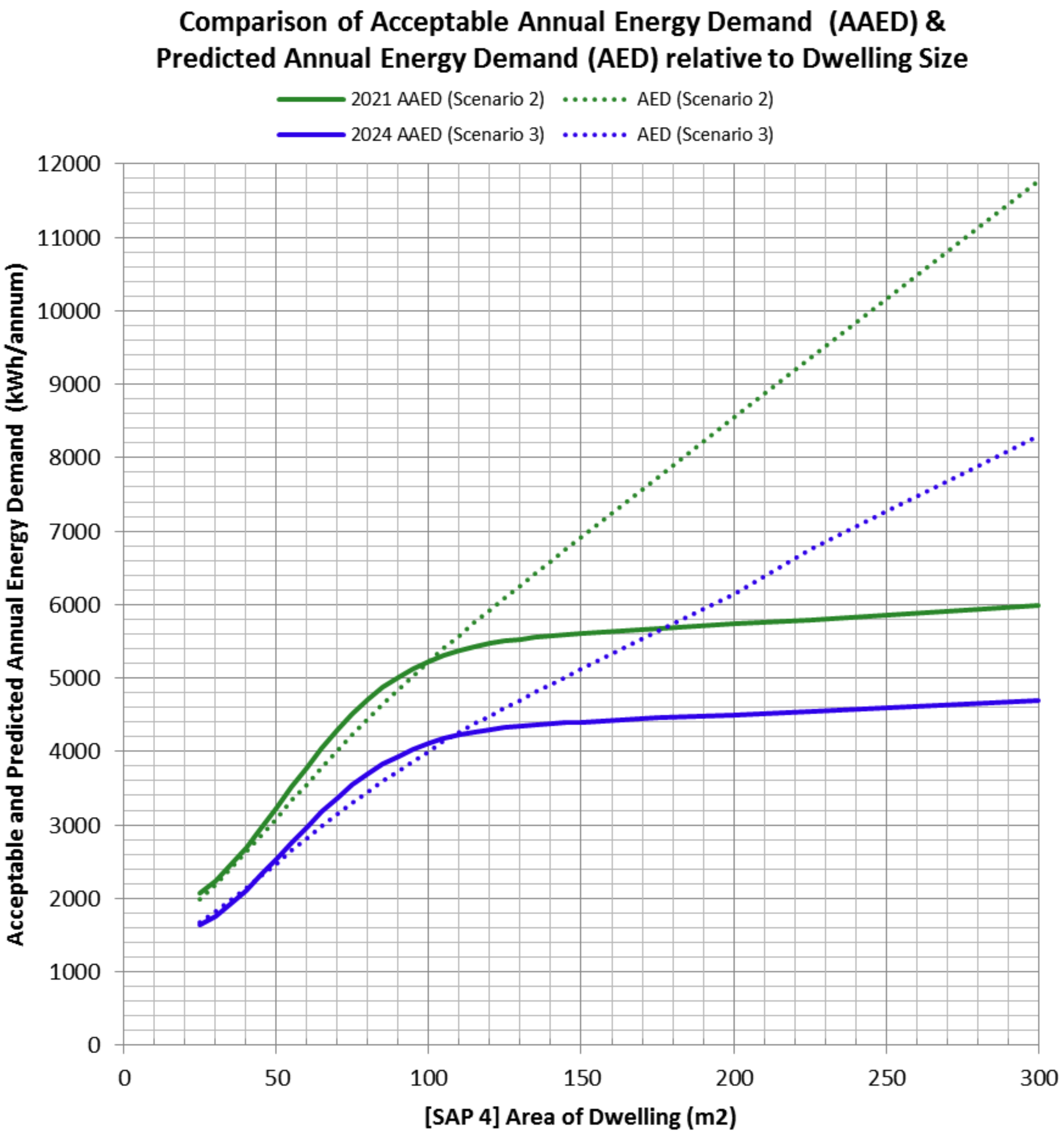


Figure 13: Predicted and Acceptable Annual Energy Demand (AAED) calculated relative to dwelling size.

Figure 14 depicts the level of fabric energy efficiency dwellings ranging in size from 25m^2 to 400m^2 would need to achieve if they wished to comply with this policy without recourse to LZCGT. This becomes progressively more onerous for large dwelling as the per capita heated living space increases, and it is expected that most of these dwellings will find use of LZCGT essential even with increased fabric energy efficiency levels.

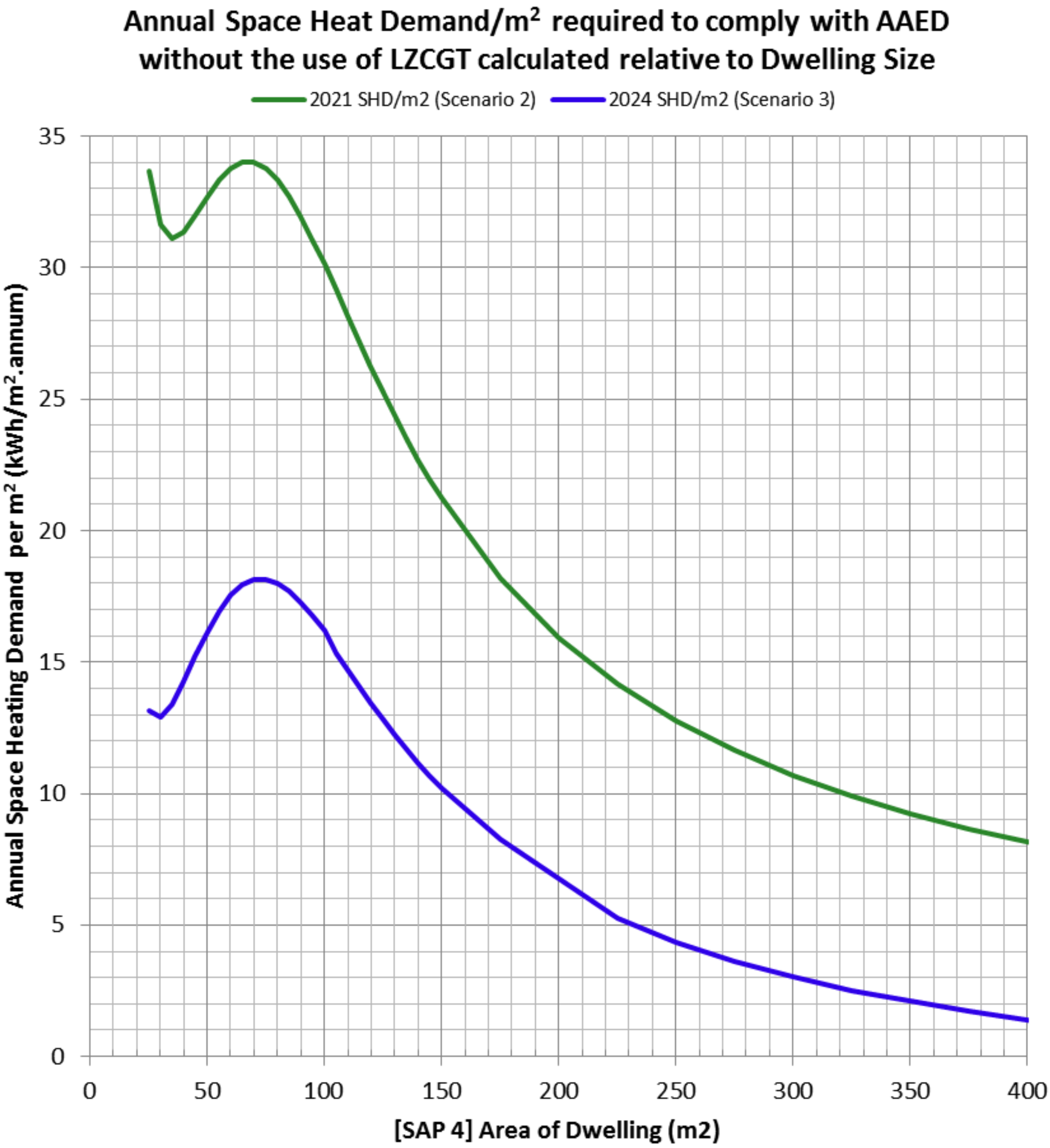


Figure 14: Approximation of the space heat demand per m^2 a dwelling would have to achieve to comply with the acceptable annual energy demand (AAED) without recourse to LZCGT, calculated relative to dwelling size for Scenario 2 and 3.
Note: Different assumptions were made relative to Pumps and Fans for Scenario 2 and 3 because it was considered at very high fabric energy efficiency (space heating demand ≤15kWh/m^2.annum) a MVHR unit would likely be required for ventilation purposes. The values depicted in Figure14 for Scenario 2 may therefore need to be reduced by a few Kwh/m^2.annum at fabric energy efficiencies approaching and below 15kWh/m^2.annum.

6.4.2 The Annual Energy Demand of the Proposed Dwelling: AED

The actual annual energy demand for the proposed dwelling will be calculated automatically by the compliance spreadsheet from the input SAP data. It will comprise of the sum of the annual energy demands per annum calculated for space heating [SAP box No. 98], space cooling [SAP box No. 107], water heating [SAP box No. 64], lighting [SAP Box 232], and pumps and fans [SAP Box 231]**.** This was previously defined in Proposal 1, by Formula 8.

AED = [SAP Box 98] + [SAP Box 107] + [SAP Box 64] + [SAP Box 232] + [SAP Box 231]

Formula 8

6.4.3 The Zero-Carbon Adjusted Annual Energy Demand for the Proposed Dwelling: ZCAED

This is the actual annual energy demand for the proposed dwelling adjusted to take into account the contribution of zero-carbon renewable energy sources that are used to meet this demand. The compliance spreadsheet will automatically calculate the contribution of each energy source used; classifying them as zero-carbon, low-carbon, grid electricity, bio-carbon or fossil fuel. It will then automatically calculate the zero-carbon adjusted annual energy demand (ZCAED).

ZCAED = AED - ∑ zero-carbon renewable energy sources

Formula 25

6.4.4 Determining Compliance:

There are two possible ways that a dwelling can achieve compliance with this policy. Both calculations will be automatically performed by the proposed compliance spreadsheet.

Compliance Method 1

The annual energy demand (AED) of the dwelling is less than or equal to the acceptable annual energy demand (AAED) calculated for it on the basis of the predicted occupancy.

AED ≤ AAED

Formula 26

It is possible to achieve compliance through sensible energy-efficient design and fabric energy efficiency measures alone, and although this method does not depend on the use of LZCGT to achieve compliance, neither does it preclude its use. This method of compliance will become progressively more difficult as dwelling size increases and the AAED target tightens.

Compliance Method 2

The annual energy demand of the dwelling adjusted to take into account the contribution of zero-carbon renewable energy sources (ZCAED) is less than or equal to the acceptable annual energy demand (AAED) calculated for it on the basis of the predicted occupancy.

ZCAED ≤ AAED

Formula 27

This method depends on the use of LZCGT to achieve compliance, and will probably be necessary for large dwellings.

6.5 Compliance Procedures

6.5.1 Compliance Workflow

Having reflected on the opinions expressed by survey respondents; we suggest that Planning should focus its efforts on getting architects and developers to prioritise making better decisions with respect to climate change, energy consumption and CO_2 emissions at an early stage in the design process (Appendix A). The recent revisions to the RIBA Plan of Work reinforce this viewpoint (RIBA, 2020). At this early stage the design is more mutable, with opportunities to incorporate passive design principles, reconsider scale and built form, explore potential LZCGT, and set ambitions relating to fabric energy efficiency.

This approach will require that architects, developers and planners move beyond relying on simplistic approaches to CO_2 emission reduction, and see the building as a holistic system and devise solutions accordingly. It also presupposes that planners have sufficient knowledge and depth of understanding of the issues to offer guidance; alongside signposting throughout the planning process that these are serious issues that need to be addressed in submitted planning applications.

The following is a suggestion of how this policy could be administered and incorporated into the existing workflow of planning officers. It is informed by insights gained by planning officers in administrating current Section 3F policy (Appendix A).

Pre-application Stage

The strategy at this stage should be to forewarn and forearm applicants. Where planners have pre-application discussions with applicants, the need to develop sustainable and energy efficient buildings and communities should be emphasised. The policy aim of reducing CO_2 emissions through reducing energy demand, increasing energy efficiency and using zero-carbon renewable energy sources should be explained and promoted, and initial advice given on the means applicants can potentially employ to meet this objective. Architects and Developers should be encouraged to use the compliance spreadsheet as a design tool to explore the impact and implications of taking different design approaches or employing specific LZCGT. They should also be advised that larger dwellings will in all probability have to perform to substantially higher standards than currently expected to achieve compliance with this policy, to compensate for their tendency to have very high per capita energy use (Figures 12, 13 and 14).

Planning Application Stage

Ideally, compliance documentation will be submitted at this stage, and if so, could form the basis of discussions between planners and applicants. If the compliance spreadsheet cannot be completed at this stage for lack of finalised SAP data, the drawings and design statements submitted should clearly indicate how the applicant intends to comply with the proposed policy. They should allow the planning officer to assess the extent to which passive design principles have been incorporated into the design, the intentions with regard to fabric energy efficiency and building energy services, and the level of LZCGT provision. Whether the design makes it easy and cost-effective to incorporate improvements such as adding a PV array or switching the heating system from a gas boiler to a heat pump at a future date should also be reflected on. Moreover, in the absence of the compliance spreadsheet, the planning officer will need to judge whether these measures seem sufficient to meet policy requirements. Depending on the level of information provided different responses may be appropriate.

i. **An informal chat:** If the drawings fail to meet the expected standards by a large margin and/or there are other issues with the application that arise during the public consultation, then the first response should be an informal chat with the applicant. This should draw attention to climate change issues and offer advice on the specific expectations of the policy. Where appropriate, planners could make recommendations as to potential improvements to the application. The applicant then has the choice to submit revised drawings and statements, or withdraw the application and resubmit at a later date.
ii. **A formal letter or email:** If the information submitted is incomplete or there are discrepancies between drawings and statements, a formal letter or email asking for clarification and drawing attention to the policy and its expectations would be in order. An invite to discuss the issues further could also be issued.
iii. **Planning approval subject to a suspensive condition:** If it is clear from the drawings and design statements that the application has considered policy requirements and there are no other major issues; planning permission should be granted subject to a suspensive condition. If the compliance spreadsheet has not yet been submitted, this should instruct the applicant that 'as designed' compliance documentation should be submitted once SAP has been finalised and prior to any works starting on site. Applicants should also be advised that they will be required to submit 'as built' compliance documentation once the building is complete.

Building Warrant Stage

As soon as the design has been finalised and the SAP calculation performed, the applicant should complete and submit the policy compliance spreadsheet to show that the building will meet its acceptable annual energy demand target by either of the permitted compliance methods. Works should not start on site before this document has been received. If an applicant is struggling with compliance, planning officers should be available to offer free guidance on how this might be practically achieved. The compliance methodology is flexible in this regard.

Construction Phase

At the end of the construction phase, applicants should submit 'as built' compliance documents to both planning and building standards to ensure that any changes during the construction phase have not been to the detriment of the policy. If building standards does not receive this document they should advise the applicant that it is required prior to them issuing the completion certificate.

Reporting and Future Planning

Ideally for ongoing reporting, research and planning of future energy infrastructures, the key information contained within the compliance documents should be recorded in a national database.

Key statistical data should include:

i. Size of dwelling (m^2)
ii. Annual Energy demand (kWh/annum)
iii. Specified systems, fuels and LZCGT
iv. The contribution of individual LZCGT to the energy mix (kWh/annum)
v. The means of compliance

6.5.2 Design of Compliance Documentation

The proposed compliance documentation will consist of a standardised Excel spreadsheet submitted to planning either during the planning application process or prior to the commencement of building works (Appendix C). This spreadsheet will record details about the proposed building's annual energy demand and the type of systems, fuels and LZCGT employed. The data used to complete the spreadsheet will be extracted from the finalised SAP calculation submitted to Building Standards. The Excel spreadsheet will automatically calculate whether the dwelling is in compliance, and clearly tabulate the contribution of individual energy sources with particular emphasis on capturing the zero-carbon contribution of LZCGT. The metric used will be kWh/annum.

The compliance documentation was designed with the objective of making the entire process as easy as possible for all stakeholders whilst providing the opportunity to collect energy data for forward planning of local and national energy networks. The design parameters included:

1. A clear and concise standardised compliance document in Microsoft Excel to allow for familiarity, ease of completion and comprehension by all stakeholders.
2. Input data to be the minimum necessary to accurately describe the building's energy systems and should be solely sourced from the SAP 2012 document submitted to Building Standards.
3. The spreadsheet should document and/or calculate:
    i. The size of the dwelling (m^2).
    ii. The occupancy of the dwelling.
    iii. The annual energy demands for space heating, space cooling, hot water, lighting and pumps & fans (kWh/annum).
    iv. The contribution of each specified system, fuel and LZCGT (kWh/annum)
    v. The total contribution of zero-carbon renewable energy sources (kWh/annum)
4. It should provide a clear statement of how compliance is achieved.
    i. Compliance Method 1: AED ≤ AAED
    ii. Compliance Method 1: ZCAED ≤ AAED

5. The calculation methodology should be transparent, and information should be presented in an easy to understand tabulated format so that designers and planners can quickly comprehend the impact and implications of specific design choices and use the spreadsheet as a conceptual design tool.
6. The use of certain technologies and systems should be encouraged or discouraged through simple colour-coding.
7. The data collected should be capable of being compiled into a database and used for research and reporting purposes to aid in the development of appropriate government energy policies and regional or national energy networks.

6.5.3 The Calculation Methodology

To avoid undue complexity and reduce the amount of information that is needed to be input into the compliance spreadsheet, the calculation methodology has been simplified as far as possible. It should be noted that this methodology remains firmly focussed on energy demand, energy consumption and the contribution made by zero-carbon renewable energy sources. The metrics used throughout are kWh/annum.

Unlike SAP it does not apply carbon factors or attempt to quantify CO_2 emission reduction in any way. This is after all adequately legislated for through Building Standards. Instead it takes a much more broad brush approach; in the certain knowledge that reducing annual energy demand and/or replacing a proportion of that demand with zero-carbon renewable energy sources will inevitably reduce CO_2 emissions. It therefore simply defines the energy sources used as zero-carbon, low-carbon, grid electricity, bio-carbon or fossil fuels, and uses a simple colour coding system to indicate preferable choices. Only zero-carbon designated energy sources are used to mitigate the annual energy demand.

It should be noted that different LZCGT are accounted for in different ways within the calculation process. Most zero-carbon renewable energy sources and heat recovery processes require at most only a minor energy input for their effective operation. If this is clearly recorded and attributed to a certain LZCGT in the SAP calculation [SAP box Nos. 230 a-h] this is simply subtracted from their calculated contribution. Heat pumps however require a substantial amount of electricity to operate. To account for this, the electricity consumed is simply subtracted from the heat demand delivered effectively reducing the heat pump's zero-carbon contribution in line with their efficiency. It should be noted that grid electricity has specifically been separated into its own category, as the proportion generated nationally from zero-carbon or renewable energy sources might be captured and reflected within the zero-carbon total in future refinements of the calculation process.

In general, the convention in SAP is to consider the heat output of CHP plants as the intentional product of the process to which CO_2 emissions are attributed, and the electrical output is treated as a zero-carbon energy resource. However, depending on the fuel source, CHP plants can emit substantial amounts of CO_2, so within this calculation methodology they are recorded as low-carbon or bio-carbon. As they are not considered zero-carbon, their contribution is not used to mitigate annual energy demand. An exception would be geothermal and hydrogen fuel cell CHP which are zero carbon. In some circumstances local authorities might elect to relax this definition and allow a proportion of the energy produced to be used to mitigate annual energy demand in order to promote local community heat or electricity networks, but we do not recommend this. For similar reasons biomass and biogas are recorded as bio-carbon energy sources and similarly not used to mitigate annual energy demand (CCC, 2018, 2019b). Waste heat recovered from power stations, or industrial and agricultural processes will however be designated as zero-carbon.

6.5.4 The Compliance Spreadsheet

Evidencing compliance is simply a matter of completing the relevant data input section of the compliance spreadsheet, with information extracted from the DER worksheet of the SAP document submitted to Building Standards (Appendix C). Excel will perform all necessary calculations automatically. The process is as follows:

STEP 1: Data Input

Applicants complete the data input worksheet relevant to their proposed building: Section 1 is for dwellings with individual heating systems and micro-cogeneration; Section 2 is for dwellings with community heating systems (Appendix C: Figures C.3, C.5). Applicants need only fill in those shaded boxes that are relevant. Some boxes are pre-populated to reduce input further.

There is no need to understand SAP calculation to complete the spreadsheet, because the required SAP box numbers are clearly indicated on both documents. Particular care should be taken to ensure the SAP convention of entering generated or recovered energy as a negative value is followed. The only other information needed is knowledge of the type of heating system, fuel or LZCGT employed. This is usually contained within the summary of input data at the beginning of the SAP document. This type of data is entered into the worksheet using one of the system codes listed at right-hand edge of the spreadsheet. For clarity, when entering data related to pumps and fans the system code associated with their end use should be used, not electricity.

Unless the building is very complex, many of the boxes will equal zero, and can be left blank. The data input worksheet should therefore take less than 10 minutes to complete. Excel utilizes this information to automatically complete the relevant Compliance Calculation worksheets (Appendix C: Figures C.4, C.6).

STEP 2: Compliance Method 1

This method of compliance relies on an inherently low annual energy demand (AED) rather than the use of LZCGT; although it should be noted that the contribution of some LZCGT (Solar Thermal, MVHR, WWHR and FGHR) will already be embedded within the calculated AED if they are used.

i. Excel calculates the acceptable annual energy demand (AAED) measured in kWh/annum for the proposed dwelling, using Formula 24. (Note: both the

2021 AAED and the 2024 AAED are shown on the example worksheets in Appendix C. In reality only the level currently sought would be included).

ii. Excel calculates the annual energy demand (AED) measured in kWh/annum for the proposed dwelling, using Formula 8.
iii. Excel compares the AAED and the AED. If AED ≤ AAED (Formula 26) then the dwelling is considered to be in compliance without the need to employ LZCGT, unless these are required to meet CO_2 emissions reduction target set by Section 6 of the Scottish Building Standards. A compliance/non-compliance statement is automatically generated.

STEP 3: Compliance Method 2

If the AED of the proposed dwelling is greater than its calculated AAED, the dwelling can still achieve compliance, if the energy demand in excess of the acceptable level is met by zero-carbon renewable energy sources. This method of compliance relies on the use of LZCGT. However large buildings may have to employ design and fabric energy efficiency measures as well to lower energy demand sufficiently to make the use of LZCGT feasible and cost effective.

i. Excel uses the input SAP data to calculate and tabulate the contribution of each energy source used in the proposed dwelling in kWh/annum. The results are then clearly defined as zero-carbon, low-carbon, grid electricity, bio-carbon or fossil fuels; and colour-coded green, amber or red to help visually identify which technologies are considered most favourable. Zero-carbon energy contributions are colour-coded green.
ii. Excel calculates a zero-carbon adjusted annual energy demand (ZCAED) using Formula 25, by taking into consideration all the zero-carbon renewable energy sources used in the proposed dwelling.
iii. Excel compares the AAED and the ZCAED. If ZCAED ≤ AAED (Formula 27) then the dwelling is considered to be in compliance. A compliance/non-compliance statement is automatically generated.

STEP 4: Resolving Non-Compliance

If the AED and ZCAED for the proposed dwelling are both greater than its calculated AAED, then the dwelling is NOT in compliance and the designer must make alterations to the design, fabric energy efficiency and/or the LZCGT employed to bring it into compliance. The compliance procedure is quite flexible and there are several ways that a designer can bring a non-compliant building into compliance, either by reducing the annual energy demand (i. – iv.) or employing additional zero-carbon renewable energy systems (iv. – vii.). The compliance spreadsheet used alongside SAP can be exploited as a design tool to explore these options. The options are:

i. Revise the Building Design: consider scale, built form, solar orientation, and other passive measures to reduce overall heat demand.
ii. Increase fabric energy efficiency.
iii. Increase air tightness and employ Mechanical Ventilation Heat Recovery (MVHR). Consider a near Passivhaus approach.
iv. Consider Thermal Solar or Waste Water Heat Recovery (WWHR).

v. Consider Zero Carbon Electricity Generation: PV, Wind, Water etc.
vi. Consider Zero Carbon Heat Generation: All types of Heat Pumps: GSHP, GWSHP, SWSHP, ASHP, EASHP, and SASHP. Be aware that in calculating the zero-carbon contribution, the electrical input will be subtracted from the output.
vii. Community Heating: Numerous different energy sources may be employed within district heating schemes; these will be considered on their individual merits. Scaled zero-carbon renewable energy systems might include PV, Wind, Water, Tidal or Geothermal Energy, Waste Heat Recovery from Power Stations, or Waste Heat Recovery from Industrial or Agricultural processes.

For more details about the compliance spreadsheet and worked examples, see Appendix C.

7. Conclusions

In responding to the brief we have considered both the established literature in relation to reducing CO_2 emissions from buildings, and the issues raised by planning officers in local authorities across Scotland who are administrating current Section 3F policies. As a result, two distinct proposals, that might be appropriate for the Scottish Government to consider at this juncture, are developed and presented. However, in conclusion, it is necessary to comment on the strengths and weaknesses of each proposal, and highlight the limitations of some of the assumptions made in formulating these approaches, target levels, and workflows for demonstrating compliance.

7.1 The Scenarios

Both proposals took an essentially pragmatic approach to determining target levels; and deliberations were based on the predicted energy demand of dwellings ranging in size from 25m^2 to 300m^2 calculated using formulae prescribed in the Standard Assessment Procedure SAP 2012 (BRE, 2014). Particular attention was paid to dwellings between 45m^2 and 100m^2 as it was felt this size range would include the majority of social and affordable housing.

Three scenarios were developed to provide a better appreciation of how improvements in fabric energy efficiency could potentially impact on annual energy demand and the viability of certain LZCGT solutions (Table 10). In the absence of a firm timetable of commitment to improving CO_2 emission reduction in new buildings, a future scenario based on a space heat demand of 15kWh/m^2.annum was developed. This is in line with the recommendation by the Committee on Climate Change that by 2025 at the latest all new buildings should be built to an ultra-high fabric energy efficiency standard commensurate with a space heat demand of 15 – 20 kWh/m^2.annum and be designed to use low carbon heat (CCC, 2019b, p66; 2019d, pp 14-15).

	Space Heat Demand	**Time Period**	**Standard of Fabric Energy Efficiency & Ventilation**
Scenario 1:	45kWh/m^2.annum	Past 2012	Good FEE Natural Ventilation
Scenario 2:	30kWh/m^2.annum	Present/Near Future 2020 - 2021	High FEE Natural Ventilation
Scenario 3:	15kWh/m^2.annum	Future 2024 - 2050	Ultra-High FEE MVHR

Table 10: Scenario outline

Modelling was based on domestic buildings because these are the most frequent building type encountered by planning authorities; they consume a much larger proportion of energy for space heating, hot water and lighting than other sectors; and avoiding any unintended impact on the ability to deliver affordable housing was considered of paramount importance (BEIS, 2019a). Potentially this data will need to be revised slightly if the way that annual energy demands are calculated is changed with the adoption of SAP10 (BRE, 2019, pp 73-75). However as each proposal focusses on the subgroup of dwelling in the 45m^2 and 100m^2 size range this change is not expected to impact substantially on the recommendations made herein. Each proposal employed the data contained in these scenarios in different ways.

7.2 Proposal 1

Proposal 1 satisfies the research objectives as stated in the brief relative to Section 3F Policy as enacted in current legislation. Although Section 3F is a single issue policy, the proposal acknowledges that other factors also contribute to reducing emissions from buildings. It therefore defines a realistic minimum LZCGT contribution to CO_2 emission reduction in new buildings that could be sought by Section 3F policy without undermining the viability of a fabric first approach or the development of innovative passive design solutions. This approach does not preclude architects and developers from using a higher proportion of LZCGT to meet their Target Emission Rate (TER) if they so desire.

The methodology used to determine an appropriate LZCGT contribution level was simple and pragmatic. The scenarios were used to explore what would be a reasonable expectation of the contribution LZCGT would make to the annual energy demand in new buildings under different CO_2 emission reduction standards. This was achieved by gauging the impact on annual energy demand of utilising LZCGT to either replace a proportion of the annual energy demand or generate electricity to offset that demand, and identifying real-world practical limitations that might be encountered in doing so.

Although target levels were determined with respect to empirical quantitative data, the methodology used to determine what would be ‘reasonable’ under different CO_2 emission reduction standards was essentially a qualitative judgement. In exercising this judgement it was recognised that setting a minimum LZCGT contribution that was too high might have unintended adverse consequences on long-term goals for CO_2 emission reduction, energy security and the ability to achieve wider societal goals. It was also acknowledged that what is ‘reasonable’ is open to interpretation. As a consequence the level of LZCGT contribution calculated by this method was subsequently evaluated with respect to interim targets and aspirations set by the Scottish Government (Scottish Government, 2018a, pp. 87-89; CCC, 2019b, p66; Scottish Parliament, 2019a). The results were found to be in general accord.

Having determined what would be a reasonable LZCGT contribution as a percentage of annual energy demand under different emission reduction standards, it was necessary to express this in terms of a percentage CO_2 emission reduction to comply with the requirements of Section 3F policy. Three alternative ways of defining LZCGT contribution relative to CO_2 emissions were identified in current Section 3F policies: A%, C% and E%. The relationship between these metrics is defined by Figure 8.

A% An absolute percentage CO_2 emission reduction relative to the 2007 baseline established by Scottish Building Standard 6.1.

C% A percentage of the percentage CO_2 emission reduction sought through Scottish Building Standard 6.1 relative to the 2007 baseline.

E% An avoidance of a percentage of the building projected CO_2 emissions as calculated by SAP/SBEM.

We found several distinct advantages to be gained from a regulatory standpoint of using the metric C%, as this effectively links Section 3F policy directly to whatever is the CO_2 emission reduction required by the current Scottish Building Standard 6.1. However, we note that this metric is problematic from a practical design standpoint. Consequently there is a need to ensure that stakeholders can understand the practical implications of this metric in terms of the LZCGT contribution to annual energy demand that would be required to meet this target under different emission reduction standards. This could be achieved through reference to Figure 8, Table 9 and/or the type of graphical data developed for each scenario (Appendix B).

Showing compliance is relatively straightforward and a standard excel spreadsheet has been developed for this purpose (Appendix C: Proposal 1). The compliance calculation utilizes the emissions rates (DER and TER) calculated for the dwelling by the SAP methodology. However it also requires a second SAP calculation to be conducted to determine the dwelling emission rate with the LZCGT removed and replaced with pre-defined conventional system (DERNT). What these replacement systems will consist of needs to be clearly defined. The final compliance calculation is then a simple matter of substituting these factors and the required emission reduction standard (R%) into the formula and if the result is greater than or equal to percentage indicated in Table 9 the building is in compliance. For C% this has been calculated as 12% for both domestic and non-domestic buildings under all emission reduction standards.

7.3 Proposal 2

By contrast proposal 2 takes a whole building approach to CO_2 emission reduction which diverges significantly from the enacted Section 3F policy and would therefore require new legislation. It was not part of the brief but we arrived at it based on our own lessons and insights from undertaking the study. It re-invents this policy in a way that focuses on the strengths, skillsets and wider objectives of Planning whilst complementing and supporting the existing whole building approach to CO_2 emission reduction taken by Building Standards. This proposal concentrates on domestic buildings only, and centres on the idea of limiting annual energy demand (AED) in new dwellings to an acceptable per capita level. Through this mechanism, it aims to leverage better design solutions, prioritise fabric energy efficiency, promote the use of LZCGT, and address fundamental issues not tackled by the current system.

Compliance with the proposal will be allowed through any combination of design, fabric energy efficiency, equipment efficiency or LZCGT. Applicants will be actively encouraged to meet the acceptable annual energy demand (AAED) calculated for their proposed building through good design and fabric energy efficiency measures alone, if that is feasible and cost effective. However if a dwelling does not manage to achieve this, then all remaining energy demand in excess of the acceptable level must be met by zero-carbon renewable energy sources. Policy compliance will be established by completing a simple standardised spreadsheet with data taken directly from the building's SAP document.

The methodology used to determine an acceptable annual energy demand per capita (AAED/Capita) is based on a simple calculation; with the judgement of what is reasonable primarily embedded in the space heat demand deemed appropriate to the timeframe in question and the range of dwelling sizes taken under consideration. It should be noted that if either of these variables is changed the resultant AAED/Capita would be substantially different.

The AAED/Capita was established with respect to the predicted annual energy demand (AED) and assumed occupancy (N) of modest-sized dwellings. For the purpose of this study a modest-sized dwelling was defined as between 45m^2 and 100m^2. This size range was defined with reference to statistical data and provides the critical cut-off points in calculating the target AAED/Capita level (BRE, 2008; Joyce, 2011; Scottish Government, 2017b; Appendix E). It also acknowledges the excess per capita energy consumption in large dwellings due to their large heated living space and relatively low average occupancy rates (BRE, 2008; Burford et al., 2019). Scenario 2 and 3 were used to define the AAED/Capita for 2021 and 2024 respectively.

This AAED/Capita will apply to all dwellings regardless of size. However by calculating this value with respect to modest sized dwellings the target rate can be set at an ambitious but achievable level, whilst ensuring that it does not impact adversely on the ability to deliver essential domestic infrastructure such as affordable housing. It is recognised that it will be potentially more challenging for large dwellings, but it is still readily achievable (Appendix C). It should also be remembered that it is not the intention of this proposal that dwellings should meet the AAED/Capita target purely by dint of passive design principles or increased fabric energy efficiency. It is accepted in the compliance methodology that some of the annual energy demand can be effectively offset through the use of zero-carbon energy sources. By whatever means it is achieved, reducing the per capita annual energy demand of large dwellings to bring them in line with more modest dwellings, could deliver substantial CO_2 emission reductions in this sector (Appendix E).

As the country evolves towards 2045 and net-zero carbon buildings, it is envisaged that that the AAED/Capita could be progressively reduced until it reaches zero. At this point any remaining regulated energy demands in new dwellings would have to be met by zero-carbon renewable energy sources.

The proposal takes an unashamedly broad brush approach to CO_2 emission reduction, certain in the knowledge that reducing annual energy demand and/or replacing a proportion of that demand with zero-carbon renewable energy sources will inevitably have a positive impact. It does not apply carbon factors, compare the proposed building to a notionally similar one, or require a second SAP calculation to be performed. Rather than attempting to quantify CO_2 emissions; the methodology remains firmly focussed on the annual energy demand and annual energy consumption and the contribution made by zero-carbon renewable energy sources as calculated for the proposed building.

The aim in this approach is to keep the focus on variables that architects, developers and planners can easily identify with and manipulate by taking good decisions in these early stages of the design process. Making the use of zero-carbon energy sources compulsory only if a building fails to meet its acceptable annual energy demand effectively promotes and rewards sensible passive design decisions and good fabric energy efficiency standards, and allows these factors to do much of the heavy lifting in reducing emissions. Only taking into account high quality zero-carbon energy sources (renewables, heat pumps and heat recovery) also effectively dis-incentivises low-carbon approaches and small scale biomass without carbon capture in line with recommendations made by the Committee on Climate Change (2018).

Compliance is evidenced by completing a standard excel spreadsheet using data extracted from the SAP calculation (Appendix C: Proposal 2). Although more complex than proposal 1, the spreadsheet should take no more than 10 minutes to complete and excel performs all necessary calculations automatically. The compliance documentation was designed with the objective of making the entire process as easy and transparent as possible for all stakeholders. The compliance procedure is quite flexible and there are several ways that a designer can bring a non-compliant building into compliance, either by reducing the annual energy demand or employing additional zero-carbon renewable energy systems. Used alongside SAP data, the compliance spreadsheet can be exploited as a design tool for architects, developers and planners to objectively explore these different options.

7.4 Both Proposals

Both proposals actively consider protecting the ability to deliver essential domestic infrastructure such as social and affordable housing as a critical parameter. This is achieved by focussing on the impact of the proposals on the sub-group of dwellings in the 45m^2 to 100m^2 size range.

The compliance procedure for both proposals is based around a simple standardised spreadsheet that should take no more than 10 minutes for the building's designer to complete. This will help promote clarity in terms of the evidence required to show compliance and develop familiarity with the compliance procedure. Hopefully it will also address some of the issues regarding the standard of evidencing currently being received by planning officers.

Both proposals depend on data extracted directly from the SAP worksheet so should incur little in terms of additional expense. Although as proposal 1 does require a second SAP calculation so some small costs might be incurred. The use of SAP data to quantify LZCGT contributions does however mean that neither proposal truly addresses the intransigent issue of the stage in the design process at which this data becomes available and the implications this has in terms of enforcement and delivering better built outcomes.

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Appendix A: Survey

Survey Response and Analysis

Introduction

The survey sought the views of planning authorities across Scotland in order to learn from the experiences they have gained as a result of administrating current Section 3F policies. The aim was to benchmark current policy and procedures, and reveal where practical issues or concerns were being raised because of specific approaches. The survey was divided into three sections:

1. **LZCGT Targets:**
   Addressing what LZCGT targets have been set; what factors and parameters were used to determine these levels; and to what extent local or regional contexts have influenced policy.
2. **Evidence & Procedures:**
   Addressing what evidence, procedures and calculation methodologies are used to determine compliance; and what practical issues need to be addressed within these approaches.
3. **Going Forward:**
   Addressing trends in LZCGT uptake; respective roles of planning and building standards and how they can coordinate efforts; and what additional support the Scottish Government could offer to afford clarity of expectation for all stakeholders.

Survey Response

The planning service in Scotland is primarily delivered by 32 local authorities and 2 national park authorities (the Cairngorms; Loch Lomond and the Trossachs). Each of these were invited to take part in the survey so that the researchers could better understand the practical implications of the current Section 3F Policy and what issues need to be addressed in developing a Scotland-wide Section 3F policy. 14 full survey responses were received; 3 of which were from different regional offices of the same planning authority. This response therefore represents 35% of potential respondents and a broad range of geographic contexts and regional approaches.

Section 1: LZCGT Targets

Key Points

- Clarity in terms of the target LZCGT contribution sought, how it is calculated, and the context in which the policy is applied is vital going forward.
- Good quality supplementary guidance is essential to raise awareness of the Section 3F policy, clarify expectations and designate compliance procedures.
- The majority of planning authorities defined the LZCGT contribution as a percentage of the percentage CO_2 emissions reductions sought through Scottish Building Standard 6.1: carbon dioxide emissions (Figure A1.1)
- Section 3F policy is applied to all new development with certain exceptions. In general these mirror the exceptions made to Standard 6.1.
- Typically there is a period between planning consent and building warrant consent when building design and technical details are refined. Compliance with Standard 6.1 is usually determined during this period through the submission of SAP/SBEM calculations to Building Standards.
- Information contained within these SAP/SBEM calculations is used as a means of calculating LZCGT contribution and determining compliance with Section 3F policy.
- LZCGT Target contributions vary considerably across planning authorities. The most frequent contribution recorded in this survey is 10% of the percentage CO_2 emissions reductions sought through Standard 6.1.
- Many planning authorities have taken advice from Scottish Government on the level of LZCGT contribution that should be sought, but there appears to be little understanding of how this figure was determined.
- Meeting the LZCGT target does not appear to be an issue (Figure A.2); but the difficulty of demonstrating compliance at the planning application stage is. This is because of the lack of availability of accurate SAP/SBEM data this early in the design process.

Question 1
Does your Local Development Plan or associated Supplementary Guidance QUANTIFY the contribution LZCGT should make in reducing GHG emissions?

(14 Respondents)

11 respondents (79%) indicated that their local authorities quantified the contribution LZCGT should make in reducing GHG emissions, 3 respondents (21%) indicated that theirs did not.

Questions 2, 2a, 2b
What is the current LZCGT contribution sought by your planning authority?
In what terms does your planning authority define this target?
Is this quantified LZCGT contribution to GHG emissions reductions applied universally to all applications or in only specific circumstances e.g. specific development types or those over a certain size?

(11 Respondents)

The majority of respondents (8/11) indicated that their planning authority defined the LZCGT contribution in terms of a percentage of the percentage CO_2 emissions reductions sought through Scottish Building Standard 6.1: carbon dioxide emissions (Figure A.1). The remaining respondents (3/11) indicated that the metric used was a percentage of the building energy demand or consumption. We can deduce therefore that all must use the SAP/SBEM calculation as a means of determining compliance.

The most frequent level of LZCGT contribution (3/10) sought was 10% of the percentage CO_2 emissions reductions sought through Scottish Building Standard 6 (Figure A.1). The current CO_2 emissions reductions sought through Standard 6.1 for Domestic Buildings is 45% relative to the 2007 standard (Scottish Government, 2019a). This LZCGT target therefore represents a 4.5% (10% of 45%) reduction in CO_2 emissions in absolute terms relative to the 2007 standard. If this 10% LZCGT target is maintained and the CO_2 emissions reduction target within building standards is improved to 60%; this would result in an automatic increase in absolute terms to a 6% (10% of 60%) reduction in CO_2 emissions. See Figure 4 for full Scotland wide distribution pattern.

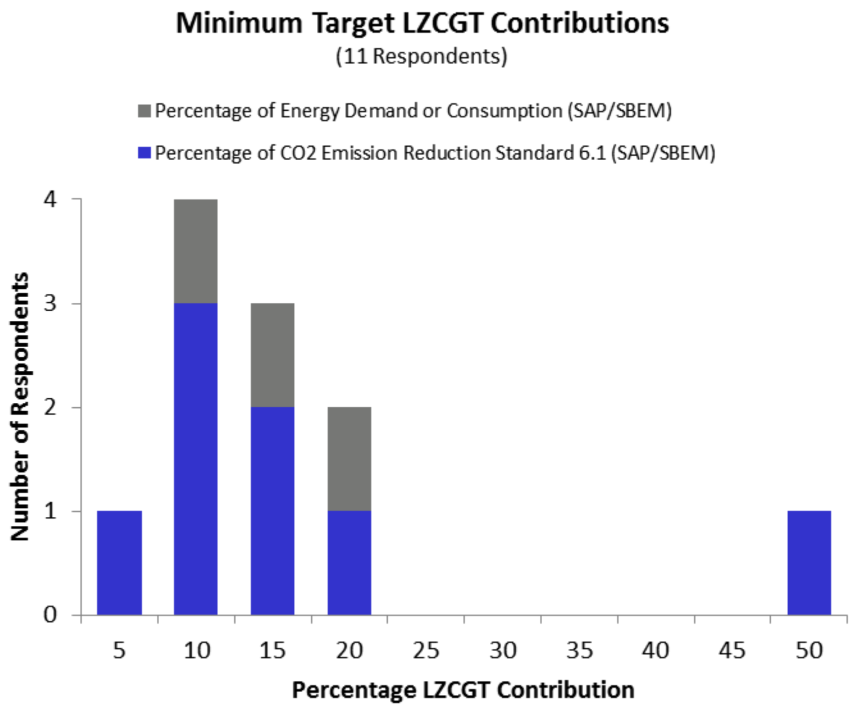


Figure A.1. Question 2: LZCGT target definitions

The planning authority which sought a LZCGT contribution of 20% of the energy demand also required that new buildings deliver Section 7: sustainability standards at Gold Level Aspect 1 (CO_2 emissions reduction at 60% relative to the 2007 standard) and Silver Level Aspects 2 – 8 (Scottish Government, 2019a).

Most respondents report that the Section 3F policy is applied to all new development with certain exceptions, generally mirroring those exceptions in the Scottish Building Standard 6.1: carbon dioxide emissions (Scottish Government, 2019a):

a. alterations and extensions to buildings
b. conversions of buildings and change of use
c. non-domestic buildings and buildings that are ancillary to a dwelling that are standalone and have an area less than 50 m^2
d. buildings, which will not be heated or cooled, other than by heating provided solely for the purpose of frost protection
e. limited life buildings which have an intended life of less than 2 years.

Two planning authorities noted other exceptions to Section 3F, these were:

f. where buildings are designed to such a high degree of fabric energy efficiency that minimal additional mechanisation is required (Passivhaus concept) (1/11)
g. where application of LZCGT would have a detrimental impact on the historic environment as detailed in an accompanying energy statement / design statement (1/11).

One respondent felt that going forward alterations, extensions and refurbishments should be included in Section 3F policy.

Question 3
Do applicants require any additional support from planning officers to help them understand and comply with your Section 3F policy? What form does this take?

(11 Respondents)

About a third of respondents (4/11) felt that applicants needed additional support from planning officers to help them understand and comply with the policy, particularly when it was first introduced. The need for help varied between applicants. One respondent reported that the planning officers themselves did not understand the policy, so could not enforce it. Another respondent referred all enquiries about SAP calculations to Building Standards for clarification.

Approximately half of respondents (6/11) felt that applicants did not need additional support from planning officers. Most of them (5/11) said this was because there was sufficient guidance available to applicants in the Local Development Plan (LDP) or Supplementary Guidance. Typically this guidance might include: information requirements, calculation processes, and a standardised compliance form to be submitted with the application. One respondent also noted that they took the opportunity to raise awareness of the requirements of the Section 3F policy during pre-application enquiries and meetings.

Another respondent noted that the Section 3F policy was new to their planning authority, and how best to implement it was still under discussion between the Planning Policy, Development Management and Building Standards. Their initial approach will be one of upfront engagement; flagging the policy during consideration of the application and applying a suspensive condition requiring details of LZCGT contribution as that becomes available. They also anticipate developing a standard template or spreadsheet for easy calculation of compliance.

Approximately half of respondents (5/11) commented on compliance procedures. The issue not necessarily being eventually meeting the LZCGT targets, but the difficulty of showing compliance at the planning application stage. It was noted that most planning applications do not include proposals for LZCGT and where applications do the standard of information provided is generally poor.

Because of the technical nature of the policy, compliance is typically demonstrated through submission of calculations based on SAP/SBEM. The process is one of self-certification, and the applicant will normally need to employ a qualified SAP/SBEM consultant and submit a statement of compliance. However, it was also widely recognised that the planning application stage is too early in the building design process to ask for detailed calculations which will only be finalised later for building standards. As a consequence, respondents reported that at the planning application stage they will ask applicants for basic information on energy conservation measures and their choice of LZCGT in order to determine basic policy compliance. This will usually take the form of an email to the applicant, highlighting Section 3F policy requirements and asking for further information on the type of LZCGT they propose to use.

Acknowledging the difficulty in timing, applicants are often given the choice of providing compliance documentation either as part of the application process or subject to a suspensive planning condition. One respondent stated that many applicants chose the latter path to compliance.

Another respondent stated that although they provided clear supplementary guidance, and they often applied the standard suspensive condition detailed therein; the calculations submitted often did not follow the methodology that had been set out or lacked enough information to accurately determine if the policy had been complied with. Another respondent felt that the compliance methodology was convoluted and confusing to all parties. They felt that a single route to demonstrate compliance at building standards would be preferable.

Question 4
In your opinion, how easy do applicants find meeting your current LZCGT contribution target?

(11 Respondents)

Most respondents (8/11) felt the current LZCGT target was neither too difficult nor too easy to meet. The issue was with demonstrating compliance and planning officers being able to understand the information that was submitted (Figure A.2).

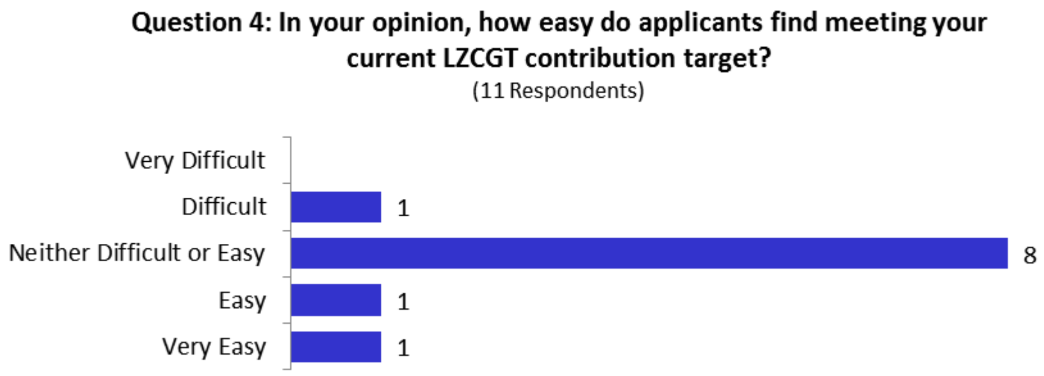


Figure A.2. Question 4: Ease of meeting LZCGT target

Question 5
When preparing your LDP; what were the deciding factors and parameters used to determine the specified contribution of LZCGT to GHG emissions reductions? Were these factors local or national in origin?

(11 Respondents)

Approximately half of respondents (5/11) stated that the level of their LZCGT target was a product of guidance they had received from official sources including national legislation and guidance. In some cases this had been sought. For example one respondent stated that they had worked with Scottish Government planners to develop a methodology specifically appropriate for their context. In another case the entire policy and LZCGT target had been ‘suggested’ by Scottish Ministers when their LDP had been determined deficient because it lacked a LZCGT target. In this case the precise wording of the policy and LZCGT target (10% of the percentage CO_2 emissions reduction sought by Standard 6.1) was supplied by Scottish Ministers, and the council ‘invited’ to agree to the inclusion of this additional policy.

Approximately a quarter of respondents (3/11) admitted that their LZCGT target was a result of simply following the lead of other planning authorities. Whilst one respondent reported this had followed discussions with other planning authorities about their Section 3F policy, another respondent stated they had simply copied the Section 3F policy that another planning authority had been instructed to include by Scottish Ministers.

Approximately half of respondents (5/11) also reported that their LDP had included a Section 3F policy for some time and some had undergone fairly dramatic revisions. This is in part related to the fact that early adopters were working on the assumption that the timetable to zero-carbon building outlined in the Sullivan Report would be adopted and that LZCGT should play the pivotal role in achieving this target. In reality, neither of these assumptions proved true. Some of the responses indicate that there was at some level a basic misreading of the intentions of the Sullivan Report, the emphasis it placed on fabric energy efficiency and equipment efficiency in preference to LZCGT, and indeed it highlighting concerns with regards to the Section 3F policy (Sullivan, 2007, 2013).

One respondent reported that their original policy was written to reflect the timetable set out in the Sullivan Report. It appears from their response that they had presumed that the 30% increase in CO_2 emission reductions the Sullivan Report had called for between 2011 and 2013 should be met by LZCGT. This resulted in them adopting a policy that required a 15% increase per annum in the contribution of LZCGT to CO_2 emissions reduction. When in 2015, the Scottish Building Standards were revised and absorbed the increase in the CO_2 emission reduction target; they revised their policy to avoid an excessive increase in the proportion of CO_2 emission reduction being met by LZCGT. Their current LDP requirement of 5% of the percentage CO_2 reduction sought by Standard 6.1 was determined on the basis that it was considered the most reasonable figure.

Two respondents reported that their original Section 3F policies took a two-pronged approach in which there was a locally determined LZCGT target and additional Section 7 Sustainability requirements. One of these respondents described this as a staged approach which started with 10% LZCGT contribution to Energy Demand and Bronze Active, advanced to 15% LZCGT and Silver Active, and is currently 20% LZCGT, Gold Aspect 1 and Silver Aspects 2 - 8. The other respondent reported that they had since revised their policy and instead adopted a policy the Scottish Government had suggested to another planning authority. This had increased the LZCGT contribution to 10% of the percentage CO_2 emission reduction sought by Standard 6.1, and removed Section 7 requirements. The respondent felt this was an improvement; with clearer wording, greater clarity on the circumstances in which it would be applied and a clear focus on LZCGT rather than Section 7.

Another respondent stated that their policy was based on early guidance on sustainable building developed prior to the adoption of national CO_2 emission reduction standards. In 2010, their initial LZCGT target had been 10%, but by 2016 this had risen to 50% of the percentage CO_2 emission reduction sought by Standard 6.1. In other words they expect half of CO_2 emission reductions to be met by Fabric Energy Efficiency and half by LZCGT. Their definition of LZCGT included renewables, heat pumps, combined heat and power (CHP), district heating and notably, mechanical ventilation and heat recovery (MVHR).

Approximately a third of respondents (4/11) indicated that they had taken a balanced and restrained approach to setting their LZCGT target. One respondent reported that because this was a new policy in their region they had made a conscious decision to keep the percentage low and monitor thereafter. Their target is 15% of the percentage CO_2 emissions reduction sought by Standard 6.1. Another respondent stated that they had analysed their existing policy in relation to national guidance and what other planning authorities were doing. The target they arrived at was 20% of the percentage CO_2 emissions reduction sought by Standard 6.1 which they felt was in line with their previous policy.

Another respondent reported that there was no particular reason for their LZCGT target choice of 10% of the percentage CO_2 emissions reduction sought by Standard 6.1, other than it seemed a reasonable compromise. They stated:

> ‘It was a balance between a figure which was large enough to be meaningful, but not so high as to be overly onerous and deter development, given that the housing market was in a delicate state at the time. A compromise between national priorities and local circumstance’
>
> (Respondent 13)

They propose to raise this level of LZCGT contribution to 12% in their forthcoming LDP due in 2020. A further respondent stated they had deliberately chosen a low LZCGT target to help push a fabric first approach. They had tried to be clear with applicants that they were seeking to reduce CO_2 emissions through the provision of highly efficient buildings. Their LZCGT target was 20% of the energy demand as defined by SAP/SBEM. Therefore the better the insulation and fabric of the building, the lower the amount of LZCGT required. They were clear that LZCGT should not be 'eco-bling' bolted on to a poorly performing building.

One respondent reported that their council had reservations about the technical complexity and potential resource implications of assessing development proposals at the planning application stage. They had argued at the LDP Inquiry that energy efficiency and sustainable design matters were on the whole better addressed through the regulatory framework of Building Standards because they largely related to construction details and internal works. However they accepted their statutory obligation under Section 3F and adopted the suggested LZCGT target of 10% of the percentage CO_2 emissions reduction sought by Standard 6.1, because they were assured that at this level it would not impose any additional burdens on developers.

Question 6
When preparing your LDP; what were the deciding factors and parameters used in determining NOT to include a specific LZCGT contribution to GHG emissions reductions?

(3 Respondents)

The main reasons cited for not defining a specific LZCGT target were a lack of guidance from the Scottish Government as to what would be an appropriate level, and the lack of resources, expertise and understanding of the issues within the local authority that would allow them to assess what would be appropriate themselves. One of the respondents also stated that they lacked the resources to establish whether the policy had been complied with, and felt that these issues would be more appropriately dealt with by Building Standards.

Section 2: Evidence and Procedures

Key points

Evidence & Procedures

- The majority of respondents reported that their planning authority did not have clearly defined standard assessment procedures and calculation methodologies for determining whether applications comply with Section 3F Policy.
- Compliance is most commonly evidenced through a self-certification process; typically by submission of a statement containing detailed information about the proposed LZCGT.
- The information that might be requested includes: the type of LZCGTs proposed; the scale, location and visual impact of the installation; ongoing operation and maintenance issues; SAP/SBEM calculations; and a calculation to show compliance with the LZCGT target contribution.
- Where calculation methodologies have been defined these require two separate SAP/SBEM calculations; one for the building as designed with LZCGT, and one with the proposed LZCGT removed and replaced with pre-defined conventional systems. The values generated by these are substituted into a formula to calculate compliance.
- None of the formulae defined by respondents accurately defined the LZCGT target in terms of a percentage of the percentage reduction in CO_2 emissions sought by building standard 6.1.
- The standard of compliance evidence received is very variable in terms of format and content, even when planning guidance has been given and compliance procedures and calculations have been defined.
- Some planning officers use pre-application meetings and the application determination process as an opportunity to highlight to applicants the specific requirements of Section 3F policy, and in general the importance of sustainable design and carbon dioxide emission reduction.
- Approximately half of respondents aim for evidence of compliance to be submitted at the planning stage. However the majority of respondents accept that this is not practically feasible in many circumstances. This is because the detailed information needed to calculate the amount LZCGT contributes to overall CO_2 emissions reduction is simply not available at the planning stage.
- If information is not available at planning stage, the most common response is to apply a suspensive condition to the planning consent decision notice requiring that compliance documentation be submitted to planning prior to commencement on site.
- Many applicants prefer to submit Section 3F compliance documents at this later stage, because it fits better with their workflow and reduces duplication of effort in having to resubmit revised documents.

Implementation Issues

- Virtually all respondents reported that they had experienced some difficulties in applying their current Section 3F policy and procedures.
- Over half of respondents reported they had struggled to implement their Section 3F policy in a consistent and systematic way. Working with development management teams to raise awareness and provide guidance on how to apply the policy in practice has had a beneficial impact in this respect.
- Difficulties were reported in gaining developer cooperation with current Section 3F policies. Confusion primarily arises because different planning authorities have different Section 3F policy requirements and compliance procedures and calculation methodologies are often not clearly defined. A consistent Scotland-wide approach would improve this situation.
- A lack of clearly defined compliance requirements and calculations methodologies has resulted in the standard of evidence submitted to show compliance varying widely and being of a general poor quality.
- Many respondents stated that in the absence of clear guidance they didn't have sufficient knowledge and experience of the issues involved, and therefore felt ill-equipped to interpret the technical information submitted as proof of compliance.
- Two thirds of respondents reported that the main issue for them was attempting to implement a policy at the planning stage, when the information that was required to confirm compliance with the LZCGT target was typically not available until later in the design process during the building warrant stage.
- The use of suspensive conditions has resulted in a complex ongoing situation of monitoring the progress of developments and trying to gather evidence of compliance, and left planning in a vulnerable position with little or no means to force applicants to improve their proposals or effectively enforce compliance with Section 3F policy.
- Almost half of respondents had concerns about the strength of suspensive conditions and the subsequent ability to enforce compliance.
- Half of respondents would like to see improved inter-departmental cooperation between planning and building standards on the implementation of Section 3F policy. However it was noted that it is beyond the legal remit of building standards to take an active role in checking or enforcing compliance with any planning policy or condition.
- A third of respondents felt that whilst planning had a role in promoting the uptake of LZCGT; the LZCGT contribution target would be better suited to inclusion within the Scottish Building Standards than in Planning.

Question 7
Has your planning authority defined a standard procedure and calculation methodology for determining whether applications comply with Section 3F Policy requirements?

(14 Respondents)

Only 5 respondents (36%) indicated that their local authority had defined a standard procedure and calculation methodology for determining whether applications comply with Section 3F Policy requirements. The rest (64%) indicated that no standard procedures and calculation methodologies were in place (Figure A.3).

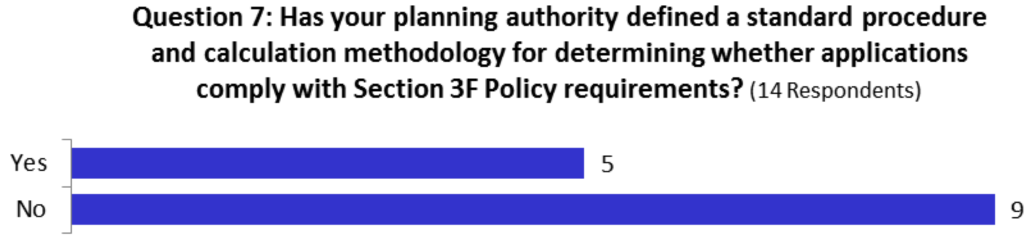


Figure A.3. Question 7: Standard procedure and calculation methodology to determine compliance?

Question 8, 9
What evidence are applicants required to submit to show compliance with Section 3F Policy requirements and by what stage in the development management process?
Please describe the typical workflow patterns that planning officers follow in determining whether applications comply with Section 3F Policy requirements.

(13 & 12 Respondents)

Most respondents report that they expect compliance with Section 3F policy to be evidenced with a statement (9/13 Respondents). This is variously described as a design statement, energy statement, sustainability form or simply a statement to demonstrate compliance with Section 3F policy. Essentially it is a process of self-certification.

Some planning authorities are clearer than others in their planning guidance on what they expect to be included within this statement. Few appear to have standardised forms to complete. Typically the applicant will be asked to provide details about the proposed LZCGT e.g. the proposed type of LZCGT, the scale of the installation, where it is located, what is the visual impact, whether there are any potential negative impacts on the historic built environment, as well as ongoing maintenance and energy output of the LZCGT as evidenced by the manufacturer or supplier.

Quantification of the contribution LZCGT makes to CO_2 emission reduction requires more detailed information on a par with that included in SAP/SBEM calculations. It should be noted that SAP/SBEM calculations are used to establish the energy demand of a building, describe how this is met in practice and determine whether the building as a whole meets the CO_2 emission reduction target set by Building Standard 6.1: carbon dioxide emissions. SAP/SBEM calculations do not specifically calculate the contribution LZCGT makes to CO_2 emissions reduction.

Bearing this comment in mind; approximately half of respondents state that they require SAP/SBEM calculations as evidence (7/13 Respondents). Only a few of these respondents indicate that they require two alternative SAP calculations, with and without LZCGT, which can be compared and used to calculate the LZCGT contribution to CO_2 emission reduction. In such cases the calculation required to show compliance is typically set out in their planning guidance (See Question 10). One respondent commented that they received a wide range of material in various formats to evidence Section 3F policy, but 2 alternative SAP calculations tended to be the most frequent response from applicants.

Two respondents reported that their planning authority also required enhanced sustainability measures as part of Section 3F policy. These measures are detailed in Building Standards Section 7. These planning authorities looked for these measures being evidenced in the design, and asked for self-certification in the form of a Sustainability Label at the building warrant stage and again at completion.

One respondent indicated that only applicants for the Council Development Priority Sites were asked to submit an Energy Statement. All other developments were asked to incorporate CO_2 emission reduction measures and energy efficient design. Another respondent stated that only non-domestic applications had to complete their Sustainability Form.

Two respondents commented that, where possible, they flagged Section 3F policy requirements at an early stage in the planning application process and directed applicants towards the planning guidance on this issue. Approximately half of respondents (6/13) aim for evidence of compliance to be submitted at the planning stage, although many of them accept that this is not practically feasible in many circumstances. If information is received at the planning stage it is included in reports of handling or committee reports and formed part of the planning officer's assessment report. See Question 12 with regards to the potential benefits of having good information submitted early in the application process.

One respondent stated that some development management officers flag the policy at the planning stage, but ask simply for a statement to ascertain how the applicant intends to comply; leaving the need for firmer details about the LZCGT and its contribution to CO_2 emissions reduction for the purification of planning conditions. Another respondent reported that because they struggled in practice to obtain information at the planning stage; they took a pragmatic approach, and if LZCGT had been included, the application was assessed as meeting policy even if the exact percentage contribution had not yet been calculated and a condition applied to the decision notice.

There is a general acceptance among most respondents (10/13) that the information required to calculate the contribution of LZCGT to CO_2 emissions reduction is simply not available at the planning stage, because many of these technical decisions have yet to be made. Although one respondent also felt that the poor level of evidence submitted was in part due to developer apathy and lack of understanding of the Section 3F policy.

If information is not available at the planning stage, the most common response is to apply a suspensive condition to the planning consent decision notice (9/13 Respondents). Typically, this will require that information be submitted to planning, prior to commencement on site. One respondent supplied the current wording used for their standard condition in this respect:

> "Prior to the commencement of development hereby approved, a scheme shall be submitted to, and approved in writing by, the Council as Planning Authority that demonstrates how at least 10% of the current carbon emissions reduction set by the Scottish Buildings Standards will be met through the installation and operation of low and zero-carbon technologies. This scheme shall detail for each building:
>
> a) the technology types
> b) illustrate, through technical calculations, that these will meet at least the 10% reduction;
> c) their siting and location; and
> d) ongoing operation and maintenance.
>
> Once approved, the development shall be completed in accordance with the approved scheme and no individual unit shall be occupied until the scheme has been installed and operating."
>
> (Respondent 14)

One respondent noted that given the option, many applicants prefer to submit Section 3F information at this stage, as the design has been finalised, information is available and the necessary SAP/SBEM calculations have been completed for Building Warrant applications. One respondent stated that they required applicants to submit an energy statement which they then asked Building Standards to verify.

One respondent reported that they require applicants to submit a copy of the sustainability label, as built SAP/SBEM calculations and the notification of completion of development to planning, prior to occupation. Another respondent, whose planning authority incorporated Section 7 requirements into their Section 3F policy, reported a more complex 3-staged process, requiring two forms of self-certification. At planning; they sought a commitment to the Section 7 requirements evidenced in the design and a statement on energy signed off by a SAP/SBEM assessor. At building warrant; they required self-certification with regard to Section 7 and an updated statement on energy signed off by a SAP/SBEM assessor which should reflect the requirements of Section 6. At completion; they demanded submission of the sustainability label and the updated 'as built' statement on energy certified by a SAP/SBEM assessor.

One respondent from a planning authority that did not currently specify a LZCGT target reported that they did not request any evidence or have any procedures to confirm compliance. Another respondent from a planning authority that did specify a LZCGT target described the evidence they requested but admitted that they currently did not apply the policy. A final respondent noted that this policy was a recent addition to their LDP and the evidence required for compliance, workflow and calculation methodologies were still under development.

Question 10

If your Section 3F Policy quantifies the contribution LZCGT should make to GHG emissions reductions, please describe the calculation method used to show compliance.

(10 Respondents)

Three respondents detailed their calculation methods. All three used two separate SAP/SBEM calculations as a means to determine the percentage of the CO_2 emission reduction that could be attributed to the use of LZCGT. The first SAP/SBEM calculation defines the Dwelling Emission Rate (DER) / Building Emission Rate (BER) of the building as designed with LZCGT. This is the SAP/SBEM calculation used to determine if the building complies with Standard 6.1: carbon dioxide emissions. To determine the impact of the LZCGT, the second SAP/SBEM calculation removes the proposed LZCGT and replaces it with pre-defined conventional systems and recalculates the Dwelling Emission Rate (DERNT) / Building Emission Rate (BERNT) of the building with no LZCGT. Typically this SAP/SBEM calculation will fail to meet the requirements of Standard 6.1. These values are then substituted in a formula to determine whether the LZCGT contribution is in compliance with Section 3F policy.

The first of these respondents stated that they used the calculation outlined in Planning Advice Note PAN 84: Reducing Carbon Emissions in New Development, which is now obsolete (Scottish Government, 2008). The calculation contained in this document can be summarised by the formula:

LZCGT contribution to CO_2 emission reduction as an absolute percentage

$$= \left(\frac{DERNT - DER}{TER}\right) \text{x } 100$$

Where

TER	=	Target Emissions Rate of the ‘notional’ dwelling or building. This is the baseline 2007 building regulation CO_2 emissions standard.
DER	=	Dwelling Emission Rate
DERNT	=	Dwelling Emission Rate with no LZCGT

When PAN84 was written this calculation gave an absolute percentage reduction in CO_2 emissions due to the use of LZCGT. However, in the intervening years the definition of the Target Emissions Rate (TER) has changed. Initially the Target Emissions Rate (TER) represented the baseline CO_2 emissions of the notional building built relative to the 2007 standards (with reference to Figure 7 the original definition of TER would equate to OER). The current Target Emission Rate (TER) defines the CO_2 emissions level for the notional building that the actual building must equal or better to pass SAP (DER ≤ TER to pass SAP). It is therefore obvious that this calculation is no longer valid. Further, the respondent had already indicated that they defined their LZCGT target as a percentage of the percentage CO_2 emissions reduction sought by Building Standard 6.1, not an absolute percentage reduction.

Although the second respondent did not reference PAN84, they outlined in their planning guidance the same calculation methodology. However, they did appear to recognise that it needed updating because Building Standards had been revised. They too had defined their LZCGT target as a percentage of the percentage CO_2 emission reduction sought by Building Standard 6.1, not an absolute percentage reduction.

In the third situation the planning authority clearly defines the calculation methodology and formula to be used to show compliance within their supplementary guidance. This included an instruction as to what should replace the LZCGT in the second SAP calculation to determine DERNT. The formula is described as providing the percentage reduction in carbon due to renewables and is given by:

The percentage reduction in carbon due to renewables

$$= \left(1 - \left(\frac{DER}{DERNT}\right)\right) \times 100$$

Where

DER	=	Dwelling Emission Rate
DERNT	=	Dwelling Emission Rate with no LZCGT

However the respondent also indicated in Question 2 that the planning authority framed their LZCGT contribution target in terms of a percentage of the energy demand as defined by SAP/SBEM.

This formula is in fact a variant of Formula 13 which in our analysis is used to define E%. It defines the LZCGT contribution to CO_2 emission reduction in terms of avoidance of a percentage of projected CO_2 emissions as calculated by SAP/SBEM, and given certain assumptions is a fair estimate of LZCGT contribution in terms of a percentage of the energy demand of the building as defined by SAP/SBEM.

One of the remaining respondents stated that they simply require that the LZCGT provide 10% of the energy requirement of the building as defined in the SAP/SBEM calculation. With a basic knowledge of SAP/SBEM calculations, this is easy enough to calculate. The remaining respondents were generally vague about the exact nature of the compliance calculation they are seeking. One respondent simply stated:

> 'The Statement should set out how the appropriate reduction in carbon dioxide emissions is to be achieved as a result of low and zero-carbon generating technologies using the Standard Assessment Procedure Energy Rating (SAP) for dwellings and the Simplified Building Energy Model (SBEM) for all other developments.'
>
> (Respondent 6)

Another respondent noted that they had observed no single consistent approach to showing compliance.

The lack of a clear approach to calculating the contribution of LZCGT might be a result of the metric being difficult for stakeholders to easily comprehend (a percentage of the percentage CO_2 emissions reduction sought by Building Standard 6.1) or simply uneasiness on the part of planning officers of dealing with technical issues and mathematical formula. One respondent dismissed this question by simply saying technical requirements are met at the building warrant stage. Another respondent stated that SAP calculations required Building Standards scrutiny because it was hard for them to accurately assess the amount of CO_2 emission reduction that was actually secured by LZCGT.

Question 11
Have you experienced any difficulties in applying your current Section 3F policy or procedures? How might these be improved?

(12 Respondents)

Virtually all respondents (11/12) had experienced difficulties in applying their current Section 3F policy and procedures. The only respondent that did not report difficulties stated that they had only recently adopted the policy and could not really comment on the implementation so far, although they were monitoring the situation.

Over half of respondents (7/12) reported they had struggled to implement their Section 3F policy in a consistent and systematic way. Unfamiliarity with a new policy and the technical nature of the requirements may play a role in this. Several respondents noted there were inconsistences in the way the policy was being applied and admitted that there was no standard procedure to determine compliance. One respondent stated that their yearly monitoring had revealed that the policy was not being implemented as often as they would like. They were currently prioritising action on this and were seeing some improvements through working with development management teams to raise awareness and giving guidance on how to apply the policy.

Another respondent stated that even though they had a Section 3F policy which specified a LZCGT contribution, in practice it was not being applied because planning officers didn't have sufficient knowledge to understand the technical calculations that were being submitted. This need for support was a recurring theme; with almost half of respondents (5/12) uncomfortable in assessing this type of technical information. Several stated that in the absence of guidance they lacked basic knowledge and experience of the issues involved, as well as the technical ability to assess submitted information or calculate the CO_2 emission reduction themselves.

One respondent also reported that recent monitoring revealed there was an issue relating to conditions not being applied universally to all applications that fail to submit relevant documentation at the planning stage. Although where it was applied, the standard condition included in the supplementary guidance was used exclusively (see Question 8, 9). The same respondent noted that there was a lack of any guidance as to any technical or practical constraints that might warrant exemption from Section 3F policy.

A third of respondents (4/12) also reported issues relating to getting developers to cooperate and submit the relevant information. One respondent reported a bit of a push back from developers which had led them to not implementing their Section 3F policy. Another respondent felt it was difficult to challenge developers who hadn't submitted the required information. Some respondents suggest that getting applicants to submit information that had enough detail to be able to make a firm judgement at the planning stage was a challenge. One respondent felt all they could do was attach a planning condition to the consent, and trust that the applicant would comply with the policy and submit information later in the process. Another respondent took a pragmatic approach and determined that if LZCGT were included the application was in compliance, even if the percentage contribution had not been explicitly calculated.

One respondent stated that their monitoring suggested that the submission of energy statements was patchy, the information they contained varied widely and was generally poor, there was no standard process for determining whether an application met the requirements of the policy and LZCGT conditions were frequently not addressed. It was clear that applicants were not following guidelines contained in supplementary guidance. Some applicants submitted sustainability certificates whilst others submitted SAP calculations; but none submitted SAP calculations with and without LZCGT as instructed. It was therefore difficult for planning officers to ascertain if the developments met the LZCGT target contribution to CO_2 emissions reduction.

Two respondents raised issues relating to SAP calculations. One respondent stated that some applicants had a problem obtaining SAP calculations with and without LZCGT because of a software issue. This may have been an issue with a specific piece of software as we believe there should be no technical barriers to running two SAP calculations one with and one without LZCGT.

The other respondent reported that they had received requests from some non-domestic applicants for permission to use the new draft SAP10 carbon emissions factors for electricity. These new carbon emission factors reflect the decarbonisation of the national grid that has taken place over the past decade which puts electricity on a similar footing to natural gas. The council allowed this because it has resulted in very different and less carbon intensive energy strategies being proposed for buildings e.g. a change from gas-fired CHP to Air Source Heat Pumps (ASHP) in a large 200 bed hotel. So, whilst they had experienced some other difficulties with the policy, they also felt they had a number of positive outcomes too.

In terms of improvement; one respondent felt that a consistent Scotland-wide approach would be beneficial as this would mean that developers would know what is expected of them in terms of policy requirements no matter where they were working. Another respondent suggested that a standard self-certification process and sign off would assure case officers that a building did indeed meet Section 3F requirements.

Half of respondents (6/12) would like to see improved cross department working between planning and building standards on this issue, perhaps integrating the policy across both planning and building standards. The majority of these respondents (4/12) also felt that the LZCGT contribution target would be better suited to inclusion within the Scottish Building Standards rather than Planning. The logic behind this conclusion was that building standards officers are familiar with technical issues, compliance calculations and complex SAP data, and applicants already have to submit SAP data to them as part of the building warrant process. Therefore, on a purely practical level it was considered sensible that building standards officers should be also given the responsibility of checking LZCGT compliance. It was felt this would avoid a lot of the confusion and duplication of effort that currently surrounds enforcing the policy and would probably improve compliance. (For more details about where planning and building standards should focus their efforts see Question 24).

Question 12
What problems, if any, have you experienced enforcing your Section 3F policy?

(11 Respondents)

Two thirds of respondents (8/11) reported that the main enforcement issue for them was attempting to implement a policy at the planning stage, when the information that was required to confirm compliance was typically not available until later in the design process during the building warrant stage. As a result they had to place suspensive conditions on notices of consent requesting information is submitted when available and before commencement on site. This resulted in a complex ongoing situation of monitoring the progress of developments and trying to gather evidence of compliance when the applicant had moved on to other issues with building standards. In practice, they felt that relying on suspensive conditions left planning officers in a vulnerable position when trying to enforce the policy. Some respondents felt that this disjoint between the policy being placed in the remit of planning and choices about energy strategy and material specification being taken at the building warrant stage had left them with little or no means to enforce compliance with the policy or force applicants to up their game.

One respondent highlighted that receiving good quality data at the planning stage could have a significant impact on the eventual outcome. If planning has sufficient information to be able to conclude that an application will not comply, it has the power to withhold planning consent and leverage a better solution from the applicant. They illustrated this point by relating an example of how an application for a fairly generic large drive-through restaurant had been completely revised because SBEM calculations were available to the planning officer. The result was a revised building that achieved an almost a 50% cut in CO_2 emissions beyond the current building regulations. If they had not had SBEM data until the building warrant stage they would not have been in a position to leverage this change from the applicant.

Almost half of respondents (5/11) had concerns about the strength of suspensive conditions and the subsequent ability to enforce compliance. One respondent stated that they had applied suspensive conditions but had not as yet implemented many of them so it was still too early to tell if this would cause enforcement issues. Another respondent stated that in their monitoring they could not determine whether applications that they had deemed not to comply with Section 3F had actually included LZCGT and simply not purified the suspensive condition as a matter of course. The data available to them through planning applications and building standards was simply not detailed enough.

Approximately a quarter of respondents (3/11) raised potential conflicts between Planning and Building Standards over implementing Section 3F policy. Two respondents highlighted the fact that there is no mandatory requirement for the use of LZCGT in the Scottish Building Standards, and this causes confusion for applicants.

Another respondent felt that planning and building standards need to work more closely with regards to CO_2 emissions reduction. They stated that most planning conditions were purified prior to building warrant, but as their authority was seeking as built confirmation of the LZCGT contribution the suspensive condition could not be purified until completion. They also noted that it is out with the remit of building standards to take an active role in checking or enforcing compliance with any planning policy or condition. Building standards will therefore not refuse to grant a building warrant on the basis that an application does not comply with a planning condition. Further building standards will not refuse to grant a completion certificate on the grounds of an outstanding planning condition. This could result in the difficult situation where a building is occupied prior to planning conditions being purified, and calls into question the strength of using a suspensive planning condition. They had yet to test the enforcement over this issue, but in conclusion felt that the Section 3F requirements would sit better as a mandatory part of the Scottish Building Standards (See Question 11).

The same respondent also raised the issue of continuity in enforcement. They used the example of a flagship development of a block of flats, which was given planning consent on the basis that all the flats would achieve Gold level Aspect 1: CO_2 emission. At building warrant this standard became an aggregate level for the entire block, with 53% of flats failing to reach the Gold standard and a huge disparity between individual flats. Further the entire benefit of the 20% LZCGT accrued to the landlord not the tenants. This was not the intention of the Section 3F policy with regards to reduction of CO_2 emissions and fuel poverty.

One respondent reported that they knew of no enforcement activity being applied but questioned the enforceability of the policy. Another respondent simply stated that they had no need to enforce conditions as they were not actively applying their Section 3F policy.

Section 3: Going Forward

Key Points

LZCGT Trends

- Photovoltaics were the most frequently specified LZCGT; followed by ASHPs, MVHR, Solar Thermal, Biomass and GSHPs in descending order (Figures A.5 & A.6).
- However ASHPs have seen the greatest increase in uptake over the past 5 years, followed by Photovoltaics, Biomass, MVHR, GSHPs, District Heating and Solar Thermal in descending order (Figures A.5 & A.6).
- One respondent reported that Air Source Heat Pumps (ASHP) had really begun to take off in the non-domestic sector, particularly large-scale offices and hotels, over the last year.
- The majority of respondents thought planning authorities should be able to promote their preferred regional, local or site specific solutions to GHG emissions reductions (Figure A1.7).
- Approximately three quarters of respondents also thought that planning authorities should be able to compel new developments to link to existing local large scale LZCGT initiatives or heat networks in order to support such schemes (Figure A1.8). However this was not without serious reservations about how this would work in practice.
- The local context was identified as a potential barrier to the development of large scale LZCGT and heat networks.
- Low density rural communities were seen as not conducive to the development of shared heat networks.
- Large scale LZCGT and heat networks would need to be delivered upfront so that developers can be confident they will be in place from the first day of occupation. This raises questions about who would be responsible for the planning, financing, delivery and ongoing maintenance of this energy infrastructure.
- Liberalisation of the energy market means that the choice of energy provider is up to the developer or occupant, and there is no legal means for planning authorities to compel connection to or delivery of specific energy services.
- There was concern that this type of policy would restrict developers and future occupants to one energy provider with no choice to change to a cheaper supplier or a less carbon intensive system in the future.
- Danish systems are often cited as exemplars for Scotland to follow, but these are all municipally owned and run on a not for profit basis.
- Currently it was felt that planning professionals lacked the technical knowledge, skillset and expertise to make sensible joined-up decisions about large scale LZCGT and heat networks.

LZCGT Target

- Section 3F policy seeks to define, and over time increase, the level of CO_2 emission reductions that are achieved through the deployment of LZCGT in new buildings. Overall CO_2 emission reduction requirements for new buildings are defined by Scottish Building Standard 6.1: carbon dioxide emissions.
- Whilst not rejecting the use of LZCGT; several respondents advocated strongly for taking a fabric first response to reducing CO_2 emissions in new buildings. They underlined the need for any LZCGT target to be a minimum standard rather than an aspirational one, so that it would not interfere with a fabric first approach.
- Clearly defined policy and targets were considered essential so that all stakeholders understand what is expected of them In this respect a Scotland wide standard would provide clarity for architects and developers, the majority of who work across planning authority boundaries.
- Although respondents felt there was a need to accelerate CO_2 emission reduction; the majority of respondents felt there was no case to be made for planning policies that attempt to accelerate the reduction in CO_2 emissions beyond that required by Building Standards (Figure A.10).
- It was considered essential for successful engagement with stakeholders that Planning and Building Standards have a clear and consistent message to avoid contradiction and confusion.
- Half of respondents questioned the positioning of the LZCGT policy within the remit of Planning because they felt it could be more effectively applied and enforced through Building Standards.

Respective Roles of Planning and Building Standards

- The need for better collaboration between planning and building standards on policies relating to CO_2 emission reduction was highlighted by several respondents.
- All respondents felt that Planning should concentrate their efforts in the fight to reduce GHG emissions and mitigating Climate Change on Landscape Scale Planning, Sustainable Planning, Large Scale LZCGT, Architectural Design, and Architectural Design Details. Approximately two thirds of respondents also felt Planning had a major role to play in Building Scale LZCGT and Assessing Sustainability (Figure A.11)
- Virtually all respondents felt that Building Standards should concentrate their main efforts on Fabric Energy Efficiency, Building Scale LZCGT, Assessing Energy Consumption, Assessing CO_2 emission reductions and Assessing the Contribution of LZCGT. Approximately three quarters of respondents also felt they had a major role in Assessing Sustainability and Architectural Design Details (Figure A.11).

- A joint responsibility was suggested for Assessing Sustainability. A less even split of responsibility was suggested for Large Scale LZCGT, Building Scale LZCGT, Architectural Design and Architectural Design Detailing (Figure A.11).
- Several respondents felt that Planning's role was more aligned to delivering CO_2 emission reduction through good design, placemaking and strategic planning of large scale LZCGT and heat networks where appropriate; and this complemented the role of Building Standards with its more technical regulations that ensure buildings meet CO_2 emissions reduction targets.
- Planning is well-placed to prioritise action on climate change and the reduction of CO_2 emissions at an early stage in the design process. Engaging with applicants and developers and obtaining their commitment to these aspirations is fundamental to success in this area.
- Early engagement with applicants, either through pre-application advice or during the process of determining planning applications, can be used to advise applicants of their responsibilities in relation reducing energy consumption and CO_2 emissions at a stage where it could positively influence design responses.
- If planning and building standards officers are to play an active role in shaping responses to climate change they need proper training with regards to these issues to enable them to offer better informed advice to applicants and developers.
- Virtually all respondents thought the development of Scotland-wide sustainable design guidelines and simple assessment procedures would be useful for both planning officers and applicants to clarify expectations (Figure A.12).
- Development of Scotland-wide Design Guidelines would be welcomed in all subject categories. These included: Sustainable Urban Planning; Sustainable Rural Planning; Sustainable Building Design; Large Scale LZCGT; Energy Efficient Architectural Design; Sustainable Construction, Materials and Embodied Energy; Fabric Energy Efficiency; and Small Scale LZCGT (Figure A.13).
- Clarity in terms of the target LZCGT contribution sought, how it is calculated, and the context in which the policy is applied is vital going forward.

Question 14
How would you characterise your planning authority area?

(13 Respondents)

Respondents were asked to select all that were relevant to their planning authority area. Six respondents selected more than one response. Of the remaining seven respondents, three indicated they were responsible solely for urban environments; and one apiece indicated they were solely responsible for suburban, rural, and remote rural environments (Figure A.4).

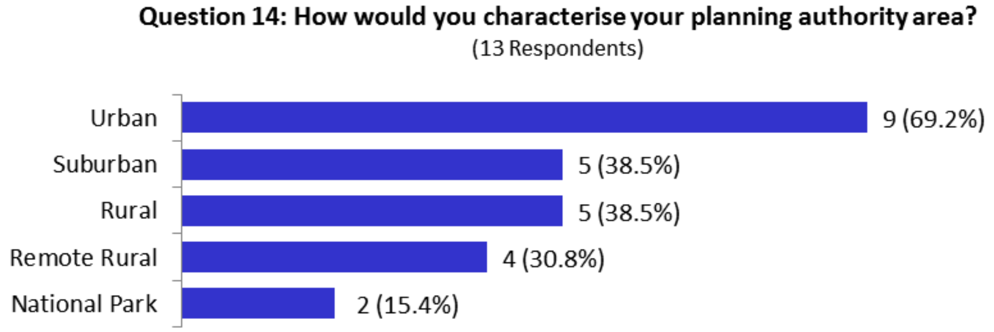


Figure A.4. Question 14: Character of planning authority area.

Question 15, 16
With what frequency have you encountered these different types of LZCGT deployed in relation to Section 3F Policy within your planning authority area? How has the uptake of these technologies changed over the last five years?

(11 Respondents)

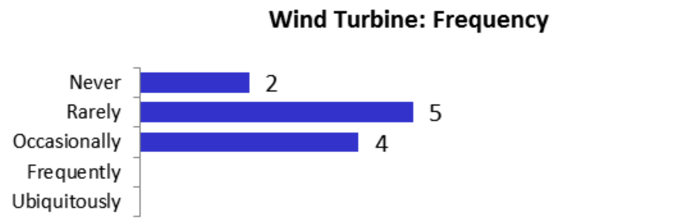
The trends in frequency and uptake of each LZCGT observed by the planning officers that responded to the survey are detailed in Figure A.5. It should be noted that respondents were asked specifically to denote LZCGT deployed in relation to Section 3F Policy, not other large scale commercial developments such as wind farms or solar arrays.

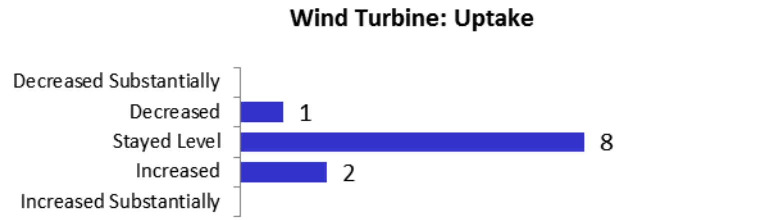
This data was further analysed to determine which LZCGT were most commonly encountered (responded to Question 15 as occasionally, frequently or ubiquitously), most frequent specified (responded to Question 15 as frequently or ubiquitously) and had increased in uptake the most in the last 5 years (Question 16 as increased or increased substantially). These results are summarised in Figure A.6.

The most commonly encountered LZCGT were photovoltaics (11/11) and ASHP (11/11), closely followed by GSHP (10/11). Over half of respondents reported that MVHR (7/11), Biomass (7/11) and Solar Thermal (6/11) were also relatively common. Photovoltaics (8/11) were the most frequently specified LZCGT according to the respondents, followed by ASHP (5/11), MVHR (4/11), Solar Thermal (2/11), Biomass (2/11) and GSHP (1/11). However ASHP (8/11) had seen the greatest increase in uptake over the past 5 years, followed by photovoltaics (6/11), biomass (6/11), MVHR (5/11), GSHP (5/11), District Heating (4/11) and Solar Thermal (3/11).

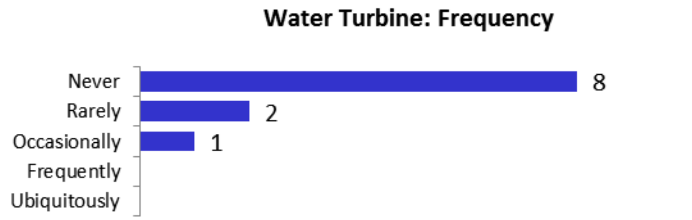
LZCGT FREQUENCY UPTAKE

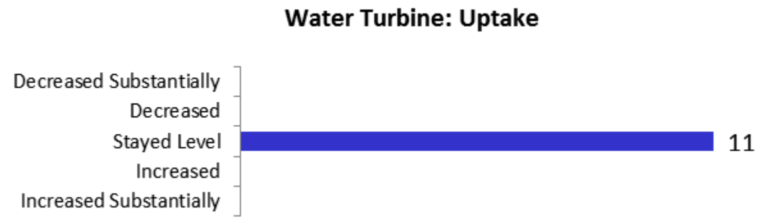
Wind Turbine



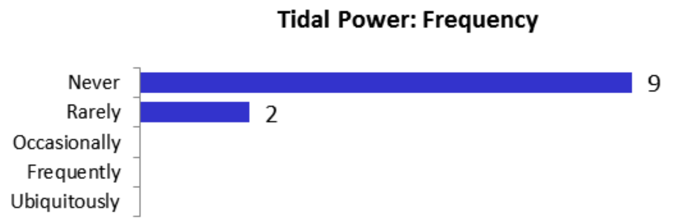


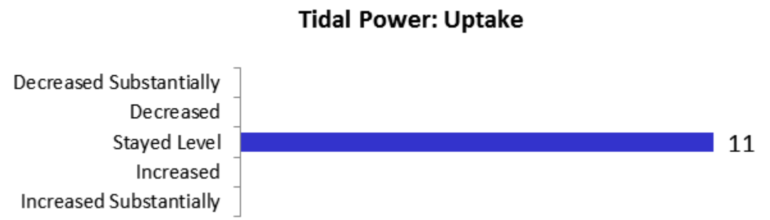
Water Turbine



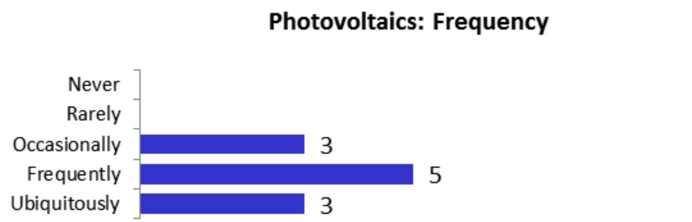


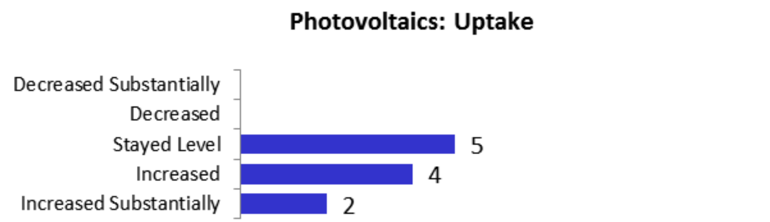
Tidal Power





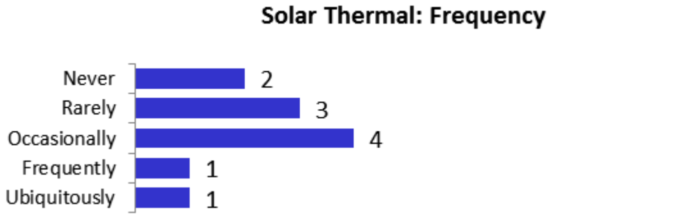
Photovoltaics (PV)

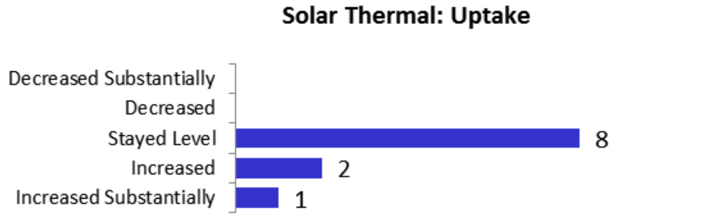




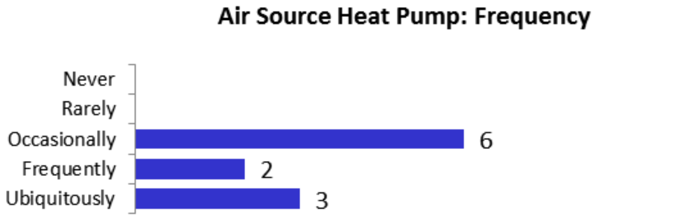
LZCGT | FREQUENCY | UPTAKE

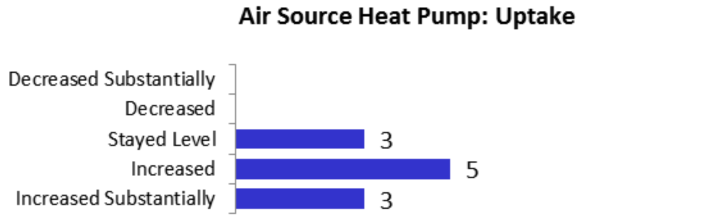
Solar Thermal



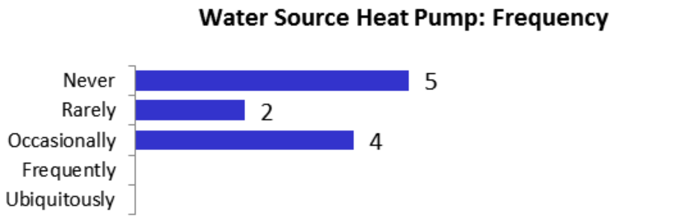


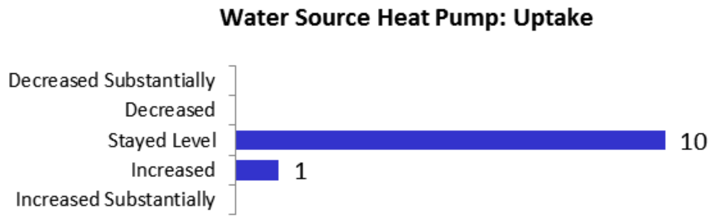
Air Source Heat Pump (ASHP)



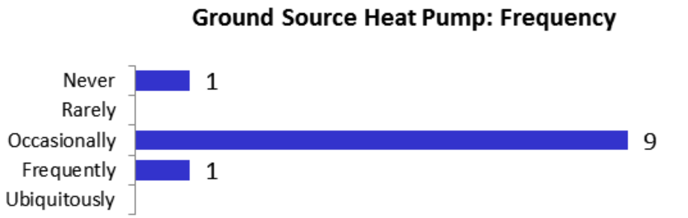


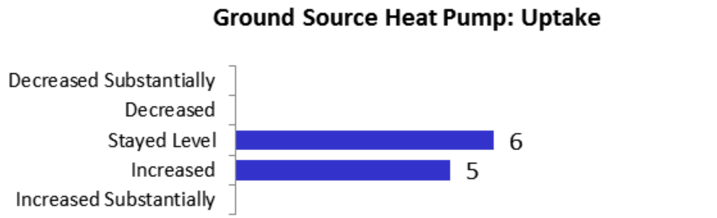
Water Source Heat Pump (WSHP)





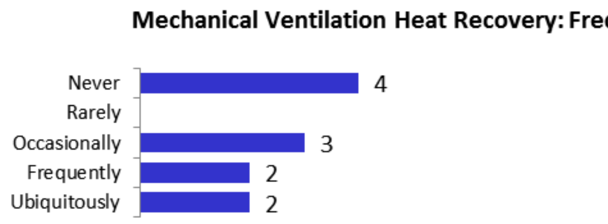
Ground Source Heat Pump (GSHP)

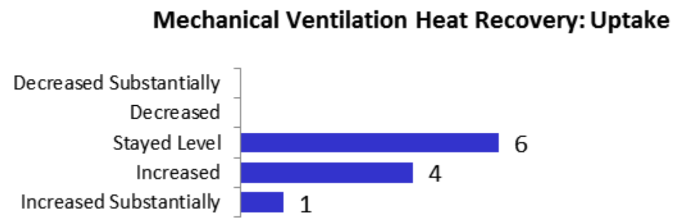




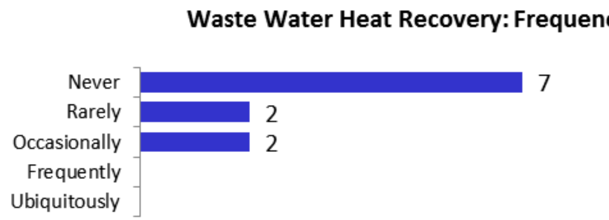
LZCGT **FREQUENCY** **UPTAKE**

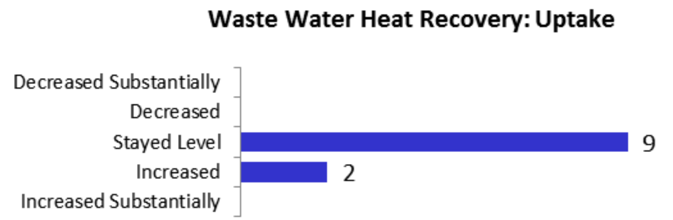
Mechanical Ventilation Heat Recovery (MVHR)



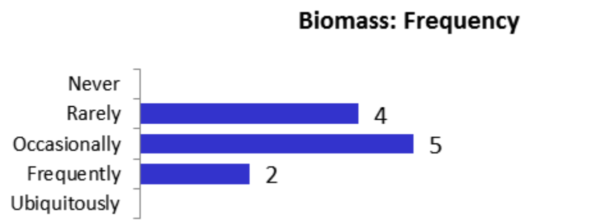


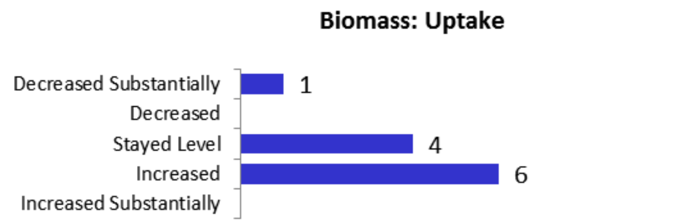
Waste Water Heat Recovery (WWHR)



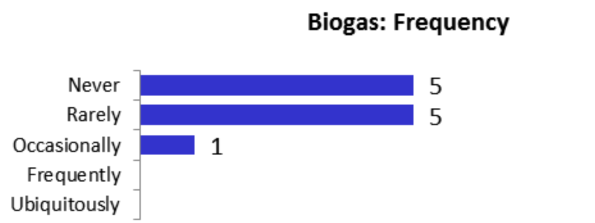


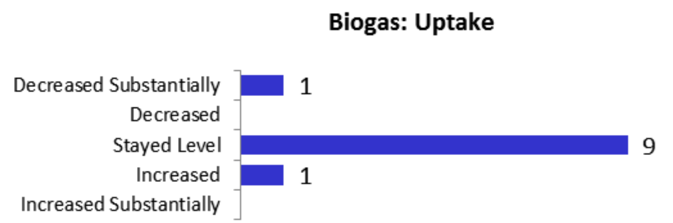
Biomass





Biogas





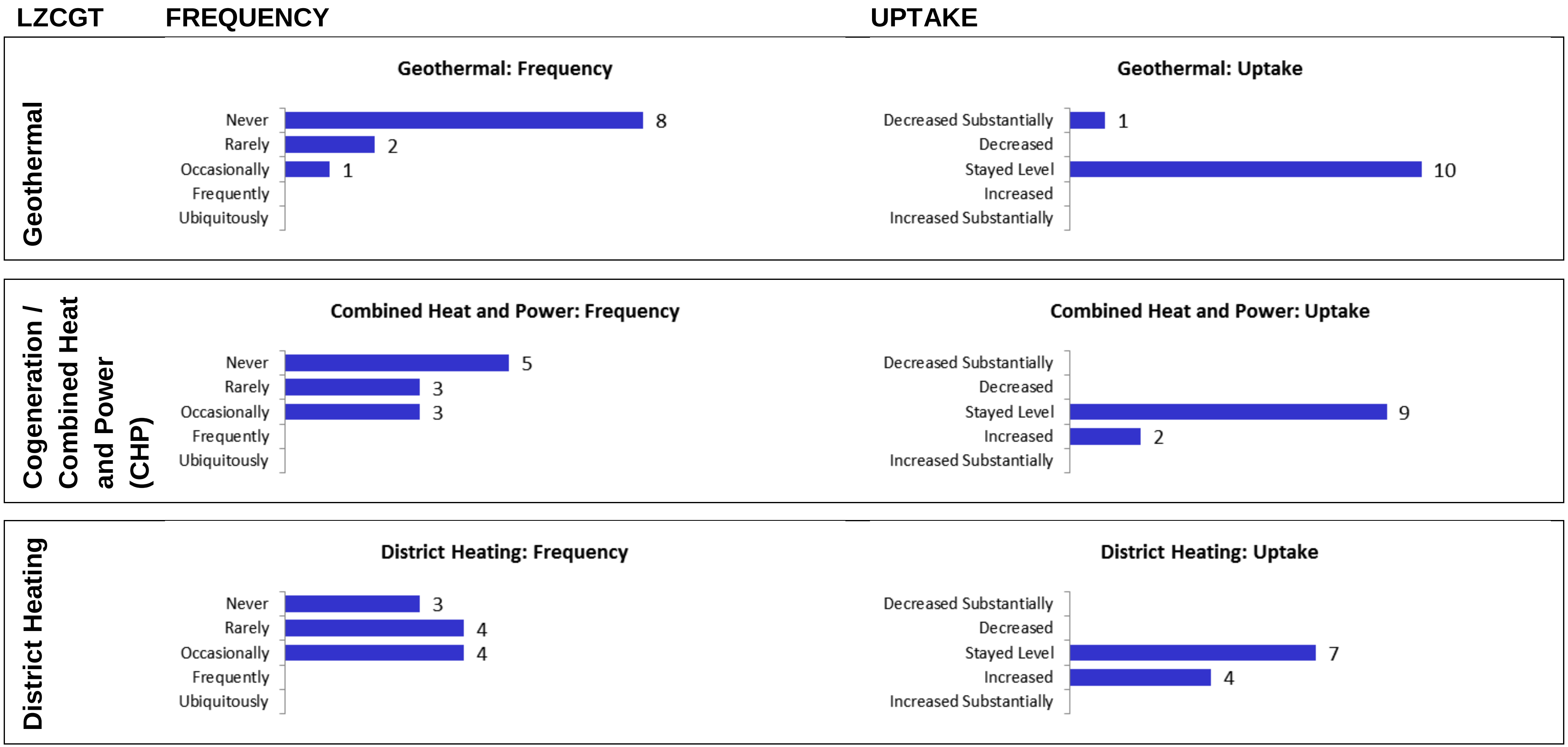


Figure A.5. Questions 15, 16: The changes in frequency and uptake of LZCGT observed in the past 5 years

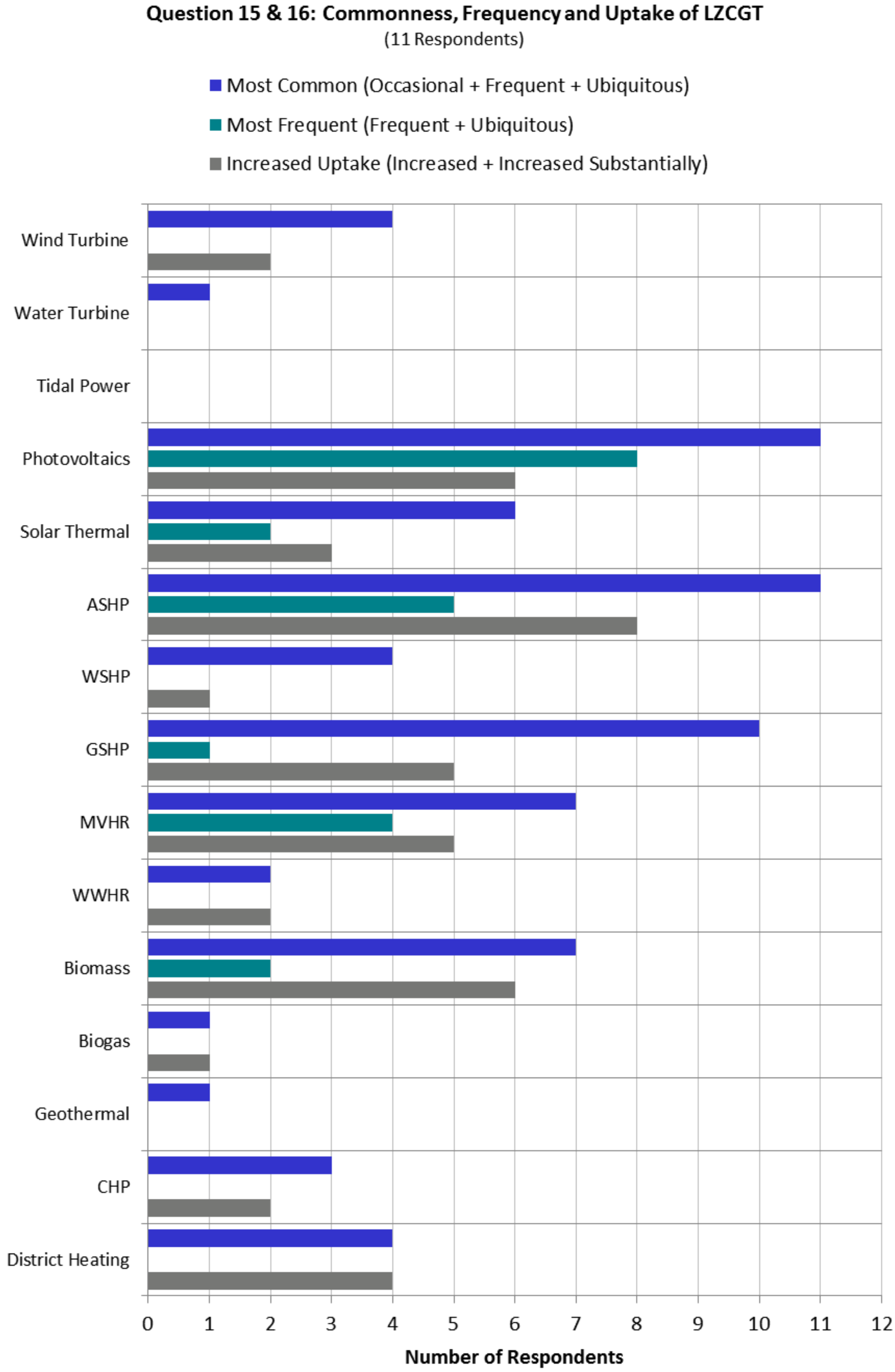


Figure A.6. Questions 15 & 16: Commonness, Frequency and Increased Uptake of LZCGT observed in the past 5 years

Question 17
Do you have any further observations about trends in LZCGT in relation to Section 3F Policy, or have you encountered emergent technologies not detailed above?

(2 Respondents)

Two respondents made further comments with regards to LZCGT trends they had observed over the past 5 years.

The first respondent worked primarily within a urban and suburban environment. They reported that they had seen the use of Air Source Heat Pumps (ASHP) really begin to take off in the non-domestic sector, particularly large-scale offices and hotels, over the past 7 months. They also commented that as a matter of course they do not consider gas-fired CHP as a LZCGT, so if applicants used this they would still be required to meet their LZCGT target by other means. They also raised two reservations that they had with specific LZCGT. Firstly, in respect to photovoltaics, they were noticing in some cases the landlord not the occupant was benefitting from the installation. Secondly they had some public health concerns with regards to the need to change or clean the filters used in MVHR units, and whether householders would be aware of this ongoing requirement. Finally they felt there was a lot of untapped potential in Waste Water Heat Recovery which needed to be explored.

The second respondent commented that further research may be needed to consider the impact that a reduction in space heat demand due to an increase in fabric energy efficiency will have on the deployment of LZCGTs and their cost effectiveness.

Question 18
How important is it that planning authorities should be able to promote their preferred regional, local or site specific solutions to GHG emissions reductions e.g. the use of local renewable energy resources, heat networks etc.?

(13 Respondents)

The majority of respondents (8/13) felt it was important that planning authorities should be able to promote their preferred regional, local or site specific solutions to GHG emissions reductions (Figure A.7)

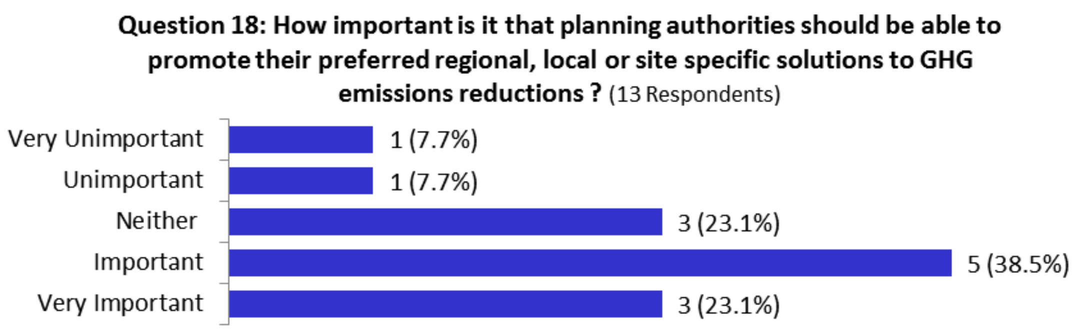


Figure A.7. Questions 18: Importance of being able to promote a preferred regional, local or site specific LZCGT.

Question 19
Do you think that planning authorities should be able to compel new developments to link with existing local large scale LZCGT initiatives or heat networks?

(13 Respondents)

The majority of respondents (10/13) felt that planning authorities should be able to compel new developments to link to existing local large scale LZCGT initiatives or heat networks in order to support such schemes (Figure A.8). However this was not without serious reservations about how this would work in practice.

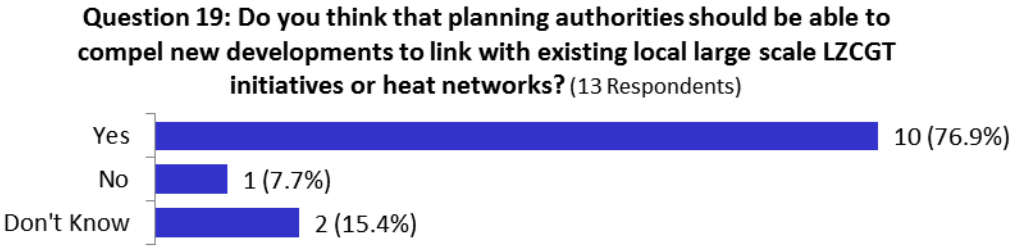


Figure A.8. Questions 19: Should planning authorities be able to compel new developments to link with local large scale LZCGT initiatives or heat networks?

Question 20
What are the barriers preventing planning authorities from developing these types of policies?

(12 Respondents).

Discourse was roughly split between reservations relating to the practicalities of developing large scale LZCGT initiatives and heat networks, and concerns about the potential political and legal ramifications of attempting to compel developers and occupants to use these networks.

A third of respondents (4/12) raised the issue of context in relation to large scale LZCGT and heat networks. One respondent stated that as all planning authorities vary in terms of geography, scale of development and natural resources, each needs to be able to develop policies to suit their particular context. Several respondents (3/12) reported there was a lack of opportunity for large scale LZCGT and heat networks in their locale. One respondent stated that the rural context was simply not conducive to shared schemes. This is because of the low density and the overall scale of new development in these communities. Development in rural areas usually takes the form of individual new buildings constructed by a number of small scale developers; rather than large scale development constructed by a single developer. Another respondent reported that in their area there were only a few large scale LZCGT schemes and highly localised heat networks that new developments could potentially tap into. As a result they felt that the most they could ask of developers was to consider feasibility, or potentially include ducting on the possibility that a heat network be developed in the future. The latter would incur an additional cost in construction.

Half of respondents (6/12) were concerned about the practicality of delivering large scale LZCGT and heat networks, and the implications of attempting to compel developers and consumers to connect to these.

A third of respondents (4/12) raised potential issues relating to the planning, financing and delivery of large scale LZCGT and heat networks. They concluded that in practice the concept would require the energy infrastructure to be delivered upfront, so that the developer would be assured it would be in place from the first day of occupation. If the municipality was not responsible for the planning, financing and delivery of such schemes; then the question is, who would fund it, implement it in a timeframe to suit the new development and see to its ongoing maintenance. Respondents (2/12) thought upfront costs and implementation issues were a significant barrier to the development of large scale LZCGT and heat networks and questioned the viability of such schemes in the eyes of developers. In particular, capital investment in heat infrastructure was considered prohibitive for small low density new builds with no economies of scale.

One respondent discussed the energy infrastructure developed as part of a prestigious urban redevelopment project. They stated that this had only been possible because of the scale of the development, the long lead time and crucially the local authority had control as the landowner. They could therefore compel the developer to come forward with an energy partner to deliver the energy infrastructure. Although generally considered a success, it had not been without issues, some of which still had to be resolved, notably those surrounding non-domestic rates. Another respondent spoke about a large-scale Energy Project which included the proposed development of a heat network making use of waste heat from local industrial processes. Unfortunately this is currently stalled, with potential projects being pursued through the Council's Investment Zone Bid.

Respondents (2/12) were also concerned that this type of planning policy would restrict developers and future occupants to one energy provider. In the UK's deregulated energy market this would mean persuading occupants to give up their right to change to a cheaper energy provider. One respondent explained that the Danish schemes that were often cited as exemplars for Scotland to follow were all municipally owned and run on a not for profit basis. This respondent did not see this happening in Scotland, and warned that if zones were carved up for the private sector they would definitely not be run on a not for profit basis. Consequently, these respondents questioned how the government would ensure the best value for money for citizens forced into these schemes, and whether it was reasonable to insist that new developments link to local large scale LZCGT and heat networks at all, if developers could provide their customers with cheaper options. One respondent observed that the capital cost of gas was still lower than LZCGT such as heat pumps or CHP supplied district heating, and there was still a lack of clarity on the proposed ban on new gas grid connections from 2025.

A third of respondents (4/12) simply stated that planning authorities lack the legal power to take this sort of action. Liberalisation of the energy market means that the choice of energy provider is up to the developer or occupant, and there is no legal means for planning authorities to compel connection to or delivery of specific energy services. This legal position would need to change if the government were to pursue this idea; however it might make the proposition of providing large scale LZCGT and heat networks more attractive for energy providers as it would reduce their risk. One respondent also had concerns about the proliferation of small energy companies, how the government would ensure the integrity of these large energy infrastructures, and who would become the owner of last resort if these companies were to fail.

Because of these practical and legal issues; respondents felt that there would be resistance from both developers and the public to planning policies that compelled new developments to link to large scale LZCGT and heat networks. One respondent felt this push back would continue until there was Scotland-wide level playing field in respect to this, and in their opinion that would need a change in statutory legislation.

Almost half of respondents (5/12) were acutely aware that new policies would require building technical knowledge and expertise within their departments to enable them to make sensible joined up decisions about large scale low and zero carbon energy infrastructures. This would have resource implications. It would require raising the awareness of planning professionals of LZCGT initiatives and heat networks through training and connecting with experts in the field. Currently it was felt that planning professionals lacked the technical knowledge, skillset and expertise to make these types of decisions. They also lack the resources and capacity to monitor or enforce these measures.

Respondents (2/12) also felt that the development of these types of policy would need political support. One respondent commented that local elected members were not very proactive on climate change and viewed planning as obstructive to local development and the economy. Another respondent stated that the lack of clarity at a national level with regards to grant funding and financing for heat networks meant that volume housebuilders were not engaged with the feasibility of such projects

Question 21
How important is it that the contribution LZCGT plays in delivering the CO2 emissions reductions required by Section 6 of the Scottish Building Standards be QUANTIFIABLY specified in Planning Policy? Why do you hold this view?

(13 Respondents)

54% of respondents (7/13) thought it was important that the contribution of LZCGT be quantifiably specified in planning policy. However 15% of respondents (2/13) thought it very unimportant and a further 31% of respondents (4/13) were ambivalent about its importance (Figure A.9). When comments were considered this fairly even split between those who felt it was important to quantify a target LZCGT contribution at planning and those who didn’t was more clearly defined.

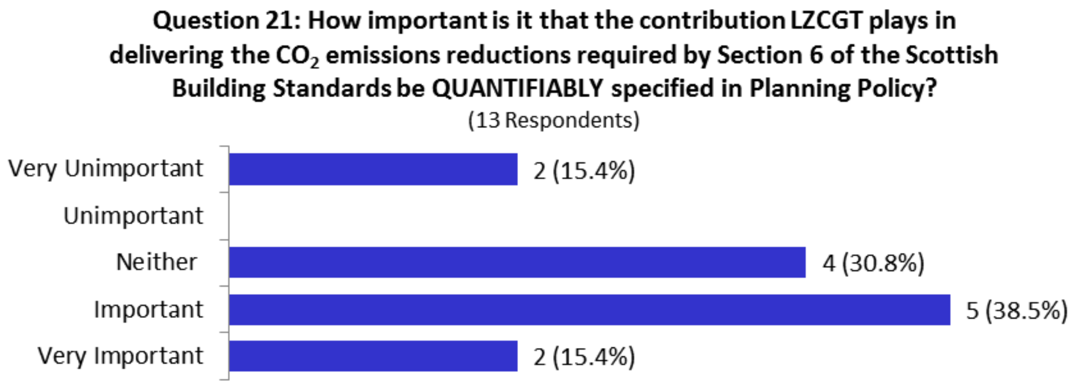


Figure A.9. Questions 21: How important is it that the contribution of LZCGT to CO_2 emissions reduction is quantifiably specified in planning policy?

Of those who expanded on their reasons for holding a particular view, approximately half of respondents (5/11) were generally supportive of quantifying the contribution of LZCGT to CO_2 emissions reduction within planning policy. Several of these respondents (3/11) felt the LZCGT target was crucial and it enabled them to effectively evaluate the LZCGT measures deployed. In addition they also considered it a useful means of quantifying and monitoring the overall effectiveness of Section 3F policy.

Several respondents also (3/11) thought that a clearly defined target was essential so that all stakeholders understood what was being sought. Although one of these respondents added that a Scotland wide standard would be preferable to the current situation where different regions had different requirements because it would provide clarity and it would be easier for volume housebuilders and developers to respond to.

Whilst not rejecting the use of LZCGT completely; two respondents (2/11) advocated very strongly for a fabric first approach to CO_2 emission reduction in new buildings. Both respondents were of the opinion that improving building fabric energy efficiency was the most cost effective means of tackling CO_2 emissions. As a result they both supported incentivising developers to take a more hierarchical approach towards emission reduction which prioritised fabric energy efficiency over the deployment of LZCGT. Although unconcerned whether the LZCGT target was set by planning or building standards; one of these respondents underlined the need for any target to be a minimum standard so that it would not interfere with a fabric first approach.

Over half of respondents (6/11) reflected on the respective roles and skillsets of Planning and Building Standards in reducing CO_2 emissions, and questioned the positioning of this LZCGT policy within the remit of Planning. One respondent concluded that Planning was better positioned to deliver CO_2 emission reduction through good design and placemaking; although they also acknowledged planning had an important role in delivering large scale LZCGT and heat networks where applicable. This was seen as complementing the role of Building Standards with its more technical regulations that ensure buildings meet CO_2 emissions reduction targets.

On consideration of all the issues, over a third of respondents (4/11) felt that Section 3F policy was better suited to inclusion in Building Standards rather than Planning. In particular they felt that its current positioning led to duplication of effort and unnecessary work that could be avoided. One respondent plainly stated that at a fundamental level they thought that the delivery of these worthy targets and ambitions has been made more complicated and difficult by trying to give planning a responsibility that is technically better delivered through the building standards process only.

Comments were also received that alluded to the difficulties surrounding implementation, verifying compliance and enforcement already discussed (Section 2: Evidence and Procedures). One respondent considered it vital that should LZCGT policy remain in the provenance of Planning, there needed to be an official and certifiable way to demonstrate compliance at the planning application stage. Two other respondents did not see the need for the LZCGT contribution to be quantified at the planning level at all, since they felt this could be better accomplished through building standards.

A further respondent stated that Scottish Building Standards relating to CO_2 emission reductions were applied and enforced effectively and that should be sufficient; if not, then the contribution of LZCGT should be addressed directly through the Scottish Building Standards.

Question 22
Do you think there is a case to be made for Scotland wide Planning Policies that attempt to accelerate the reduction in CO_2 emissions beyond the current Scottish Building Standards?
Why do you hold this view? How might this be best achieved?

(13 Respondents)

54% of respondents (7/13) felt there was no case to be made where planning policy should attempt to accelerate CO_2 emission reduction beyond that called for in Scottish Building Standard 6.1 CO_2 emissions (Figure A.10). 38% of respondents (5/13) disagreed and felt there was a case to be made. One respondent was undecided but the comment they left was quite negative to the concept.

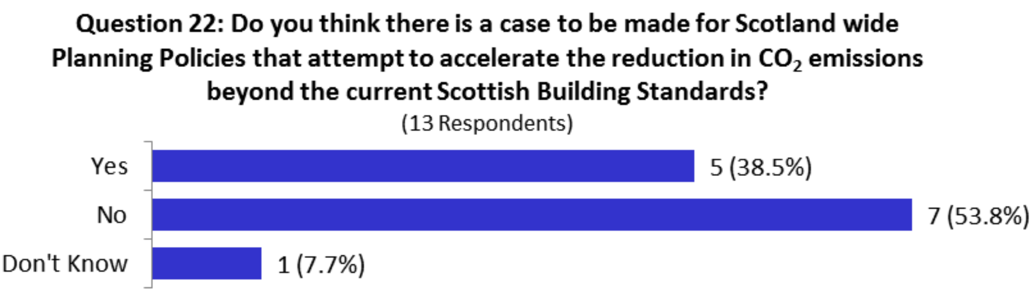


Figure A.10. Questions 22: Is there a case for a Scotland -wide planning policy to attempt to accelerate reductions in CO_2 emissions beyond building standards?

Of those who expanded on their reasons for holding this view, a quarter of respondents (3/12) were keen to see planning take action to accelerate CO_2 emission reduction in response to the climate emergency. One respondent reported that their urban local authority had led the way in promoting CO_2 emissions reduction in new buildings since 2010. During this time they have pushed the development industry to deliver better quality buildings and have required new buildings to go beyond building standards. With the recently declared climate emergency, they acknowledge that new buildings need to go further. They also recognise that the current building standards will change and demands will increase over the 10 year timeframe of the local development plan (LDP). The role of the LDP is therefore seen to be one of setting high targets and meeting this pace of change. They are currently consulting on the requirement that all new building be net zero carbon. Another respondent stated that the technologies and materials were readily available to go beyond the current position of building standards on CO_2 emission reductions and significant impacts could be made given the right impetus. They felt developers were stalling because of costs.

A third respondent suggested planning could accelerate CO_2 emission reductions by developing a consistent sustainable design approach, with supplementary guidance advising developers on issues such as location, siting, design and materials. Many planning authorities already provide some basic supplementary guidance relating to this approach in an attempt to promote better design choices (See Question 25 for more details).

One respondent was keen to remind us that that the Section 3F policy does not seek to increase CO_2 emission reduction, just the proportion of this that is achieved through LZCGT. Another respondent clearly stated that planning simply did not have the remit to go beyond other legislative standards.

Just under half of respondents (5/12) felt that the most logical and straightforward way to increase CO_2 emission reduction is to simply increase the amount required by Scottish Building Standard 6.1: CO_2 emissions. One respondent stated that Section 3F policy was useful in promoting general awareness of the role LZCGT could play in reducing CO_2 emissions, but had yet to be applied successfully by any Scottish planning authority. Two respondents went further and suggested Section 3F should be removed from Scottish planning policy, to avoid duplication of effort and unnecessary work. They felt that building standards were sufficient to the task and offered a consistent national target for CO_2 emissions reduction. Taking this approach would also avoid potentially contradictory targets and information being issued from planning and building standards.

Just under half of respondents (5/12) clearly expressed the need for clarity and consistency in policy between different planning authorities and between planning and building standards. One respondent simply stated:

> 'I think it would be better to simply increase the amount required by building standards and remove it from planning instead of duplicating it. However if it is to be the responsibility of Planning I think this is best achieved by having a national policy requiring it in order to contribute effectively to the commitments of the Scottish Government rather than leaving it to local government and allowing for disparity.'

(Respondent 2)

Although these respondents felt there was a need to accelerate CO_2 emission reduction, they were also clear that it would unhelpful and confusing to have planning and building standards set different targets in this respect. It made no sense to them to consider doing so as it would be wasteful of public resources. They stated that it is essential for successful and productive engagement with stakeholders that planning and building standards have a clear and consistent message to avoid contradiction and confusion.

Two respondents thought there was scope for collaboration on this issue between planning and building standards. One respondent stated that local authorities would benefit from best practice guidance on how to achieve this type of joint working, including the resource implications. The other respondent suggested that targets should be set that are appropriate to meet the challenge of climate change management at the planning stage, but building standards be empowered to enforce compliance.

Question 23

Are there opportunities for taking a different approach to reducing energy consumption and CO_2 emissions at the Planning stage, which might accelerate change whilst not necessarily clashing with Building Standards? What might these be?

(12 Respondents)

A third of respondents (4/12) replied with general suggestions about how policy and process could be used to achieve these aims. One respondent suggested that all planning policies should reference the impact on climate change and CO_2 emissions reduction; so there is no misunderstanding the priority that is being given to this issue. Another respondent thought that in general, planning authorities are better placed to promote and champion the practical means of achieving reductions in energy consumption and CO_2 emissions, than compelling compliance to specific targets. This respondent felt planning policies have the potential to promote and encourage developers to adopt alternative energy solutions or adhere to Local Heat and Energy Efficiency Strategies (LHEES). A third respondent felt the process could be used to advise applicants of their responsibilities in relation reducing energy consumption and CO_2 emissions at a stage where it could positively influence design responses.

> ‘Certainly pre-application advice and the process of determining planning applications should be used to advise developers of the targets that they will have to meet through the determination of their building warrant and to tell them to check out what this may mean for the design of their project.’

(Respondent 12)

The fourth respondent emphasised that it was important that the planning implications of LZCGT be captured during the planning permission process and not applied retrospectively. Planning officers could potentially flag any building standard requirements for specified LZCGT as a way of front-loading the system and avoiding retrospective changes (see Question 25).

A third of respondents (4/12) focused on design. Two respondents suggested planning could develop a comprehensive sustainable design approach, with supplementary guidance advising developers on issues such as location, siting, design and materials (See Question 25 for more details). One of these also suggested the better use of design tools such as design briefs to set out what the planning authority expects of new development in terms of reducing energy consumption and CO_2 emissions. A third respondent suggested developing a formal national process of self-certification, whilst the fourth commented that they had referenced nationally recognised sustainable design standards (EcoHomes, BREEAM and CEEQUAL) in previous local development plans to promote energy conservation and the reduction of greenhouse gas emissions.

A quarter of respondents (3/12) focused on LZCGT. One respondent thought there should be increased permitted development rights for micro-renewables, subsidies for private sector adoption of renewable solutions and a public sector commitment that all properties include micro-renewables. Two respondents discussed the potential implementation of district heating schemes. One of these respondents thought more could be done to plan developments that leant themselves to the development of heat networks i.e. high density developments close to potential heat sources. The other respondent was more sceptical about the benefits of district heating and thought we needed to rigorously question our assumptions in this area. They also felt that if it was decided to proceed with district heating at a scale beyond individual developments, then that would require proper public intervention with the resources and expertise to deliver it.

One respondent thought it might be worthwhile investigating the potential of an offset fund, as an allowable solution mechanism that developers could pay into if a new building were for some reason unable to meet its entire CO_2 emission reduction target. (This is unlikely at the current 45% CO_2 emission reduction target, but may become more relevant as we near net zero carbon). The money from such funds would be used for carbon saving projects.

A quarter of respondents (3/12) simply thought the best way to address this issue was through building standards. If these standards needed to be more ambitious then that change should happen. One of these respondents suggested that a fairly swift and easy action that could be taken was to make the currently optional higher sustainability standards of Section 7 of the building standards mandatory, when they are next revised. This respondent also felt that colleagues from planning and building standards would benefit from proper training with regards to these issues to enable them to make better informed decisions.

Question 24
Given the current Climate Crisis, it is important that everyone contributes to reducing GHG emissions and mitigating Climate Change; but on what specific issues do you think Planning and Building Standards should focus their efforts to best achieve these aims?

(12 / 13 Respondents)

With reference to Figure A.11; all respondents felt that Planning should concentrate their main efforts on Landscape Scale Planning (13/13), Sustainable Planning (13/13), Large Scale LZCGT (12/12), Architectural Design (13/13) and Architectural Design Details (13/13). Approximately two thirds of respondents also felt Planning had a major role to play in Building Scale LZCGT (8/13) and Assessing Sustainability (8/12). Only one respondent felt that Assessing Energy Consumption (1/12), Assessing CO_2 emission reductions (1/12) or Assessing the Contribution of LZCGT (1/12) and no respondents felt that Fabric Energy Efficiency (0/13) should be a specific focus for Planning.

All or nearly all respondents felt that Building Standards should concentrate their main efforts on Fabric Energy Efficiency (13/13), Building Scale LZCGT (12/13), Assessing Energy Consumption (12/12), Assessing CO_2 emission reductions (12/12) and Assessing the Contribution of LZCGT (12/12). Approximately three quarters of respondents also felt they had a major role in Assessing Sustainability (8/12) and Architectural Design Details (8/13). Approximately a third of respondents also felt Building Standards had a role in Large Scale LZCGT (5/12), Architectural Design (4/13). Only one respondent felt that Sustainable Planning (1/12), and no respondents felt that Landscape Scale Planning (0/13) should be a specific focus for Building Standards.

A joint responsibility was suggested for Assessing Sustainability (Planning 8/12 & Building Standards 9/12). A less even split of responsibility was suggested for Large Scale LZCGT (Planning 12/12 & Building Standards 5/12), Building Scale LZCGT (Planning 8/12 & Building Standards 12/12), Architectural Design (Planning 13/13 & Building Standards 4/13) and Architectural Design Detailing (Planning 13/13 & Building Standards 9/13).

Question 25
What specific functions can Planning perform at an early stage in the design and development process to help reduce GHG emissions, which would be difficult or impossible to apply effectively at the Building Warrant stage?

(11 Respondents)

Over 80% of respondents (9/11) made reference to planning and design decisions taken either by the planning authority in the development of their local development plan (LDP), early in design development process or during the planning application process. One respondent highlighted a need for local policy guidance on how to design developments that would be sustainable in the long-term.

Two respondents referenced issues in the category of Landscape Scale Planning. These included decisions relating to climate mitigation and adaption, flood risk, environmental impact, landscaping, tree planting and biodiversity. One respondent considered tree planting should be a requirement for all new development and sufficient space allocated to such in proposals. This included town centre and industrial development.

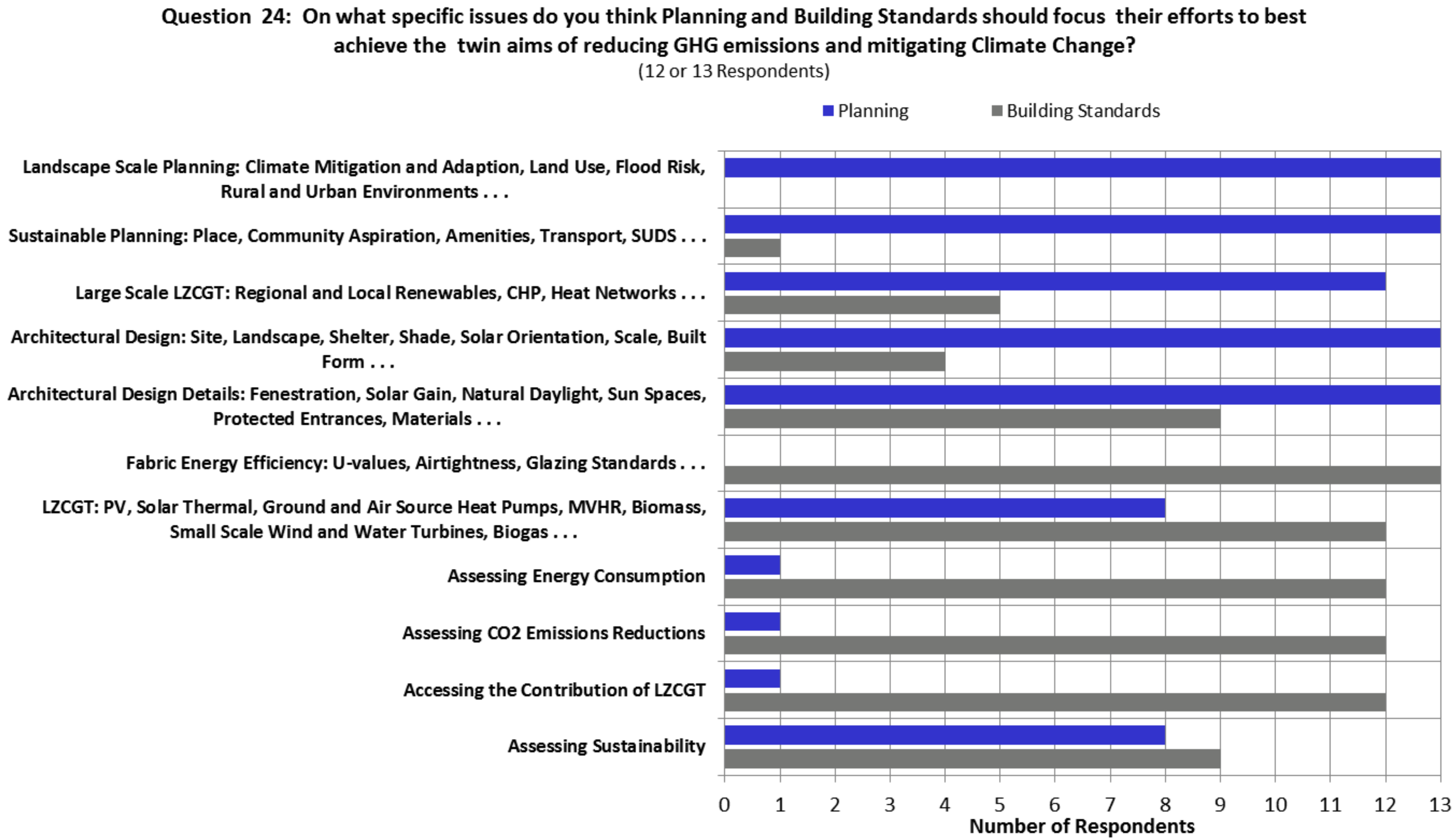


Figure A.11. Question 24: On what specific issues do you think Planning and Building Standards should focus their efforts to reduce GHG emissions and mitigating Climate Change?

Three respondents referenced issues in the category of Sustainable Planning. These included decisions relating to placemaking, location, connectivity and transport. The appropriateness of the development and its location and connectivity to users was raised by all these respondents as a principle of sustainable planning. One respondent suggested avoiding development in isolated rural locations with little in the way of transport links. However they also recommended that the Scottish Government, Local Authorities and developers be required to invest more in public transport, cycle paths and paths. Reflecting on the suggestion that high density development is more sustainable; one respondent considered the possibility of reducing privacy and parking standards provided that the development is high quality in terms of placemaking and associated public transport is available. They also suggested requiring the provision of infrastructure for electrical vehicle charging points.

Two respondents referenced issues in the category of Large Scale LZCGT, primarily focused on strategic planning and the development of Local Heat and Energy Efficiency Strategies (LHEES). It was considered that gains could be made by the thinking strategically about the development of large scale LZCGT and heat networks; for example by identifying and supporting potential synergies between neighbouring developments with shared or complementary heating needs and clustering development accordingly.

Four respondents referenced issues in the category of Building Scale LZCGT. One respondent stated that the planning process should be used to flag potential opportunities to incorporate LZCGT into the design. The other three respondents were keen to ensure that developers accurately reflect building scale LZCGT at the design stage; so that the planning implications are captured during the planning application process, rather than applied retrospectively. This is especially important for external LZCGT plant because there might be a need to discuss the appropriateness of the site location or screening.

Four respondents referenced issues in the category of Architectural Design & Architectural Design Detailing. They discussed implementing practical passive design responses that utilise the topographical, environmental and micro-climatic features of a site to minimise energy consumption. In particular they mentioned appropriate siting, shelter, solar orientation, solar gain, massing, scale and materials. One respondent suggested that planning guidance could give advice on these measures and material choices to encourage developers to consider the whole life cycle of the building.

Approximately a quarter of respondents (3/11) commented on the planning process. Two of these respondents thought that planning played more of an advisory role, facilitating discussions on feasibility and influencing the choices developers made with respect to different types of LZCGT and other carbon mitigation measures at an early stage in the design process. Underlying these comments was a presumption that firm commitment to any particular option would not be reached until the building warrant stage, whereupon building standards would ensure greenhouse gas emission reduction targets are met. The other respondent stated they could simply apply planning policy effectively.

Question 26
Would the development of Scotland wide sustainable design guidelines and simple standard assessment procedures be of use to planning officers and applicants to clarify expectations in relation to sustainable building design or Section 3F policy?

(13 Respondents)

Nearly all respondents (12/13) thought the development of Scotland-wide sustainable design guidelines and simple assessment procedures would be useful for both planning officers and applicants to clarify expectations (Figure A.12). The one remaining respondent was undecided.

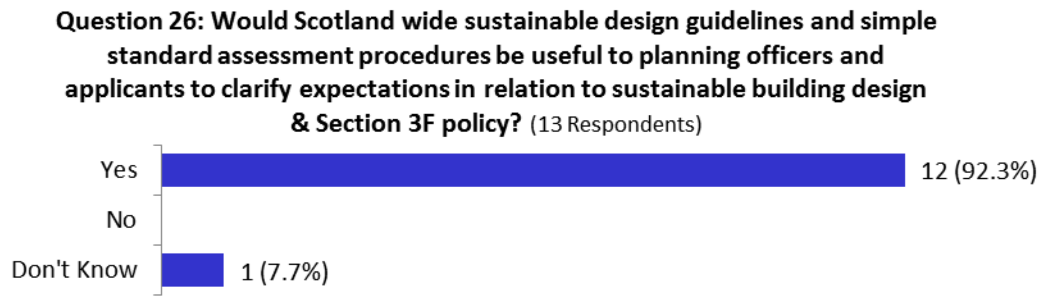


Figure A.12. Question 26: Would the development of Scotland wide sustainable design guidelines and simple standard assessment procedures be of use to planning officers and applicants?

Question 27
If design guidance and assessment procedures were defined at a Scotland wide level, which of the following do you think would be useful to planners and applicants at the design and planning stage?

(13 Respondents)

Scotland-wide Design Guidelines were welcomed by the majority of respondents in all subject categories (Figure A.13). Design guidance relating to Sustainable Urban Planning, Sustainable Building Design, Sustainable Rural Planning, Energy Efficient Architectural Design and Large Scale LZCGT were widely welcomed. Guidance on Small Scale LZCGT, Sustainable Construction, Materials and Embodied Energy, and Fabric Energy Efficiency, were less popular choices but still had the support of over 60% of respondents.

There was generally slightly less support for Scotland-wide simple assessment procedures in relation to these categories, although support for most was still high (Figure A.13). The most popular subject matters in this respect were Fabric Energy Efficiency, Small Scale LZCGT and Sustainable Construction, Materials and Embodied Energy. However simple assessment procedures for Energy Efficient Architectural Design and Large Scale LZCGT were also considered valuable by the majority. There was seen to be less need for Scotland-wide simple assessment procedures in relation to Sustainable Urban Planning, Sustainable Rural Planning and Sustainable Building Design.

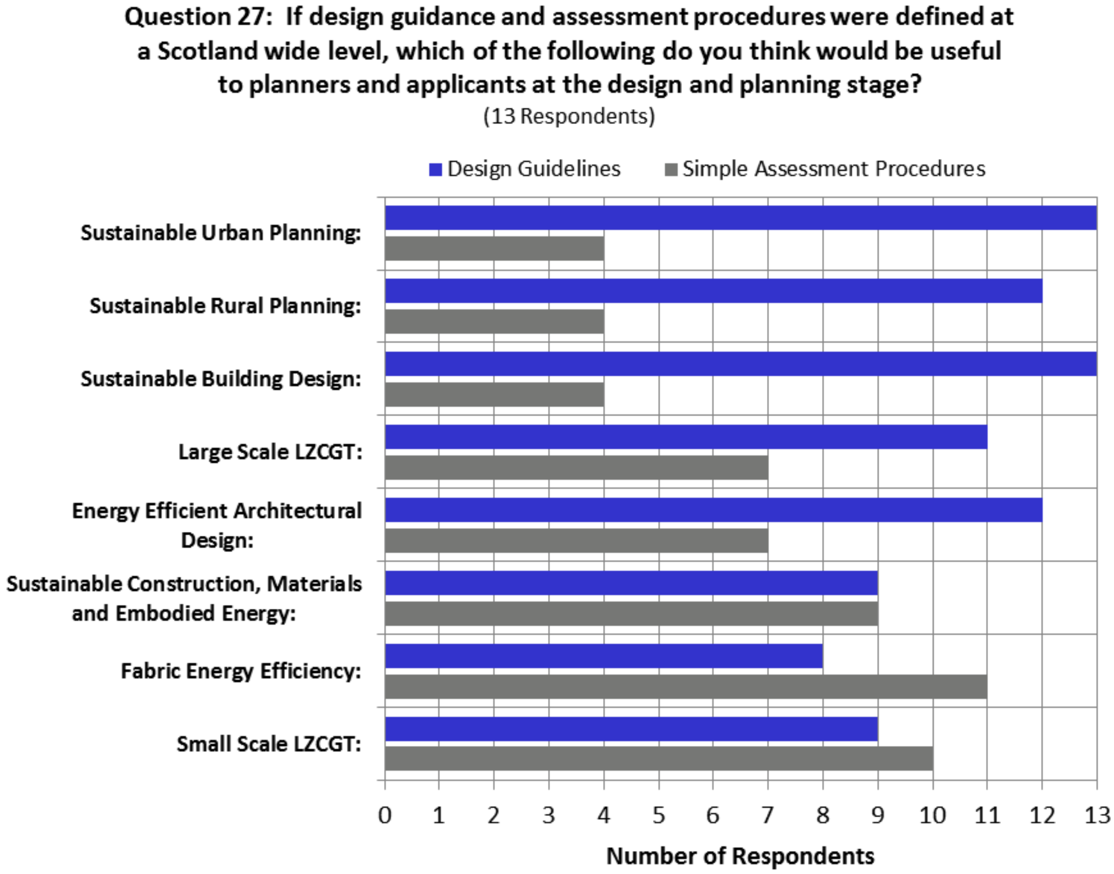


Figure A.13. Question 27: If design guidance and assessment procedures were defined at a Scotland wide level, which would be useful to planners and applicants at the design and planning stage?

Question 28
Additional comments or concerns related to Section 3F Policy or the issues raised.

(4 Respondents)

Two respondents commented about the challenges of engaging developers in the aspirations and process of Section 3F policy. It was felt that small scale developers perhaps lacked the expertise, whilst large scale developers did not want to engage. One respondent concluded;

> ‘As with many of the design challenges; this requires a buy-in from large scale developers, in particular house builders; and it requires policy and/or legislation to ensure that the technologies are integral to design and not add-ons to standard house types that have not changed for several years.’

(Respondent 9)

Two of the respondents raised the need for more collaborative working between planning and building standards over this issue. One of these respondents recognised the unique skillsets contained in each department and considered what role in the process each might best tackle;

> ‘Planning can play a role in increasing awareness and facilitating discussion around LZCGT technology and carbon mitigation at an early stage in the development process. However it does not provide an easy solution to measuring and calculating GHG emission reductions as planning officers do not necessarily have the detailed skills and technical knowledge of Building Standards in order to assess this information, which is where greater collaboration between Planning and Building Standards could be beneficial.’
>
> (Respondent 13)

The other respondent commented mainly on the difficulties of the compliance and enforcement process and concluded that in relation to Section 3F policy, the process was broken in the gap between planning and building standards. Planning has tried to enforce Section 3F planning policy through suspensive conditions but this hasn’t worked very well. Whilst building standards has felt unable to help because their legal remit is only to the statutory regulations contained within the Scottish Building Standards. They concluded that planning and building standards desperately need to find a way to work together on this issue;

> ‘We push on a daily basis for higher standards but it will all be for nothing if those requirements don't translate into better buildings on the ground at the completion stage.’
>
> (Respondent 4)

The final respondent felt an easy way out of this complex situation would be to simply include a new mandatory standard within the Scottish Building Standards that meets the requirements of Section 3F policy. Planning could then simply reference this standard as a requirement, only one calculation would be necessary and it would be enforced by building standards. They felt the obvious solution was to upgrade the Section 7: Sustainability “Active” aspect to include a specified LZCGT contribution, and make it mandatory.

They also commented more generally on potential future UK government energy strategies. They felt there were both benefits and constraints to the national grid, of pursuing a policy of micro-generation of electricity for household needs over and above those already regulated through the SAP/SBEM process. However they felt planning could play a role by requiring a certain percentage of the average household electricity use to be provided by shared or micro-generation. They also commented positively about the Passivhaus concept and its ability to reduce energy demand for heating and cooling.

Appendix B: Scenario Development

Scenario Graphs & Summary Tables

The following graphs and summary tables were used to determine what would be an appropriate LZCGT contribution to the energy demand in new domestic buildings under different CO_2 emission reduction standards. The data represented here is the predicted energy demand for dwellings ranging in size from $25m^2$ to $300m^2$ under three different fabric energy efficiency standards. It was generated as described in the main report using formula prescribed in the Standard Assessment Procedure SAP 2012 (BRE, 2014).

The three modelled scenarios were developed to represent a level of fabric energy efficiency that might be reasonably expected and achievable by a moderate sized dwelling built under the Scottish Building Standards (Table: B.1). These scenarios were developed to provide a better understanding of how changes to the fabric energy efficiency context impact on overall annual energy consumption and the size of LZCGT installations that would be required to meet proposed contribution targets. The annual space heat demands used to represent these fabric energy efficiency scenarios are $45kWh/m^2$.annum, $30kWh/m^2$.annum and $15kWh/m^2$.annum respectively.

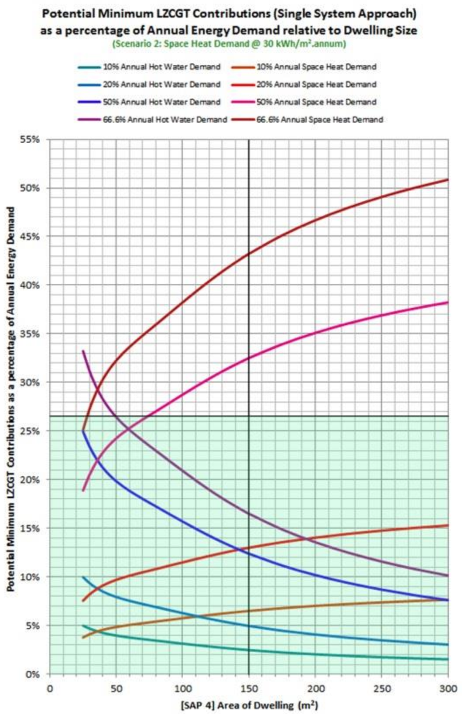
These scenarios can be viewed as representing past (2012), present (2020 - 2021) and future (2024 -2050) fabric energy efficiency contexts, and thus allow a more accurate model of how tightening CO_2 emission reduction standards may impact on the contribution and cost-effectiveness of LZCGT. Alternatively, they may be viewed sociologically in terms of diffusion theory as representing: laggards and the late majority; the early majority; and early adopter and innovators respectively (Gladwell, 2000). The impact of not improving fabric energy efficiency on the size and capacity of LZCGT installations needed to meet contribution targets can be clearly seen by comparing the same graphs from different scenarios.

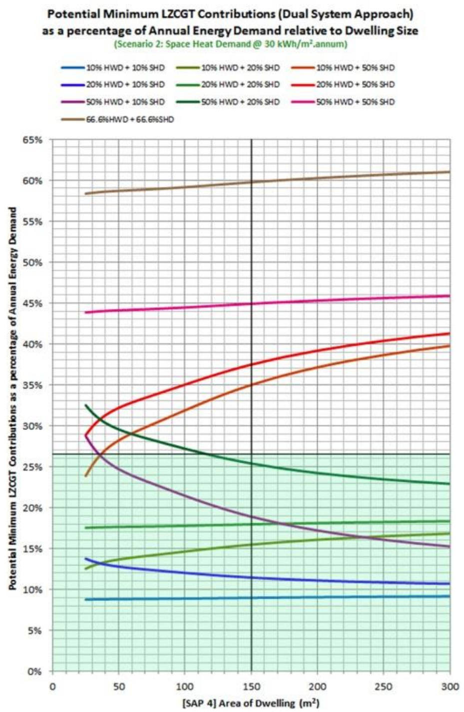
Scenario 1:	**$45kWh/m^2$.annum**	Past	2012	Laggards & Late Majority
Scenario 2:	**$30kWh/m^2$.annum**	Present / Near Future	2020-2021	Early Majority
Scenario 3:	**$15kWh/m^2$.annum**	Future	2024-2050	Early Adopters & Innovators

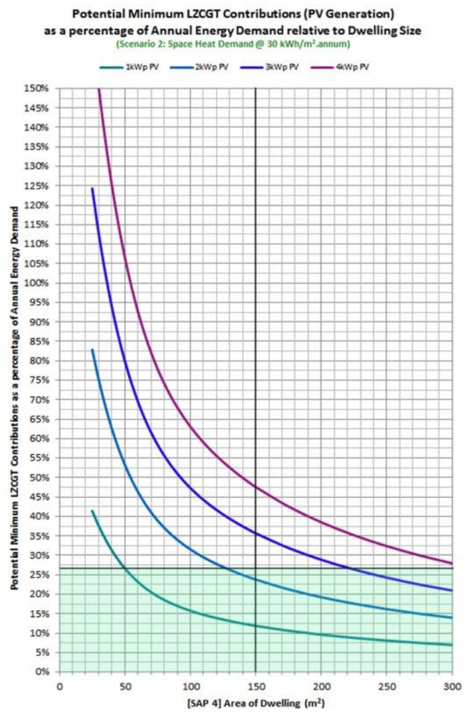
Table B.1: Summary of Scenarios

Interpreting the Graphs

For help understanding how the graphs can be used to evaluate whether potential LZCGT options will meet a specific emission reduction targets see Figure B.1 below.







Interpreting the Graphs

1. Select relevant scenario
2. Select relevant graphs
3. Draw a line vertically on each graph to indicate the size of dwelling being investigated
4. Draw a line horizontally on each graph to represent the E% relevant for the CO_2 emission reduction standard (R%) being investigated
5. Options above the line should meet this target on their own
6. Options below the line wil not meet this target on their own, but by summing their percentage contributions it might be possible to combine two strategies to meet the target E%
7. Determine possible LZCGT options by considering how much of the specific energy demand the potential LZCGT will be capable of delivering or how much roof area is available for PV.

Example:

Determine what LZCGT options might be available to a 150m² dwelling built to a space heat demand of 30 kWh/m².annum, to meet a 75% CO_2 emission reduction standard

Scenario 2: SHD = 30kWh/m².annum
Figures S2.5, S2.6 and S2.7
150m²
R% = 75% ; E% = 26.5% (See Table 1)

Unshaded Area
Shaded Area

Note: Heat Pumps use substantial amounts of electricity so their contribution should be adjusted in accordaance with their efficency e.g. a 300% efficient heat pump could be considered to provide 66.6% of SHD & HWD with little or no emissions.

Figure B.1 Interpreting the graphs

SCENARIO 1: PAST (2012)

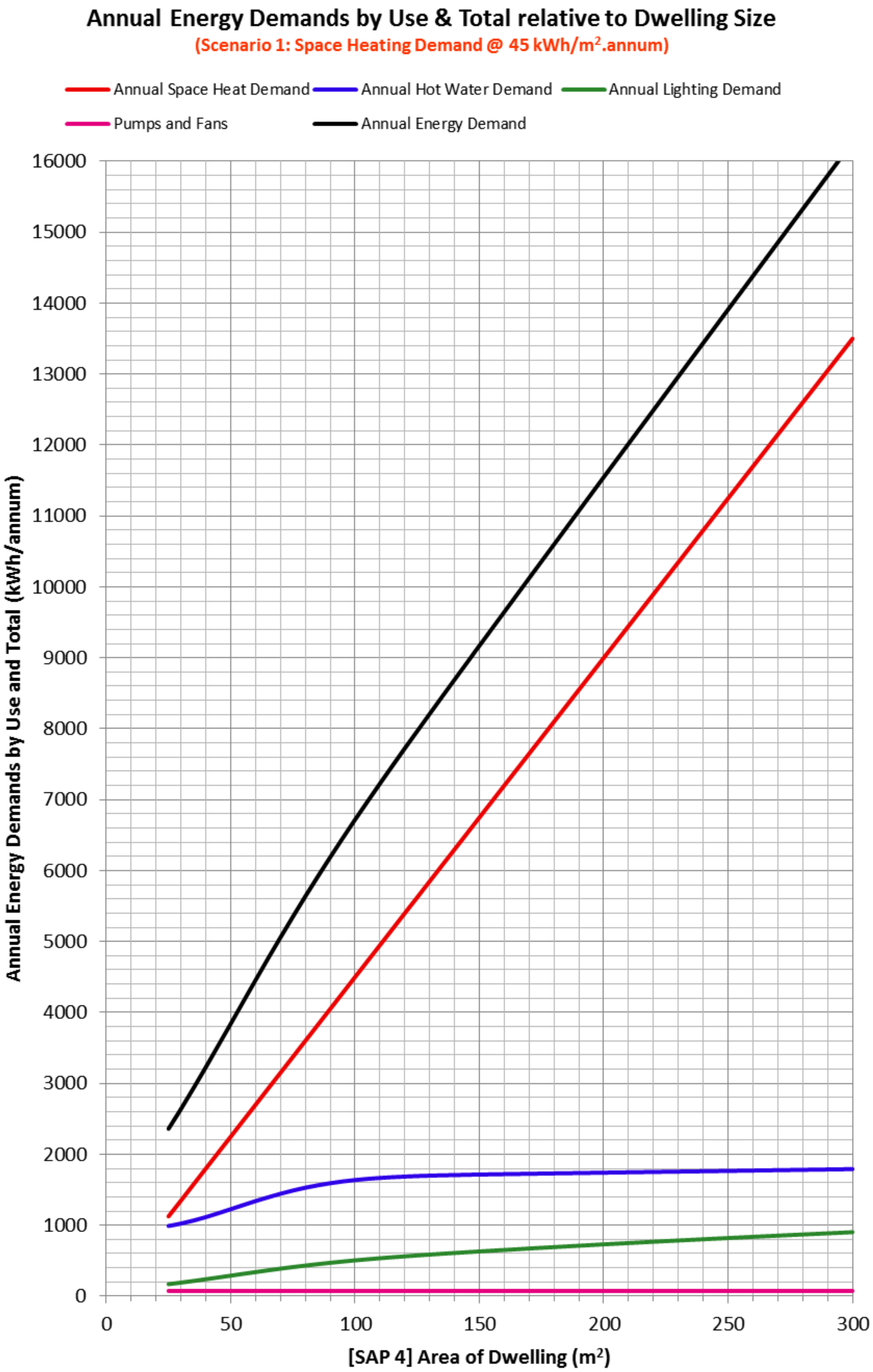


Figure S1.1: Scenario 1: Annual Energy Demands by use and total relative to dwelling size.

SCENARIO 1: PAST (2012)

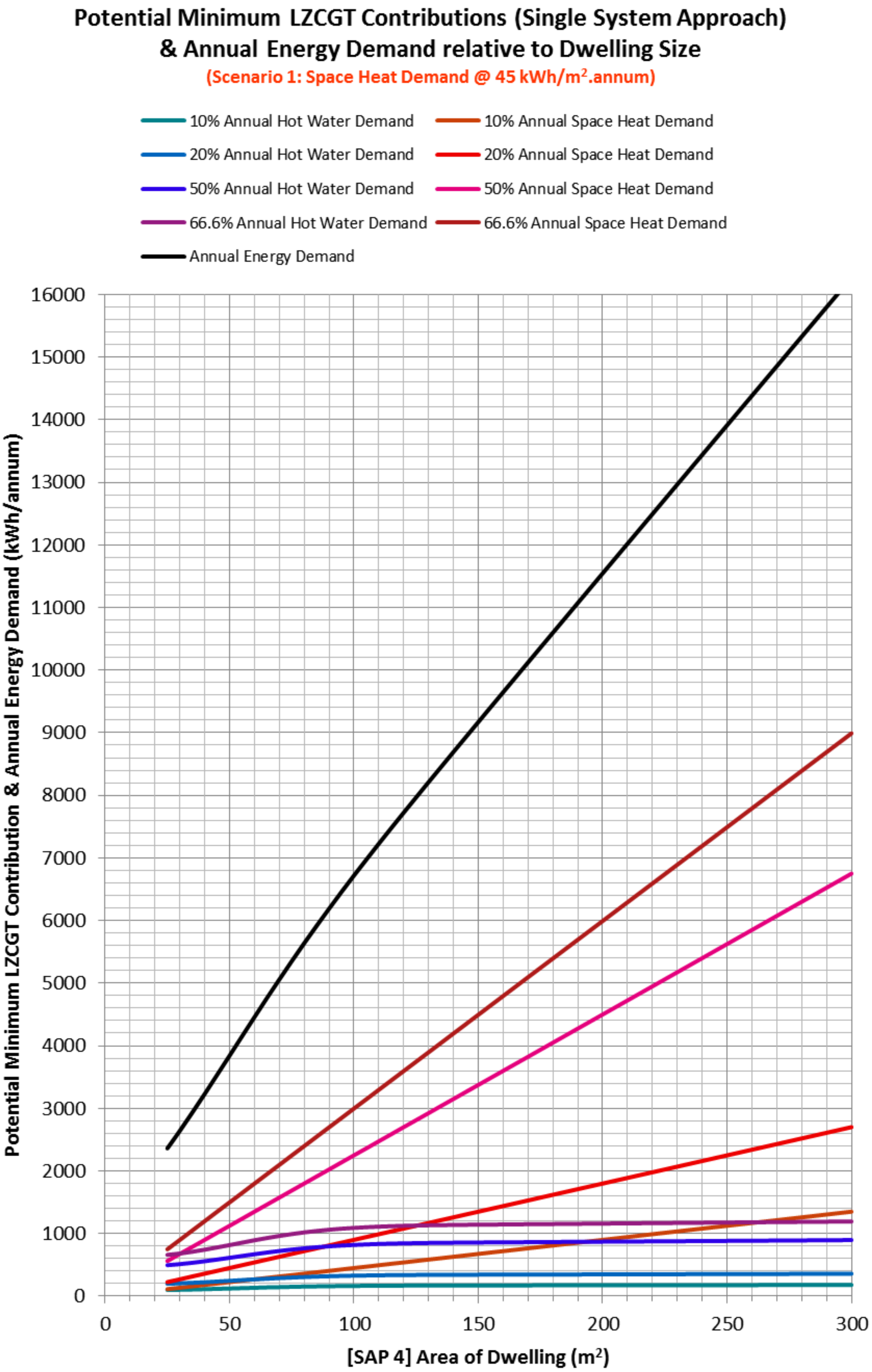


Figure S1.2: Potential Minimum LZCGT Contribution (Single System Approach) and AED relative to dwelling size

SCENARIO 1: PAST (2012)

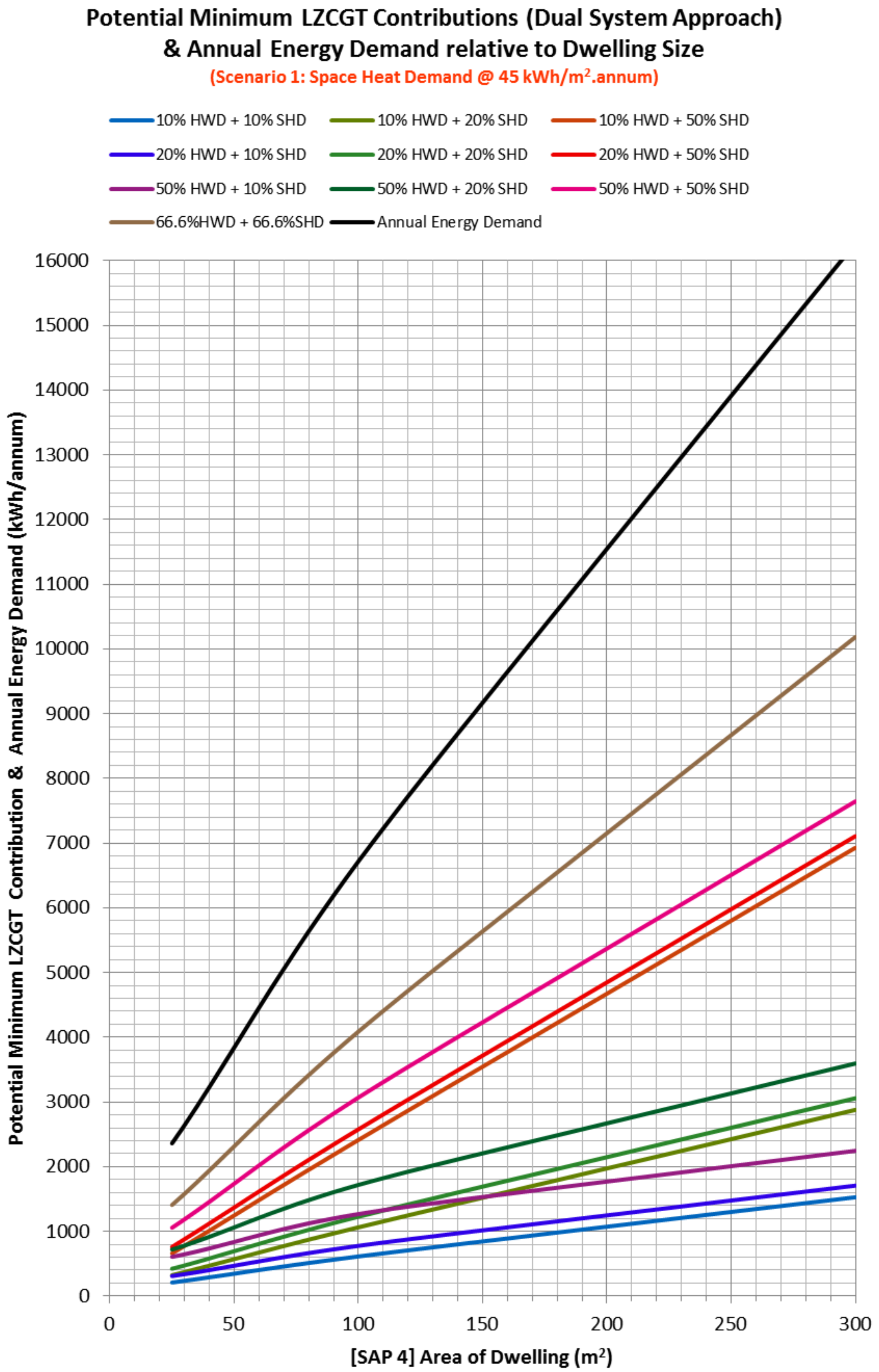


Figure S1.3: Potential Minimum LZCGT Contribution (Dual System Approach) and AED relative to dwelling size

SCENARIO 1: PAST (2012)

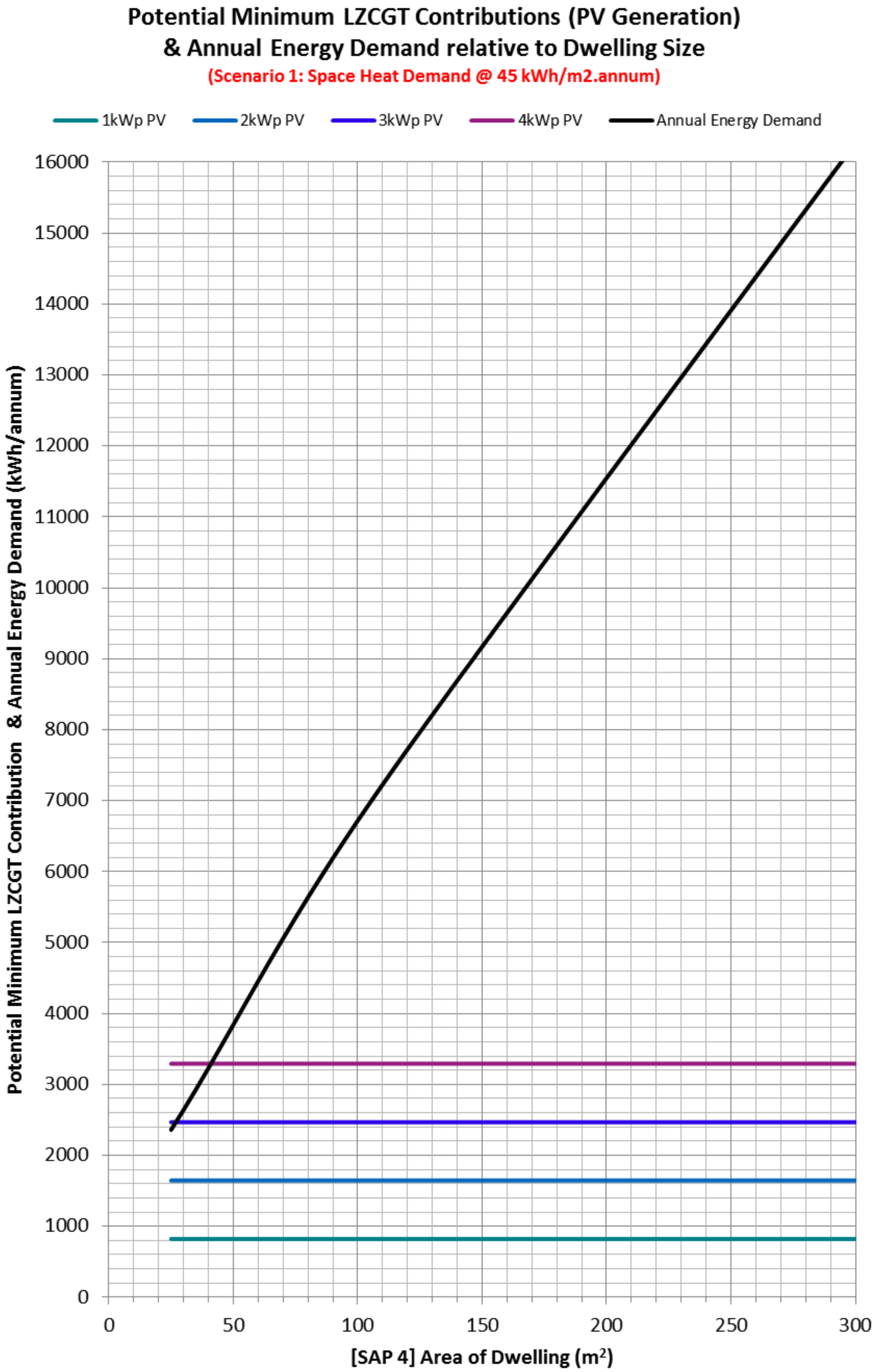


Figure S1.4: Potential Minimum LZCGT Contribution (PV Generation) and AED relative to dwelling size

SCENARIO 1: PAST (2012)

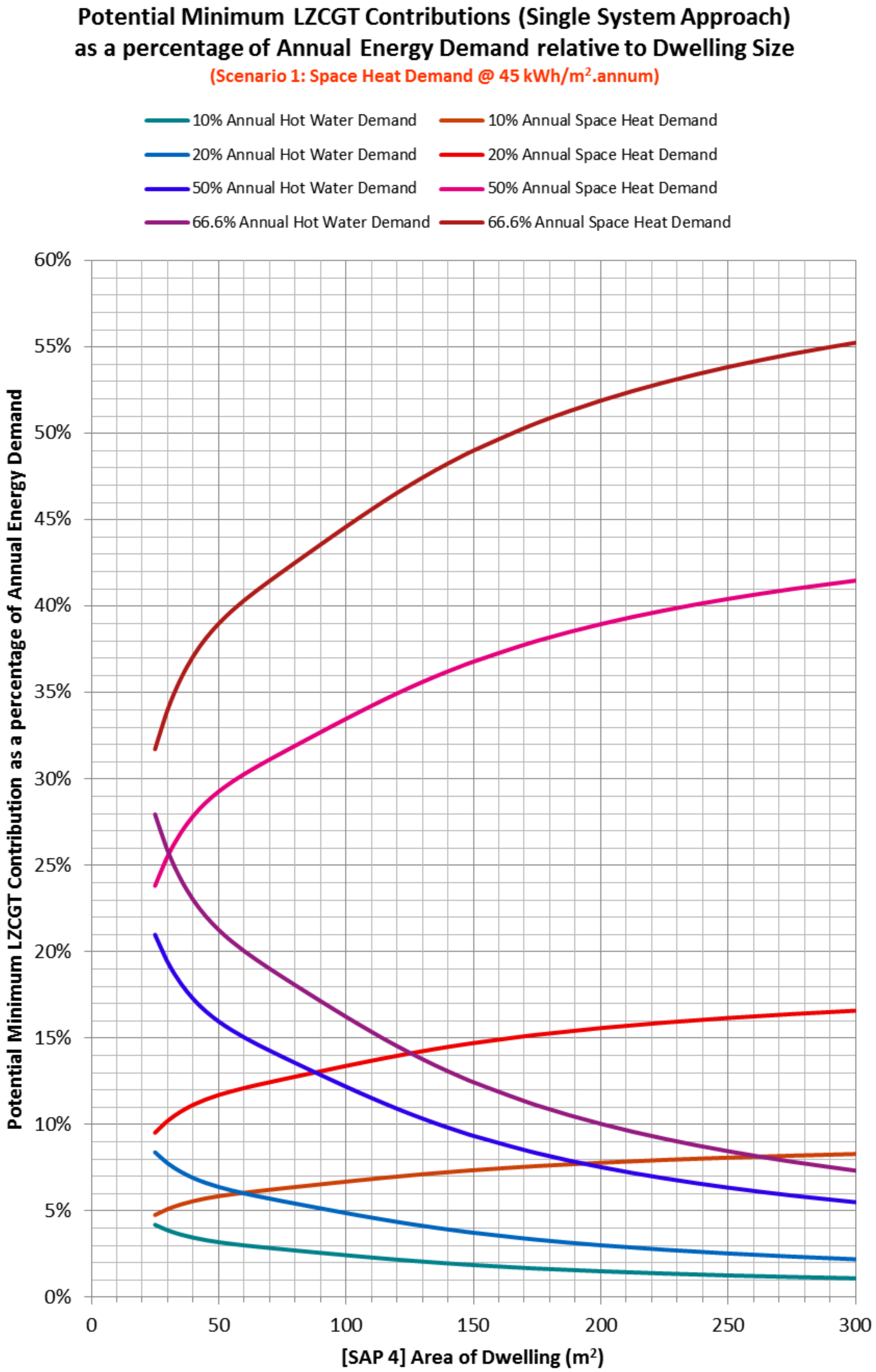


Figure S1.5: Potential Minimum LZCGT Contributions (Single System Approach) as a % of AED relative to dwelling size

SCENARIO 1: PAST (2012)

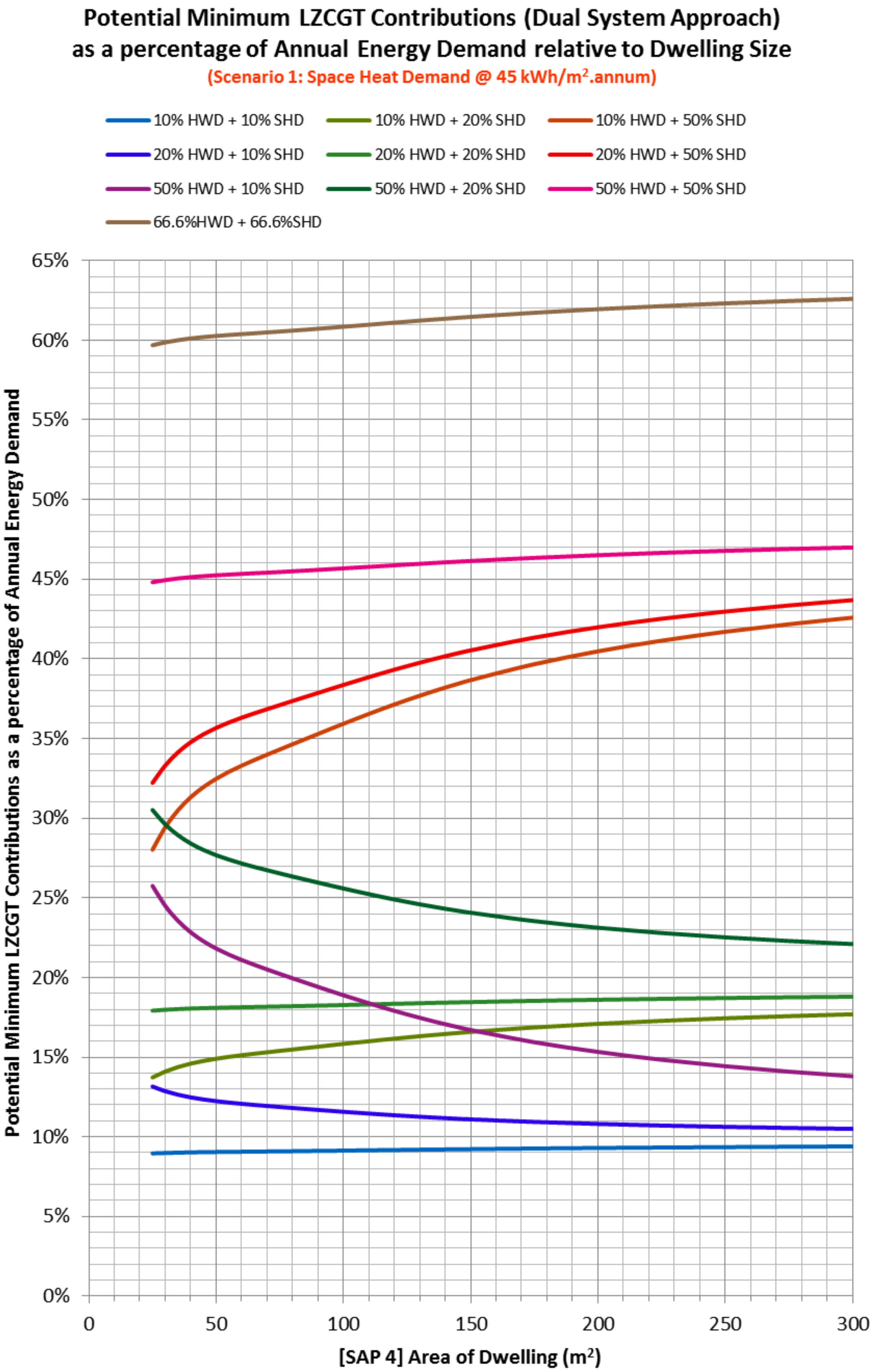


Figure S1.6: Potential Minimum LZCGT Contribution (Dual System Approach) as a % of AED relative to dwelling size.

SCENARIO 1: PAST (2012)

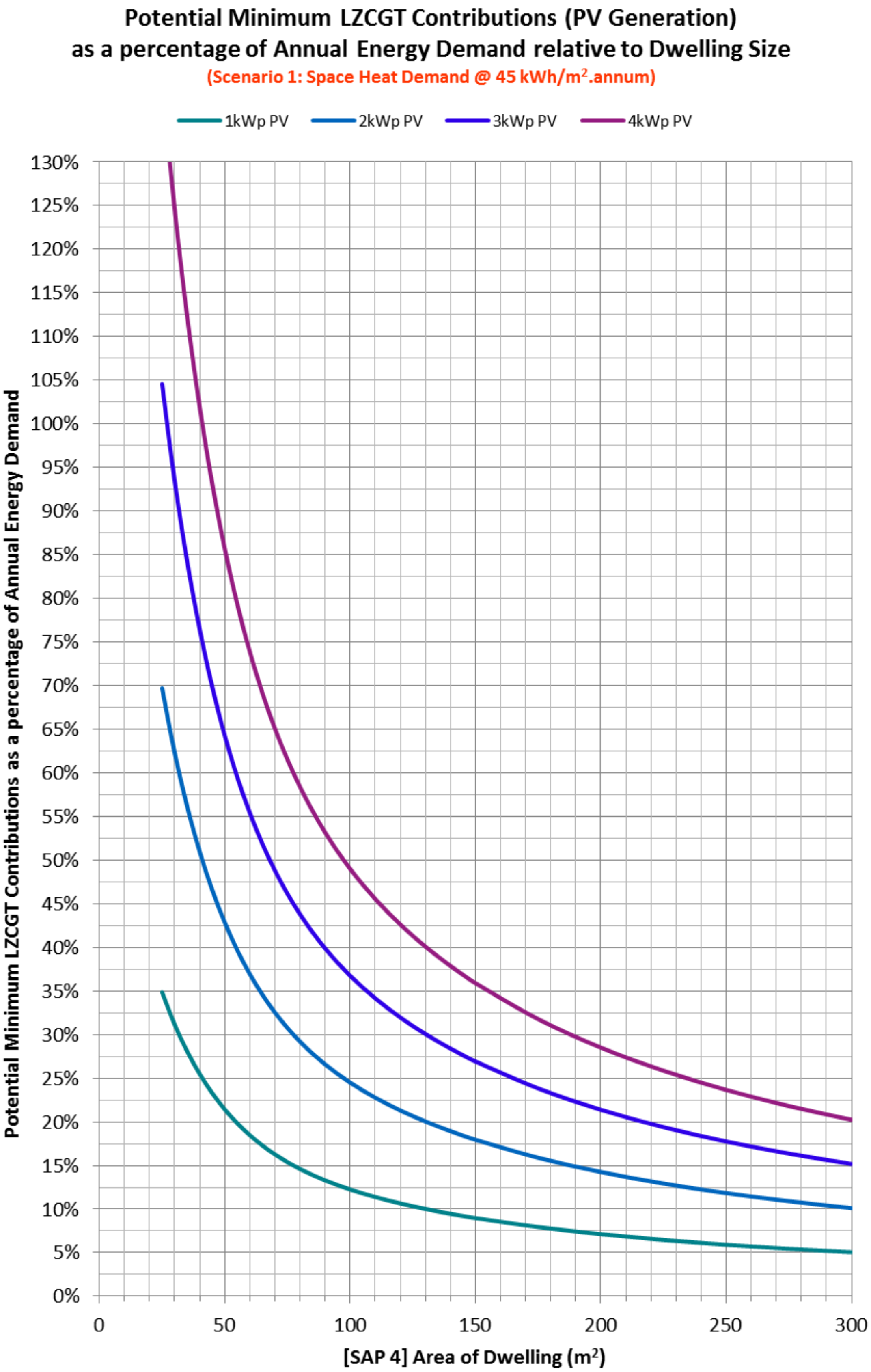


Figure S1.7: Potential Minimum LZCGT Contribution (PV Generation) as a % of AED relative to dwelling size.

SCENARIO 1: PAST (2012)

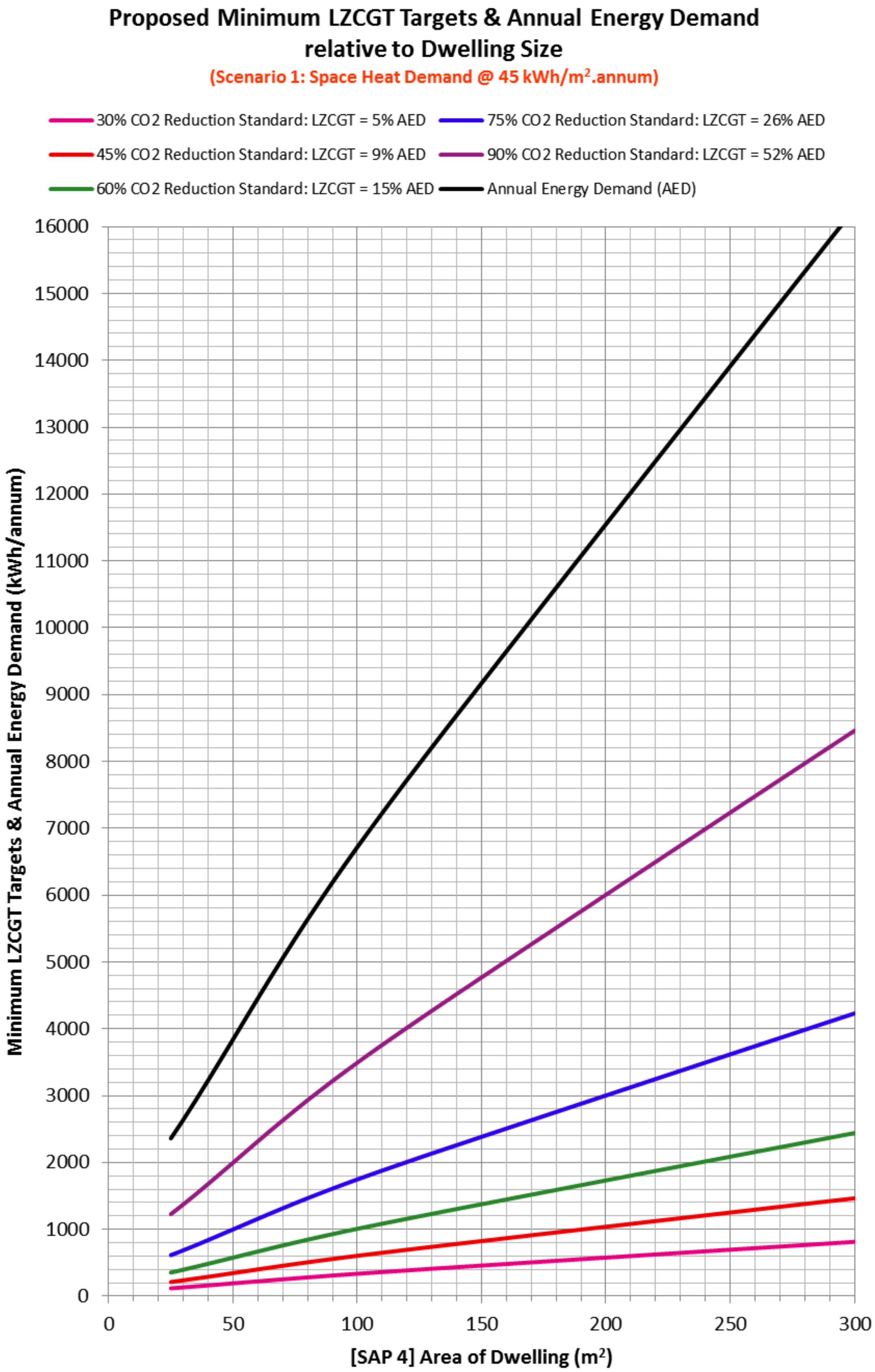


Figure S1.8: Proposed Minimum LZCGT Contribution Targets and Annual Energy Demand relative to dwelling size

Energy Demands	SHD		HWD		LD		P&F		AED	Electric Generation (PV) 1kWp	2kWp	3kWp	4kWp
Total Floor Area	kWh	%AED	kWh	%AED	kWh	%AED	kWh	%AED	kWh	%AED	%AED	%AED	%AED
45 m²	2025	57%	1170	33%	265	7%	75	2%	3534	23.3%	46.6%	69.9%	93.1%
50 m²	2250	59%	1227	32%	290	8%	75	2%	3842	21.4%	42.8%	64.3%	85.7%
55 m²	2475	60%	1285	31%	316	8%	75	2%	4150	19.8%	39.7%	59.5%	79.3%
60 m²	2700	61%	1341	30%	341	8%	75	2%	4457	18.5%	36.9%	55.4%	73.9%
65 m²	2925	61%	1395	29%	365	8%	75	2%	4760	17.3%	34.6%	51.9%	69.2%
70 m²	3150	62%	1445	29%	389	8%	75	1%	5059	16.3%	32.5%	48.8%	65.1%
75 m²	3375	63%	1490	28%	411	8%	75	1%	5351	15.4%	30.8%	46.1%	61.5%
80 m²	3600	64%	1530	27%	432	8%	75	1%	5637	14.6%	29.2%	43.8%	58.4%
85 m²	3825	65%	1564	26%	452	8%	75	1%	5917	13.9%	27.8%	41.7%	55.6%
90 m²	4050	65%	1594	26%	471	8%	75	1%	6190	13.3%	26.6%	39.9%	53.2%
95 m²	4275	66%	1618	25%	489	8%	75	1%	6457	12.7%	25.5%	38.2%	51.0%
100 m²	4500	67%	1638	24%	505	8%	75	1%	6719	12.2%	24.5%	36.7%	49.0%

LZCGT Contribution	Single System Approach								Dual System Approach									
HWD	10%	20%	50%	66.6%					10%	10%	10%	20%	20%	20%	50%	50%	50%	66.6%
SHD					10%	20%	50%	66.6%	10%	20%	50%	10%	20%	50%	10%	20%	50%	66.6%
Total Floor Area	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED
45 m²	3.3%	6.6%	16.5%	22.0%	5.7%	11.5%	28.6%	38.2%	9.0%	14.8%	32.0%	12.3%	18.1%	35.3%	22.3%	28.0%	45.2%	60.2%
50 m²	3.2%	6.4%	16.0%	21.3%	5.9%	11.7%	29.3%	39.0%	9.0%	14.9%	32.5%	12.2%	18.1%	35.7%	21.8%	27.7%	45.2%	60.3%
55 m²	3.1%	6.2%	15.5%	20.6%	6.0%	11.9%	29.8%	39.7%	9.1%	15.0%	32.9%	12.2%	18.1%	36.0%	21.4%	27.4%	45.3%	60.3%
60 m²	3.0%	6.0%	15.0%	20.0%	6.1%	12.1%	30.3%	40.3%	9.1%	15.1%	33.3%	12.1%	18.1%	36.3%	21.1%	27.2%	45.3%	60.4%
65 m²	2.9%	5.9%	14.7%	19.5%	6.1%	12.3%	30.7%	40.9%	9.1%	15.2%	33.7%	12.0%	18.2%	36.6%	20.8%	26.9%	45.4%	60.4%
70 m²	2.9%	5.7%	14.3%	19.0%	6.2%	12.5%	31.1%	41.5%	9.1%	15.3%	34.0%	11.9%	18.2%	36.8%	20.5%	26.7%	45.4%	60.5%
75 m²	2.8%	5.6%	13.9%	18.5%	6.3%	12.6%	31.5%	42.0%	9.1%	15.4%	34.3%	11.9%	18.2%	37.1%	20.2%	26.5%	45.5%	60.5%
80 m²	2.7%	5.4%	13.6%	18.1%	6.4%	12.8%	31.9%	42.5%	9.1%	15.5%	34.6%	11.8%	18.2%	37.4%	20.0%	26.3%	45.5%	60.6%
85 m²	2.6%	5.3%	13.2%	17.6%	6.5%	12.9%	32.3%	43.1%	9.1%	15.6%	35.0%	11.8%	18.2%	37.6%	19.7%	26.1%	45.5%	60.7%
90 m²	2.6%	5.1%	12.9%	17.1%	6.5%	13.1%	32.7%	43.6%	9.1%	15.7%	35.3%	11.7%	18.2%	37.9%	19.4%	26.0%	45.6%	60.7%
95 m²	2.5%	5.0%	12.5%	16.7%	6.6%	13.2%	33.1%	44.1%	9.1%	15.7%	35.6%	11.6%	18.3%	38.1%	19.2%	25.8%	45.6%	60.8%
100 m²	2.4%	4.9%	12.2%	16.2%	6.7%	13.4%	33.5%	44.6%	9.1%	15.8%	35.9%	11.6%	18.3%	38.4%	18.9%	25.6%	45.7%	60.8%

SCENARIO 1: PAST (Space Heat Demand = 45 kWh/m^2.annum)

Table S1.1: Annual Energy Demand by use and total & potential LZCGT Targets as a percentage of AED relative to critically dwelling sizes for affordable housing (45-100 m^2)

SCENARIO 2: PRESENT/NEAR FUTURE (2020-2021)

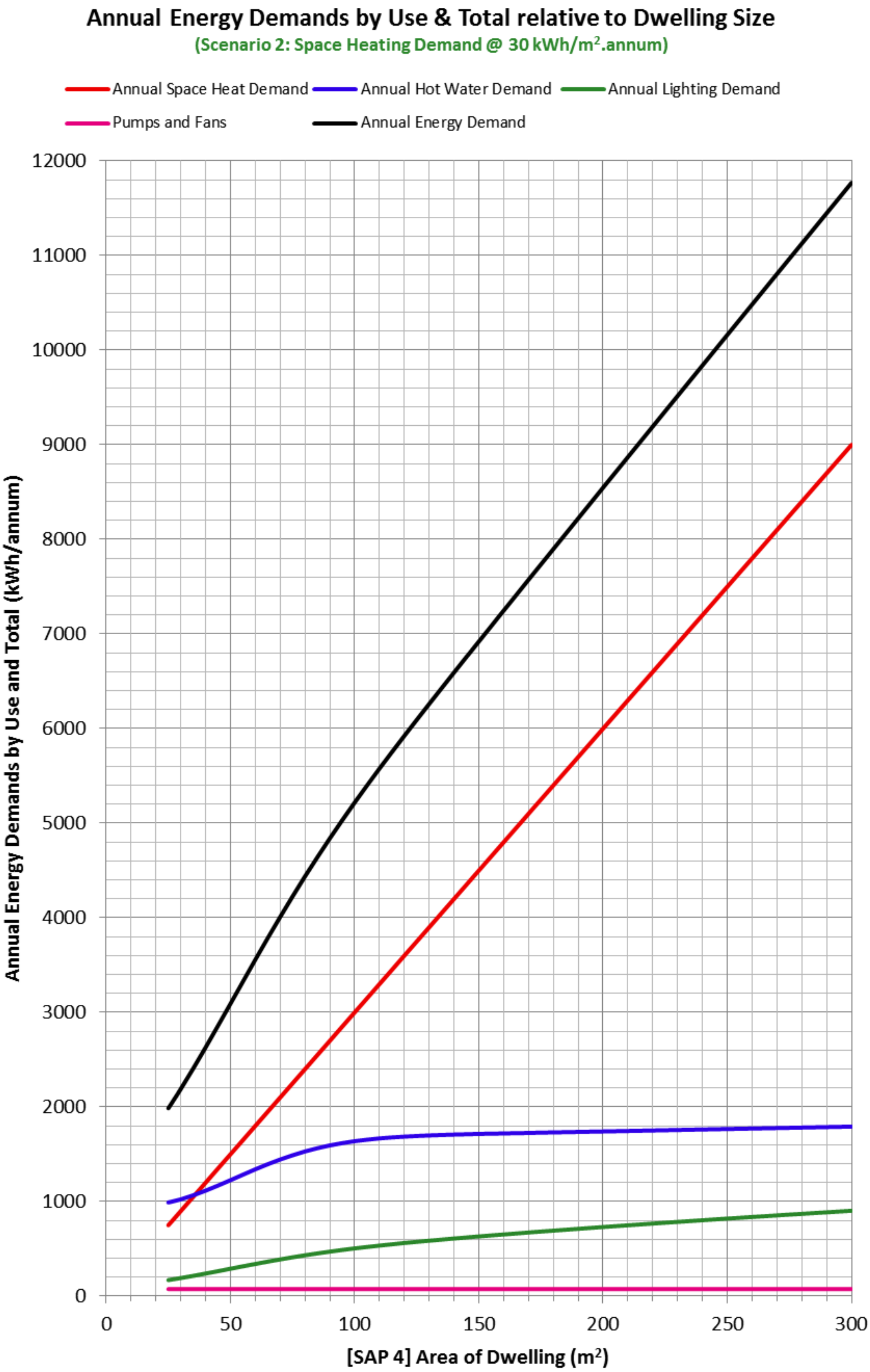


Figure S2.1: Annual Energy Demands by use and total relative to dwelling size.

SCENARIO 2: PRESENT/NEAR FUTURE (2020-2021)

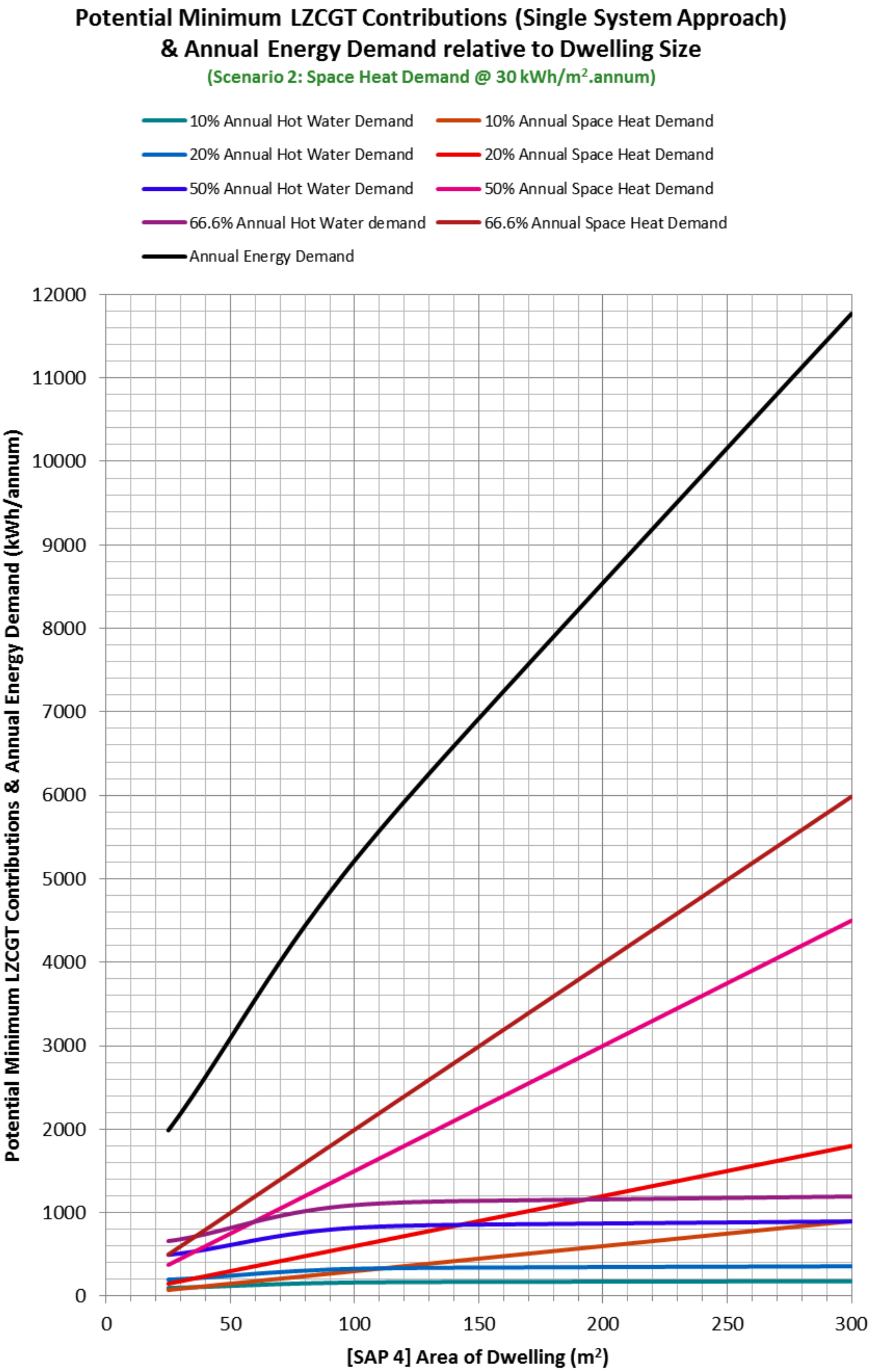


Figure S2.2: Potential Minimum LZCGT Contributions (Single System Approach) and AED relative to dwelling size.

SCENARIO 2: PRESENT/NEAR FUTURE (2020-2021)

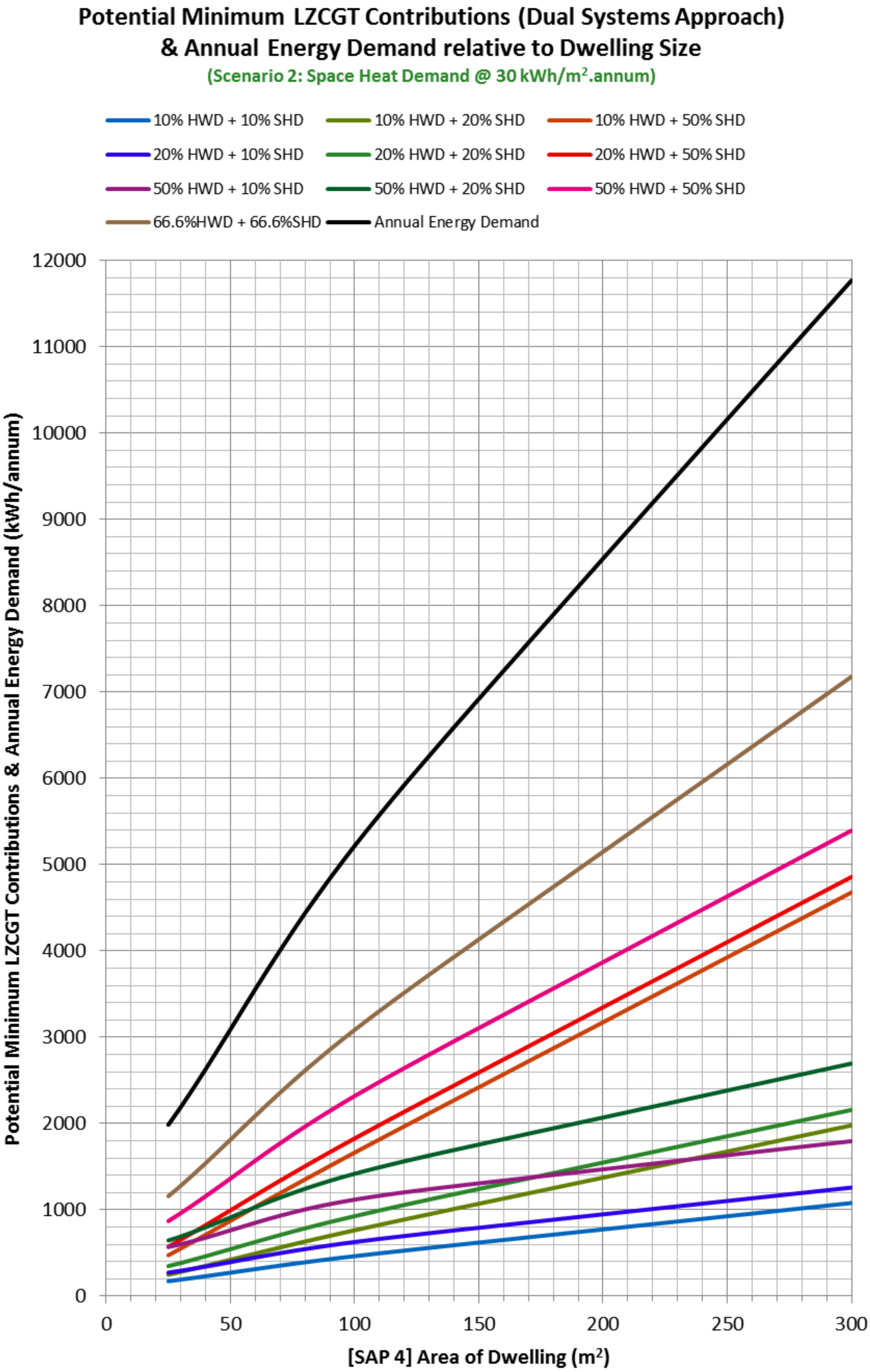


Figure S2.3: Potential Minimum LZCGT Contributions (Dual System Approach) and AED relative to dwelling size.

SCENARIO 2: PRESENT/NEAR FUTURE (2020-2021)

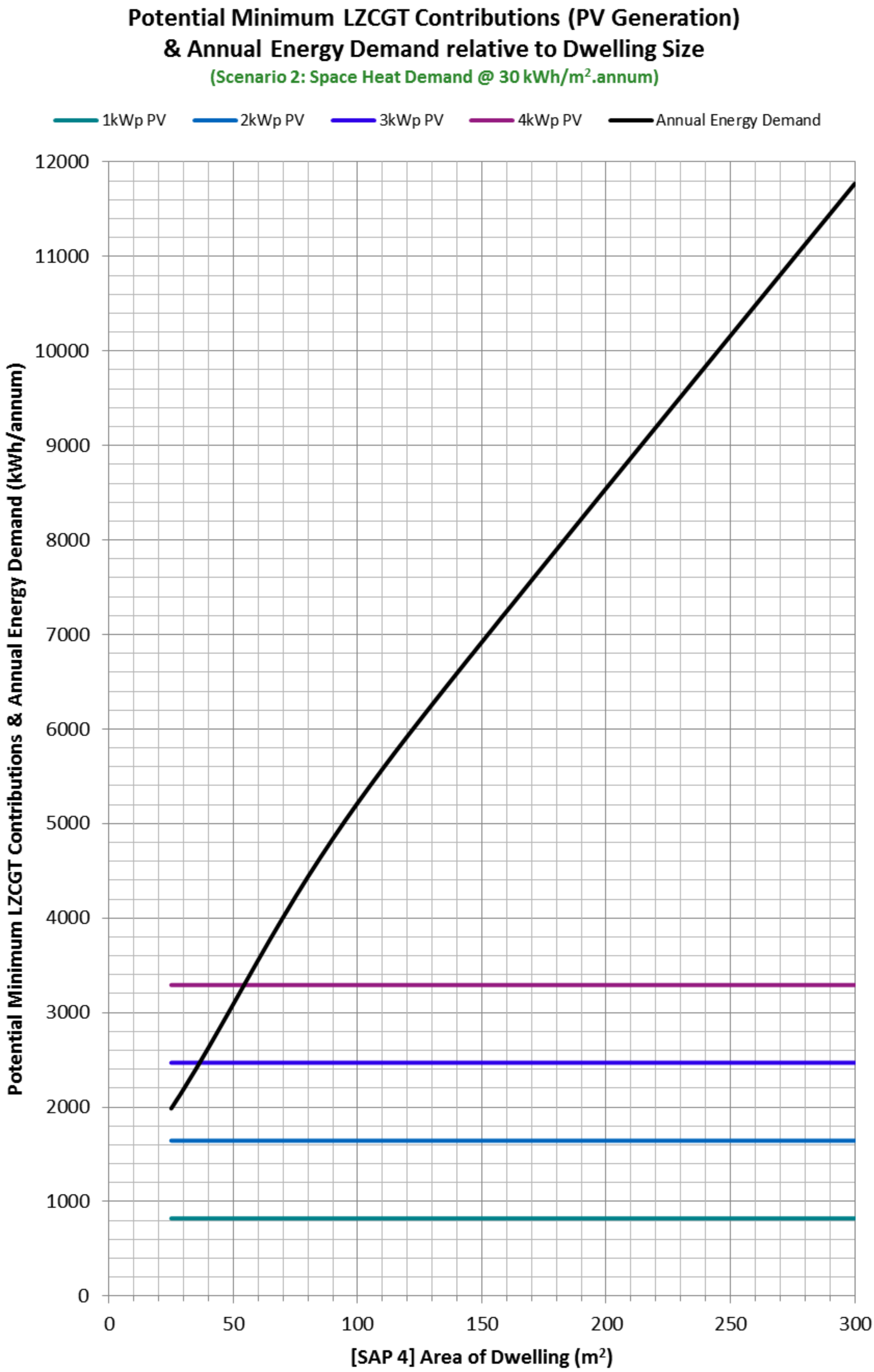


Figure S2.4: Potential Minimum LZCGT Contribution (PV Generation) and AED relative to dwelling size

SCENARIO 2: PRESENT/NEAR FUTURE (2020-2021)

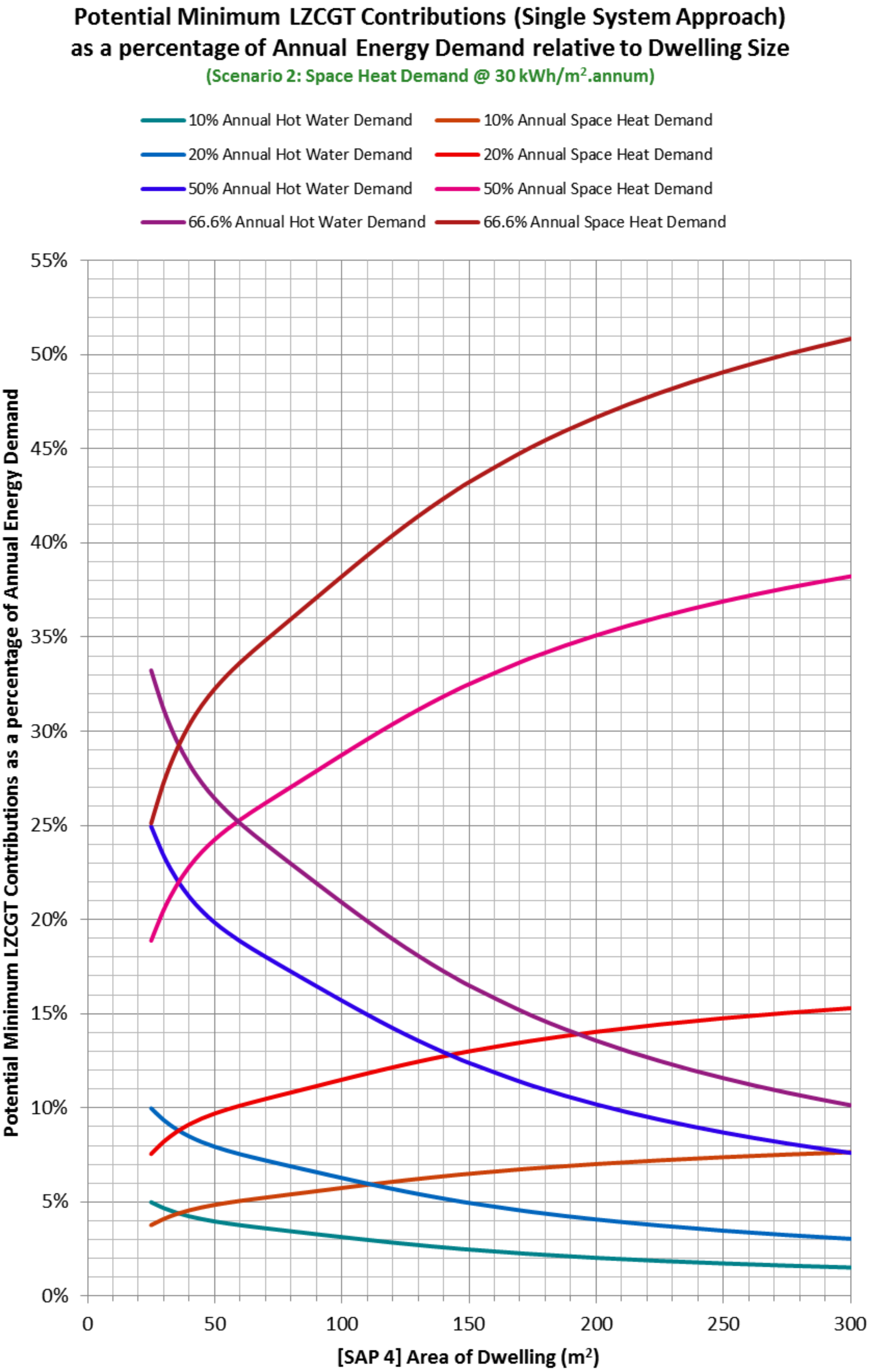


Figure S2.5: Potential Minimum LZCGT Contributions (Single System Approach) as a % of AED relative to dwelling size.

SCENARIO 2: PRESENT/NEAR FUTURE (2020-2021)

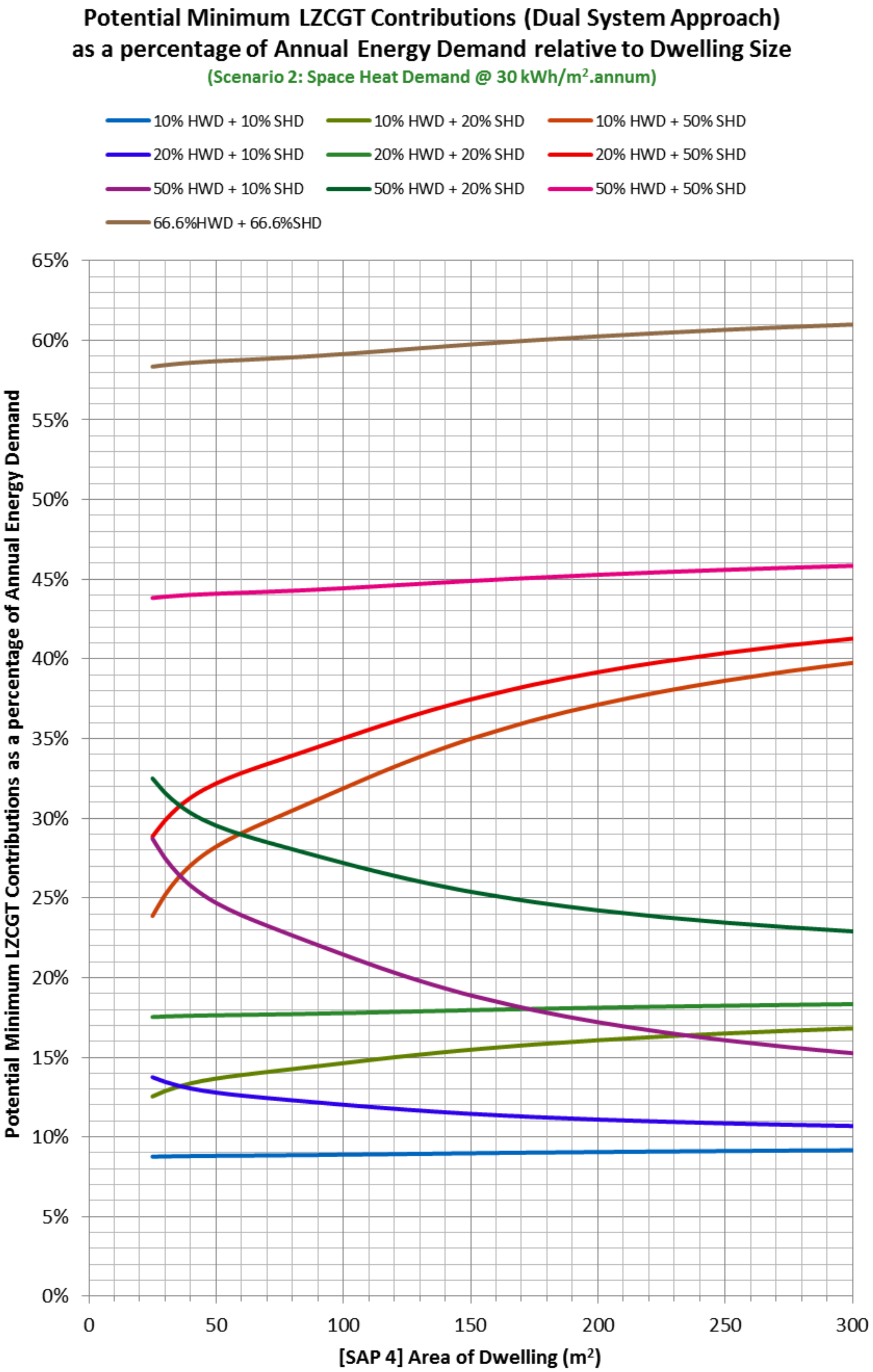


Figure S2.6: Potential Minimum LZCGT Contributions (Dual System Approach) as a % of AED relative to dwelling size.

SCENARIO 2: PRESENT/NEAR FUTURE (2020-2021)

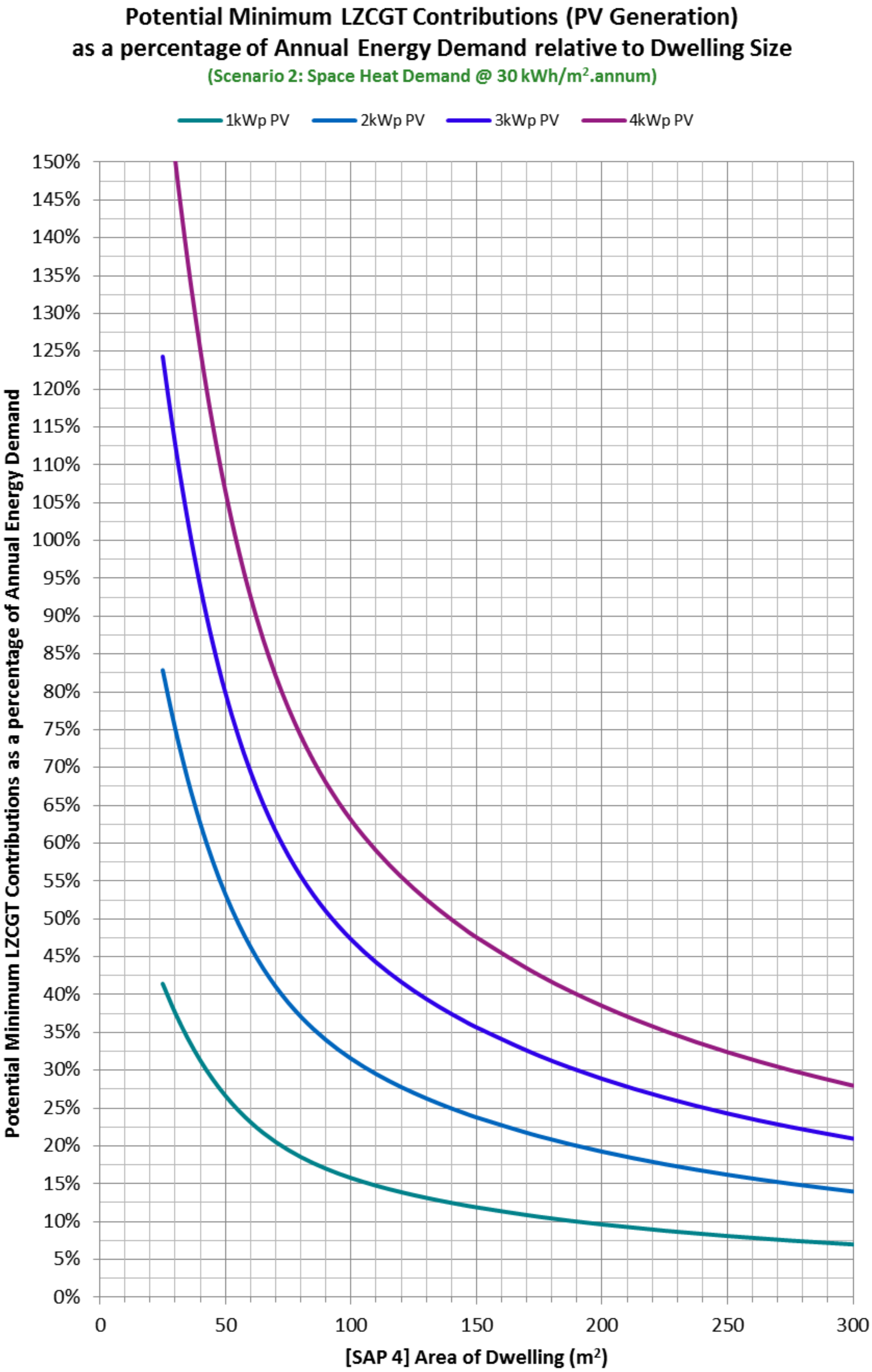


Figure S2.7: Potential Minimum LZCGT Contribution (PV Generation) as a % of AED relative to dwelling size.

SCENARIO 2: PRESENT/NEAR FUTURE (2020-2021)

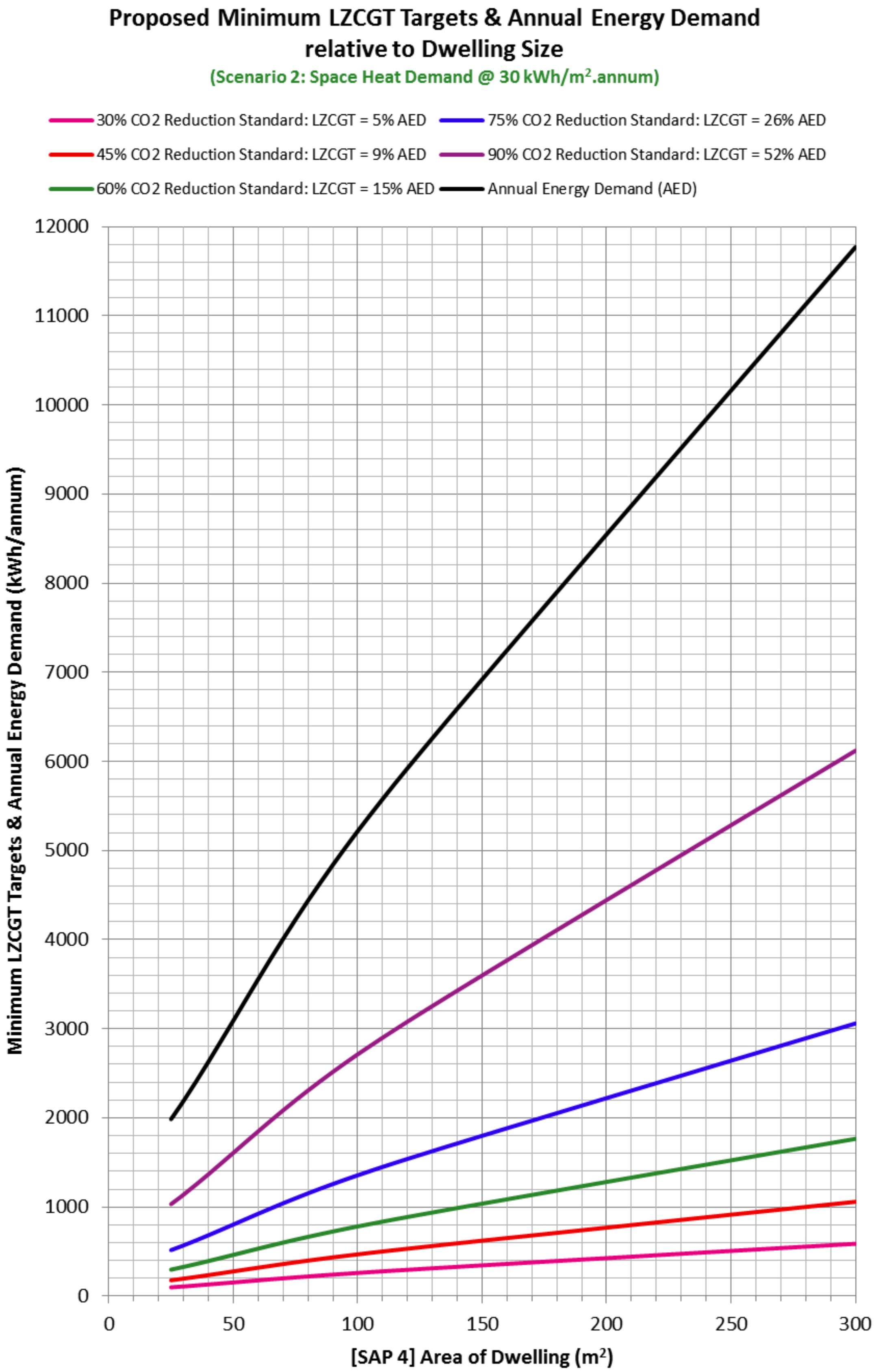


Figure S2.8: Proposed Minimum LZCGT Targets and Annual Energy Demand relative to dwelling size

Energy Demands	SHD		HWD		LD		P&F		AED	Electric Generation (PV)	1kWp	2kWp	3kWp	4kWp
Total Floor Area	kWh	%AED	kWh	%AED	kWh	%AED	kWh	%AED	kWh		%AED	%AED	%AED	%AED
45 m²	1350	47%	1170	41%	265	9%	75	3%	2859		28.8%	57.6%	86.3%	115%
50 m²	1500	49%	1227	40%	290	9%	75	2%	3092		26.6%	53.2%	79.9%	106%
55 m²	1650	50%	1285	39%	316	9%	75	2%	3325		24.8%	49.5%	74.3%	99.0%
60 m²	1800	51%	1341	38%	341	10%	75	2%	3557		23.1%	46.3%	69.4%	92.6%
65 m²	1950	52%	1395	37%	365	10%	75	2%	3785		21.7%	43.5%	65.2%	87.0%
70 m²	2100	52%	1445	36%	389	10%	75	2%	4009		20.5%	41.1%	61.6%	82.1%
75 m²	2250	53%	1490	35%	411	10%	75	2%	4226		19.5%	38.9%	58.4%	77.9%
80 m²	2400	54%	1530	34%	432	10%	75	2%	4437		18.5%	37.1%	55.6%	74.2%
85 m²	2550	55%	1564	34%	452	10%	75	2%	4642		17.7%	35.5%	53.2%	70.9%
90 m²	2700	56%	1594	33%	471	10%	75	2%	4840		17.0%	34.0%	51.0%	68.0%
95 m²	2850	57%	1618	32%	489	10%	75	1%	5032		16.4%	32.7%	49.1%	65.4%
100 m²	3000	57%	1638	31%	505	10%	75	1%	5219		15.8%	31.5%	47.3%	63.1%

LZCGT Contribution	Single System Approach								Dual System Approach									
HWD	10%	20%	50%	66.6%					10%	10%	10%	20%	20%	20%	50%	50%	50%	66.6%
SHD					10%	20%	50%	66.6%	10%	20%	50%	10%	20%	50%	10%	20%	50%	66.6%
Total Floor Area	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED
45 m²	4.1%	8.2%	20.5%	27.2%	4.7%	9.4%	23.6%	31.4%	8.8%	13.5%	27.7%	12.9%	17.6%	31.8%	25.2%	29.9%	44.1%	58.6%
50 m²	4.0%	7.9%	19.8%	26.4%	4.9%	9.7%	24.3%	32.3%	8.8%	13.7%	28.2%	12.8%	17.6%	32.2%	24.7%	29.5%	44.1%	58.7%
55 m²	3.9%	7.7%	19.3%	25.7%	5.0%	9.9%	24.8%	33.0%	8.8%	13.8%	28.7%	12.7%	17.7%	32.5%	24.3%	29.2%	44.1%	58.7%
60 m²	3.8%	7.5%	18.9%	25.1%	5.1%	10.1%	25.3%	33.7%	8.8%	13.9%	29.1%	12.6%	17.7%	32.8%	23.9%	29.0%	44.2%	58.8%
65 m²	3.7%	7.4%	18.4%	24.5%	5.2%	10.3%	25.8%	34.3%	8.8%	14.0%	29.4%	12.5%	17.7%	33.1%	23.6%	28.7%	44.2%	58.8%
70 m²	3.6%	7.2%	18.0%	24.0%	5.2%	10.5%	26.2%	34.8%	8.8%	14.1%	29.8%	12.4%	17.7%	33.4%	23.3%	28.5%	44.2%	58.8%
75 m²	3.5%	7.1%	17.6%	23.5%	5.3%	10.6%	26.6%	35.4%	8.8%	14.2%	30.1%	12.4%	17.7%	33.7%	23.0%	28.3%	44.2%	58.9%
80 m²	3.4%	6.9%	17.2%	23.0%	5.4%	10.8%	27.0%	36.0%	8.9%	14.3%	30.5%	12.3%	17.7%	33.9%	22.6%	28.1%	44.3%	58.9%
85 m²	3.4%	6.7%	16.9%	22.4%	5.5%	11.0%	27.5%	36.5%	8.9%	14.4%	30.8%	12.2%	17.7%	34.2%	22.3%	27.8%	44.3%	59.0%
90 m²	3.3%	6.6%	16.5%	21.9%	5.6%	11.2%	27.9%	37.1%	8.9%	14.5%	31.2%	12.2%	17.7%	34.5%	22.0%	27.6%	44.4%	59.0%
95 m²	3.2%	6.4%	16.1%	21.4%	5.7%	11.3%	28.3%	37.7%	8.9%	14.5%	31.5%	12.1%	17.8%	34.8%	21.7%	27.4%	44.4%	59.1%
100 m²	3.1%	6.3%	15.7%	20.9%	5.7%	11.5%	28.7%	38.2%	8.9%	14.6%	31.9%	12.0%	17.8%	35.0%	21.4%	27.2%	44.4%	59.1%

SCENARIO 2: PRESENT/NEAR FUTURE (SHD = 30kWh/m^2.annum)

Table S2.1: Annual Energy Demands by use and total & potential LZCGT Targets as a percentage of AED relative to critically dwelling sizes for affordable housing (45-100 m^2)

SCENARIO 3: FUTURE (2024-2050)

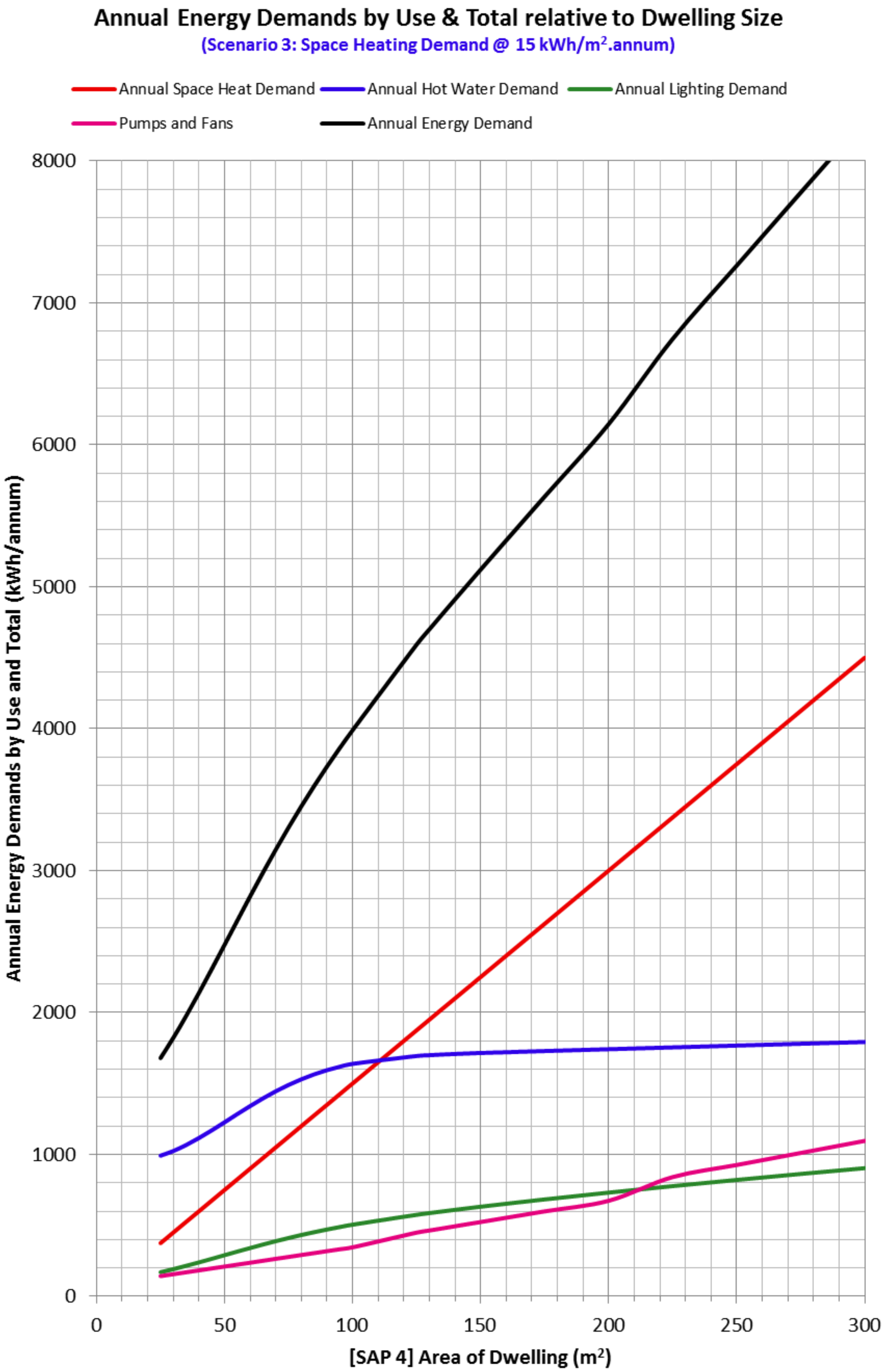


Figure S3.1: Annual Energy Demands by use and total relative to dwelling size.

SCENARIO 3: FUTURE (2024-2050)

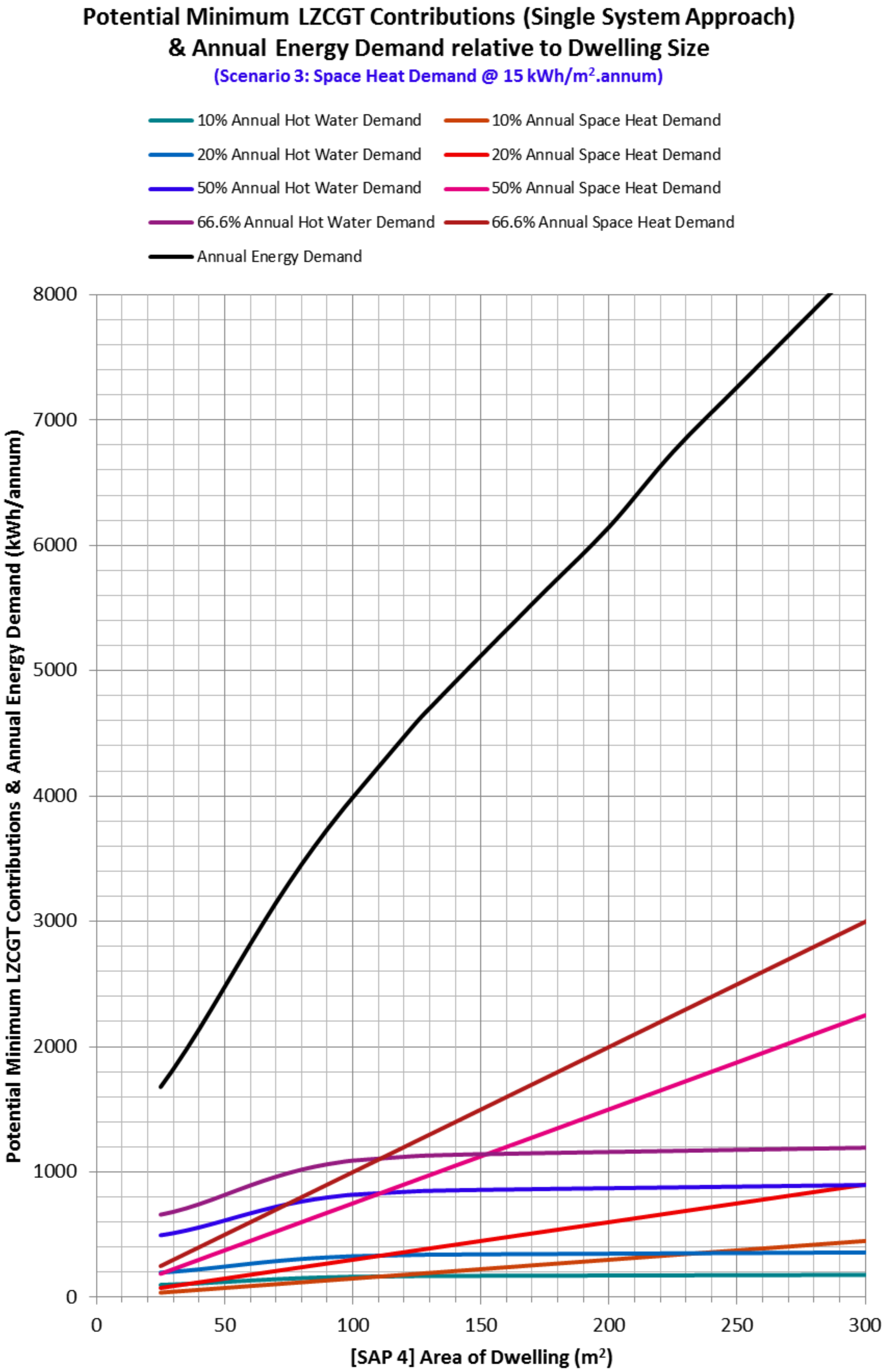


Figure S3.2: Potential Minimum LZCGT Contributions (Single System Approach) and AED relative to dwelling size.

SCENARIO 3: FUTURE (2024-2050)

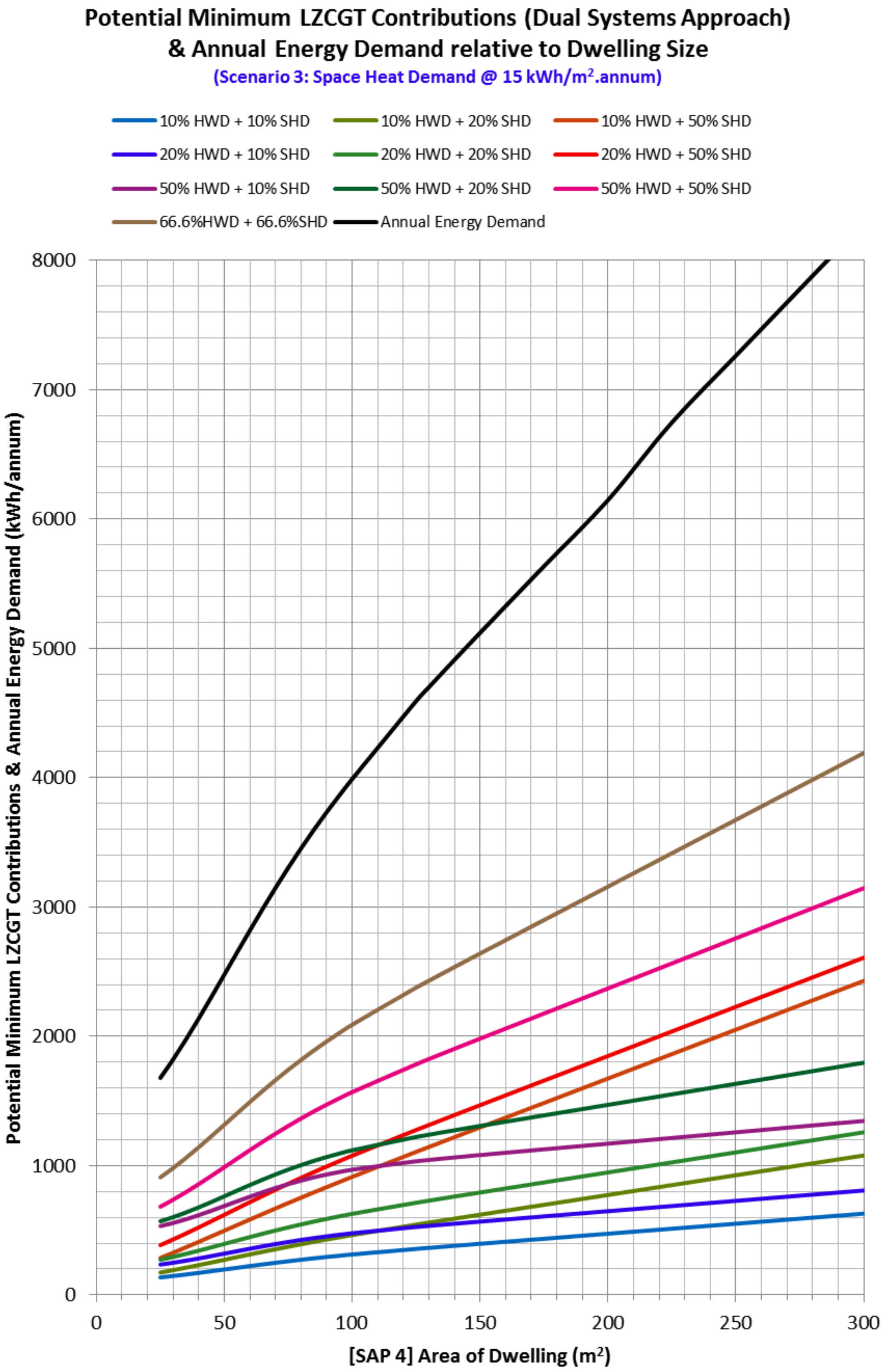


Figure S3.3: Potential Minimum LZCGT Contributions (Dual System Approach) and AED relative to dwelling size.

SCENARIO 3: FUTURE (2024-2050)

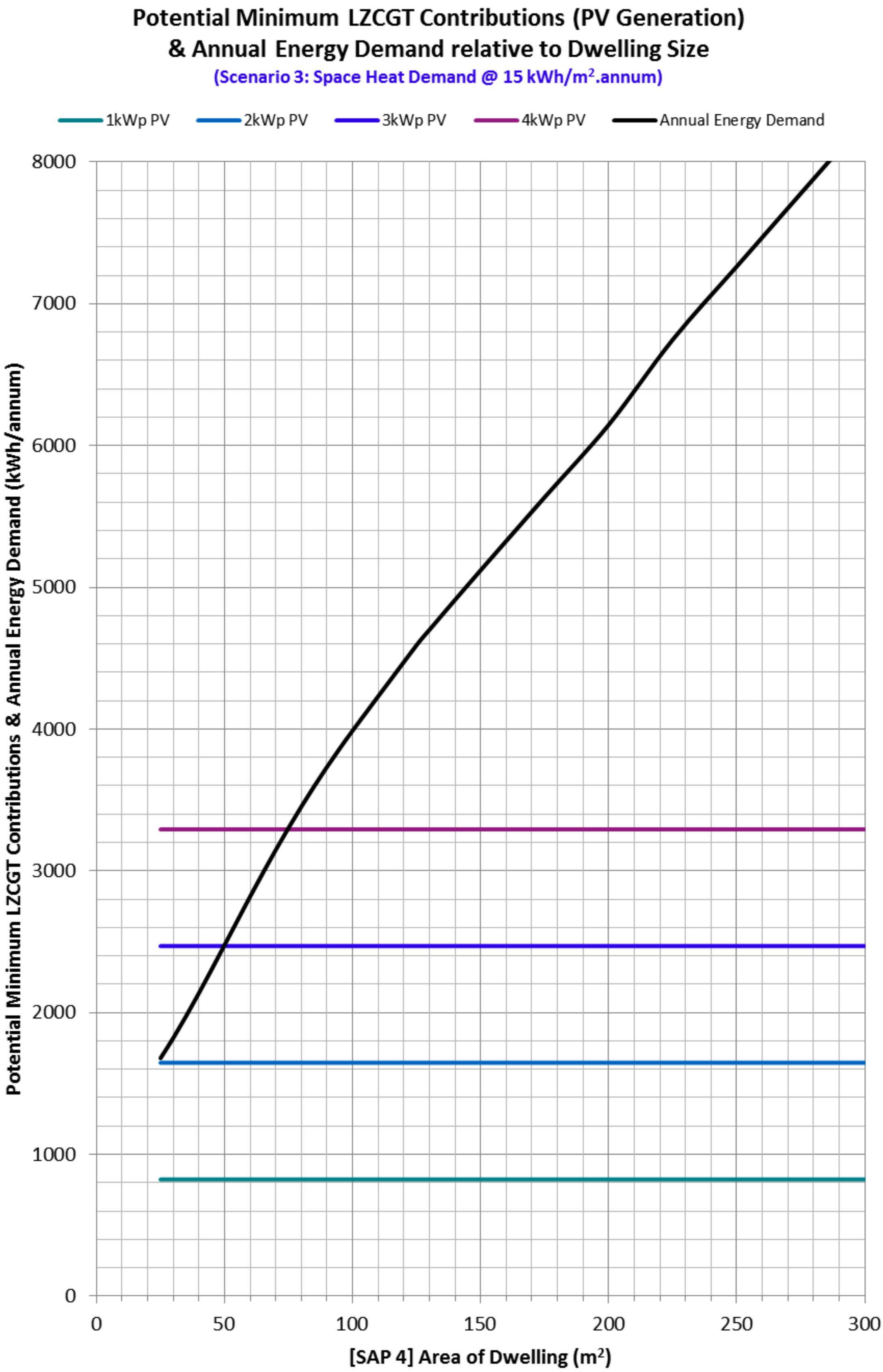


Figure S3.4: Potential Minimum LZCGT Contribution (PV Generation) and AED relative to dwelling size

SCENARIO 3: FUTURE (2024-2050)

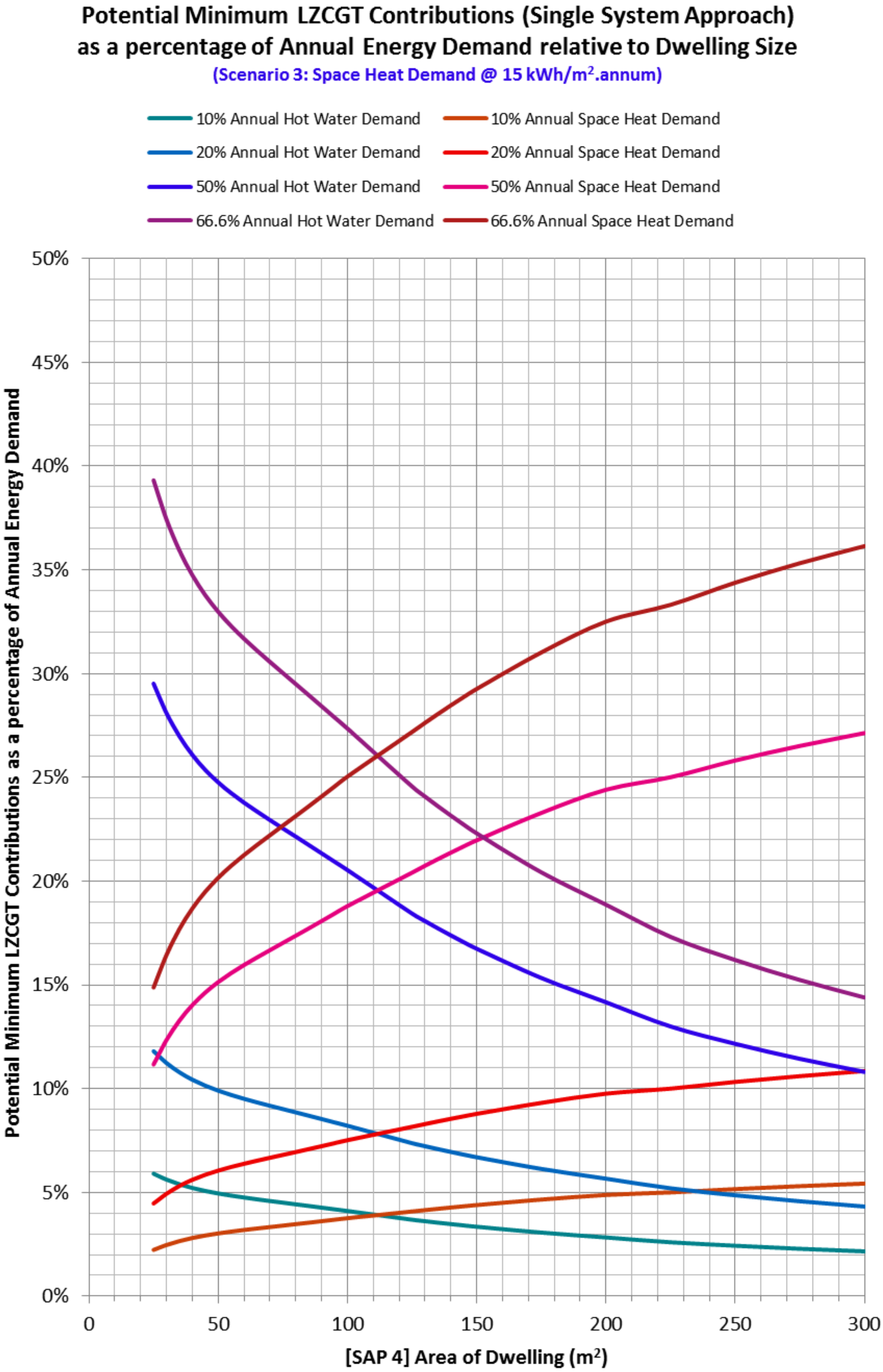


Figure S3.5: Potential Minimum LZCGT Contributions (Single System Approach) as a % of AED relative to dwelling size.

SCENARIO 3: FUTURE (2024-2050)

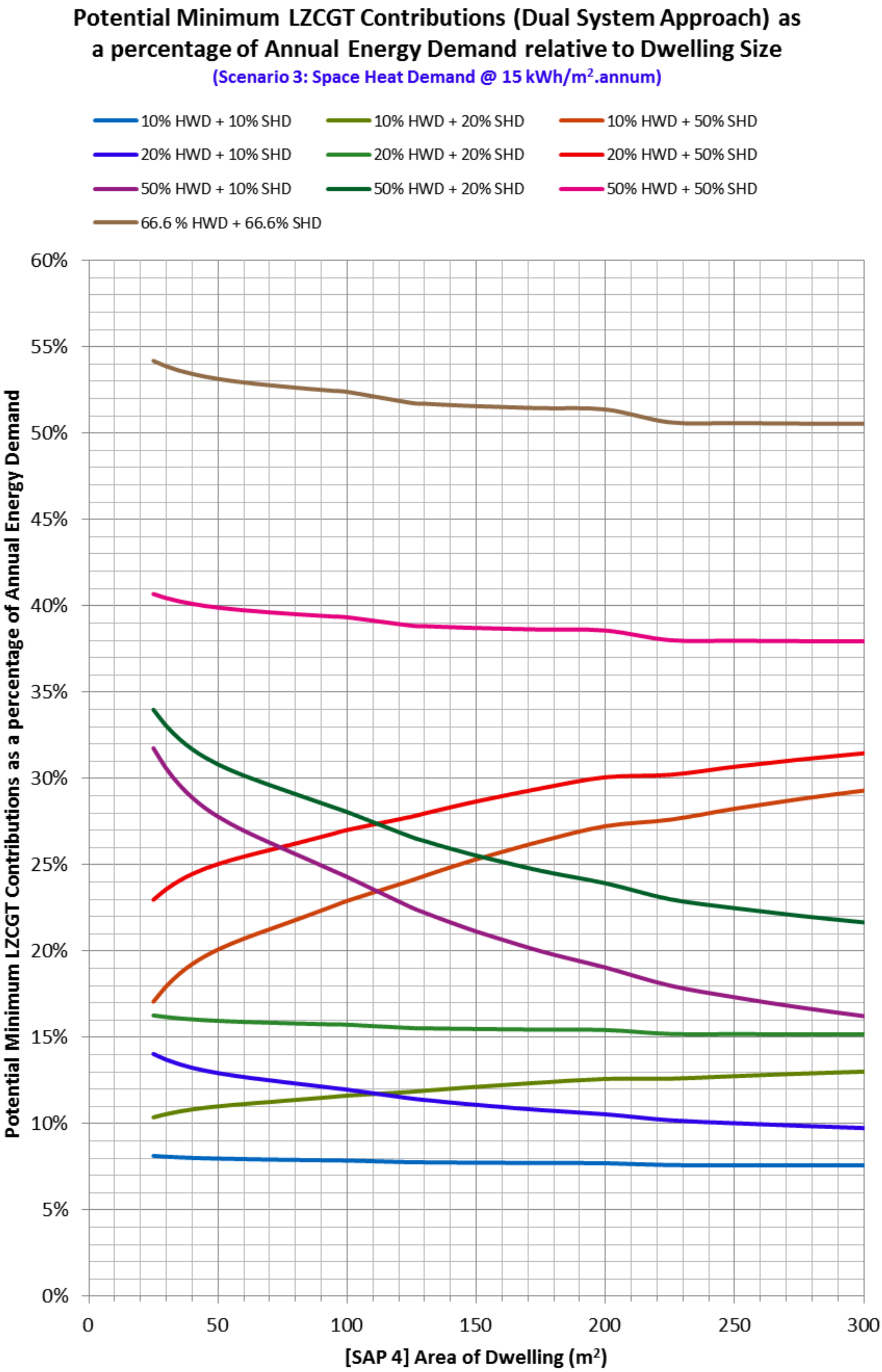


Figure S3.6: Potential Minimum LZCGT Contributions (Dual System Approach) as a % of AED relative to dwelling size.

SCENARIO 3: FUTURE (2024-2050)

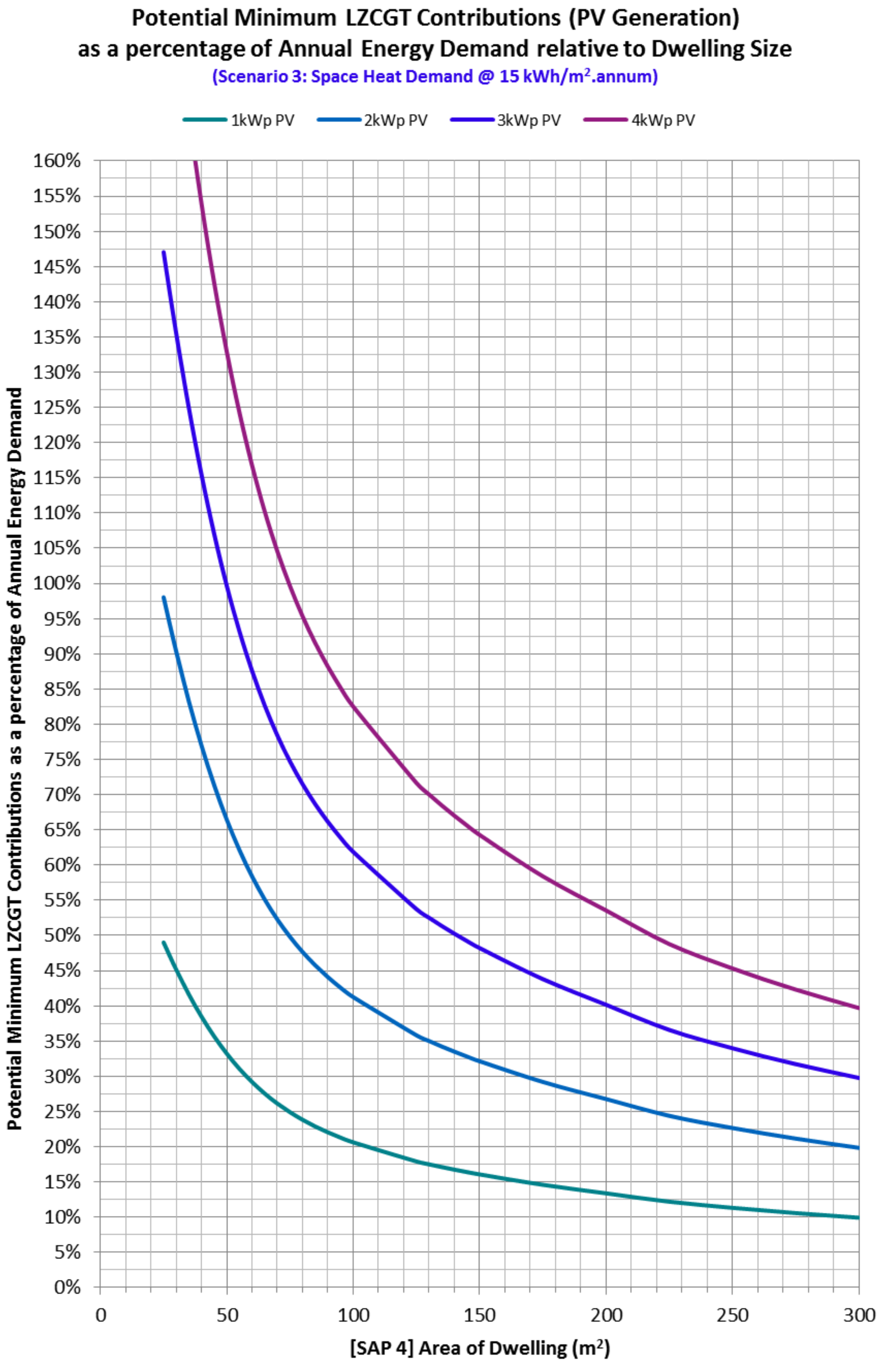


Figure S3.7: Potential Minimum LZCGT Contribution (PV Generation) as a % of AED relative to dwelling size

SCENARIO 3: FUTURE (2024-2050)

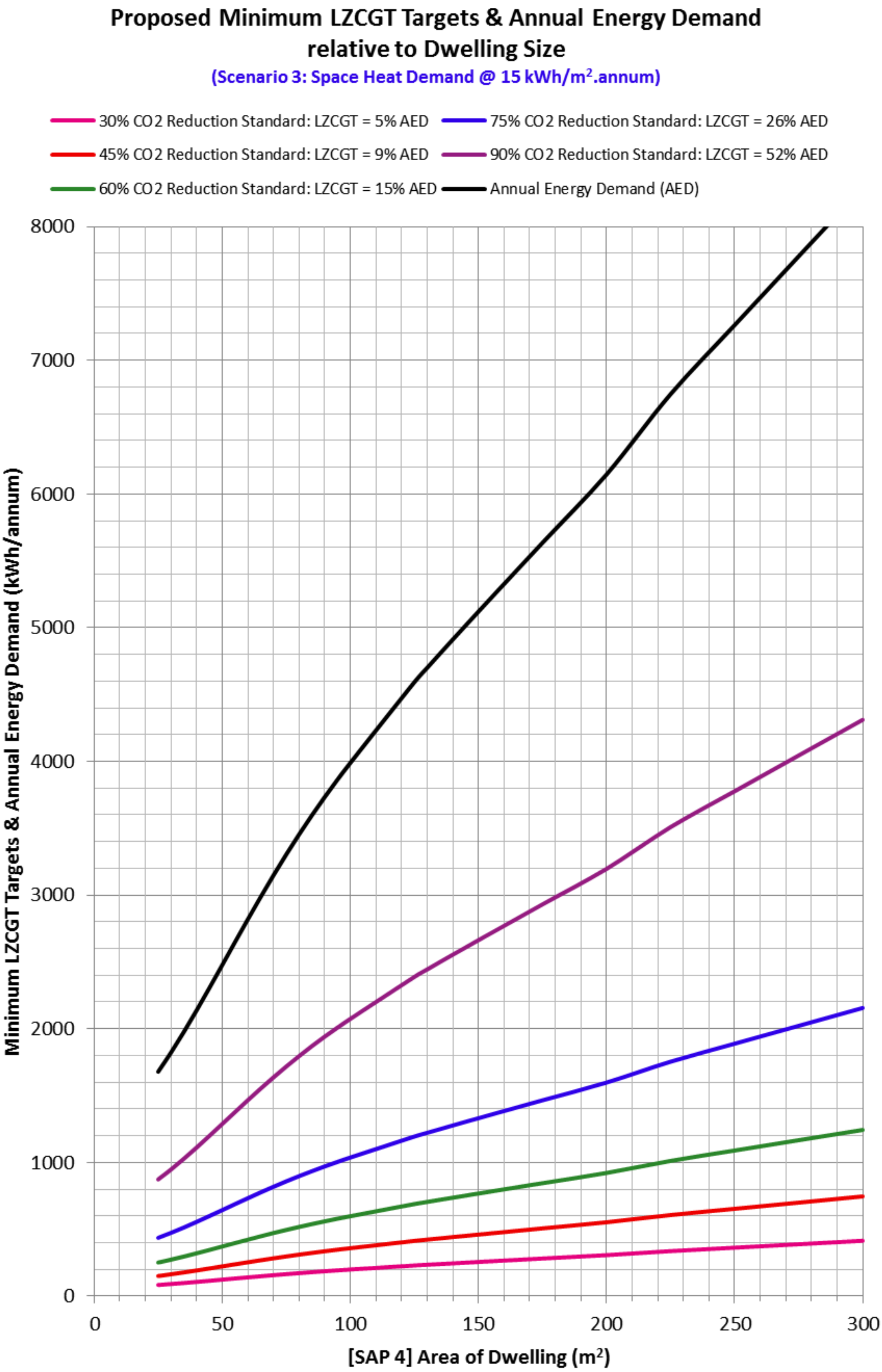


Figure S3.8: Proposed Minimum LZCGT Targets and Annual Energy Demand relative to dwelling size

Energy Demands	SHD		HWD		LD		P&F		AED	Electric Generation (PV)	1kWp	2kWp	3kWp	4kWp
Total Floor Area	kWh	%AED	kWh	%AED	kWh	%AED	kWh	%AED	kWh		%AED	%AED	%AED	%AED
45 m²	675	29%	1170	51%	265	11%	197	9%	2306		35.7%	71.4%	107%	143%
50 m²	750	30%	1227	50%	290	12%	210	8%	2477		33.2%	66.4%	99.7%	133%
55 m²	825	31%	1285	48%	316	12%	224	8%	2649		31.1%	62.1%	93.2%	124%
60 m²	900	32%	1341	48%	341	12%	237	8%	2819		29.2%	58.4%	87.6%	117%
65 m²	975	33%	1395	47%	365	12%	251	8%	2986		27.6%	55.1%	82.7%	110%
70 m²	1050	33%	1445	46%	389	12%	264	8%	3148		26.1%	52.3%	78.4%	105%
75 m²	1125	34%	1490	45%	411	12%	278	8%	3304		24.9%	49.8%	74.7%	99.6%
80 m²	1200	35%	1530	44%	432	13%	291	8%	3454		23.8%	47.7%	71.5%	95.3%
85 m²	1275	35%	1564	43%	452	13%	305	8%	3597		22.9%	45.8%	68.6%	91.5%
90 m²	1350	36%	1594	43%	471	13%	318	9%	3733		22.0%	44.1%	66.1%	88.2%
95 m²	1425	37%	1618	42%	489	13%	332	9%	3864		21.3%	42.6%	63.9%	85.2%
100 m²	1500	38%	1638	41%	505	13%	346	9%	3989		20.6%	41.3%	61.9%	82.5%

LZCGT Contribution	Single System Approach								Dual System Approach									
HWD	10%	20%	50%	66.6%					10%	10%	10%	20%	20%	20%	50%	50%	50%	66.6%
SHD					10%	20%	50%	66.6%	10%	20%	50%	10%	20%	50%	10%	20%	50%	66.6%
Total Floor Area	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED	%AED
45 m²	5.1%	10.1%	25.4%	33.8%	2.9%	5.9%	14.6%	19.5%	8.0%	10.9%	19.7%	13.1%	16.0%	24.8%	28.3%	31.2%	40.0%	53.3%
50 m²	5.0%	9.9%	24.8%	33.0%	3.0%	6.1%	15.1%	20.2%	8.0%	11.0%	20.1%	12.9%	16.0%	25.0%	27.8%	30.8%	39.9%	53.1%
55 m²	4.8%	9.7%	24.2%	32.3%	3.1%	6.2%	15.6%	20.7%	8.0%	11.1%	20.4%	12.8%	15.9%	25.3%	27.4%	30.5%	39.8%	53.0%
60 m²	4.8%	9.5%	23.8%	31.7%	3.2%	6.4%	16.0%	21.3%	7.9%	11.1%	20.7%	12.7%	15.9%	25.5%	27.0%	30.2%	39.7%	52.9%
65 m²	4.7%	9.3%	23.4%	31.1%	3.3%	6.5%	16.3%	21.7%	7.9%	11.2%	21.0%	12.6%	15.9%	25.7%	26.6%	29.9%	39.7%	52.9%
70 m²	4.6%	9.2%	22.9%	30.6%	3.3%	6.7%	16.7%	22.2%	7.9%	11.3%	21.3%	12.5%	15.9%	25.9%	26.3%	29.6%	39.6%	52.8%
75 m²	4.5%	9.0%	22.5%	30.0%	3.4%	6.8%	17.0%	22.7%	7.9%	11.3%	21.5%	12.4%	15.8%	26.0%	26.0%	29.4%	39.6%	52.7%
80 m²	4.4%	8.9%	22.1%	29.5%	3.5%	6.9%	17.4%	23.1%	7.9%	11.4%	21.8%	12.3%	15.8%	26.2%	25.6%	29.1%	39.5%	52.6%
85 m²	4.3%	8.7%	21.7%	29.0%	3.5%	7.1%	17.7%	23.6%	7.9%	11.4%	22.1%	12.2%	15.8%	26.4%	25.3%	28.8%	39.5%	52.6%
90 m²	4.3%	8.5%	21.3%	28.4%	3.6%	7.2%	18.1%	24.1%	7.9%	11.5%	22.3%	12.2%	15.8%	26.6%	25.0%	28.6%	39.4%	52.5%
95 m²	4.2%	8.4%	20.9%	27.9%	3.7%	7.4%	18.4%	24.6%	7.9%	11.6%	22.6%	12.1%	15.8%	26.8%	24.6%	28.3%	39.4%	52.5%
100 m²	4.1%	8.2%	20.5%	27.4%	3.8%	7.5%	18.8%	25.0%	7.9%	11.6%	22.9%	12.0%	15.7%	27.0%	24.3%	28.1%	39.3%	52.4%

SCENARIO 3: FUTURE (SHD = 15kWh/m^2.annum)

Table S3.1: Annual Energy Demands by use and total & potential LZCGT Targets as a percentage of AED relative to critically dwelling sizes for affordable housing (45-100 m^2)

Appendix C: Compliance Calculations

The figures included in Appendix C are screenshots of proposed standardised compliance calculations. For stakeholder familiarity these have been generated in Microsoft Excel.

Proposal 1: Compliance Calculation Spreadsheet

The compliance calculation spreadsheet for Proposal 1 consists of two worksheets. The first is a Data Input sheet where applicants simply record the type of LZCGT employed in the building and input the four values used in the calculation formula: the percentage CO_2 emission reduction sought by Scottish Building Standards for the building type (R%), the target emission rate (TER), the dwelling/building emission rate (DER or BER) and the dwelling/building emission rate calculated without the specified LZCGT (DERNT or BERNT) (Figure C.1). The second is the Compliance Calculation sheet, which simply substitutes the input data into the compliance formula to calculate the contribution LZCGT makes to the CO_2 emission reductions and then delivers a clear statement as to whether the building is in compliance with Section 3F policy (Figure C.2).

DATA INPUT

NOTES:
Please fill in shaded boxes:
All input data to be sourced from the SAP/SBEM Document for the proposed building:
The DERNT/BERNT values should be calculated according to Scottish Government guidelines
Enter all numerical data without units (i.e. enter 45 rather than 45%)

What type of LZCGT are employed in the building?		
What is the percentage CO_2 emission reduction relative to the 2007 standard sought by Scottish Building Standard 6.1 for this building type?		**(R%)**
What is the Target Emission Rate of the building?		**(TER)**
What is the Dwelling/Building Emission Rate of the building?		**(DER or BER)**
What is the Dwelling/Building Emission Rate of the building calculated without the specified LZCGT?		**(DERNT or BERNT)**

Figure C.1: Proposed Data Input Excel Spreadsheet for Proposal 1

COMPLIANCE CALCULATION

The LZCGT contribution to CO_2 emission reduction defined as a percentage of the percentage CO_2 emission reduction sought by Scottish Building Standard 6.1 is given by the formula:

$$\left(\frac{100\,(100 - R\%)}{R\%}\right)\left(\frac{(DERNT - DER)}{TER}\right)$$

The LZCGT Contribution to CO_2 emission reduction is: **0.00%**

The building is NOT COMPLIANT as the LZCGT Contribution < 12%

Figure C.2: Proposed Compliance Calculation Excel Spreadsheet for Proposal 1

Proposal 2: Compliance Calculation Spreadsheet & Worked Examples

The compliance spreadsheet for Proposal 2 is split into two sections; Section 1 is to be completed for dwellings that have individual energy systems and micro-CHP (Figures C.3 and C.4), Section 2 for those with community heating systems (Figures C.5 and C.6). Each Section is sub-divided into a Data Input sheet and a Compliance Calculation sheet.

To use the spreadsheet, the applicant simply extracts relevant data from the DER worksheet of the SAP calculation for the proposed dwelling, and inputs this into the appropriate Data Input worksheet. SAP box numbers are clearly indicated for guidance. Excel completes all necessary calculations automatically on the Compliance Calculation worksheet, and displays both a clear statement of policy compliance/non-compliance and a breakdown of the contribution of individual energy systems and LZCGT which are characterised as zero-carbon, low-carbon, grid electricity, bio-carbon or fossil fuel. Only zero-carbon energy sources are used to mitigate annual energy demand (AED). The whole process should take no more than 10 minutes.

Three worked examples are also included, to illustrate the methodology (Table C.1). All three buildings were designed between 2012 and 2014, and were part of the data set described in Appendix E.

	Worked Example 1 (Figures C.7, C.8)	Worked Example 2 (Figures C.9, C.10)	Worked Example 3 (Figures C.11, C.12)
Description:			
Context	Suburban	Urban	Remote Rural
Building Type	Detached Passivhaus	Mid-Terrace Flat	Detached House
Area	255m^2	66m^2	182m^2
Main Heating System	ASHP	GAS	ASHP
Secondary Heating System			Biomass
Zero-Carbon Energy sources	ASHP PV MVHR	MVHR	ASHP Solar Thermal MVHR
Energy Demands:			
AED	7,372 kWh/annum	3,587 kWh/annum	7,636 kWh/annum
ZCAED	1,674 kWh/annum	3,587 kWh/annum	4,469 kWh/annum
Compliance:			
2021AAED	5,870 kWh/annum	4,117 kWh/annum	5,689 kWh/annum
2021AAED Compliant	YES (Method 2)	YES (Method 1)	YES (Method 2)
2024AAED	4,610 kWh/annum	3,233 kWh/annum	4,467 kWh/annum
2024AAED Compliant	YES (Method 2)	NO	NO

Table C.1: Summary details of Worked Examples (Figures C.7 – C.12). The contribution of MVHR systems are embedded within the calculated annual energy demand (AED).

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SECTION 1: DATA INPUT SHEET

NOTES:
Please fill in all relevant shaded boxes:
All input data to be sourced from the SAP 2012 Document DER worksheet for the proposed building:
Use the SAP box numbers and System / Fuel Codes indicated:
The convention in SAP data is to indicate Energy Demands as positive values; and Energy Generation as negative values.
[1] The boxes marked are usually recorded as negative values
[2] For Pumps & Fans: If associated with a specific building system use that System Code, if not use Grid Electricity (E)

INDIVIDUAL ENERGY SYSTEMS & MICRO-CHP

GENERAL INFORMATION:

Total Floor Area	SAP 4	
Occupancy	SAP 42	1.00

	Energy Demand		System/Fuel	Fraction of Demand		Fuel Consumed	
SPACE:							
Space Heating : Main System 1 (MS1)	SAP 98			SAP 204		SAP 211	
Space Heating : Main System 2 (MS2)				SAP 205		SAP 213	
Space Heating: Secondary System (SS)				SAP 201		SAP 215	
Space Cooling (SC)	SAP 107				1	SAP 221	
WATER:							
Water Heating (W)	SAP 64				1	SAP 219	
[1] Solar Thermal	[1] ∑ SAP 63		ST				
[1] Waste Water Heat Recovery	[1] ∑ SAP 63a		WWHR				
[1] Flue Gas Heat Recovery	[1] ∑ SAP 63b		FGHR				
LIGHTS:							
Lighting (L)	SAP 232		E				
PUMPS, FANS & ELECTRIC KEEP HOT:							
[2] Mechanical Ventilation Fans			[2]			SAP 230a	
[2] Warm Air Heating System Fans			[2]			SAP 230b	
[2] Central Heating Pump/Water Pump in Warm Air Heating Unit			[2]			SAP 230c	
[2] Oil Boiler Pump			[2]			SAP 230d	
[2] Boiler Flue Fan			[2]			SAP 230e	
[2] Electric Keep-Hot Facility for Gas Combi Boiler			[2]			SAP 230f	
Pump for Solar Water Heating			ST			SAP 230g	
Pump for Storage WWHR			WWHR			SAP 230h	
Total All Pumps & Fans (P&F)			E			SAP 231	

	Electricty Generation				
ELECTRICITY GENERATION:					
[1] Photovoltaics	[1] SAP 233		PV		
[1] Wind Turbine	[1] SAP 234		W		
[1] Hydro Electric Generator	[1] SAP 235a		H		
[1] Micro-Cogeneration	[1] SAP 235				
OTHER: (Appendix Q Items):					
Other 1 (Please describe under Valid System Codes)	[1] SAP 236A		OTHER 1	SAP 237A	
Other 2 (Please describe under Valid System Codes)	[1] SAP 236B		OTHER 2	SAP 237B	

VALID SYSTEM / FUEL CODES:

GAS	Gas Boiler/Fire
LPG	LPG Boiler/Stove
OIL	Oil Boiler/Stove
SF	Solid Fuel Boiler/Stove
BM	Biomass Boiler/Stove
BG	Biogas Boiler/Fire
E	Grid Electricity
GSHP	Ground Source Heat Pump
GWSHP	Ground Water Source Heat Pump
SWSHP	Surface Water Source Heat Pump
ASHP	Air Source Heat Pump
EASHP	Exhaust Air Source Heat Pump
SASHP	Solar Assisted Source Heat Pump
MVHR	Mechanical Ventilation Heat Recovery
FGHR	Flue Gas Heat Recovery
WWHR	Waste Water Heat Recovery
ST	Solar Thermal
PV	Photovoltaics
W	Wind Turbine
H	Hydro Electric Generator/Tidal
MCHPC	Micro-Cogeneration/CHP - Carbon Based Fuel
MCHPB	Micro-Cogeneration/CHP - Bio Based Fuel
MCHPBW	Micro-Cogeneration/CHP - Bio Waste Based Fuel
OTHER 1	
OTHER 2	

Figure C.3: Proposed Section 1: Data Input Excel Spreadsheet for dwellings with individual energy systems and micro-CHP

SECTION 1: COMPLIANCE CALCULATIONS:

ACCEPTABLE ANNUAL ENERGY DEMAND

AAED 2021	1910	kWh/annum
AAED 2024	1500	kWh/annum

ANNUAL ENERGY DEMAND:

AED	0	kWh/annum

2021: Compliance Method 1:
Building is 2021 COMPLIANT on basis of AED < 2021 AAED

2024: Compliance Method 1:
Building is 2024 COMPLIANT on basis of AED < 2024 AAED

ZERO CARBON ADJUSTED ANNUAL ENERGY DEMAND:

ZCAED	0	kWh/annum

2021: Compliance Method 2:
Building is 2021 COMPLIANT on basis of ZCAED < 2021 AAED

2024: Compliance Method 2:
Building is 2024 COMPLIANT on basis of ZCAED < 2024 AAED

SECTION 1: BREAKDOWN OF CONTRIBUTION OF INDIVIDUAL ENERGY SOURCES & LZCGT

NOTES:
The convention in SAP data is to indicate Energy Demands as positive values; and Energy Generation as negative values.
Only Zero-Carbon Generation is used to calculate ZCAED.
[1] The contributions of Solar Thermal, WWHR, FGHR & MVHR are already embedded within the AED so are excluded from the calculation of ZCAED
[2] The Grid Electricity consumed by Pumps, Fans and Electric Keep Hot (Not including that used in Heat Pumps) is already embedded within the AED so is excluded from the calculation of Zero-Carbon & Low Carbon Contribution

INDIVIDUAL HEATING SYSTEMS & MICRO-CHP:		DEMAND & GENERATION								GENERATION		CONSUMPTION		
		Energy Demand Subtotals by System:						Totals		[2] Zero-Carbon	[2] Low-Carbon	Grid Electricity	Bio-Carbon	Fossil Fuel
		MS1	MS2	SS	SC	W	L	Heat	Electric	kWh/annum	kWh/annum	kWh/annum	kWh/annum	kWh/annum
Ground Source Heat Pump	GSHP	0	0	0	0	0		0		0		0		
Ground Water Source Heat Pump	GWSHP	0	0	0	0	0		0		0		0		
Surface Water Source Heat Pump	SWSHP	0	0	0	0	0		0		0		0		
Air Source Heat Pump	ASHP	0	0	0	0	0		0		0		0		
Exhaust Air Source Heat Pump	EASHP	0	0	0	0	0		0		0		0		
Solar Assisted Source Heat Pump	SASHP	0	0	0	0	0		0		0		0		
Micro-Cogeneration/CHP - Carbon Based Fuel	MCHPC	0	0	0	0	0		0	0		0	0		0
Micro-Cogeneration/CHP - Bio Based Fuel	MCHPB	0	0	0	0	0		0	0		0	0	0	
Micro-Cogeneration/CHP - Bio Waste Based Fuel	MCHPBW	0	0	0	0	0		0	0		0	0	0	
Biomass Boiler/Stove	BM	0	0	0	0	0		0				0	0	
Biogas Boiler/Fire	BG	0	0	0	0	0		0				0	0	
Gas Boiler/Fire	GAS	0	0	0	0	0		0				0		0
LPG Boiler/Stove	LPG	0	0	0	0	0		0				0		0
Oil Boiler/Stove	OIL	0	0	0	0	0		0				0		0
Solid Fuel Boiler/Stove	SF	0	0	0	0	0		0				0		0
Grid Electricity	E	0	0	0	0	0	0	0	0			0		
[1] Mechanical Ventilation Heat Recovery	MVHR											0		
[1] Flue Gas Heat Recovery	FGHR							0		[1] 0		0		
[1] Waste Water Heat Recovery	WWHR							0		[1] 0		0		
[1] Solar Thermal	ST							0		[1] 0		0		
Photovoltaics	PV								0	0				
Wind Turbine	W								0	0				
Hydro Electric Generator	H								0	0				
0	OTHER 1	** This contribution needs to be evaluated separately*						0	0					
0	OTHER 2	** This contribution needs to be evaluated separately*						0	0					

TOTALS

	Zero-Carbon	Low-Carbon	Grid Electricity	Bio-Carbon	Fossil Fuel
Zero-Carbon Energy (including FGHR, WWHR & ST)	0				
[1] Zero-Carbon Energy (excluding FGHR, WWHR & ST)	[1] 0				
Low-Carbon Energy		0			
Grid Electricity			0		
Bio-Carbon Energy				0	
Fossil Fuel Energy					0

Figure C.4: Proposed Section 1: Compliance Calculation Excel Spreadsheet for dwellings with individual energy systems and micro-CHP

SECTION 2: DATA INPUT SHEET

NOTES:
Please fill in all relevant shaded boxes:
All input data to be sourced from the SAP 2012 Document DER worksheet for the proposed building:
Use the SAP box numbers and System / Fuel Codes indicated:
The convention in SAP data is to indicate Energy Demands as positive values; and Energy Generation as negative values.
[1] The boxes marked are usually recorded as negative values
[2] For Pumps & Fans: If associated with a specific building system use that System Code, if not use Grid Electricity (E)

COMMUNITY HEATING

	Energy Demand	System/Fuel	Adjusted Demand / Fraction of Demand	Fuel Efficiency	Fuel Consumed
GENERAL INFORMATION:					
Total Floor Area	SAP 4				
Occupancy	SAP 42 1.00				
SPACE:					
Space Heating : CHP (CHP)	SAP 98			SAP 361	
			SAP 307a	SAP 362	
Space Heating : Heat Source 2 (HS2)			SAP 307b	SAP367b	
Space Heating : Heat Source 3 (HS3)			SAP 307c	SAP367c	
Space Heating : Heat Source 4 (HS4)			SAP 307d	SAP367d	
Space Heating : Heat Source 5 (HS5)			SAP 307e	SAP367e	
Space Heating: Secondary System (SS)			SAP 301		SAP 309
Space Cooling (SC)	SAP 107		1		SAP 315
WATER:					
Water Heating : CHP (CHP)	SAP 64		SAP 310a		
Water Heating : Heat Source 2 (HS2)			SAP 310b		
Water Heating : Heat Source 3 (HS3)			SAP 310c		
Water Heating : Heat Source 4 (HS4)			SAP 310d		
Water Heating : Heat Source 5 (HS5)			SAP 310e		
Water Heating: Immersion/Instantaneous Heater (WI)		E			SAP 312
[1] Solar Thermal	[1] ∑ SAP 63	ST			
[1] Waste Water Heat Recovery	[1] ∑ SAP 63a	WWHR			
LIGHTS:					
Lighting (L)	SAP 332	E			
HEAT DISTRIBUTION, PUMPS & FANS:					
Electric for Heat Distribution		E			SAP 313
[2] Mechanical Ventilation Fans		[2]			SAP 330a
[2] Warm Air Heating System Fans		[2]			SAP 330b
Pump for Solar Water Heating		ST			SAP 330g
Pump for Storage WWHR		WWHR			SAP 330h
Total All Pumps & Fans (P&F)		E			SAP 331
	Electricty Generation				
ELECTRICITY GENERATION:					
[1] Photovoltaics	[1] SAP 333	PV			
[1] Wind Turbine	[1] SAP 334	W			
[1] Hydro Electric Generator	[1] SAP 335a	H			
OTHER: (Appendix Q Items):					
Other 1 (Please describe under Valid Fuel Type Codes)	[1] SAP 336A	OTHER 1			SAP 337A
Other 2 (Please describe under Valid Fuel Type Codes)	[1] SAP 336B	OTHER 2			SAP 337B

	VALID SYSTEM / FUEL CODES:
GAS	Gas Boiler/Fire
LPG	LPG Boiler/Stove
OIL	Oil Boiler/Stove
SF	Solid Fuel Boiler/Stove
BM	Biomass Boiler/Stove
BG	Biogas Boiler/Fire
E	Grid Electricity
GSHP	Ground Source Heat Pump
GWSHP	Ground Water Source Heat Pump
SWSHP	Surface Water Source Heat Pump
ASHP	Air Source Heat Pump
EASHP	Exhaust Air Source Heat Pump
SASHP	Solar Assisted Source Heat Pump
MVHR	Mechanical Ventilation Heat Recovery
FGHR	Flue Gas Heat Recovery
WWHR	Waste Water Heat Recovery
ST	Solar Thermal
PV	Photovoltaics
W	Wind Turbine
H	Hydro Electric Generator/Tidal
MCHPC	Micro-Cogeneration/CHP - Carbon Based Fuel
MCHPB	Micro-Cogeneration/CHP - Bio Based Fuel
MCHPBW	Micro-Cogeneration/CHP - Bio Waste Based Fuel
CHPC	Cogeneration/CHP - Carbon Based Fuel
CHPB	Cogeneration/CHP - Bio Based Fuel
CHPBW	Cogeneration/CHP - Bio Waste Based Fuel
CHPG	Cogeneration/CHP - Geothermal
WHRPS	Waste Heat Recovery from Power Stations
WHRIA	Waste Heat Recovery from Industry/Agriculture
OTHER 1	
OTHER 2	

Figure C.5: Proposed Section 2: Data Input Excel Spreadsheet for dwellings with community heating

SECTION 2: COMPLIANCE CALCULATIONS:

ACCEPTABLE ANNUAL ENERGY DEMAND

AAED 2021	1910	kWh/annum
AAED 2024	1500	kWh/annum

ANNUAL ENERGY DEMAND:

AED	0	kWh/annum

2021: Compliance Method 1:
Building is 2021 COMPLIANT on basis of AED < 2021 AAED

2024: Compliance Method 1:
Building is 2024 COMPLIANT on basis of AED < 2024 AAED

ZERO CARBON ADJUSTED ANNUAL ENERGY DEMAND:

ZCAED	0	kWh/annum

2021: Compliance Method 2:
Building is 2021 COMPLIANT on basis of ZCAED < 2021 AAED

2024: Compliance Method 2:
Building is 2024 COMPLIANT on basis of ZCAED < 2024 AAED

SECTION 2: BREAKDOWN OF CONTRIBUTION OF INDIVIDUAL ENERGY SOURCES & LZCGT

NOTES:
The convention in SAP data is to indicate Energy Demands as positive values; and Energy Generation as negative values.
Only Zero-Carbon Generation is used to calculate ZCAED.
[1] The contributions of Solar Thermal, WWHR & MVHR are already embedded within the AED so are excluded from the calculation of ZCAED
[2] The Grid Electricity consumed by Heat Distribution, Pumps and Fans (NOT including that used in Heat Pumps) is already embedded within the AED so is excluded from the calculation of Zero-Carbon & Low Carbon Contribution
[3] For simplicaity the grid electricity consumed in Heat Distribution is recorded under Grid Electricity rather than subdivided between each of the contributing power sources

COMMUNITY HEATING:

		DEMAND & GENERATION: Energy Demand Subtotals by System: CHP	HS2	HS3	HS4	HS5	SS	SC	WI	L	Totals: Heat	Electric	GENERATION: [2] Zero-Carbon kWh/annum	[2] Low-Carbon kWh/annum	CONSUMPTION: Grid Electricity kWh/annum	Bio-Carbon kWh/annum	Fossil Fuel kWh/annum
Cogeneration/CHP - Carbon Based Fuel	CHPC	0									0	0		0	0		0
Cogeneration/CHP - Bio Based Fuel	CHPB	0									0	0		0	0	0	
Cogeneration/CHP - Bio Waste Based Fuel	CHPBW	0									0	0		0	0	0	
Cogeneration/CHP - Geothermal	CHPG	0									0	0	0		0		
Ground Source Heat Pump	GSHP		0	0	0	0	0	0			0		0		0		
Ground Water Source Heat Pump	GWSHP		0	0	0	0	0	0			0		0		0		
Surface Water Source Heat Pump	SWSHP		0	0	0	0	0	0			0		0		0		
Air Source Heat Pump	ASHP		0	0	0	0	0	0			0		0		0		
Exhaust Air Source Heat Pump	EASHP		0	0	0	0	0	0			0		0		0		
Solar Assisted Source Heat Pump	SASHP		0	0	0	0	0	0			0		0		0		
Biomass Boiler/Stove	BM		0	0	0	0	0	0			0				0	0	
Biogas Boiler/Fire	BG		0	0	0	0	0	0			0				0	0	
Waste Heat Recovery from Power Stations	WHRPS		0	0	0	0	0	0			0		0		0		
Waste Heat Recovery from Industry/Agriculture	WHRIA		0	0	0	0	0	0			0		0		0		
Gas Boiler/Fire	GAS		0	0	0	0	0	0			0				0		0
LPG Boiler/Stove	LPG		0	0	0	0	0	0			0				0		0
Oil Boiler/Stove	OIL		0	0	0	0	0	0			0				0		0
Solid Fuel Boiler/Stove	SF		0	0	0	0	0	0			0				0		0
[3] Grid Electricity	E		0	0	0	0	0	0	0	0	0	0			[3] 0		
[1] Mechanical Ventilation Heat Recovery	MVHR														0		
[1] Waste Water Heat Recovery	WWHR										0		[1] 0		0		
[1] Solar Thermal	ST										0		[1] 0		0		
Photovoltaics	PV											0	0				
Wind Turbine	W											0	0				
Hydro Electric Generator	H											0	0				
0	OTHER 1	** This contribution needs to be evaluated separately*									0	0					
0	OTHER 2	** This contribution needs to be evaluated separately*									0	0					

TOTALS

	Zero-Carbon	Low-Carbon	Grid Electricity	Bio-Carbon	Fossil Fuel
Zero-Carbon Energy (including WWHR & ST)	0				
[1] Zero-Carbon Energy (excluding WWHR & ST)	[1] 0				
Grid Electricity		0			
Low-Carbon Energy			0		
Bio-Carbon Energy				0	
Fossil Fuel Energy					0

Figure C.6: Proposed Section 2: Compliance Calculation Excel Spreadsheet for dwellings with community heating

SECTION 1: DATA INPUT SHEET

NOTES:
Please fill in all relevant shaded boxes:
All input data to be sourced from the SAP 2012 Document DER worksheet for the proposed building:
Use the SAP box numbers and System / Fuel Codes indicated:
The convention in SAP data is to indicate Energy Demands as positive values; and Energy Generation as negative values.
[1] The boxes marked are usually recorded as negative values
[2] For Pumps & Fans: If associated with a specific building system use that System Code, if not use Grid Electricity (E)

INDIVIDUAL ENERGY SYSTEMS & MICRO-CHP

GENERAL INFORMATION:							
Total Floor Area	SAP 4	255					
Occupancy	SAP 42	3.07					
	Energy Demand		**System/Fuel**	**Fraction of Demand**		**Fuel Consumed**	
SPACE:							
Space Heating : Main System 1 (MS1)	SAP 98	3501	ASHP	SAP 204	1	SAP 211	1056
Space Heating : Main System 2 (MS2)				SAP 205		SAP 213	
Space Heating: Secondary System (SS)				SAP 201		SAP 215	
Space Cooling (SC)	SAP 107				1	SAP 221	
WATER:							
Water Heating (W)	SAP 64	2447	ASHP		1	SAP 219	1254
[1] Solar Thermal	[1] ∑ SAP 63		ST				
[1] Waste Water Heat Recovery	[1] ∑ SAP 63a		WWHR				
[1] Flue Gas Heat Recovery	[1] ∑ SAP 63b		FGHR				
LIGHTS:							
Lighting (L)	SAP 232	672	E				
PUMPS, FANS & ELECTRIC KEEP HOT:							
[2] Mechanical Ventilation Fans			[2] MVHR			SAP 230a	752
[2] Warm Air Heating System Fans			[2]			SAP 230b	
[2] Central Heating Pump/Water Pump in Warm Air Heating Unit			[2]			SAP 230c	
[2] Oil Boiler Pump			[2]			SAP 230d	
[2] Boiler Flue Fan			[2]			SAP 230e	
[2] Electric Keep-Hot Facility for Gas Combi Boiler			[2]			SAP 230f	
Pump for Solar Water Heating			ST			SAP 230g	
Pump for Storage WWHR			WWHR			SAP 230h	
Total All Pumps & Fans (P&F)			E			SAP 231	752
	Electricty Generation						
ELECTRICITY GENERATION:							
[1] Photovoltaics	[1] SAP 233	-2060	PV				
[1] Wind Turbine	[1] SAP 234		W				
[1] Hydro Electric Generator	[1] SAP 235a		H				
[1] Micro-Cogeneration	[1] SAP 235						
OTHER: (Appendix Q Items):							
Other 1 (Please describe under Valid System Codes)	[1] SAP 236A		OTHER 1			SAP 237A	
Other 2 (Please describe under Valid System Codes)	[1] SAP 236B		OTHER 2			SAP 237B	

	VALID SYSTEM / FUEL CODES:
GAS	Gas Boiler/Fire
LPG	LPG Boiler/Stove
OIL	Oil Boiler/Stove
SF	Solid Fuel Boiler/Stove
BM	Biomass Boiler/Stove
BG	Biogas Boiler/Fire
E	Grid Electricity
GSHP	Ground Source Heat Pump
GWSHP	Ground Water Source Heat Pump
SWSHP	Surface Water Source Heat Pump
ASHP	Air Source Heat Pump
EASHP	Exhaust Air Source Heat Pump
SASHP	Solar Assisted Source Heat Pump
MVHR	Mechanical Ventilation Heat Recovery
FGHR	Flue Gas Heat Recovery
WWHR	Waste Water Heat Recovery
ST	Solar Thermal
PV	Photovoltaics
W	Wind Turbine
H	Hydro Electric Generator/Tidal
MCHPC	Micro-Cogeneration/CHP - Carbon Based Fuel
MCHPB	Micro-Cogeneration/CHP - Bio Based Fuel
MCHPBW	Micro-Cogeneration/CHP - Bio Waste Based Fuel
OTHER 1	
OTHER 2	

Figure C.7: Worked Example 1: Proposed Section 1: Data Input Excel Spreadsheet: Suburban Detached Passivhaus

SECTION 1: COMPLIANCE CALCULATIONS:

ACCEPTABLE ANNUAL ENERGY DEMAND

AAED 2021	5870	kWh/annum
AAED 2024	4610	kWh/annum

ANNUAL ENERGY DEMAND:

AED	7372	kWh/annum

2021: Compliance Method 1:
Building is 2021 NON-COMPLIANT on basis of AED > 2021 AAED

2024: Compliance Method 1:
Building is 2024 NON-COMPLIANT on basis of AED > 2024 AAED

ZERO CARBON ADJUSTED ANNUAL ENERGY DEMAND:

ZCAED	1674	kWh/annum

2021: Compliance Method 2:
Building is 2021 COMPLIANT on basis of ZCAED < 2021 AAED

2024: Compliance Method 2:
Building is 2024 COMPLIANT on basis of ZCAED < 2024 AAED

SECTION 1: BREAKDOWN OF CONTRIBUTION OF INDIVIDUAL ENERGY SOURCES & LZCGT

NOTES:
The convention in SAP data is to indicate Energy Demands as positive values; and Energy Generation as negative values.
Only Zero-Carbon Generation is used to calculate ZCAED.
[1] The contributions of Solar Thermal, WWHR, FGHR & MVHR are already embedded within the AED so are excluded from the calculation of ZCAED
[2] The Grid Electricity consumed by Pumps, Fans and Electric Keep Hot (Not including that used in Heat Pumps) is already embedded within the AED so is excluded from the calculation of Zero-Carbon & Low Carbon Contribution

INDIVIDUAL HEATING SYSTEMS & MICRO-CHP:		DEMAND & GENERATION: Energy Demand Subtotals by System: MS1	MS2	SS	SC	W	L	Totals: Heat	Electric	GENERATION: [2] Zero-Carbon kWh/annum	[2] Low-Carbon kWh/annum	CONSUMPTION: Grid Electricity kWh/annum	Bio-Carbon kWh/annum	Fossil Fuel kWh/annum
Ground Source Heat Pump	GSHP	0	0	0	0	0		0		0		0		
Ground Water Source Heat Pump	GWSHP	0	0	0	0	0		0		0		0		
Surface Water Source Heat Pump	SWSHP	0	0	0	0	0		0		0		0		
Air Source Heat Pump	ASHP	3501	0	0	0	2447		5948		-3638		2310		
Exhaust Air Source Heat Pump	EASHP	0	0	0	0	0		0		0		0		
Solar Assisted Source Heat Pump	SASHP	0	0	0	0	0		0		0		0		
Micro-Cogeneration/CHP - Carbon Based Fuel	MCHPC	0	0	0	0	0		0	0		0	0		0
Micro-Cogeneration/CHP - Bio Based Fuel	MCHPB	0	0	0	0	0		0	0		0	0	0	
Micro-Cogeneration/CHP - Bio Waste Based Fuel	MCHPBW	0	0	0	0	0		0	0		0	0	0	
Biomass Boiler/Stove	BM	0	0	0	0	0		0				0	0	
Biogas Boiler/Fire	BG	0	0	0	0	0		0				0	0	
Gas Boiler/Fire	GAS	0	0	0	0	0		0				0		0
LPG Boiler/Stove	LPG	0	0	0	0	0		0				0		0
Oil Boiler/Stove	OIL	0	0	0	0	0		0				0		0
Solid Fuel Boiler/Stove	SF	0	0	0	0	0		0				0		0
Grid Electricity	E	0	0	0	0	0	672	0	672			672		
[1] Mechanical Ventilation Heat Recovery	MVHR											752		
[1] Flue Gas Heat Recovery	FGHR							0		[1] 0		0		
[1] Waste Water Heat Recovery	WWHR							0		[1] 0		0		
[1] Solar Thermal	ST							0		[1] 0		0		
Photovoltaics	PV								-2060	-2060				
Wind Turbine	W								0	0				
Hydro Electric Generator	H								0	0				
0	OTHER 1	** This contribution needs to be evaluated separately*						0	0					
0	OTHER 2	** This contribution needs to be evaluated separately*						0	0					

TOTALS

	Zero-Carbon	Low-Carbon	Grid Electricity	Bio-Carbon	Fossil Fuel
Zero-Carbon Energy (including FGHR, WWHR & ST)	-5698				
[1] Zero-Carbon Energy (excluding FGHR, WWHR & ST)	[1] -5698				
Low-Carbon Energy		0			
Grid Electricity			3734		
Bio-Carbon Energy				0	
Fossil Fuel Energy					0

Figure C.8: Worked Example 1: Proposed Section 1: Compliance Calculation Excel Spreadsheet: Suburban Detached Passivhaus

SECTION 1: DATA INPUT SHEET

NOTES:
Please fill in all relevant shaded boxes:
All input data to be sourced from the SAP 2012 Document DER worksheet for the proposed building:
Use the SAP box numbers and System / Fuel Codes indicated:
The convention in SAP data is to indicate Energy Demands as positive values; and Energy Generation as negative values.
[1] The boxes marked are usually recorded as negative values
[2] For Pumps & Fans: If associated with a specific building system use that System Code, if not use Grid Electricity (E)

INDIVIDUAL ENERGY SYSTEMS & MICRO-CHP

GENERAL INFORMATION:

Total Floor Area	SAP 4	66.4
Occupancy	SAP 42	2.16

	Energy Demand		System/Fuel	Fraction of Demand		Fuel Consumed	
SPACE:							
Space Heating : Main System 1 (MS1)	SAP 98	1234	GAS	SAP 204	1	SAP 211	1331
Space Heating : Main System 2 (MS2)				SAP 205		SAP 213	
Space Heating: Secondary System (SS)				SAP 201		SAP 215	
Space Cooling (SC)	SAP 107				1	SAP 221	
WATER:							
Water Heating (W)	SAP 64	1697	GAS		1	SAP 219	1931
[1] Solar Thermal	[1] ∑ SAP 63		ST				
[1] Waste Water Heat Recovery	[1] ∑ SAP 63a		WWHR				
[1] Flue Gas Heat Recovery	[1] ∑ SAP 63b		FGHR				
LIGHTS:							
Lighting (L)	SAP 232	339	E				
PUMPS, FANS & ELECTRIC KEEP HOT:							
[2] Mechanical Ventilation Fans			[2] MVHR			SAP 230a	272
[2] Warm Air Heating System Fans			[2]			SAP 230b	
[2] Central Heating Pump/Water Pump in Warm Air Heating Unit			[2]			SAP 230c	
[2] Oil Boiler Pump			[2]			SAP 230d	
[2] Boiler Flue Fan			[2] GAS			SAP 230e	45
[2] Electric Keep-Hot Facility for Gas Combi Boiler			[2]			SAP 230f	
Pump for Solar Water Heating			ST			SAP 230g	
Pump for Storage WWHR			WWHR			SAP 230h	
Total All Pumps & Fans (P&F)			E			SAP 231	317

	Electricty Generation						
ELECTRICITY GENERATION:							
[1] Photovoltaics	[1] SAP 233		PV				
[1] Wind Turbine	[1] SAP 234		W				
[1] Hydro Electric Generator	[1] SAP 235a		H				
[1] Micro-Cogeneration	[1] SAP 235						
OTHER: (Appendix Q Items):							
Other 1 (Please describe under Valid System Codes)	[1] SAP 236A		OTHER 1			SAP 237A	
Other 2 (Please describe under Valid System Codes)	[1] SAP 236B		OTHER 2			SAP 237B	

VALID SYSTEM / FUEL CODES:

GAS	Gas Boiler/Fire
LPG	LPG Boiler/Stove
OIL	Oil Boiler/Stove
SF	Solid Fuel Boiler/Stove
BM	Biomass Boiler/Stove
BG	Biogas Boiler/Fire
E	Grid Electricity
GSHP	Ground Source Heat Pump
GWSHP	Ground Water Source Heat Pump
SWSHP	Surface Water Source Heat Pump
ASHP	Air Source Heat Pump
EASHP	Exhaust Air Source Heat Pump
SASHP	Solar Assisted Source Heat Pump
MVHR	Mechanical Ventilation Heat Recovery
FGHR	Flue Gas Heat Recovery
WWHR	Waste Water Heat Recovery
ST	Solar Thermal
PV	Photovoltaics
W	Wind Turbine
H	Hydro Electric Generator/Tidal
MCHPC	Micro-Cogeneration/CHP - Carbon Based Fuel
MCHPB	Micro-Cogeneration/CHP - Bio Based Fuel
MCHPBW	Micro-Cogeneration/CHP - Bio Waste Based Fuel
OTHER 1	
OTHER 2	

Figure C.9: Worked Example 2: Proposed Section 1: Data Input Excel Spreadsheet: Urban Mid-Terrace Flat

SECTION 1: COMPLIANCE CALCULATIONS:

ACCEPTABLE ANNUAL ENERGY DEMAND

AAED 2021	4117	kWh/annum
AAED 2024	3233	kWh/annum

ANNUAL ENERGY DEMAND:

AED	3587	kWh/annum

2021: Compliance Method 1:
Building is 2021 COMPLIANT on basis of AED < 2021 AAED

2024: Compliance Method 1:
Building is 2024 NON-COMPLIANT on basis of AED > 2024 AAED

ZERO CARBON ADJUSTED ANNUAL ENERGY DEMAND:

ZCAED	3587	kWh/annum

2021: Compliance Method 2:
Building is 2021 COMPLIANT on basis of ZCAED < 2021 AAED

2024: Compliance Method 2:
Building is 2024 NON-COMPLIANT on basis of ZCAED > 2024 AAED

SECTION 1: BREAKDOWN OF CONTRIBUTION OF INDIVIDUAL ENERGY SOURCES & LZCGT

NOTES:
The convention in SAP data is to indicate Energy Demands as positive values; and Energy Generation as negative values.
Only Zero-Carbon Generation is used to calculate ZCAED.
[1] The contributions of Solar Thermal, WWHR, FGHR & MVHR are already embedded within the AED so are excluded from the calculation of ZCAED
[2] The Grid Electricity consumed by Pumps, Fans and Electric Keep Hot (Not including that used in Heat Pumps) is already embedded within the AED so is excluded from the calculation of Zero-Carbon & Low Carbon Contribution

INDIVIDUAL HEATING SYSTEMS & MICRO-CHP:		DEMAND & GENERATION								GENERATION		CONSUMPTION		
		Energy Demand Subtotals by System:						Totals		[2] Zero-Carbon	[2] Low-Carbon	Grid Electricity	Bio-Carbon	Fossil Fuel
		MS1	MS2	SS	SC	W	L	Heat	Electric	kWh/annum	kWh/annum	kWh/annum	kWh/annum	kWh/annum
Ground Source Heat Pump	GSHP	0	0	0	0	0		0		0		0		
Ground Water Source Heat Pump	GWSHP	0	0	0	0	0		0		0		0		
Surface Water Source Heat Pump	SWSHP	0	0	0	0	0		0		0		0		
Air Source Heat Pump	ASHP	0	0	0	0	0		0		0		0		
Exhaust Air Source Heat Pump	EASHP	0	0	0	0	0		0		0		0		
Solar Assisted Source Heat Pump	SASHP	0	0	0	0	0		0		0		0		
Micro-Cogeneration/CHP - Carbon Based Fuel	MCHPC	0	0	0	0	0		0	0		0	0		0
Micro-Cogeneration/CHP - Bio Based Fuel	MCHPB	0	0	0	0	0		0	0		0	0	0	
Micro-Cogeneration/CHP - Bio Waste Based Fuel	MCHPBW	0	0	0	0	0		0	0		0	0	0	
Biomass Boiler/Stove	BM	0	0	0	0	0		0				0	0	
Biogas Boiler/Fire	BG	0	0	0	0	0		0				0	0	
Gas Boiler/Fire	GAS	1234	0	0	0	1697		2931				45		3262
LPG Boiler/Stove	LPG	0	0	0	0	0		0				0		0
Oil Boiler/Stove	OIL	0	0	0	0	0		0				0		0
Solid Fuel Boiler/Stove	SF	0	0	0	0	0		0				0		0
Grid Electricity	E	0	0	0	0	0	339	0	339			339		
[1] Mechanical Ventilation Heat Recovery	MVHR											272		
[1] Flue Gas Heat Recovery	FGHR							0		[1] 0		0		
[1] Waste Water Heat Recovery	WWHR							0		[1] 0		0		
[1] Solar Thermal	ST							0		[1] 0		0		
Photovoltaics	PV								0	0				
Wind Turbine	W								0	0				
Hydro Electric Generator	H								0	0				
0	OTHER 1	** This contribution needs to be evaluated separately*						0	0					
0	OTHER 2	** This contribution needs to be evaluated separately*						0	0					

TOTALS	Zero-Carbon	Low-Carbon	Grid Electricity	Bio-Carbon	Fossil Fuel
Zero-Carbon Energy (including FGHR, WWHR & ST)	0				
[1] Zero-Carbon Energy (excluding FGHR, WWHR & ST)	[1] 0				
Low-Carbon Energy		0			
Grid Electricity			656		
Bio-Carbon Energy				0	
Fossil Fuel Energy					3262

Figure C.10: Worked Example 2: Proposed Section 1: Compliance Calculation Excel Spreadsheet: Urban Mid-Terrace Flat

SECTION 1: DATA INPUT SHEET

NOTES:
Please fill in all relevant shaded boxes:
All input data to be sourced from the SAP 2012 Document DER worksheet for the proposed building:
Use the SAP box numbers and System / Fuel Codes indicated:
The convention in SAP data is to indicate Energy Demands as positive values; and Energy Generation as negative values.
[1] The boxes marked are usually recorded as negative values
[2] For Pumps & Fans: If associated with a specific building system use that System Code, if not use Grid Electricity (E)

INDIVIDUAL ENERGY SYSTEMS & MICRO-CHP

	Energy Demand		System/Fuel	Fraction of Demand		Fuel Consumed	
GENERAL INFORMATION:							
Total Floor Area	SAP 4	181.9					
Occupancy	SAP 42	2.98					
SPACE:							
Space Heating : Main System 1 (MS1)	SAP 98	4904	ASHP	SAP 204	0.9	SAP 211	1765
Space Heating : Main System 2 (MS2)				SAP 205		SAP 213	
Space Heating: Secondary System (SS)			BM	SAP 201	0.1	SAP 215	754
Space Cooling (SC)	SAP 107				1	SAP 221	
WATER:							
Water Heating (W)	SAP 64	1210	ASHP		1	SAP 219	692
[1] Solar Thermal	[1] ∑ SAP 63	-1036	ST				
[1] Waste Water Heat Recovery	[1] ∑ SAP 63a		WWHR				
[1] Flue Gas Heat Recovery	[1] ∑ SAP 63b		FGHR				
LIGHTS:							
Lighting (L)	SAP 232	558	E				
PUMPS, FANS & ELECTRIC KEEP HOT:							
[2] Mechanical Ventilation Fans			[2] MVHR			SAP 230a	759
[2] Warm Air Heating System Fans			[2]			SAP 230b	
[2] Central Heating Pump/Water Pump in Warm Air Heating Unit			[2] ASHP			SAP 230c	130
[2] Oil Boiler Pump			[2]			SAP 230d	
[2] Boiler Flue Fan			[2]			SAP 230e	
[2] Electric Keep-Hot Facility for Gas Combi Boiler			[2]			SAP 230f	
Pump for Solar Water Heating			ST			SAP 230g	75
Pump for Storage WWHR			WWHR			SAP 230h	
Total All Pumps & Fans (P&F)			E			SAP 231	964
	Electricty Generation						
ELECTRICITY GENERATION:							
[1] Photovoltaics	[1] SAP 233		PV				
[1] Wind Turbine	[1] SAP 234		W				
[1] Hydro Electric Generator	[1] SAP 235a		H				
[1] Micro-Cogeneration	[1] SAP 235						
OTHER: (Appendix Q Items):							
Other 1 (Please describe under Valid System Codes)	[1] SAP 236A		OTHER 1			SAP 237A	
Other 2 (Please describe under Valid System Codes)	[1] SAP 236B		OTHER 2			SAP 237B	

	VALID SYSTEM / FUEL CODES:
GAS	Gas Boiler/Fire
LPG	LPG Boiler/Stove
OIL	Oil Boiler/Stove
SF	Solid Fuel Boiler/Stove
BM	Biomass Boiler/Stove
BG	Biogas Boiler/Fire
E	Grid Electricity
GSHP	Ground Source Heat Pump
GWSHP	Ground Water Source Heat Pump
SWSHP	Surface Water Source Heat Pump
ASHP	Air Source Heat Pump
EASHP	Exhaust Air Source Heat Pump
SASHP	Solar Assisted Source Heat Pump
MVHR	Mechanical Ventilation Heat Recovery
FGHR	Flue Gas Heat Recovery
WWHR	Waste Water Heat Recovery
ST	Solar Thermal
PV	Photovoltaics
W	Wind Turbine
H	Hydro Electric Generator/Tidal
MCHPC	Micro-Cogeneration/CHP - Carbon Based Fuel
MCHPB	Micro-Cogeneration/CHP - Bio Based Fuel
MCHPBW	Micro-Cogeneration/CHP - Bio Waste Based Fuel
OTHER 1	
OTHER 2	

Figure C.11: Worked Example 3: Proposed Section 1: Data Input Excel Spreadsheet: Remote Rural Detached House

SECTION 1: COMPLIANCE CALCULATIONS:

ACCEPTABLE ANNUAL ENERGY DEMAND

AAED 2021	5689	kWh/annum
AAED 2024	4467	kWh/annum

ANNUAL ENERGY DEMAND:

AED	7636	kWh/annum

2021: Compliance Method 1:
Building is 2021 NON-COMPLIANT on basis of AED > 2021 AAED

2024: Compliance Method 1:
Building is 2024 NON-COMPLIANT on basis of AED > 2024 AAED

ZERO CARBON ADJUSTED ANNUAL ENERGY DEMAND:

ZCAED	4469.4	kWh/annum

2021: Compliance Method 2:
Building is 2021 COMPLIANT on basis of ZCAED < 2021 AAED

2024: Compliance Method 2:
Building is 2024 NON-COMPLIANT on basis of ZCAED > 2024 AAED

SECTION 1: BREAKDOWN OF CONTRIBUTION OF INDIVIDUAL ENERGY SOURCES & LZCGT

NOTES:

The convention in SAP data is to indicate Energy Demands as positive values; and Energy Generation as negative values.

Only Zero-Carbon Generation is used to calculate ZCAED.

[1] The contributions of Solar Thermal, WWHR, FGHR & MVHR are already embedded within the AED so are excluded from the calculation of ZCAED

[2] The Grid Electricity consumed by Pumps, Fans and Electric Keep Hot (Not including that used in Heat Pumps) is already embedded within the AED so is excluded from the calculation of Zero-Carbon & Low Carbon Contribution

INDIVIDUAL HEATING SYSTEMS & MICRO-CHP:		DEMAND & GENERATION: Energy Demand Subtotals by System: MS1	MS2	SS	SC	W	L	Totals: Heat	Electric	GENERATION: [2] Zero-Carbon kWh/annum	[2] Low-Carbon kWh/annum	CONSUMPTION: Grid Electricity kWh/annum	Bio-Carbon kWh/annum	Fossil Fuel kWh/annum
Ground Source Heat Pump	GSHP	0	0	0	0	0		0		0		0		
Ground Water Source Heat Pump	GWSHP	0	0	0	0	0		0		0		0		
Surface Water Source Heat Pump	SWSHP	0	0	0	0	0		0		0		0		
Air Source Heat Pump	ASHP	4413.6	0	0	0	1210		5623.6		-3166.6		2587		
Exhaust Air Source Heat Pump	EASHP	0	0	0	0	0		0		0		0		
Solar Assisted Source Heat Pump	SASHP	0	0	0	0	0		0		0		0		
Micro-Cogeneration/CHP - Carbon Based Fuel	MCHPC	0	0	0	0	0		0	0		0	0		0
Micro-Cogeneration/CHP - Bio Based Fuel	MCHPB	0	0	0	0	0		0	0		0	0	0	
Micro-Cogeneration/CHP - Bio Waste Based Fuel	MCHPBW	0	0	0	0	0		0	0		0	0	0	
Biomass Boiler/Stove	BM	0	0	490.4	0	0		490.4				0	754	
Biogas Boiler/Fire	BG	0	0	0	0	0		0				0	0	
Gas Boiler/Fire	GAS	0	0	0	0	0		0				0		0
LPG Boiler/Stove	LPG	0	0	0	0	0		0				0		0
Oil Boiler/Stove	OIL	0	0	0	0	0		0				0		0
Solid Fuel Boiler/Stove	SF	0	0	0	0	0		0				0		0
Grid Electricity	E	0	0	0	0	0	558	0	558			558		
[1] Mechanical Ventilation Heat Recovery	MVHR											759		
[1] Flue Gas Heat Recovery	FGHR							0		[1] 0		0		
[1] Waste Water Heat Recovery	WWHR							0		[1] 0		0		
[1] Solar Thermal	ST							1036		[1] -1036		75		
Photovoltaics	PV								0	0				
Wind Turbine	W								0	0				
Hydro Electric Generator	H								0	0				
0	OTHER 1	** This contribution needs to be evaluated separately*						0	0					
0	OTHER 2	** This contribution needs to be evaluated separately*						0	0					

TOTALS

	Zero-Carbon	Low-Carbon	Grid Electricity	Bio-Carbon	Fossil Fuel
Zero-Carbon Energy (including FGHR, WWHR & ST)	-4202.6				
[1] Zero-Carbon Energy (excluding FGHR, WWHR & ST)	[1] -3166.6				
Low-Carbon Energy		0			
Grid Electricity			3979		
Bio-Carbon Energy				754	
Fossil Fuel Energy					0

Figure C.12: Worked Example 3: Proposed Section 1: Compliance Calculation Excel Spreadsheet: Remote Rural Detached House

Appendix D: Overview of Global Policy

Overview of Global Policy on LZCGT Contribution to GHG Emission Reduction

A systematic review of literature was undertaken, focusing on GHG reduction policies and proportion of contribution from LZCGTs. Keywords (LZCGT policy; GHG reduction policies; new buildings) were used to search for peer-reviewed papers in 3 leading scholarly search engines (Google Scholar, Scopus, World of Science); abstracts were perused for reference to GHG policies and LZCGT for new buildings and housing, and most cited 30 papers were downloaded for the literature review.

Key Points

- Two trends are identifiable in the global literature: one, showing what is mostly addressed / covered in the policies and the other, what is not. The former, represents a vast majority of papers discussing GHG emission reduction policies and LZCGT, emphasising various elements, e.g. policy types, energy consumption and efficiencies, carbon emissions and savings, and cost-effectiveness. The latter, shows a dearth of focus in policies setting specific proportions of GHG reductions from LZCGT.
- Existing policies are instead predicated on specifying Building Energy Efficiency (BEE) standards (in building regulations and code) as the foremost choice to tackle GHG reductions. Two main reasons are given:
    i. Efficacy of BEE as a surrogate for GHG reductions;
    ii. Balancing act to avoid a maladjustment where LZCGT is complied with at the expense of BEE, which is a more cost-effective approach, with potential for deep long-term abatements.
- The most common approach has been to prioritise BEE in policies, via holistic design principles.
- While BEE standards offer significant opportunities for low carbon transition especially through direct regulation, they can be politically controversial e.g. in Australia.
- Scotland is a pioneer in considering explicit requirements for quantifying LZCGT contributions towards GHG reductions, in the policy.
- Policy robustness that is the factors that can weaken or support a policy are determined by design and wider societal factors including political economy, macro level external factors, and institutional constraints and opportunities.
- The three factors identified that could strengthen policy were to control the societal cost of the policy, distribute costs incurred fairly across all stakeholders and develop adaptive frameworks that can respond more effectively to innovation and change, to prevent stagnation of ambition.

- In relation to the design of energy policies, six policy design principles were identified:
    i. Keep additional burdens for building owners light.
    ii. Create long-term regulatory certainty.
    iii. Beware technologically specific requirements.
    iv. Anticipate the impact of new regulations on small actors.
    v. Promote knowledge of innovative policy designs.
    vi. Integrate building energy policy in the local context.

Some Lessons from Policy Design

In the vast literature on policies for building energy performance, a notable piece of work (Schwartz et al., 2019) that is informed by other relevant studies, suggests the following six principles when designing building energy policies:

i. Keep additional burdens for building owners light
ii. Create long-term regulatory certainty
iii. Beware of technology-specific requirements
iv. Anticipate the impact of new regulations on small actors
v. Promote knowledge of innovative design
vi. Integrate building energy policies in local context

However, balancing these issues appears challenging, with policies being progressively enhanced or weakened as a consequence (Bauer and Knill, 2014) and highlighting the contested nature of policy designs and aims amid the influence of politics and government (Gurtler et al., 2019; Figure 3).

Holistic Design and BEE Focus

Various empirical works from different parts of the world agree that the inter-linked issues of carbon emissions, building energy and cost-effectiveness, and environmental protection, are significantly addressed via Building Energy Efficiency (BEE). BEE and use of renewable energy has gained prominence in the building policy due to its potential consequences for climate change (Nieboer et al., 2012). This is attested to by the review of building energy consumption and the state-of-the-art technologies for near-zero-energy buildings (nZEB) and zero-energy buildings (ZEBs), based on data from the USA, UK, the EU and China (see Xing et al., 2011; Cole and Fedoruk, 2015; Pan, 2014; Annunziata et al., 2013). The BEE approach is also central to the E.U. recast Directive on Energy Performance of Buildings (EPBD) and the Promotion of the Use of Energy from Renewable Sources Directive 2009/28/EC (EC, 2015), underpinning the nZEB & ZEB targets for new buildings by 2020. According to Cao et al. (2016), a cost-optimal nZEB has an energy need for heating and cooling less than 30 kWh/m^2/annum.

In the U.S., BEE approaches are evident in a hierarchy of national, regional, and local polices: For example the Energy Independence and Security Act of 2007 setting a zero-energy target of 50% for new commercial buildings by 2040 (Cassidy and Schneider, 2018), and; The Executive Order 13514 requiring new builds to be net ZEB by 2030 (The President, 2009). In China the central government has shown a keen interest in BEE policies to reduce actual energy consumption and mitigate GHG emissions. In their 13th National Five-year plan 2015-2020, BEE is crucial, with stricter building codes to reduce heating loads for buildings by 45% in 2030 (McNeil et al., 2016).

BEE has also been justified based on providing a low cost solution (Ürge-Vorsatz et al., 2012); and energy efficiency requirements in building codes or energy standards for new buildings becoming the single most important measure for ensuring the energy efficiency of new buildings (Laustsen, 2008). In setting minimum requirements for the energy-efficient design, energy codes and policies can ensure reduced energy consumption for the life of the building (Evans et al., 2017). BEE codes that consider the life cycle of a building can help overcome the many barriers to implementation and become key instruments for GHG mitigation in the buildings sector.

Poor Leverage of LZCGT Potential

However, although energy efficiency in buildings is an important objective of energy policy and strategy among the European Union Member States (Annunziata et al., 2013; Economidou, 2011), studies have found that calculations of the contribution of LZCGT in new building energy performance was not prominently addressed (Beerepoot, 2006, 2013). While the policies often mentioned the strategic purposes of renewable sources of energy, the role of LZCGTs was often subsumed therein, and the potential for LZCGTs in their own capacity either downplayed or not optimally leveraged. This is exemplified in Scotland (Onyango et al., 2020), Sweden and Austria (Annunziata et al., 2013), where policy did not explicitly require or specify any contribution from LZCGT to the savings in GHG emission reductions.

Yet the centrality and potential of LZCGT can for example be evidenced in McDonald and Laustsen's (2013) comprehensive analysis of BEE policies for new buildings. They identified 5 themes, 15 criteria and 17 questions for analysing new building policies (Tables D.1 and D.2) which emphasise key areas where LZCGT can be directly applied: making the call for this study futuristic and welcome as it pioneers in an appropriate direction with significant potential for deeper abatements.

Other studies reveal that by 2021 LZCGTs could deliver GHG abatement at a negative economy-wide cost per tonne of CO2; with global estimates of almost 30% reduction being achieved cost-effectively by 2020 (Ürge-Vorsatz et al., 2008) in stark contrast to other sectors such as power generation. The potential of LZCGT is further acknowledged in a study (IPEEC, 2015) that concluded that by delivering energy savings in buildings, GHG emissions could be curbed, human health and well-being, and prosperity, enhanced. The study states that effective implementation of energy efficiency policies has the potential to save in the range of 53 EJ per year globally by 2050 - an amount equivalent to the 2012 combined building energy use of China, France, Germany, Russia, the United Kingdom, and the United States in 2012 (IEA, 2015).

A Holistic Approach to Buildings	A Dynamic Process	Proper Implementation	Technical Requirements	Overall Performance
Performance Based Approach	Zero Energy Target	Good Enforcement	Building Shell	On-site
All Energy Types / Uses	Revision Cycles	Certification	Technical Systems	Primary Energy
Energy Efficiency & Renewable Energy	Levels Beyond Minimum	Policy Packages	Renewable Energy Systems	GHG Emissions

Table D.1: themes and 15 sub-themes distilled from 25 state of art BEE policies, on how to assess BEE performance (source: McDonald and Laustsen, 2013). Shaded boxes show there is direct potential for LZCGT to play a key role in 8/15 (53.3%) of them.

Performance	Performance including All Energy	Energy Efficiency and Renewable Energy
Set overall performance frame for buildings?	Most consumption (i.e. heating, cooling, ventilation and dehumidification)?	Set requirements for buildings efficiency and renewable energy?
Consider primary energy use, GHG emissions?	Domestic hot water?	Strongly encourage passive heating and passive cooling?
Consider passive heating & cooling, natural ventilation, light and shading?	Lighting?	Strongly encourage natural ventilation?
Encourage integrated or bio-climatic design?	Energy consumption e.g. elevators, appliances, pumps and fans?	Encourage daylight use?
Clear definition of building performance?	Conversion and transportation losses?	Encourage shading? Encourage reduction for energy demand from renewables? Life cycle assessment?

Table D.2: In a set of criteria and sub-questions for policy assessment (source: McDonald and Laustsen, 2013), shaded boxes show there is direct potential for LZCGT to play a key role in 10/17 (58.8%) of them.

Crucial Role of Government

Studies providing an international profile of Low and Zero Carbon homes policy agenda show a mix of policy instruments, state-led, national, mandatory and voluntary, requiring increased levels of building fabric energy efficiency (FEE) (DCLG, 2008b; Shen et al., 2016) (Table D.3). The message is a clear commitment to a performance-based regulatory approach, Beerepoot (2013), with policy that provides flexibility by specifying outcomes rather than prescribing particular technologies (DCLG, 2008a). A comparative analysis of BEE policies for new buildings, on behalf of the GBPN involving over 65 global building code experts, large international organisations and reference to 25 best practice BEE codes (McDonald and Laustsen, 2013), concluded that to achieve nZEB mandatory energy efficiency codes are a central element in achieving near zero emission savings. In this context, an increasing amount of empirical work analysing policy instruments (see Ürge-Vorsatz et al., 2008; Boza-Kiss et al. 2013; Lemprière, 2016; Levinson, 2014), acknowledges the strong central role for government in setting mandatory standards and supporting their delivery (Greenwood, 2012); with supplementary role for voluntary tools and local authority discretion, albeit with risks of divergence when different instruments promote diverging roadmaps towards a policy goal (Jordan et al., 2013).

Country Level Approaches and nZEB Targets

Policies for NZEB in China (Liu et al., 2019) offer interesting lessons given that China's carbon emission share of the building sector will double (OECD, 2013) and hit 50% by 2050 (Rhodes, 2016) if current trends continue. In response, China has adopted codes for nZEB, aimed at not only reducing carbon emissions, but also at achieving affordable housing through energy efficiency strategy (Liu et al., 2019; Lin, 2008).

Researchers in China have proposed BEE regulations at levels close to ZEBs (Lovell, 2009): with a roadmap for 2016-2030 building codes upgrade asking 30% of new buildings to reach nearly zero energy by 2030, 30% of existing buildings convert to nearly zero energy by 2030, and 30% of energy consumption in the building sector to come from renewable energy sources by 2030 (APEC, 2019). China's 5-Year plan required green buildings to account for 20% of new total floor space constructed by 2015. Although it is implicit that the ZEB/nZEB targets should be covered by energy from renewable sources (Liu et al., 2019; Annunziata et al., 2013), as is practice in most jurisdictions, the proportions of contribution from LZCGT is not explicitly stated.

Sweden, which introduced detailed building energy standards in the late 1970s, highlights the tension between national building standards and those set by more ambitious local authorities (Enker and Morrison, 2017). Similar tensions were identified in Scottish experience, between the roles of planning policy and building regulations (Onyango et al., 2020). In Switzerland, *CO_2 emission limits* for buildings could be introduced from 2029, implying potential significant obligations for the integration of renewables (Annunziata et al., 2013) and LZCGTs.

In Switzerland, for all categories of building except newly built single-family homes, the expected energy consumption per surface area must be declared and verified. For new single-family homes and apartment blocks 38kWh/m^2.annum must not be exceeded; for refurbishment projects the limiting value is 60kWh/m^2.annum; for buildings at altitudes above 800m, the limit values are increased. New buildings must leak less than or equal to 0.9 air changes per hour at 50 Pascal.

A few countries, e.g. Bulgaria, have set a quantitative requirement for renewable energies in all new and refurbished buildings, without clarifying how this requirement will be implemented, monitored and controlled (Annunziata et al., 2013). Bulgaria's principles for nZEBs acknowledges principles such as fixing thresholds on energy demand, on renewable energy share and on associated CO2 emissions, on overall and primary energy demand. For meeting the EU's long-term climate targets, it is recommended that the buildings' CO_2 emissions linked to energy demand is below 3kgCO_2/m^2.annum).

Portugal and Spain define quantitative targets for the integration of renewable sources in buildings and minimum threshold for the mandatory communication about the effects of the refurbishment on energy performance in buildings, without specifying contributions from LZCGT (Annunziata et al., 2013). In Norway, all new buildings should be at "Passive House" level in 2015, and NZEB by 2020, with two Norwegian standards for passive houses and low-energy buildings already in place (NS 3700 for residential buildings, and NS 3701 for non-residential buildings).

COUNTRY & POLICY TITLE	BASIS FOR BUILDING ENERGY PERFORMANCE
Germany Energy Conservation Regulations (EnEV), 2013, residential, non-residential	Based on equivalent model building and measured as kWh/m^2/year of primary energy **Renewable Energy (solar, PV, others)** - heat supply based on renewable energy 15 ~ 50% depending on type of renewable energy and building **Values for new buildings: U-Value (W/m²K):** roof 0.2; wall 0.28; floor 0.28; window 1.3; others 1.4. **Airtightness**: naturally ventilated n50 is 3.0h^{-1}, mechanically ventilated n50 is 1.5h^{-1} **National target:** carbon free buildings by 2020; nZEB should be operating without fossil fuel; reduce primary energy demand by 80% by 2050 **Efficiency improvements:** with first milestone of a 20% reduction in heat demand levels by 2020 **Minimum levels:** Residential Low Energy Building = 60kWh/(m^2/a) or (40 kWh/(m^2/a)) maximum energy consumption or Passive House = KfW-40 buildings with an annual heat demand lower than 15 kWh/m^2 and total consumption lower than 120 kWh/m^2; Actual energy consumption target relative to 2009 level: 30%.
Austria OIB - Richtlinie 6, 2011, residential, non-residential, renovations	Code requires mandatory calculation for expected primary energy consumption with buildings undergoing renovation at 25-38% higher than new builds; allowable primary energy depending on type of building and ventilation (stricter requirement for ventilation using heat recovery); voluntary low energy classes; implementation of Passive House standards by 2015 for residential buildings **Renewable Energy (solar, PV, others):** for new builds net floor area > 1000 m^2, alternative systems (renewable sources, CHP, district and refrigeration, heat pumps, fuel cells) allowed **Values for new buildings U-Value (W/m²K):** roof 0.2; wall 0.35; floor 0.4; window 1.4 **Airtightness:** n50 is 3.0 & n50 is 1.5 (residential and non-residential).

	National targets: annual heating below 60-40 KWh/m^2 gross area (30 % above standard performance) or Passive building (15 kWh/m^2 per useful and per heated area) by 2015; nZEB 2018 public buildings, 2020 all other buildings; Energy Performance 66.00kWh
Denmark BR10, 2011 Residential and non-residential	Performance-based code with some prescriptive elements; calculation considers supplied energy; Life Cycle Assessment considered (embedded energy), partially -voluntary **Renewable Energy (solar, PV, others):** Buildings outside district heating areas where expected hot water consumption exceeds 2000 litres per. day, solar power must be installed **Values for new buildings: U-Value (W/m²K):** roof 0.2; wall 0.3; floor 0.2; window 1.4; Airtightness: 1.5l/m^2 @ 50 Pa; heating performance 72.12kWh **National targets:** set 8 years in advance; maximum energy demand 52.5 + 1650/A kWh/m^2/pa (residential) and 71.3 + 1650/A kWh/m^2/a (non-residential); 75% less energy to be used in buildings by 2020 **Zero Energy Targets:** realistic roadmap in place to CO_2-emission free country by 2050; nZEB to use 75% less energy by 2020 (base year 2008); Primary Energy Performance Frame Residential: 30 kWh/m^2/a + 1000/A kWh/m^2/a by 2015 and 20 kWh/m^{2}a by 2020; Primary Energy Non-Residential: 41 + 1000/A kWh/m^2/a by 2015 and 25 kWh/m^2/a.
Finland National Building Code of Finland 2012 – Section D3 on Energy Management in Buildings	Mandatory calculation of expected monthly final energy consumption of residential and non-residential; allowable final energy kWh/m^2/a depends on type of building - ten different scales for ten different building types; Annual energy consumption calculated using monthly calculation **Values for new buildings: U-Value**: (W/m²K): roof 0.09; wall 0.17; floor 0.09; window 1; total window area < 50% area of external walls **Airtightness:** 4 m^3/(h.m^2) at 50 Pa; heating performance 225kWh **National targets:** Zero Energy Targets for 2015, 2018 and 2020; But no realistic roadmap; National Target date set for nZEB; partially-Passive house standards set for 2015, 2020.
Ireland Building Regulations: Part L Conservation of Fuel and Energy: Dwellings and Part L - Conservation of Fuel and Energy Buildings other than Dwellings. 2008	Mandatory calculation of Energy Performance Coefficient (EPC) and Carbon Performance Coefficient (CPC) in reference to notional building; primary energy calculation establishes the CO_2 emissions and energy consumption associated with the 1) 'dwellings' (2011) and 2) 'buildings other than dwellings' (2008) using DEAP/NEAP software **Renewable Energy (solar, PV, others):** reasonable proportion energy provided by renewable energy in dwellings - 10 kWh/m^2/a for domestic hot water heating, space heating or cooling; or 4 kWh/m^2/a of electrical energy; or a combination **Values for new buildings:** Minimum performance levels for ventilation, for fully pumped hot water-based central heating systems utilising oil or gas, the boiler seasonal efficiency should be not less than 90% as specified in DEAP manual **Airtightness:** 7 m^3/hr/m^2 at 50 Pa; energy performance 60kWh;

	national target to build nZEB by 2013; Zero Energy Targets: realistic roadmap in place.
Sweden Boverket's Building Regulations, BBR18 - (BFS 2011:26)	Codes for new builds and refurbishments based on calculated final energy and post occupancy energy measurement; must meet an overall performance frame and continuously monitor building's energy use by a method of measurement; Final Energy (kWh/m^2) by area of building intended to be heated to over 10 °C - depending on location and type of heating system; Compliance by measuring actual energy use of the (occupied) completed building and showing it to be less than or equal to allowable energy frame; Renewable Energy (solar, PV, others): no requirement in building regulations, but there are requirements in relation to electricity supply mix by RE certificates **National targets set:** 2015-2020 roadmap for nZEB **Primary Energy Performance Residential:** 55 -75 kWh/m^{2}a or 30 - 50 kWh/m^{2}a, 55-75 kWh/m^{2}a depending on climate zone (non-electric heating) and 30-50 kWh/m^{2}a depending on climate zone (electric heating) – 2020; Primary Energy Performance Frame Non-Residential: 50-105 kWh/m^{2}a or 30-75 kWh/m^{2}a 50-105 kWh/m^{2}a depending on climate zone (non-electric heating) and 30-75 kWh/m^{2}a depending on climate zone (electric heating) - 2020.
Netherlands Bouwbesluit 2012 - Chapter 5 (NEN 7120:2011)	Mandatory code requires calculation to establish the maximum allowed Energy Performance Coefficient (EPN) for residential and non-residential buildings; energy performance requirements are expressed in terms of the EPN coefficient factor; Primary Energy and Life Cycle Assessment considered (embedded energy) **Renewable Energy (solar, PV, others):** Partially, no specific requirement, but renewables included in EPN calculation **Values for new buildings:** U-Value (W/m^{2}K): roof 0.4; wall 0.4; floor 0.4; window 1.4; overall value 0.4. **Airtightness:** 200dm^3/s @10Pa or 200dm^3/s per 500m^3 @10 Pa. For residential buildings, 200 dm^3/s @10Pa and for non-residential buildings 200dm^3/s per 500m^3 @10Pa; energy performance 100kWh; Separate policy for the overall share of energy from renewable sources in The Netherlands **National targets:** 2020 Zero Energy Targets: realistic roadmap in place: As of 31-12-2018 new governmental buildings EPC near 0, all other new buildings EPC near 0 as of 12-31-2020.
California (USA) California: 2008 California Code of Regulations: Title 24 (Part 6). 2010	Mandatory for all new residential, non-residential, alteration or addition to existing; All urban buildings; State-wide prescriptive Codes; Model / reference Building: Energy Budgets expressed in Btu/sf/a; performance frame: Time Dependent Valuation (TDV) - value of electricity differs depending on time-of-use (hourly, daily, seasonal), value of natural gas depends on season; Final Energy: calculation is for 'Site' energy. Life Cycle Assessment considered (embedded energy): Partially, not for individual buildings **Renewable Energy (solar, PV, others):** can be used for compliance; many cities have own codes with increased

	requirements for renewable energy; no minimum requirements. **Values for new buildings (San Diego):** U-Value (W/m²K): roof 0.19; wall 0.44; floor 0.3; window 2.27 **State targets:** Zero Energy, residential by 2020 and commercial by 2030 - (energy use to decrease by 60-70%; targets are policy at this stage, not regulation or law.

Table D.3: National level policy on building performance requirements for new buildings and NZEBs (source: adapted from Hermelink et al. (2013).

Ambition in Policy

Despite existence of a vast number of policies worldwide, results of these policies in terms of reduced energy consumption in buildings are still below target (UNEP, 2012). Commenting on the governance for BEE, Visscher et al. (2016) warn that the effectiveness of current instruments and their impact on actual CO_2 reductions have been inadequate for ensuring actual (not hypothecated) energy performance is achieved. While they admit that strict requirements are needed, they also acknowledge that to realize very ambitious energy-saving goals a radical rethink is needed. A study of building energy policies (IPEEC, 2015) concluded that ambitious building energy codes are consistently regarded as a most cost-effective approach for delivering large-scale and long-term energy savings and GHG emissions reductions. Periodic ratcheting up of targets to improve energy performance will lower operating costs in the long run.

To achieve greater results, energy efficiency policy-making must be more dynamic in terms of a continuous closed-loop process that involves and balances “policy design, implementation and evaluation” (Morvaj and Bukarica, 2010). Key to altering current trends is to prescribe mandatory, dynamic and ambitious building codes and supporting policy packages that are incorporated into long-term strategies, aimed at reducing the consumption of new buildings to zero or close to zero energy.

Whilst the dynamic and ambitious policies requires policy packages with long-term targets of achieving zero or positive energy (McDonald and Laustsen, 2013), sight must not be lost of the holistic thinking and to set the standards at a higher level, taking the total energy consumption of the building into consideration. A shift to zero energy could not take place in one single step, requiring zero energy targets to be met via a dynamic approach based on several phases of improvement of energy requirements. This avoids bottlenecks and excessive costs (McDonald and Laustsen, 2013).

Summary

In many countries, BEE and building regulations are often subject to debate and reviews as conflicting goals are evident: between minimising regulatory and administrative burden on citizens and businesses and addressing socio-economic and environmental concerns. Studies looking at worldwide policies for low and near zero carbon buildings found that cross-context learning was largely constrained because of differences in the concepts and calculating methodologies of ‘zero carbon’ or ‘zero energy’: significantly hampering benchmarking of energy performance and carbon reduction practices (Pan and Li, 2016). In the raft of the many available building energy policies, Hermelink et al. (2013) highlights a lack of attention to and a mismatch in the design (and energy demand) of new buildings and their interaction with the energy grid; Hogeling (2012) stating an assumed infinite capacity and storage in the grid as a failure to account for timing of electricity generation and use.

Appendix E: Supporting Statistical Data

Statistical Data Relating to new Dwellings in Scotland

The data detailed within Appendix E relates to a study carried out in 2015, which looked at Section 3F Policy and the deployment of Low and Zero Carbon Generating Technologies (LZCGT) in Scotland (Onyango et al., 2016; Burford et al., 2019). The dwellings within this study were randomly selected from five planning authority areas which were early adopters of Section 3F policy. These planning authorities represented regions ranging from remote rural to major urban centres. The designs for all the 402 new dwellings within the data set were submitted to planning between 2012 and 2014, and were either completed or under construction at the time of the study. The data represented here was all extracted from SAP documents submitted to and approved by building standards. All dwellings met the 30% reduction in CO_2 emissions (relative to the 2007 standard) legislated for in Scottish Building Standard 6.1 at the time of the study.

Although consisting of a limited number of new dwellings built to less onerous requirements than the current Scottish Building Standards; it was felt that if these limitations were borne in mind, the data was contemporary and comprehensive enough to give a fair representation of the distribution of size, occupancy, and energy demands in new dwellings in Scotland. The data was therefore utilized as an aid to determining and confirming the rationality of some of the assumptions made in the development of Proposal 1 and Proposal 2.

Defining a Modestly-sized Dwelling

A key parameter for both Proposal 1 and Proposal 2 was that although the targets should be ambitious, they also needed to be readily achievable. In particular they should not be overly onerous or impact negatively on the ability to deliver essential domestic infrastructure such as affordable housing in a cost-effective way. For Proposal 1, protecting this sub-group of modestly-sized dwellings was used as the critical limiting context in determining what would be a reasonable minimum LZCGT contribution to annual energy demand that could be sought by the existing Section 3F policy.

Recognising the need to reduce energy demand as the essential first step to achieving CO_2 emission reduction, Proposal 2 took a different tack than current Section 3F policy (Urge-Vorsatz et al., 2013; Beradi, 2016; Grove-Smith et al., 2018). The aforementioned LZCGT study had clearly revealed that the majority of large new dwellings had proportionally larger annual energy demands per capita (AED/Capita) than more modest dwellings. This is primarily a result of large heated living spaces and low average occupancy rates (Figure E.7, E.8, E.9; BRE, 2008; Burford et al., 2019). Proposal 2 therefore sought to limit annual energy demand in new dwellings to an acceptable level, and defined that level relative to a modest-sized energy-efficient dwelling.

Both proposals therefore needed to define what would be considered a modestly-sized dwelling.

The data collected during the 2015 study represents 402 new dwellings ranging in size from 48.7m^2 to 480.9 m^2 (Figures E.1 – E.10). The average total floor area was calculated at 125.3 m^2 for the complete data set. This was surprisingly large. In Scotland the average size of a dwelling built post 1982 is 101m^2. However whilst the average urban dwelling is just 93m^2, the average rural dwelling is 47% larger at 137m^2. Further the average detached house is 139m^2, whilst the average flat is just 58m^2 (Scottish Government, 2017b, pp. 18-19). The larger than average floor area of the sample might therefore have several simple explanations. Only one of the five local authority areas studied could be considered a major urban centre, whilst two could be considered fairly remote rural areas. The sample therefore might have a higher percentage of larger rural dwellings. It may also be representative of the fact that during this period the construction sector was still recovering from the financial crisis and there were very few large scale developer housing projects being undertaken. These typically contain more modest sized housing. As a result the distribution of dwelling sizes within the study might be slightly skewed towards larger architect designed one-off housing than would have normally been expected.

The lower limit of this critical size range was therefore simply defined as 45m^2. However two figures were considered for the upper limit, 100m^2 and 130m^2. The statistical data for each is summarised in Table E.1, along with data for the complete data set. On consideration of these factors and the recognition that the occupancy rate of dwellings appears to alter at around 90m^2 and saturates at about 3 occupants soon thereafter, it was decided that the upper limit would be set at 100m^2 (BRE, 2008).

A modestly-sized dwelling was therefore defined for both Proposal 1 and Proposal 2 as between 45m^2 and 100m^2. This critical sized range represented 56% of all dwellings in the data set, and provided accommodation for 50% of all occupants (Table E.1).

Defining Levels of Fabric Energy Efficiency for Modelling

The methodology used to determine target levels in both Proposal 1 and 2 were based on modelling the expected annual energy demand of dwellings in past, present and future contexts. This necessitated making assumptions about the level of fabric energy efficiency that was likely to be encountered in these scenarios.

The data from this previous study is a real world representation of the level of fabric energy efficiency that could be expected and was readily achievable under the earlier 30% CO_2 emission reduction standard. The average annual space heat demand per m^2 for the entire data set was calculated at 46.3kWh/m^2.annum, with actual values ranging from 13.7kWh/m^2.annum to 93.4kWh/m^2.annum. For dwellings within the critical size range of 45m^2 to 100m^2 this average value was slightly lower at 41.6kWh/m^2.annum (Table E.1). This was probably partly because smaller dwellings tend to have simpler, more compact designs and more efficient form factors (Cotterell and Dadeby, 2013). Figure E.6 shows the distribution of annual space heat demand per m^2 (SHD/m^2) for the entire data set. The peak is clearly within the 40 to 45kWh/m^2.annum range, with 66.9% of new dwellings achieving an annual SHD/m^2 of less than or equal to 45kWh/m^2.annum. This fabric energy efficiency was therefore determined as suitable for modelling past energy demand scenarios (Appendix B: Scenario 1).

Since this study was completed, the CO_2 emission reduction required by Standard 6.1 has increased to 45% for new domestic buildings. We should therefore expect a corresponding increase in fabric energy efficiency and the use of LZCGT. Further the Committee on Climate Change (2019d) recommends that all new homes in the UK should be designed to deliver ultra-high levels of energy efficiency as soon as possible, and by 2025 at the latest. This was considered consistent with an annual space heat demand of 15 to 20kWh/m^2.annum. Also Currie and Brown (2019) suggest that a rapid shift to a very high fabric energy efficiency standard comparable to Passivhaus (15kWh/m^2.annum), MVHR and heat pump technology will be more cost-effective by the mid-2020s than taking a slower stepped approach to increasing fabric energy efficiency.

It was therefore determined to simply split the difference and use a space heat demand of 30kWh/m^2.annum for present/near future energy demand modelling (Appendix B: Scenario 2). It was felt this would accurately represent a naturally ventilated highly energy efficient dwelling built to current standards. For future contexts post 2025 a space heat demand of 15kWh/m^2.annum was selected (Appendix B: Scenario 3). This would represent an ultra-high energy efficient dwelling with mechanical ventilation heat recovery (MVHR).

Although the percentages are small, several dwellings within the 2015 data set achieved these values (Table E.1). There was only one Passivhaus in the data set and this was the only dwelling to meet the higher fabric energy efficiency target, although several others were fairly close. It had a floor area of 255m^2, and an annual space heat demand of 13.7kWh/m^2.annum (Appendix C: Worked Example 1). Ironically the dwelling with the highest space heat demand of 93.4kWh/m^2.annum was a similar size at 266m^2.

Determining whether the Acceptable Annual Energy Demand per Capita calculated for 2021 and 2024 are reasonable and achievable

Figures E.7, E.8, E.9 and E.10 analyse the data set in relation to predicted occupancy (BRE, 2008). Figure E.9 depicts the average annual energy demand per capita (AED/Capita) relative to dwelling size. The histogram sub-divides the data set into 10m^2 groupings and calculates the average AED/Capita relative to these. This gives a reasonable indication of the changes in AED/Capita that are observed as the size of dwellings increase. The cumulative average traces the average AED/Capita for all dwellings up to and including that size grouping. The average AED/Capita for dwellings up to 100m^2 was calculated as 2,369kWh/annum; this average encompasses individual AED/Capita ranging from 1,646kWh/annum to 3,514kWh/annum. For the entire data set the average AED/Capita was calculated as 3,258kWh/annum. The largest individual value recorded was for a 312m^2 house which had an AED/Capita of 9,372kWh/annum (Table E.1).

Figure E.10 depicts the general distribution of AED/Capita values observed in the data set. There is a clear peak with 34.3% of dwellings recording AED/Capita between 2,200 and 2,600kWh/annum. In total 50.5% of the dwellings recorded an AED/Capita of less than or equal to 2,600kWh/annum.

When considering these figures it should be remembered that the CO_2 emission reduction standard has increased since these dwellings were designed and built, and it can be expected that higher fabric energy efficiency standards will have been adopted and the use of LZCGT will have increased. Also it is not the intention of Proposal 2 that dwellings should meet the acceptable annual energy demand/capita (AAED/Capita) target purely by dint of increased fabric energy efficiency. It is accepted in the compliance methodology that some of the annual energy demand will be offset through the use of zero-carbon energy sources.

On reflection, the 2021 AAED/Capita target, for the present or near future, calculated as 1,910kWh/annum seems reasonable. Sixteen dwellings within the 2015 data set achieved this level without taking into consideration the use of zero-carbon energy to offset annual energy demand. All these dwellings were below 100m^2 in area and some did utilize MVHR (which is embedded in the annual energy demand figure). It is presumed that a larger proportion of dwellings would achieve this level once other zero-carbon energy offsetting was taken into account.

The proposed 2024 AAED/Capita of 1,500kWh/annum is more challenging, especially for larger dwellings. None of the dwellings in the data-set achieved this level without zero-carbon energy offsetting. Two dwellings came fairly close with an AED/Capita of 1,646 and 1,652kWh/annum respectively. These were both 66.4m^2 mid-terrace flats, with inherently good form factors, high levels of fabric energy efficiency and an MVHR system (Appendix C: Worked Example 2). However other dwellings were shown to be able to achieve this target through zero-carbon energy offsetting, including the Passivhaus example mentioned previously (Appendix C: Worked Example 1). The value calculated, though ambitious, therefore appears to be reasonable and achievable given the ambitions to build all new homes with ultra-high levels of fabric energy efficiency by 2025 at the latest (CCC, 2019b, p66; 2019d, pp 14-15).

	Area ≤ 100m^2	Area ≤ 130m^2	All Dwellings	Range: All Dwellings	Figures
General Distribution:					
Percentage of total dwellings	56%	66%	100%		Figure E.1
Percentage of total area of built accommodation	34%	43%	100%		Figure E.2
Percentage of total number of occupants	50%	61%	100%		Figure E.3
Percentage of total space heat demand	31%	40%	100%		Figure E.4
Percentage of total annual energy demand	36%	46%	100%		Figure E.5
Fabric Energy Efficiency:					
Average Space Heat Demand/m^2 (kWh/m^2.annum)	41.6	42.9	46.3	13.7 - 93.4 kWh/m^2.annum	
Dwellings with a SHD/m^2 ≤ 45 kWh/m^2.annum	**72.4% (163 Dwellings)**	**70.7% (188 Dwellings)**	**66.9% (269 Dwellings)**		
Dwellings with a SHD/m^2 ≤ 30 kWh/m^2.annum	**7.1% (16 Dwellings)**	**6% (16 Dwellings)**	**4.9% (20 Dwellings)**		
Dwellings with a SHD/m^2 ≤ 15 kWh/m^2.annum	**0% (0 Dwellings)**	**0% (0 Dwellings)**	**0.25% (1 Dwelling)**		
Per Capita Analysis:					
Average Heated Living Space/Capita (m^2)	33	34	48	29.5 - 142.7 m^2	Figure E.7
Average Space Heat Demand/Capita (kWh/annum)	1,356	1,460	2,218	573 - 8,106 kWh/annum	Figure E.8
Average Annual Energy Demand/Capita (kWh/annum)	2,369	2,471	3,258	1,646 - 9,372 kWh/annum	Figure E.9
Dwellings with a AED/Capita ≤ 1910 kWh/annum	**7.1% (16 Dwellings)**	**6% (16 Dwellings)**	**4% (16 Dwellings)**		
Dwellings with a AED/Capita ≤ 1500 kWh/annum	**0% (0 Dwellings)**	**0% (0 Dwellings)**	**0% (0 Dwellings)**		

Table E.1: Summary of key data extracted from SAP documents submitted to Scottish Building Standards for 402 randomly selected new dwellings designed between 2012 and 2014. This data was taken from a 2015 study into Section 3F Policy (Onyango et al., 2016; Burford et al., 2019). Key analysis sections are shown in blue.

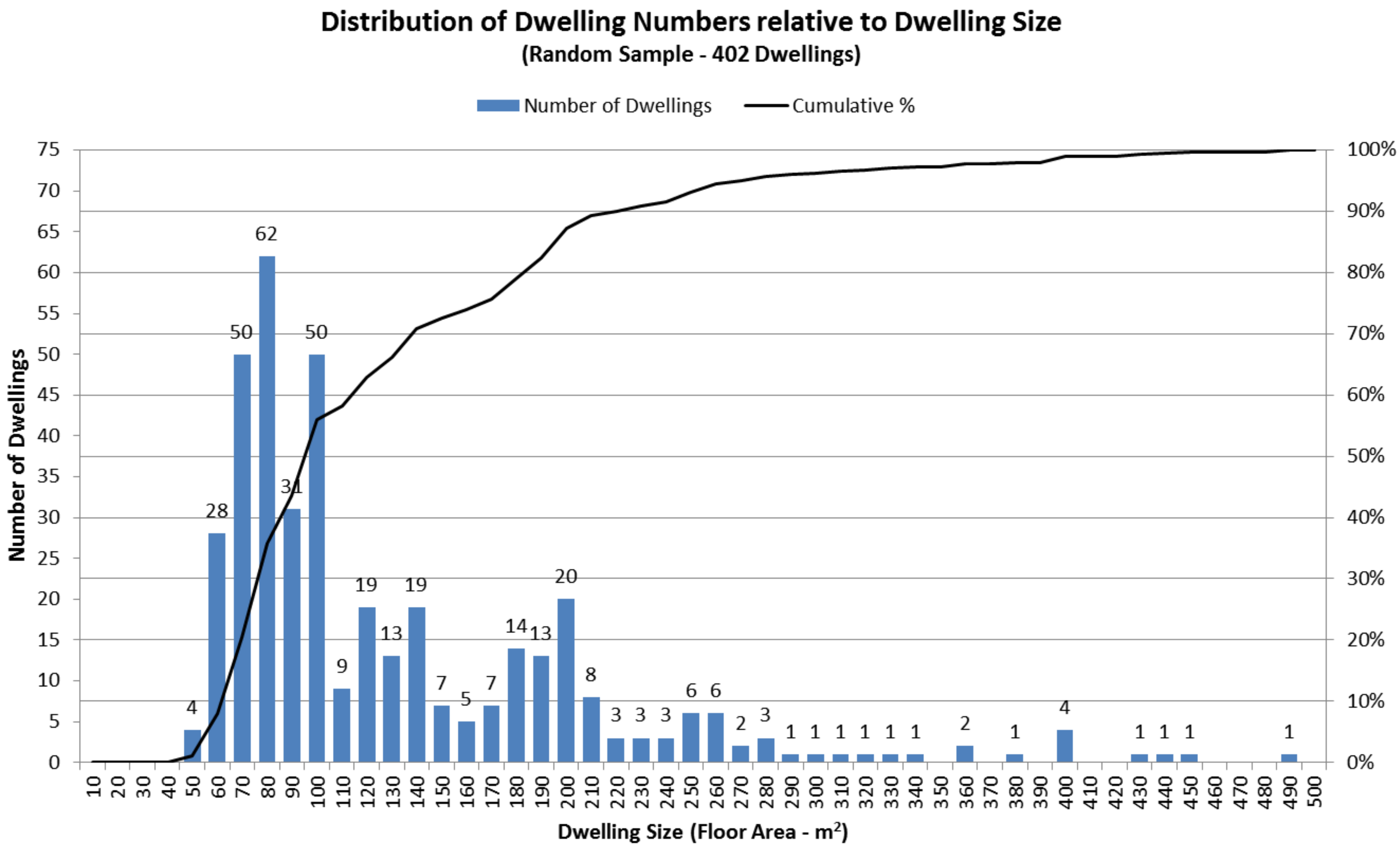

Figure E:1 Distribution of number of dwellings relative to the range of dwelling sizes (Histogram & Cumulative Percentage) within sample data.

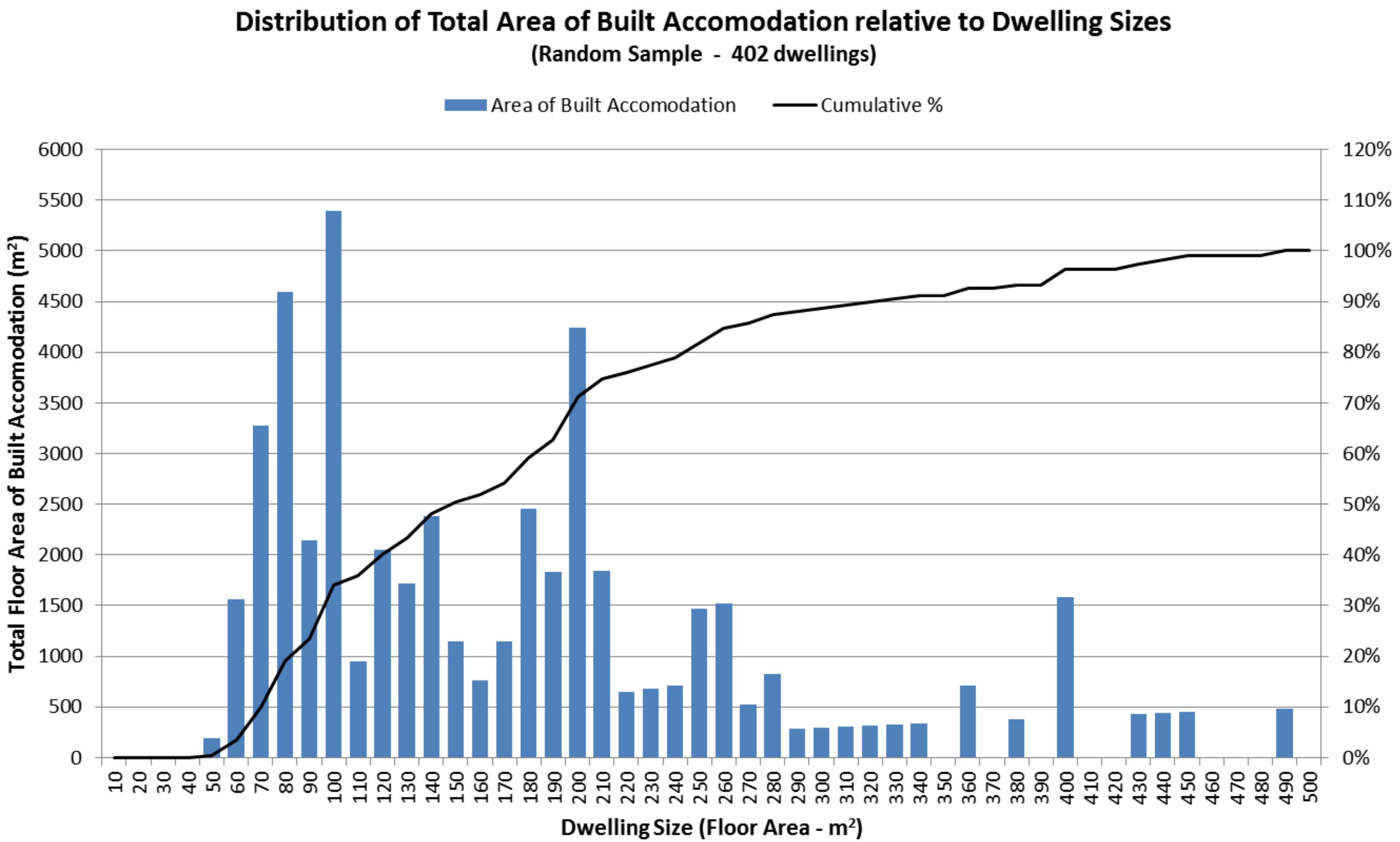

Figure E:2 Distribution of total floor area of built accommodation relative to the range of dwelling sizes (Histogram & Cumulative Percentage) within sample data

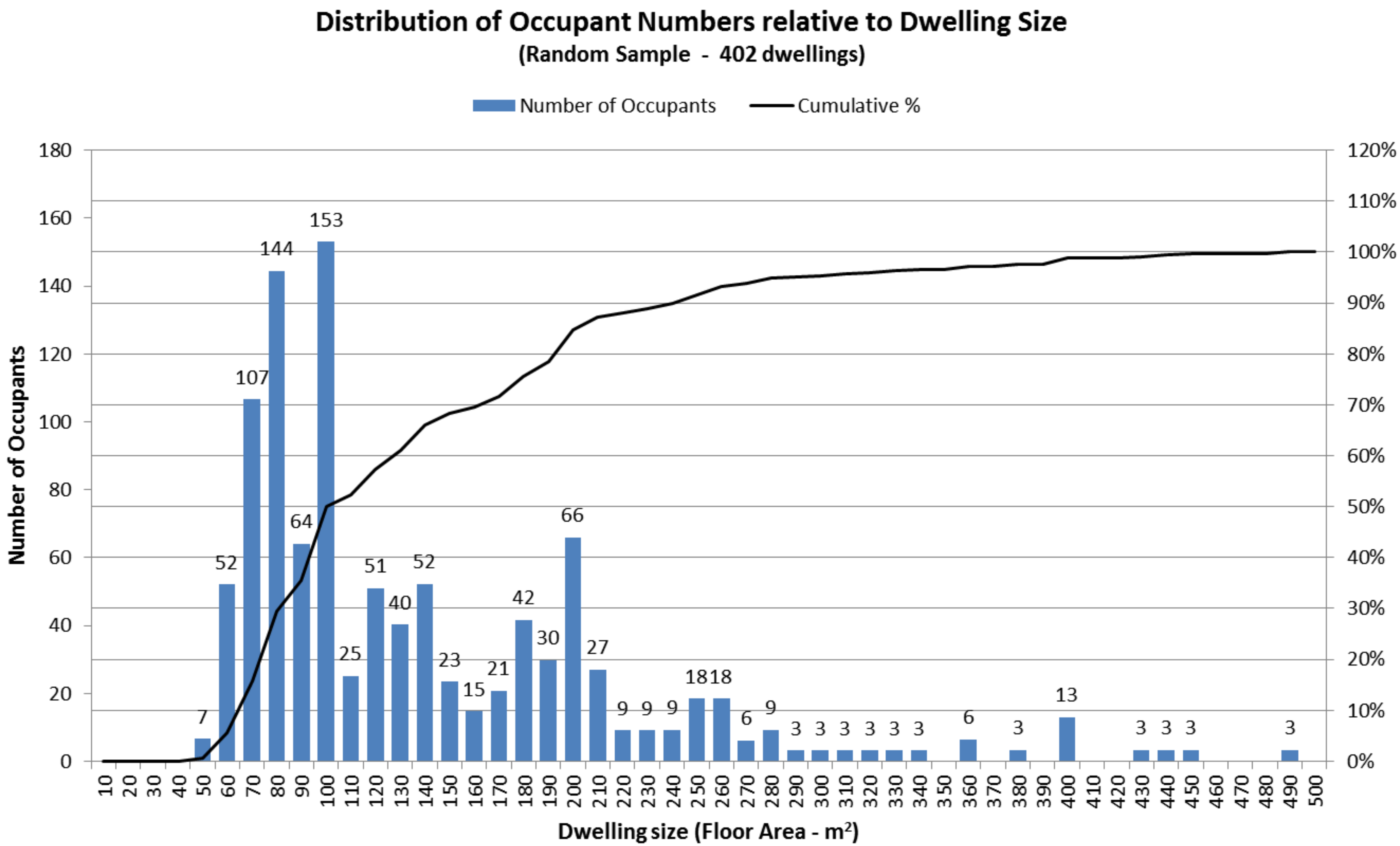

Figure E:3 Distribution of occupant numbers relative to the range of dwelling sizes (Histogram & Cumulative Percentage) within sample data

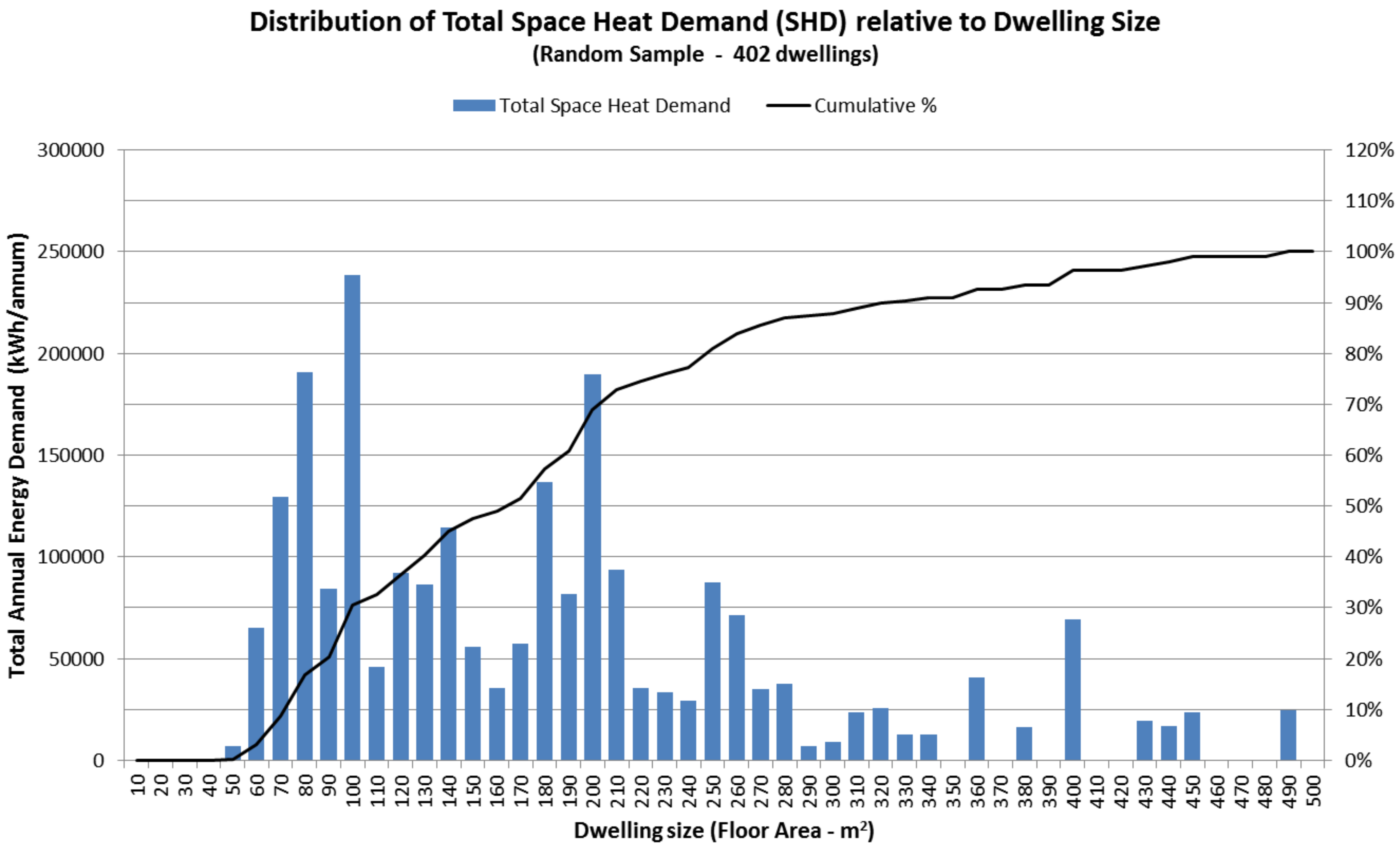

Figure E:4 Distribution of total space heat demand (SHD) for the sample data set relative to the range of dwelling sizes (Histogram & Cumulative Percentage)

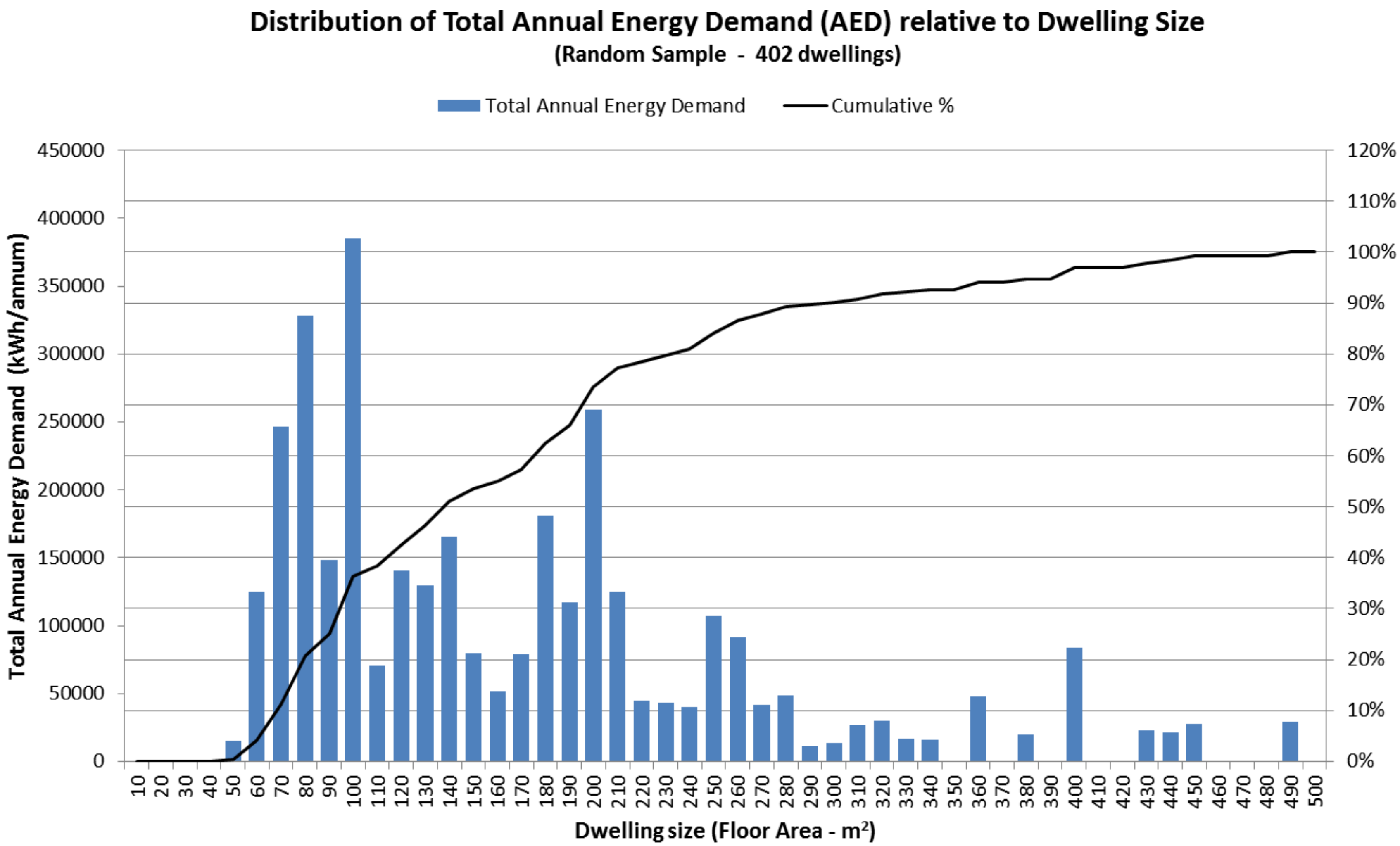

Figure E:5 Distribution of total annual energy demand (AED) for the sample data set relative to the range of dwelling sizes (Histogram & Cumulative Percentage). This is the annual energy demand recorded for space heating, space cooling, hot water, lighting and pumps & fans (including MVHR where specified).This is NOT the same as the total annual energy consumption which can be substantially less or more depending on the systems/fuels employed.

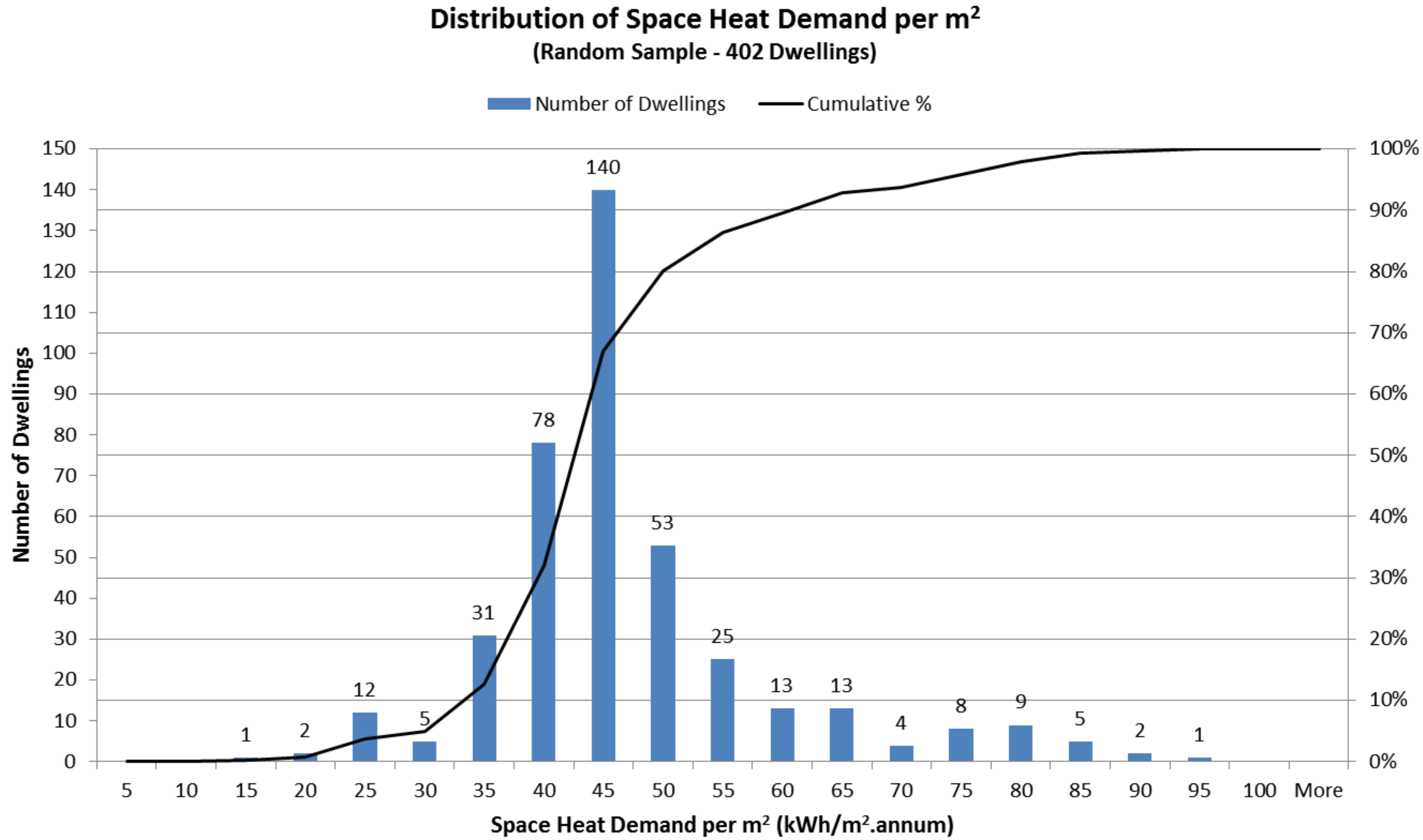

Figure E:6 Distribution of space heat demand/m^2 observed within the sample data (Histogram & Cumulative Percentage). Dwellings within this sample were submitted for planning between 2012 and 2014, and were either completed or under construction in 2015 when the study was undertaken. They were all built under the Scottish Building Standard 6.1 requirement for a 30% reduction in CO_2 emissions.

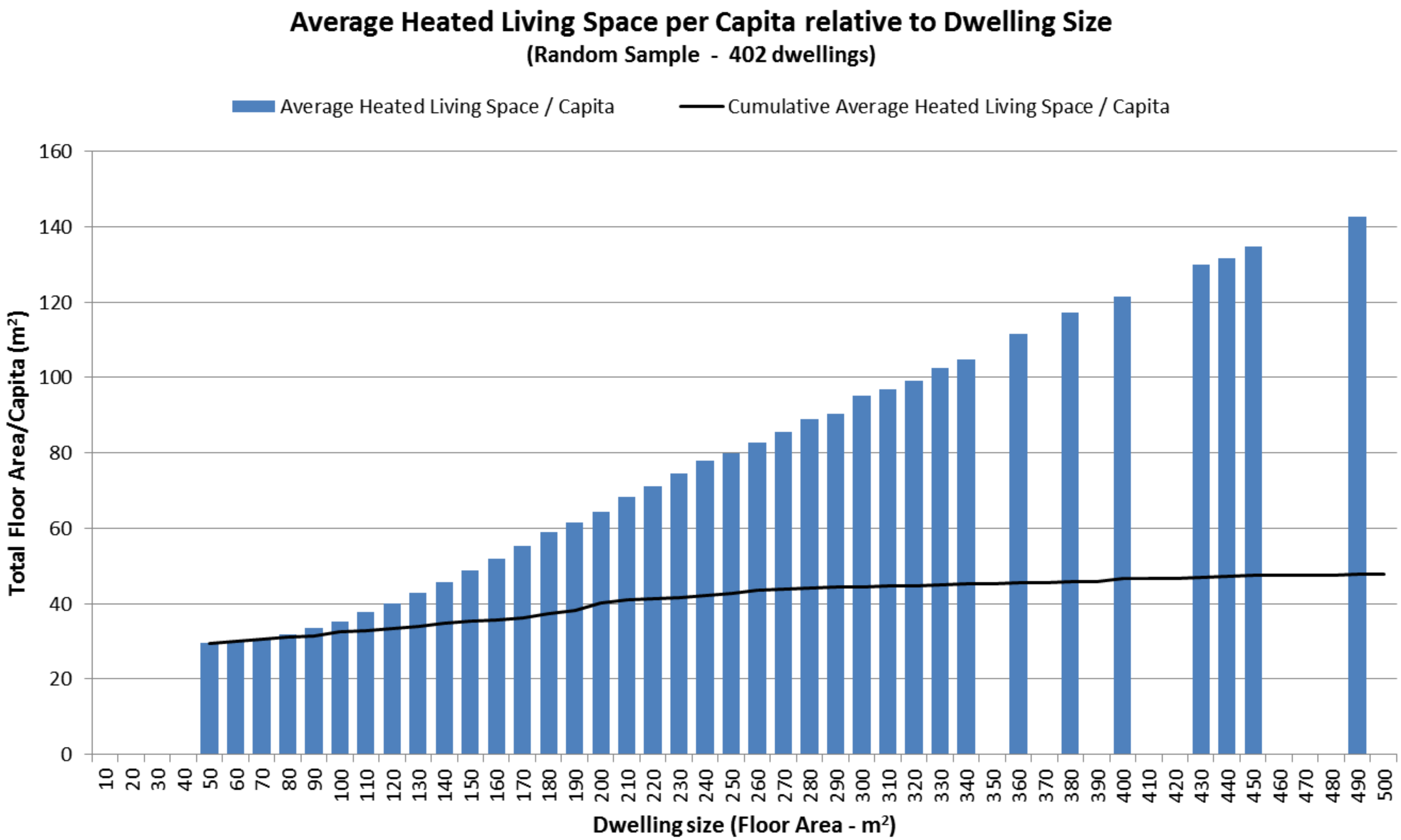

Figure E:7 Average heated living space per capita (AED/Capita) relative to the range of dwelling sizes (Histogram and Cumulative) within sample data. Note: Occupancy is calculated relative to total floor area using Formula 1, the histogram is therefore a reflection of the relationship described by Figure 5 (BRE, 2014).

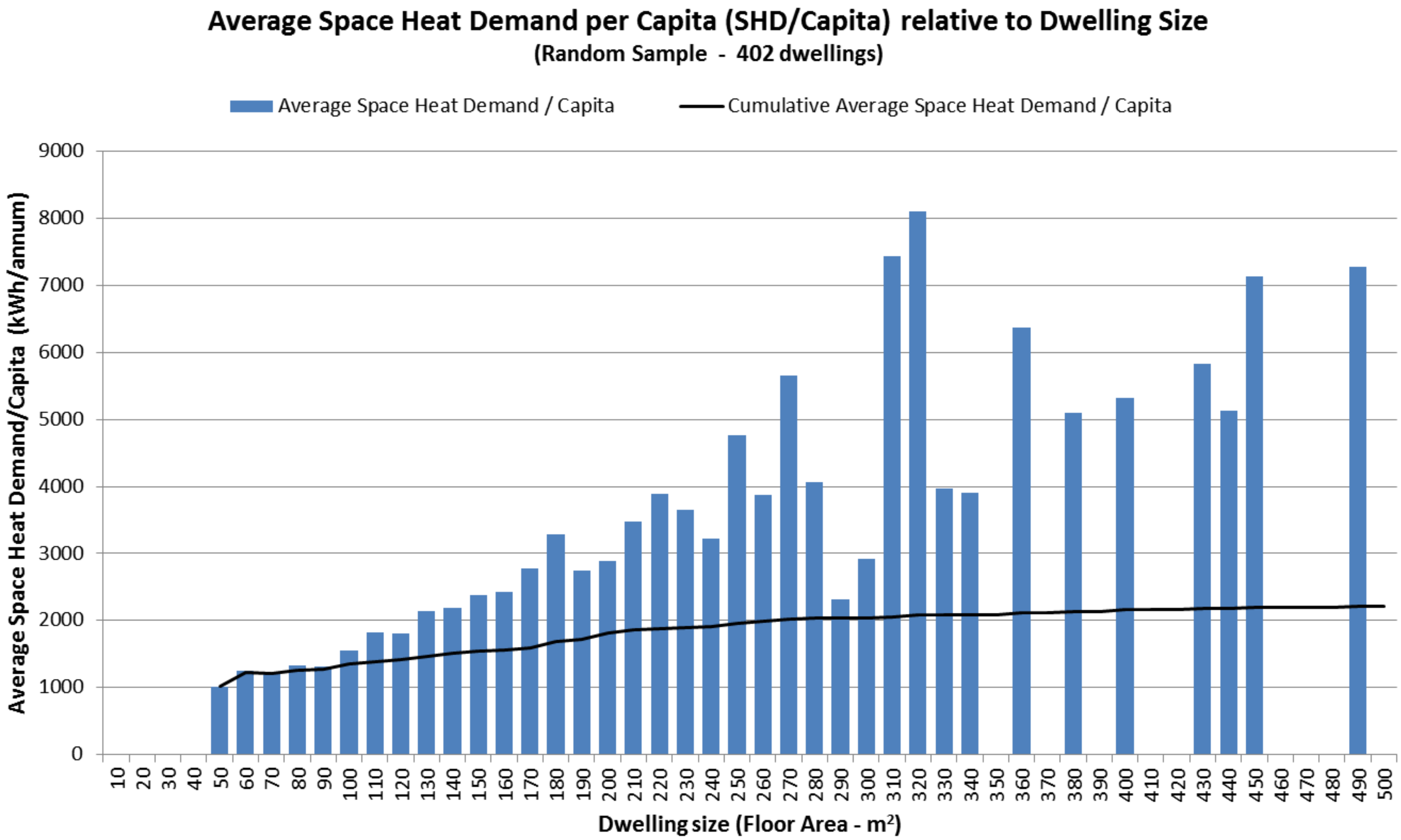

Figure E:8 Average space heat demand per capita (SHD/Capita) relative to the range of dwelling sizes (Histogram and Cumulative) within sample data. Histogram data more random at large dwelling sizes because of the lower numbers of dwellings.

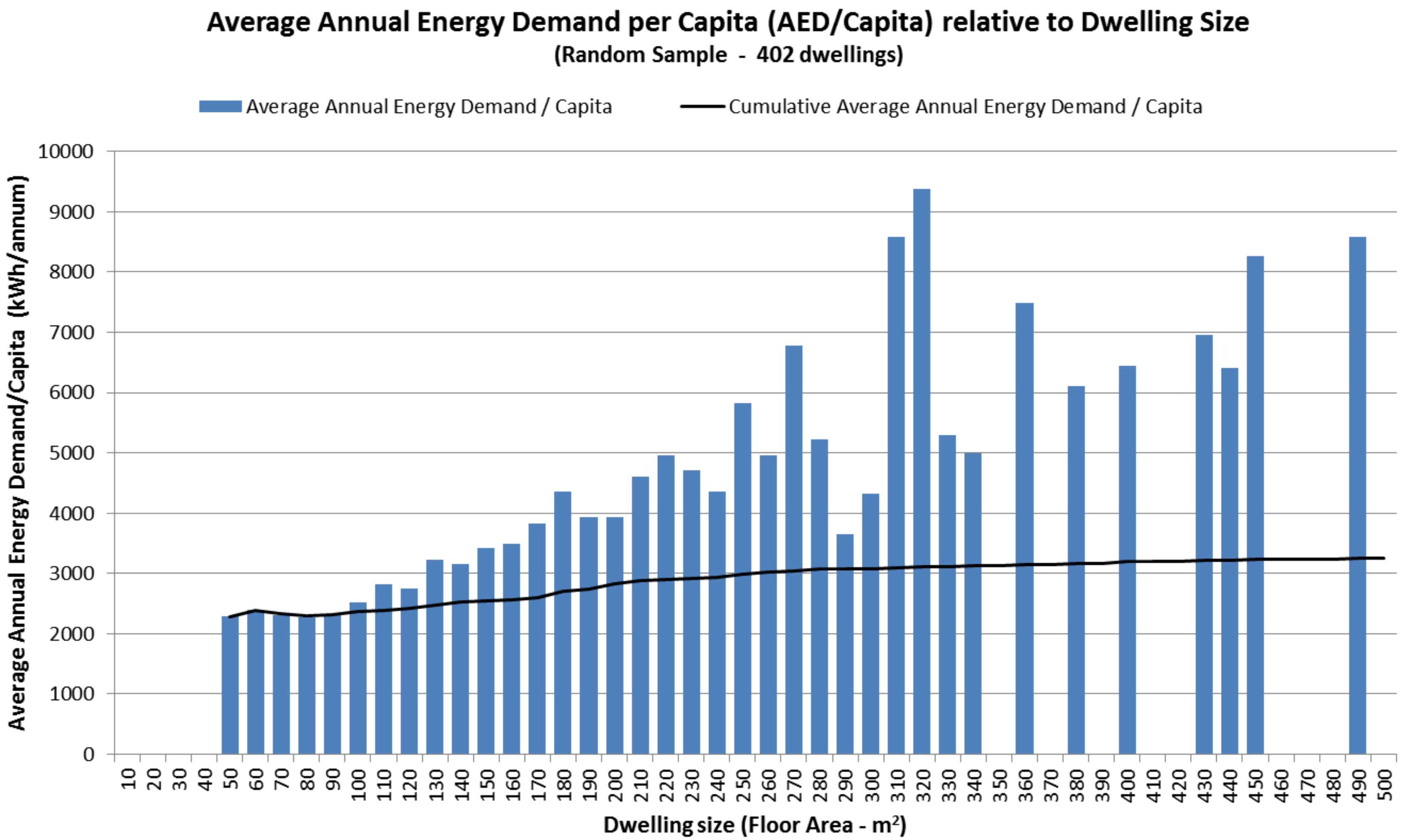

Figure E:9 Average annual energy demand per capita (AED/Capita) relative to the range of dwelling sizes (Histogram and Cumulative) within sample data. Histogram data more random at large dwelling sizes because of the lower numbers of dwellings.

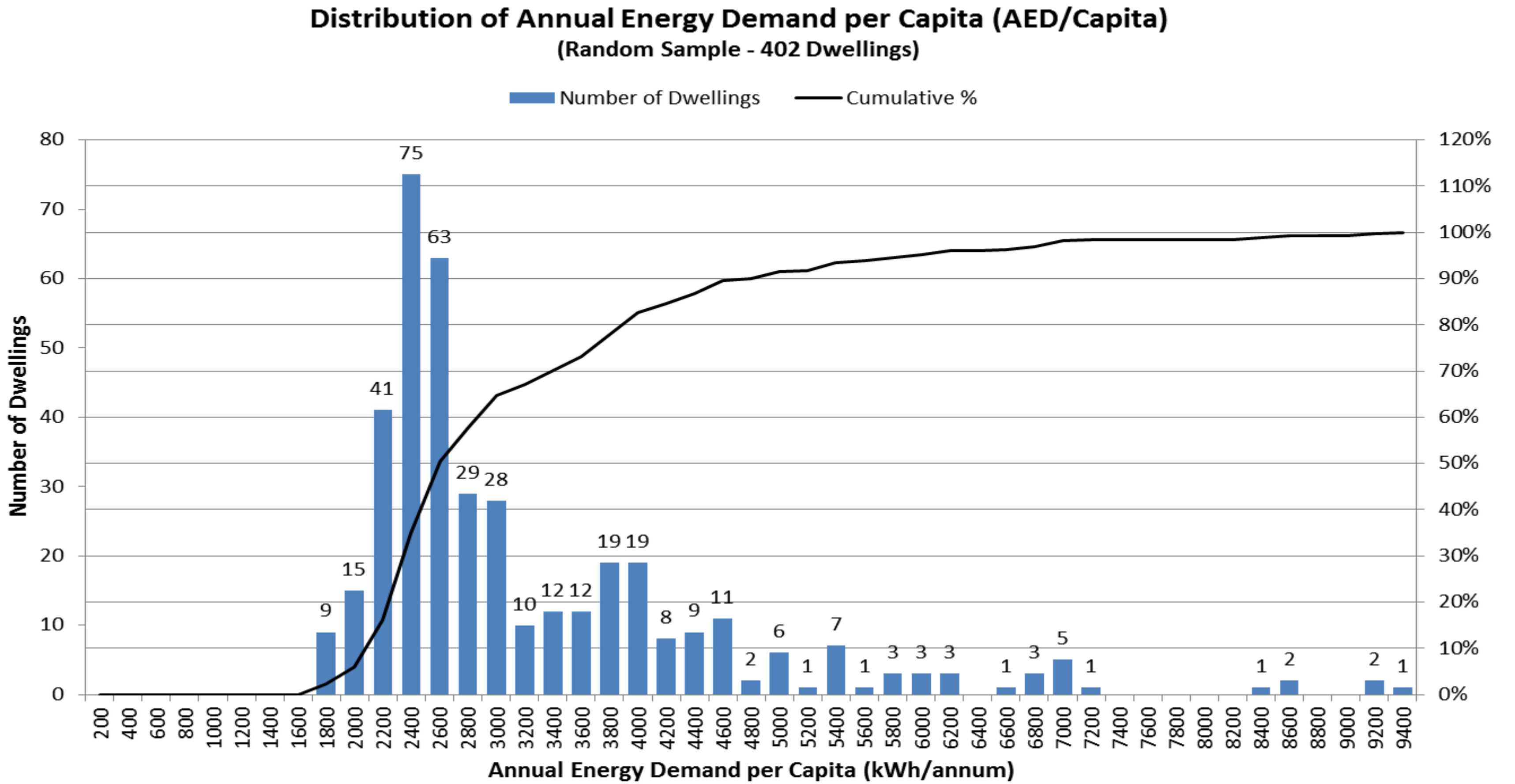

Figure E:10 Distribution of annual energy demand per capita (AED/Capita) observed within sample data (Histogram and Cumulative). Dwellings within this sample were submitted for planning between 2012 and 2014, and were either completed or under construction in 2015 when the study was undertaken. They were all built under the Scottish Building Standard 6.1 requirement for a 30% reduction in CO_2 emission.

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