Can you make money from active buildings? Challenges facing business models

A white paper on behalf of the Active Buildings Centre Research Programme

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Executive summary

To meet the UK's legally binding target for Net Zero carbon emissions in 2050, energy use in buildings will have to be almost completely decarbonised. In 2017, space and water heating were directly responsible for 85 million tonnes of CO_2 emissions, 17% of the UK total (Committee on Climate Change, 2019). These emissions have only fallen by 11% since 1990, far below the rate achieved by the UK overall, and the buildings sector is widely regarded as "hard to decarbonise". Nonetheless, analysis for the Committee on Climate Change has shown that improving the energy efficiency of buildings and switching to low-carbon heating systems can reduce emissions to very low levels by 2050.

Other changes will greatly increase the proportion of electricity generated by wind and solar power, and electricity demand will have to become more flexible. Active Buildings can help.

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An active building (as we define it) goes beyond the high insulation standards and low-carbon heating expected of all new buildings, adding thermal and electric storage devices and control and communication equipment. The technology will be smartly and automatically controlled so that a comfortable temperature interval is maintained in the building. During periods of electricity or network capacity scarcity, active buildings will reduce electricity demand and take power from their own storage, moving demand towards times with relatively more electricity generation.

The bodies involved in today's electricity (and gas) retailers will likely be replaced by energy service companies. These companies, or independent aggregators, will offer flexibility services to the system operators. The electricity industry will have to establish communication protocols and regulations that allow the necessary data to be transferred between multiple parties.

One key obstacle to finding a successful business model is that creating an active building involves up-front costs – in storage and communications equipment – borne by the developer. Without strong expectations of a higher price when the building is sold, developers will not spend more than the minimum required by regulation. Some business models, such as Build-to-Rent, may avoid this problem because the developer intends to be the long-term owner, and to attract tenants based on the building's amenity value, which should be enhanced by a high environmental performance.

When the building is in operation, other challenges must be overcome. Domestic users will need control systems that can reflect their preferences – and changes in these – without more complexity than they are willing or able to handle. Operating an active building involves giving up some data and some degree of control, in return for payment (or bill savings) and households may expect payments that are larger than the benefits an active building can create. Non-domestic users may be able to cope with more complexity but will also be (even) less forgiving of failures, given the often-critical nature of energy supply for their businesses. On the other hand, there are already several aggregators offering demand response services to the transmission system, offering useful experience for the scaling-up of these business models.

We identify several questions for policymakers. Are there aspects of current regulations, such as the supplier hub model in which each consumer has a single energy supplier, which might inhibit the development of active buildings and a more complex set of trading? Do active buildings offer better prospects for local energy trading within communities, and should this be encouraged? How far do the benefits of this trading depend on arbitraging the gap between retail and wholesale prices, a gap which mostly exists to recover the fixed costs of the networks and government environmental policies? How far can expected demand response from active buildings be used to reduce the amount of spare capacity in the electricity system (particularly local networks), if the delivery of that response is uncertain? How much do the benefits from otherwise-identical buildings depend on their location or usage, and in that case, are blanket national approaches sensible? Since the benefits from active buildings are very likely to grow with the amount of variable renewable generation and the electrification of the energy system, is there a case for initial subsidies or other support measures to ensure that the technologies, business models and supply chains are developed in good time?

Several things need to be done to allow active buildings to move beyond the "bespoke" stage. Standards must be developed so that equipment developed by different manufacturers can work together. Work is needed to understand the benefits from active buildings of different types in different locations, so that their optimal number can be estimated, and supply chains developed. To allow a range of approaches to operating active buildings, network operators and their regulators should designate "sandpits" where regulations can be relaxed in a limited way on a temporary basis. Any obstacles discovered should be removed from the energy industry's network and settlement codes, in consultation with all relevant stakeholders (including those currently outside the industry's normal consultation constituencies). To demonstrate the benefits that active buildings can already provide for their users and the electricity system, lessons from the Active Buildings Centre's demonstrator projects will be widely publicised.

Introduction

To meet the UK's legally binding target for Net Zero carbon emissions in 2050, energy use in buildings will have to be almost completely decarbonised. In 2017, space and water heating were directly responsible for 85 million tonnes of CO_2 emissions, 17% of the UK total (Committee on Climate Change, 2019). These emissions have only fallen by 11% since 1990, far below the rate achieved by the UK overall, and the buildings sector is widely regarded as "hard to decarbonise". Nonetheless, analysis for the Committee on Climate Change has shown that improving the energy efficiency of buildings and switching to low-carbon heating systems can reduce emissions to very low levels by 2050.

Many of these heating systems will use electricity, often to power heat pumps. Power station emissions from generating the electricity used in buildings were 10% of the UK total in 2017, but by 2050, most of the UK's electricity will be from low-carbon sources. Much will come from solar PV panels and wind farms, with variable outputs that will not match the pattern of demand for energy services. The demand side will have to become more flexible, and Active Buildings can help.

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Active Buildings will store heat and electricity to offset changes in the amount of power available from the grid. This can create value for their occupants and the electricity system (Section 2), but are there any business models that can capture this value as an incentive for the consumers and profit-making firms that need to be involved? The value and the costs of creating it are distributed across a network of developers, their supply chains, the building occupants, their energy suppliers and electricity system operators (Section 3). Are the networks too fragmented, or do current regulations prevent Active Buildings from reaching their potential? Residential and non-residential buildings face some different issues, which we consider separately (Sections 4 and 5). There are important questions for policymakers (Section 6). While some of these cannot yet be answered, we set the next steps required to make progress with Active Buildings (Section 7).

1. Active buildings

How does an active building provide flexibility? Any new building (and this consortium is focused on new buildings) will be highly insulated and equipped with a low carbon heating system instead of gas heating. An active building (as we define it) goes further, with thermal and electric storage devices and control and communication equipment. The technology will be smartly and automatically controlled so that a comfortable temperature is maintained in the building. During periods of electricity or network capacity scarcity, active buildings will take power from their own storage or avoid running the heating system and other power loads, if remunerated accordingly. Sometimes, the heating can be delayed or shifted forward without the temperature falling out of the comfort interval, moving demand towards times with relatively more electricity generation. This approach is illustrated by previous work undertaken by the Energy Systems Catapult (2019) who demonstrated the heating component of energy consumption could be shifted to help reduce peak load, as shown in Figure 1.

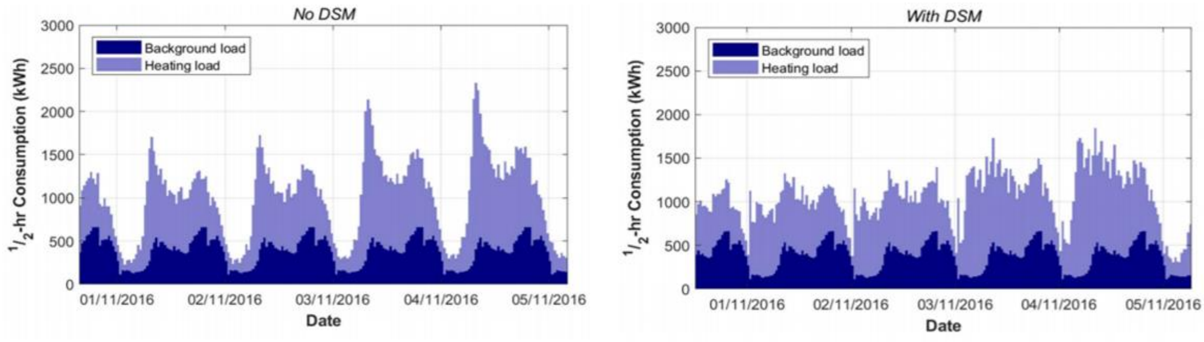

Figure 1: Electricity consumption profiles with and without DSM, for a four-day period of the simulation. Source: *Energy Systems Catapult (2019).*

Since most UK buildings are currently heated by gas, switching some of them to electric heating would add a significant additional electrical load, even if per-building requirements were significantly lower.[1] The thermal inertia of active buildings can be exploited to shift electricity demand, in the same way that hot water could be preheated (given insulated storage tanks) or electric vehicles could be charged exploiting times of excess (and hence cheap) electricity supply.

Average annual electricity consumption per household in kWh		**2012**	**Future**
Shiftable load	Dish washer, washing machine, dryer	197	197
	Hot water	436	436
	All private vehicles electrified	0	3,650
	Electrified heating (Passivhaus; 10% of today's load)	0	1,500
Total shiftable load		634	5,784
Non shiftable load		2,703	2,703
Total load		3,337	8,487

Table 1: Annual electricity consumption per typical (gas-heated) household in kWh in 2012 and a future scenario with additional demand from an electric vehicle and electrified heating; 2012 data from the sample presented in Palmer et al. (2013); Future EV and heat consumption based on 100% EV diffusion, 20 kWh/100 km and 1 EV per household; heating a building of Passivehaus standard needs 15 kWh/m^2 p.a.

The UK builds around 200,000 homes a year, so that over a decade, 2 million homes will be added to the stock. These homes would have annual electricity loads of around 17 TWh, two-thirds of it potentially shiftable (Table 1). The non-heating load of 23 GWh per day could be shifted throughout the year. If heating was only required for half of the year, that would give an additional 18 GWh per day on average during those days. Without demand-shifting, those 41 GW would be unevenly distributed across the day and it is likely that several GW of load-shifting would be available from active buildings in some hours, before considering any contribution from energy storage.

Active buildings will require control systems to manage all these sub-activities, and further coordination of neighbouring active buildings could in theory generate additional gains.

[1] New buildings require significantly more insulation than those from the past, and one that met the Passivhaus standard (which is stricter than currently-planned requirements) would have heating needs around 90% lower than the current building stock. Hydrogen-based heating systems would not directly contribute to electrical load, but the hydrogen might come from electrolysers that could be a significant source of flexibility.

Standardising these elements and their communication protocols would improve competition, facilitate interoperation and allow for the capture of data.

Data can be considered as a further important source of value added for active buildings which could help electricity system operators to plan more efficiently. However, it may be problematic to collect, secure and sell such private data, without affecting the acceptance of active buildings (Spence *et al*, 2015). On the other hand, the residents need to be able to set the control unit to reflect their preferences (like the comfort interval for heating or exceptions from routines) without too much complexity.[2] These issues have already been considered for electric mobility (Kempton and Letendre, 1997). In particular, customers are more willing to join Vehicle to Grid (V2G) energy storage schemes if these guarantee that they will always have enough range for unforeseen journeys (Geske & Schumann, 2018).

Given the advances made in building design and operation, previous research has developed scoring-criteria to help differentiate and explain the evolution of passive, smart and intelligent buildings to challenge the ambiguity which exists regarding the features of these building categories (Buckman *et al.* 2014). The features and requirements of buildings have progressed from maximising occupant comfort based on indoor conditions such as relative humidity and temperature, to the use of multiple integrated and advanced systems which rely on controls, sensors and actuators to react to conditions outside of the building envelope. Integrating the technology required for these services will require additional capital investment but could be enabled by new business models which ensure a clear and well-defined value proposition, service and solution for the building's user.

The challenge for 'active' buildings will be to deliver on the requirements as mentioned whilst also characterising and prioritising loads to enable a response to the grid power balance challenge caused by more renewables and low carbon technology being introduced to the system (Wang, 2016). The integration of communication between building devices and the grid plus specific algorithms to control power management functionality will be required.

In a conventional fossil electricity system (Figure 2), appliances in buildings are a source of load only. Buildings receive electrical energy to satisfy these loads through the distribution network, which is operated - mostly passively - by a distribution network operator. They in turn are supplied by power generators via the transmission network, and the transmission system operators stabilise the network by buying flexibility on markets. Electricity supply and the use of the network are metered and billed by an energy supply company which has an exclusive contract with each of its customers.[3] The energy supplier buys power in the wholesale electricity markets and pays infrastructure usage fees to transmission and distribution system operators according to the measured loads.

[2] For some older people, in particular, "smart controls" can be perceived as complex and disturbing (Hine, 2019). The active buildings consortium is researching user experiences with these control systems and how they can be improved.

[3] Each household or business is typically a separate customer, but the landlord or largest user in a multi-occupancy building will occasionally deal with the electricity supplier on behalf of others.

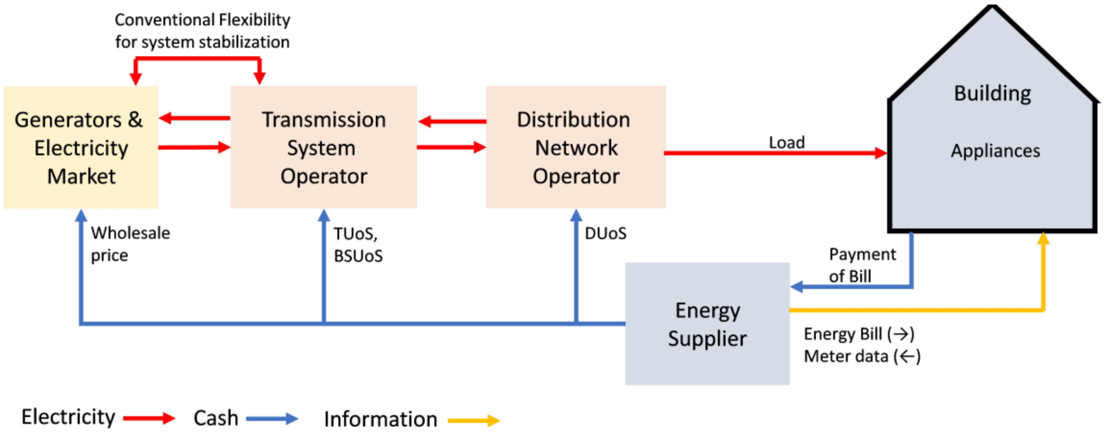

Figure 2: Classical electricity system driven by passive loads

In a system with active buildings (figure 3), the institution of the aggregator will be added. They will be responsible for collecting (in a more or less close relationship with the energy supplier) flexibility signals (e.g. prices) from the wholesale markets, transmission and distribution system operators, bundling them and communicating the demand for flexibility towards the buildings or directly controlling the loads or storage in the buildings. There are already several well-known concepts around the provision of flexibility: Demand Side Response, Vehicle to Grid exchanges of power and combining buildings to create Virtual Power Plants.

This additional flexibility and the spatially distributed renewable generation have made the flows of electrical energy bidirectional and larger. As the operation of the system will be more active to improve the efficiency of the assets the complexity of the system will increase sharply. Therefore, beneficiaries of the flexibility potential are distributed across the entire value chain of electricity, which complicates the design of business models.

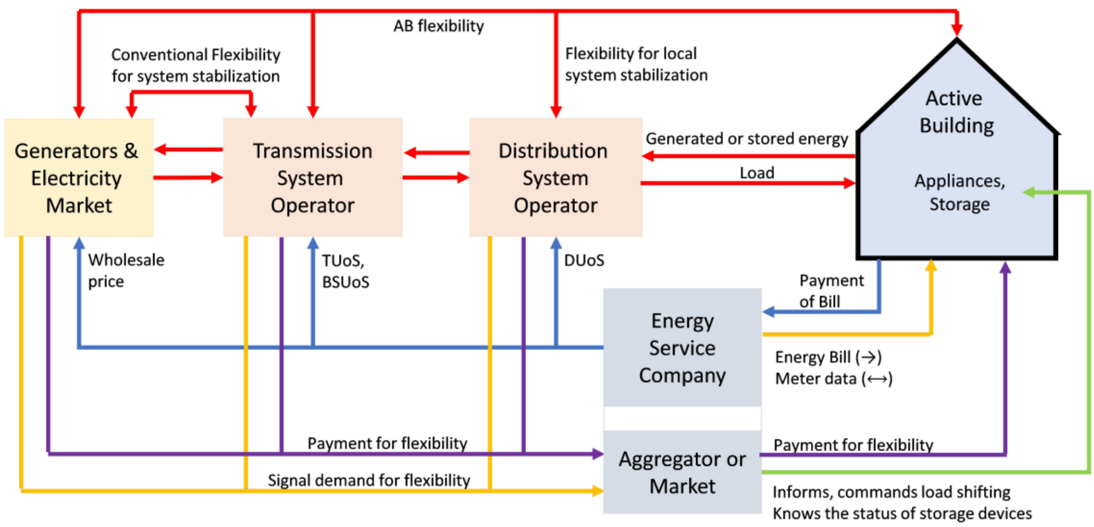

Figure 3: Electricity system design with active buildings, aggregator or market and additional flexibility provision by the building. The aggregator or market receives signals from markets or system operators and provides signals for the operation of appliances and storages within the building. TUoS: Transmission use of system charges, DUoS: Distribution use of system charges, BSUoS Balancing services use of system charges.

The responsibility for creating and capturing value from the services mentioned is not confined to one market stakeholder and will rely on energy retailers, aggregators, energy services companies and project developers, and the business model innovation associated with active buildings is reliant on the convergence between the building, energy and ICT technology industries (Boston Consulting Group, 2018). However, current market arrangements prevent the value creation opportunities from being realised. For example, the supplier hub model imposed by the regulatory framework allows for end customers to interact with the energy system only via a licensed supplier, therefore limiting the ability of active buildings to share resources between one another. Therefore, it is vital to understand the value proposition and associated services and solutions created by an active building in today's market whilst also considering future market arrangements, given the pace of transition within the energy system (UKERC, 2019). Understanding the non-economic value created by active buildings such as whole life cycle embedded carbon and energy are additional important considerations, but existing regulations do not provide an appropriate mechanism to quantify their value (Chau, 2015).

2. Who is involved?

The life span of buildings can be split into the construction (or development) and the operation phase, with different actors involved. The building and the estate are initially developed by the builder, in coordination with the potential homeowner or in anticipation of their wishes (if the building is sold on the market). The building is then used by the occupant in interaction with energy service companies and system operators. In the 35% of UK homes that are not owner-occupied, and in tenanted business properties, there are additional economic problems, since the up-front costs of investments that reduce operating cost are borne by developers and owners (left branch in figure 4), while it is the occupants that later benefit from lower operating costs (right branch of figure 4). This problem arises when investing in energy-saving technology e.g. energy-efficient building renovation, but also with investments in the activation of buildings. However, transferring the energy costs to the building's owner does not solve the problem, as the residents lose any financial incentive to save energy.[4]

The active building interacts on the investment side with the owner (who may be the occupier), the developer of the building and on the operational side with the occupier, the distribution network operator (DNO), the (Transmission) System Operator, aggregators and the energy service company (ESCo). The operational relationships are also presented in figure 3.

[4] It is worth noting that some occupants would still conserve energy for environmental or other reasons.

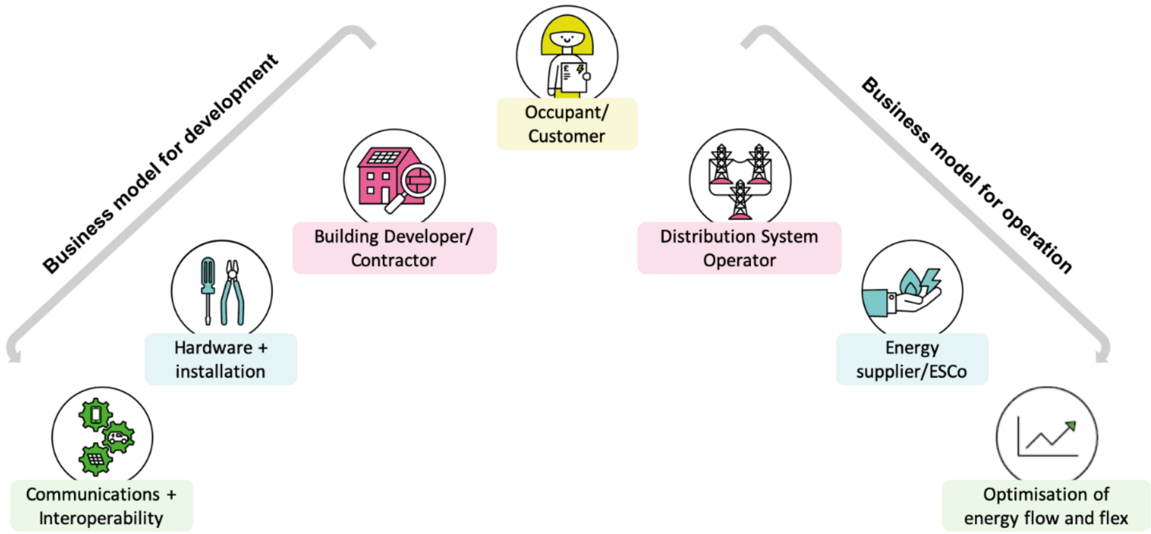

Figure 4: Business models for development and operation of buildings.

The principal-agent problem creates a significant barrier to the realisation of economic benefits created by active buildings, particularly in scenarios where building developers are required to invest in the technology to enable flexibility services as they may not be in a position to capture the value themselves. This value may instead be captured by the occupant, services company, aggregator or network operator, which would give the developer little incentive to invest time, money and effort to create it.

The developer's business model is ultimately founded on a value proposition which delivers a satisfactory product to the end customer whilst managing the value chain, from land acquisition to product delivery. Each component of the value chain also relies on a business model which satisfies the developer's delivery requirements and many developers have established supply chain partners to ensure the process is streamlined and standardised

In contrast, the active building business model for operation is reliant on a value proposition where user comfort is maintained and ideally optimised. The control system must be able to minimise the inconvenience to consumers by providing a level of automation in the decision-making process whilst also retaining sufficient flexibility or override for the consumer. Therefore, a communication network that connects the key electrical appliances and allows them to be remotely controlled, monitored or accessed will be required along with commitment and acceptance from the building user, as some may prefer not to relinquish control of their building (Spence *et al*., 2015). The risk of this is dependent on the building type and sector (i.e. domestic or non-domestic), and the control systems used within active buildings must account for and factor in the adaptability of different load profiles and occupancy patterns of these building/user types. Here, adaptability is referred to as the ability (and willingness) of the consumer (or their automated equipment) to respond to demand response signals and requirements while achieving the comfort levels they desire. Therefore, a highly interconnected controller, actuator and aggregation solution eco-system is likely to be required from a range of different manufacturers within a fragmented supply chain.

Given the need for integration of multiple technologies, a remote and potentially predictive control system could be utilised to enable the integration and optimisation of hardware, communications networks and optimisation platforms and it is unlikely that consumers would wish to manage and control all three of these elements. It is more likely they will be controlled by a third-party service company or aggregator as discussed later in this report. The inclusion and integration of these service companies early in the building design process will be required to help support the creation of new opportunities for the supplier, aggregator and energy services business models within the value chain, as shown in figure 4. Co-ordination of these stakeholders across the entire build process will likely be costly, time consuming and present commercial risks as the value of the flexibility services will be set in the future and be unquantified. Therefore, the viability of the business model will likely be improved if these resources and activities are integrated into a single commercial entity leading to the creation of energy service developers, a strategy which is now appearing in the market.

Similarly, other sectors of the new build market, such as build to rent (BTR), may offer more feasible routes to realising the value associated with active buildings. BTR business models are still reliant on rental income, however there is less focus on the transactional nature of a landlord and tenant lease and more emphasis placed on onsite services and quality of build. BTR developers have identified that tenants focus on 'internal' factors, such as amenity within an apartment and therefore management efficiencies such as communal heating systems and new technology are often included to help reduce operating costs and satisfy user demand. The inclusion of utilities, long-term tenancy, optimisation of operational costs and customer experience are key advantages and create clear opportunities for energy service providers/developers who can deliver innovative services using modern technology, such as on-site generation and EVs. An indication of how this service flow could operate is illustrated is shown in Figure 5.

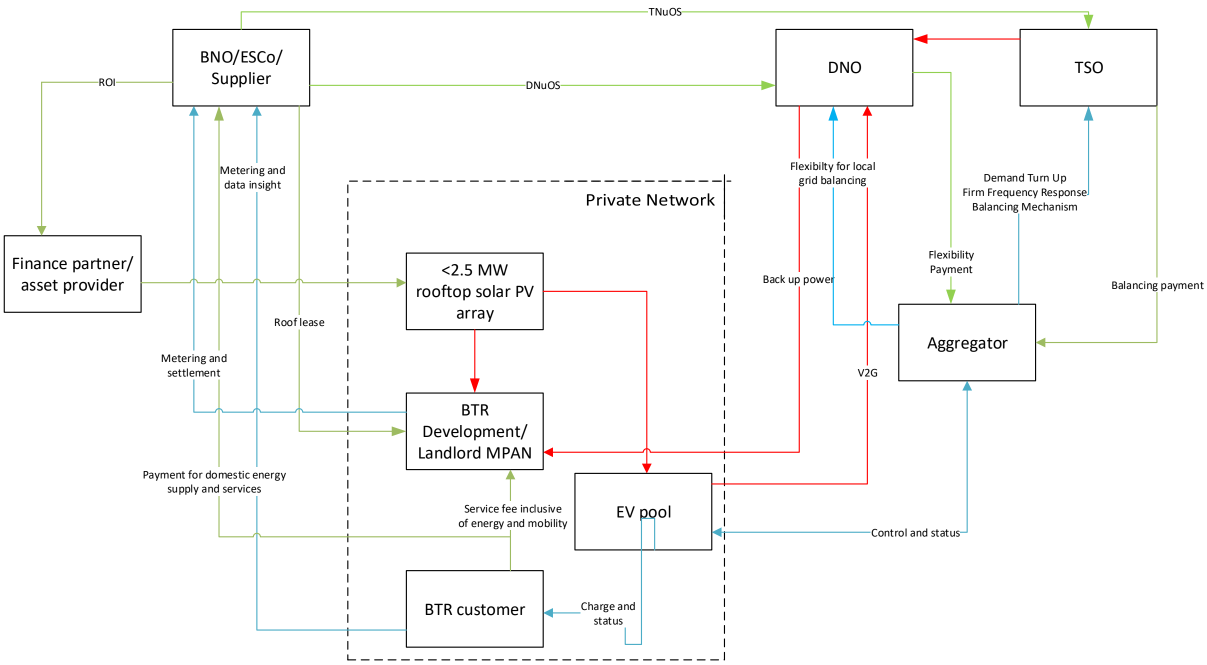

Figure 5: Illustrative service (blue), cash (green) and power (red) flow on a build to rent development, where ESCo is investing in and utilising PV generation to lower the average unit cost of electricity supply to domestic customers within the building, whilst also enabling local flexibility services to DNO through V2G. The ESCo would act as building network operator (BNO) and energy supplier (BRP), maximising value of on-site generation through minimising use of DNO cables and infrastructure.

Box 1: Demand response trials

A new Smart Community

Engie, the energy and services group, is transforming the former 1GW Rugeley coal fired power station site into an entirely new sustainable and smart community. The regeneration of Rugeley Power Station will be the first time a major UK energy company has led the repurposing of one of its own sites, and could be entirely maintained by green/renewable energy, up to 50% of which could be generated on site. The scheme aims to present an innovative, replicable, and scalable energy solution – with new energy business models, local energy marketplaces and inclusive design offering benefits to the surrounding community.

Aggregating Heat Pumps

The "Greater Manchester Smart Community Demonstration Project" (NEDO, 2017) installed smartly controlled heat pumps in 550 social housing properties to test a range of demand response strategies. Each pump provided an average 0.6 kW of initial demand reduction in trial periods on winter mornings and evenings (falling to 0.2 kW in summer), although the amount fell over time, given the need to maintain the occupants' thermal comfort (which was achieved). The trial was less successful in turning up the pumps at times when the grid might have a surplus of power, but the installations did not did not include the predictive controls that could have turned down the heat pumps before such events became likely, creating the space for additional demand without breaching thermal limits.

An intelligent energy platform in operation

Kaluza is an intelligent energy platform that introduces new flexibility into the energy system by optimising individual devices and is part of the energy supplier OVO Group. Over the period of a few weeks a range of household batteries aggregated through the Kaluza platform responded to signals dispatched from Western Power Distribution's control centre, highlighting the potential for smart, active homes to not only provide solutions to peak loads but also compete with larger batteries and loads. This example indicates that commercial opportunities for smaller scale batteries and V2G exist and indicates that active buildings are a viable and competitive solution in the market.

As we have sketched the sources of flexibility supply, the question arises of how this flexibility can be marketed? The trials and business models (see box 1) show that a supply of flexibility is possible today already. It can potentially be supplied on day-ahead electricity, intraday and ancillary service markets. However, currently minimum supply quantities on those markets require bundling by an aggregator and digital solutions.

Küfeoglu et al. (2019) have analysed digital business models for response services, but found that few were earning revenue from their services, indicating that demand and the price of flexibility is still too low to establish viable (sustainable) business models. This is likely to change in the future as increasing shares of renewable generation coupled with increasing electrification of the buildings, raise demand and thus prices of flexibility. Active buildings could then get competitive advantages. However, a rising price of flexibility would also increase the incentives to reduce demand for flexibility by expanding the distribution network infrastructure and to expand flexibility supply by industrial providers (Grünewald & Torriti, 2013) and centrally operated storage facilities. The net effect must be analysed quantitatively.

A further demand for flexibility could arise locally if distribution network design is based on the availability of flexibility (Klyapovskiy et al., 2019). In this case, distribution system capacity would be adapted incompletely to future bidirectional and variable electricity flows and additional electricity demand (from electric vehicles and heat pumps) in terms of contemporary design practice that does not rely on flexibility. This incomplete adaptation reduces investment costs (or delays them) but creates the problem that the flexibility provider may not be committable to its supply of flexibility. This situation may easily occur if ownership of a connection changes. If the distribution system operator cannot extend capacities quickly, they may not be able to operate the grid sufficiently safely and risk massive costs. Anticipating the risk of default, traditional network operators can be expected to refrain from a design practice relying on flexibility; however non-traditional network operators may be more willing to consider this type of strategy (Vattenfall, 2020).

3. Challenges for domestic buildings

The UK's domestic buildings account for 84% (table 2) of new buildings' total floor area, and 73% of the energy consumed in buildings (table 2), which is one third of total annual energy consumption in the UK. These numbers stress the high potential load shifting in buildings could have in principle to relieve stress on networks. However, the ability to provide demand response is not only dependant on the technology within the building but also the willingness of the occupants, who are ultimately the main customer of the business model. Consumers can take voluntary action and reduce electricity consumption in response to a price signal or reliability-based action (Shariffa et al, 2019), and Eissa (2019) suggests that consumers should manage their loads and generation themselves to help balance the system. However previous research has indicated that altering daily routines to provide flexibility is regarded as difficult for consumers and referenced as 'response fatigue' (Shafie-Khah & Siano, 2018), instead suggesting an automated home energy management system (HEMS) to minimise energy costs whilst ensuring user comfort is not impacted.

Buildings			Residential	Commercial		Total
				Non-Industry	Industry	
Population		Mio	66			
Households		Mio	24			
Size	New builds p.a.	Units	c.200,000			
		Mio m^2	21	4		25
	Stock	Mio units	24	1.1	0.26	25
		Mio m^2	2,256	387	208	2,851
	Owner occupied	%	62	45		
	Mean floor area	m^2/unit	94	332	797	114
Value	Value	bn £	5,915	*32,530	*5,943	
	Average price	£/m^2	2,567	*84,000	*29,000	
		Mio £/unit	0.246	* 28	*23	
Energy Consumption	Buildings (Space+ water heating)	TWh	398	127	22	546
	Non-Buildings	TWh	89	109	218	416
	Total	TWh	487	235	240	962
	Transport	TWh				662
	Total UK	TWh				1625
	Buildings per area	kWh/m^2	176	328	106	189

*Table 2: Key data for the UK building stock in 2018 (*industrial and commercial values from 2008) Source: Ministry of Housing, Communities & Local Government, BPF, gov.uk, own calculation.*

For domestic buildings, consumers are likely to demand compensation for remote control of their appliances and are ultimately at the heart of the flexible residential energy market, the development of which will be reliant on smart electricity service platforms and energy demand aggregators. Previous research (Richter & Pollitt, 2018) highlighted the complexities associated with the development of service contracts which include remote and automated control of consumer appliances. The challenge of building a viable serviced-based value proposition for the consumer is revealed by choice experiment results showing consumers would demand a mean payment of £2.64 per month for accepting remote and automated control (£1.64 per month) and sharing their real-time data with third parties (£1 per month). However, the study also revealed that consumers perceive on-going technical support to be valuable and were willing to pay £0.45 per month for this (on average), giving a mean net payment of £2.19 per month. It is worth noting that as auction prices for Firm Frequency Response (FFR) and Short-Term Operating Reserve (STOR) averaged around £6/MWh in 2019, a customer willing to accept even £1 per month would have to provide over 150 kWh of response, or between a third and a half of typical[5] monthly consumption! Even though the results of choice experiments are sensitive to the way in which questions are asked, the very wide gap between these estimates and the revenues likely to be available suggests that the active building business model should rely on additional sources of value, for example comfort, convenience and the environmental impact, at least until the prices for flexibility increase as more is required. It should be noted the results highlighted a significant standard deviation among respondents, understood to be caused by the heterogeneity of respondents and suggesting that

[5] BEIS statisticians calculate electricity bills on annual consumption of 3,600 kWh for standard customers, and 5,100 kWh for Economy 7 (who are likely to have electric heating).

individual service contracts would be required for each customer. This highlights the importance of data and learning to help tailor service contracts to the occupant of the building rather than a standard tariff and contractual arrangement.

The challenge associated with basing the value proposition of the business model on financial savings alone is highlighted by Godina et al (2018) who find that the use of Model Predictive Control (MPC) and an optimal time-of-use tariff in an energy efficient home can achieve total savings of up to 40% compared to an average home. Additional research focused on understanding the potential cost savings from employing an advanced control method and MPC for heating loads on a sustainable home, and concluded cost savings of 16% and 52% respectively when delivering temperature set points of 24°C (Afram & Janabi-Sharifi, 2017). Cost-based signals could help to further reduce demand during peak price periods which creates financial savings for the consumer. These results are further demonstrated through Octopus Energy's (2020) agile tariff which revealed the most engaged consumers were willing to shift their electricity consumption out of peak periods by 28% or 15.62 kWh over a six-month period. They also reported that costs savings of up to £188 per year compared with standard variable tariffs of other energy suppliers.[6] These results are encouraging and highlight the potential value to the consumer which could be increased further when considering mobility and flexibility services. However, the results of these trials vary significantly and highlight that financial savings alone are not enough to deliver a sustainable business case and cover additional capital requirements.

In addition to high quality build standards like that of Passivhaus, the active building will require the incorporation of a shared communication protocol to enable two-way communication between HEMS and in-home appliances to maximise economic benefits for customer and services to the network. Even without the communications infrastructure described the capital uplift required for Passivhaus is reported to be 8%, which although not a striking deviation still poses a major barrier to wider adoption. HEMS optimisation may help to bridge this gap and research has focused on value creation through technology and identified the benefits of lower consumer energy bills and energy load profile smoothing. However, less attention has been given to how best to integrate the various components and devices which typically operate under a closed protocol Application Programming Interface, and therefore realisation of value within the supply chain will be limited by the lack of commercial and data interoperability (Box 2).

Box 2: Interoperability

Commercial interoperability between businesses in the supply chain refers to their ability to influence another and be able to form commercial agreements. For example, where an electricity distribution network company wants to influence domestic retailers to enable dynamic pricing (with the aim of influencing time of use pricing) then a means of incentivising behaviour is needed

Data interoperability refers to the requirement of a third-party to be able to communicate with end-devices (to affect real outcomes) through energy management applications regardless of which components have been used in the active building. For example, one consumer uses a brand of heating controller and a connected home device to drive it but wants to offer the flexibility to a 3rd

[6] We do not know which companies' tariffs Octopus are using here, and if they have included high-price incumbent suppliers, the saving might be exaggerated in comparison to cheaper firms' offers.

party, who needs to be able to interface with it (and all the other competing market offers).

Speculative housebuilding by the high-volume builders relies upon product and process standardisation to minimise risk and realise profit margins through maximising the value of land. Therefore, any attempts to disrupt this will likely be resisted by the industry, as previously demonstrated by the Government's decision to scrap the zero-carbon policy which was heavily influenced by the housebuilding lobby (UK Parliament, 2019). Similarly, the parties responsible for creating and capturing value from active buildings are not well aligned at present due to appropriate incentives and mechanisms missing from the market.

For example, businesses motivations should be reflected in cost structures so that price and value discovery is truly possible i.e. being able to set the network price to discover whether people are willing to pay for its use at a given time of day rather than avoiding the cost by shifting time of use.

Consider the value created by a proposed business model for an active home which removes the spikes in the demand curve, therefore reducing the costs associated with reserve and peaking plants. The building has removed cost and therefore created value for the network stakeholders. The value from this service would likely be captured via existing demand-side response market mechanisms, however given the additional costs associated with the control technologies required to respond to these signals, the likelihood of the housebuilder absorbing them into their build process is low, for a range of reasons:

1. Due to the speculative nature of the housebuilding industry and fundamental reliance on the reward through efficient delivery and quick sale being greater than the risk/cost of low return and sales, these actors in particular will focus more on regulatory requirements rather than supporting the innovation required to deliver flexibility services, unless they can see the economic advantage of doing so.
2. Housing markets are notoriously complex and vulnerable, given the high number of external variables which impact on the value of housing assets. Housebuilders rely upon product and process standardisation to minimise risk and realise profit margins. Therefore, the industry is unlikely to add further risk to their operations unless the reward is clear and viable.
3. There is uncertainty over whether increased costs for low carbon and flexibility solutions can be recouped via higher market values and therefore valuers and mortgage lenders may be reluctant to incorporate a premium for new active homes. There is also little in the way of environmental value appraisals, given that the environment has no supply cost and no monetary value. Helping people to afford the upfront cost of active buildings with low carbon solutions will be key. The Green Finance Taskforce (2018) showed how new long-term low carbon finance can help, through green mortgage-style products which promote 'green factors' into UK mortgage lending decisions. These options can help to reduce lender risk without distorting competition and can also be bundled with added value and services, as new energy-as-a-service or subscription propositions enter the market. This type of approach has already been launched in the Netherlands where the purchase of a net-zero home allows for an additional £25,000 of borrowing to the purchaser.

Housebuilders therefore require at least one of two things: the purchaser is willing to pay more upfront for a higher-performing home (with subsequent savings),[7] and/or there are alternative ways to capture value using the measures which are typically relied upon to deliver environmental outcomes – energy efficiency, on-site generation and low carbon heating.[8] The business model therefore should outline how the associated value and risk can be distributed amongst the supply chain and may include:

1. Increased sale value of home, since in principle the price of the building (or the rent) could capture the revenue potential and the increase in comfort and therefore provide the incentive to invest. This is still risky for the housebuilder and is reliant on the utility offered to the consumer which is dependent on a service contract and many uncontrollable variables such as lifestyle, affluence, and occupancy. Past evaluations of building prices suggest that the savings potential of energy efficiency investment is only partially monetised (Box 3).
2. Removal of the associated technology costs from housebuilder to services company CAPEX, therefore transferring the risk onto the services company who would need to comply with regulations e.g. key standard license conditions
3. A share of revenues derived from flexibility services – recovery of investment through demand side response (DSR) services, although the flexibility value is still unclear and likely to offer a variable £/kWh.
4. Supply chain diversification - are technology companies required to supplement the existing skills available? The development and use of smart data and networked technology infrastructure must be aligned to capture maximum value from domestic active buildings. The data will guide the control automation systems and ultimately realise the value of the metering infrastructure.

Box 3: Lessons learnt – energy efficiency investment in buildings

As making buildings active involves investment now in return for future savings, it is insightful to look back to experiences of energy efficiency regulation in the past.

Many government policies are based on the fear that investments fail to materialize, even though they offer savings potential, a concept known as the Energy Efficiency Gap. Gerarden *et al.* (2017) review the many possible causes for this, including lack of information, behavioural biases affecting the way that it is used, and problems caused by split incentives (described below). Its existence is controversial, as some economists (e.g. Allcott and Greenstone, 2012) argue that few genuine opportunities are missed; other costs (such as inferior product features; for example, energy-efficient cars are often relatively small) are ignored and engineering estimates of the savings available are often exaggerated. van Dronkelaar *et al.* (2016) carry out a meta-evaluation study of this Energy Performance Gap, finding that actual energy consumption in buildings was on average 34% above technical predictions. The main causes for this are specification uncertainties, user behaviour and poor construction practice.

These studies show that variations in user behaviour are of crucial importance for the performance

[7] An owner-occupier would gain directly from these savings; a social landlord might believe it worth accepting the investment cost to benefit its tenants, while a for-profit landlord would presumably hope to recoup the money via higher rents for higher-quality buildings.
[8] Higher-quality homes can also bring substantial health benefits, amongst others, but few policies currently target these co-benefits of environmental improvements.

of energy efficiency investments, as users have different trade-offs between increased comfort and lower bills. It is nonetheless helpful to have transparent performance indicators that are measured independently of such variations, while still reflecting the building “in use”. Exactly this has been the aim of the European Union’s Energy Performance of Buildings Directive (EPBD). This directive, which came into force in 2008, requires all buildings to have their energy performance certified at the time of their completion, sale or rental (in the UK: Energy Performance Certificate, EPC).

Even allowing for problems in measuring energy efficiency, among others the IEA (2007) believes that energy saving potential in the building sector remains untapped, as there are interpersonal and dynamic split incentive problems (for quantification IEA, 2007; Bird and Hernandez, 2012). In particular, only in the rare cases when developers are the long-term occupiers of the buildings they have invested in do they bear all the building's energy and maintenance costs and face the optimal incentive to weigh savings potential against the cost of investments in energy efficiency. In all other cases, for example a rental or a sale, the potential to lower future energy costs must be reflected in mark-ups to rental or sales prices in order to maintain the full investment incentive.[9]

The first empirical evidence for these mark-ups was found in the 1980s (Laquatra et al., 2002). Back then, energy efficiency was operationalized indirectly through utility bills. However, the investigations are inaccurate because the measurement did not systematically consider the impact of residents’ behaviour. This only changed with the energy performance measurement. Today's studies of how this efficiency measure affects the rental and purchase price of apartments and buildings (Mudgal et al., 2013) find a significant mark-up. The premium is in the order of the investment for the corresponding efficiency measure (Fuerst et al, 2015). However, it is not clear what the ratio of the investment to the potential savings is and the premium on the rental markets is significantly (50%) lower than on the sales markets (Mudgal et al., 2013). So, it is not even possible to fully price in the investment costs, let alone a profit margin. Investors may also fail to capture co-benefits for the occupants such as in-use convenience and better health.

Even if the evidence is still incomplete, it must be concluded that there is an energy efficiency gap due to the split incentive problem in the building sector. Against this background, it is doubtful that active buildings will be adopted in an automatic, market-driven, way when financial incentives are even smaller. Therefore, approaches to solving the split incentive problem must be considered carefully (e.g. Bird and Hernandez, 2012). Finally, many estimates of efficiency gaps use actual energy prices, ignoring the climate externality which offers an additional reason for investment in energy efficiency and active buildings when carbon is under-priced.

Advanced control, digitalisation and connectivity will help to reveal customer needs and preferences towards tailored services which include heat, power and mobility. Companies who process data into useful information will emerge and accelerate the growth of services enabled through the digital revolution, helping the supply chain to innovate, integrate, deliver scale and help lower the cost to serve.

Therefore, it would appear that the business model for active buildings is heavily reliant on the supply chain and their ability to integrate niche technical solutions into existing market based

[9] However, transferring a share of the energy costs to the developer does not solve this problem. If the tenant's marginal costs for energy consumption decreased, the tenant would then lack the right incentive to use energy optimally. Levinson and Niemann (2004) show how this results in economic and environmental damage.

production methods well in advance of the project commencing. Not forgetting, the creation of service contracts to help implement this technological innovation. Product design changes as part of the volume being delivered will also be a requirement of the supply chain as the value of active buildings will be determined by the characteristics of the occupant and enabled through tailored service contracts coupled with appropriate technology, such as HEMS and grid-aware controls.

4. Challenges for non-domestic buildings

While non-domestic buildings account for 27% of the energy consumed in buildings, their value per square metre is more than a magnitude higher than that of residential buildings and energy consumption is twice as high (324kWh/m^2 compared to 170kWh/m^2 in the residential building stock; table 2). This puts a higher pressure on the economic operation of commercially used buildings. However, non-domestic buildings to a certain extent pose the same principal-agent problems already discussed, although in some circumstances the entire development and operation process is managed under one organisation (commercial and retail) and therefore greater incentives exist. Furthermore, many (though not all) non-domestic buildings are larger than almost all homes, so have greater loads that could potentially be shifted. This should lower the transactions costs per unit of flexibility offered; larger organisations often employ energy managers who should be more aware of the opportunities than the average domestic customer.

However, sources of flexibility are likely to differ, as users would not wish to shift loads in ways that interrupt daily working patterns. Understanding and being able to elicit customer requirements is essential to the delivery of service contracts associated with non-domestic active buildings and these service level agreements will require an intelligent scheduling strategy to ensure the customer is not without power when they need it, whilst also integrating on-site generation with storage and loads. Retail, education and commercial offices have been previously highlighted as the top three sub-sectors capable of providing flexibility services, with hot water, heating, ventilation and air conditioning (HVAC), lighting, refrigeration highlighted as suitable sub-loads for services including FFR, demand turn up and STOR (Element Energy, 2012).

Ancillary Service	Service Description	Demand side reduction/load shifting	Energy Storage	Distributed Generation	Direction of policy change
Firm Frequency Response (FFR)	Generation and demand; Monthly tenders.	Minimum 1 MW (single unit or aggregated) Response – within 2–30 seconds (depending on service time). Dynamic frequency – continuous (via operation in frequency sensitive mode). Static frequency – upon instruction (via automatic relay). Dispatch – single point of dispatch or method to provide monitoring for ESO needed.			Trialling weekly auctions.
Short term operating reserve (STOR)	Provision of additional generation or demand reduction	Minimum 3 MW; can be aggregated. Response requirement – within max 240 minutes (20 mins preferable). Sustain requirement – sustain for min 120 minutes; recovery period not more than 1200 minutes.			Transition smaller scale (non-BM) STOR providers to a new IT system to enable efficient dispatch.
Demand Turn Up	Large energy users and generators at times of high renewables output and low demand	Minimum 1 MW; can be aggregated from sites of at least 0.1 MW Average response time and duration - average notice period (2017) - 6 hours 40 minutes. Average length of delivery - 3 hours 34 minutes. Equipment - minute by minute or half hourly metering required.			Designed for near-term (not viewed as lasting "negative" reserve solution)

Table 3: Policy change direction for ancillary services in non-domestic buildings

The services described here are enabled by aggregators as previously mentioned, and at present are critical to the realisation of active building business models. The number of aggregators in the UK market has increased following National Grid's efforts to open up the market for ancillary services and the balancing mechanism. However, their business model is at risk due to the reliance on political support and regulatory mechanisms which have the potential to create unstable market conditions particularly in the capacity market (Goulden, 2018), which has been the subject of recent judicial review. The price volatility in National Grid's auctions may lead to consolidation within the market as aggregators struggle to adapt to the reactive nature of regulatory intervention leading to increased risk of short-term instability. For example, the STOR market utilisation rate decreased significantly in 2019 and as a result of reduced capacity being procured and the auction price settled at £2/MWh. In contrast, for the majority of 2019 the price for FFR was £4.76/MWh but a surge in demand towards the end of the year increased the average price to £11.50/MWh encouraging providers back into the market (National Grid ESO, 2019). Therefore, non-domestic customers may not feel confident that the market for DSR services offers a worthwhile commercial opportunity in the long-term.

The increased costs and risks associated with losing electrical load for these building types mean that the contractual requirements are likely to be more stringent and complex, placing more emphasis on comprehensive service contracts to underpin the business model. Consider a situation where the business model of an active building is compromised as a result of an actuator being replaced with a new device from an unknown manufacturer, resulting in the existing controller being unable to command and achieve desired outcomes. Innovative contract design is required to ensure the feasibility and flexibility of the business model in this scenario. For example, should performance contracts exist between control and actuator suppliers and does accuracy error need to be built into the active building dynamics to form a contract based on range or accuracy (Bathge, 2018)? This research proposed a contract between sensor and actuator on an MPC scheme which consisted of a bound on the error resulting from an unknown intermediate actuator. If such a contract were agreed, how would this correspond to the requirements of the network operator and other stakeholders in the value chain? Further research into this area including the appropriate allocation of risk and how this is best quantified to ensure a successful business model is required.

This complexity coupled with volatile market prices results in the business model of non-domestic active buildings being dependent on the reliability of the demand resource and the ability of the load to be assessed against market technical requirements. Offering insightful profile analysis across a range of sub-loads to enable the forecast of baselines which estimate what share of the load is responsive, potentially through market-wide assessment criteria, is required. Further consideration as to what extent such an assessment or indicator tool is required to enable the business model is required. The assessment criteria would need to be robust and well defined but could cover a range of features including communications, control, interoperability, storage and response time. A certified building may overcome some of the contractual complexities mentioned and also allow those buying or aggregating flexibility to take confidence in the building's ability to provide the services, lowering transaction costs and reducing barriers to entry.

5. Policy questions

The discussion above raises questions for policymakers. No discussion of policy for heating can ignore the fact that the low rate of VAT on domestic fuel could be seen as a negative carbon price for domestic gas and non-electric heating, when the target level is £80/tCO2. The carbon signal for gas in commercial buildings has also been found to be significantly lower than that of electricity (Frontier Economics, 2019), while subsidies for renewable generation add to electricity prices.

Low carbon choices and innovation are not currently rewarded through energy bills, and cost-reflective pricing for network, environmental and social costs would improve the overall efficiency of the electricity system and reduce costs. This would help to shift the balance of energy consumption over time so that low carbon demands become cheaper and mainstream. Through the use of smart meter data, the carbon performance of a property could be incentivised through a carbon credit scheme operated by energy suppliers, rewarding consumers for occupying buildings with lower emissions. However, the distributional consequences need to be assessed to understand any trade-offs between incentives and the effect on those less able to shift to lower-carbon consumption: would a large number of low-income and vulnerable consumers be in this category?

Although tradeable permit schemes and equivalent taxes are thought to be more economically efficient, a carbon intensity standard is considered more practical for tackling hard-to-treat sectors such as buildings and transport, especially as current price signals are low. Appropriate carbon intensity standards would incentivise the industry and create demand for the services mentioned helping to lower the associated costs.

Moving to issues specific to active buildings, what aspects of current regulations and market design are likely to impede their spread? For example, the electricity retail market is based on the concept of the supplier hub, where a single company acts as the interface between the customer and the electricity system. Some suppliers are already developing the aggregation tools needed to allow active buildings to fulfil their potential, but others may not have the skills to do so. Should all suppliers be required to offer these tools, which could dilute the commercial advantage of the early adopters? Should customers be allowed to contract with an aggregator as well as their main supplier? Recent market prices for reserve imply that consumers could only receive their hoped-for levels of returns by offering very large amounts of flexibility; does this imply that government should initially support the market for services from active buildings with subsidies to ensure that they can be deployed at scale when their value increases?

The concept of local energy communities, with active buildings selling power not to the grid as a whole but to their neighbours, is attractive to many people. Can such trading be combined with the single supplier model? Would the supplier need to offer this as an option for their customers (for both buying and selling)? How far should such "local energy" models be promoted, in any case, given that the first principle of electricity market design should be to recognise that the flow of electrons depends upon the physical injections and withdrawals at each point of the network, rather than the contractual arrangements around them – although those contractual arrangements create incentives that may affect those injections and withdrawals. One attraction of "bypassing the grid" is the wide gap between the price that consumers pay when buying power and the much smaller amounts that suppliers offer for taking surplus self-generation. Selling to a neighbour at an intermediate price offers an attractive arbitrage opportunity. Policymakers need to remember that much of the gap between buying and selling prices is required to pay the cost of the networks. Local energy trading might do little to reduce those costs, which depend on the peak flows the system has to handle, but could reduce the share of the costs that the trading customers pay, unless alternative charges for using the networks are introduced.

In some cases, active buildings *can* reduce the cost of the network. This occurs when the system operator chooses to rely on energy supplied (or at least not demanded) by active buildings at peak times to allow it to meet the remaining local demand, rather than investing in more network capacity (Klyapovskiy et al, 2019). This could lead to significant savings at a time when the overall demand for electricity is expected to increase as heating and vehicles are electrified. It also poses a performance risk if some active buildings are not operated as expected (perhaps when a new occupant is less engaged than their predecessor). Should performance guarantees be placed on the occupants of active buildings, or is it sufficient to take account of an assumed degree of underperformance when designing the network?

This example shows that the benefits from an active building are likely to depend on its location as well as on its features – a building on a heat network will not be able to shift as much of its (lower) electrical load as one with electrical heating. Does this imply that it would be inefficient to drive the adoption of active building technologies through nationwide regulations such as building standards? If it is sensible to enhance the standards in this way, would it be politically achievable, given the added cost and uncertain returns to developers? Otherwise, would an incentive mechanism – probably some kind of subsidy – be better? How should such a mechanism be designed? Is the lack of up-front financing more of a problem than the overall profitability of the technology once installed? Questions such as these need answers, and this leads us to suggest the next steps to adopting suitable business models for active buildings.

6. What needs to be done?

To allow active buildings to move beyond the "bespoke" stage, standards must be developed so that equipment developed by different manufacturers can work together. Protocols for exchanging information will be critical, but it will also be important for occupiers and purchasers to know whether their building is active or not. A companion white paper, *Buildings as Infrastructure, not Passive Consumers* (Nikolaidou, E., et. al., 2020), outlines a set of building standards that can be applied at the design stage to determine how far a building, or a development, is active. These should be complemented by a set of ratings that can be applied once the building is in operation, along the lines of existing Energy Performance Certificates. Without suitable certifications, the term "active building" risks becoming discredited from over-use.

Similarly, further work to understand user preferences and the demand for active buildings based on location, the impact on the design and on the business model should be conducted. The existing business model of the housebuilding industry has been cited as a barrier to the development of zero carbon homes, thanks in part to a lack of collaboration and location specific solutions (Heffernan, 2015). This revelation warrants further thought as to whether local area energy planning through more advanced modelling and analytical tools can help support the business model of active buildings. This could be achieved by identifying opportunities for integration and trade-off between energy vectors and their associated networks including demand side energy efficiency measures. Similarly, consideration of local supply chain capabilities and the option to build alongside upgrade of assets such as energy networks and heating systems may help to support the viability of the active building business model.

To gauge the size of the potential market, modelling studies should estimate the benefits available from different numbers of active buildings in different situations. The need for and value from active buildings is likely to vary based on location, and therefore the features may differ due to local factors. For example, a state-of-the-art active building's heating source may depend on whether it is located within a constraint managed zone or if there is a heat network. Local authority housing and social priorities may also increasingly influence the services required from the building. The benefits from two million active buildings are unlikely to be double those of having one million, if some of the services they can provide become oversupplied. Larger buildings will be able to provide more flexibility in most situations than smaller ones of similar design while incurring few extra transactions costs. The Active Buildings Centre are carrying out studies of this kind (Strbac, G., et. al., 2020).

To allow a range of approaches to operating active buildings, network operators and their regulators should designate "sandpits" where regulations can be relaxed in a limited way on a temporary basis. Such small-scale experiments might not be viable commercially, and funding should be available to allow participation by a range of companies beyond well-financed incumbents.

To demonstrate the benefits that active buildings can already provide for their users and the electricity system, lessons from the Active Building Centre Research Programme's demonstrator projects will be widely publicised. These will include a Behind-the-Meter study for an existing low-carbon housing development, amongst others.

To allow for the regular, remunerated, export of electricity from active buildings, the bodies responsible for the industry's network and settlement codes need to review those codes for possible obstacles, and work with stakeholders (including those currently outside the industry's normal consultation constituencies) to remove them. In particular, the role of the supplier hub approach, and the possibility of having a second agent helping the customer to interact with the power system, must be reviewed. Ofgem and other regulatory bodies should review their own rules and procedures for other barriers.

7. Conclusions

While the details need to be developed, we are confident that active buildings will find a viable business model in a high-renewable energy system. They can provide significant amounts of demand-side flexibility, which will prove valuable as supply-side flexible generation decreases.

Unfortunately, buildings are static, and we are in a dynamic environment. This poses several challenges for active buildings. The current energy system still has large amounts of generation-side flexibility, holding down the rewards available for demand-side providers such as active buildings. But the buildings sector cannot wait until these rewards rise. The building sector moves slowly, and three-quarters of the 2050 building stock already exists. Retrofits are sometimes possible, but typically more expensive than building to high standards from the start. A new building without the space for (e.g.) thermal storage has been locked out of the opportunity to profit from its use in future. It takes time to train the construction workforce and gain experience in new techniques and technology; learning-by-doing accumulates gradually. Original Equipment Manufacturers (OEMs) are likely to play a more significant role in a market with active buildings and will be responsible for integrating the sensors and controls required to respond to grid signals. Developing these integrated solutions should help to reduce the supply chain risks imposed on the developers through the provision of 'off the shelf' active solutions. If developers ultimately prefer to walk away from the asset once built, this could allow for OEMs to develop a relationship with the customer and potentially enable long-term recurring revenues. Data collection from the building will allow for continued performance optimisation and ultimately build trust with the customer. This in turn will allow for tailored service propositions which deliver valuable outcomes.

Other new business models combining energy with data and other home services are likely to develop; some will also involve charging (and maybe even leasing) electric vehicles. Charge Point Operators (CPO) are already partnering with automotive OEMs to leverage their sales channels. Could this go a step further and we see developers partnering with automotive manufacturers to offer combined building and mobility services? Should CPOs partner with the low carbon supply chain to offer combined integrated systems to remove risk from the supply chain? As with physical products, these business models need to be proved by the experience of early adopters before the mass market can take off.

There is a gap to be bridged, ensuring that it is attractive to create active buildings now so that they can contribute to the energy system later when they are most needed. Some of the steps are preparatory in nature: using demonstrator projects to learn about both the physical-technical and human aspects of active buildings; improving skills in the construction industry to cover the design and installation of active buildings’ features. Others are financial, supporting the early-stage costs in order to gather a societal reward later. The work of the Active Building Centre Research Programme is already showing that this investment would be worthwhile.

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The Active Building Centre Research Programme

Funded as part of the UKRI Transforming Construction Challenge, the Active Building Centre Research Programme is delivering an evidence-based transformation of the UK's built environment.

Led by the team at Swansea University, the research programme brings together ten leading universities, businesses and service providers to develop and test innovative technologies and ideas that will ensure buildings of all scale contribute to a more stable power grid.

Our collaborative research framework is delivering valuable insight into novel heat storage, data gathering and analytics, building design and optimisation, software development and human interfacing, social science, and wellbeing.

Active Building Centre Research Programme activities are focused on enabling the construction industry to transform into a net zero emissions building sector within the next 30 years.

Transforming Construction Challenge

The Transforming Construction challenge is part of the Industrial Strategy Challenge Fund and brings together the UK's world-leading research with business to meet the major industrial and societal challenges of our time. It provides funding and support to UK businesses and researchers, aiming to transform productivity in the construction industry through the adoption of innovative technologies and the development of a more highly skilled workforce. part of the government's £4.7 billion increase in research and development over the next 4 years. It plays a central role in the Government's modern Industrial Strategy.

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