V2BUILD Final Report

November 2023

ERM

The business of sustainability

About this report

Report details

Report title: V2BUILD Final Report

Project: Vehicle-to-Building User Interface Learning Device (V2BUILD)

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Project partners: Wallbox UK Limited & UK Power Networks

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Project funding and delivery partners

- The V2BUILD project was funded by the UK Government's Department for Energy Security and Net Zero (DESNZ) and delivered by Innovate UK.
- The project was funded as part of Phase 1 of the Vehicle-to-Everything (V2X) funding stream and ran from 1st September 2022 until August 31st 2023.

- The Sustainable Energy Systems team from ERM led delivery of the project. The other project partners were Wallbox UK Ltd, a developer of bi-directional electric vehicle charging technology, who were a funded partner in the project and UK Power Networks, the distribution network operator for electricity covering South East England, the East of England and London. UK Power Networks were an un-funded observer partner, providing valuable insights into the potential network benefits from bi-directional charging.

Project funders

Innovate UK

Department for Energy Security & Net Zero

Project partners

ERM

wallbox

UK Power Networks

Project background and objectives

Project background

- In March 2022, the UK Government's Department for Energy Security and Net Zero (DESNZ, formerly BEIS) launched Phase 1 of the Vehicle-to-Everything (V2X) innovation programme
- The programme allocated £2 million of funding for research and development projects aimed at:
  - Unlocking and expanding the energy flexibility potential of EV bi-directional charging technologies and business models in the UK
  - Accelerating the commercialisation of V2X technologies and services
  - Increasing business and consumer interest in V2X
  - Bringing together diverse stakeholders across the energy and transport sectors to overcome barriers to V2X deployment
- V2BUILD was one of 17 projects funded during Phase 1
- Phase 2 of the programme is now in progress providing £9.4 million to support small-scale V2X demonstrations

Objectives of the V2BUILD project

- Bi-directional chargers are a new technology that has not yet been deployed on a commercial basis. Initial focus in the sector has been on the potential for the technology for domestic buildings, and little work has been carried out to understand the potential for the technology in commercial buildings
- The Vehicle-to-Building User Interface Learning Device (V2BUILD) project aimed to increase understanding of the technical and economic potential for Vehicle-to-Building (V2B) technology for commercial buildings in two main ways:

1. Conduct detailed modelling of V2B operation in different commercial buildings to understand where V2B could be commercially viable
2. Develop a user-friendly online tool to allow stakeholders such as property managers and electricity distribution network operators (DNOs) to engage with the results of the modelling to increase awareness of the potential for V2B

Contents

Summary of aims, objectives and modelling approach

V2BUILD project aim:
Improve understanding of the business case for bi-directional chargers in buildings – Vehicle-to-Building (V2B)

The V2BUILD project set out to understand how V2B could support the decarbonisation of commercial buildings by:

- Maximising the benefit of time-of-use tariffs, to reduce electricity bills for businesses
- Reducing peak building electricity demands to reduce or offset the need for grid connection upgrades
- Helping manage increased electricity demand and system complexity from low carbon technologies
- Making use of vehicle batteries to offset the need for additional stationary energy storage
- Avoiding some of the regulatory and technical complexity of engaging in Vehicle-to-Grid (V2G)

Techno-economic modelling:
This report sets out the results of detailed modelling of the operation of bi-directional chargers in 5 building archetypes

Focus on 3 commercial building archetypes:

- **Offices**
- **Storage warehouses**
- **Hospitals**

2 additional domestic building archetypes:

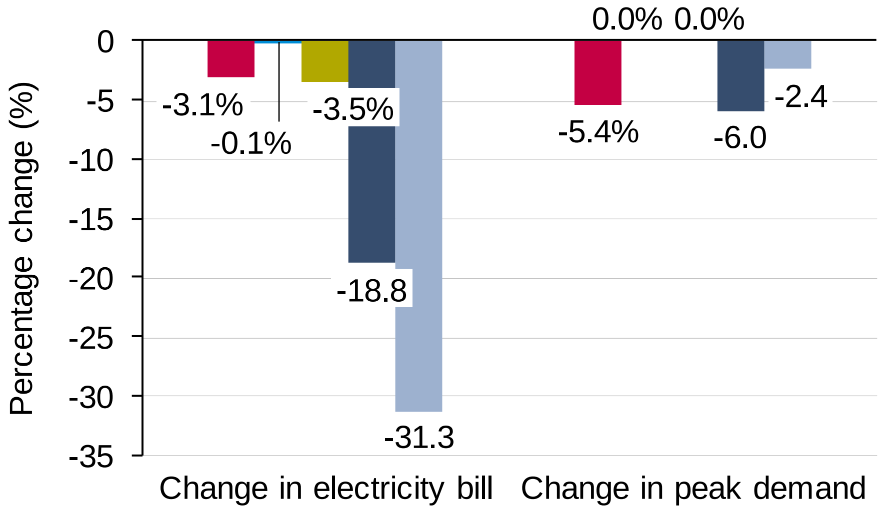
- **Blocks of flats**
- **Semi-detached houses**

Key features of the modelling:

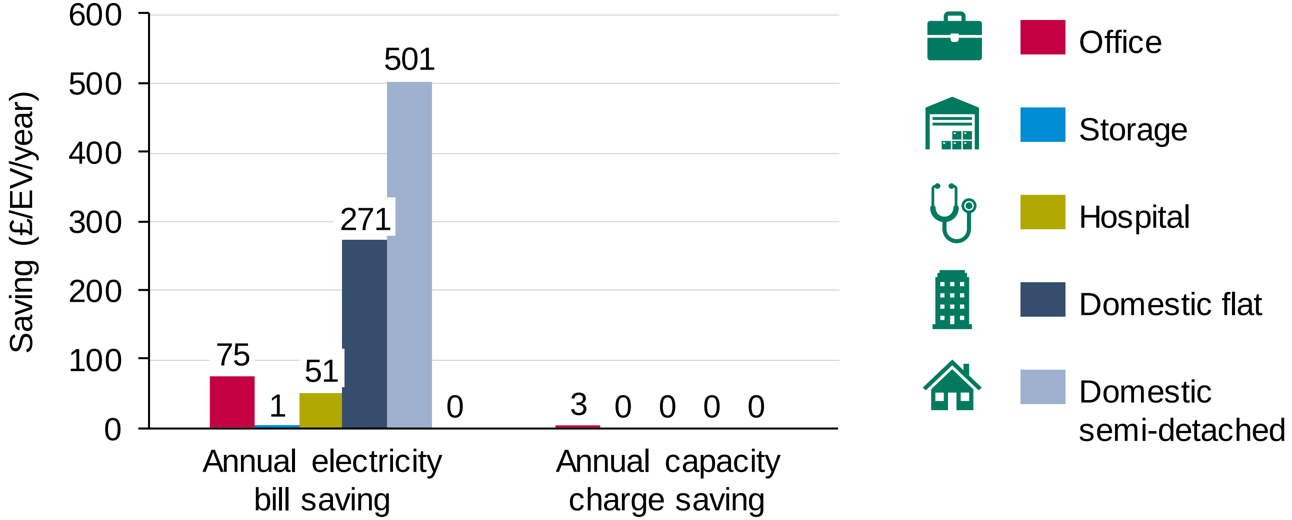
- **Smart chargers are the baseline** – modelling has quantified savings achieved with bi-directional charging that are ***additional*** to savings achieved with smart charging
- Modelling **only considered V2B services to the building** and excluded potential revenues from V2G
- Bi-directional charger operation optimised for 2 priorities: **electricity bill** and **peak demand** reduction

Summary of modelling results: V2B provides limited electricity bill savings and peak demand reduction beyond smart charging for the commercial archetypes, but savings are significantly higher for domestic buildings

Total change in electricity bill and peak demand achieved (%) using V2B compared to smart charging[1]



Total savings in annual electricity bill and capacity charge (£/EV/year) using V2B compared to smart charging[1,2]



- The results above show the electricity bill and peak demand reduction and savings achieved when the model is optimised to balance both electricity bill and peak demand reduction
- All commercial building archetypes achieved bill reductions through V2B without increasing peak demand, however only in the office was it possible to achieve electricity bill savings and peak demand reduction simultaneously
- When optimising only for electricity bill reductions, further savings were achieved in all commercial building types, howeverno peak demand reduction was achieved in the storage warehouse or hospital archetypes
- The greatest electricity bill savings from V2B were identified in the domestic semi-detached house, but flats also benefitted

1: The analysis modelled the operation of smart chargers and bi-directional chargers and the reductions in electricity bills and peak demands are those that are achieved by bi-directional chargers in addition to what is achieved by smart chargers
2: Cost savings shown are achieved by co-optimising both electricity bills and peak demand, assuming high grid connection constraints.

Alignment of vehicle plug-in windows, peak building electricity demand and high electricity prices determines V2B savings

The key advantage of bi-directional chargers over smart chargers is their ability to draw additional charge during certain periods, storing the energy in the vehicle's batteries to be discharged at a later point. This charging and discharging can be optimised to maximise electricity bill reductions and reduce peak demand.

£ Electricity bill savings are determined by alignment of:

- Vehicle plug in windows (**green** and **yellow** lines)
- Periods of high electricity prices (**light blue** line)
- Periods of high building electricity demand (**dark blue** lines)

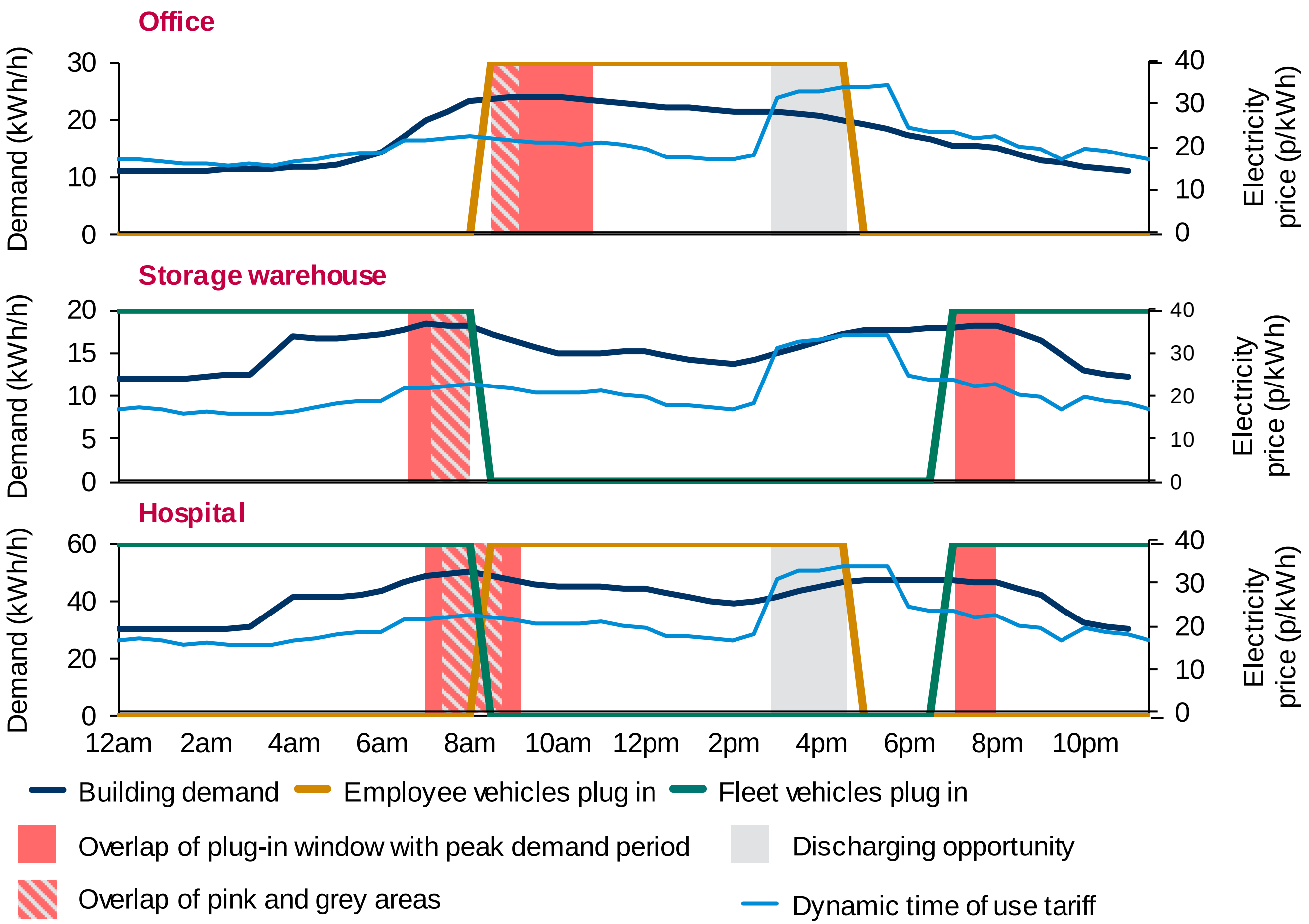
When these three factors are aligned (**grey** areas) there is an opportunity for the chargers to discharge, providing savings beyond what can be achieved with smart charging.

Peak demand reduction is determined by alignment of:

- Vehicle plug in windows
- Periods of high building electricity demand

When these two factors are aligned (**pink** areas), discharging can be used to reduce peak demands on the day of highest demand in the year. If successful, this can reduce the size of the grid connection required by the building, leading to savings.

Vehicle plug-in windows and typical daily electricity demand profiles for commercial building archetypes



Overall, a strong business case already exists for V2B in domestic buildings, however the benefits for commercial buildings are much more limited, when only services to the building are considered

	V2B upfront investment	Commentary on business case for V2B (assuming 15-year lifetime)		
		Baseline case	Significant connection upgrade	Avoid exceeding capacity*
Office	£27,600	No payback on upfront investment expected within lifetime of chargers from savings on electricity bill and fixed capacity chargers	If within ca. 5% of Low Voltage-High Voltage upgrade threshold, V2B may be a preferable investment	No payback on upfront investment by avoiding exceeding capacity charges
Storage	£165,600		Investment in V2B solution may be lower than Low Voltage-High Voltage connection upgrade, but limited peak demand reduction suggests V2B may not be suitable	No payback on upfront investment by avoiding exceeding capacity charges, and limited peak demand reduction potential suggests V2B would not be a suitable solution
Hospital	£176,640			
Domestic flat	£8,280	Payback on upfront investment within ca. 10 years of electricity bill savings	N/A	N/A
Domestic semi-detached	£5,520	Payback on upfront investment within ca. 6 years of electricity bill savings		

- Bi-directional chargers are significantly more expensive than smart chargers, so the additional benefits they offer need to outweigh this
- Domestic properties can expect to make a return on investment for purchasing bi-directional rather than smart chargers
- The modelled commercial building archetypes did not identify sufficient savings to make a business case for bi-directional chargers
- However, it should be noted that this analysis did not consider potential additional revenues from vehicle to grid services, which these chargers could provide. There may also be certain circumstances, such as where bi-directional chargers achieve a small peak demand reduction that avoids a costly grid connection upgrade, where there could be a strong return on investment

*Note: Assumes V2B ensures site avoids exceeding capacity on extreme days once per year

Contents

Report structure

Introduction to V2B	Provides a general introduction to the challenges of decarbonising commercial buildings, the potential for smart and bi-directional chargers and an introduction to Wallbox's bi-directional charging technology.
Risks and limitations	Sets out the results of a literature review conducted during the project, highlighting 6 key risks and limitations for the V2B business case and identifying potential opportunities.
Techno-economic modelling of V2B	This extensive section details the modelling work carried out to understand the operation of V2B chargers in three representative commercial building contexts: offices, storage warehouses and hospitals.
V2BUILD Tool	A key output of the project accompanying this report is an open-access online tool that allows users to interact with the results of the modelling and this section provides information about the development of the tool.
Business case assessment	This section explores the implications of the V2B modelling, assessing the cost of the technology against the potential for electricity bill reductions and savings from reducing peak electricity demand.
Conclusions & future work	The final chapter identifies 10 conclusions from the project, highlighting the major findings and summarising the underlying factors and where further information can be found within the report.
Appendix	A detailed appendix section includes a range of additional material developed during the project that adds further detail to the material in the body of the report.

Contents

This section introduces some of the challenges faced by commercial buildings as they decarbonise and how V2B technology could help

In this section:

- The challenge of decarbonising heating in commercial buildings
- The impact of electric vehicle charging and the capabilities of smart chargers to minimise the cost of charging
- The additional benefits offered by bi-directional chargers to increase the electricity used in low-cost periods of the day and discharge that electricity back to the building when prices increase
- An overview of Wallbox's Quasar 2 bi-directional charging product on which the modelling in this project was based

Overview of the section

Electrification of heating

Electrification of vehicle fleets

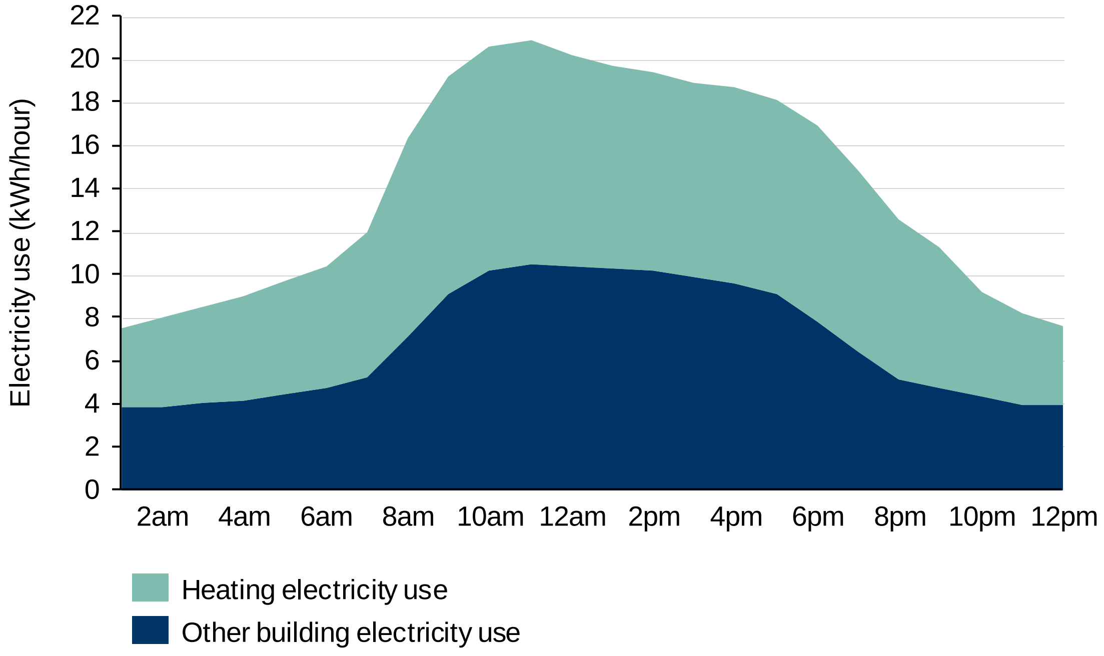
Optimisation with bi-directional chargers

Introduction to Wallbox's Quasar 2 bi-directional charger

Electrifying heating in commercial buildings reduces carbon emissions but increases electricity demand

- Owners, managers and users of commercial buildings are increasingly under pressure to reduce energy use and achieve cost and carbon emissions reductions for their buildings
- Heating systems in commercial buildings typically use natural gas, but electric heating systems such as heat pumps are much more efficient and can reduce emissions even if the electricity they use originally came from burning natural gas
- The chart to the right shows the impact on a typical office's electricity use during a winter day if gas heating is replaced with electric heating
- The **dark blue** region represents the electricity that the office would have used before the installation of electric heating, for computers, lighting, lifts and other building electrical systems
- The **light green** area represents the additional electricity required to heat the building
- This demonstrates how electrifying heating will significantly increase the electricity used at commercial buildings

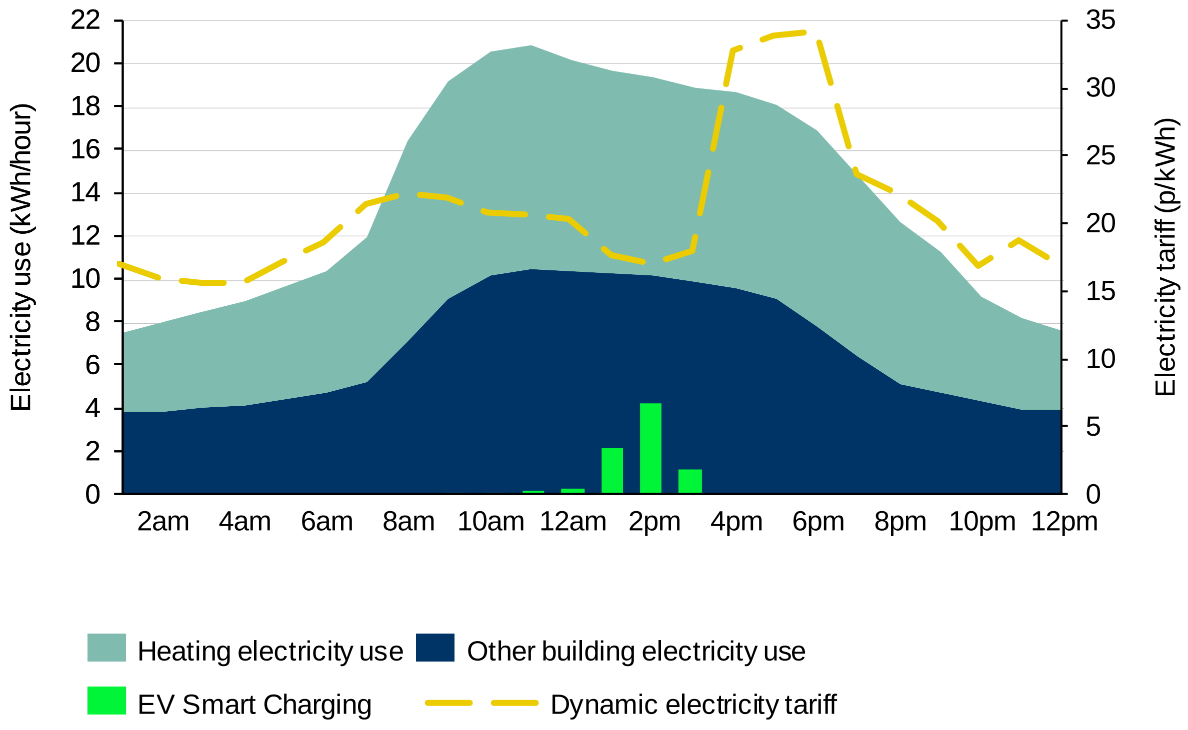
Illustrative winter day electricity use for an office with electrified heating



As vehicles connected to commercial buildings also become electrified, smart chargers can help to reduce charging costs

- Many commercial buildings have parking facilities for vehicles connected to the organisations that occupy them, including cars and vans that are used by the organisation, or employee vehicles that are parked during working hours
- As vehicles transition to electric vehicles (EVs), commercial buildings are increasingly coming under pressure to offer charging facilities, and this can further add to electricity use at the building
- National UK regulations require that since June 2022 any EV charger sold for use in a workplace or domestic setting must have ‘smart’ functionality. This means they must be able to stop, start or reduce the charging speed in response to a signal, such as a change in the price of electricity
- The chart to the right shows how a smart charger might charge a fleet of 10 employee EVs plugged in at the office shown on the previous slide if the building had a dynamic time of use tariff
- The **bright green** bars represent the vehicles charging, while the **yellow line** represents the dynamic electricity tariff that the chargers are desponding to
- Instead of charging when the vehicles arrive in the morning, the smart chargers wait until a dip in the price of electricity in the afternoon, ensuring that the lowest cost charging is achieved

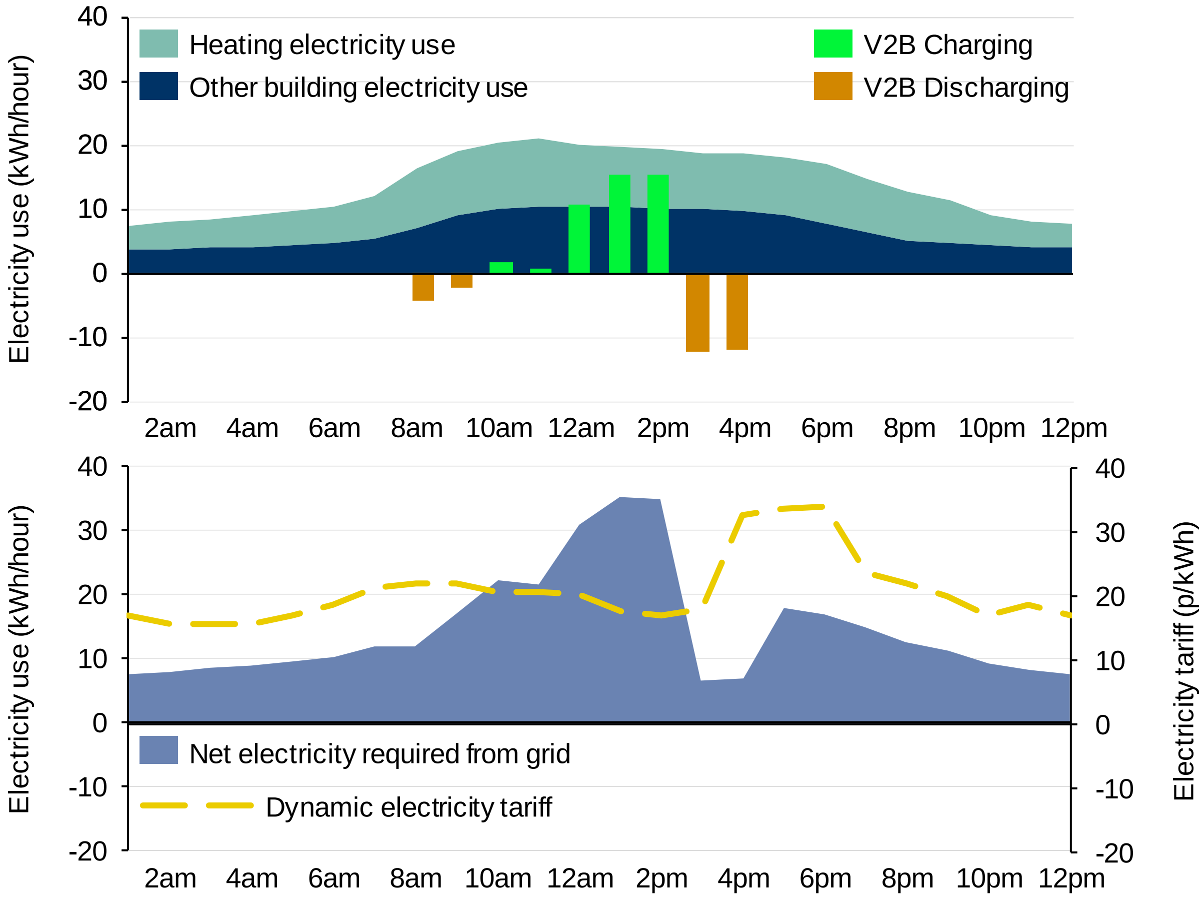
Illustrative winter day electricity use for an office with electrified heating and smart EV charging for employee vehicles



Bi-directional chargers can discharge electricity back to buildings, offering further cost saving opportunities

- The charts to the right show the electricity use at the same office as the previous slide, but with employee vehicles plugged into bi-directional chargers during the day, instead of smart chargers
- The top chart shows the electricity use in the building, overlayed with the charging and discharging of the bi-directional chargers. The **bright green bars** represent the vehicles charging and the **orange bars** below the horizontal axis represent the vehicles discharging to the building
- The total net electricity used by the building from the electricity grid, taking into account the charging and discharging of EVs is shown in the **light blue area** in the bottom chart.
- Net electricity use is overlaid with the **yellow line** representing the dynamic electricity price to show how the charging and discharging of the vehicles is maximised during low-cost periods and the discharging during high-cost periods significantly offsets electricity use in the rest of the building
- In this instance the system is optimised to reduce electricity bills, but it can also be optimised to reduce periods of peak electricity use at the building. This could help reduce or avoid costly grid connection upgrades in some circumstances

Illustrative winter day electricity use for an office with electrified heating and bi-directional EV charging for employee vehicles



This report analyses the potential of bi-directional chargers such as Wallbox’s Quasar 2 to provide V2B services

- Wallbox offer a range of EV charging products for domestic and commercial customers
- Initial products include smart charger providing up to 22kW AC
- Wallbox’s latest product is the Quasar 2 which is a DC bi-directional charger that is initially being marketed for use in domestic properties
- Sirius is an energy management system for commercial buildings that Wallbox are developing to allow the Quasar 2 to be integrated and optimised with other electrical systems in commercial buildings
- Sirius monitors and manages electricity demand and generation from systems such as electrified heating, solar PV and EV chargers. The system optimises energy use across all these systems to ensure that the lowest-cost electricity is used, and peak demands are reduced
- The modelling conducted in this project analyses how this kind of technology would interact with the energy systems in a range of building types, to understand the business case for deploying this technology in commercial buildings

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12.8kW DC fast charging power

5m CCS2 Type connector cable

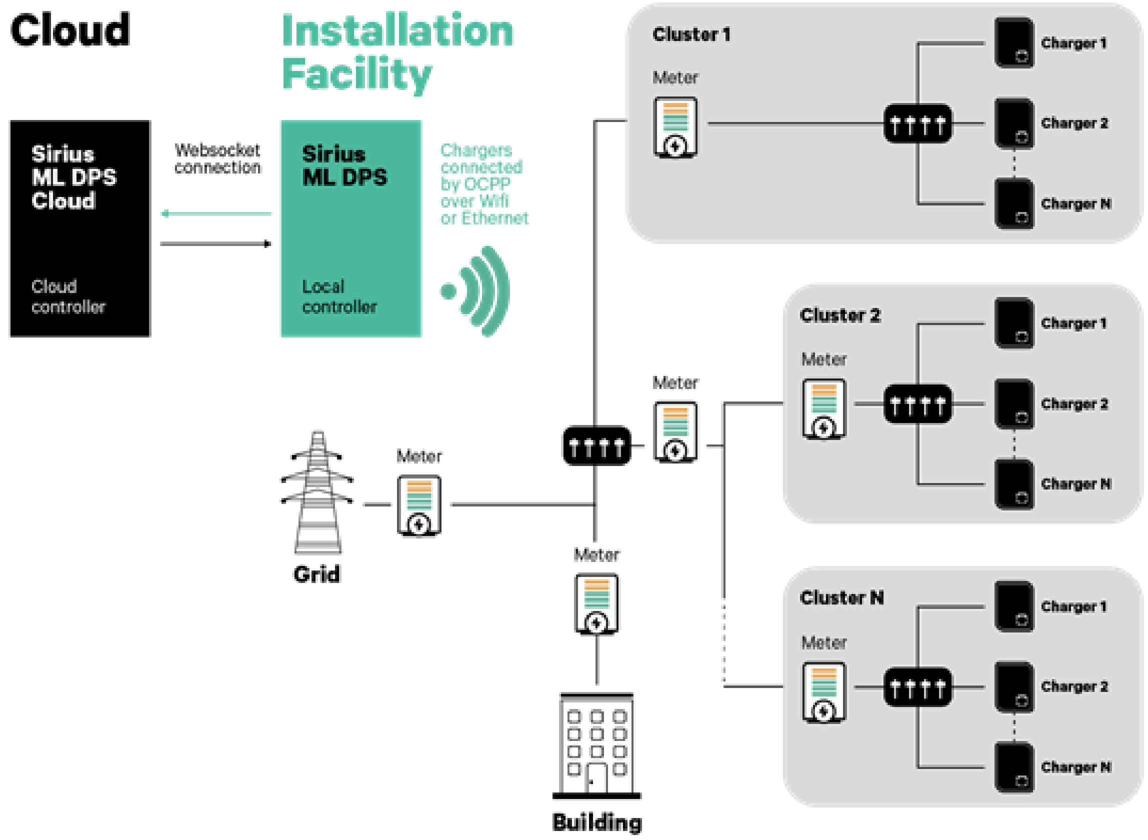
Compact design (747x368x135mm)

Indoor & outdoor installation (IP54C/IK10)

Interactive charging status LED

RFID authentication

Wallbox's Quasar 2 product is controlled by their Sirius software system to integrate into building energy systems



Sirius is the solution Wallbox offers for EV charging management. The main components needed for building a system that can provide V2B energy solutions is composed of:

Cloud controller: software running on cloud so that the client can interact with the system: configure restrictions, set load and chargers priorities, modify system preferences, see the dashboard, etc.

Local controller: a local computer that runs the Sirius software to manage electrical equipment installed at the building such as electrical heating, solar PV or stationary batteries. The local controller is connected to the cloud by an internet connection, this allows it to send real time measurements and state of the devices and to receive parameters and settings defined by the user.

Energy Meters: measure the power and energy consumption at different points in the electrical system, these are necessary for the DPS functionality

Network communication: The local controller needs to be connected to every local device via two protocols, Ethernet or WiFi communication (available in most devices) and RS485 (required for meters, inverters, batteries).

Endpoint Energy Devices: This category includes EV chargers, stationary batteries, pv solar inverters, heating systems, etc.

Contents

This section summarises the results of a literature review that identified V2B business model risks and uncertainties

6 key risks and uncertainties for the V2B business model were identified, considering technology constraints, revenue potential, and customer willingness to engage:

	Key identified risks and uncertainties
1	Sharing revenues with different owners /operators e.g., of building and EVs poses a challenge
2	Competition from alternative flexibility solutions
3	Significant code review has socialised connection costs up to a high cost threshold
4	Consumer behaviour is key to ensure engagement in the V2B business model
5	Battery degradation may add ongoing costs to V2B business model
6	Future work could consider additional revenues from Vehicle-to-Grid (V2G) services

For each of the 6 areas, a literature review was conducted to assess the risk level to the V2B business model and details of this analysis are set out in the appendix.

Overview of approach

1. Identify potential risks and uncertainties
2. Conduct literature review
3. Assess the impact and risk level for the V2B business model
4. Include findings in V2BUILD modelling

Sharing revenues with different owners

The ownership of buildings and EVs by different actors poses the significant challenge of establishing how revenues can be shared across entities in a practical V2B business model – detail in the appendix

Overview:

- Commercial buildings are likely to have different entities that own building(s) and EVs, and revenues will need to be shared fairly with EV owners to incentivise participation in V2B
- Limited research has been conducted thus far into how a robust economic relationship can be established between building and vehicle owners that face significant technical & regulatory challenges

Key findings / Sources:

- Academic studies focusing specifically on designing a V2B system for commercial buildings were reviewed to understand proposed business model for establishing an economic relationship between building and EV owners.
- The simplest business model reviewed involves establishing contractual agreements with EV owners that ensure fair monetary compensation, but this may only capture a portion of the total EV stock available to a building.
- Other solutions consider e.g. real-time transactive systems that offer real-time revenues to EV owners, but existing regulation would likely prevent two-way trading of electricity between EVs and buildings.
- More complex solutions that rely on smart energy management require a vast range of real-time data from EV users that would be difficult to obtain.

Impact on V2B business model:

- How revenues are shared among entities within a viable V2B business model is likely to vary by archetype depending on the number of entities involved and the nature of their relationship.
- There are practical challenges to all proposed solutions, including regulatory barriers and ensuring that EV owners are fairly compensated for participating in V2B
- May be impacted by consumer attitudes e.g., willingness to form contracts

Competition from flexibility alternatives

Alternative solutions could create competition for the flexibility offered by V2B, but V2B typically requires less space and investment – detail in the appendix

Overview:

- Key alternative solutions to provide distributed flexibility are thermal storage, stationary battery storage, and hybrid heat pumps
- Key advantage is higher availability – but they require more space and investment

Key findings / Sources:

- The considered alternative flexibility solutions are stationary and thus don't share the availability / reliability risk inherent to V2B solutions dependent on mobile vehicles
- Alternative solutions use dedicated assets instead of the EV battery; deploying these solutions thus does not lead to increased EV battery degradation
- Thermal storage technology is being developed and costs are expected to decrease. However thermal storage requires significant amount of space which often is not available in dense urban areas.
- Stationary battery storage comes at a significantly higher cost than a bi-directional charger
- Hybrid heat pumps require installation of a gas boiler in addition to a heat pump, leading to additional space requirements and costs[1]; they also lead to carbon emissions
- While alternative solutions have either higher cost or higher space requirements, V2B makes use of batteries in vehicles which would be parked anyway

Impact on V2B business model:

- Building owners might choose to install an alternative flexibility solution instead of V2B
- V2B may be preferrable in locations with significant space constraints for installing additional energy storage equipment
- Even where other energy storage solutions are deployed, V2B could play a role in optimising their operation, particularly as some storage solutions are unable to dispense electricity back to the building (e.g. thermal storage)

1) Cost of boiler is to some extent offset by the smaller size of the heat pump and subsequently lower cost than in the case of a pure heat pump

Connection costs have been socialised up to a defined high threshold

Key saving for V2B had been the reduction in new connection costs for commercial buildings, but UK regulation is limiting connection costs, which may reduce the benefits of V2B – detail in the appendix

Overview:

- A key potential benefit of V2B is reducing peak demands and therefore size and cost of grid connections required for a building , particularly when new electrical assets are installed
- These savings are difficult to predict because there is huge variability in connection costs
- Payments for network reinforcement which are often a large component of these costs have been socialised for non-domestic buildings up to a defined high cost cap in 2023 due to Ofgem's strategic code review (SCR) decision

Key findings / Sources:

- Upstream reinforcement costs are no longer included in the cost for increasing electrical capacity, below a defined high cost cap, as of April 2023
- This removes the risk of incurring high connection costs as a result of upstream reinforcement costs below the high cost cap set out by Ofgem
- However, some aspects of grid connections still mean that commercial buildings could benefit from V2B reducing the size of the grid connection required:
  - The cost of extension assets (new cabling etc) must be paid by the connecting customer
  - Connecting customers still have to pay a fixed capacity charge per kVA
  - Significant connection upgrades may lead to lengthy waiting times especially if upstream reinforcement works are needed, further incentivising reducing the size of grid connections

Impact on V2B business model:

- The SCR has negatively impacted the business model for V2B by socialising significant grid reinforcement costs
- Savings from lower peak demands can still be made for the cost of 'extension' assets and fixed capacity charge
- Avoiding lengthy waiting times for grid connections could also be a valuable benefit if V2B allows a site to stay within existing capacity
- In some cases, likely rare, V2B could help a site to remain below the HV threshold

Consumer behaviour

Consumer behaviour is key to predict level of engagement in the V2B business model – detail in the appendix

Overview:

- Consumers are generally willing to smart charge with relatively small financial incentive.
- To participate in bi-directional charging or flexibility services involving wider energy assets (e.g., entire home demand), larger incentives may be required
- Clear communication of the technology and benefits is likely to improve engagement.

Key findings / Sources:

- Consumer engagement and willingness to participate in V2B will be essential for the V2B business model
- Several trials have investigated consumer engagement with EV flexibility and bidirectional charging
- Early smart charging trials indicate high willingness to participate in EV flexibility, motivated by modest financial incentives and optimal use of renewables
- Wider domestic flexibility services see high engagement from consumers, particularly with larger financial incentives and amongst customers with smart meters and/or dynamic tariffs
- EV drivers were incentivised to participate in bi-directional charging with financial incentives, and concerns about V2G were alleviated with clear communication of the technology and experience with it

Impact on V2B business model:

- Value of incentive seemed to have some impact on level of consumer engagement
- Ease of use and automation of process important for customer engagement
- V2B is complex, but when a clear customer offer is created and effectively communicated, consumers are willing to engage

Battery degradation

Battery degradation may add ongoing costs to V2B business model and impact consumer willingness to participate – detail in the appendix

Overview:

- Battery degradation is still not well understood, and the impact and cost of bi-directional charging on EV battery health is uncertain.
- More intensive use of vehicle batteries could lead to an additional cost for using V2B.
- Uncertainty around the impacts may impact consumer willingness to participate.

Key findings / Sources:

- Battery degradation and the costs associated with it remain uncertain and an active area of research – a literature review has been carried out, as set out in the following slides
- It is currently understood that there are two forms of degradation for EV batteries:

1. Cycling fade, based on the number of charge/discharge cycles completed
2. Calendar fade, based on ageing of battery regardless of cycling, which is more pronounced when the battery is kept at a particularly high or low state of charge

- Poor operation of battery in bi-directional charging could result in significant degradation, but some evidence suggests that bi-directional charging can prolong battery lifetime
- Cost of degradation can be estimated by assuming that the main source of EV battery degradation is from cycle fade, and that the interaction of cycle and calendar fade can be discounted – this 'high case' battery health scenario is included in the V2BUILD techno-economic modelling and online tool

Impact on V2B business model:

- Battery degradation can lead to an additional operating cost for V2B, dependent on kWh discharged
- Concerns around degradation also likely to impact consumer willingness to participate in bi-directional charging
- Concerns around battery health are associated with loss of vehicle range and having to replace battery
- Further research and clear messaging about battery degradation is necessary to reassure EV drivers

Future work: further revenues from energy services could be investigated

V2BUILD project scope has been limited to modelling tariff optimisation and peak demand reduction, but future work could consider additional revenues from grid services – detail in the appendix

Overview:

- Scope of the V2BUILD project does not include grid services
- Several opportunities for additional revenues through grid services have been identified, but technical requirements for some of the considered services could be too onerous for EVs

Key findings / Sources:

- The V2BUILD project has focused on the potential opportunities from V2B and therefore does not include grid services in the revenue potential.
- However, National Grid ESO demand flexibility services and the capacity market could provide additional revenue opportunities for bi-directional chargers in commercial buildings
- Other services have technical requirements that are too onerous for bi-directional chargers:
  - **ESO services:** Quick response time for frequency response (FR) - 1s - might not be possible to achieve by aggregated EVs due to accumulated latencies; onerous high resolution metering requirements (20 Hz resolution for FR[1], 1 Hz for balancing mechanism); small markets dominated by grid scale batteries; services to maintain security of supply (Demand Flexibility Service (DFS) and Capacity Market (CM)) might be attractive opportunities
  - **DSO services:** moderate technical requirements but value highly location specific.

Impact on V2B business model:

- Modelling of the V2B business models does not include grid services, and additional revenue potential has not been included – this could be investigated in future work
- Business case modelling considers only tariff optimisation and peak demand reduction
- High technical requirements and competition from large scale batteries rule out some high value ESO services

1) FRED 2021 project report;
ESO = Energy System Operator

The impact of the challenges was assessed through a literature review, which suggested that none pose a major barrier to V2B

Risks overview	Impact	Risk level
1. The ownership of buildings and EVs by different entities poses the challenge of establishing how **revenues can be shared across entities**	Likely to depend on the number of entities involved and the nature of their relationship. Impacted by regulatory barriers and consumer attitudes.	Moderate
2. Alternative solutions exist to distributed flexibility such as thermal storage and stationary batteries	Building owners might choose to install an alternative flexibility solution instead of V2B, depending on the comparative costs	Moderate
3. Significant code review has socialised connection costs up to a high cost cap, limiting potential savings of V2B at constrained sites	Savings will only be made for the cost of required 'extension' assets and for fixed capacity charges.	Low
4. Consumer behaviour may impact a successful business model	Consumers may require cost incentives for flexibility, and will need automation and/or long notice periods	Moderate
5. Battery degradation from V2B is uncertain - poor operation could result in significant degradation, but optimised operation could preserve battery health.	Battery degradation could be considered as an additional operating cost, dependent on kWh discharged. Concerns around degradation is likely to impact consumer willingness to participate in bidirectional charging – clear messaging required.	Moderate
6. Future work could consider **additional revenues from energy services** through V2G to complement V2B opportunity	High technical requirements and competition from large scale batteries rule out some high value ESO services (e.g., frequency services), but could offer arbitrage, connection cost reduction**,** DSO services, DSF, and CM with potential for BM in the future	Low

Detailed analysis is set out in the appendix.

LCT = low carbon technology, EV = electric vehicle, HP = heat pump

Contents

This section sets out the findings of the techno-economic modelling carried out to assess the commercial viability of V2B and identify attractive use cases

- Techno-economic modelling of V2B operation and revenues across different commercial and domestic building types was carried out to assess the commercial viability of V2B and identify the most attractive use cases
- Key aims of the modelling carried out included:
  1. Development of **building and fleet archetypes** including demand profiles, charging behaviour and V2B profile
  2. **Optimise archetype demand profiles** considering the savings that can be achieved through **V2B**, compared to a baseline of smart charging
  3. **Quantify potential savings** on electricity bills and connection capacities through use of V2B compared to a baseline of smart charging, to understand the business case of an upfront investment in V2B solution
- This section sets out the method, building and fleet archetype development, and key findings from the modelling
  - Sensitivities were additionally carried out to consider the impact on optimised profiles of battery degradation and extreme weather

Overview of approach

Shortlist of buildings and fleet archetypes to be investigated

↓

Data collection to create comprehensive archetypes

↓

Modelling to optimise operation of flexible V2B assets

↓

Model savings and business case for V2B solution at each of the investigated archetypes

V2BUILD analysis used the Flexible Asset Model (FAM) to optimise storage profiles in response to price signals and onsite generation

ERM's Flexible Asset Model models the **operation of energy consuming and generating assets** of a building at half-hourly resolution over the course of one year. The model optimises the **charge/discharge** of V2B to **minimise peak demand, maximise capture of solar PV** and **reduce electricity costs.** The optimised operational profiles can be used to calculate savings from V2B compared to the **baseline of smart charging.**

Power from V2B depends on EV flexibility parameters	***Building draws power from grid, PV, or V2B to meet demand***	***Power from PV generation depends on PV availability (weather) & price***
Charge/ discharge power can be adjusted between 0 and the max charging capacity in every hour that an EV is plugged in to a charger. The EV SOC at the end of one plug-in window must be sufficient to meet typical EV energy consumption expected outside the plug-in window.	Total hourly energy demand must always be met by the sum of import from grid, PV generation, or V2B. The selection of power source is determined by the input energy price profiles, with the aims of reducing peak demand and maximising self-consumption.	PV generated per hour is either used to meet building energy demand or can be exported to the grid. This is determined based on the input hourly power available from PV, based on a typical location in the UK in a typical weather year.

Assumptions and limitations:

- The model assumes **perfect foresight**, so savings from V2B calculated will be an upper bound of the savings available for a given set of inputs.
- A fleet of EVs are modelled as **one aggregated asset**, so all EVs in a fleet must have the same characteristics to be aggregated.
- The model can optimise the operation of **only one "storage asset" at a time**, so can model either V2B or battery storage (not both)

Contents

Viability of non-domestic V2B business models was assessed through three core commercial building archetypes, in comparison to two domestic building archetypes

- In assessing the viability of non-domestic V2B business models, **3 core commercial building types** were selected as archetypes: **offices, storage warehouses,** and **hospitals**.
  - As modelling could not be carried out for all building types, the 3 archetypes were selected to represent the variety of profiles and attributes across the commercial building sector.
- Modelling was also carried out to assess the viability of domestic V2B, through two domestic archetypes: **flat buildings** and **semi-detached houses**
- Each of the building archetypes were developed with different assumptions behind:
  1. Baseload **electricity and heating demand** profiles
  2. **Fleet** characteristics, size and behaviour.
  3. Solar **PV generation** profiles
- A summary of key **archetype assumptions** is shown on the following slides, with detailed assumptions in the appendix
- Note: modelling assumes one EV charger per EV in the fleet.

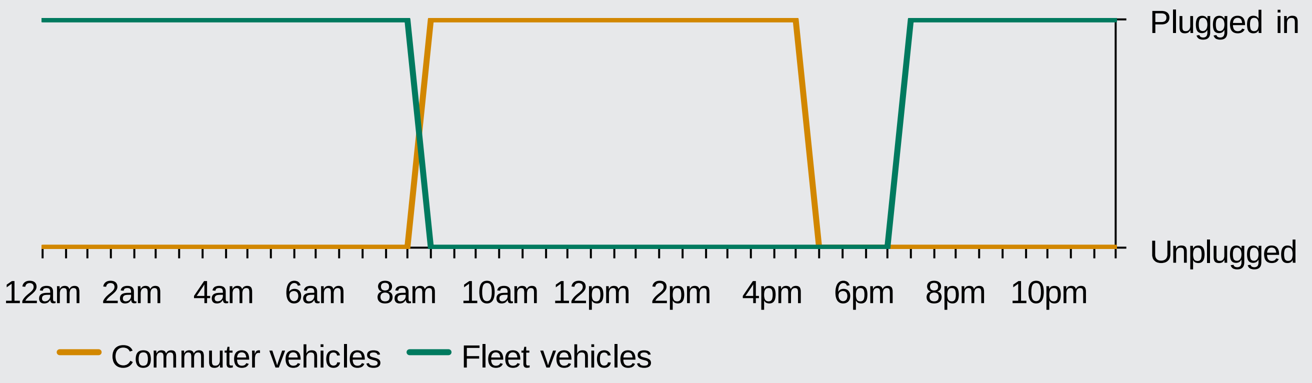
	Building Archetype	EV archetype	Fleet size
Core archetypes	**Offices**	Commuter	10
Core archetypes	**Storage warehouse**	Fleet	60
Core archetypes	**Hospitals**	Commuter	34
Core archetypes	**Hospitals**	Fleet	30
	Domestic flat building	Commuter	3 [1 per flat]
	Domestic semi-detached	Commuter	2

Summary of commercial building archetypes

Commercial building archetypes

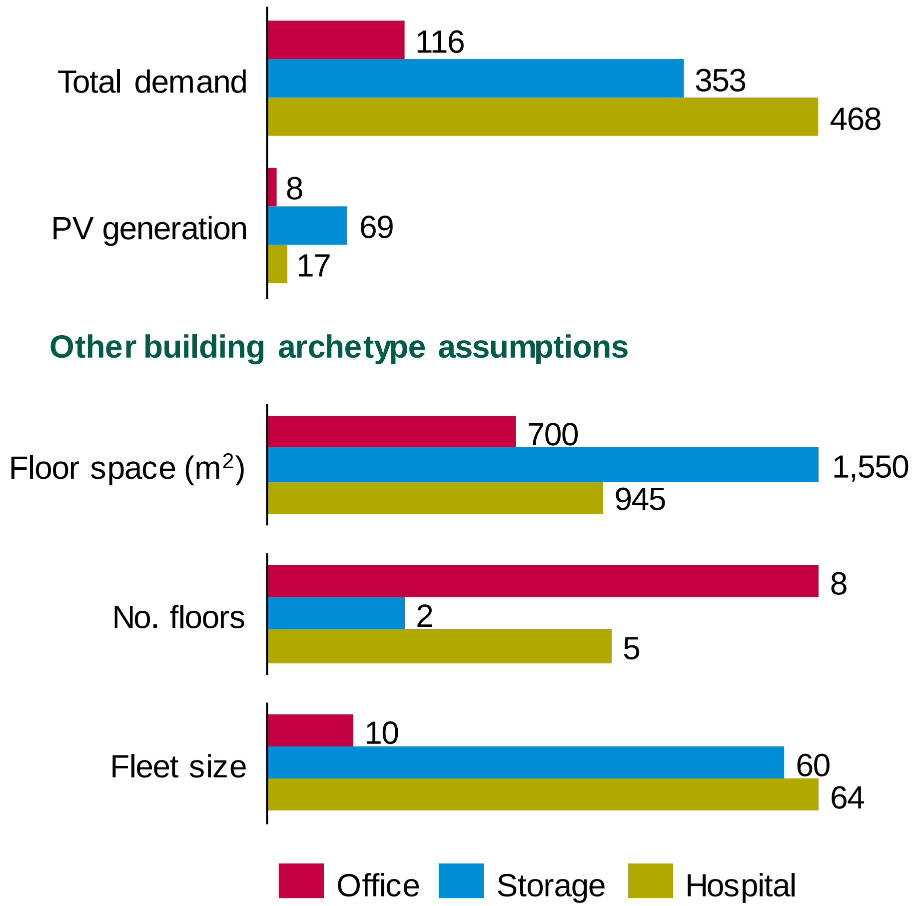
- **Office** building energy demand is dominated by heating demand during working hours, with commuter EVs that are plugged in during the day
- **Storage warehouses** have low building energy demand intensities, a large delivery fleet that charges overnight, and large rooftop area available for PV
- **Hospitals** have high building demand, limited rooftop area for PV, and a combination of non-emergency fleet EVs that charge overnight and commuter EVs with daytime charging

Plug in windows for vehicles at commercial buildings



Annual Electricity Demand & Generation (MWh)

Other building archetype assumptions

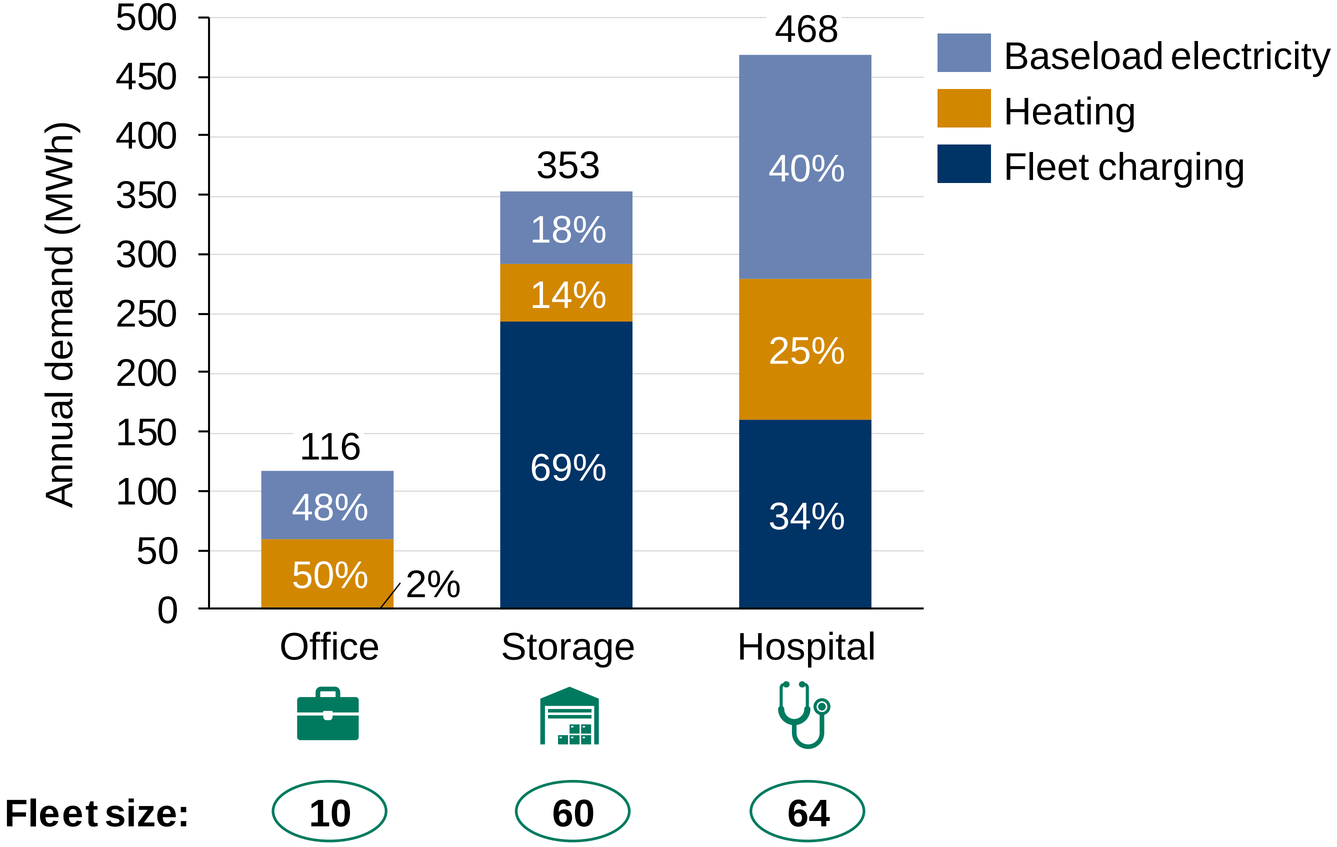


Further information on building archetype assumptions can be found in the appendix

Fleet charging demand makes up ca. 70% of total demand in storage archetype, while other commercial buildings have a higher proportion of building demand

- Total energy demand of each archetype can be broken down into the **fleet charging demand** and the **total building demand**, from electrified heating and from baseload electricity
- Fleet charging demand comprises a negligible share (2%) of demand of the office archetype due to the **small fleet size** and high heating demand
    - In contrast, the majority of the storage warehouse's energy demand is from **fleet charging** due to the large fleet size and low building demand
- Hospital demand is fairly evenly split between baseload electricity, heating, and fleet charging demand

Proportion of annual demand (MWh) made up of fleet charging across building archetypes



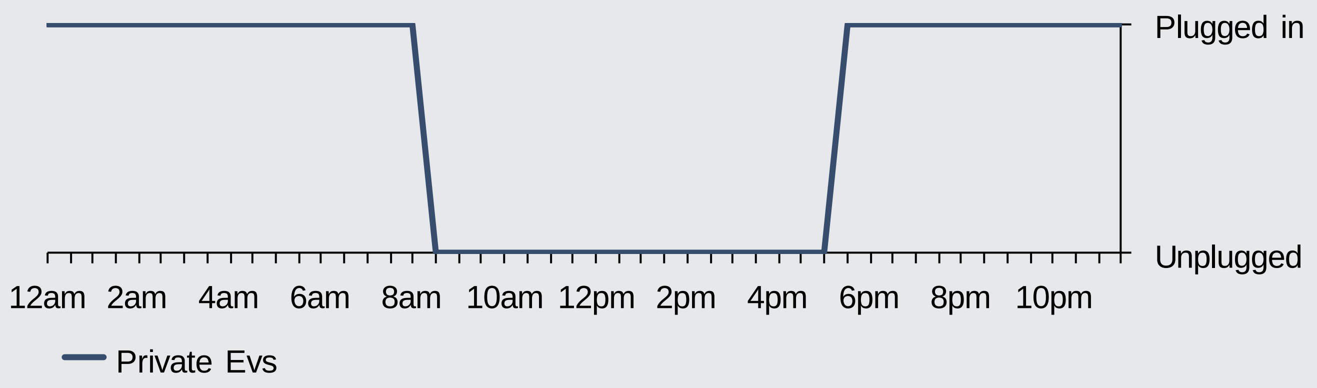
Summary of domestic building archetypes

Domestic building archetypes

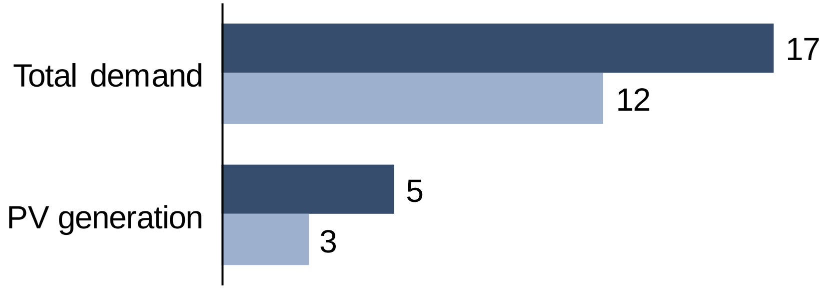
The flat buildings' baseload electricity demand make up most of the archetype's total building demand, with annual PV generation approximately 30% of total demand. Residential vehicles plug in overnight when PV generation is low.

Semi-detached homes' heating demand makes up almost half of total building demand, with annual PV generation approximately 25% of the total demand. Residential vehicles plug in overnight when PV generation is low.

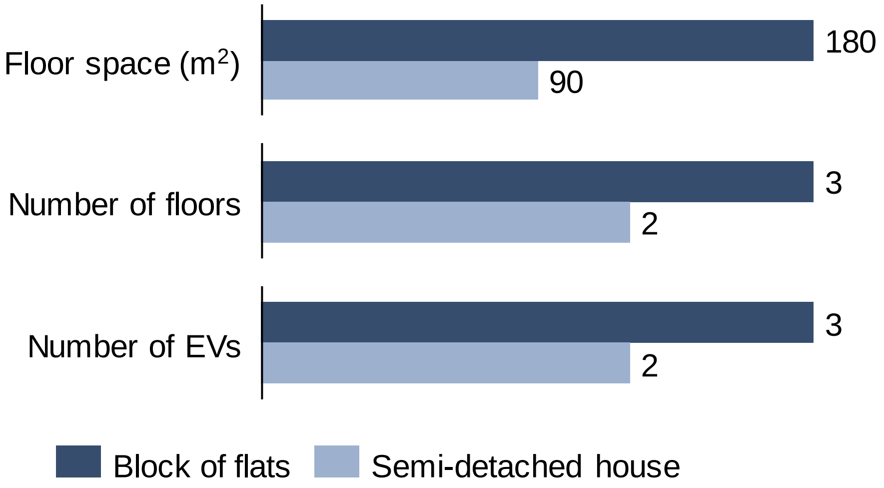
Plug in windows for vehicles at domestic buildings



Annual Electricity Demand & Generation (MWh)



Other building archetype assumptions

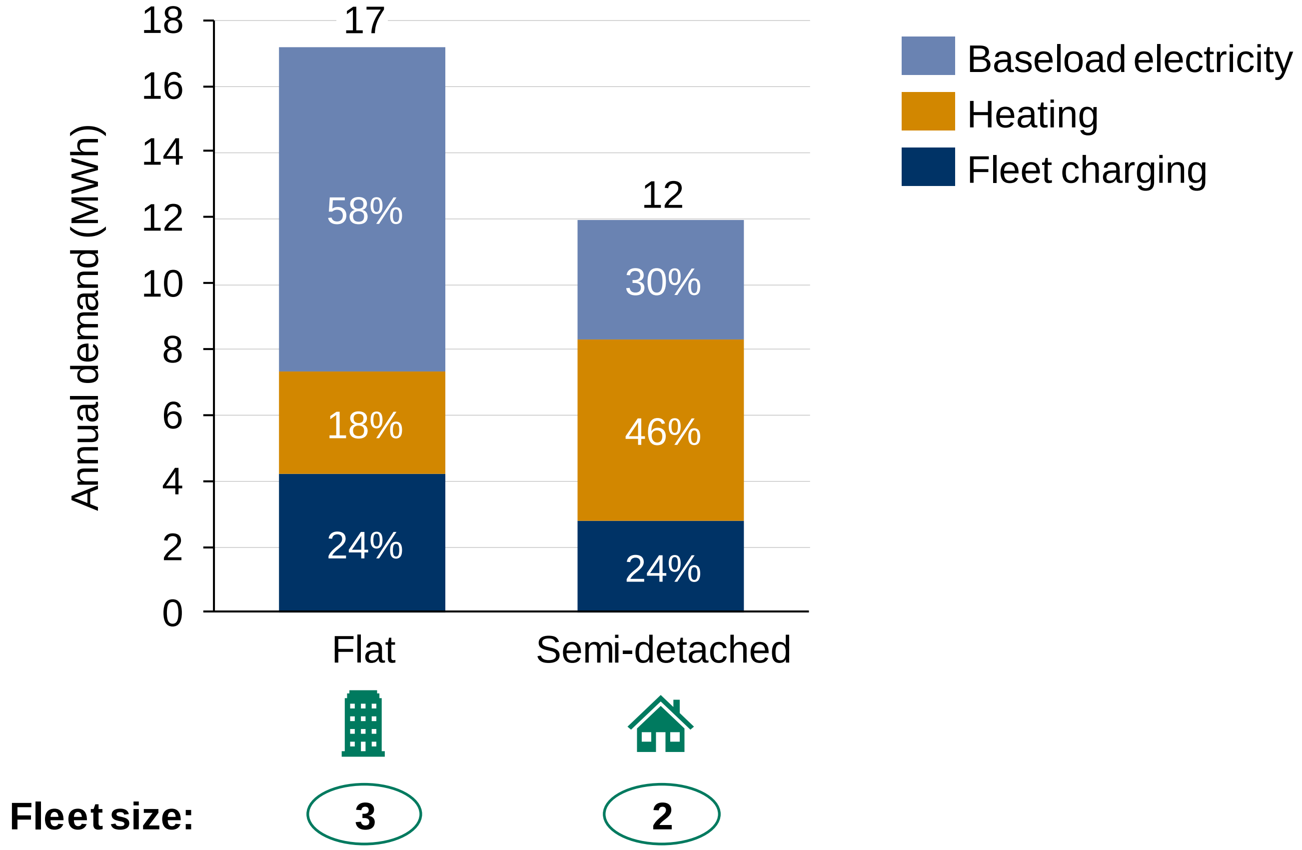


Further information on building archetype assumptions can be found in the appendix

Flat building archetype's demand is dominated by baseload electricity, while majority of semi-detached archetype's demand is made up of heating

- Semi-detached archetype has **30% lower total demand** than the flat building archetype
- Vehicle charging demand makes up ca. **25%** of the total demand of both **domestic archetypes**
- Flat building demand dominated by **baseload electricity** (over 50%), with comparatively low heating demand
  - In contrast, **heating demand** makes up the largest proportion (just under 50%) of total building demand

Proportion of annual demand (MWh) made up of fleet charging across building archetypes



Contents

Modelling optimised archetypes' EV charge/discharge profiles across 4 different scenarios to look at the relative prioritisation of peak demand and electricity bill reduction

- The Flexible Asset Model optimises operation for 2 objectives: **electricity bill reduction and peak demand reduction**
  - Relative prioritisation of the objectives is adjusted to compare optimised profiles
- As a result, four scenarios (shown, right) were carried out for each archetype to explore how the defined objectives impact results, considering:
  1. **Electricity tariff:** dynamic, static time-of-use, or flat tariffs – assumptions in appendix. Dynamic offers a high opportunity for electricity bill optimisation, flat offers no opportunity.
  2. **Grid connection constraints**: High (baseline) or no grid connection constraints were assumed, to incentivise peak demand reduction. Savings were additionally considered from reduced fixed capacity charges for commercial buildings only, assuming 4p/kVA/day[1]
- For each scenario modelled, two runs were carried out: one with **smart charging only**, and one with **V2B** to identify the benefits which V2B solutions can provide beyond what is achieved with smart charging

4 combinations of optimisation priorities were modelled:

Peak demand reduction (Peak reduction)
- Assumes high grid connection costs and a flat electricity tariff
- Bi-directional charger operation is optimised to reduce peak electricity demands, disregarding time of use

Electricity bill reduction (Bill reduction)
- Assumes no grid connection costs and a dynamic tariff
- Bi-directional chargers are optimised to charge during low-cost periods and discharge during high-cost periods

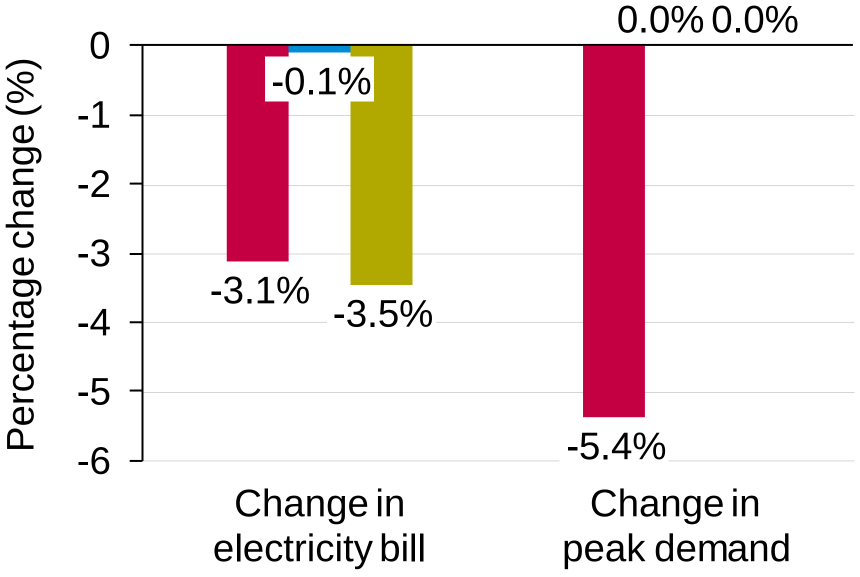
Mixed peak and bill reduction with dynamic tariff (Mixed Dynamic)
- Assumes high grid connection costs and a dynamic tariff
- Bi-directional chargers optimise benefits of reducing the peak and charge/discharge times to reduce bills

Mixed peak and bill reduction with static tariff (Mixed Static)
- Assumes high connection cost and static time of use tariff
- Investigates the potential of an alternative tariff, while still optimises peak demand reduction

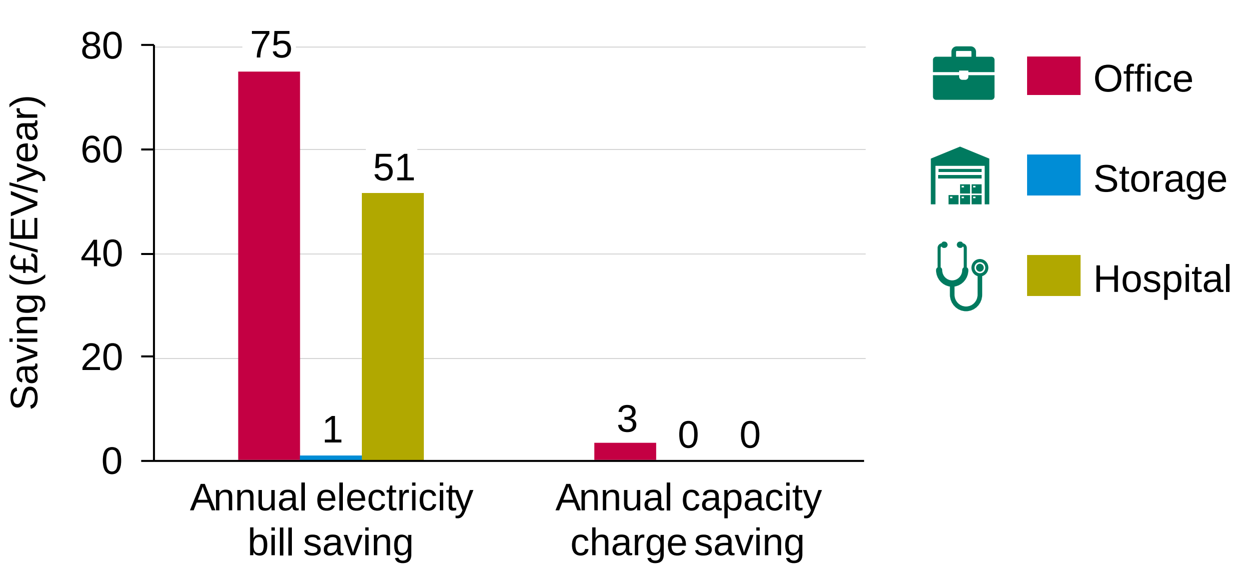
1 - UK Power Networks Distribution Use of System Charges, 2023, average fixed charge for LV sites across the three licence areas. Note: domestic properties are not subject to fixed DUoS charges

SUMMARY: V2B provides electricity bill savings for core commercial archetypes above smart charging, but peak demand reduction only achieved for office buildings

Total change in electricity bill and peak demand achieved (%) using V2B compared to smart charging



Total savings in annual electricity bill and capacity charge (£/EV/year) using V2B compared to smart charging*



- Results above shown for dynamic tariffs and assuming high grid constraints to co-optimise electricity bill and peak demand reduction
- V2B able to lower annual electricity bills of **all commercial building archetypes**, although **storage archetype sees low savings**
- V2B reduces **peak demand of office buildings** further than achieved through smart charging, leading to **small annual savings in fixed capacity charges**
- **No peak demand reduction** is achieved for **storage or hospital** archetypes – further electricity bill savings are possible with no consideration of peak demand

*Cost savings shown are achieved by co-optimising both electricity bills and peak demand, assuming high grid connection constraints.

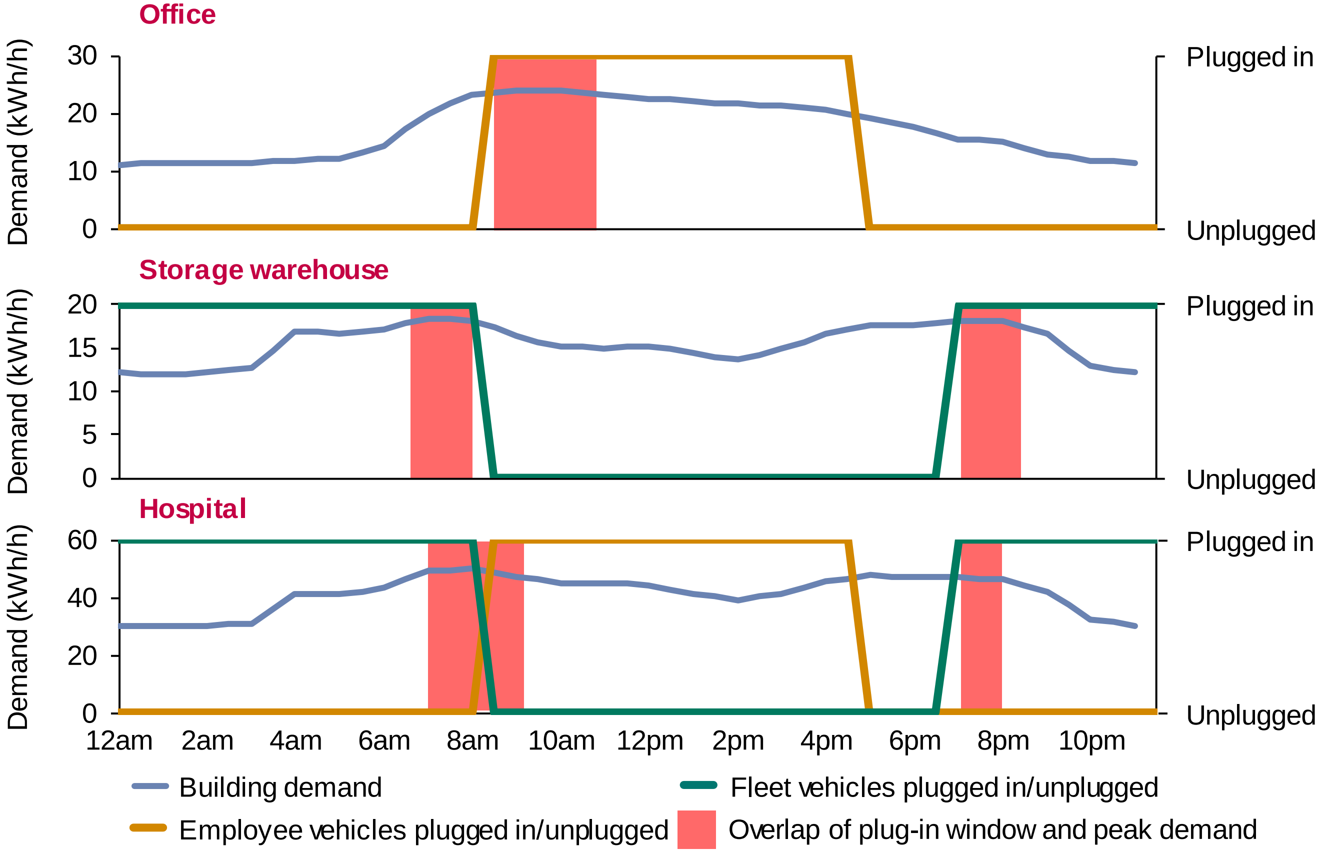
The potential for bi-directional chargers to reduce building peak demand is determined by alignment of plug-in windows and periods of peak building electricity demand

- The charts to the right show how the plug in windows for fleet and employee vehicles at the three commercial building types compare to the typical demand profiles in each
- The peak electricity demand at a commercial building over a whole year determines the size of grid connection that it requires, so for a building with electrified heating in the UK this will typically be during the winter
- The potential for bi-directional chargers to discharge and reduce the peak on the highest demand day of the year is determined by how well aligned the plug in windows are with the periods of peak demand
- Across all commercial building archetypes, plug in windows typically start or end during peak periods, limiting the ability of the bi-directional chargers to discharge and reduce peaks when needed

Implications:

- As a result, there are likely to be limited opportunities to reduce overall peak demand in commercial buildings using V2B

Vehicle plug-in windows and typical daily electricity demand profiles for commercial building archetypes



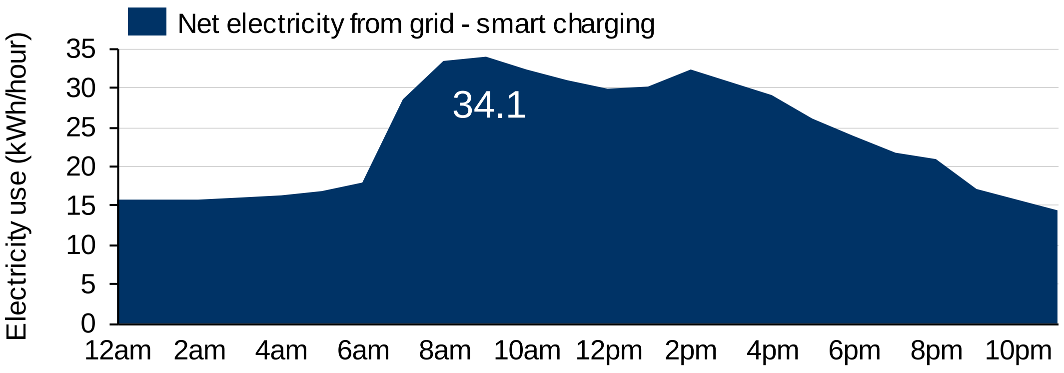
There are currently limited opportunities for commercial buildings to benefit from peak demand reduction via V2B

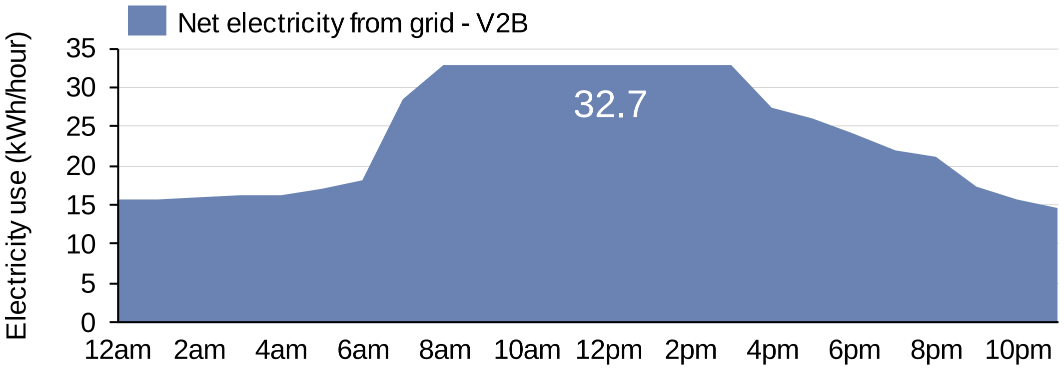
- The techno-economic modelling conducted during this project attempted to quantify the potential for V2B to contribute to peak electricity demand reduction at commercial buildings.
- Optimisation considered the building's demand profile over a **full year of operation**, with peak demand reduction taking place on days of highest demand during the winter months
  - Through the rest of the year, the optimised profile ensures **demand does not exceed this reduced peak**
- Unless optimised to reduce peaks, V2B in offices was found to increase peak demand by ca. 2% over a year. The balanced optimisation led to a ca. 5% peak demand reduction, the only peak demand reduction achieved across commercial building archetypes

Implications:

- Simply reducing peak demand does not contribute significantly to the business case for V2B technology, as the reduction potential is low, and in most cases the main benefit will be lower capacity charges which have a limited impact on the overall electricity bill
- In rare cases, substantial savings can be made by reducing peak demand by just a few percent – see next slide
- Collectively, there could be significant benefits to the network if lots of businesses were able to reduce their peak demands in this way

Net electricity required from the grid for an office with smart chargers compared to the same office with bi-directional chargers[1]





1: Winter day with high electricity use for an office with electrified heating, optimised for electricity bill and peak demand reductions

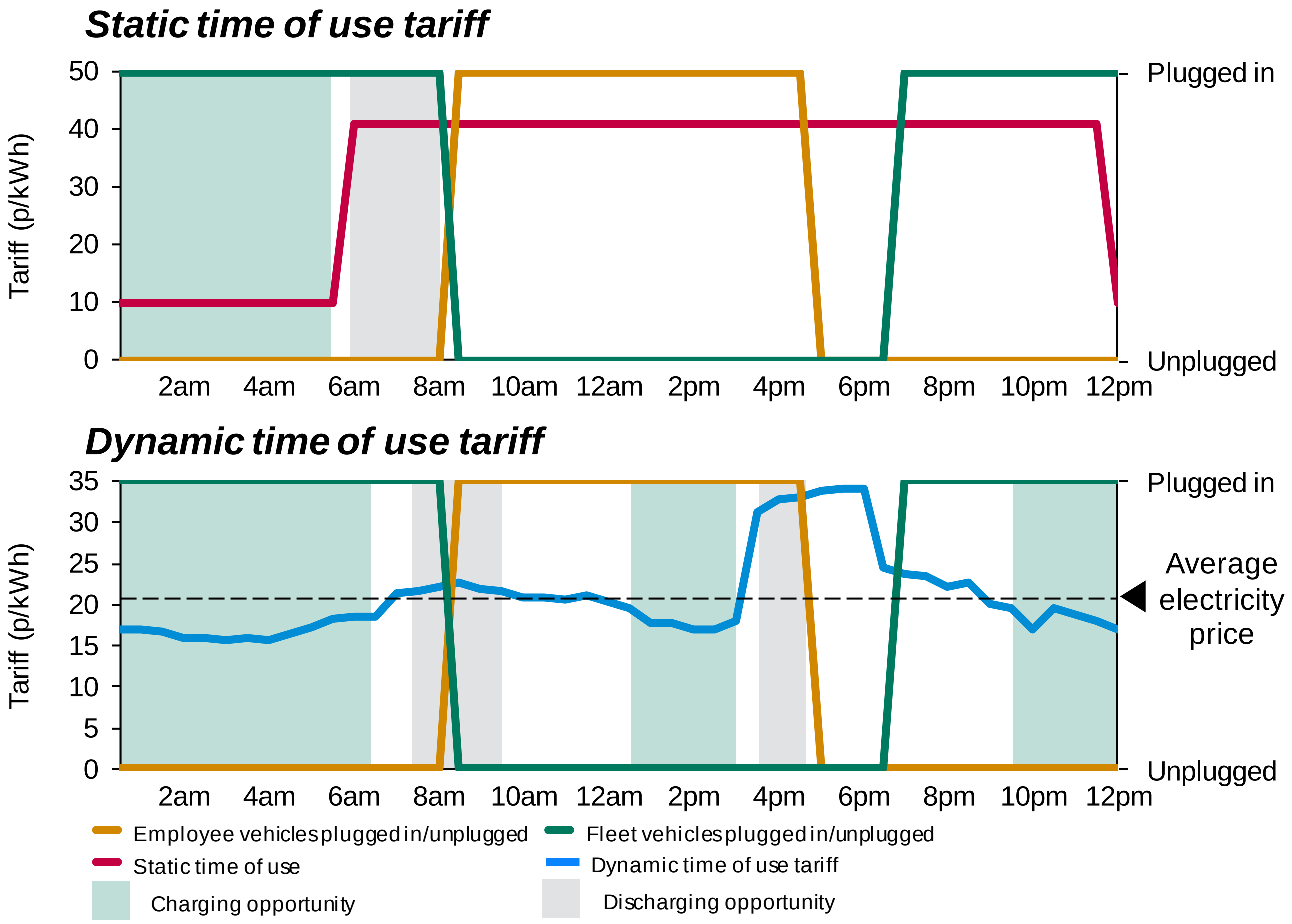
Electricity bill savings in commercial buildings are determined by the alignment of charging windows and electricity tariffs

- The charts to the right show how the plug-in windows for fleet and employee vehicles compare to a static (top) and dynamic time-of-use (bottom) tariff. The green shaded regions identify opportunities for charging, while the grey areas are opportunities for discharging

Implications:

- Bi-directional chargers at commercial buildings have more opportunities to discharge with a dynamic than a static tariff
- Smart chargers can achieve many of the bill reduction benefits of bi-directional chargers deployed in commercial buildings, because they are able to shift charging to low-cost periods (green areas)
- Bi-directional chargers can achieve additional benefits by discharging during high-cost periods of the day (grey areas), but as can be seen in both charts, these opportunities are limited by the plug-in windows, particularly limiting the opportunity during the high-cost period in the afternoon
- A further factor to consider is that there needs to be sufficient electricity demand from the building during the discharge opportunity periods to ensure that the vehicles can discharge at their maximum rate. If the vehicles could discharge more than the building actually requires, then some of this opportunity will be lost

Comparison of charging and discharging opportunities during vehicle plug-in windows for commercial buildings



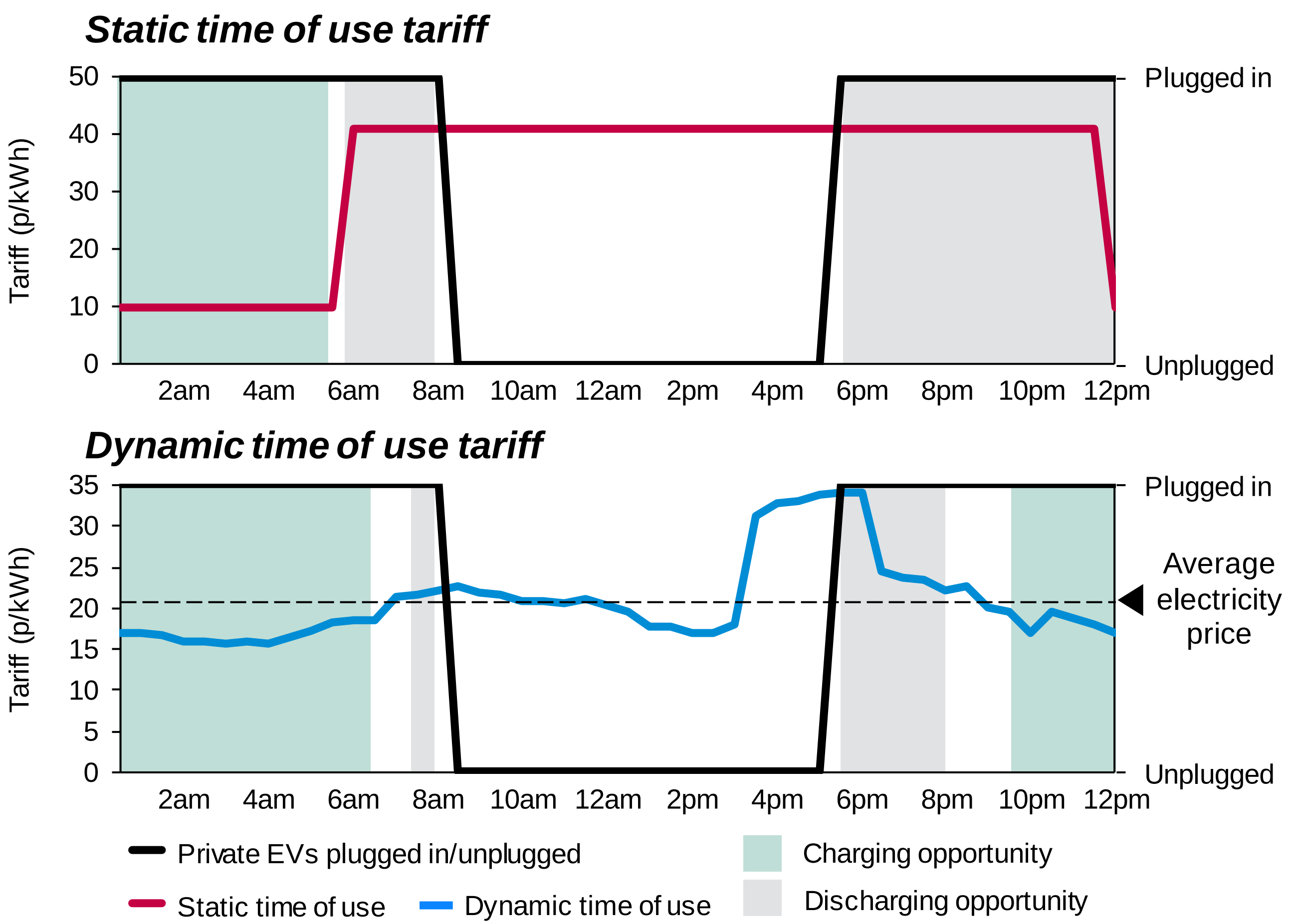
For domestic properties, plug-in windows, building demand and electricity tariffs are well aligned maximise savings

- The charts to the right show how the plug-in windows for EVs at domestic buildings compare to a static (top) and dynamic time-of-use (bottom) tariff. The green shaded regions identify opportunities for charging, while the grey areas are opportunities for discharging

Implications:

- For domestic properties, there are more opportunities to discharge with a static time-of-use tariff than a dynamic one
- Domestic EVs are typically able to take full advantage of the low-cost overnight period from the static tariff
- The high-cost period and plug-in windows also align well with periods of high demand in domestic properties in the morning and afternoon, providing significant opportunities to discharge and off-set building demand

Comparison of charging and discharging opportunities during vehicle plug-in windows for domestic properties

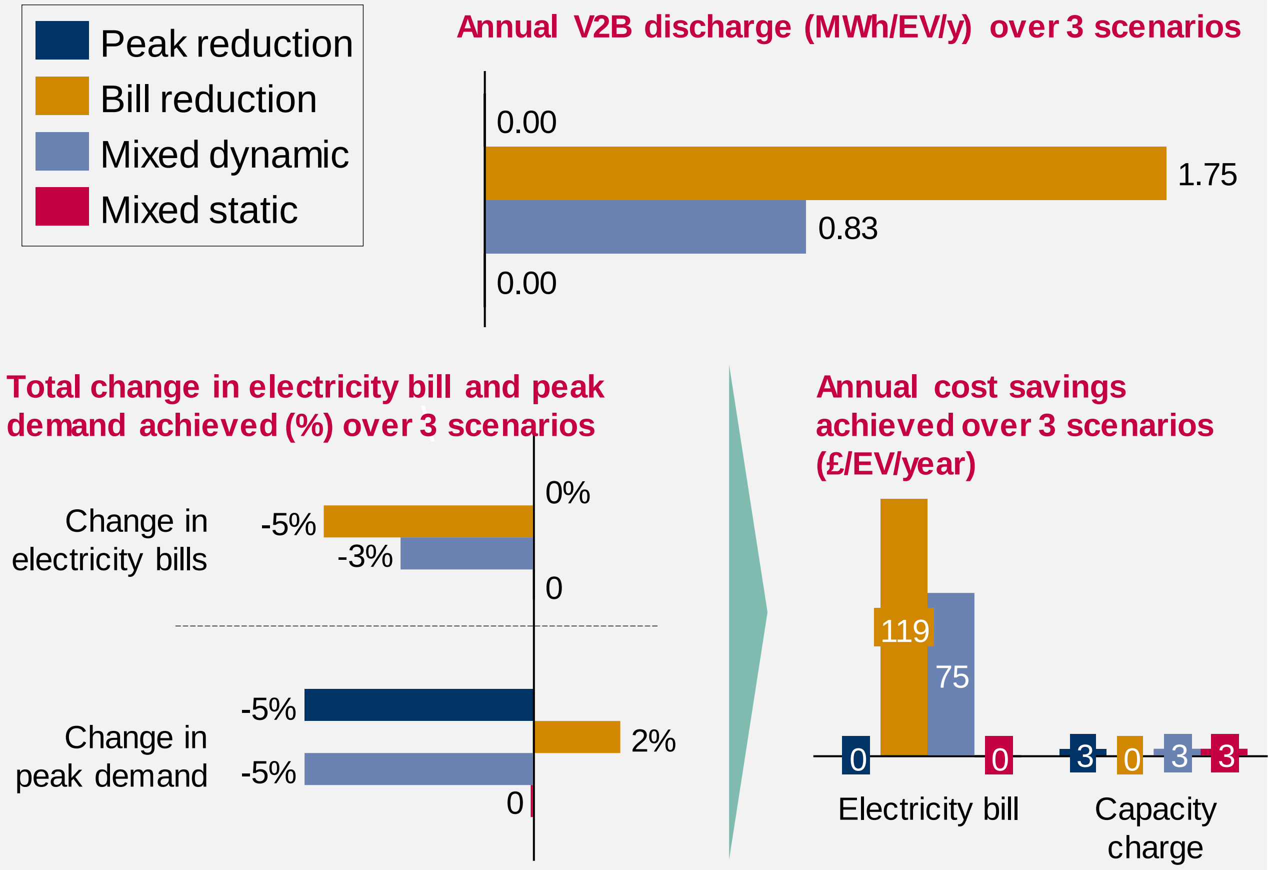


Contents

For offices, electricity bill reduction is greater with no peak connection cost, but both objectives can be co-optimised to reduce electricity bills and capacity charges

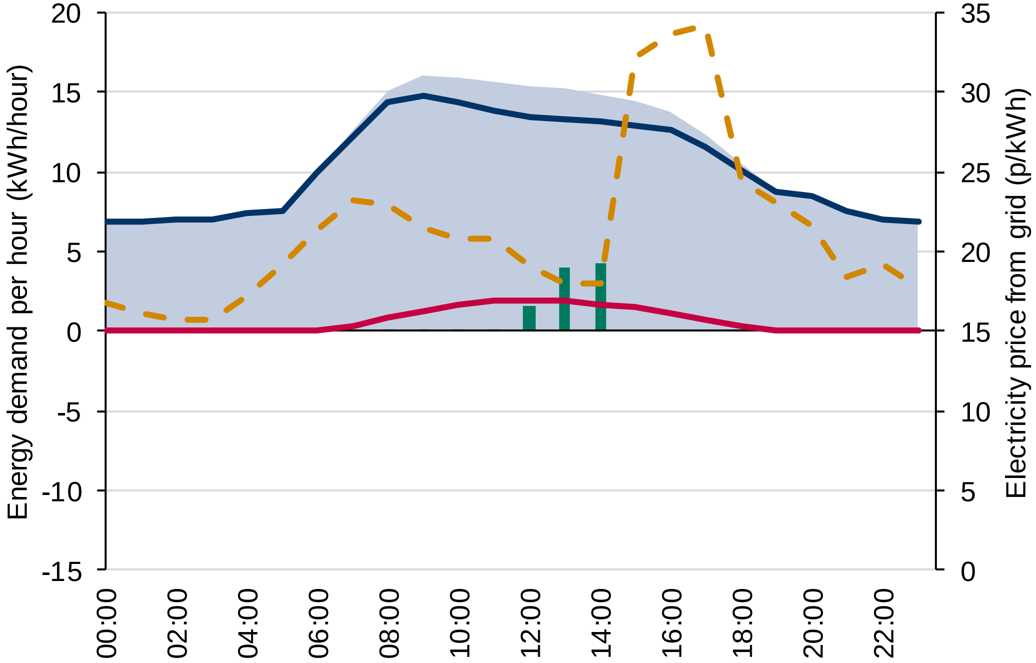
- The results show that a **static tariff would provide minimal electricity bill reductions** for an office
  - Fleet plug-in window does not align well with the off-peak tariff window
  - No V2B is used, and no further reduction in electricity bills or peak demand is achieved beyond smart charging
- Dynamic tariff provides opportunity for **electricity bill reduction**, with V2B reducing grid import during peak tariff hours
  - Without optimising peak demand, annual electricity bills can be reduced **by 5%** but peak demand increases by 2%
- **Co-optimising peak demand and electricity bills** leads to a reduction in electricity bills of 3% and a 5% decrease in peak demand
  - Both annual electricity bill and peak demand is reduced giving annual cost savings of ca. £78 per EV per year beyond what could be achieved with a smart charger

Comparison of cost savings & V2B utilisation under Office archetype, considering peak demand and electricity bill

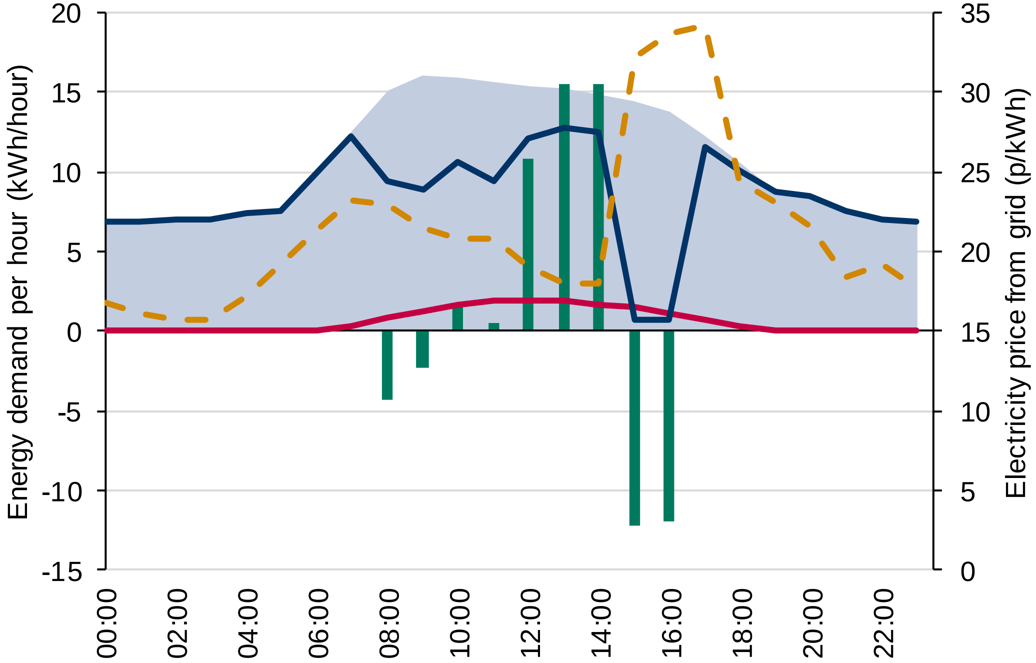


In the summer, fleet charging demand exceeds building peak demand during low-cost periods, so that the vehicles are ready to discharge to offset grid imports during peak tariff hours

Average demand profile with smart charging (kWh/hour)



Average demand profile with V2B (kWh/hour)

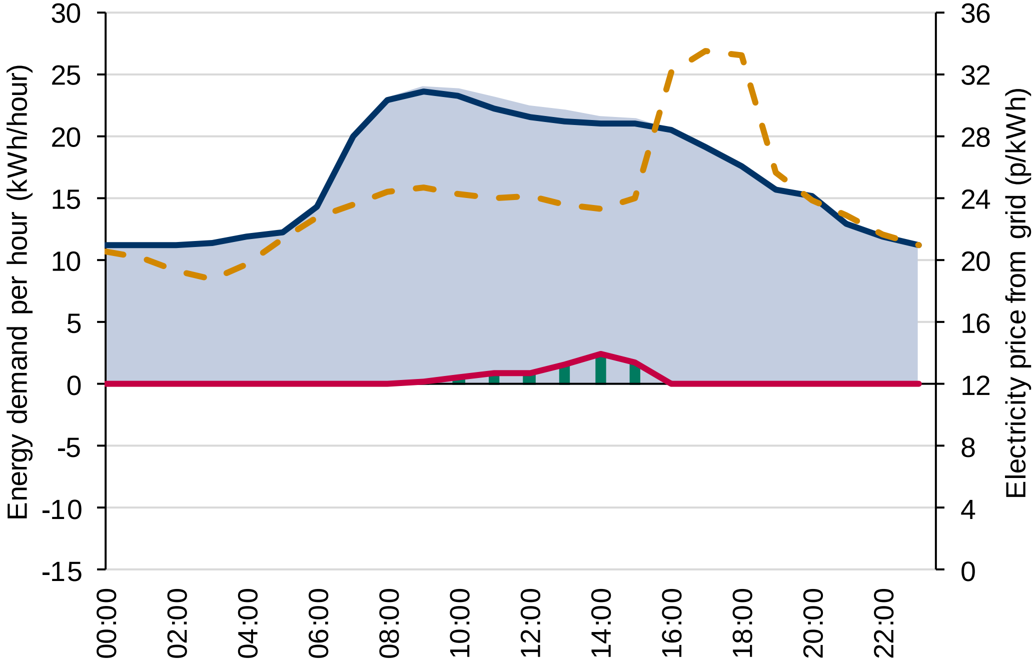


Total building energy demand (kWh)
Fleet charge/discharge (kWh)
Building demand met by onsite PV generation (kWh)
Building demand met by grid import (kWh)
Electricity price per unit from grid (p/kWh)

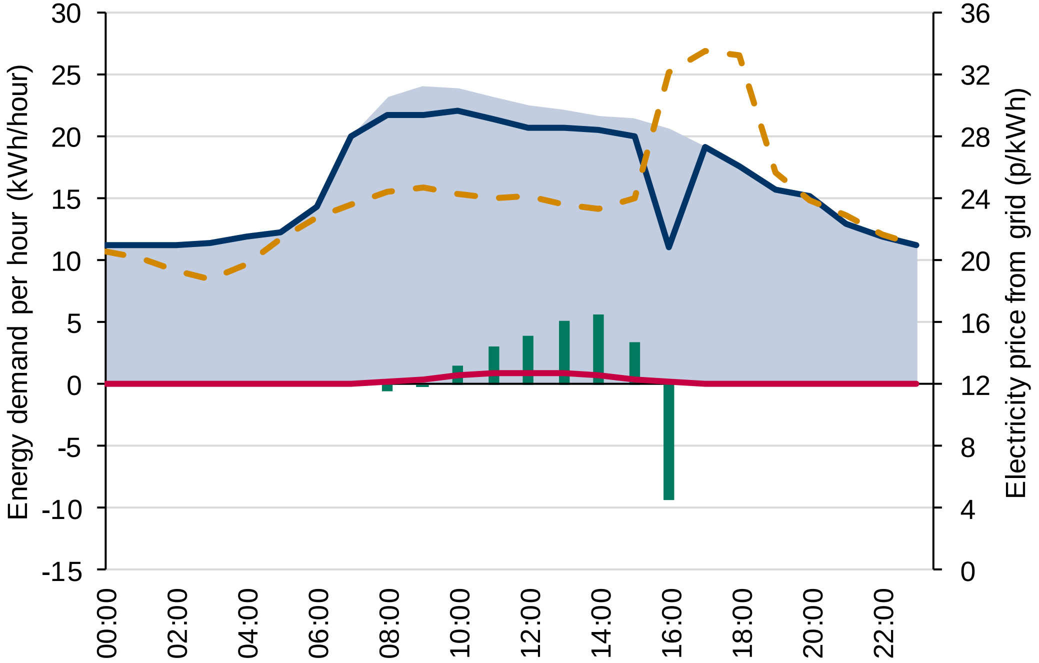
In the winter, V2B is used to reduce peak demand, with lower electricity bill reduction given the high tariffs

Mixed Dynamic

Average demand profile with smart charging (kWh/hour)



Average demand profile with V2B (kWh/hour)

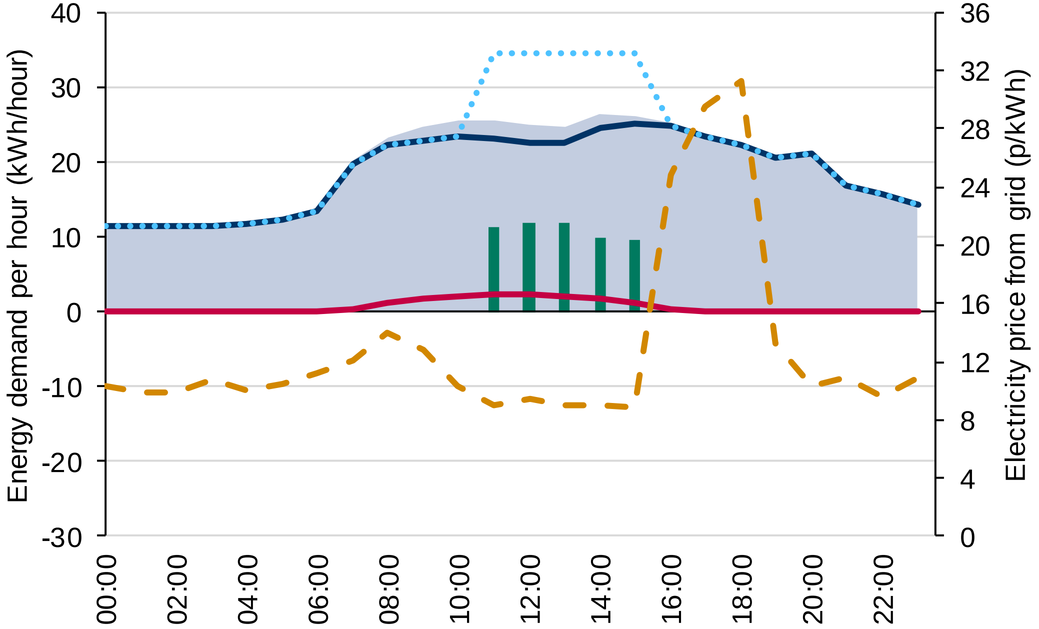


Total building energy demand (kWh)
Fleet charge/discharge (kWh)
Building demand met by onsite PV generation (kWh)
Building demand met by grid import (kWh)
Electricity price per unit from grid (p/kWh)

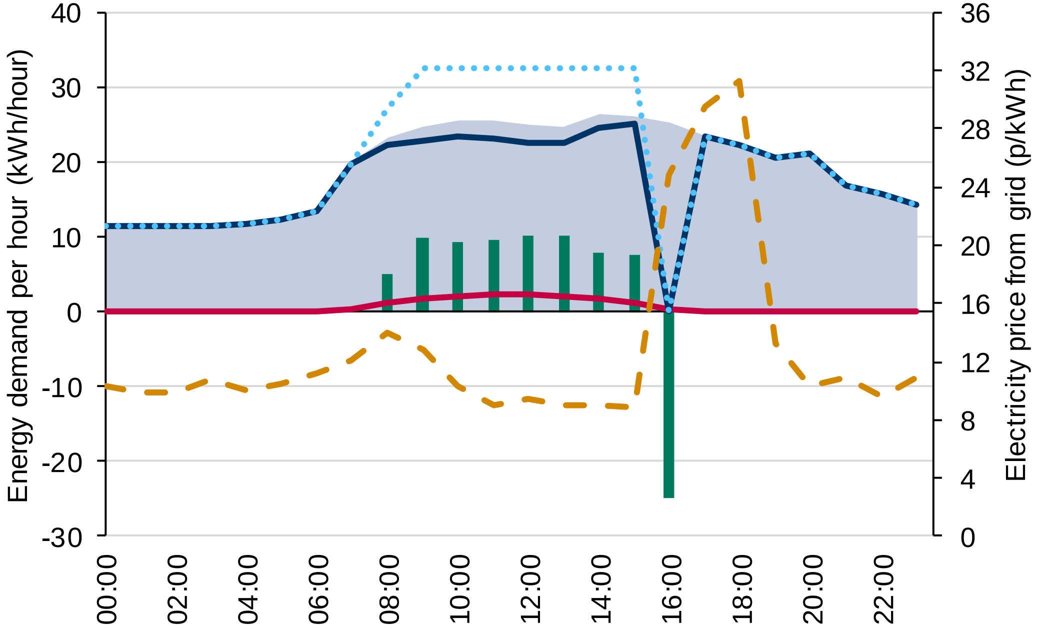
Mixed Dynamic

As building demand varies over the year, V2B reduces maximum grid import on days of peak demand, typically over winter

Optimised profile on day of peak demand with smart charging (kWh/hour)



Optimised profile on day of peak demand with V2B (kWh/hour)



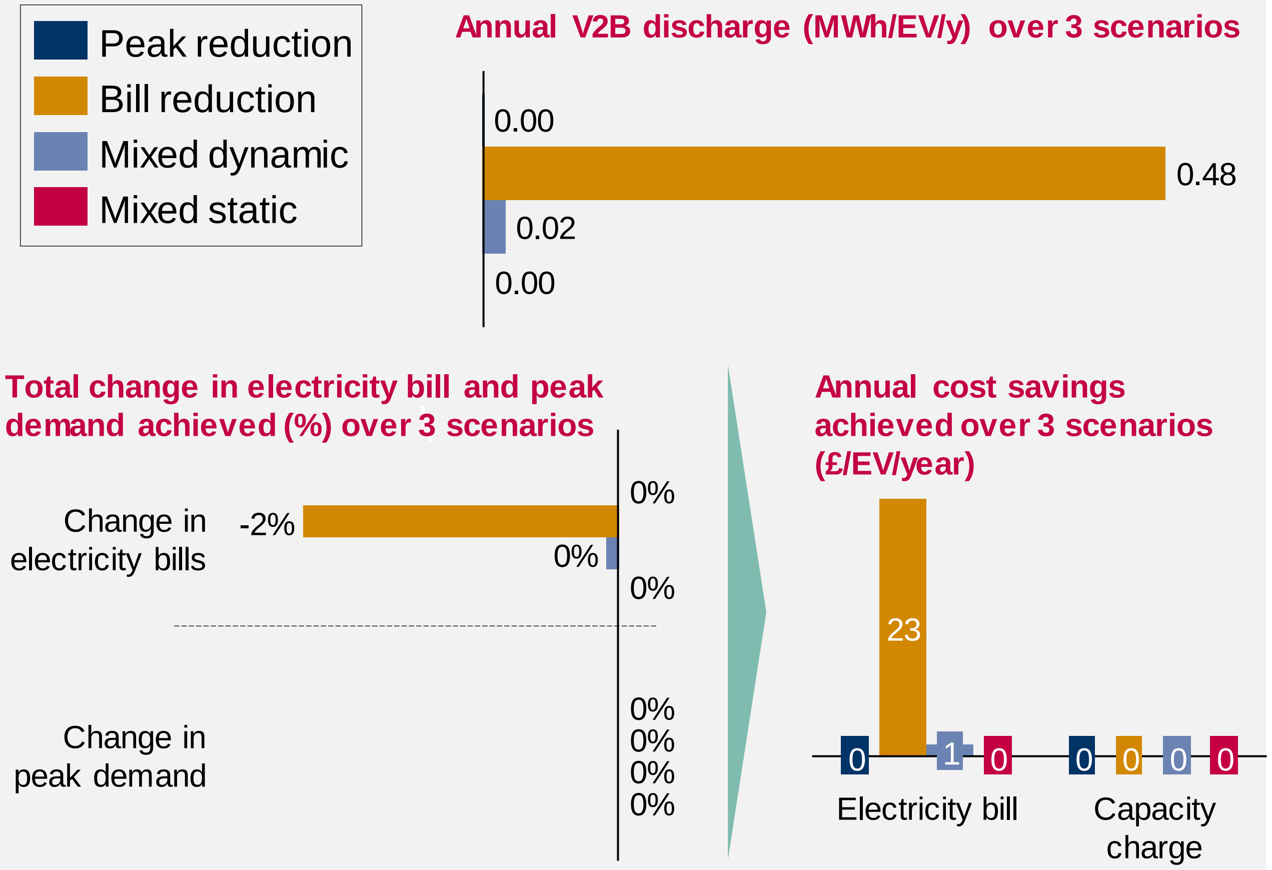
Total building energy demand (kWh)
Fleet charge/discharge (kWh)
Building demand met by onsite PV generation (kWh)
Building demand met by grid import (kWh)
Electricity price per unit from grid (p/kWh)
Total grid import (kWh)

Contents

For storage warehouses, V2B offers very limited savings compared to smart charging when considering connection capacity costs

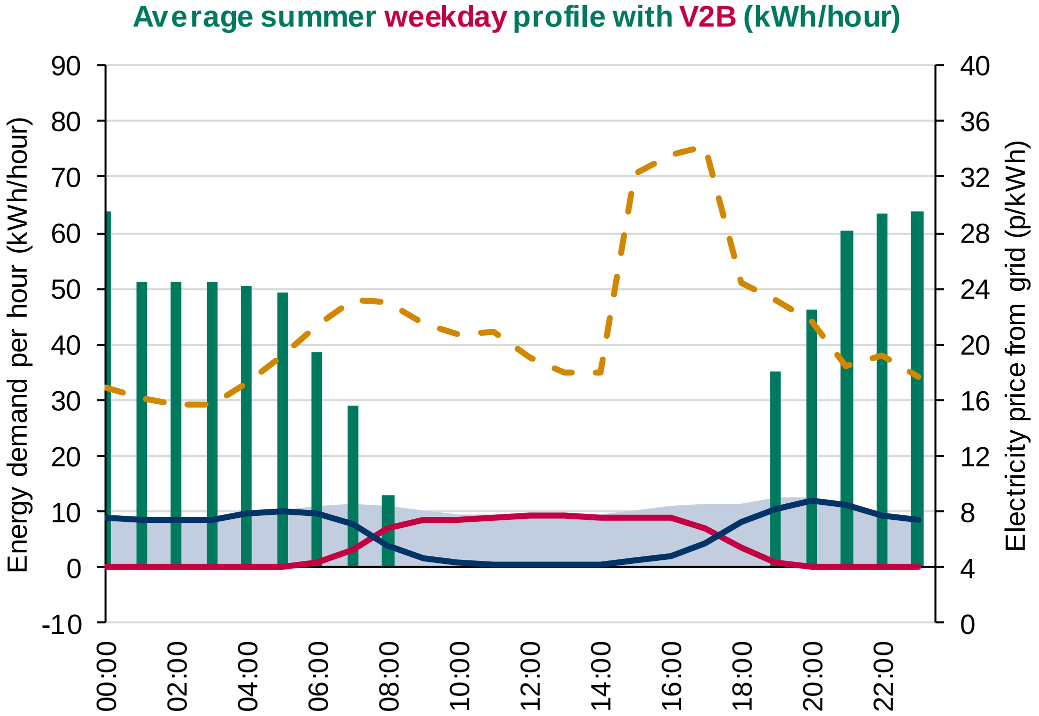
- Very limited savings achievable with V2B for storage archetype, as a result of fleet demand being **larger than building demand**
  - In particular, no peak demand reduction is achieved with V2B above what is achieved by smart charging
- Electricity bill reductions achieved only when connection cost is **not considered in optimisation**
  - Reduction is low – 2% or £23/EV/year
- When additionally optimising to minimise peak demand, small electricity bill savings are achieved with a dynamic tariff
  - Approx. 0.02 MWh/year V2B discharge per EV, resulting in a 0.1% decrease in electricity bills, saving approx. £1.1/EV/year
- V2B is unlikely to be a useful solution for the storage warehouse archetype, with limited savings from either electricity bills or reduced fixed capacity charges

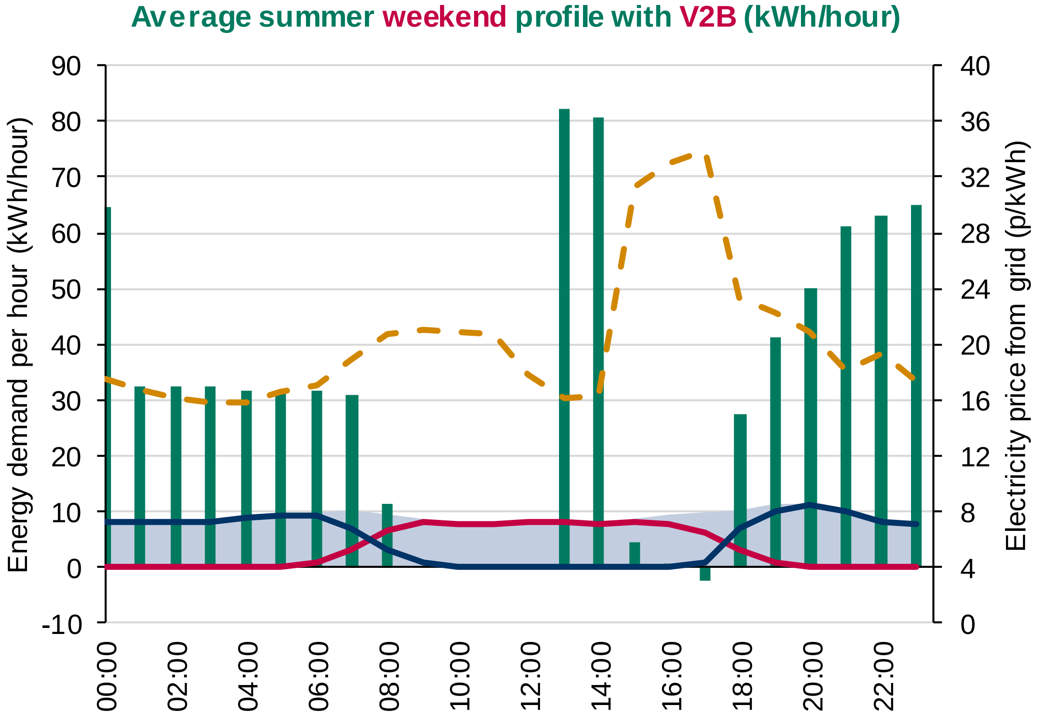
Comparison of cost savings & V2B utilisation under Storage archetype, considering peak demand and electricity bill



Summer: Dynamic tariff does not provide significant electricity bill savings, but longer weekend plug-in period allows some V2B to reduce grid import during peak tariff hours

Mixed Dynamic

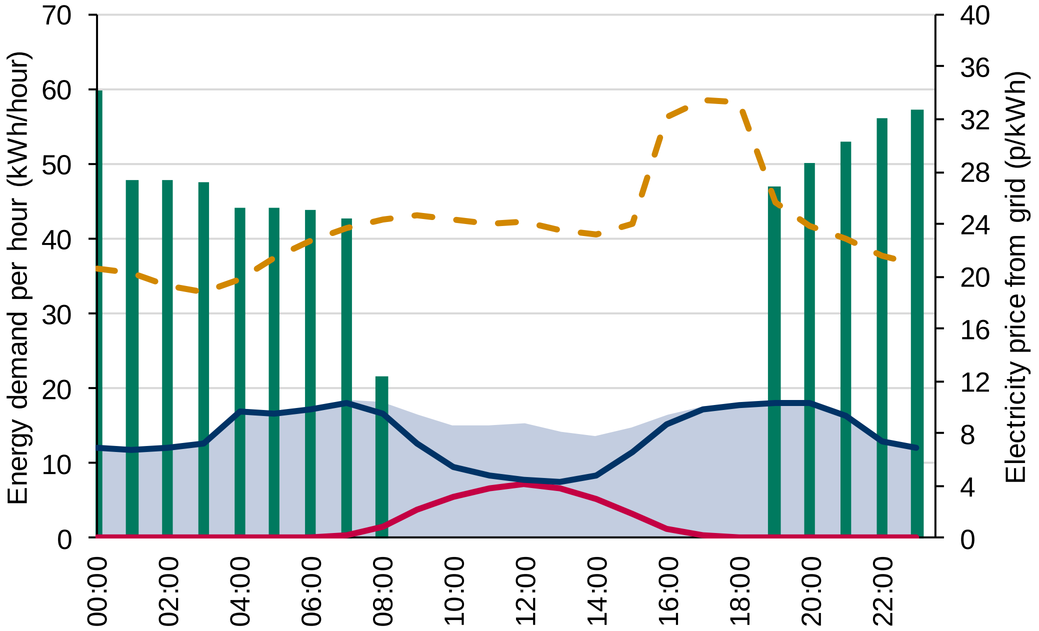




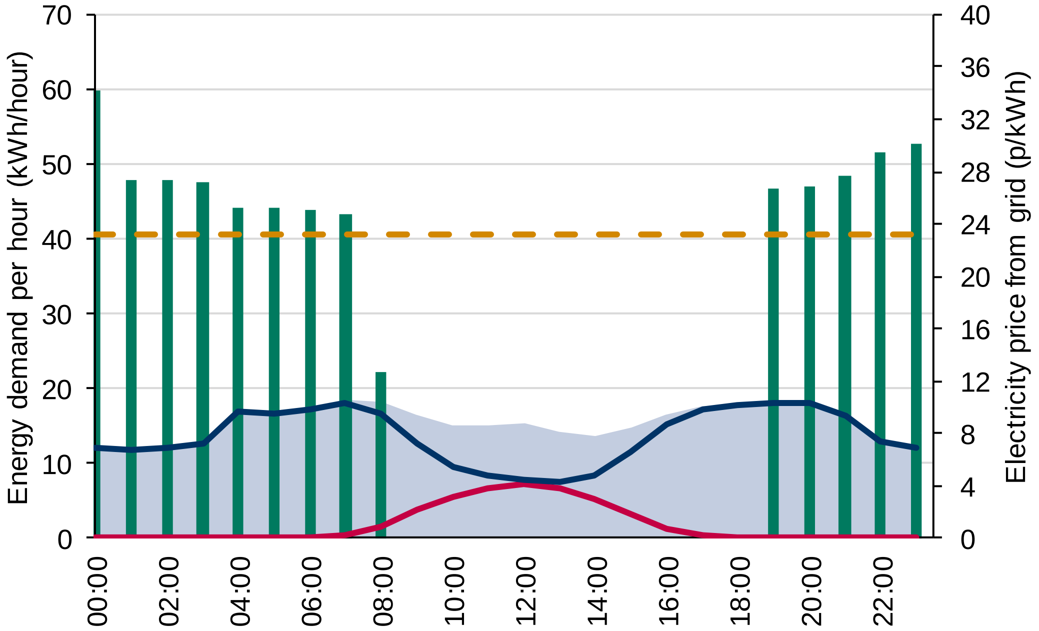
Total building energy demand (kWh)
Fleet charge/discharge (kWh)
Building demand met by onsite PV generation (kWh)
Building demand met by grid import (kWh)
Electricity price per unit from grid (p/kWh)

Winter: optimising either for electricity bill or peak demand reduction does not lead to V2B discharging on average winter days, indicating limited potential for savings

Average winter **weekday** profile with **V2B** (kWh/hour)
Dynamic tariff with no connection cost



Average winter **weekday** profile with **V2B** (kWh/hour)
Flat tariff with high connection cost



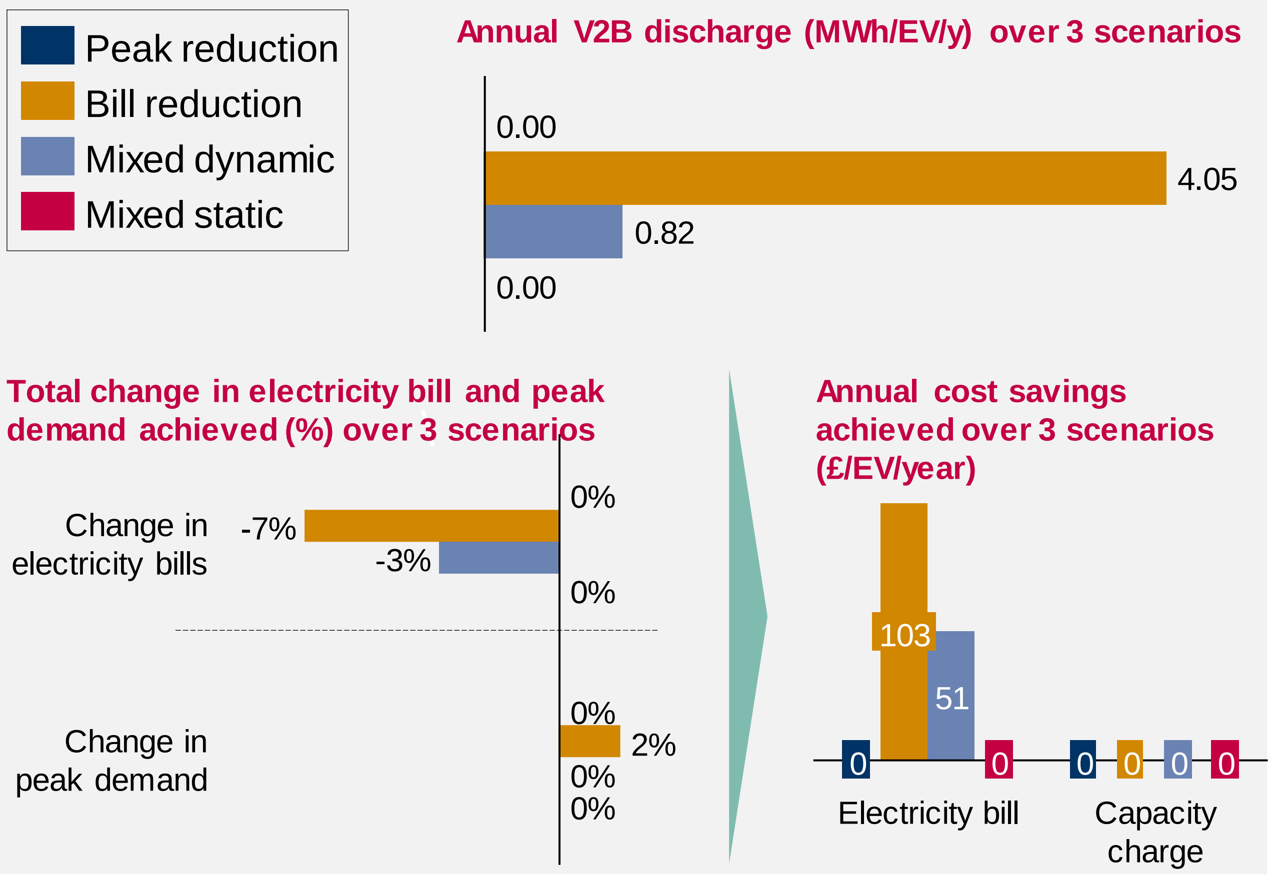
Total building energy demand (kWh)
Fleet charge/discharge (kWh)
Building demand met by onsite PV generation (kWh)
Building demand met by grid import (kWh)
Electricity price per unit from grid (p/kWh)

Contents

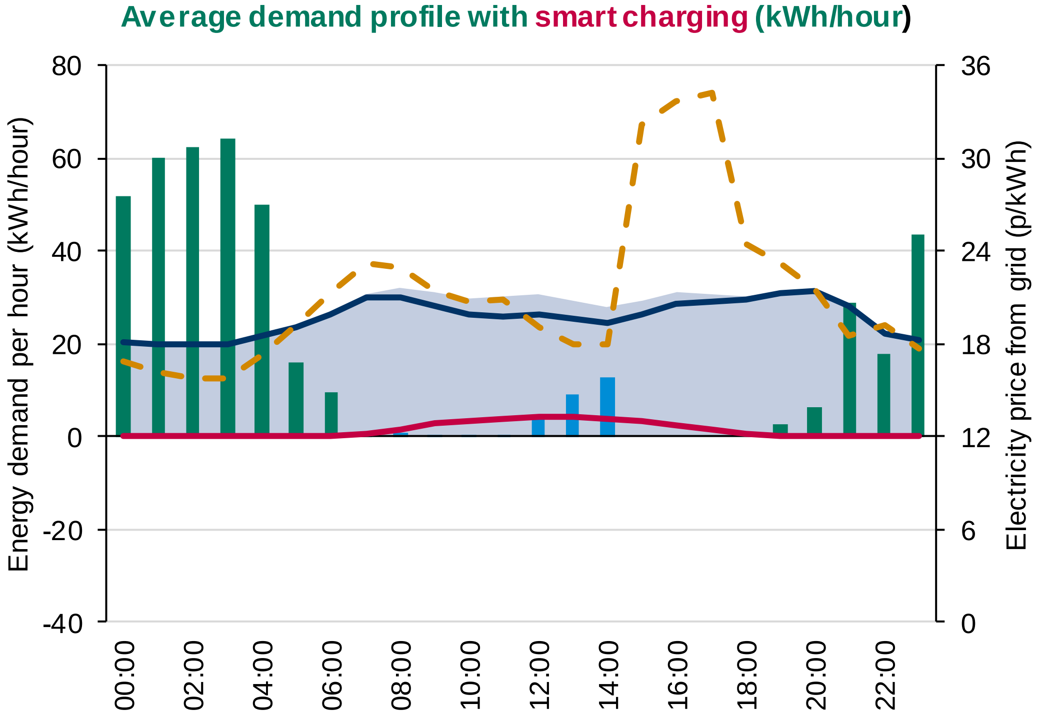
For hospitals, V2B offers electricity bill reduction, but there is no opportunity to reduce peak demand

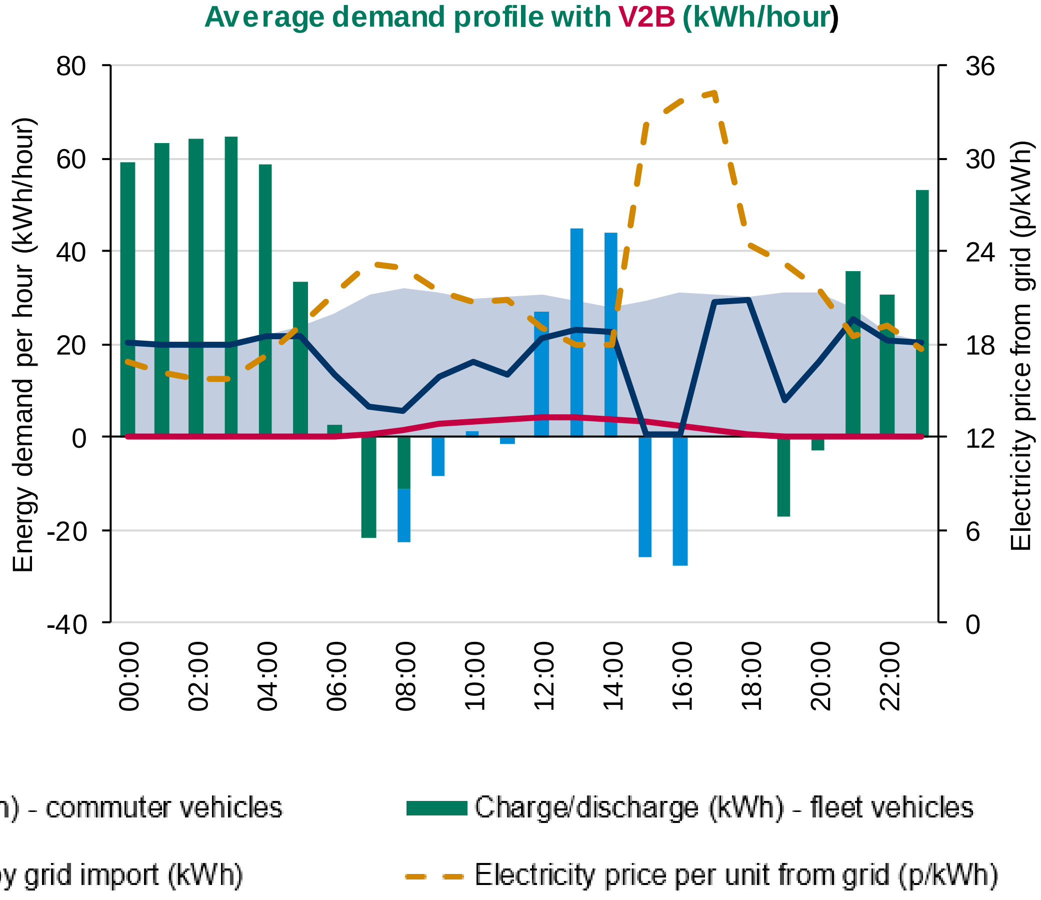
- Hospital archetype considers the potential of V2B from both the hospital's fleet (e.g. maintenance vehicles) and from commuters' vehicles
  - This is described in more detail on this slide
- The results indicate that if **connection cost is high**, V2B presents an opportunity for electricity bill savings when used alongside a **dynamic tariff**
  - A day/night tariff does not provide opportunity for V2B if peak demand reduction is additionally being optimised
- **V2B does not provide an opportunity to reduce peak demand** under the Hospital archetype beyond smart charging
  - Fleet charging demand is generally **larger than building demand**, and so significant flattening of demand profile is achieved through smart charging
- When connection cost is not considered, further electricity bill savings can be achieved but this leads to an increase in peak demand

Comparison of cost savings & V2B utilisation under Hospital archetype, considering peak demand and electricity bill



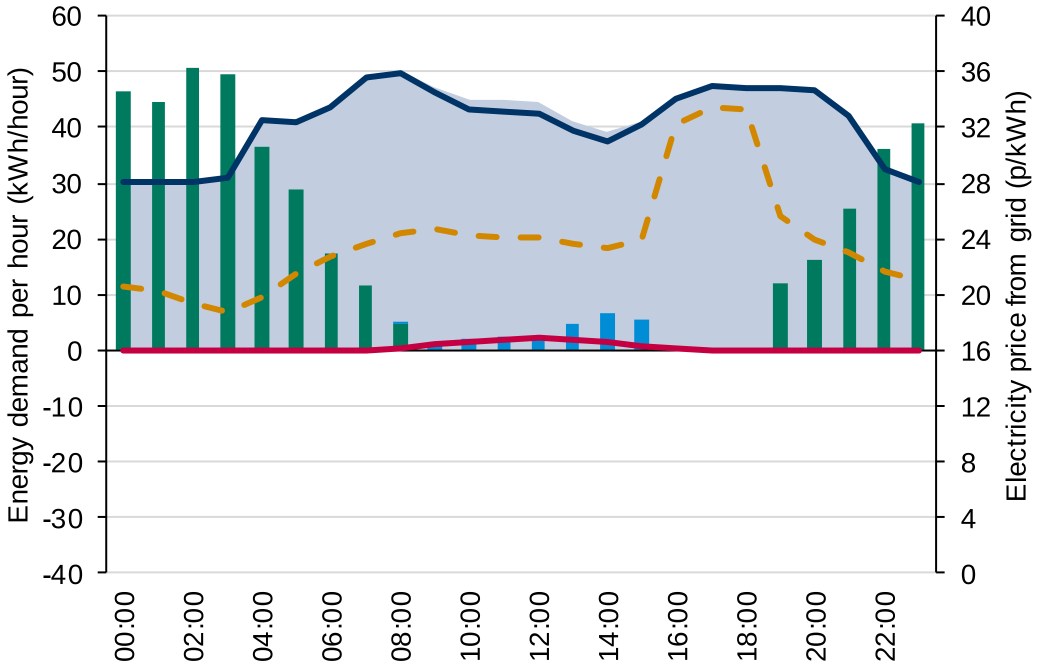
In the summer, V2B from both hospital fleet and commuter vehicles reduces grid import during peak tariff hours and charge up during periods of high PV generation



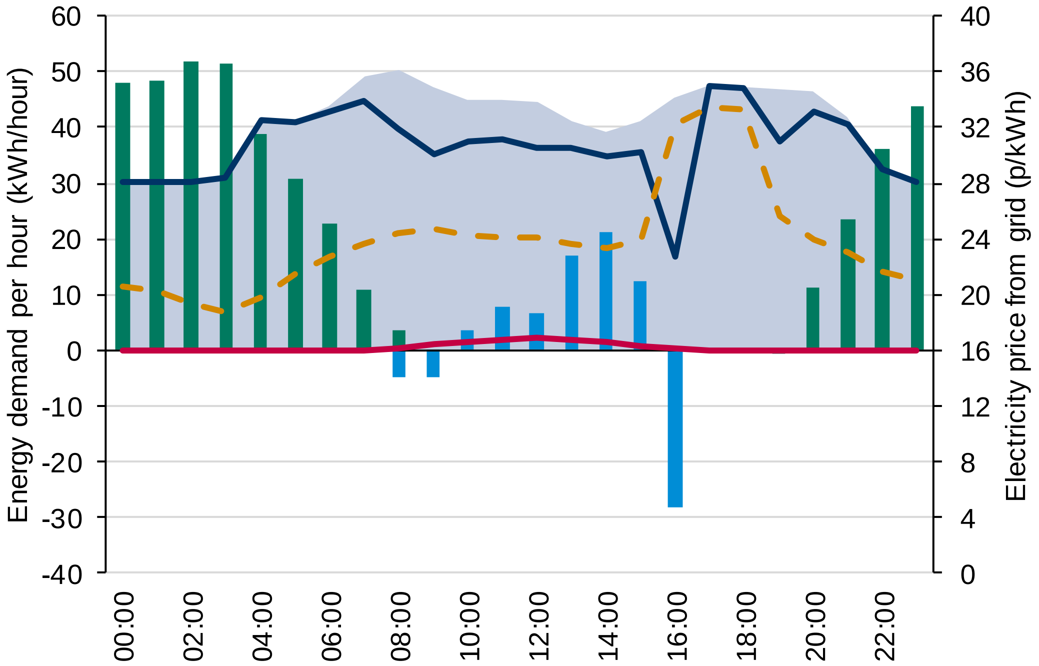


In the winter, discharge of commuter vehicles reduces grid import when electricity price is high, but hospital fleet does not participate significantly in V2B

Average demand profile with smart charging (kWh/hour)



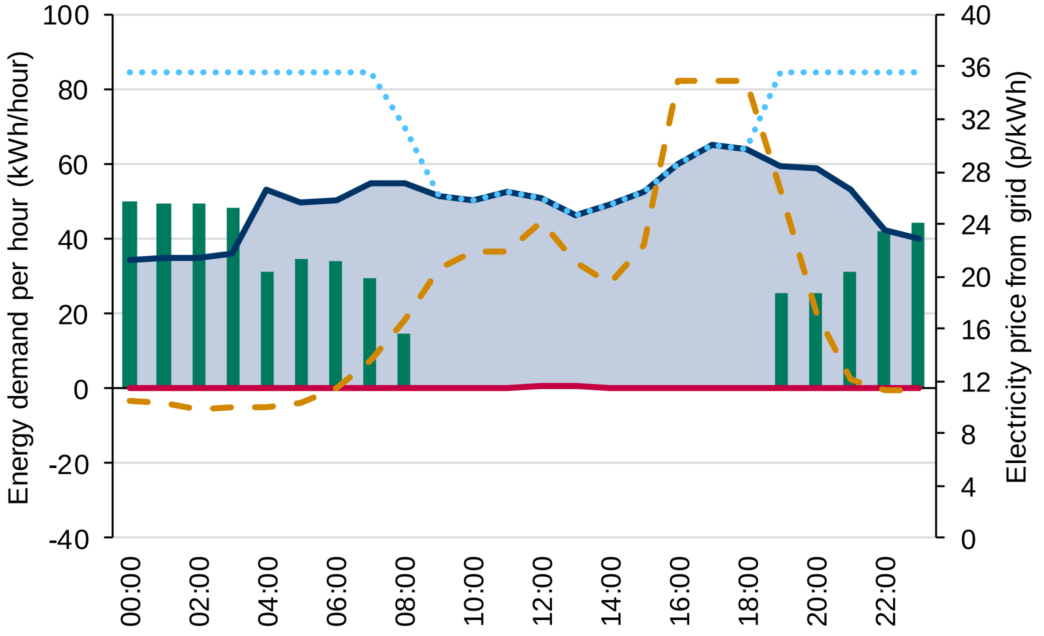
Average demand profile with V2B (kWh/hour)



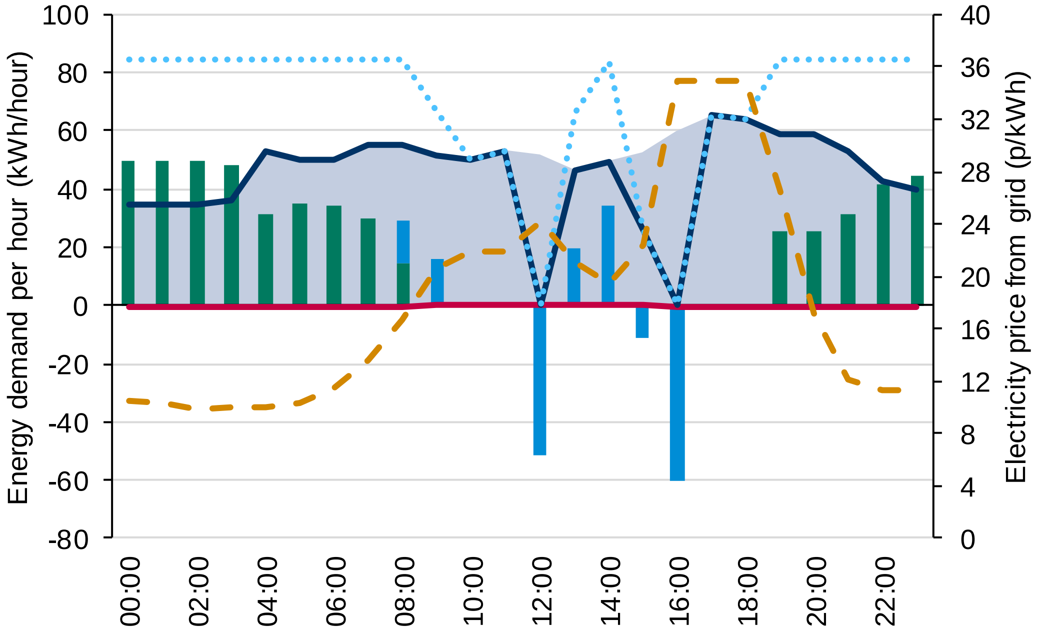
Total building energy demand (kWh) | Charge/discharge (kWh) - commuter vehicles | Charge/discharge (kWh) - fleet vehicles
Building demand met by onsite PV generation (kWh) | Building demand met by grid import (kWh) | Electricity price per unit from grid (p/kWh)

On days of peak demand, smart charges and V2B moderates charging rate to avoid exceeding peak throughout the day. There is no additional benefit from discharging to reduce the peak

Optimised profile on day of peak demand with smart charging (kWh/hour)



Optimised profile on day of peak demand with V2B (kWh/hour)

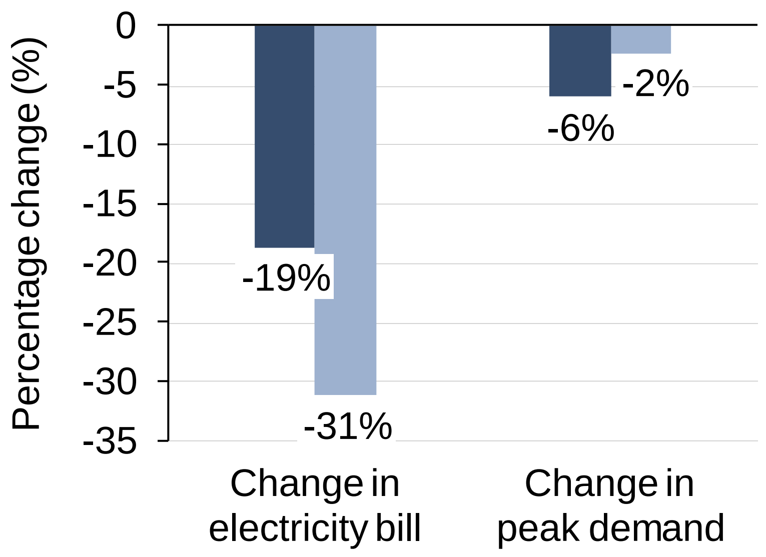


Total building energy demand (kWh)
Charge/discharge (kWh) - commuter vehicles
Charge/discharge (kWh) - fleet vehicles
Building demand met by onsite PV generation (kWh)
Building demand met by grid import (kWh)
Electricity price per unit from grid (p/kWh)
Total grid import (kWh)

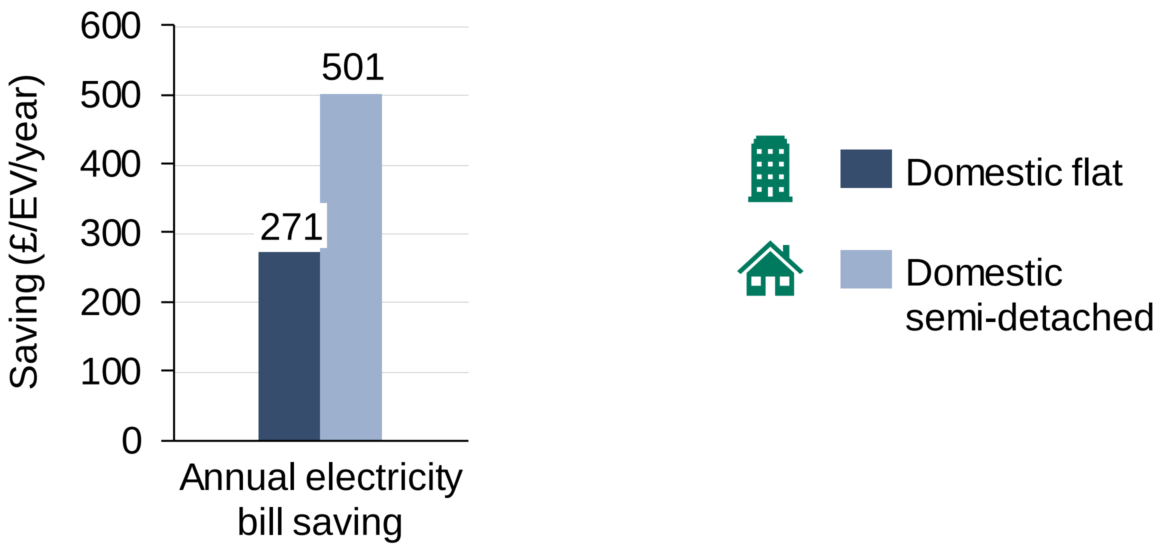
Contents

SUMMARY: Bi-directional chargers can reduce electricity bill of both domestic flat and semi-detached archetypes, and help flatten peaks in demand

Total change in electricity bill and peak demand achieved (%) using V2B compared to smart charging



Total savings in annual electricity bill (£/EV/year) using V2B compared to smart charging*



- V2B able to lower annual electricity bills and peak demand of **domestic flats and domestic semi-detached archetypes**
- For both **domestic flats and semi-detached archetypes,** the most significant electricity bill savings achieved when day/ night tariff is used due to the alignment of domestic vehicles' plug-in periods with the building demand peaks in the evening and morning and the peak tariff period of the day/night tariff
- For both archetypes, **peak demand reduction less significant** than that of electricity bill

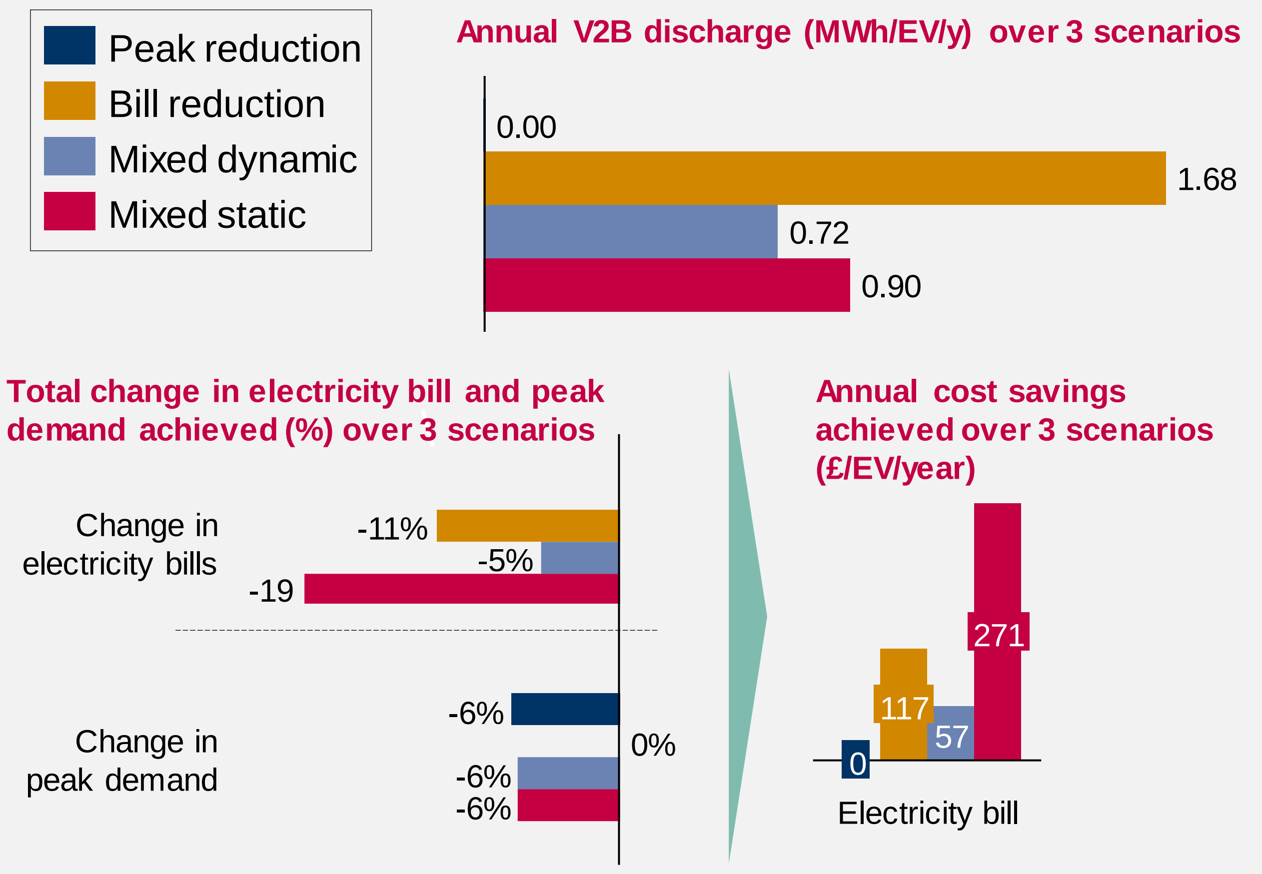
*Cost savings shown are achieved by co-optimising both electricity bills and peak demand, assuming high grid connection constraints. Note: assumed that domestic properties are not subject to fixed capacity charges for connection

Contents

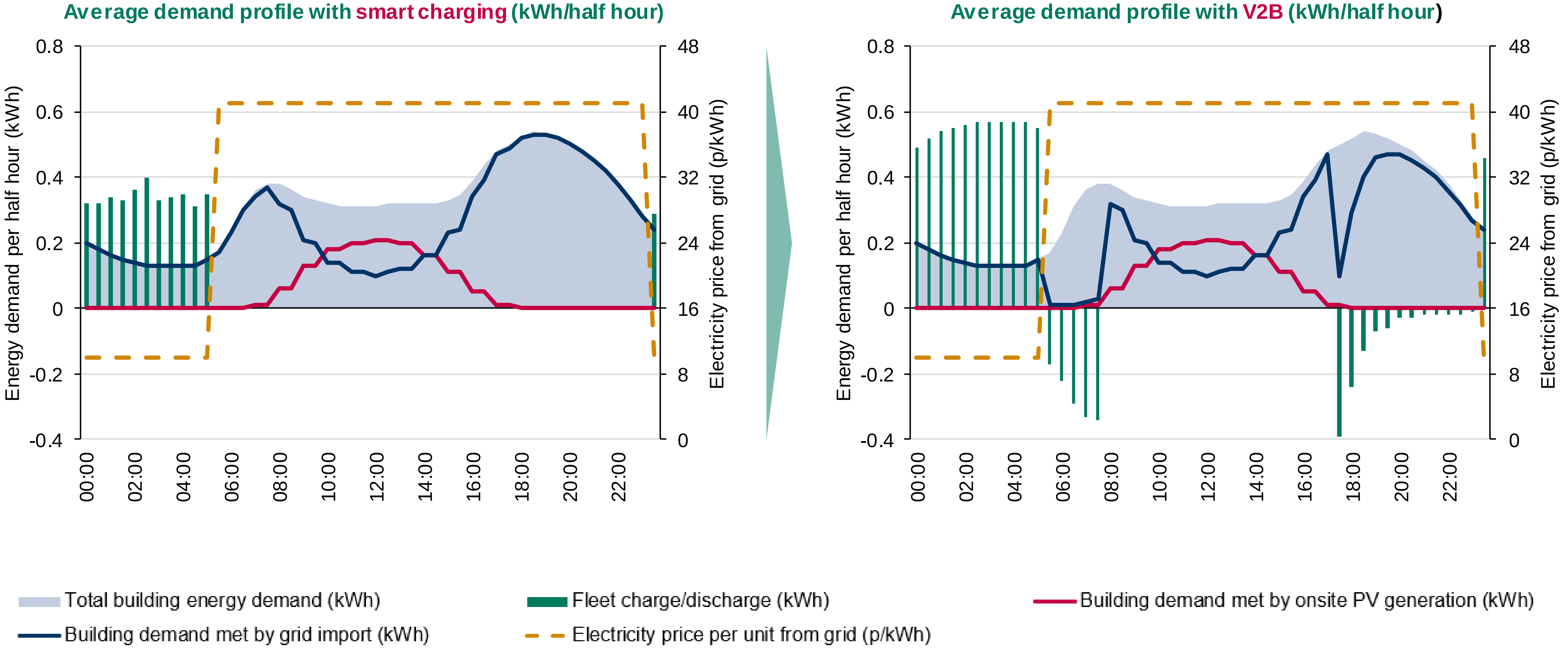
Domestic flats' electricity bills can be reduced significantly using V2B and a day/night tariff, alongside some peak reduction

- Results suggest that the most potential for cost savings for the **domestic flat archetype** would be using a **day/night tariff**
  - The off-peak pricing of electricity overnight aligns well with the domestic vehicles' plug-in periods
  - This allows V2B to significantly reduce grid import when building demand peaks in the morning and early evening
- **Dynamic tariff** also results in **electricity bill savings**, however, lower overall reduction than achieved with day/night tariff
  - Plug-in profile does not align well with the period of high demand and high dynamic prices in the early evening
- V2B additionally **reduces peak demand** by 6% when **connection cost is optimised**
  - Without consideration of connection cost, peak demand does not change

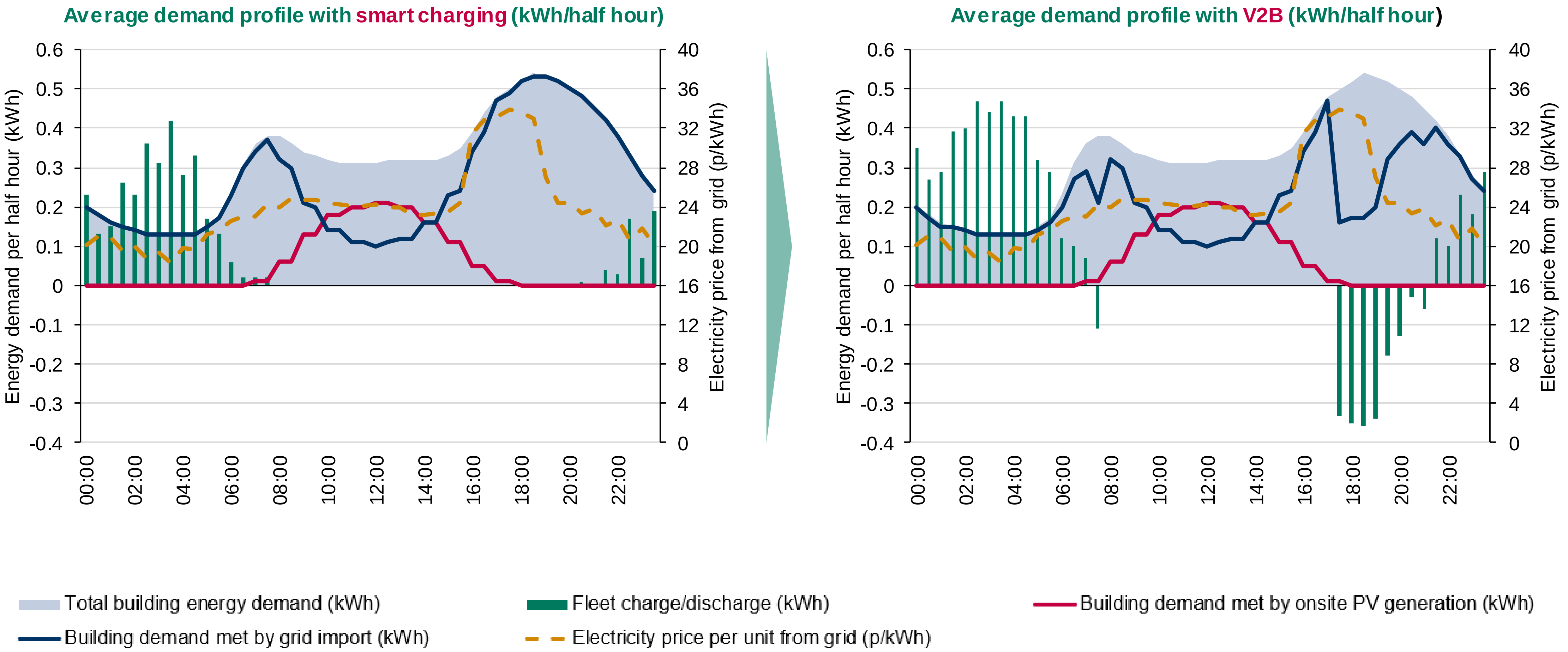
Comparison of cost savings & V2B utilisation of Domestic flat archetype, considering peak demand and electricity bill



Winter: V2B reduces grid import during morning and evening peaks in demand and peak day/night tariff prices



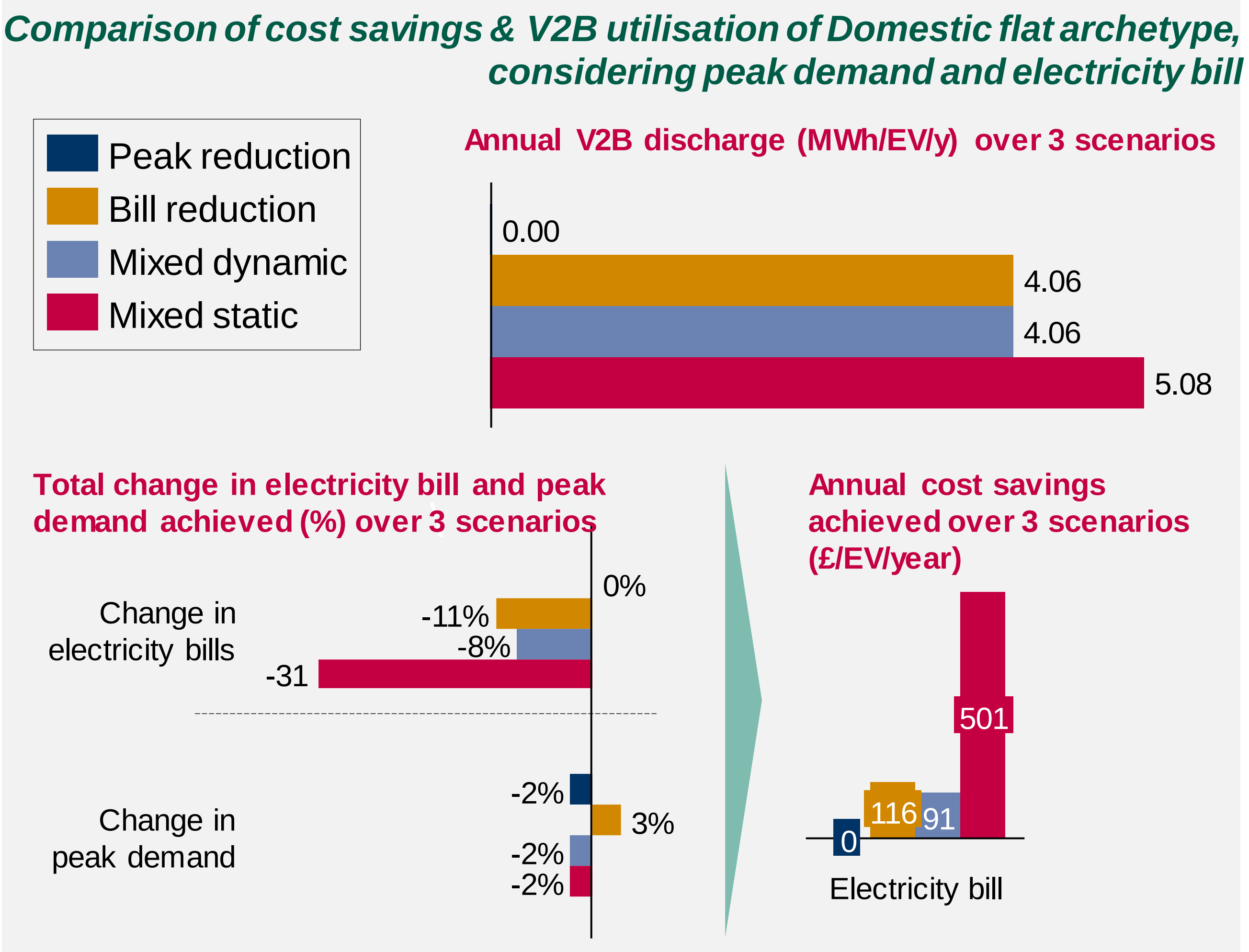
Winter: grid import somewhat reduced during high dynamic prices in the early evening



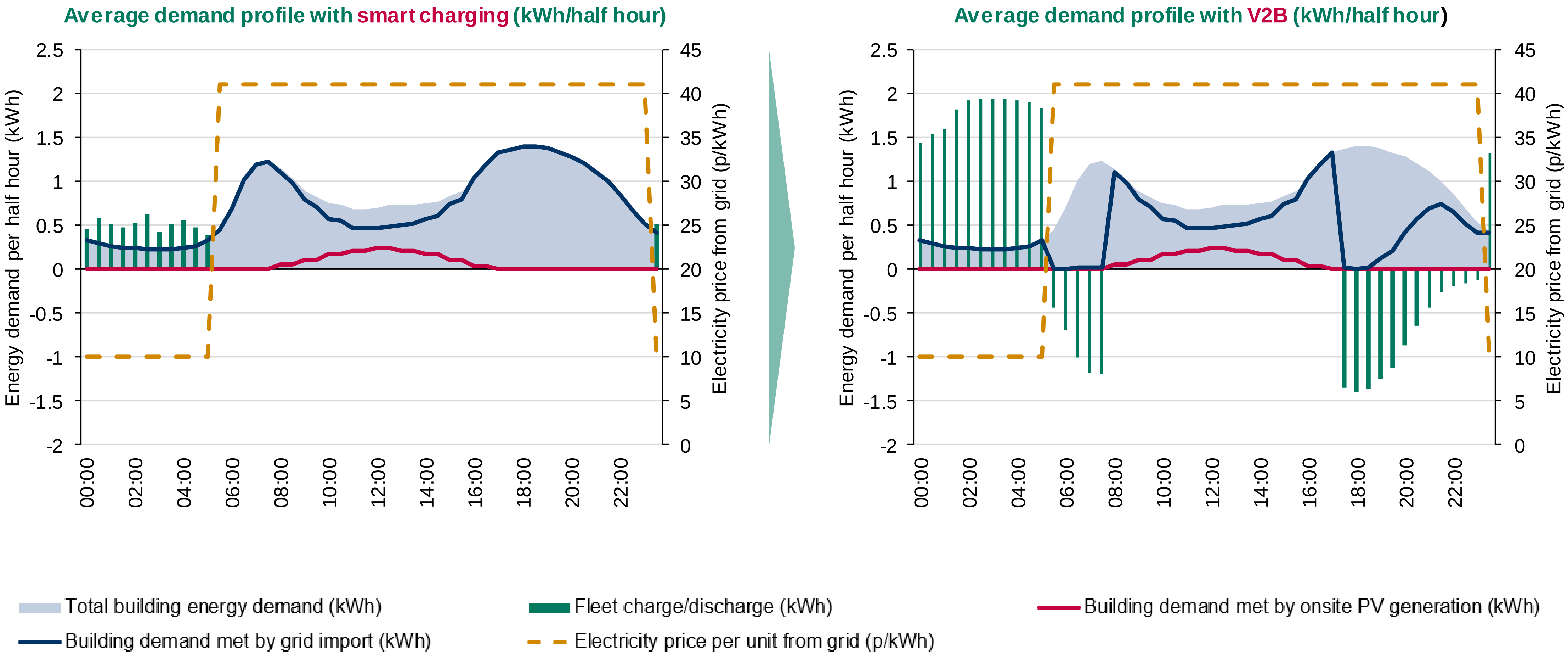
Contents

V2B lowers electricity bills of domestic semi-detached properties, but little opportunity to reduce peak demand

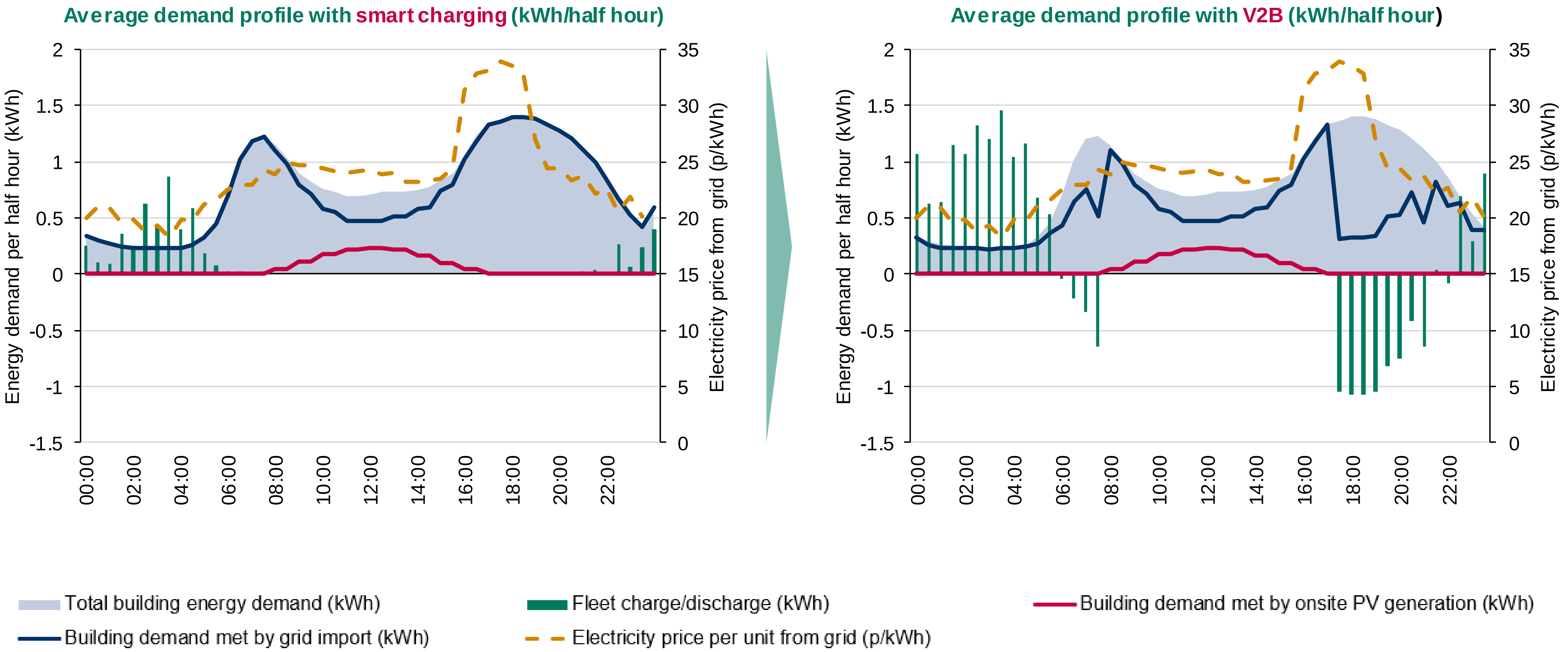
- Results suggest that the most potential for cost savings for the **domestic semi-detached archetype would be using a day/night tariff**
  - The off-peak pricing of electricity overnight aligns well with the domestic vehicles' plug-in periods, allowing V2B to lower electricity bill during peak times in the morning and early evening
  - See operational profile on next slide
- **Dynamic tariff does not offer as significant an opportunity for reducing electricity bill savings**
  - Plug-in profile does not align well with the period of high demand and high prices between 3 – 5.30pm
- There is very **low potential for peak demand reduction** relative to smart charging
  - Optimising to consider connection cost leads to **approx. 2% change in peak demand**
  - Not optimising peak demand does not further reduce electricity bills suggesting optimal solution considers both electricity bills and peak demand



In the winter, V2B reduces grid import when building demand is high during peak hours of day/night tariff



In winter, V2B lowers costly grid imports in the morning, but plug-in profile does not align well with peak in dynamic prices between 3 – 5.30pm



Contents

Sensitivities were carried out to investigate the factors investigating the business case for V2B

Two sensitivities have been carried out on core building types

- In addition to the core runs carried out investigating the impact of electricity tariff and grid capacity constraints on the building archetypes a number of **further sensitivities** have been carried out to understand the factors influencing the savings and business case for V2B
  - These sensitivities have been carried out on the **core commercial building types**
- Sensitivities have been carried out to look at the impact of:
  1. **Extreme heating days:** assess the impact of V2B on a day with extreme heating, for example, as a result of an extreme weather event. Profiles optimised assuming one day of extreme heating demand each year.
  2. **Battery degradation:** impact of assuming additional cost of vehicle discharge due to battery degradation. Profiles optimised considering no, central and high battery degradation costs when discharging.

Summary of key findings

Extreme days:

- During days of peak heating demand, **V2B discharge is increased** to meet high building demand to reduce peak demand and electricity bills
- **Vehicles charge more on the post-extreme day** than on average days to recover from the increased discharge and limited charging on the previous day

Battery degradation:

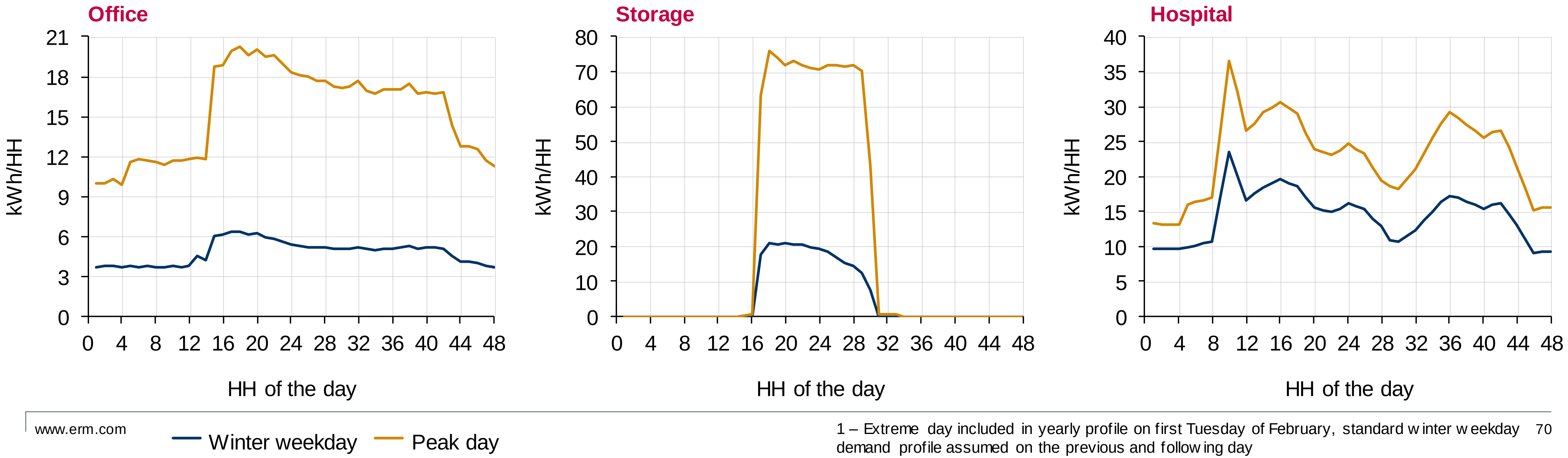
- The **central battery degradation cost** reduces the annual quantity of electricity discharged from the fleet by 10 – 15%
- This has a **low impact on the electricity bill savings achieved (<2%)**
- **High battery degradation cost** has a more significant impact on the V2B discharge, **reducing the electricity bill savings achieved** by ca. 15%

Contents

Sensitivity was carried out to look at the impact of V2B on a day of peak heating demand

- Sensitivity was carried out to model V2B on a day with **extreme heating demand**, e.g. as a result of an extreme weather event
- As set out in the modelling method, each building's demand is split between **heating demand** (assumed to be electrified) and **baseload electricity demand**
  - In core runs, heating demand profiles vary with time of year and week
  - A sensitivity was carried out assuming a **single extreme day of heating demand[1]**, as set out below

Half hourly heating demand across core building archetypes on a typical winter weekday and a peak day

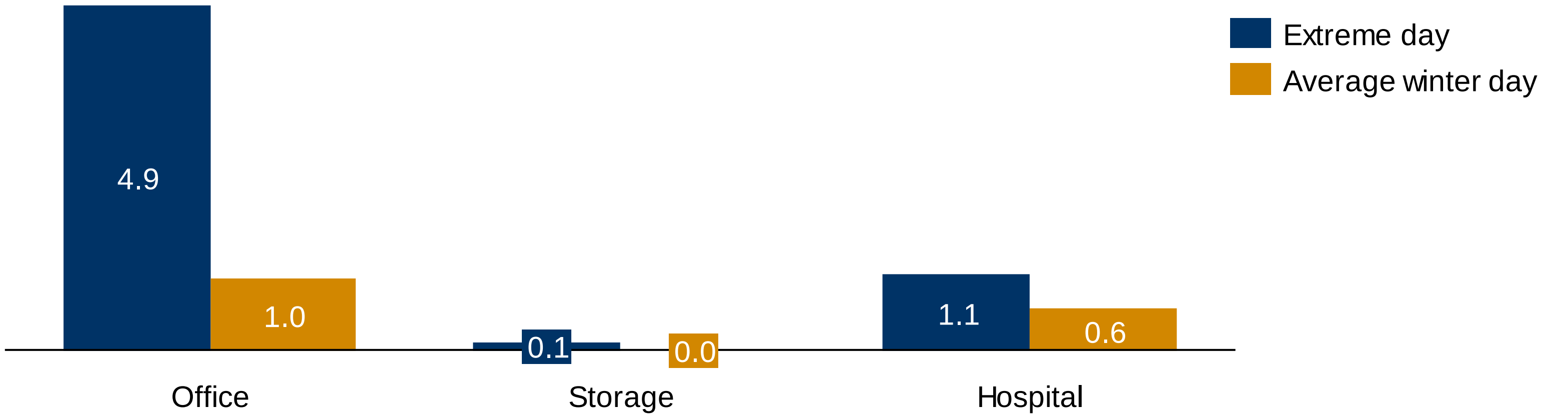


1 – Extreme day included in yearly profile on first Tuesday of February, standard winter weekday demand profile assumed on the previous and following day

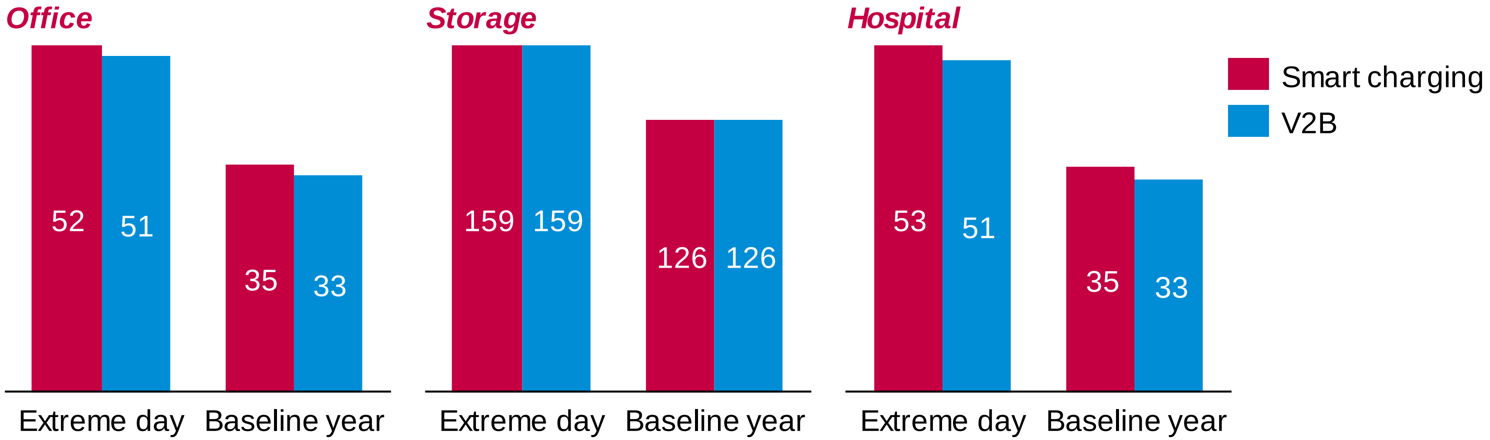
V2B is higher on days with extreme demand to reduce cost of electricity imported form the grid and to reduce peak demand

- On days with extreme weather, all archetypes have **higher V2B discharge** than on average winter weekdays
  - Offices in particular have 5 times higher V2B on extreme weather days
- V2B is able to **slightly reduce** the **extreme day peak demand** from offices and hospitals further than is achieved by smart charging
  - However, the reduction is small (3-4%) and no peak demand reduction is achieved at storage warehouses
- As shown on the following slides, increased V2B on extreme days is also used to **reduce grid import when prices are high**
  - This can lead to significant savings on extreme days when total grid consumption consumption is high

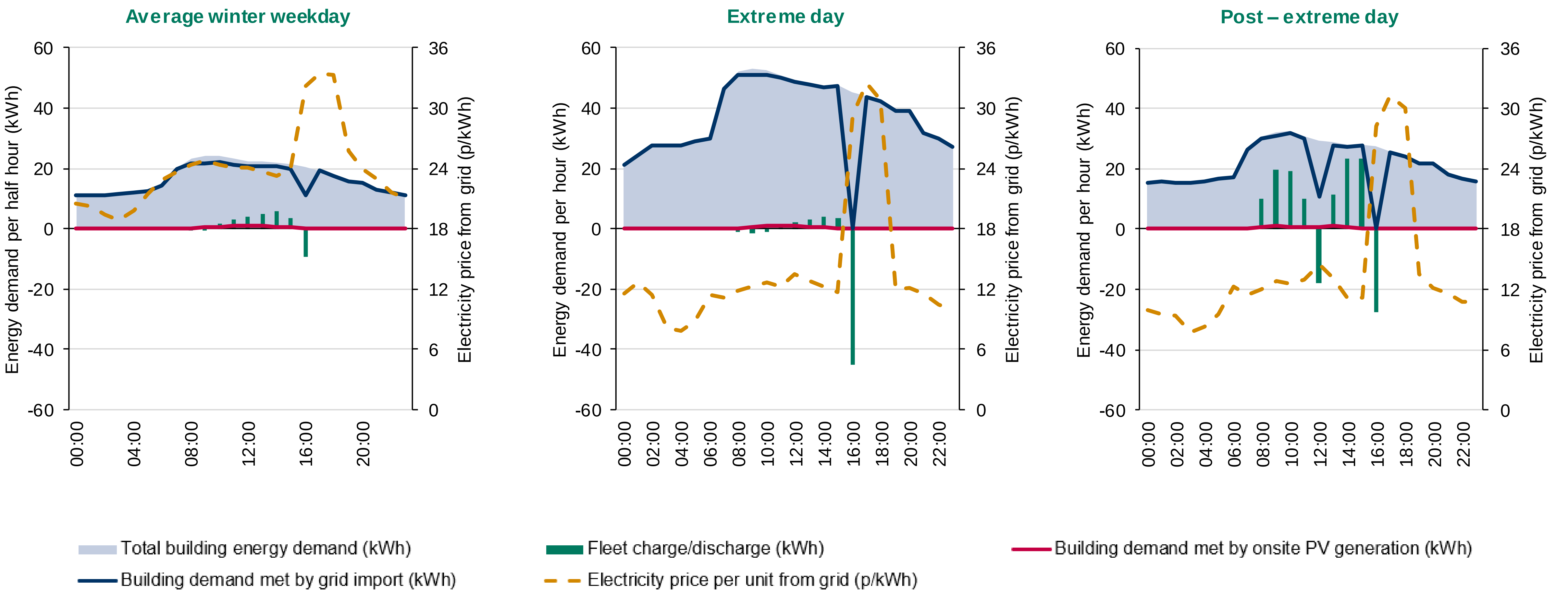
V2B discharge observed on extreme days and on average winter weekday (kWh/EV/day)



Peak demand observed on extreme days and over baseline years with smart charging only and V2B (kW)

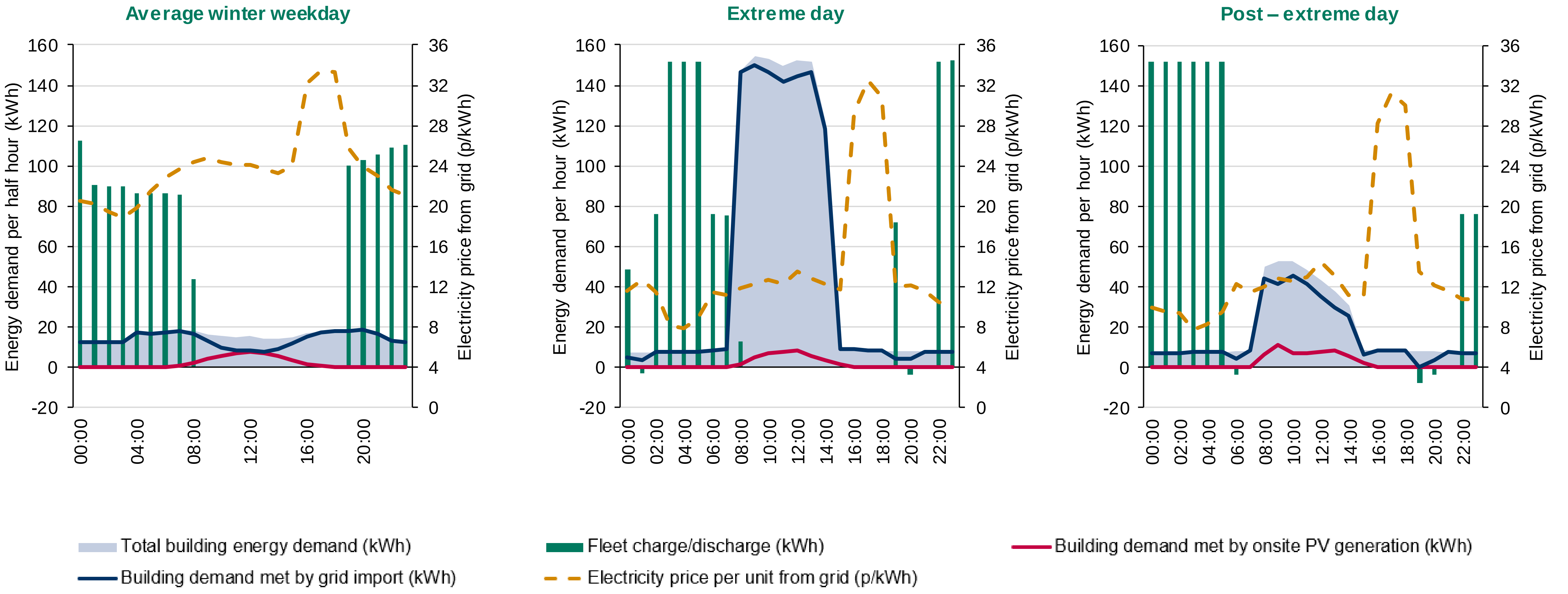


On extreme weather days, office archetype has high V2B discharge to avoid import of costly grid electricity; high net EV charging on the following day to recover

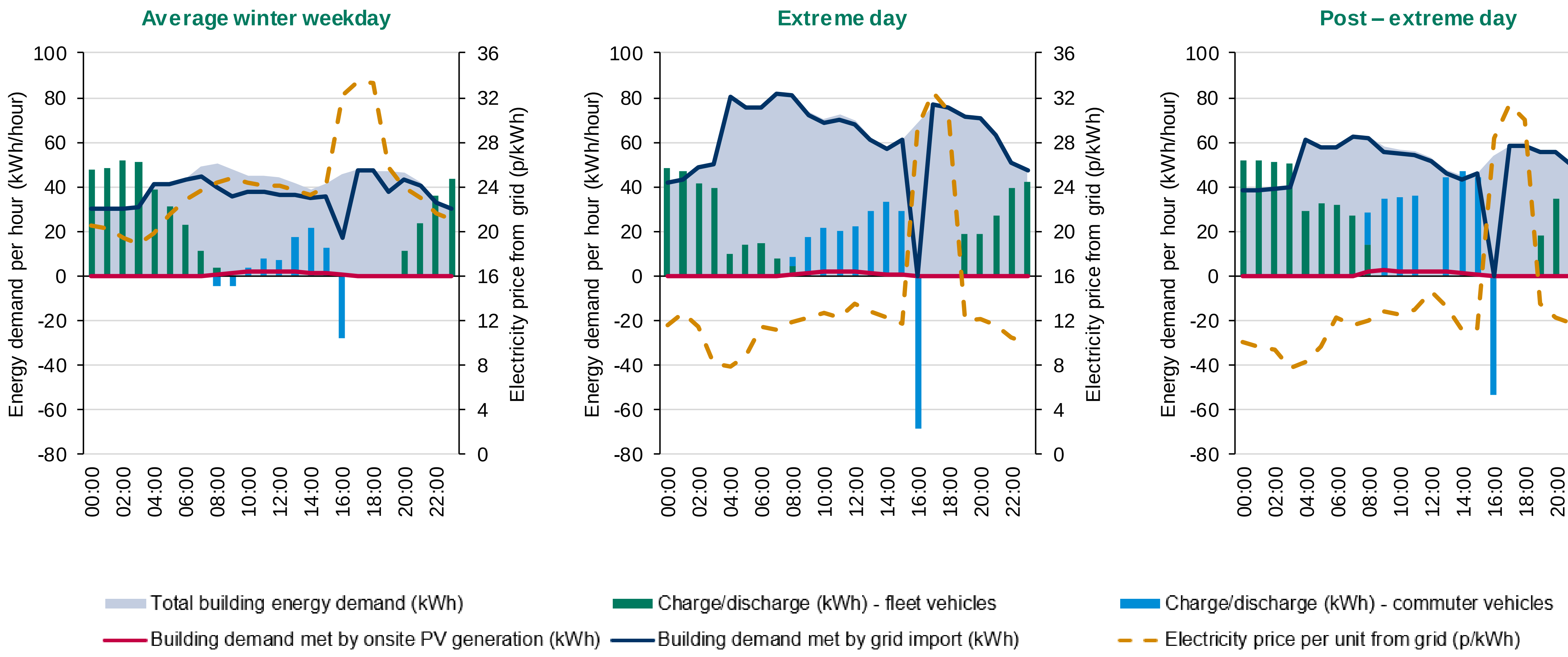


Mixed Dynamic

Small amount of V2B occurs on extreme days to reduce grid import, however, plug-in window does not align well with peak demand so limited opportunity for peak reduction



Smart charging used to smooth total hospital grid demand on extreme weather days, with high V2B from commuter vehicles in the early evening peak



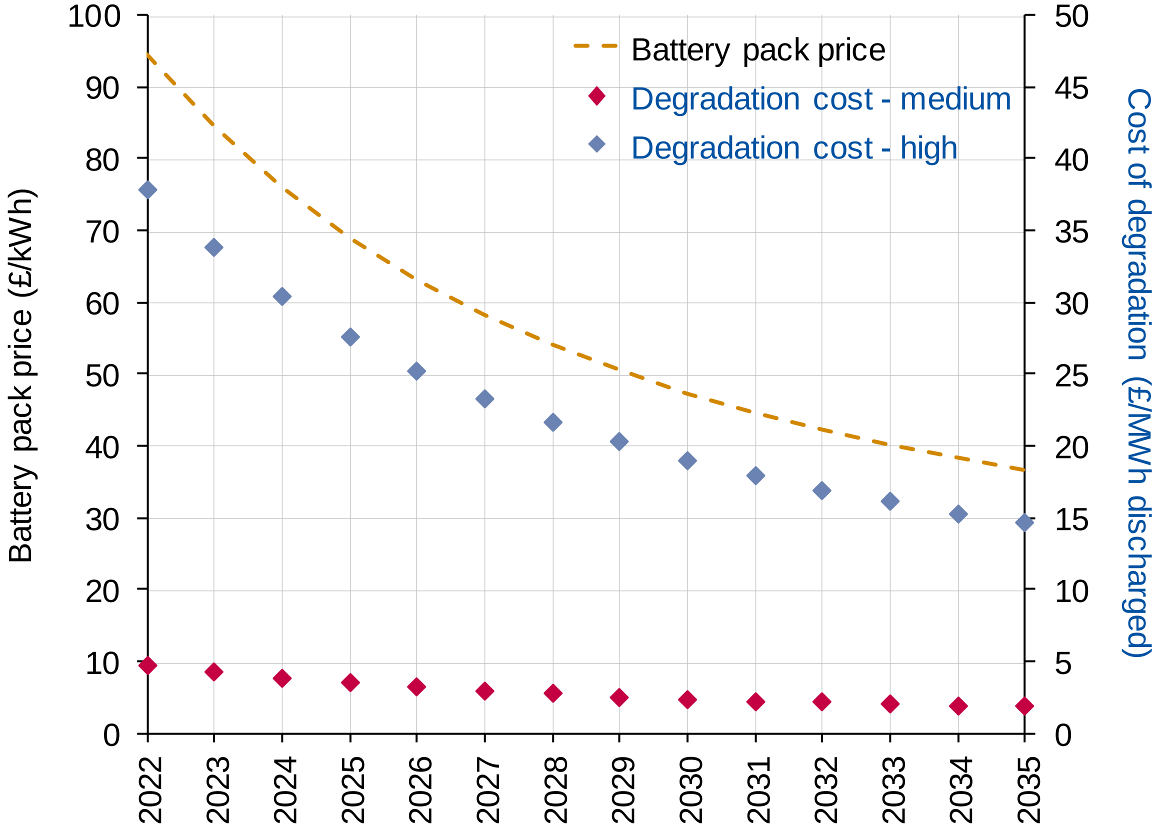
Contents

Sensitivities have been used to investigate the impact of negligible, mid, and high degradation costs

Modelling will consider the degradation impact from **increased cycling of battery**. Degradation rate will be used alongside battery pack costs to calculate the cost of degradation. 3 scenarios will be modelled, based on the literature review carried out in this section:

1. **No increased degradation** from V2B - **baseline**
   - Due to effect described on this slide[2], where calendar degradation is reduced by bidirectional charging, leading to no net increase in degradation
2. **Medium degradation rate of 0.005% decrease in SOH per discharge cycle** - £3.44/MWh discharged in 2025
   - Based on research by Technical University of Denmark[3] and ETI modelling[4], and assumes cycling and calendar degradation can be separated
3. **High degradation rate of 0.04% decrease in SOH per discharge cycle** - £27.56/MWh discharged in 2025
   - Based on Geotab data5 and considers overall observed battery degradation, without separation of cycling and calendar degradation impacts

BNEF battery pack price projections[1] (£/kWh) and resulting cost of degradation to use in modelling (£/MWh discharged) over medium and high scenarios

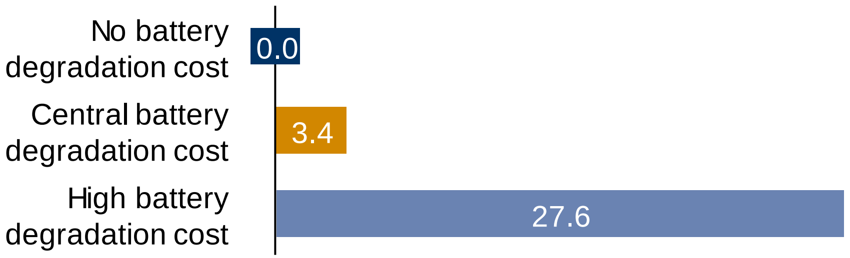


Note: prices converted from 2021 USD using 0.81 GBP/USD (March 2023). Sources: 1 – BNEF Lithium-ion battery pack price outlook, Global EV Outlook 2022; 2 - Uddin, K., et al.. (2017). *On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system*; 3 - A. Thingvad, et al. (DTU), *Empirical Capacity Measurements of Electric Vehicles Subject to Battery Degradation From V2G Services* (2021); 4 - Consumer Vehicles and Energy Integration (CVEI) Project, Element Energy for ETI, 2019; 5 – ERM analysis of **Geotab's EV battery degradation tool**

Including cost of battery degradation when optimising each archetype's operational profile has a low impact on the savings achieved and no impact on peak demand reduction potential

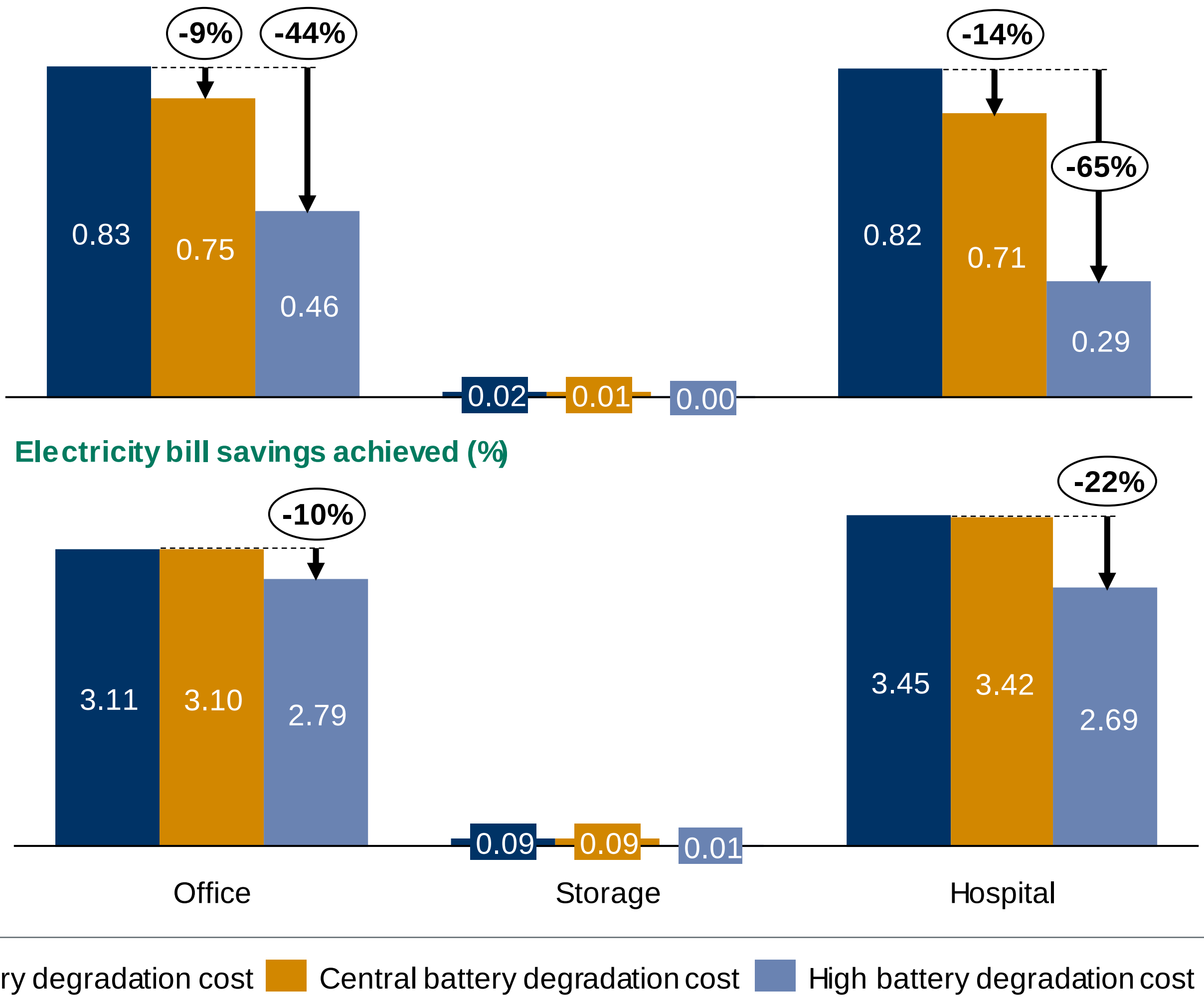
- Consideration of additional battery degradation cost as a result of V2B reduces the annual discharge of the fleet
- Central battery degradation cost of £3.44/MWh discharged has small impact on the V2B profile and the electricity bill savings achieved (<1%)
  - Small decrease in V2B, with fleet not discharging to avoid slight increase in electricity price
- High battery degradation cost has a larger impact on the V2B profile and therefore the fuel savings achieved
- Battery degradation has no impact on the peak demand reduction achieved across the commercial buildings
  - Storage and hospital archetypes remained with 0% reduction in peak demand, and offices with 5.4%

Cost of battery degradation assumed in each scenario (£/MWh)

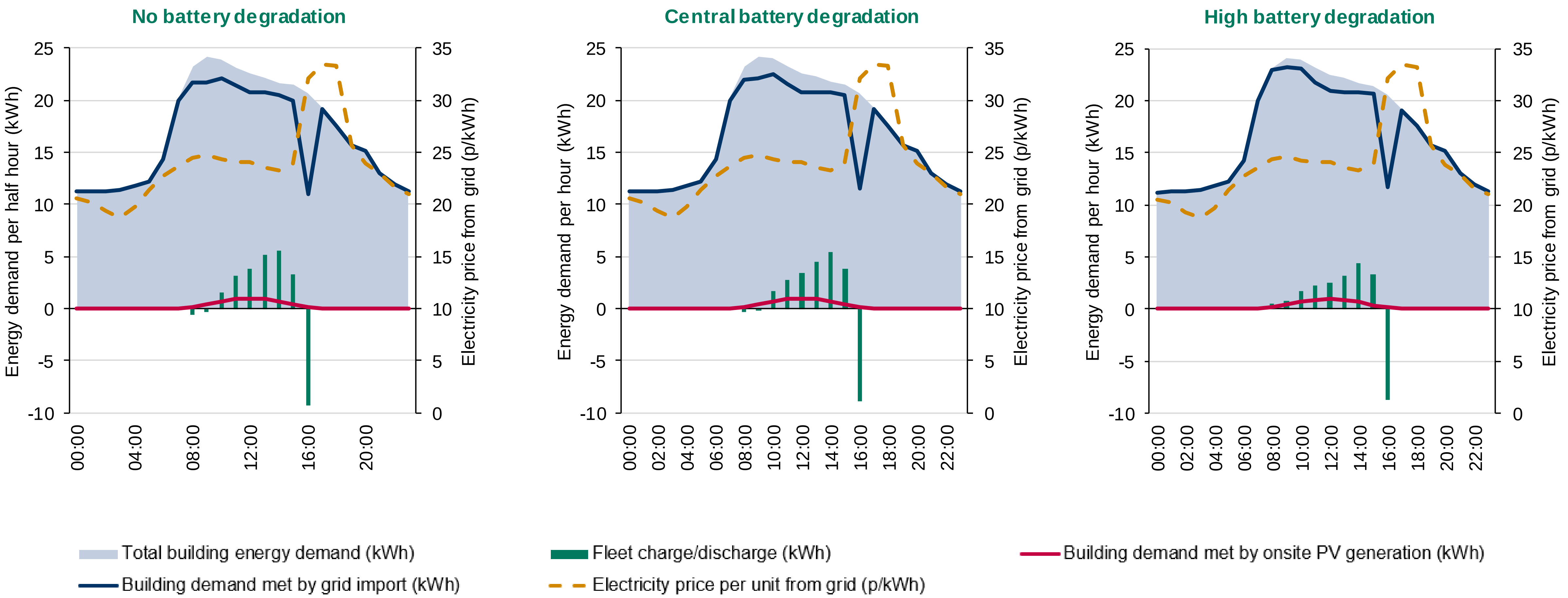


V2B discharge (MWh/EV/year)

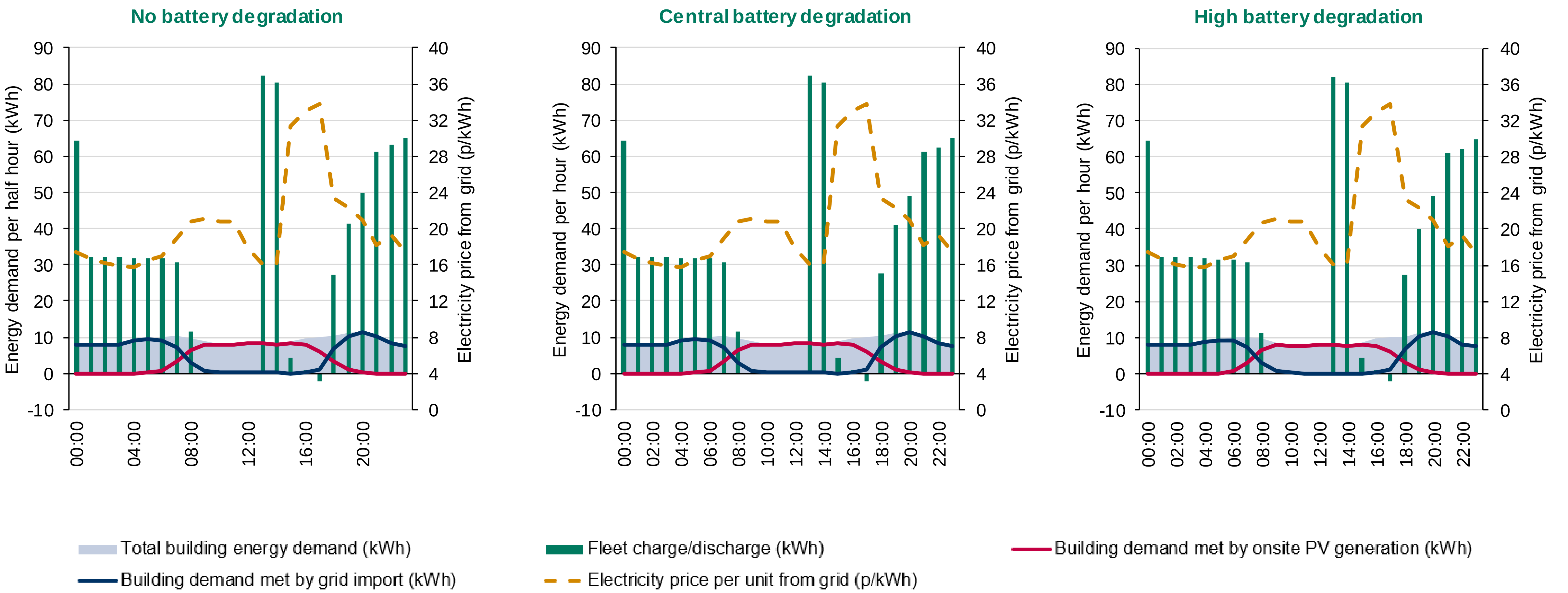
Electricity bill savings achieved (%)



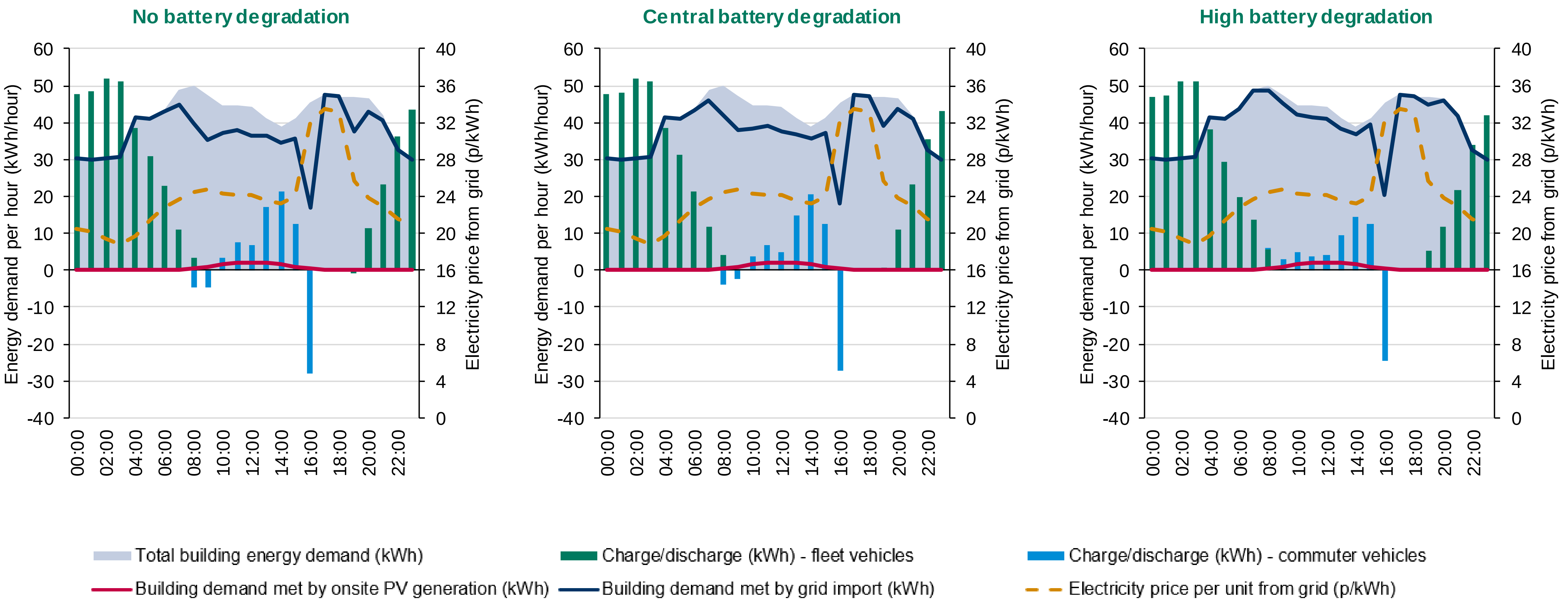
Winter weekday: high battery degradation cost prevents V2B from office fleet during small morning peak in electricity prices



Summer weekend: battery degradation does not have significant impact on storage's low V2B operation



Winter weekday: battery degradation reduces V2B during slightly raised electricity prices in the morning but does not significantly impact discharge during evening peak



Contents

This section provides a brief introduction to the V2BUILD Tool which was a key output of the project

- This report sets out the detailed techno-economic modelling conducted as part of the V2BUILD project
- To ensure that the results of the modelling are more widely accessible, particularly to stakeholders who would be responsible for purchasing V2B systems, a free interactive tool was developed to allow users to interact with the modelling results
- This section sets out the target audience for the tool and how the tool has been designed to enable them to learn about the potential for V2B
- A link can also be found at the end of this section to the V2BUILD Tool

Overview of approach

Define requirements

Agree functional specification

Develop tool and gather user feedback

Tool made available to the wider public

The V2BUILD project developed a user-friendly online tool to provide information on V2B business models

Background and context:

- The V2BUILD project aims to assess the **commercial viability of V2B** and identify the most attractive use cases
- The project developed a **user-friendly online tool** that allows DNOs, local councils, property and fleet managers to learn about V2B and their potential role in supporting the decarbonisation of commercial buildings
- This is an **opportunity** to provide information on V2B business models in an easily accessible format

	Project role	Tool priorities
elementenergy (an ERM Group company)	Responsible for data analysis, modelling, tool development and project management.	• Enable **vehicle and heat pump OEMs** to identify synergies and partnerships • **Encourage businesses** to determine the potential revenues of V2B • Encourage **knowledge sharing and development**
wallbox	Responsible for providing know-how, data and business case development.	• **Identify target customers for V2B**, and understand what would drive someone to choose a V2B solution • **Encourage businesses** to determine the potential revenues of V2B • Encourage customers to **select Wallbox solution**
UK Power Networks	Providing expertise and determining how the tool can feed into DNO and local energy planning.	• Identify **potential benefits compared to costs** of on-site V2B flexibility • Encourage **knowledge sharing** and development • Collect **data on tool users'** interest in V2B • **Independent tool**, without specific recommendation of Wallbox solution

The target audience for the V2BUILD Tool and their key interests were identified and used to define the tool's functionality

- **4 key actors for the tool** (broad categories of types of users) were identified:

General Public/ Energy Enthusiasts

Key interests: learning about V2B, particularly the cost savings potential for domestic homes and impact on EV battery health

Building Owners/ Managers/ Occupiers

Key interests: Explore cost savings potential for relevant building type when heating and fleet demand are fully electrified and understand factors that impact electricity costs

Network Operators

Key interests: Understand the grid impact of optimal V2B operation that maximizes consumer cost savings

Other V2X Innovators & Flexibility Experts

Key interests: Understand the business case for V2B, explore the details of how V2B has been modelled in this project

- The main pages and features of the **V2BUILD Tool** were implemented in line with the defined actors and their interests:

Page	Features
Home Page	• Project partners • Project background and objectives • Introduction to the tool and who it is for
V2B Background	• Challenges faced when electrifying building systems and integrating PV and EV charging • Potential benefits from smart charging and the additional benefits of bi-directional charging • Assumptions for modelled building types
V2BUILD Tool	• Main page of the website hosting the input fields for the user to provide their information • Multiple charts displaying outputs across multiple tabs presenting different themes • Explanatory text giving context to the results, particularly around grid connection cost impacts

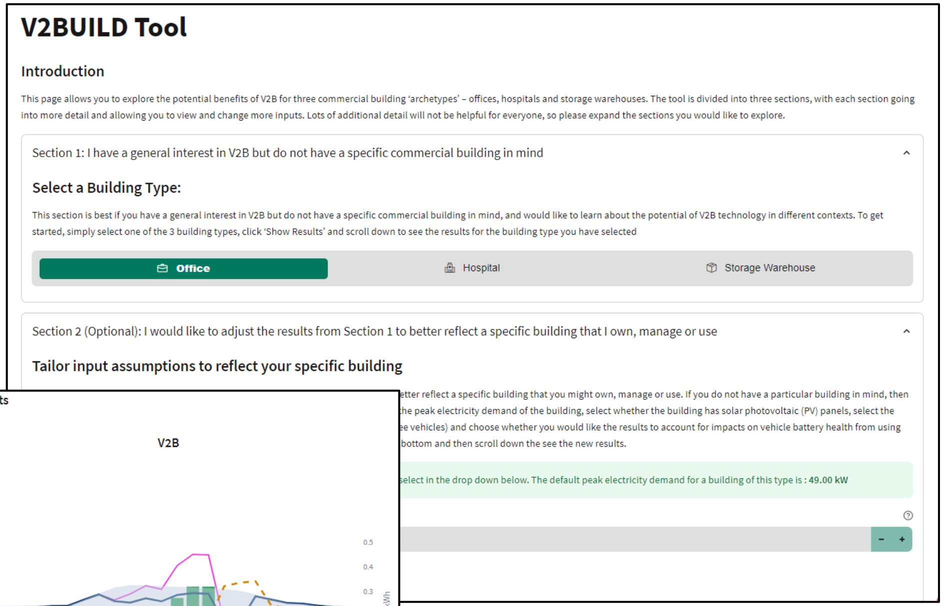
V2BUILD Tool is available for free, allowing interested stakeholders and members of the public to interact with the modelling results

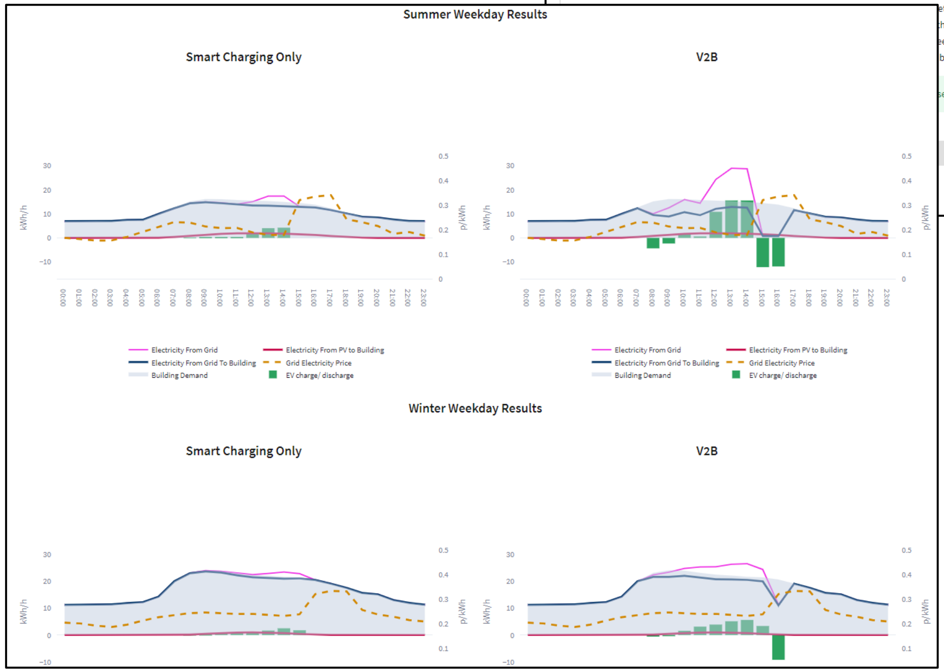
- The V2BUILD Tool website provides users with background information about V2B technology to ensure that those without previous knowledge can engage with the results
- The tool provides users with three different levels of input detail, depending on their motivation for using the tool:

1. **General interest:** users can choose between the three commercial building archetypes and see default results
2. **Specific building:** users can tailor the results to better reflect the energy system of a particular building
3. **Grid connections:** additional detail for users deploying low carbon technologies and wanting to understand how V2B could reduce the cost of grid connection upgrades by reducing peak demand

The V2BUILD Tool can be accessed by following this link: https://v2build.streamlit.app/

Users can select inputs depending on the level of detail required





Results provide insights about how bi-directional chargers can generate savings

Contents

This section assesses the business case for V2B technologies considering the cost of the equipment and the potential savings identified in the modelling

In this section:

- Comparison of the investment costs for smart and bi-directional chargers
- Details of the potential for bi-directional chargers to provide significant savings from avoiding costly grid connection upgrades in rare circumstances
- Assessment of the business case for bi-directional chargers in the 5 building archetypes considered and expected payback periods
- Summary of the factors driving the business case for bi-directional chargers

Overview of section

Costs for smart and bi-directional chargers

↓

Potential for savings from avoiding significant grid connection upgrades

↓

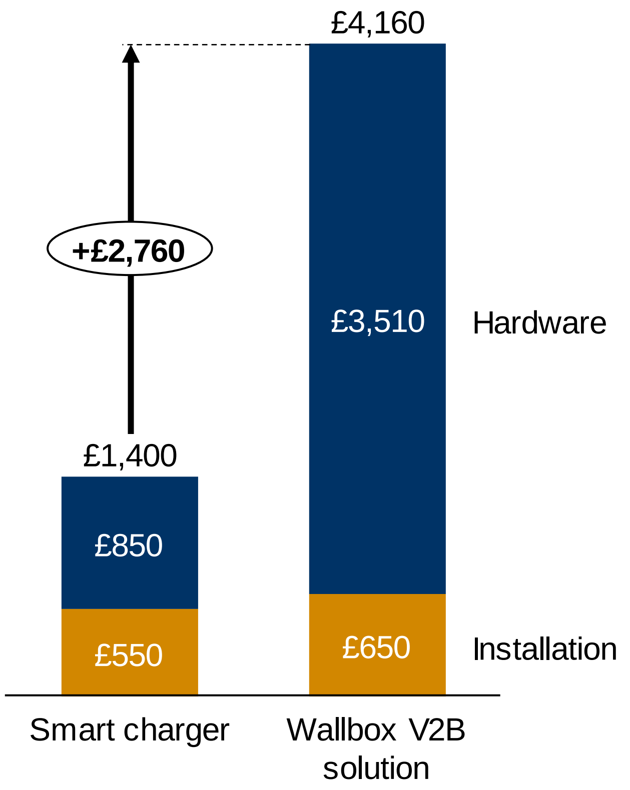
Assessment of business case for investing in bi-directional chargers

↓

Summary of the business case drivers for V2B

V2B hardware and installation costs are higher than for smart chargers – the additional costs can be compared with additional savings from V2B

Comparison of hardware and installation costs for smart and bi-directional chargers



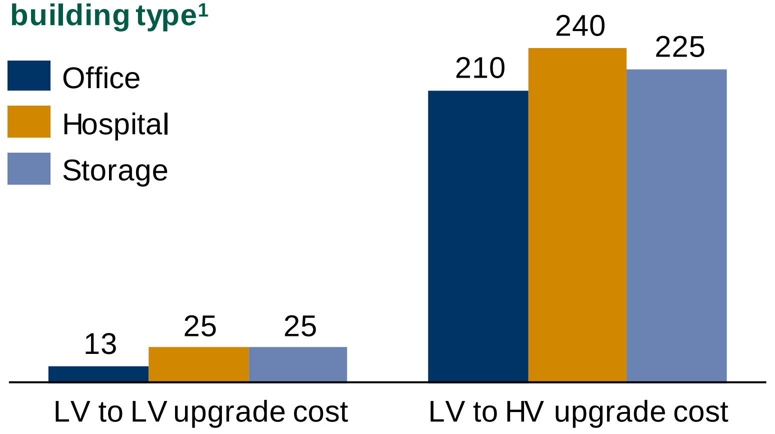
- Although V2B may lead to savings on electricity bills and fixed capacity charge, as shown in the previous section, a V2B hardware solution is typically **higher cost** than a standard smart charging solution
- Chart, left, shows the **approximate cost of Wallbox's V2B solution** (hardware and installation costs) in comparison with the typical cost of Wallbox's smart charger
  - Smart charger hardware and installation costs based on market review by ERM (2023) and discussion with clients
- The V2B solution has significantly higher technology costs than a smart charger, and therefore the V2B business model requires a **high upfront investment**
  - As V2B is a new technology, hardware costs are expected to fall over time with **increased manufacturing volumes** and **technology improvements**[1]
- The **additional costs** of each V2B charger (£2,760) can be compared with the **additional savings** achieved through V2B above smart charging to understand the suitability of the **V2B business case** across building types
- For each of the modelled archetypes, the payback period of the investment was calculated considering the modelled savings
  - Note: payback periods were calculated assuming chargers have a **15-year lifetime** and that **electricity prices remain fixed** over the lifetime

Source: 1 – V2GB Report, Element Energy, 2019

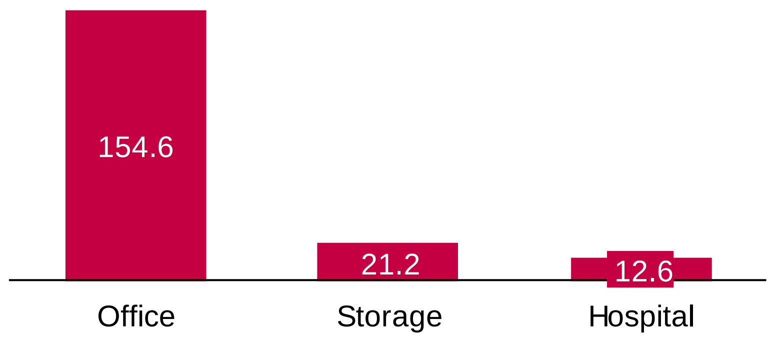
At some commercial sites, V2B could be used to avoid significant grid connection upgrade costs or fines as a result of exceeding agreed connection

- Modelling included optimisation of demand profiles to minimise peak demand from the grid and total savings for commercial buildings including **reduced fixed capacity charges** in addition to electricity bill savings
- Although customers are no longer required to pay for **network reinforcements** triggered by their new or upgraded connection, customers will still have to pay for the **extension assets required** to connect to the existing distribution network, e.g. cables, substation, etc.
- These costs may be **significant**, particularly if the connection is upgraded from a **low voltage (LV) to high voltage (HV)** connection – note: not applicable to domestic buildings
  - This typically occurs at a connection capacity of 220 kVA
  - This incurs **high costs that must be paid by the connecting customer** largely as a result of the need for a **HV substation**
- V2B could be used to reduce peak demand at sites that are **close to requiring an LV to HV upgrade** and therefore avoiding large costs
- Costs for a new LV connection and for upgrading LV to HV are estimated in the chart right for each of the commercial building archetypes although costs are **highly site specific**:
  - **LV connection upgrade:** £13k – £25k
  - **LV to HV connection upgrade:** £210k – £240k
- Additionally, consumers may be subject to charges for **exceeding agreed capacity**
  - V2B could be used to avoid charges on **extreme days** as a result of high demand
  - Approximate calculation is shown, right, considering the effect of increased grid import as a result of extreme day demand (as investigated in the modelling sensitivity) when site connection capacity may be agreed considering typical seasonal demand

Approximate connection upgrade cost (£k) by commercial building type[1]



Approximate exceeded capacity charges considering extreme day demand across archetypes (p/day)[2]



Source: 1 – Indicative costs have been estimated by UK Power Networks and are illustrative. Estimate assumes LV cable cost of 250 £/m, HV cable cost of 300 £/m, and HV substation cost of £180,000; 2 - UK Power Networks Distribution Use of System Charges, 2023, assume average exceeded capacity charge of 7p/kVA/day

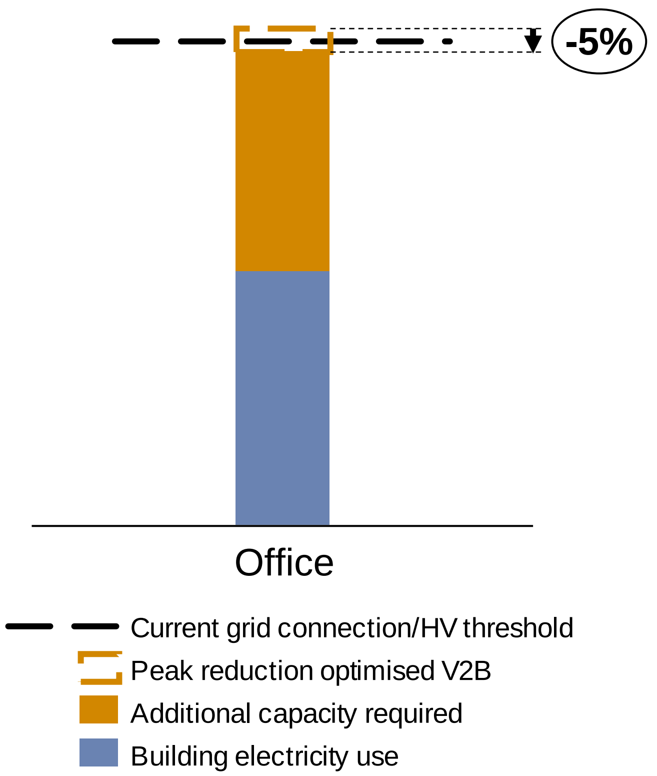
Peak demand reduction does not contribute significantly to the business case for V2B but in rare cases could provide savings

- Following the recent Significant Code Review by Ofgem which socialised the cost of reinforcement costs triggered by grid connection upgrades, the cost of individual upgrades has fallen
- However, there are still costs associated with any increase to a site's grid connection capacity (typically £15-25k). Costs could be over £200k if a site requires an upgrade from a low to a high voltage (HV) connection
- The chart to the right shows an example of a commercial building that requires a significant increase in capacity, such as to support the installation of electric heating. The current demand is shown in blue, with the additional demand in orange. If bi-directional chargers can keep the peak demand below either the current capacity or the threshold for a HV upgrade, there could be a significant return on investment for the chargers

Implications:

- Few sites will be in a position for V2B to enable them to avoid costly grid connection upgrades, but where this is possible the savings would be substantial and would also avoid the possibly lengthy waiting times for the work to go ahead
- The potential for sufficient peak demand reduction to make this viable was only identified in the office archetype

Illustrative example of when V2B could avoid significant grid connection upgrade costs



Modelled electricity bill savings are not sufficient to recover upfront cost of V2B solution at commercial buildings, but investment may be paid back in domestic buildings or specific office sites

	V2B upfront investment	Commentary on business case for V2B (assuming 15-year lifetime)		
		Baseline case	Significant connection upgrade	Avoid exceeding capacity*
Office	£27,600	No payback on upfront investment expected within lifetime of chargers from savings on electricity bill and fixed capacity chargers	If within ca. 5% of LV-HV upgrade threshold, V2B solution may be a preferable investment	No payback on upfront investment by avoiding exceeding capacity charges
Storage	£165,600		Investment in V2B solution may be lower than LV-HV connection upgrade, but limited peak demand reduction potential suggests V2B may not be a suitable solution	No payback on upfront investment by avoiding exceeding capacity charges, and limited peak demand reduction potential suggests V2B would not be a suitable solution
Hospital	£176,640			
Domestic flat	£8,280	Payback on upfront investment within ca. 10 years of electricity bill savings	N/A	N/A
Domestic semi-detached	£5,520	Payback on upfront investment within ca. 6 years of electricity bill savings		

- Savings modelled are not sufficient to recover the upfront investment in V2B charging solutions at commercial buildings
- In specific cases, such as an **office building** with demand close to the LV-HV connection upgrade threshold, investment in V2B could reduce peak demand by 5% and therefore may **avoid investment** required significant connection upgrade investment
- Similarly, if close to agreed connection capacity, V2B could be used to **avoid exceeding agreed connection capacity**
  - However, modelled savings from avoiding exceeding capacity charges are **insufficient** to recover investment costs within charger lifetime
- Domestic buildings do achieve **sufficient electricity bill savings** to recover the upfront investment in the charging solution

*Note: Assumes V2B ensures site avoids exceeding capacity on extreme days once per year

Summary: high upfront cost of V2B solution limits the potential business case for commercial buildings, but future market changes may improve the business model

- Although modelling found that **V2B solutions were able to achieve financial savings across commercial and domestic building types, the high upfront cost of the solution limits the potential business case for commercial buildings**
- Analysis found key drivers for the V2B business case, including:
  1. **Site demand and overlap of fleet plug-in windows**, to determine the flexibility potential
  2. **Price of electricity** and **design of electricity tariff** available from suppliers, which impacts the potential electricity bill savings and ability of consumers to access wholesale electricity market value
     - E.g. dynamic tariff allows consumers to optimise market volatility
  3. **Proximity of site demand to significant connection upgrade need**, and therefore potential to avoid significant investment or fines
  4. **Upfront cost of V2B solution** and therefore the required investment
- Future work could consider these key drivers to try to improve the business case for V2B

Future market changes may improve the V2B business case:

1 Reduction of V2B hardware costs

- High costs of bidirectional chargers may fall with increased manufacturing volume and technology improvements[1]
- Lower upfront costs will improve the case for investment in a V2B solution

2 Electricity price volatility

- As renewables on the system increases, electricity prices are expected to get more volatile, with times of low or negative pricing as well as high prices
- Allows further optimisation of charge/ discharge to generate electricity bill savings

3 Grid services

- There are opportunities for additional revenues from grid services to compensate for peak demand reduction and load shifting – future business models may incorporate this

Source: 1 – V2GB Report, Element Energy, 2019

Contents

This section sets out the 10 main conclusions from the V2BUILD modelling and identifies where future work is required

In this section:

- The main conclusions from the techno-economic modelling of V2B technologies in the five building archetypes, including links to the sections in the report that provide further information about each conclusion
- Opportunities for future work that have been identified during the project and which could add to the understanding of the potential for V2B developed during the project

Overview of section

Main V2BUILD conclusions

Future work

V2BUILD conclusions 1/3: The V2B business case is challenging for the commercial buildings modelled, but this work has also highlighted the criteria that determine how suitable a real building is likely to be for V2B

Commercial buildings can achieve significant benefits with smart charging

Commercially available smart chargers can deliver most of the savings offered by bi-directional chargers, avoiding peaks and providing bill savings without discharging to the building. Smart chargers are therefore a valuable and immediate solution for EV charging at commercial buildings, helping familiarise building managers with the potential of flexible EV assets while the V2B business case matures.

Bill and peak demand reduction savings alone do not provide a business case for V2B in commercial buildings

With smart charging mandated by law in the UK, they are the baseline for assessing the business case for more expensive bi-directional chargers. The ability of bi-directional chargers to discharge is constrained by the imperfect alignment of plug-in windows and high-cost tariff periods (see this slide), and the additional savings beyond smart charging are unlikely to justify the additional cost of bi-directional chargers.

Alignment of plug-in windows, high-cost and high-demand periods determines V2B bill savings potential

For commercial buildings V2B achieves the greatest electricity bill savings when optimised for a dynamic tariff, as this provides the best alignment between vehicle plug-in window and high-cost tariff periods. To maximise benefits from discharging during high-cost periods, building demand needs to exceed the capacity of the chargers to discharge or the discharging opportunity will be restricted (see this slide).

Alignment of plug-in windows and peak building demand determines V2B peak reduction potential

When plug-in windows and peak demand periods are aligned in a commercial building, bi-directional chargers can discharge at key times in the year when the highest peaks are experienced. This goes beyond the ability of smart chargers to simply shift charging away from peak times and can help to reduce or avoid costly grid connection upgrades for the building and offers wider benefits to the network (see this slide).

V2BUILD conclusions 2/3: The greatest savings from V2B for commercial buildings were found in electricity bill reduction for offices, though peak demand reduction could lead to very high savings in some cases

V2B benefits from electricity bill reduction are greater than from peak demand reduction

Across the commercial building archetypes, the alignment of plug-in windows and high-cost periods allows most of the potential benefits from discharging to be realised, though this varies by archetype. However, the economic benefits of peak demand reduction are limited in most cases as periods of peak demand do not fall completely within vehicle plug-in windows (see this slide).

Of the commercial building archetypes considered, offices receive the most benefit from V2B

Offices achieved ~3% electricity bill reduction and ~5% reduction in peak demand, beyond savings from smart chargers. The bill savings are due to the relatively well aligned plug-in windows for employee vehicles with the high-price periods of a dynamic tariff (see this slide), and some peak demand reduction achieved due to alignment of plug-in periods with periods of high/peak demand (see this slide).

In rare cases, limited reductions in peak demand from V2B could lead to very high savings

While the most promising case for peak demand reduction in offices only achieved a reduction of ~5% beyond what could be achieved with smart chargers, in cases where this reduction could avoid a grid connection upgrade, in particular a low voltage to high voltage connection upgrade, then the savings would be very substantial (see this slide). However, the necessary combination of factors is unlikely to occur often.

Battery health impacts are unlikely to significantly reduce the business case for V2B

There is significant uncertainty around battery health implications for vehicles engaging in V2B regularly. The research conducted as part of this project suggests that V2B could offer battery health benefits by reducing the amount of time that batteries remain either fully charged or discharged which could off-set the degradation cause by increased charge and discharge cycles (see this slide).

V2BUILD conclusions 3/3: There is already a strong business case for bi-directional chargers in domestic properties, and additional revenues could be generated in commercial buildings with Vehicle-to-Grid (V2G)

There is a strong business case for bi-directional chargers in domestic buildings

Plug-in windows, high demand and high-price periods on static time of use tariffs are well aligned for domestic properties. Nightly low-cost periods offer more than enough charging to meet the vehicle's requirements, and high-cost periods align well with high demand in the home to ensure there are sufficient opportunities to discharge back to the building and offset demand from the grid (see this slide).

Bi-directional chargers could increase savings by engaging in additional V2G services

This project focused on opportunities for bi-directional chargers to generate savings within building energy systems and grid services were beyond the scope. However, Demand Flexibility Services and the Capacity Market have been identified as suitable for bi-directional chargers to engage in (see this slide), and there may be opportunities for V2G revenue to supplement the benefits from V2B in commercial buildings.

Several opportunities have been identified for future work to build on the progress made during the V2BUILD project

Grid services

Future work should seek to understand how bi-directional chargers deployed in commercial buildings can be optimised to also offer services to the grid (V2G). This could lead to additional revenue at times when charging or discharging is not required to meet the building's energy needs. The Demand Flexibility Service and the Capacity Market have been identified as viable grid services for bi-directional chargers to engage in today.

Improved building data

Further analysis of the V2B business case would benefit from improved data on building energy use. Measured, in-use energy consumption data split by end use (e.g., heating, cooling) for different building types would allow electricity loads to be assessed in more detail to identify where V2B can deliver the greatest savings. This would help to identify how and when peak demands occur in different real-world contexts and how V2B can be best deployed to reduce them.

Uptake modelling and market forecasting

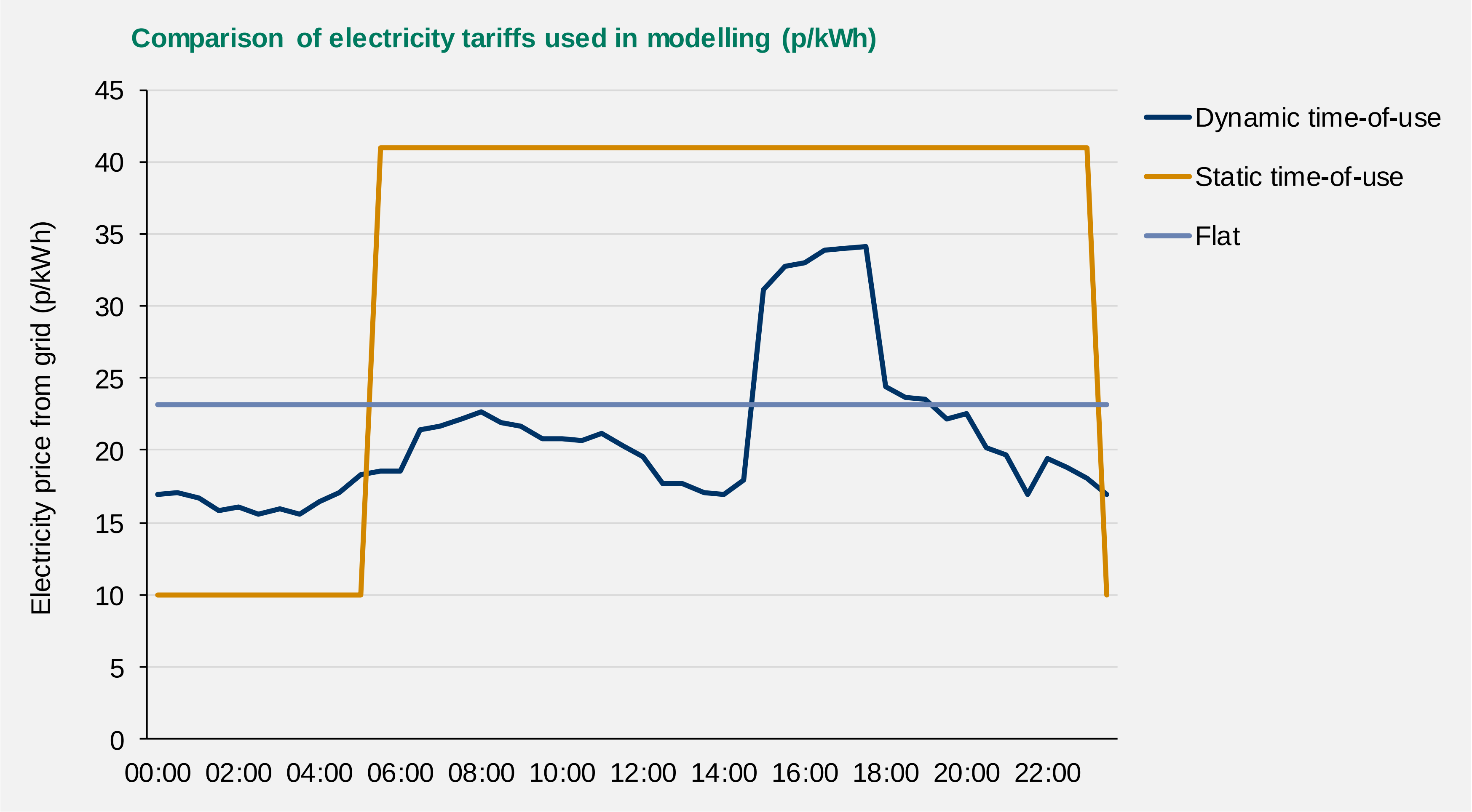
Analysis to understand the drivers of the cost difference with smart chargers and how quickly the cost of bi-directional chargers could fall, coupled with the analysis conducted in V2BUILD, would allow uptake of bi-directional chargers to be modelled. This would provide a quantification of the potential market size for V2B and the contribution that this technology could make to balancing supply from intermittent renewables and reducing periods of peak demand on the network.

Further development of V2BUILD Tool

DNOs are considering offering flexibility payments to customers to reduce peak demand periods and additional functionality in the tool could help to explore the potential for bi-directional chargers to deliver this flexibility, the revenue that could be generated and the benefits to the network. There are also opportunities to integrate the tool with existing software systems to optimise the grid connections offered to DNO customers.

Contents

Modelling runs were carried out for each archetype to explore the impact of different electricity tariffs



Optimisation of demand profiles was carried out considering different electricity tariffs:

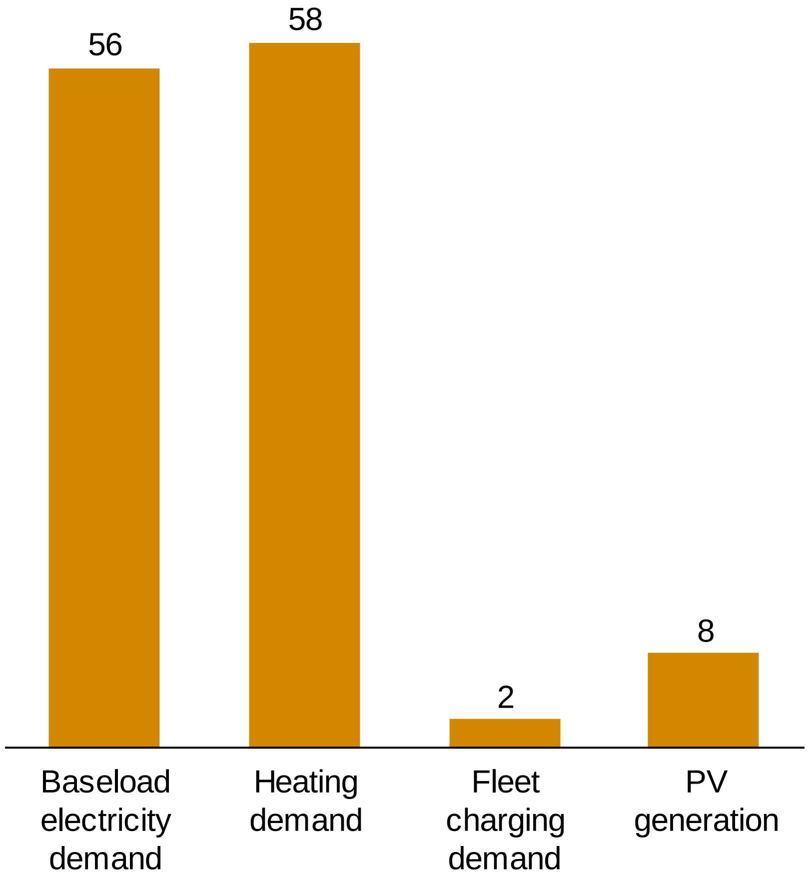
1. **Dynamic time-of-use tariff**: Historic Octopus Agile Tariff Data, 2019
2. **Static time-of-use tariff:** Historic Intelligent Octopus Tariff Data, 2019
3. **Flat tariff:** ERM Analysis of UK Retail Energy Prices

Contents

SUMMARY: Office building energy demand is dominated by heating demand during working hours, with commuter EVs that are plugged in during the day

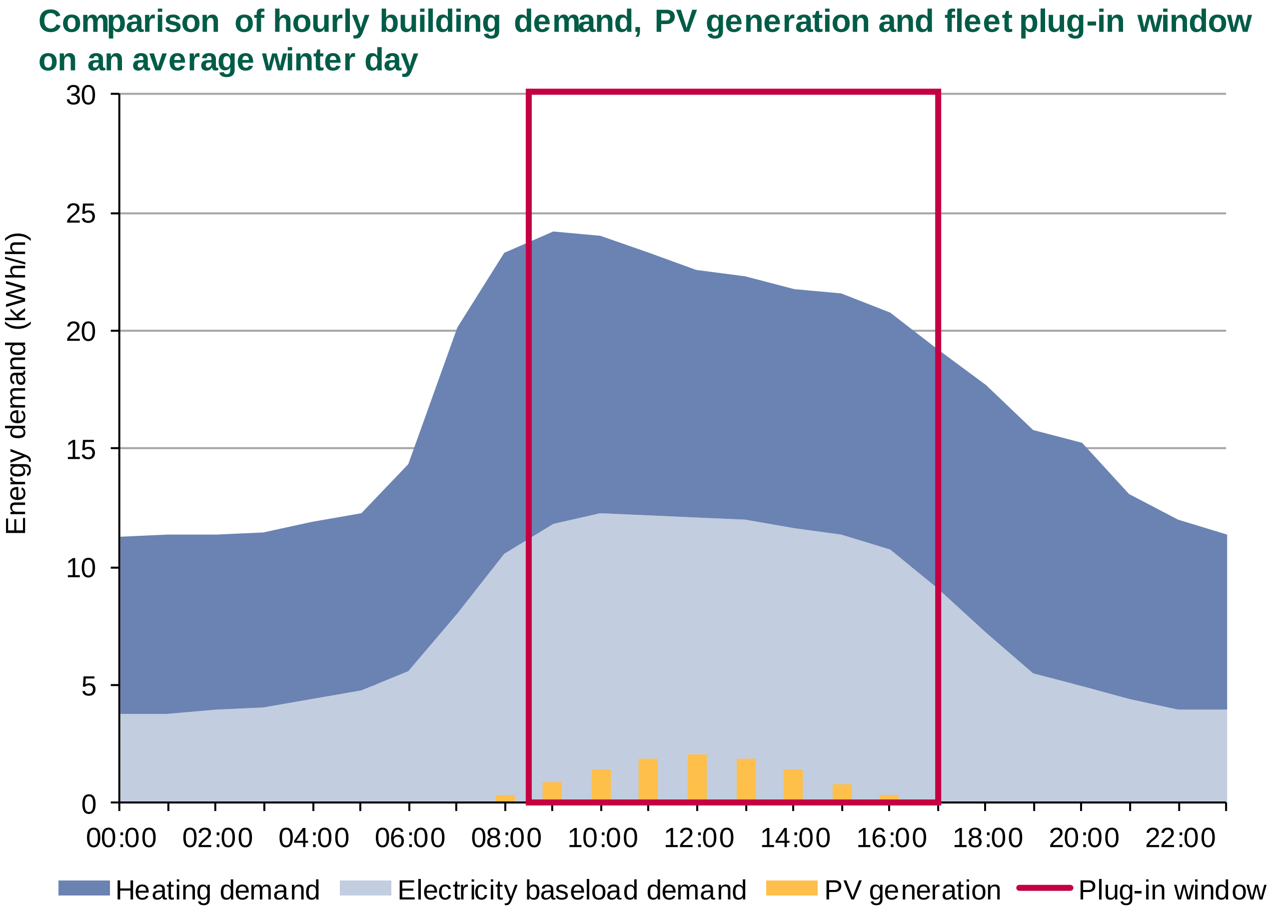
Variable	Value	Source
Total floor area (m^2), no. floors	700, 8	Building Energy Efficiency Survey
Rooftop area available for PV (m^2)	43.75	*Calculated as described here*
Peak PV generation per unit roof area (W_{peak}/m^2)	154	MCS Solar PV Standard
Baseload electricity demand intensity (kWh/m^2)	80	Building Energy Efficiency Survey, ND-NEED 2022
Heating demand intensity (kWh/m^2)	200	
Average heat pump COP	2.51	ERM modelling of an air source heat pump in an average weather year
Fleet size (no. of EVs)	10	Transport Statistics Great Britain
Fleet plug-in window	08:30-17:00	EV Charging Behaviour Study 2019, Element Energy for NGESO
Installed EV charger capacity (kW)	74	Wallbox Quasar Charger Electrical Specifications

Annual Demand & Generation (MWh)



SUMMARY: Office commuters' plug-in window coincides with the hours of peak building demand and PV generation

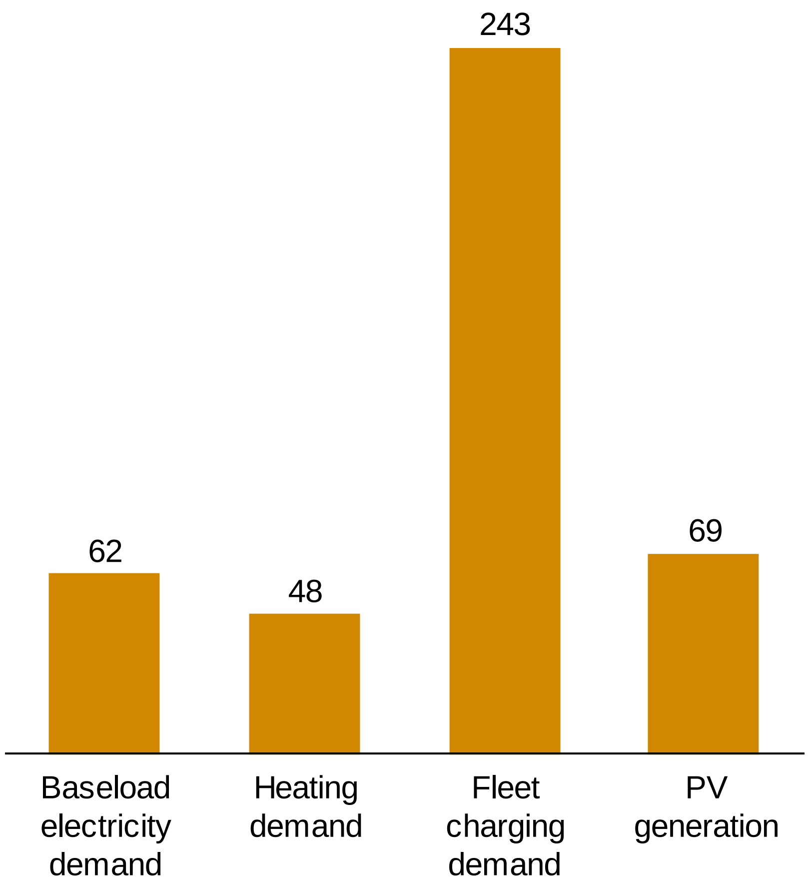
- The average winter profile shows a **discernible daytime peak in building energy demand** between 08:00 and 18:00, with low heating demand beyond these hours.
- Daytime charging of commuters mean that the **EV plug-in window aligns well with hours of building peak energy demand**.
- Offices have **small fleet and PV capacity** due to the small number of commuter EVs and small roof size, which limit the overall potential for flexibility & grid import reduction.
- The **overlap of building peak demand times and EV charging window** suggests high potential for V2B
- **Charging window aligned with solar PV generation**, but low PV capacity means PV generation doesn't exceed building demand, i.e. limited potential to increase PV self-consumption



SUMMARY: Storage warehouses have low building energy demand intensities, a large delivery fleet that charges overnight, and large rooftop area available for PV

Variable	Value	Source
Total floor area (m^2), no. floors	1550, 2	Building Energy Efficiency Survey
Rooftop area available for PV (m^2)	387.5	*Calculated as described here*
Peak PV generation per unit roof area (W_{peak}/m^2)	154	MCS Solar PV Standard
Baseload electricity demand intensity (kWh/m^2)	40	Building Energy Efficiency Survey, ND-NEED 2022
Heating demand intensity (kWh/m^2)	75	
Average heat pump COP	2. 5	ERM modelling of an air source heat pump in an average weather year
Fleet size (no. of EVs)	60	ERM analysis of Optimise Prime Depot Data
Fleet plug-in window	19:00-08:30	
Installed EV charger capacity (kW)	444	Wallbox Quasar Charger Electrical Specifications

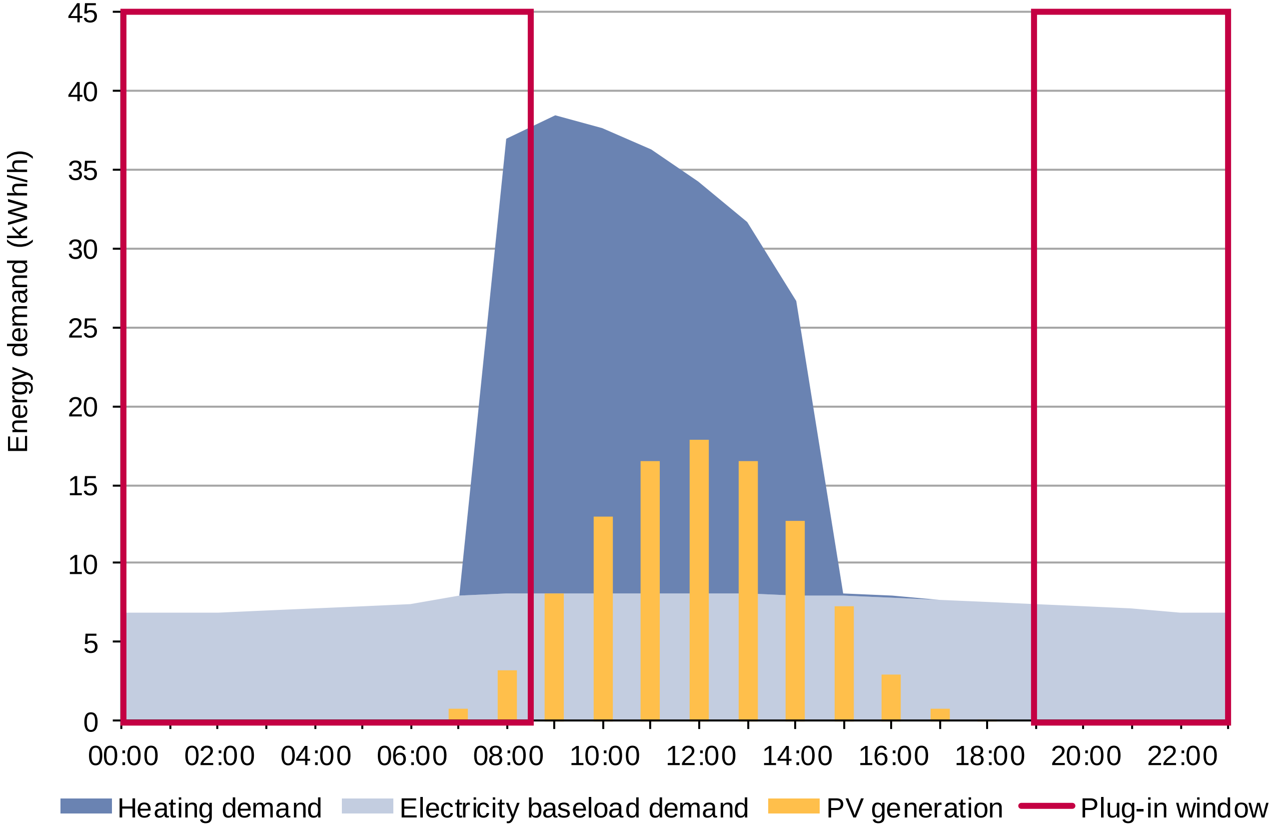
Annual Demand & Generation (MWh)



SUMMARY: Storage archetype's high fleet charging demand and overnight plug-in window limit potential for maximising PV self-consumption or reducing energy bills through V2B

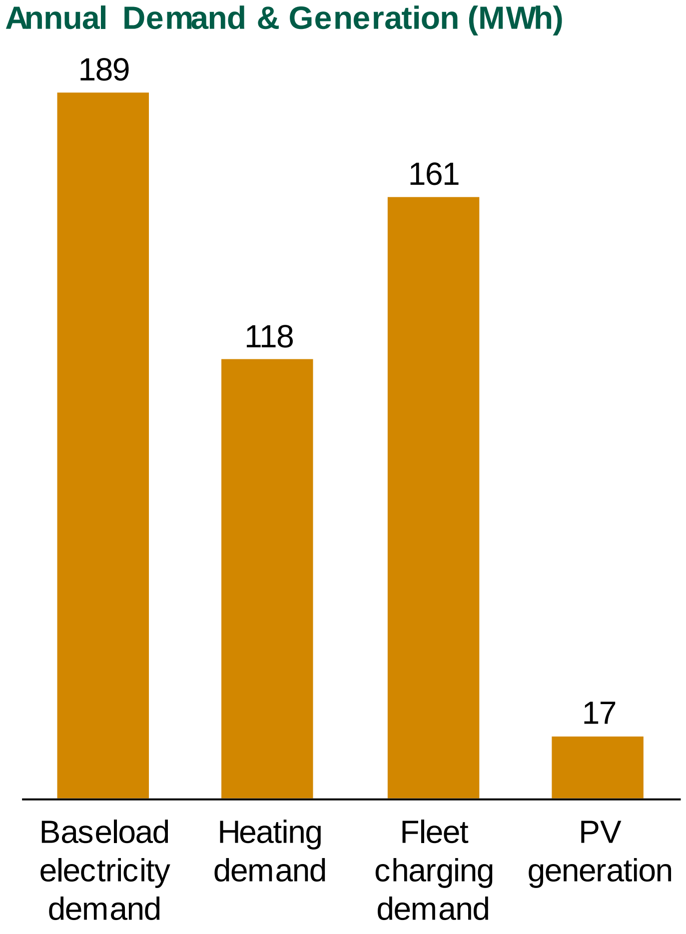
- Storage warehouse fleets are typically **plugged-in overnight**, when PV generation and heating demand are relatively low.
  - **Limited potential of V2B to reduce peak demand** of the building since EVs are not plugged in during times of high demand of the building (during the day)
- They also present a **high fleet to demand ratio**, with EV charging demand representing majority of the energy demand in this archetype.
- Lastly, the large roof area offers **high PV capacity,** resulting in great potential to reduce grid imports.
  - **Limited potential of V2B to increase PV self-consumption** by the lack of overlap between the fleet plug-in window and periods of high PV generation
- This would likely lead to **relatively low savings from V2B** relative to smart charging.

Comparison of hourly building demand, PV generation and fleet plug-in window on an average winter day



SUMMARY: Hospitals have high building demand, limited rooftop area for PV, and a combination of non-emergency fleet EVs that charge overnight and commuter EVs with daytime charging

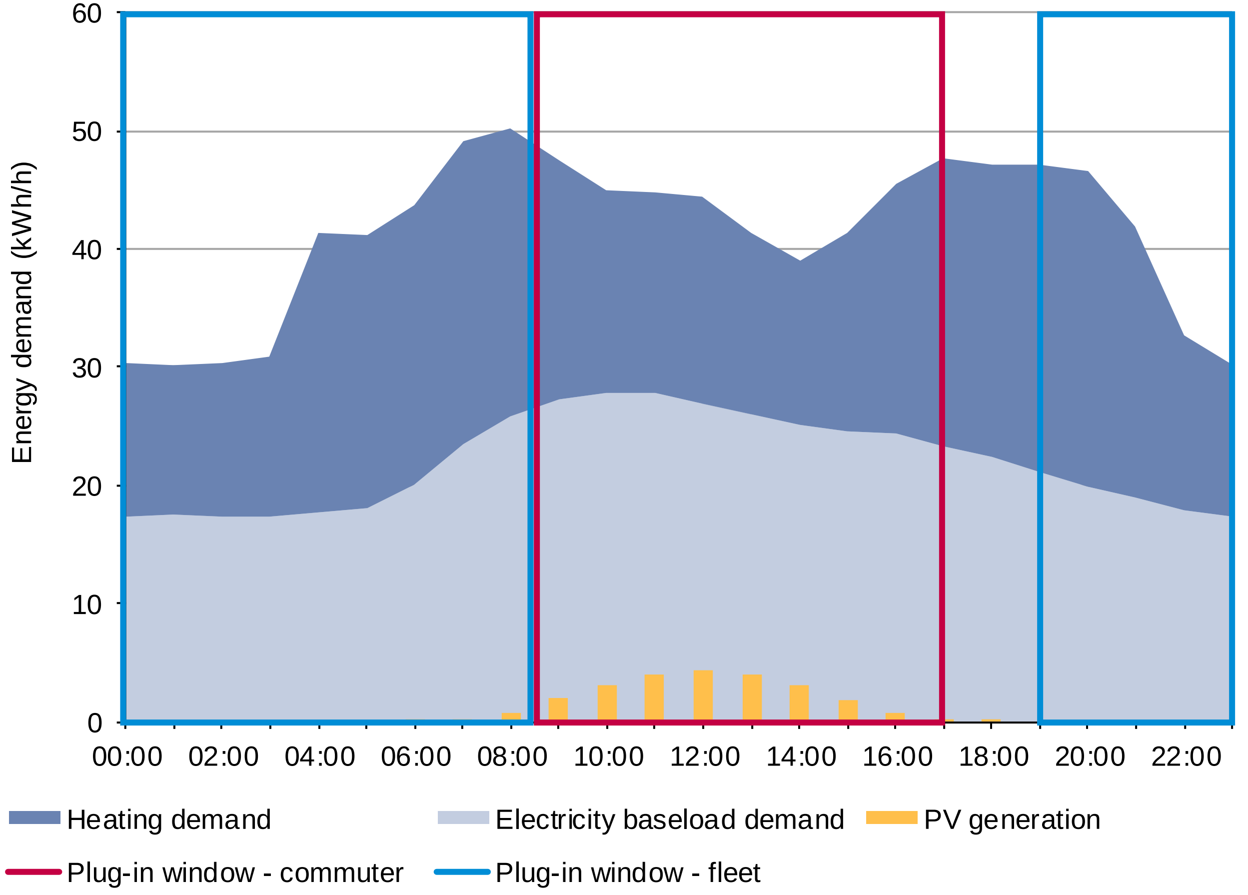
Variable	Value	Source
Total floor area (m^2), no. floors	945, 5	Building Energy Efficiency Survey
Rooftop area available for PV (m^2)	94.5	*Calculated as described here*
Peak PV generation per unit roof area (W_{peak}/m^2)	154	MCS Solar PV Standard
Baseload electricity demand intensity (kWh/m^2)	200	Building Energy Efficiency Survey, ND-NEED 2022
Heating demand intensity (kWh/m^2)	300	
Average heat pump COP	2. 5	ERM modelling of an air source heat pump in an average weather year
Fleet size (no. of EVs)	64	Transport Statistics Great Britain, ERM analysis of NHS Trust reporting
Fleet plug-in window	08:30-17:00, 19:00-08:30	ERM analysis of Optimise Prime Depot Data, EV Charging Study 2019, Element Energy for NGESO
Installed EV charger capacity (kW)	370	Wallbox Quasar Charger Electrical Specifications



SUMMARY: Hospitals' combination of non-emergency fleet EVs that charge overnight and commuter EVs with daytime charging offer flexibility over a longer duration of the day

- **Building energy demand** is significantly higher than fleet capacity, with relatively consistent heating and baseload demand throughout the day.
  - This may limit the opportunity to optimise demand to lower electricity bills and peak demand or maximise self-consumption
- Hospitals are assumed to have a **combination of commuter and fleet EVs** with different plug-in windows, which together offer flexibility potential over a longer duration of the day.
- Solar PV capacity is small relative to the scale of building energy demand, so V2B **is unlikely to improve the ability to maximise PV self-consumption**.
- The scale and plug-in durations of EVs **could enable some reduction in peak demand**, as well as energy bill savings from shifting energy demand to lower cost hours.

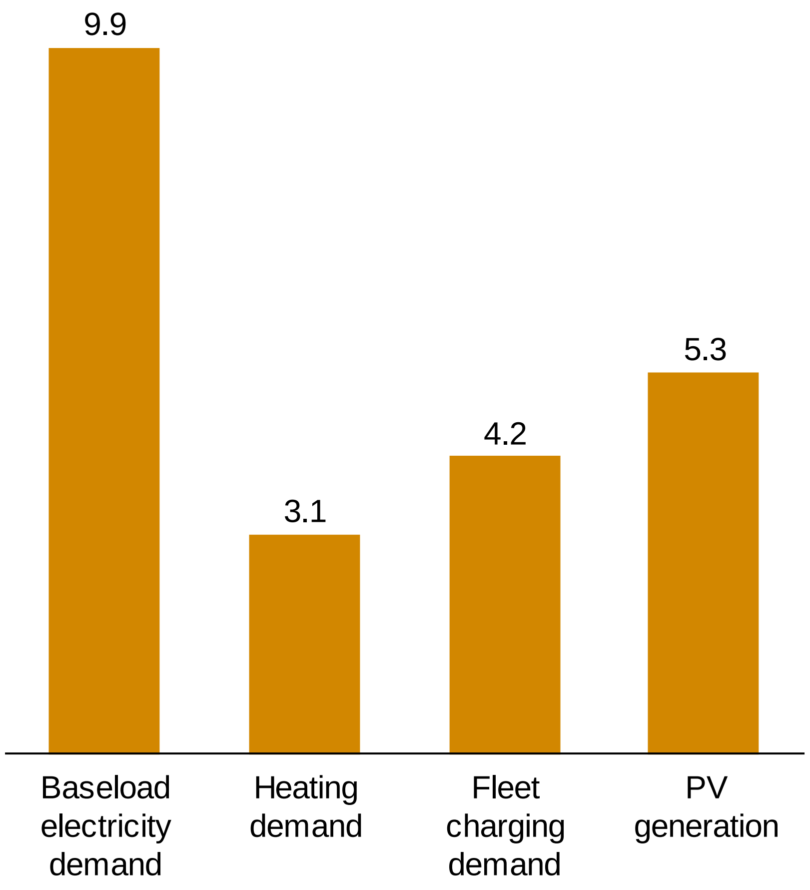
Comparison of hourly building demand, PV generation and fleet plug-in window on an average winter day



SUMMARY: Domestic flats' baseload electricity demand make up most of the archetype's total building demand, with annual PV generation exceeding both heating and fleet charging demand

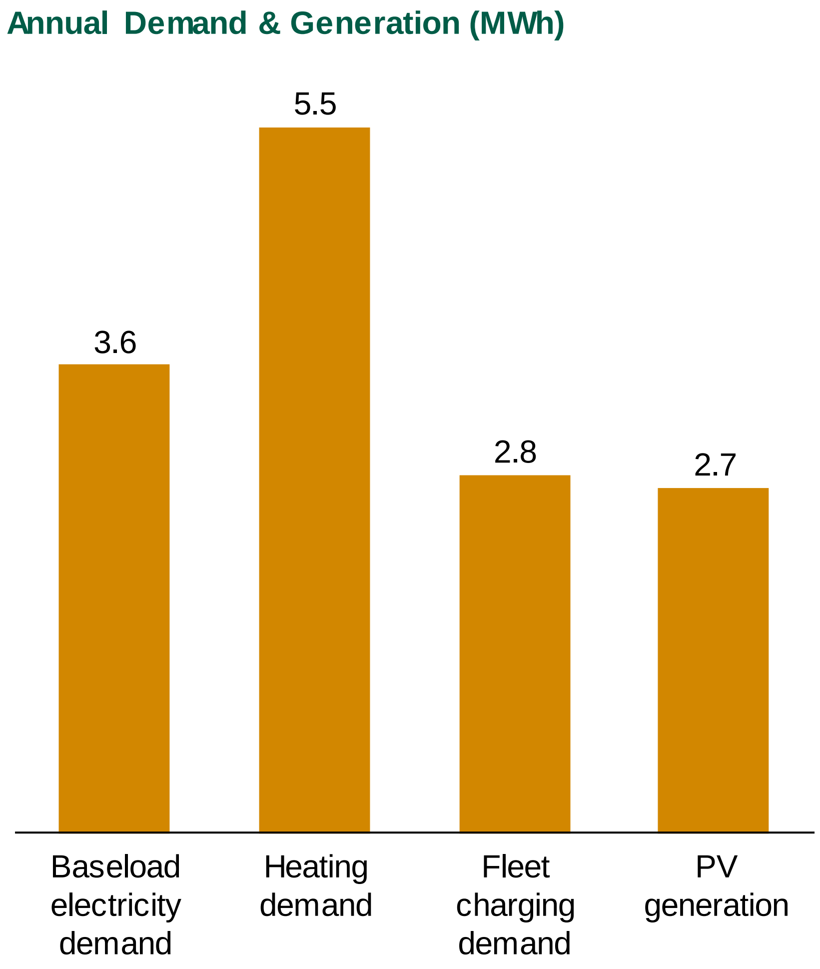
Variable	Value	Source
Total floor area (m^2), no. floors	180, 3	Domestic EPC Database
Rooftop area available for PV (m^2)	30	*Calculated as described here*
Peak PV generation per unit roof area (W_{peak}/m^2)	154	MCS Solar PV Standard
Baseload electricity demand intensity (kWh/m^2)	54.9	Energy consumption: England and Wales, NEED 2021
Heating demand intensity (kWh/m^2)	41.1	
Average heat pump COP	2.51	ERM modelling of an air source heat pump in an average weather year
Fleet size (no. of EVs)	3	1 per flat, National Travel Survey Statistics
Fleet plug-in window	17:30 – 08:00	EV Charging Behaviour Study 2019, Element Energy for NGESO
Installed EV charger capacity (kW)	22.2	Wallbox Quasar Charger Electrical Specifications

Annual Demand & Generation (MWh)



SUMMARY: Domestic semi-detached buildings' heating demand makes up almost half of total building demand, with annual PV generation close in size to fleet charging demand

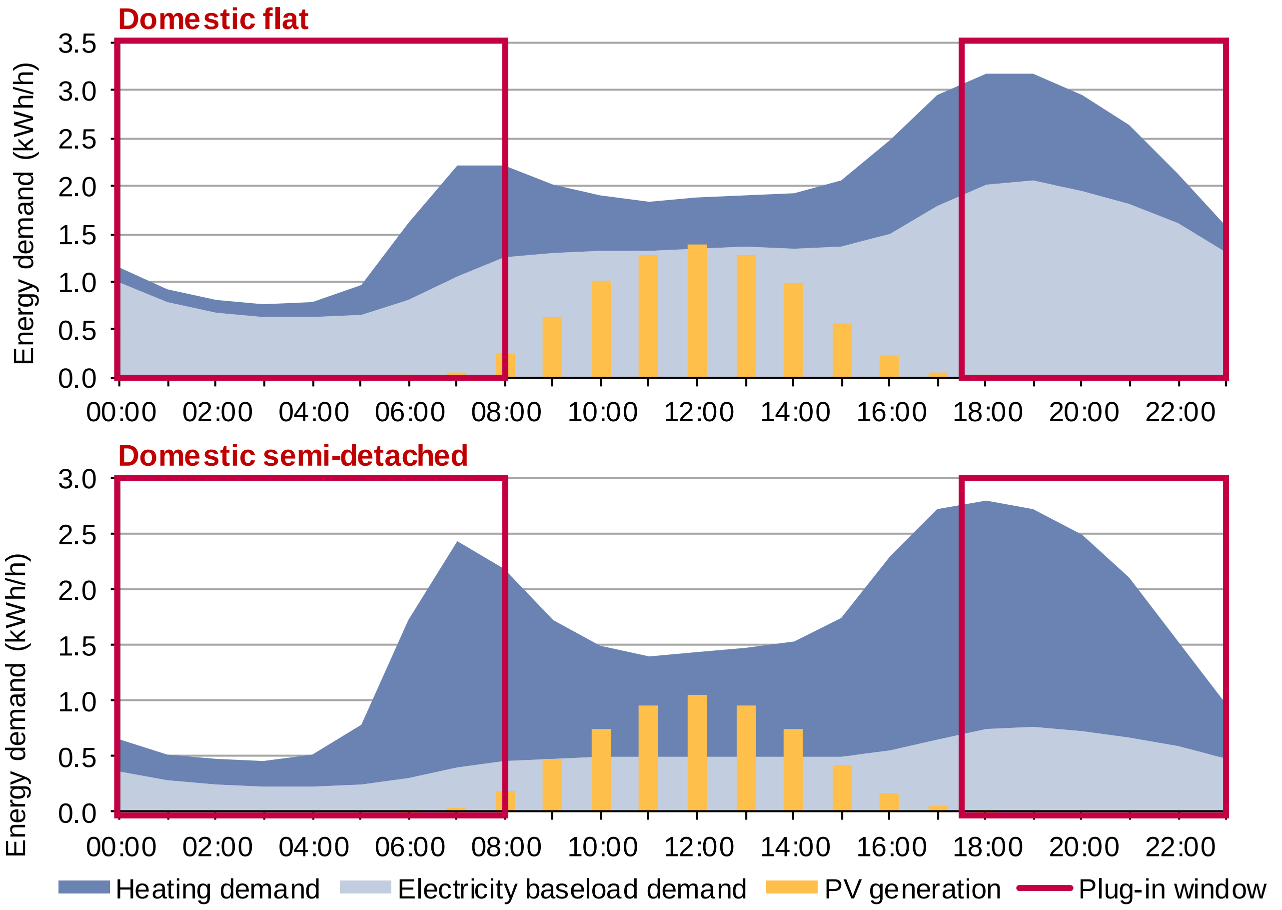
Variable	Value	Source
Total floor area (m^2), no. floors	90, 2	Domestic EPC Database
Rooftop area available for PV (m^2)	22.5	*Calculated as described here*
Peak PV generation per unit roof area (W_{peak}/m^2)	154	MCS Solar PV Standard
Baseload electricity demand intensity (kWh/m^2)	40.2	Energy consumption: England and Wales, NEED 2021
Heating demand intensity (kWh/m^2)	146.0	
Average heat pump COP	2.51	ERM modelling of an air source heat pump in an average weather year
Fleet size (no. of EVs)	2	National Travel Survey Statistics
Fleet plug-in window	17:30 – 08:00	EV Charging Behaviour Study 2019, Element Energy for NGESO
Installed EV charger capacity (kW)	14.8	Wallbox Quasar Charger Electrical Specifications



SUMMARY: Domestic flat buildings' morning and evening peaks in demand aligns well with the fleet's plug-in window, but does not align with the PV generation profile

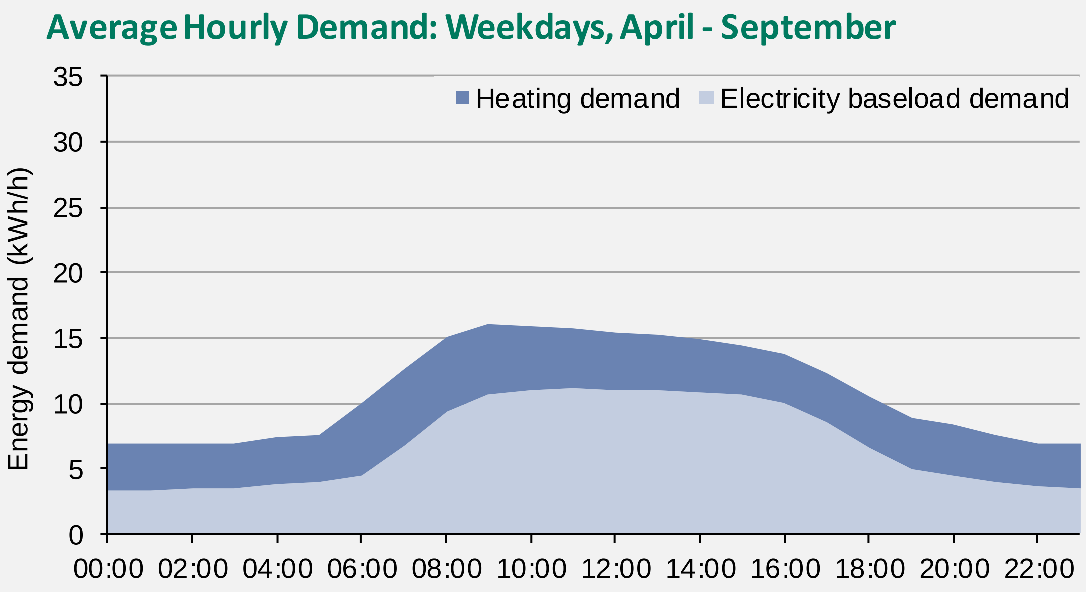
- **Domestic buildings' energy demand** has significant morning and evening peaks in demand
  - Domestic semi-detached buildings have more significant morning and evening peaks than domestic flats, due to the **high proportion of heating demand**
- Demand peaks align with the **expected plug-in window of the building's fleet**
  - Fleet charging demand is also approximately 32% of the total building demand, and therefore may be able to provide significant flexibility
- **Solar PV generation is close in magnitude to the building's total demand**, suggesting savings can be made by maximising self-consumption
  - PV generation profile does not align well with the plug-in window of the buildings' fleet, suggesting V2B is unlikely to be able to maximise self-consumption

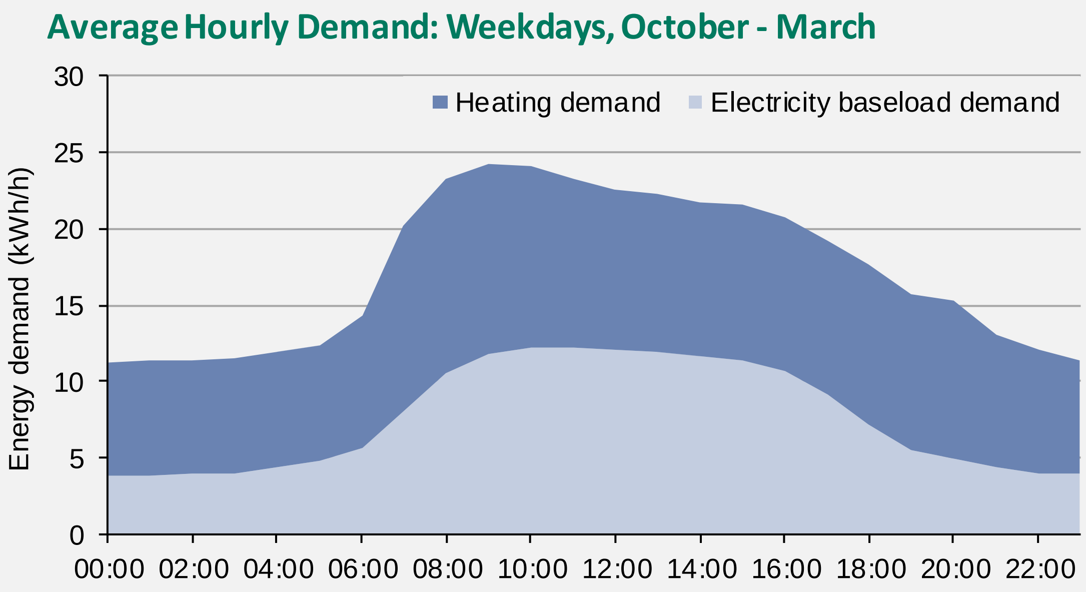
Comparison of hourly building demand, PV generation and fleet plug-in window on an average winter day



Contents

Office building demand is dominated by heating over the winter months, with peaks in the early morning and evening

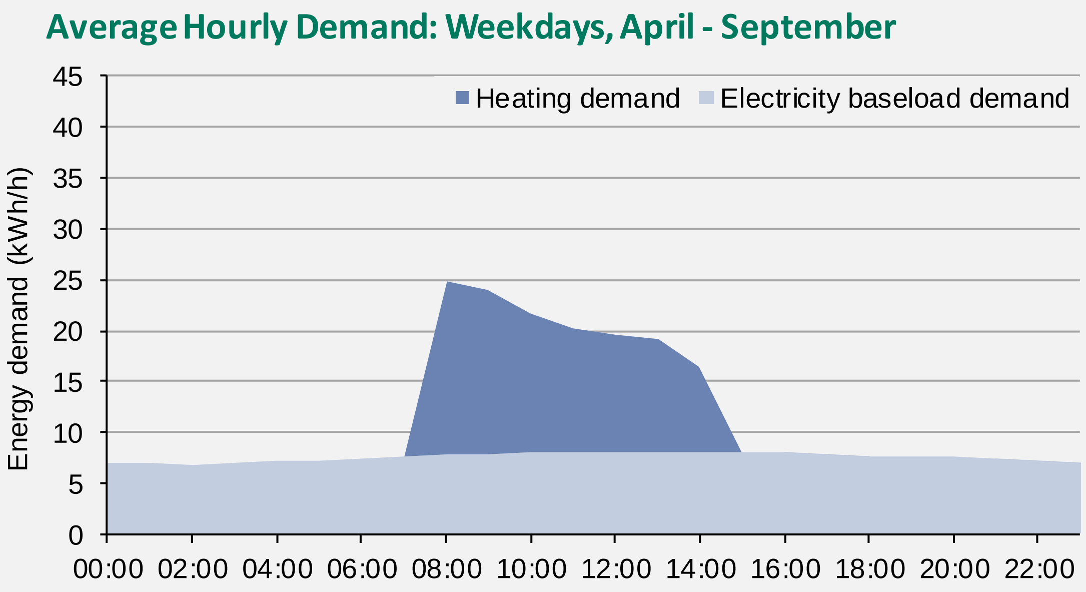


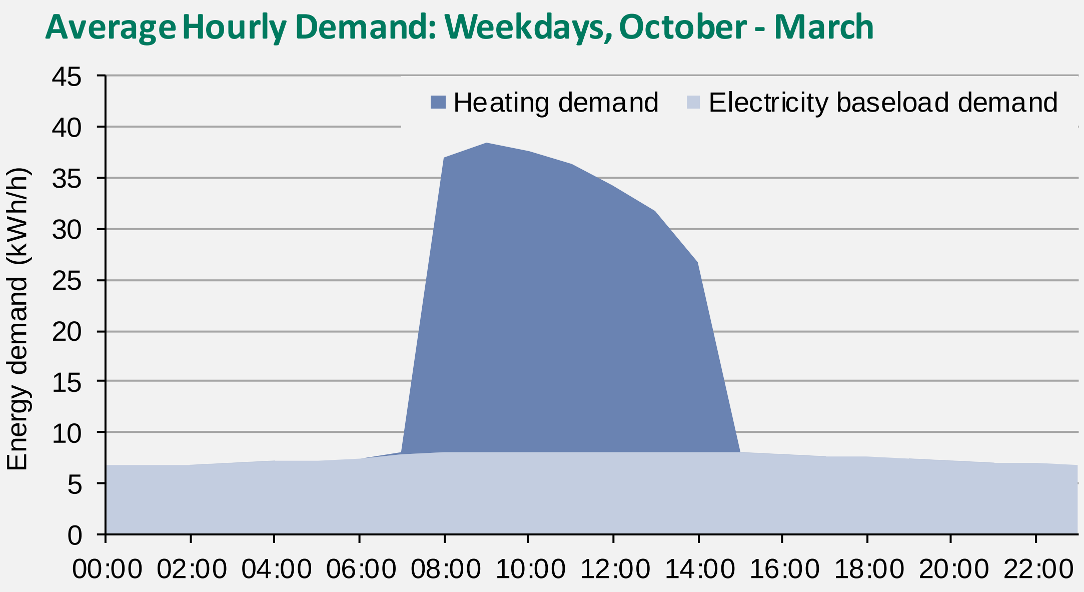


- The average summer and winter profiles shows a **discernible daytime peak in building energy demand** between 05:00 and 19:00, with low heating and baseload electricity demand beyond these hours.
- The average winter profile indicates a **higher heating demand** than in summer, with peaks in heating demand between 07:00–09:00 and 18:00 – 19:00
  - Summer heating demand is also highest within these hours but is approximately 46% of average demand over winter months

 Baseload electricity demand profile is based on an ERM study analysing half-hourly metered electricity consumption data of non-domestic building archetypes. Heating demand profile is based on the GB Heat Decarbonisation Model, developed by ERM for National Grid ESO and used in Future Energy Scenarios (FES). Note: heating demand profile assumes heating has been electrified.

Storage warehouse building demand peaks dramatically between 07:00 – 15:00 due to the heating demand



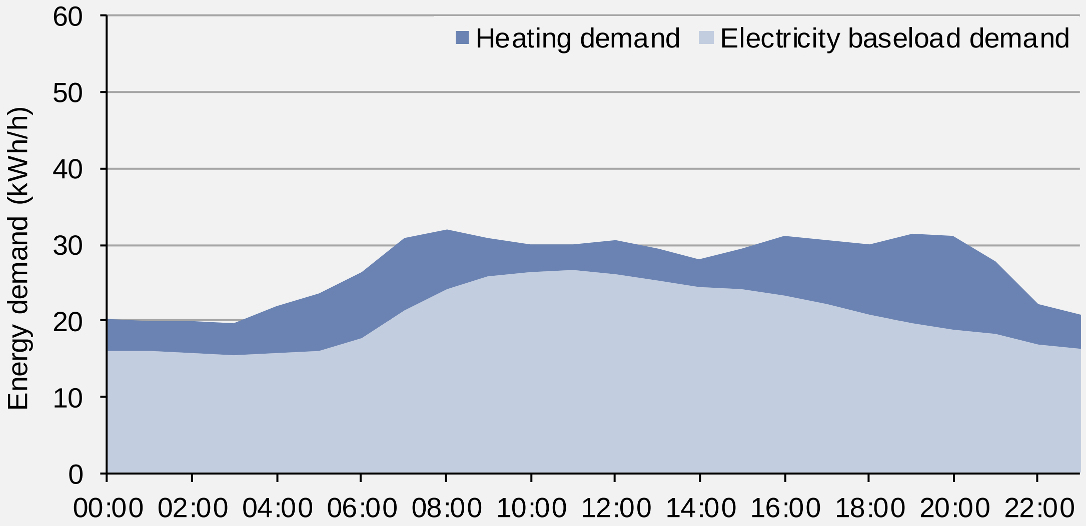


- The average summer and winter profiles shows a **discernible daytime peak in building energy demand** between 07:00 and 15:00, largely due to high heating demand
  - Baseload electricity demand remains relatively flat over the day
- The average winter profile indicates a **higher heating demand** than in summer, still within the peak hours of 07:00 and 15:00
  - Average peak heating demand over summer months is approximately 45% of that over winter months

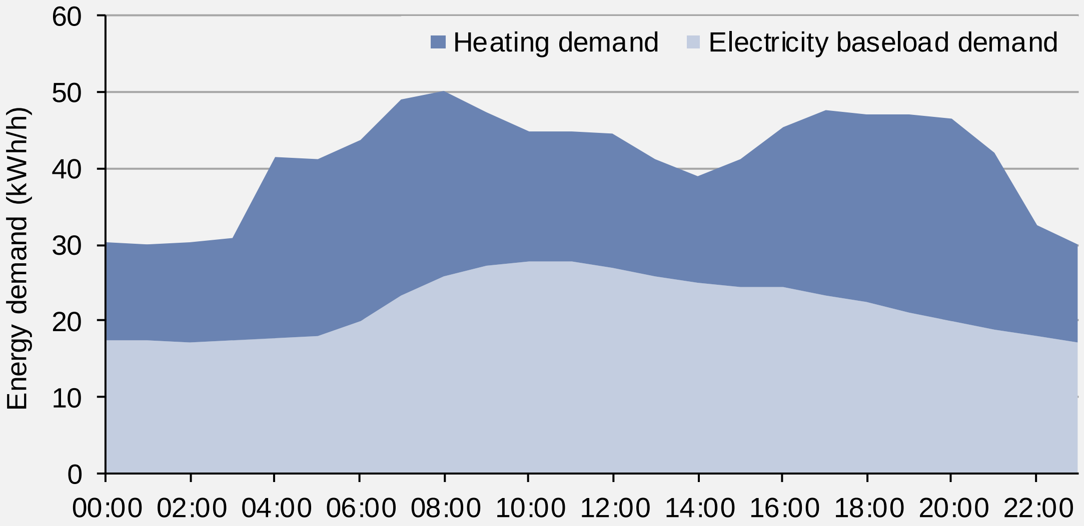
Baseload electricity demand profile is based on an ERM study analysing half-hourly metered electricity consumption data of non-domestic building archetypes. Heating demand profile is based on the GB Heat Decarbonisation Model, developed by ERM for National Grid ESO and used in Future Energy Scenarios (FES). Note: heating demand profile assumes heating has been electrified.

Hospital demand profile is dominated by electricity baseload demand over the summer months, with heating demand increasing significantly over winter

Average Hourly Demand: Weekdays, April - September



Average Hourly Demand: Weekdays, October - March

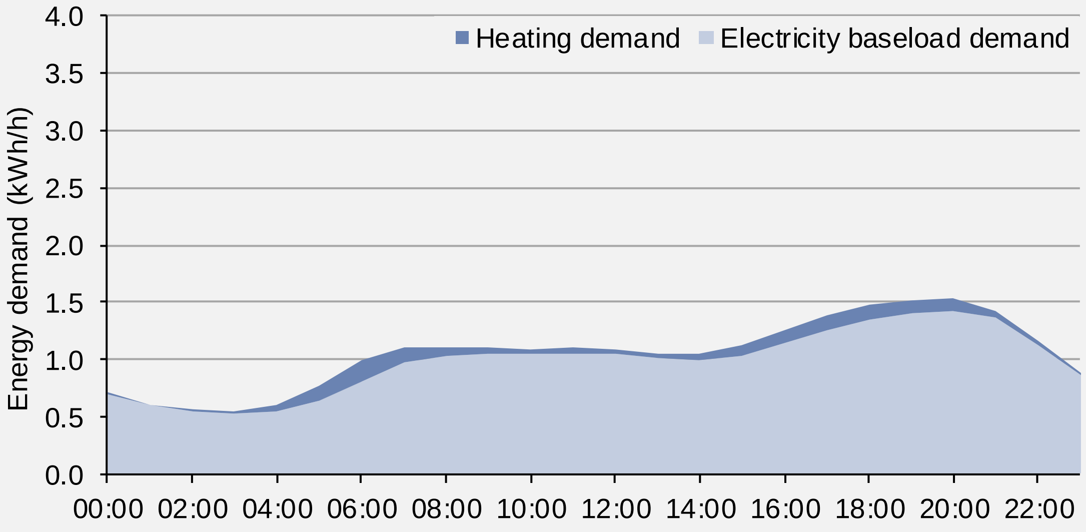


- The average summer and winter profiles show a **daytime peak in building energy demand** between 06:00 and 21:00, with lower baseload and heating demand beyond these hours
  - Daytime peak is more apparent over winter, with increased heating demand showing clear **spikes in the morning and evening**
- Peak heating demand over summer months is approx. 47% of that over the winter months, with demand more concentrated in the evening (at around 8pm) than over winter where the morning and evening peaks in heating demand are more even

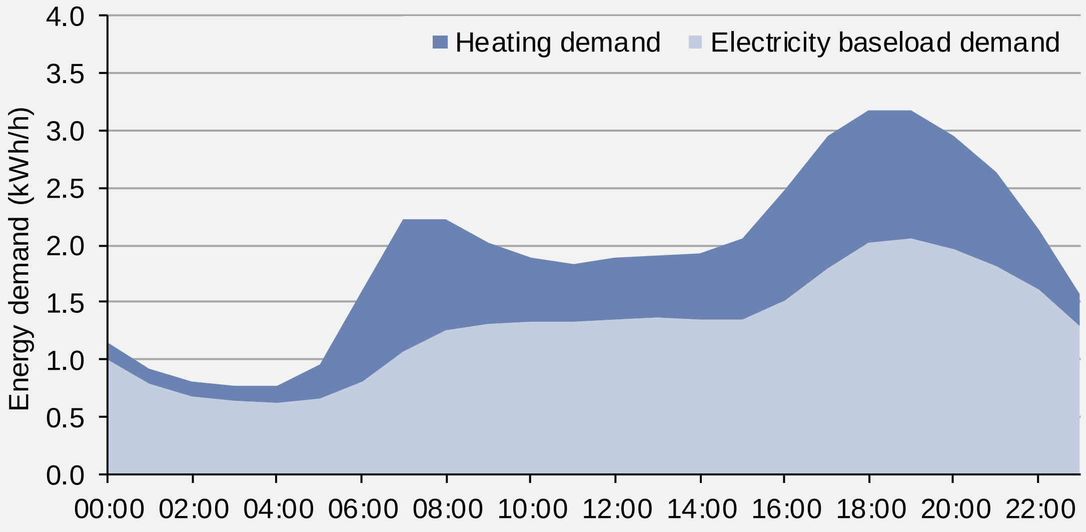
 Baseload electricity demand profile is based on an ERM study analysing half-hourly metered electricity consumption data of non-domestic building archetypes. Heating demand profile is based on the GB Heat Decarbonisation Model, developed by ERM for National Grid ESO and used in Future Energy Scenarios (FES). Note: heating demand profile assumes heating has been electrified.

Domestic flats' building demand peak in the evening, with an additional morning peak emerging in the morning as a result of high heating demand

Average Hourly Demand: Weekdays, April - September



Average Hourly Demand: Weekdays, October - March

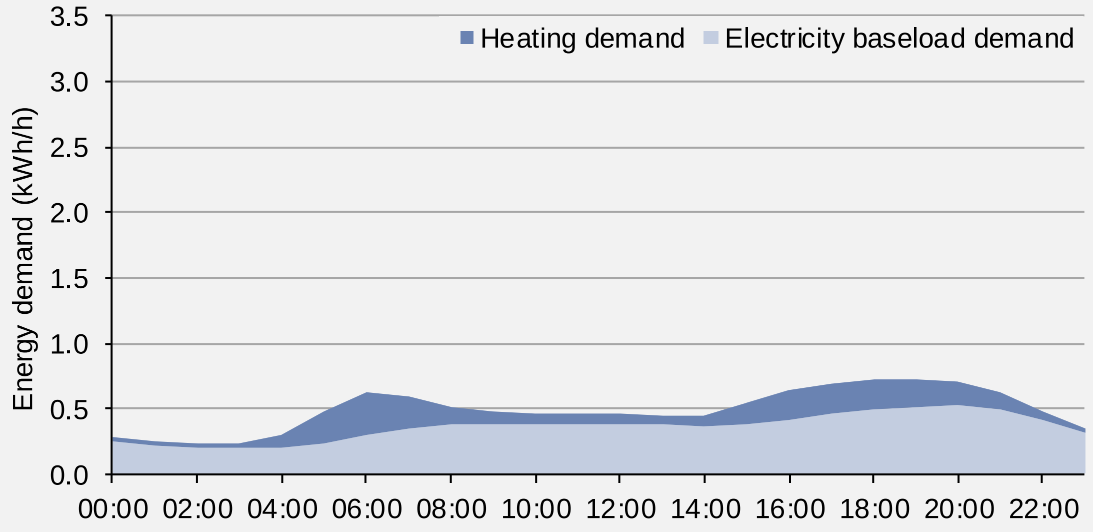


- The domestic semi-detached and domestic flat building archetypes use the same domestic electricity baseload and heating demand profiles, scaled according to their total floor area
- The average winter profile shows two clear morning and evening peaks in demand between 06:00 – 09:00 and 15:00 - 21:00.
  - The morning peak is largely due to high heating demand, while baseload electricity ramps up in the morning but stays relatively flat through the day until the evening
- The building demand has a smoother peak in the evening over the summer months, approximately 48% of the total building demand peak in the winter

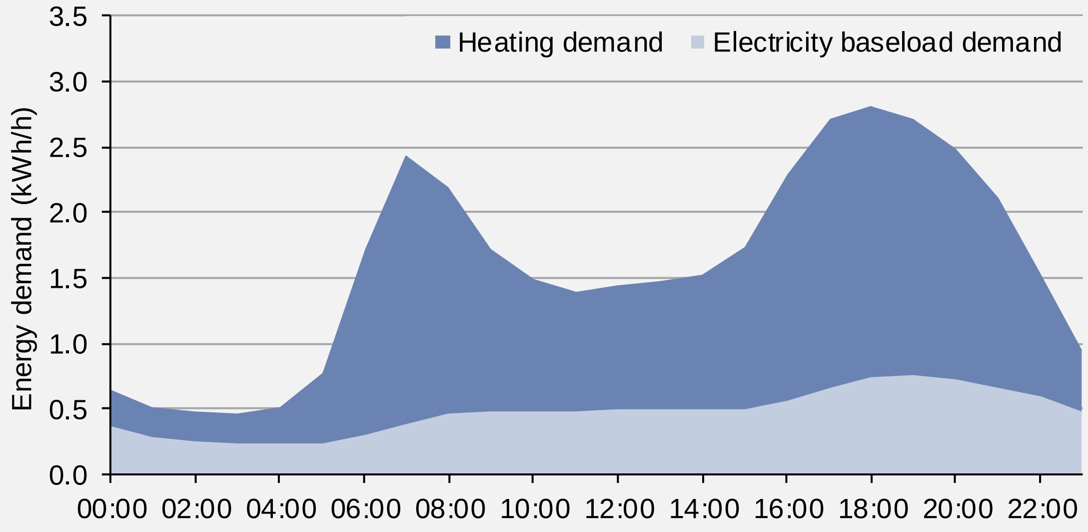
Baseload electricity demand profile is based on SmartMeter Energy Consumption Data collected in the Low Carbon London project, UK Power Networks. Heating demand profile is based on the GB Heat Decarbonisation Model, developed by ERM for National Grid ESO and used in Future Energy Scenarios (FES). Note: heating demand profile assumes heating has been electrified.

Domestic semi-detached building demand is significantly dominated by heating demand over the winter months

Average Hourly Demand: Weekdays, April - September



Average Hourly Demand: Weekdays, October - March



- The domestic semi-detached and domestic flat building archetypes use the same domestic electricity baseload and heating demand profiles, scaled according to their total floor area
- The average winter profile shows two clear morning and evening peaks in demand between 06:00 – 09:00 and 15:00 - 21:00.
  - The morning peak is largely due to high heating demand, while baseload electricity ramps up in the morning but stays relatively flat through the day until the evening
  - Over winter, the heating demand significantly dominates the total building demand
- The building demand has a smoother peak in the evening over the summer months, approximately 48% of the total building demand peak in the winter

Baseload electricity demand profile is based on SmartMeter Energy Consumption Data collected in the Low Carbon London project, UK Power Networks. Heating demand profile is based on the GB Heat Decarbonisation Model, developed by ERM for National Grid ESO and used in Future Energy Scenarios (FES). Note: heating demand profile assumes heating has been electrified.

Contents

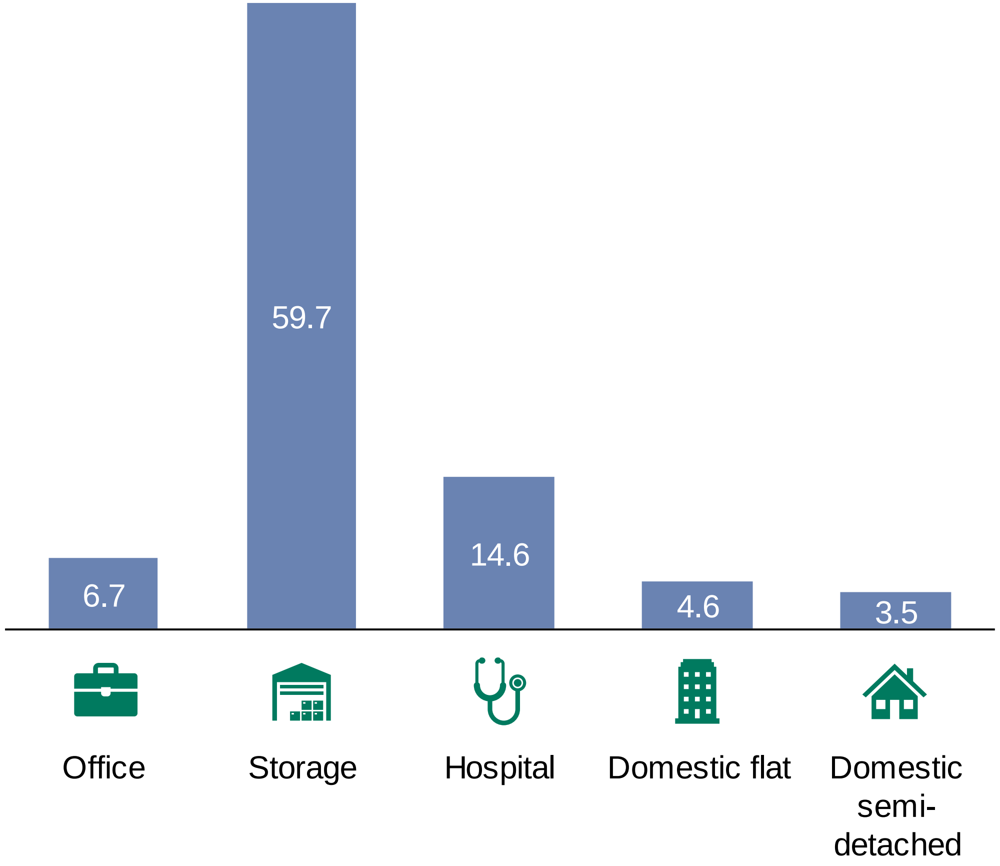
Each building archetype is assumed to have PV generating capacity proportional to its roof area

- Each building archetype is assumed to have solar PV panels on its roof, able to generate electricity for self-consumption
- The maximum generating capacity of each building archetype (kW_{peak}) can be calculated
  - Based on the archetype's roof area (see this slide), the proportion of the roof able to be used for PV and the PV generation intensity of the solar PV
  - Factors used and sources summarised in the table below

Metric	Usable roof area for PV	Peak generation intensity (kW_{peak}/m^2)
Value	50%	0.154
Source	*ERM findings from past engagements with commercial stakeholders*	MCS Solar PV Standard

- The maximum capacity can be applied to the PV generation profile (see next slide) to understand the total PV produced
- Due to the large roof area, the storage building archetype has the largest solar PV generation of approx. 60 kW_{peak}
- The high-rise office building archetype is assumed to have a similar generating capacity as the domestic archetypes

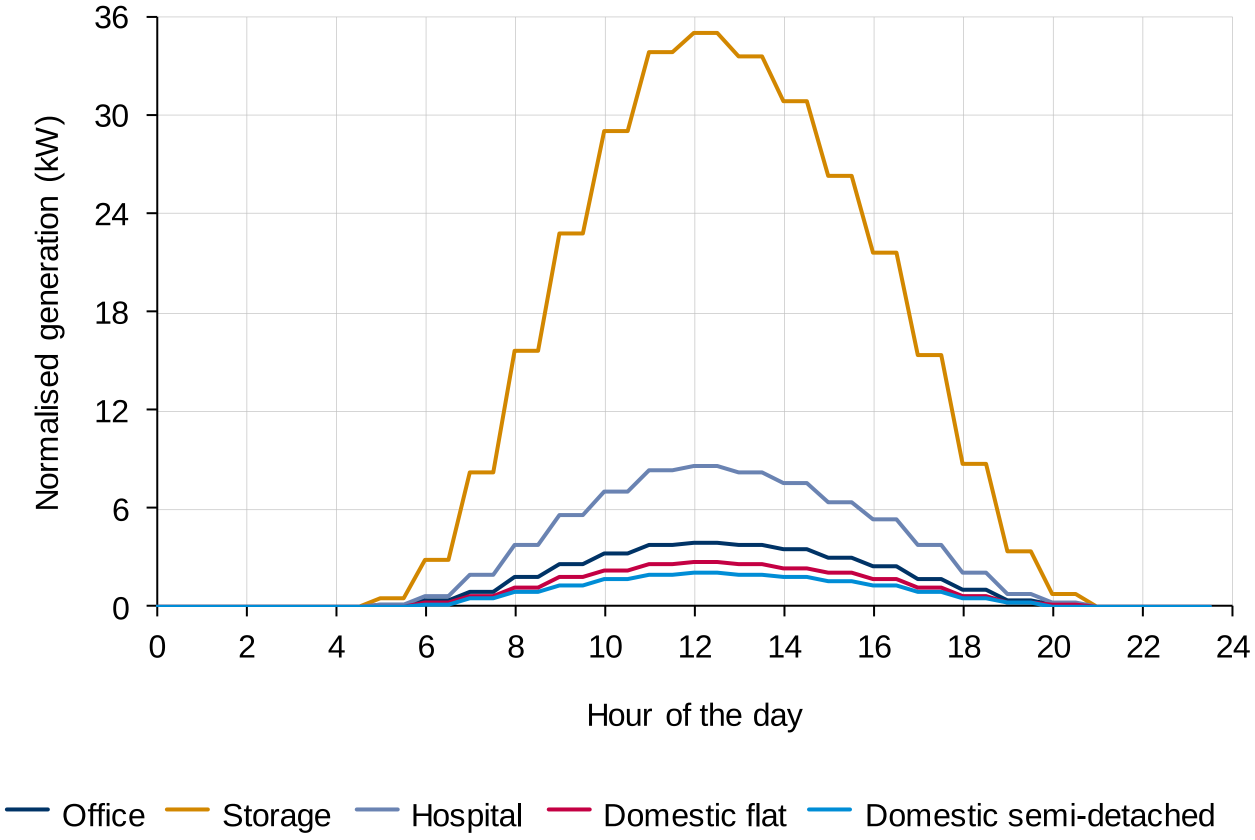
Maximum PV generation capacity of each building archetype (kW_{peak}) assuming total usable roof area used



Each archetype's modelled PV generation profile varies over the day and the year, with generation highest in July

- Modelling of each archetype's generation capabilities uses a normalised annual profile for a 1 kW_{peak} PV panel in the UK multiplied by the peak generating capability of each archetype calculated from the usable roof area
- Figure, right, shows the assumed generating profile of each building archetype in July, when PV generation is assumed to be at its highest
  - Generation does not reach each archetype's kW_{peak} due to considerations such as weather, obscuring of panels, and efficiencies
  - Generation is highest between 11:00 – 13:00, and in July falls to 0 between 21:00 – 5:00, with longer non-generating periods over winter months

PV generation profile of each building archetype in July (kW)

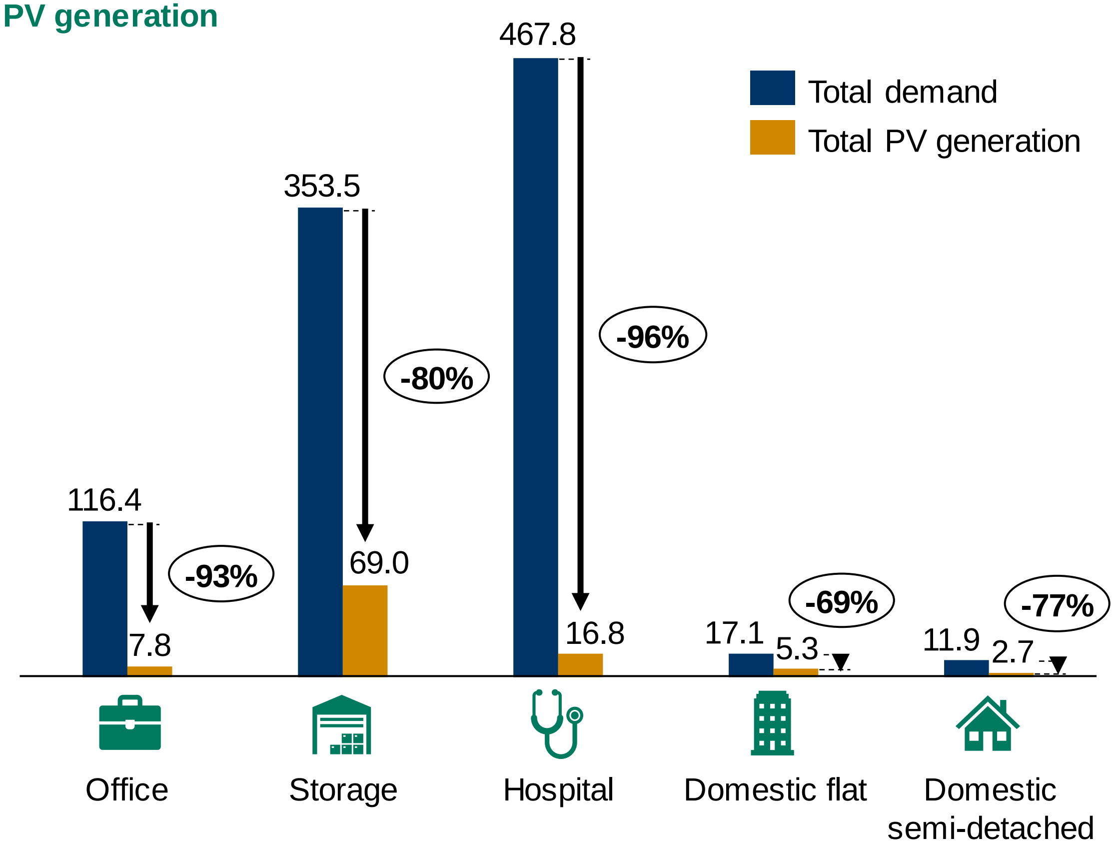


Normalised PV generation profile is based on data from Renewables.ninja.

Storage warehouses have the highest PV generation potential of the core commercial archetypes, but domestic archetypes can provide a higher proportion of demand than commercial buildings

- Figure, right, compares the total annual demand assumed for each archetype, including baseload electricity, heating and fleet charging demand, with the total PV generation assumed per year
- Due to the **high roof area** relative to the overall building floor area, the **storage archetype** offers the greatest potential for maximising PV self-consumption out of the core archetypes
  - Annual generation of 70 MWh makes up 64% of the building baseload and electricity demand
  - However, due to the large fleet size, it makes up only **20% of the overall demand** including fleet charging
- PV generation can provide a much **lower** proportion of demand **in offices and hospitals (<10%)** due to the small roof size and high energy demand respectively
- PV generation at the **domestic archetypes** is able to meet a higher proportion of total demand (**23 - 31%**) than commercial archetypes

Total annual demand of each archetype (baseload electricity and heating demand, and fleet charging demand) compared to total annual PV generation



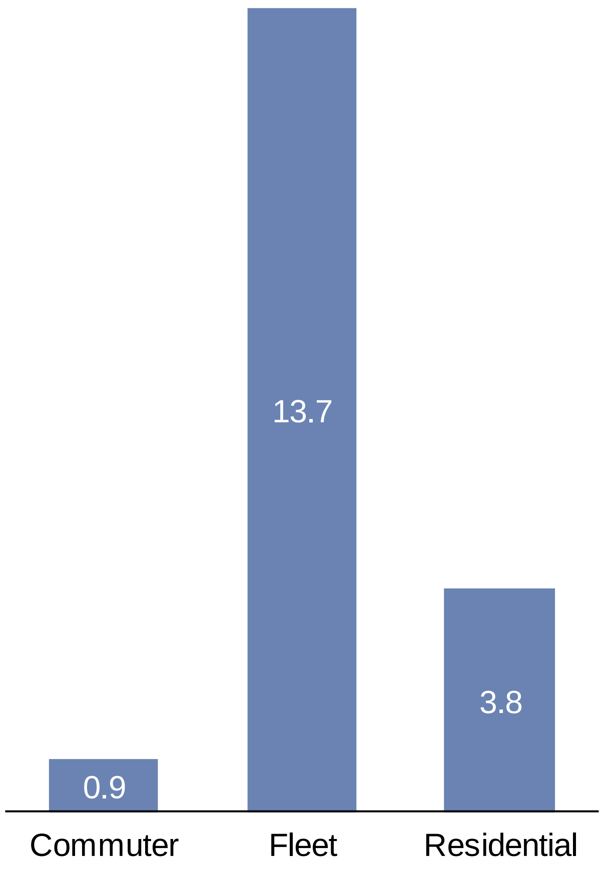
Contents

Each building archetype has been assigned 1 or 2 fleet archetypes that summarise charging behaviour

- 3 fleet archetypes have been developed based on Element Energy's EV Charging Behaviour Study for NGESO and analysis of data collected in the Optimise Prime NIC innovation project
- Archetypes include **daily charging demand and plug-in behaviour** to enable modelling of charging profiles

Building archetype	Fleet size	Fleet archetype	Daily charging demand	Plug-in window	*Source:*
Office	10	Commuter	0.9 kWh/EV	08:30 – 17:00	*EV Charging Behaviour Study 2019, Element Energy for NGESO*
Storage	60	Fleet	13.7 kWh/EV	19:00 – 08:30	*ERM analysis of Optimise Prime Depot Data*
Hospital	34	Commuter	0.9 kWh/EV	08:30 – 17:00	*EV Charging Behaviour Study 2019, Element Energy for NGESO*
	30	Fleet	13.7 kWh/EV	19:00 – 08:30	*ERM analysis of Optimise Prime Depot Data*
Domestic flat	3	Residential	3.8 kWh/EV	17:30 – 08:00	*EV Charging Behaviour Study 2019, Element Energy for NGESO*
Domestic semi-detached	2	Residential	3.8 kWh/EV	17:30 – 08:00	

Daily charging demand per EV by fleet archetype (kWh/EV/day)



Contents

Examples of business models range from contractual agreements on sharing revenues to transactive real-time charging management systems

Example 1: Contractual agreements [1]

- EV Owners set constraints: desired plug-in time, minimum and maximum SOC, planned departure time.
- Prosumer (building with onsite PV generation) benefits from flexibility offered by EVs within established constraints and associated revenues.
- Prosumer and EV owners agree on contract defining constraints, monetary compensation for participation and penalties for violating contract.
- **Most applicable option** for the range of building-fleet type combinations considered in this study (not destination charging)

Example 2: Reducing each individual entities' costs [2]

- At a large enough scale, a collaborative energy management system between a cluster of entities, such as buildings and charging stations, can ensure both building energy and charging cost reductions.
- This would involve two-way electricity flow between buildings and charging stations to manage fluctuations in demand and ensure cost savings to both.
- Risk of revenues **not being distributed fairly to individual EV owners** as charging cost savings potential would vary depending on charging windows.

Example 3: Real-time transactive charging models [3]

- Building Energy Management System (BEMS) organises a "transactive market" with EVs parked at a building at a given time.
- This considers a 2-stage system where a building first plans its optimal electricity use schedule based on wholesale market prices and assumptions on PV generation. Flexibility offered by EVs is then used to optimise real-time operation in line with planned use.
- EV owners specify their constraints (e.g. min and max SOC, max charge/ discharge periods) and the charging flexibility that they are willing to offer, and are compensated relative to the amount of flexibility they offer.

Example 4: Community energy with a central aggregator [4]

- Paper considers a renewable energy community with a range of domestic and commercial buildings, with each building being able to buy and sell electricity either to/from the grid or other buildings in the community.
- A market is established within the community that determines tariffs for renewable generation surplus within the community, facilitated by aggregation.
- EV charging costs can be determined in real-time based on present electricity costs and charging durations.

1 – Internet of Energy Approach for Sustainable Use of Electric Vehicles as Energy Storage of Prosumer Buildings, Nefedov, E.; Sierla, S.; Vyatkin, V.
2 - A collaborative energy sharing optimization model among electric vehicle charging stations, commercial buildings, and power grid, Md Abdul Quddus, Omid Shahvari, Mohammad Marufuzzaman, John M. Usher, Raed Jaradat
3 - Transactive Real-Time Electric Vehicle Charging Management for Commercial Buildings With PV On-Site Generation, z. liu, Q. Wu, M. Shahidehpour, C. Li, S. Huang and W. Wei,
4 - Management of Electric Vehicles as Flexibility Resource for Optimized Integration of Renewable Energy with Large Buildings, P. Moura, G. K. W. Yu and J. Mohammadi

Contents

Key advantages of V2B alternatives are high availability and reliability – but they come at higher cost and require additional space

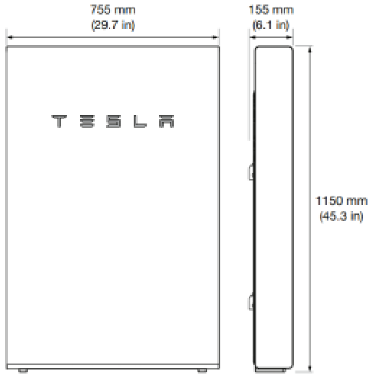
Technology	Description	Advantage over V2B	Disadvantage compared to V2B
Thermal storage	Thermal storage is charged by heat pump, discharged into heating system.	• High reliability (not depending on EV being plugged in) • No EV battery degradation • Could become cost competitive with bi-directional charger	• Significant additional space requirements • Lower round trip efficiency than battery • No electricity discharge to building – no management of building loads
Hybrid heat pump	Gas boiler is installed in addition to heat pump; only utilised on coldest days (delivering ~20-30% of annual heat demand)	• High reliability (not depending on EV being plugged in) • No EV battery degradation	• Modest additional space requirement (boiler) • Dependent on gas grid which could be decommissioned • Leads to remaining gas demand, and carbon implications • No electricity discharge to building – no management of building loads
Stationary battery storage	Battery storage storing electricity to run heat pump	• High reliability (not depending on EV being plugged in) • No EV battery degradation	• High cost • Typically shorter discharge duration and lower discharge capacity • Modest additional space requirements

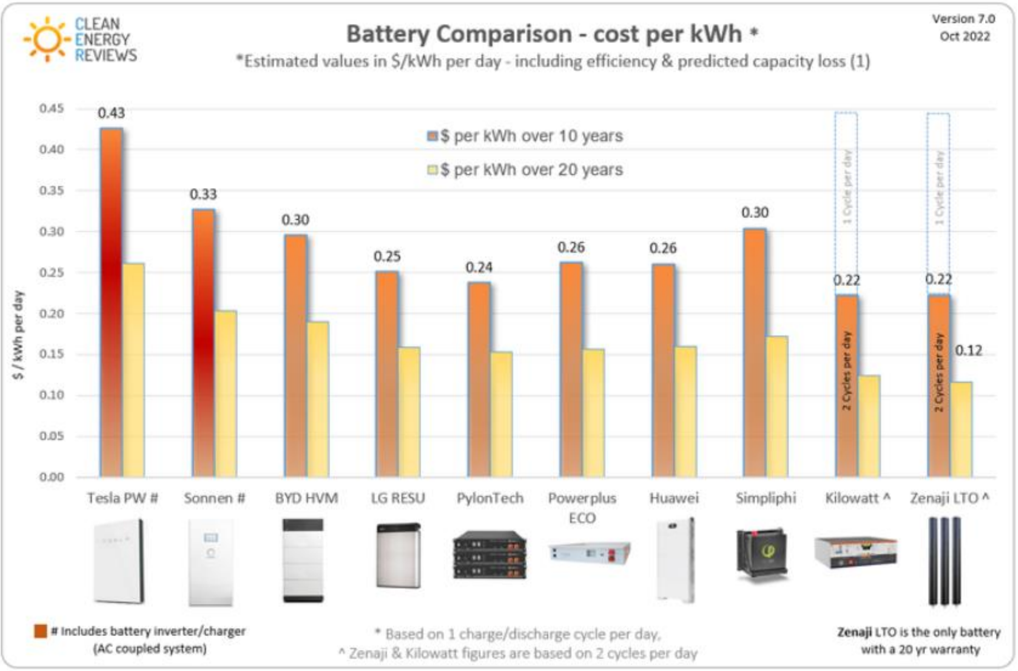
Battery storage deep dive: space requirements for stationary battery storage are relatively modest, but it comes at high cost

- Key disadvantage of installing battery stationary storage at a site instead of making use of V2B is the **additional cost and space requirements**
  - Space requirements higher, whereas EV parking space already needed
- Example specs of a 13.5 kWh Tesla Powerwall (targeting domestic and small commercial buildings) are shown, right
  - Space requirements are relatively modest
  - High cost compared to bi-directional charger ($1,100/kW for Tesla Powerwall compared to ~$4,000/7kW ~ $500/kW for bi-directional charger, but this is one of the more expensive home battery storage systems, see figure right below[3])
  - Full cost comparison needs take into account potential accelerated EV battery degradation from V2B
- Building owners **installing rooftop PV increasingly include BESS**[4] to increase PV self-consumption as export tariffs are unattractive
  - Providers such as Tesla offer combined BESS + solar inverter system, i.e. BESS and solar PV share the same inverter[2]

Example: Key specs of Tesla Powerwall 2[1]

- Width 76 cm, depth 16 cm
- Charging capacity: 13.5 kWh
- Maximum discharge/charge: 5kW
- Duration: 2.7 hours
- Warranty: 10 years
- Weight: 125kg
- Price: US$ 11,000[2]





1) Tesla Powerwall 2 AC Datasheet; 2) CER 2022 a; 3) CER 2022 b; 4) PV Magazine 2021; 5) ESN 2022; 6) ESN 2022 b

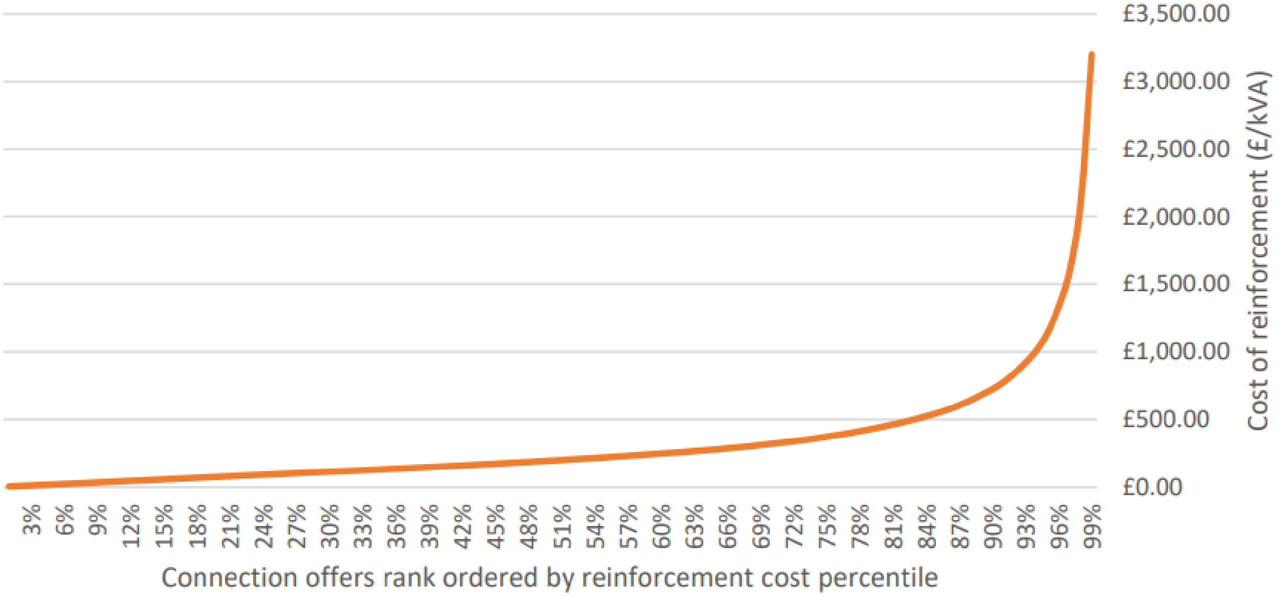
Contents

Reinforcement costs have now been socialised below a high cost cap for connecting demand customers

Previous connection payment arrangements:

- The connecting customer used to pay:
  1. All of the **costs for the extension assets** required to connect to the existing distribution network (e.g., cabling from site to network)
  2. **If reinforcement of the network is required to facilitate the connection, a contribution to the cost of that reinforcement they have triggered**[1] (e.g., reinforcing up-stream substations).
- Connecting customers encouraged to connect where there is spare capacity on the network (e.g., lower cost quotes for higher spare capacity network)
- This changed in **April 2023** – see next slide

Connection offers issued by DNOs over the course of over 2013 -2022 – ca. 95% of costs are under £1000/kVA upgrade, with a small number significantly higher



Key issues with past arrangements:

1. Customers triggering reinforcement unfairly held **liable for all the previous capacity being filled and pay significantly higher cost of connection**
2. New customers could 'free ride' and wait until another customer triggers and pays for reinforcement
3. DNOs **not incentivised to pre-empt reinforcement** – DUoS charges paid only if there is a demand (see this slide for detail)
4. Did not support rapid decarbonisation / electrification
5. Transmission + Distribution connection arrangements can be **contradictory**

Source: Access SCR - Final Decision (ofgem.gov.uk); Notes: 1 – Contribute to cost of reinforcement up to one voltage level above their point of connection. Any remaining cost of reinforcement (incl. 2 voltage levels above the point of connection) is socialised across the DNO's wider customer base

SCR – Significant Code Review by Ofgem decided to socialise reinforcement costs for new connections and change access arrangements

- The **Access and Forward-Looking Charges Significant Code Review (SCR)** was launched by Ofgem in 2018 as part of a package of reforms to improve how parties **access and pay charges for the electricity network**
- The SCR concluded that payment arrangements were **slowing down connection of low carbon technologies**
- This was accompanied by **changes to DUoS charging arrangements** from the **Targeted Charging Review** (TCR) – see next slide

In May 2022, changes to access and payment arrangements were published to be in place from April 2023, including:

1 **Connecting customers will no longer pay contribution to network reinforcements**

- Connecting customers will only pay for the **extension assets required** to connect to the existing distribution network, i.e. same as those who connect when there is capacity
- **Cost of reinforcement below a high cost cap of £1,720/kVA** will be socialised across all customers through the **ongoing DUoS costs**

2 **DNOs will provide non-firm access to all large network connections**

- Before April 2023, when connecting to the distribution network, the connection capacity to import/export electricity is specified in the agreement and is **firm** i.e., DNO must always have capacity available for the import/export without curtailment
- SCR will allow DNOs to offer **non-firm access agreements** to **large customers** (not small commercial or domestic), where they can **curtail connection capacity at certain times** (agreed curtailment limit)
- Lower connection cost as reduces need for reinforcement

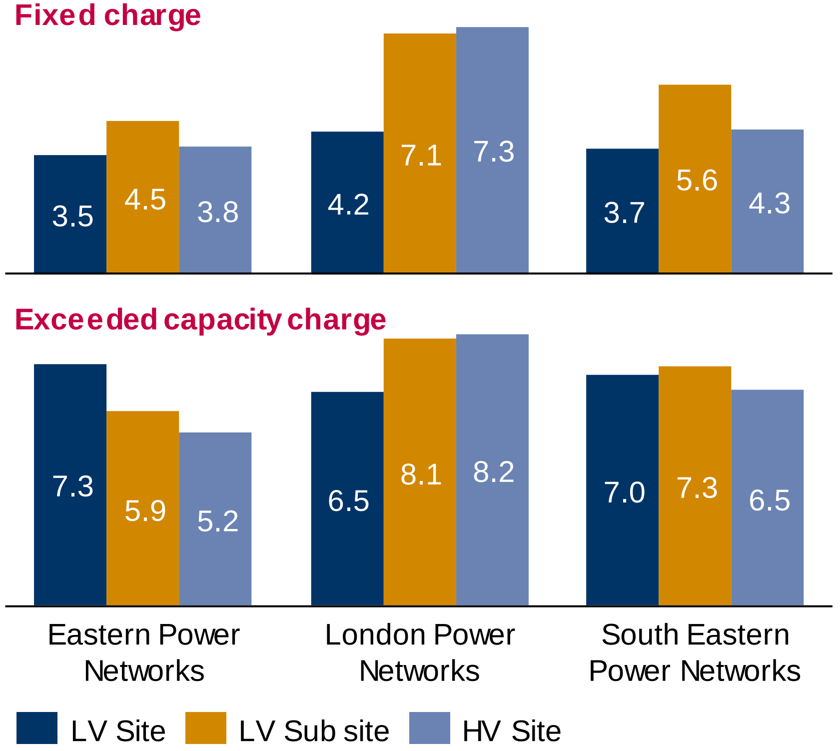
Note: connection requests that require significant upstream network reinforcement may lead to **lengthy waiting times** before the connection can be granted

Source: Access SCR - Final Decision (ofgem.gov.uk)

Consumers still pay distribution network charges based on site's connection capacity and face a fee if the site exceeds agreed capacity

- Electricity users are subject to **network charges** to recover the **cost of installing and maintaining** the distribution network and transmission network
  - The distribution network charges are called **Distribution Use of System (DUoS)** charges
- **DUoS** charges consist of:
  1. **Fixed charge:** fixed rate per kVA of site's connection capacity (p/kVA/day) or per connected metering system
     - Varies by distribution network operator, region and connecting organisation type
     - There is an additional charge for **exceeding agreed capacity**
  2. **Unit charge:** variable charge per unit energy consumed (p/kWh), differ by hour of the day and weekday/weekend
- **Ofgem** carried out a **Targeted Charging Review (TCR)** on DUoS
  - As part of the TCR, the DUoS charges were reformed to reduce the impact of the unit charges and to **increased the fixed charges**[1]
- It is unclear if DUoS charges will be further reformed to account for the socialised reinforcement cost as a result of the SCR

Fixed and exceeded capacity charges across UK Power Networks' licence areas (p/kVA/day)[2]



E.g.: a large commercial building with a 250kVA HV connection in South Eastern Power Networks would pay £3,924/year in fixed capacity charges

Source: 1) Targeted Charging Review: Decision and Impact Assessment, Ofgem, 2019; 2) UK Power Networks Distribution Use of System Charges, 2023 - domestic properties are not subject to fixed DUoS charges

Contents

Summary of consumer engagement in V2X and EV flexibility schemes

Trials found that consumers are likely to engage in EV flexibility and V2X schemes with financial incentives, and clear communication of the technology and benefits

Key actors	Trial name	Description	Incentive (£/kWh)	Consumer engagement
National Grid ESO Octopus Energy Ohme Technology SSEN WPD Element Energy	**CrowdFlex**	**Big Turn Down:** Several "events" to lower demand during 2h evening peak window in Nov 2020	1-3£/kWh reduction	• **2-4% (ca. 400) total consumers engaged**, offering **0.5-0.6 kW** (40 – 60%) reduction in demand on average per customer • 24h notice prevented some customers from participating
		Domestic Scarcity Reserve Trial: Several "events" in evening peak 2h window to lower demand, 24h notice period, Feb – March 2022	0.23£/kWh reduction	• **33% of customers signed** up and 100k total consumers engaged, offering 0.23-0.4 kW reduction in demand. • Consumers on dynamic tariff with smart meters had much higher engagement
National Grid ESO Electricity suppliers	**Demand Flexibility Service (DFS)**	Day-ahead notice of a demand 'reduction period' of 1-4h, trialled over winter 2022/23 via suppliers	~3£/kWh reduction	• Full results from all electricity suppliers not yet published • Octopus Energy: **700k customers participated** over 13 events, shifting on average 128 MWh per hour
OVO, Kaluza, Cenex	**Project Sciurus**	325 residential household V2G demonstrator over 2018 – 2021	0.30£/kWh exported	V2G EV drivers can be incentivised to plug in more and **experience of the technology alleviated most concerns**
WPD EA technology Drive Electric	**Electric Nation**	Series of smart charging trials over Jan 2017 – Dec 2018, with over 600 participants	Time of use tariff	**Clearly communicated modest financial incentive** can change people's charging behaviour, using a simple app to make changing behaviour simple.

Sources: Crowdflex Phase 1 Big Turn Down; Domestic Scarcity Reserve Trial; Demand Flexibility Service; Project Sciurus; Charge Collective; Electric Nation;

Charge Collective investigated consumer attitudes to EV flexibility

Consumer focus groups found that optimal use of renewables is more important to charge point users than cost savings

Key advantages of smart charging:

1. **Optimal use of renewable energy is a major motivator to smart charge at public charge points**
   - When asked which of the advantages of smart charging were **most important** to the focus group participants, optimal use of renewable energy was the **most frequent response**

'It's not just a token thing of using renewable energy, but also about attacking the use of fossil fuels in the system'

2. **Charge point users consider optimal use of renewable energy as more important than cost savings**
   - Although most focus group participants (92%) consider cost savings as an important advantage of smart charging, optimal use of renewable energy was cited as the **most important advantage** more frequently
   - This is consistent with results from Amsterdam's Flexpower trial, which found that Dutch EV drivers ranked optimal use of sustainable energy as more important than financial advantages[1]

'Electric cars are so much cheaper to run than old combustion engine cars that for cost to be the driving factor it would have to be a big differential'

3. **Short term savings in charging cost was considered more important than reducing the cost of electricity in the long-term and for everyone**
   - No participant viewed the long-term reduction of electricity cost as the most important advantage

'Preventing a future increase in electricity price is not a primary motivator for me … saving money on the cost of charging is more important'

1 - Behaviour research report, Flexpower, Amsterdam University of Applied Sciences, ElaadNL (May 2020)

Source: Element Energy for UK Power Networks, Charge Collective Report on on-street smart charging, 2022, Total participants in focus groups = 13

Contents

Battery degradation and associated costs remain uncertain

Poor operation could result in significant degradation, but optimised operation could preserve battery health

There are two forms of degradation to consider for EV batteries:

Cycling degradation: Battery capacities fade based on the number of charge/discharge cycles it completes.

Calendar degradation: Battery capacities fade over time, exacerbated by being left at 0% or 100% SOC

Both may be impacted by**:** *battery temperature, charge/discharge rate, depth of charge/discharge*.

Argument for bidirectional charging accelerating degradation:

- Bidirectional charging increases the annual cycling of batteries, although extent of cycling depends on services carried out, e.g. to capture max value from energy arbitrage, batteries are required to completely charge/discharge
- This adds a significant number of cycles per year, accelerating cycling fade
- The reduction in range and need to replace batteries over the course of the EV's lifetime is likely to put off consumers

Argument for bidirectional charging maintaining SOH:

- Battery capacities fade as a result of being stored at empty/full SOC – calendar fade. Regardless of charging type (passive or smart), ageing happens
- Calendar fade is impacted by SOC battery is held at, and bidirectional charging may lower calendar fade. As a result, the battery may not see significantly higher overall degradation from bidirectional charging
- Some papers argue that by operating the battery at around 50% SOC, battery life can be prolonged
- It is still too early in the research to understand for certain the impact of bidirectional charging on battery degradation

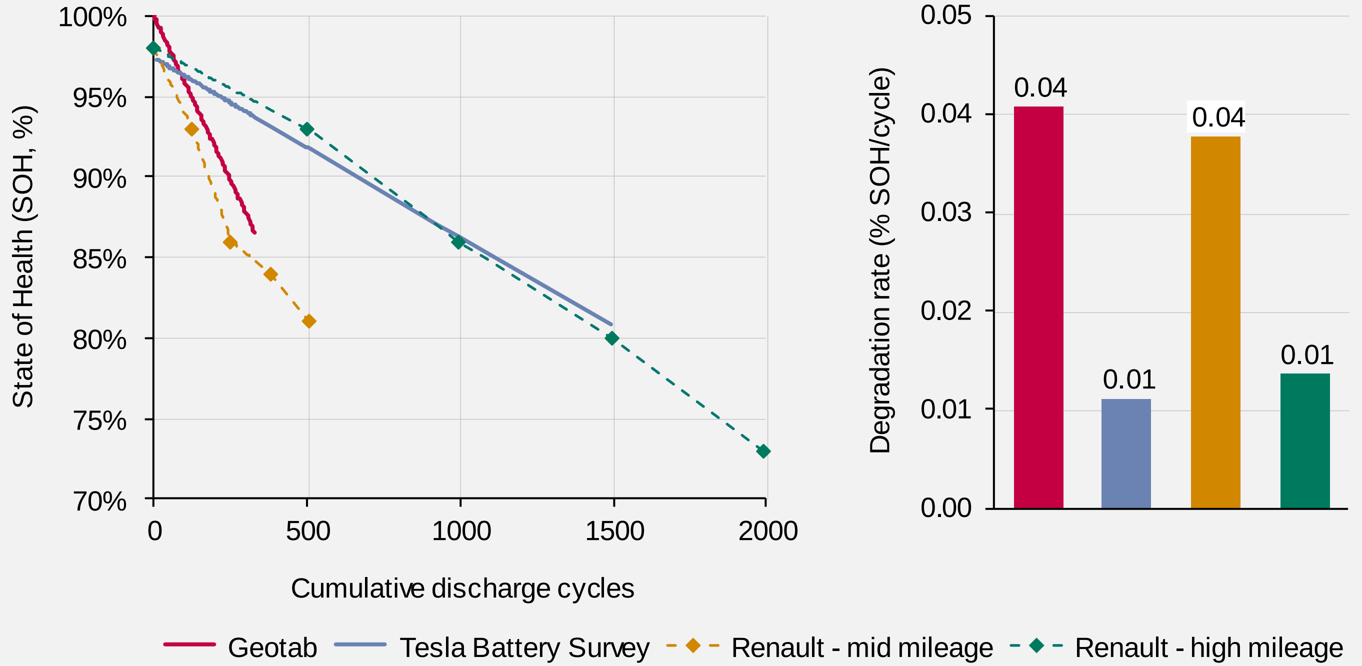
Sources: *1)* Wang, D., Coignard, J., Zeng, T., Zhang, C., & Saxena, S. (2016). *Quantifying electric vehicle battery degradation from driving vs. vehicle-to-grid services; 2)* Uddin, K., Jackson, T., Widanage, W. D., Chouchelamane, G., Jennings, P. A., & Marco, J. (2017). *On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system*

 SOH = Battery state of health (current capacity over original capacity); SOC = battery state of charge;

Literature review: Degradation data collected over different vehicles' lifetimes shows large variation

- Data collected on **real-world battery state of health (SOH) over vehicle lifetimes** indicate large variation in degradation as the battery is cycled (figure, right)
  - Observed degradation can be used to determine **degradation rate** calculated as decrease in SOH (%) per cycle of battery
- Degradation shown includes both **cycling and calendar fade** and is impacted by factors including charging behaviour and battery cycling frequency
  - E.g. high mileage vehicle with frequent cycling of battery is likely to result in impact of cycling degradation superseding that of calendar degradation
  - Data on 1st generation Renault Zoe show **lower degradation rate** per cycle with **higher mileage**
- Battery degradation is also dependent on the **battery management system**, with **newer and/or more sophisticated** management systems allowing batteries to retain higher SOH over lifetime
  - Tesla models' batteries reported to have lower degradation rate than typical models (e.g. Renault, Geotab) likely as it is a premium make

Battery degradation observed over cumulative cycles of vehicles' batteries and resulting degradation rate

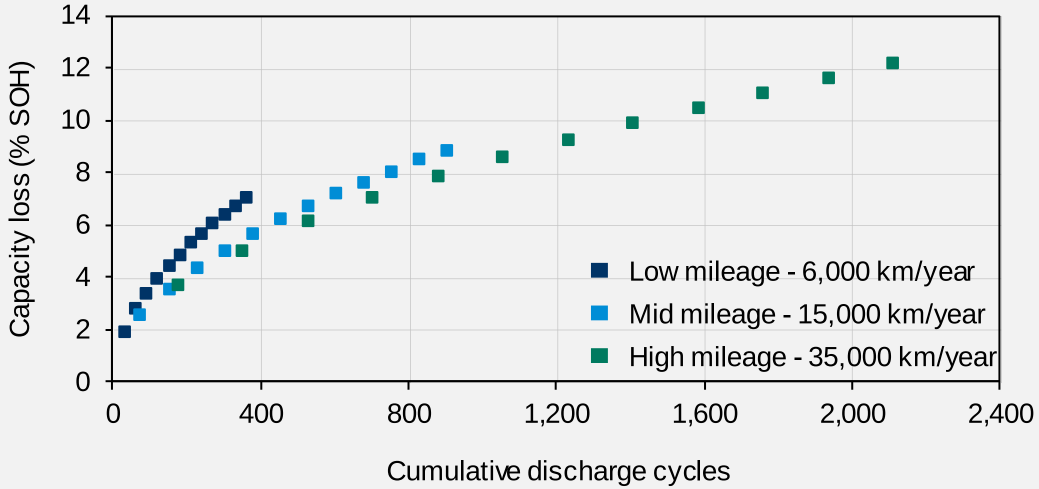


Summary of sources:

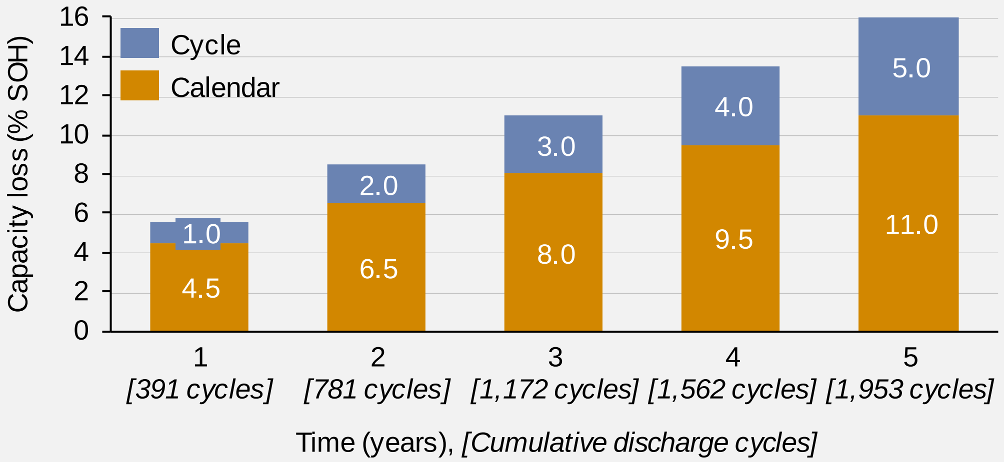
1. Geotab's EV battery degradation tool has data across vehicle makes and models, March 2023. ERM analysis assumed mileage of 15,000 km/year and 56 kWh usable capacity;
2. ERM analysis of self-reported SoH data collected from Tesla drivers as part of the Tesla Battery survey, assuming 56 kWh usable battery capacity;
3. Degradation data from 1st generation Renault Zoe over a 12-year lifetime with mid mileage (approx. 7,000 km/year) and with high mileage (approx. 30,000 km/year)

Literature review: Degradation rate highest at start of battery life, largely due to calendar degradation

Total modelled battery degradation calculated across cumulative discharge cycles (% decrease in SOH). Source: Element Energy for ETI[1]



Modelled total battery degradation (% decrease in SOH) split by cycle and calendar degradation effects over 5 years, assuming ca. 400 discharge cycles per year. Source: Technical University of Denmark.[2]

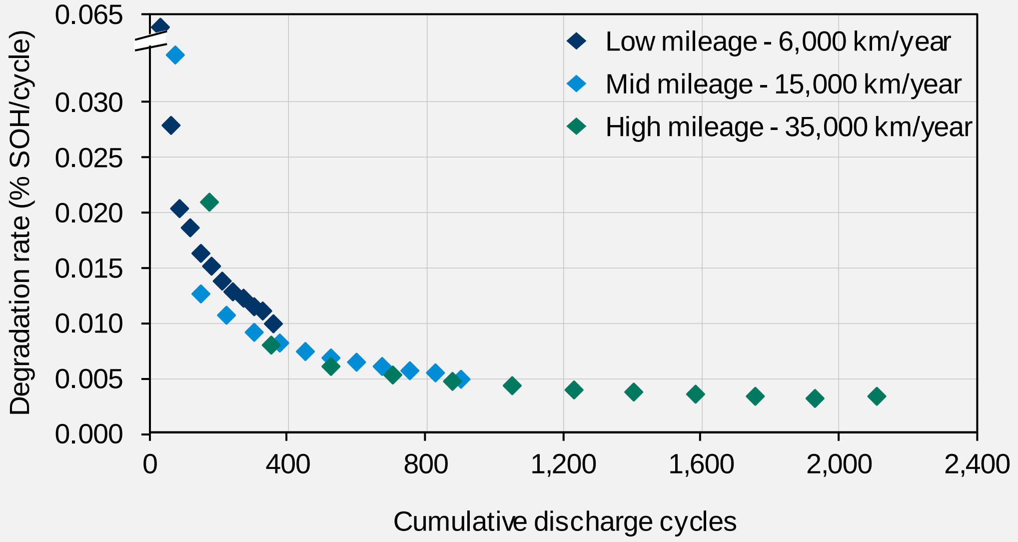


- Significant research has been carried out to understand degradation and the impacts on cycling and calendar life, **combining modelling with empirical data**[1,2]
- Element Energy carried out a detailed analysis of battery degradation for the Energy Technologies Institute (ETI), producing an Excel-based state of health model based on reviewed literature and real-world degradation data collected as part of the project[1]
  - Modelled capacity loss across cumulative discharge cycles for vehicle batteries with range of mileages shown above, in comparison with empirical data-based modelling from Technical University of Denmark[2]
- Results suggest that **degradation most impactful in first year of batteries life**, before plateauing at a lower degradation rate[1,2]
  - Largely due to the effect of high **calendar degradation rate**, while **cycling degradation rate** remains more consistent over battery lifetime

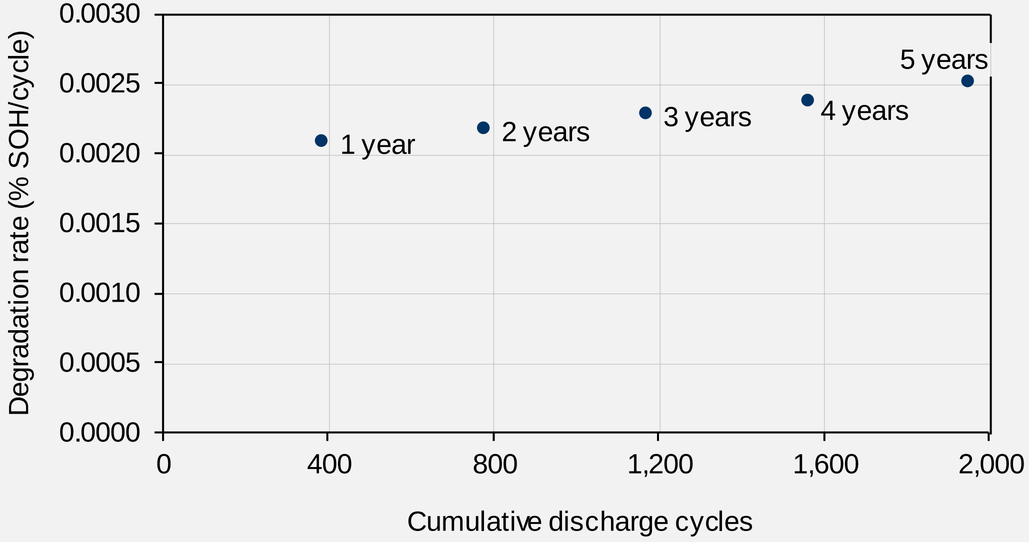
Sources: 1 – Consumer Vehicles and Energy Integration (CVEI) Project, Element Energy for ETI, 2019; 2 - A. Thingvad, L. Calearo, P. B. Andersen and M. Marinelli (DTU – Technical University of Denmark), *Empirical Capacity Measurements of Electric Vehicles Subject to Battery Degradation From V2G Services* (2021);

Literature review: Modelling suggests that cycling degradation becomes dominant at a rate of approx. 0.002 - 0.005%/cycle

Total battery degradation rate calculated across cumulative discharge cycles (% decrease in SOH per cycle)[1]



Cycling degradation rate (% decrease in SOH per cycle) across cumulative discharge cycles over 5 years. Source: Technical University of Denmark[2]



- Element Energy's modelling for ETI suggests that after initial rapid calendar degradation, overall degradation rate **plateaus between 0.007 - 0.003% SOH/cycle** (range of degradation rate following 400 discharge cycles)
  - Element Energy's model additionally calculated the total cycling degradation after 12 years, which resulted in an **average cycling degradation rate of 0.005% SOH/cycle**
- Empirical data based modelling by DTU[2] suggest cycling degradation could be even lower, between **0.002 - 0.003% SOH/cycle**

Sources: 1 – Consumer Vehicles and Energy Integration (CVEI) Project, Element Energy for ETI, 2019; 2 - A. Thingvad, L. Calearo, P. B. Andersen and M. Marinelli (DTU – Technical University of Denmark), *Empirical Capacity Measurements of Electric Vehicles Subject to Battery Degradation From V2G Services* (2021);

Contents

Most ESO services involve high technical requirements, competition from large assets, and small markets – but Demand Side Flexibility and Capacity Market could provide opportunities for additional V2B revenue

	Technical	Commercial	Degradation	Aggregation required
DSO services: Secure/ Sustain/ Dynamic	Half hourly metering; value highly location specific	Competition from embedded BESS; location specific value	Utilisation only on few days of the year	No aggregation required; minimum bid size 10 kW[2]
ESO services: Frequency Response (FR)	Very short response time; high resolution metering	Competition from grid scale batteries; small markets	Services typically require relatively low level of utilisation	Aggregation likely to be required; 1 MW[1] minimum bid size
ESO services: Balancing Mechanism (BM)	Slower response than for FR; high resolution metering	Competition from grid scale batteries; larger market than FR	Level of utilisation can be managed	Aggregation likely to be required; 1 MW[2] minimum bid size
ESO services: Reserve	Slower response than for frequency response; high resolution metering	Competition from hydro power plants, small markets	Services typically require relatively low level of utilisation	Aggregation likely to be required; 3 MW[3] minimum bid size
ESO services: Demand Flexibility Service	Low technical requirements	Competition from industrial and residential DSR	Low utilisation; only used on days of peak demand	Aggregation likely to be required; 1 MW[4] minimum bid size
Capacity Market	Moderate technical requirements	Competition from large scale assets but large market size	Low utilisation; only used on days of peak demand	Aggregation likely to be required; minimum bid size 1 MW[5]

1) NGESO 2020 a; 2) NGESO 2020 b; 3) NGESO 2020 c; 4) Watt Logic 2022; 5) Current News 2020; 6) NGESO 2020 d; 7) Modo Energy 2022; 8) Energy Storage News 2022
ESO = Energy System Operator; BESS = Battery Energy Storage System