atamate

Going Net-Zero

Atamate Approach
for Non-Domestic Retrofit

Overview

This white paper will outline the Atamate approach to improving the energy efficiency of an existing non-domestic building so that it makes no net contribution to the level of greenhouse gases in the atmosphere.

Global warming is driven by the release of carbon dioxide and other greenhouse gases (see Box 1: eCO_2) into the atmosphere, mostly from burning fossil fuels to generate energy. The only available solution to global warming is to stop releasing greenhouse gases, which the UK government has committed to achieving by 2050.[1]

Buildings account for 36% of global energy use and 39% of global greenhouse gas emissions.[2] The UK is approximately in line with the global average with buildings accounting for around 40% of energy use.[3]

An important part of achieving net-zero across the whole economy will be cutting greenhouse gas emissions from buildings, which is why a major part of the British net-zero strategy is improving building energy performance.

The relevant regulations are currently undergoing a major revision with consultation on the 'Future Homes' process for revising regulation of domestic buildings completed in 2020,[4] while the 'Future Buildings' consultation[3] on regulatory updates in the non-domestic sector is ongoing at the time of writing.

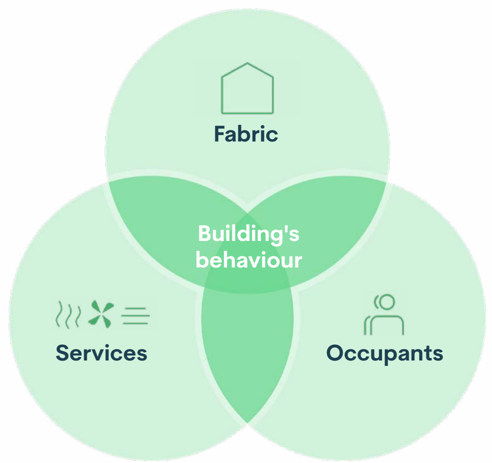

Figure 1: The building as a dynamic entity.

However, more than two-thirds of Britain's building stock predates the current building regulations[5] and will continue to be in use long after decisions based on the Future Buildings consultation are written into regulation.

Cutting carbon emissions associated with these existing buildings will require them to be renovated.

Cutting building-associated carbon emissions requires an understanding of the building as a dynamic entity.

The building's behaviour arises out of the interaction of three elements (Figure 1):

- Occupants who perform the function of the building by working, living, learning, visiting or otherwise using the building.
- Services that facilitate the activities of the occupants and keep the internal environment comfortable for them.
- Fabric makes up the building envelope and forms the interface between the internal and external environments.

The internal environment is constantly changing because of the activities of and interactions between the occupants and services. It is further affected by its interactions with the external environment across the fabric, while the external environment itself is constantly changing according to season, weather and time of day.

The non-domestic sector includes all buildings not designed as homes, encompassing buildings in the private or the public sector and may be at least partly residential, such as care homes or student accomodation blocks.

With such a diversity of buildings, there is a corresponding diversity in building behaviours which precludes any generic roadmap to bringing a building to net-zero. The ideal approach for a school in Torquay will be very different from the ideal approach for an office block in Birmingham or a gym in Dundee. Renovating any of those buildings to improve energy performance requires a bespoke approach based on a detailed understanding of the building's behaviour and its physical structure.

Overview

The Atamate approach to building renovations is based on the see-think-do framework:

- See: collect data on a building's behaviour and performance.
- Think: use the data to model the costs and effects of possible interventions.
- Do: implement the interventions that deliver the greatest reductions in net carbon emissions.

Based on the see-think-do framework, we have developed the four-stage Atamate Energy Hierarchy (Figure 2). This document will describe the four stages of the Atamate Energy Hierarchy and how to achieve them using the Atamate Building Operating System (atBOS).

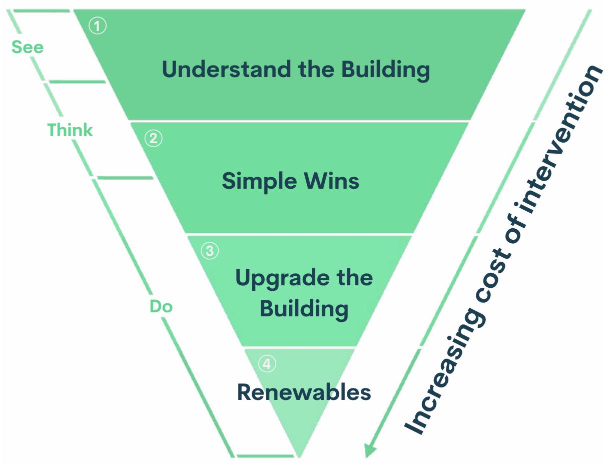

Figure 2: The four-stage Atamate Energy Hierarchy.

Box 1: eCO_2

Carbon emissions encompass all greenhouse gases: gases that increase the thermal capacity of the atmosphere and contribute to global warming. The most important greenhouse gas is carbon dioxide because it is released in large quantities from burning fossil fuels and persists in the atmosphere for a long period of time.

The effect of greenhouse gasses other than carbon dioxide is quantified in terms of their contribution to global warming as a multiple of the contribution of carbon dioxide, expressed as an equivalent weight of carbon dioxide (eCO_2).

Hence the sum effect of different greenhouse gasses expressed as $10MteCO_2$ would have a warming effect equivalent to ten megatons of pure carbon dioxide.

What is net-zero?

As the goal for the whole of the UK is to achieve net-zero carbon emissions, the goal of refurbishing a building for energy efficiency should be to reduce the carbon emissions of that building to net-zero.

Different organisations have suggested different definitions for 'net-zero' but at Atamate, our preferred definition is that suggested by the UK Green Building Council:

> *'When the amount of carbon emissions associated with a building's embodied and operational impacts over the life of the building, including its disposal, are zero or negative'.*[6]

Calculating carbon

The UK Green Building Council divides the carbon emissions associated with a building into three categories (Figure 3):

- **Embodied carbon emissions:** The carbon emissions associated with producing and assembling structure and fittings of the building (see Box 2: Embodied carbon). Embodied carbon can be minimised, such as by selecting low-carbon construction methods and using materials that can be recycled or reused directly. However, there is no way to construct, renovate or demolish a building without accumulating embodied carbon.

- **Operational carbon emissions:** The carbon emissions associated with the running of the building, mostly associated with energy consumption. Reducing operational carbon is the main objective of renovating an existing building for improved efficiency.

- **Offsets:** Any scheme that actively lowers carbon emissions such as investment in a carbon fund, direct investment in carbon-saving projects or generating energy onsite that is distributed offsite to replace energy sources that would otherwise have higher associated carbon emissions.

If the sum of all three elements is zero or negative across the whole lifespan of a building from construction to disposal, the building has achieved net-zero.

Measurement before estimation

Confirming that a building has achieved net-zero requires each of the three variables to be quantified. Atamate follows the UK Green Building Council's principle that as far as possible, emissions should be measured rather than estimated.[6] This is easier to do for some parts of the net-zero equation than others.

Operational carbon emissions and offsets can usually be quantified directly, although when calculating the lifetime operational energy of an existing building, some estimation may be needed to calculate its operational carbon emissions retrospectively.

Embodied carbon is more difficult to estimate. It involves many different elements and direct measurement is simply not possible for many of them. Carbon emissions associated with disposal represent a particular problem as they are usually projected decades before the building is demolished. A solution is offered by the Royal Institute of Chartered Surveyors (RICS), whose framework for quantifying embodied carbon can be applied to any building.[7]

Figure 3: Calculation of the carbon emissions associated with a building.

Box 2: Embodied carbon

Quantifying a building's embodied carbon (sometimes called embedded carbon) involves a cradle-to-grave analysis that takes account of all carbon emitted by processes associated with the structure and fittings of a building. Embodied carbon may be divided into two categories:

- Directly emitted carbon: Carbon emitted by the processes involved in the construction, maintenance and demolition of the building, including extraction and refining of raw materials, manufacture and assembly of components and all associated transport.
- Sequestered carbon: Carbon physically contained in the building materials that may be released after demolition, such as the carbon in timberframe construction or accumulated as the calcium oxides in concrete react with atmospheric carbon dioxide.

For a cradle-to-grave analysis, it can be helpful to break down the building's lifespan into three parts:[8]

- Initial embodied carbon: Carbon emissions associated with the initial construction and commissioning of the building.
- Recurring embodied carbon: Carbon emissions associated with maintenance and renovation carried out during the building's lifespan.
- Demolition carbon: Carbon emissions associated with the demolition of the building and the disposal of its components.

Not all components of embodied carbon can be directly measured, especially in existing buildings where there may never have been a past assessment of embodied carbon. The Royal Institute of Chartered Surveyors (RICS) provide a framework[7] for assessing a building's embodied carbon which can be used to assess initial and recurring embodied carbon to date as well as projecting the demolition carbon.

Stage ① : Understand the building

A successful intervention to cut a building's carbon emissions must be based on a thorough understanding of the building's behaviour (Figure 1). That understanding needs to encompass its fabric, the operation of its services and critically, how the building is used.

Collecting data

This is the 'see' part of the see-think-do framework. The more detailed the data that can be collected on a building, the better an intervention.

Energy meters reveal what energy is being used and where. Most buildings have meters that record the total gas or electricity usage by the building, but a more detailed picture can be developed by metering subcircuits or individual devices.[9]

However, understanding the building as a dynamic entity requires an understanding of how all aspects of the building interact. It is usually worth installing a network of sensors and meters to build a comprehensive model of the behaviour of the building and the people who live, work, learn or play in it. The sensors and meters may include:

- Environmental sensors to capture a broad range of parameters relating to the internal environment that services use energy to control, such as temperature, lighting and humidity. Combined with occupancy detection, environmental monitoring in each room can build a picture of the building's internal environment as its occupants experience it.
- Occupancy detection combined with environmental sensors can highlight how the building's internal environment is experienced by its occupants.
- Specialist sensors that measure a limited range of parameters that cannot be captured by environmental sensors, such as the temperature and pressure inside a hot water pipe or the airflow through a ventilation duct.
- Equipment meters fitted to building services like air handling units or heat pumps, or to items of equipment that perform the building's function like computers or machinery. Meters indicate how often device is used and what its energy consumption is.
- External sensors such as temperature, wind, sunlight and rain provide data that allows the building's internal environment to be related to its external environment.

In many buildings, data from existing meters is only used to generate bills and is not used to inform improvements to energy efficiency. Adding more meters and sensors can produce an overwhelming amount of data so if that data is to be useful, they need to be part of an operating system that can store and process the data.

Using data

Moving from seeing to thinking, the collected data is analysed to reveal inefficiencies in how the building services are used.

Comparing data on occupancy, temperature and air quality can establish whether the building's services are being used poorly or whether the services themselves are using an unwarranted amount of energy. For example, if meter data reveals a high air conditioning demand in an open-plan office, it may be because nobody switches off the air conditioner when the room is empty or it may be that the air conditioner is unable to cool the room to the thermostat temperature when the room is occupied.

The latter case would suggest that the room is uncomfortably hot when the staff are at work, which is an example of how collecting data can add value to the building management in ways that go beyond the primary goal of achieving net-zero.

Stage ② : Simple wins

Applying the seeing and thinking stages of the see-think-do framework usually reveals simple wins that can be realised without needing major investments. Simple wins fall into two broad categories: changing the operation of the building or changing the behaviour of the people who interact with the building.

Managing a building for energy efficiency

Savings based around occupant behaviour are usually based around eliminating glaring inefficiencies rather than dramatically changing their behaviour.

The difficulties in changing occupant behaviour have been highlighted by the domestic smart meter programme.
The intention was to supply homes with gas and electricity meters that show real-time energy consumption which would encourage people to change their behaviour to cut their energy consumption. In practice, the programme's lack of effect on energy consumption revealed the weakness of the approach.[10]

Most people think about building services in terms of how they will improve comfort or enable them to perform a task. Few people consider the mechanical or engineering processes of the service, let alone the financial cost or operational carbon emissions. The smart meter programme exposed the fact that most people are unable or unwilling to make a substantial change in their behaviour for the sake of their bills:

- Unable because most people schedule their day around work, leisure and family life and understand that they were using energy to support those priorities before they received a smart meter. Quantifying the energy does not rearrange priorities.

- Unwilling because once the energy use that cannot be rearranged is removed from consideration, the potential savings from the remaining energy use are rarely worth the inconvenience of realising them.

Applying the lessons of the domestic smart meter programme to the non-domestic setting requires consideration of two key differences:

- Most occupants of non-domestic buildings are not responsible for the energy bills, so they have even less of an incentive to arrange their behaviour around energy costs.

- Many non-domestic buildings are used in a more predictable way than homes, in that all or part of a building may only be in use at certain times or may need to be pre-booked.

Hence the most fruitful way for a building manager to use the collected data is to find ways to optimise efficiency that do not demand a major change in the way that people use a building.

Atamate's experience is that data collection often reveals major inefficiencies that can be corrected without requiring significant changes in the behaviour of the building's users. Common examples include:

- Heating or cooling empty rooms is a common source of energy waste that occurs when it is not a priority for a building's occupants.

- Uncoordinated window opening leading to windows being opened while the heating or air conditioning is running.

- Under/over ventilation with the ventilation either being turned off while the air quality is still poor or continuing to run unnecessarily when air quality is already good.

- Simultaneous heating and cooling in which one system is switched on without the other being switched off.

Such gross inefficiencies can usually be corrected without requiring a substantive difference to the occupants' behaviour.

Data often suggest other efficiency improvements that can be realised without occupants needing to rearrange their priorities. For example, detailed data on how much it costs to run a boiler can allow a building manager to compare the costs of keeping the boiler temperature high while the building is unoccupied at night and over weekends with the costs of allowing the water temperature to cool and then heating it again before the staff come back to work.

Quick wins provide efficiency improvements that can be implemented quickly, but any change that requires a building's occupants to reorder their priorities is unlikely to be sustained. Further improvements require changes in the management of the services themselves.

Optimising control of building services

Where a building's occupants cannot fine-tune their behaviour to maximise the energy efficiency of the building, automation may be able to fine-tune the building's services to meet their needs more efficiently.

A comprehensive guide of all the possibilities for automation is beyond the scope of this white paper but some examples are:

- A switch on a window may detect it being opened and automatically switch off the heating or air conditioning. Alternatively, the windows may be motorised and automated as part of the building's ventilation system.
- Air quality data can be used to control a mechanical ventilation system, maintaining high air quality throughout a building but also avoiding over-ventilation, in which fans are running when air quality is already high.
- The sensor network can detect whether a room is occupied so lighting and fast-response temperature control systems like air conditioning and infra-red heaters can switch on when someone enters a room and switch off when the last person leaves it.
- Service controls may be linked to a room booking system so the heating or air conditioning of a meeting room or hotel room may be switched on a few minutes before it is used and switched off as soon as it is vacated.
- Thermostatic radiator valves attached to radiators and underfloor heating can improve the efficiency of a central heating system by ensuring that heat is only piped to where it is needed when it is needed.

All of the above interventions are likely to enhance the comfort and wellbeing of the building's users at the same time as they save energy which eliminates any conflict between priorities.

Stage ③ : Upgrade the building

Major renovation will significantly increase a building's embodied carbon as well as incurring a substantial financial cost but sometimes data analysis shows the investment is justified over the lifespan of the building.

Upgrades must be tailored to the individual building and the full range of options is beyond the scope of this document. However, the approaches may be divided into the broad categories of service and fabric upgrades.

Fabric upgrades tend to be more expensive, more disruptive and to involve more embodied carbon than service upgrades. Atamate's experience is that the principle of 'services first', in which fabric upgrades are only carried out if the data shows they will deliver significant improvements after the services have been upgraded, delivers the best results in most cases.

Service upgrades: optimising existing services

A service upgrade involves replacing all or part of a service, which is a more expensive and complex operation than the simple wins achieved by automating an existing service.

An upgrade may be a simple modernisation. For example, air conditioning units have been substantially improving in their energy efficiency in recent years. Sometimes the financial and embodied carbon costs of replacing air conditioning units are repaid through savings in operational carbon and costs over the lifetime of the new units.

Alternatively, upgrading key elements of a service may improve the efficiency of the whole service. Such upgrades often involve incorporating an element of automation that may be connected to the sensor network. Examples include:

- Replacing single-speed fans and pumps, which necessarily run at the maximum output needed, with variable speed drives that usually run at a lower speed with the potential to increase speed if needed.
- Demand controlled ventilation (DCV) operates mechanical ventilation based on the air quality so that heated or cooled air is not vented when the air quality is high.
- Thermostatic radiator valves that only allow heated water into a radiator in a room that needs heating, which reduces the energy demand on the heating system.
- Chilling water using a free cooling system, using a heat exchanger to make use of low external air temperatures.

Service upgrades: replacing gas

Most older buildings use boilers that provide low-temperature hot water (LTHW) to a 'wet' heating system, distributing heat through terminal heating devices such as radiators, fan coil units or underfloor heating. This system may also provide the building with hot water although in larger buildings an independent set of water heaters are likely to be used. The majority of boilers are powered by mains gas although some use heating oil.

The UK's dependence on gas heating is reflected in the dramatic seasonal fluctuations in gas consumption. Gas demand is typically five to six times higher in winter than in summer while demand for electricity, which is less affected by heating demand, is far less variable (Figure 4).

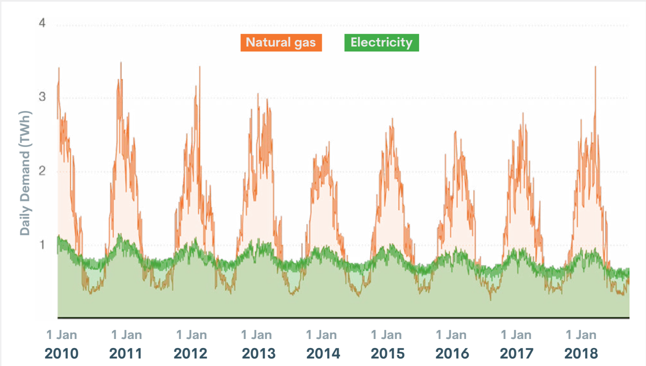

Figure 4: Fluctuations in the UK's gas and electricity demands.[11]

A gas or oil-powered boiler is likely to be the single largest source of a building's operational carbon emissions. Moreover, burning gas or oil indoors degrades indoor air quality by producing nitrogen oxides.[12]

By contrast, mains electricity has been undergoing a paradigm shift in recent years. The replacement of coal-fired power stations with wind turbines and solar power accounts for most of the 43% drop in UK greenhouse gas emissions between 1990 and 2018.[13]

The speed at which the national grid is moving away from fossil fuels can be seen in the number of days in which it operated at 'coal zero', meaning that no coal was burned in a 24h period. In 2017, the national grid hit the headlines by running at coal zero for two full days. In 2018, the national grid achieved coal zero for 21 days and in 2019, it was 83 days,[14] amounting to an increase in more than 4,000% in coal zero operation in two years.

For a building with a gas or oil-powered boiler, replacing heating with mains electrical power is likely to be the single biggest step toward achieving net-zero which is why moving buildings away from fossil fuel power is a key part of the British decarbonisation strategy.[15]

However, while mains electricity is far more carbon-efficient than gas or oil, it is considerably more expensive per unit energy (Table 1) and the price difference between gas and electricity is expected to increase further by 2030.[16]

Moving from fossil fuels to electricity is likely to incur higher costs for an individual building but those costs can be mitigated by planning the restructured services for efficiency.

Minimising the electricity used not only minimises the bills but, as mains electricity provides low-carbon but not zero-carbon energy, minimises carbon emissions.

There is no 'one to one' electrical replacement for a gas or oil-powered boiler so switching to electric involves completely changing how a building's heating and hot water needs are met. A data-driven approach informs the selection of the services best suited to a given building's behaviour.

Some examples include:

- Spaces that are intermittently occupied at high densities, such as classrooms, require fast-response heating such as infra-red, which can immediately provide heat when people enter the room and switch off as they warm it with their body heat.
- A building like a care home, which is permanently occupied and has a higher need for hot water than most non-domestic buildings, may be better served by retaining the central heating system but powering it with electricity, possibly powered by a heat pump (see Box 3: Air-source heat pumps).
- In some buildings with fabric that does not retain heat, fan-assisted storage heaters fitted with occupancy controls give a better balance between cost and operational carbon emissions.
- Reconfiguring the plumbing of many buildings can reduce energy losses from the hot water distribution system.

Table 1: Comparison of the prices and carbon emissions of main sources of domestic space and water heating.[17]

Fuel Type	Carbon emissions (eCO_2/kWh)	Price (pence/kWh)
Mains electricity	0.136	17.56
Mains gas	0.210	3.93
Heating oil	0.298	4.35

Fabric upgrades

Assessing the potential of a fabric upgrade involves assessing the transfer of heat energy across the building's fabric.

Keeping a building comfortable requires the indoor air temperature to be maintained at 20-25°C (68-77°F),[18] which is often lower or higher than the outdoor temperature.
The more heat energy is exchanged between the internal and external environment, the more energy is required for heating or air conditioning. Minimising heat transfer was not a design priority for many older buildings so fabric upgrades can significantly cut operational carbon emissions.

However, fabric performance often varies from one part of a building to another and upgrading a part of a building where there is little heat transfer will cost money and increase embodied carbon without affecting energy use.

Upgrades can be targeted using data that reveals where heat transfer is high enough to be worth addressing. The first step is to find the rooms that lose the most heat (see Box 4: Calculating the heat loss coefficient).

The next step is a more detailed assessment of those rooms to find out exactly where the heat is being lost and how.

There are two ways in which heat energy can be transferred across a building's fabric (Figure 5):

- Conduction of heat energy across the fabric, which can be minimised with high-quality insulation.
- Infiltration of outside air which needs to be heated or cooled to the temperature of a comfortable internal environment only for it to flow out of the building and take the energy used to regulate its temperature with it.

When investigating heat loss from a given room, there are various ways to identify where and how the heat is being lost:

- Thermal imaging of a building from the outside can identify the fabric elements that allow significant conduction (Figure 6).
- Pressure sensors can compare the effect of fans on the pressure inside a room, which indicates how much infiltration takes place there.
- Fans and smoked pencils can identify where the fabric allows drafts through the fabric.

A detailed model of heat exchange across the building fabric directs upgrades to where they will be effective, while fabric elements that are performing adequately can be left alone.

Figure 5: Heat losses through a building's fabric.

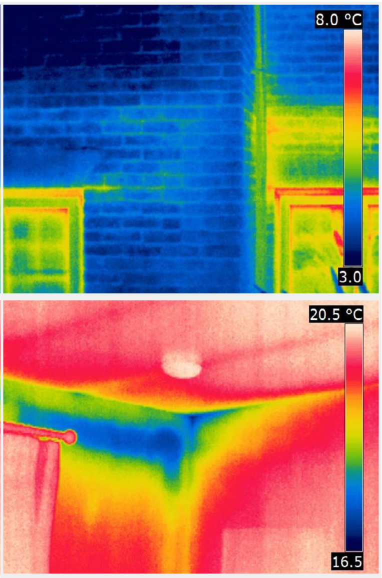

Figure 6: Thermal imaging.

Box 3: Air-source heat pumps

Field trials of air-source heat pumps (ASHPs) have shown that they can draw enough heat energy from the air to double or triple the energy drawn from mains electricity, which can then be used to heat water. The government's Future Buildings Standard[3], which is under consultation at the time of writing, suggests a broad role for ASHPs as a carbon-efficient approach to heating and cooling in the non-domestic sector.

Atamate's view is that the government tends to present ASHPs as having a broader role than is justified by the evidence, both in the Future Buildings consultation and in last year's Future Homes consultation which laid out proposals for decarbonising domestic buildings.[19]

The limitation of ASHPs is that they are most efficient when the external air temperature is above 6°C (43°F) and the flow temperature is 35°C (95°F). However, the heating load is highest when the external air temperature is well below 6°C and many existing buildings are designed around flow temperatures of 75°C (45°F).

Incorporating ASHPs is likely to necessitate either significant fabric upgrades or replacing the heat emitters, such as radiators or underfloor heating, with systems with much higher surface areas.

A further problem with low flow temperatures arises when there is a high hot water load as commercial regulations mandate temperature must be maintained at over 60°C (140°F) at all times to kill Legionella bacteria.[20]

There are situations where a thorough understanding of the building's behaviour will support ASHPs as the most carbon-efficient option, but they should always be considered as one of several possible solutions.

Box 4: Calculating the heat loss coefficient

The heat loss coefficient is a measure of the heat energy conducted across a part of the building's fabric. Any fabric upgrade aims to lower the u-value of the part of the fabric being upgraded.

Part L of the UK building regulations mandate that the heat loss coefficients of a building's fabric should be projected before a new building is constructed or a major renovation of an existing building starts. The Atamate approach is to use direct measurement instead of projection wherever possible.

Sensor data can be used to compare the outside temperatures with the internal temperature. By knowing the area of external fabric and energy consumption in the space a heat loss coefficient can be calculated across a wall, window, floor or ceiling to provide such a direct measurement.

Stage ④ : Utilise local energy

One way of cutting operational emissions is through renewable energy generation onsite, avoiding the carbon factors associated with mains electricity (Table 1). There are several possible ways to do so and as with everything else, the best option varies from one building to another and, a cost-benefit analysis is necessary to decide which is best for a given building.

Energy generated onsite tends to fluctuate according to the weather, the time of day and the season of the year so it needs to be combined with a control system that makes full use of all available onsite energy and makes up the difference with energy bought from a provider.

The three main sources of local energy generation are described below.

Photovoltaic cells

Photovoltaic cells generate electricity from sunlight and are the commonest source of onsite electricity generation. They are most likely to be used in buildings that have a high cooling demand, which will be at its highest in the summer when the longer days provide ample solar power.

Examples include supermarkets that need to power fridges and freezers or office blocks that require air conditioning for most of the year. Both are situations where electricity demand is likely to be higher in the summer when the longer days guarantee a higher electricity supply through the solar panels.

Photovoltaic panels are less likely to deliver value where the major energy demand is heating, which is required most during the shorter days of winter. For instance, they may deliver little usable energy to a school that is unoccupied for much of the summer.

Figure 7: Photovoltaic cells on a rooftop.[29]

Solar thermal panels

Like photovoltaic cells, solar thermal panels draw energy from the sun but instead of converting it into electricity, they collect heat energy directly. They work by heating fluid that is then pumped through a heat exchanger to heat a building's water supply.

Solar thermal panels are most likely to deliver significant savings to a building with a high demand for hot water. For example, they may be worthwhile in a hotel that is busiest in the summer and needs to heat a swimming pool while an office block with little demand for hot water would be better served by photovoltaic cells.

Figure 8: Solar thermal panels on a rooftop.[30]

Energy storage

A limitation of onsite renewables is that they generate energy when the sun is shining rather than when the building needs it. Storing energy onsite can help to balance discrepancies between supply and demand. A building without onsite generation can still use onsite storage to take advantage of flexible tariffs that vary the price of mains electricity according to demand, making it cheaper at night when demand is lowest. At present, the biggest fluctuations in the space of a day are driven by variable heating demand which is mostly met by mains gas (Figure 9). As gas is replaced by electricity in the coming years, fluctuations in electricity demand are likely to increase which will lead to bigger differences between the highest and lowest prices on flexible tariffs

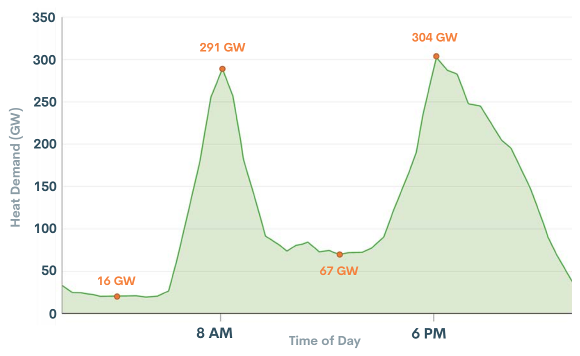

Figure 9: UK heating demand over 24h during winter, exemplified by 18th December 2018.[21]

Most current systems are based on thermal energy storage:[22] excess energy is used to heat or cool a medium with a high thermal capacity. Most systems use water although some use solid mediums like ceramic bricks and some use ground storage, in which hot or cold water is pumped underground to heat or cool the geology underneath the building.

If the storage medium is water, the process may be as simple as heating or chilling a tank of water that is used to supply a building's hot water supply or a wet heating or cooling system. With other storage media, a heat pump is needed to discharge the energy into the water supply.

Thermal storage is the most efficient approach to storage in terms of the ratio between the energy collected and the energy discharged, but only if that discharge is used to meet a demand for hot or cold water.

Batteries offer an alternative approach that is likely to be more efficient for a building with low demand for temperature-controlled water but a high electricity demand.

Battery storage is already widely used where blackouts are common. However, building batteries are not a mature technology and in Britain, they rarely justify their capital costs or embodied carbon.

In future, technology may improve to the point where new batteries become a viable solution but another approach was suggested by a recent study by Warwick University and Element Energy[23] which suggests that in the next few years, buildings may be able to make use of second-hand batteries repurposed from electric vehicles. By 2030, the first wave of electric vehicles purchased in the UK will be reaching the end of their lifespans and while their batteries will have degraded in that time, many will still have a capacity of 65% or more and be considerably cheaper than a brand-new battery while avoiding the embodied carbon implications of disposing of an old battery while manufacturing a new one.

Offsetting greenhouse gas emissions

The four-step programme outlined above can minimise a building's operational carbon emissions but that is only part of the route to net-zero. Unless a building can be completely independent of mains power, operational carbon emissions cannot be completely eliminated. Even the greenest building cannot avoid accumulating embodied carbon throughout its lifespan.

Achieving net-zero requires a building's operational emissions and embodied carbon to be offset by actively reducing carbon emissions elsewhere.

Various approaches to offsets can be divided into:

- Operational approaches use the building to distribute low-carbon energy in a way that reduces the need for higher carbon energy.

- Polluter pays is the principle recommended by the UK Green Building Council,[6] and is achieved by payments into schemes that reduce emissions or sequester atmospheric carbon elsewhere.

Some possible ways to achieve the two approaches are described in the following.

Operational offsets

If a building can be used to lower greenhouse gas emissions in other areas of an organisation's operations, those reductions may be counted as offsets against the building's operations.

If the organisation that operates the building operates vehicles or issues company cars, then using the building as a distribution hub may allow it to replace petrol or diesel vehicles with electric vehicles (see Box 5: Electric vehicles).

If so, then the balance between the carbon emissions associated with the mains electricity and the equivalent energy produced by burning petrol or diesel may be counted as an offset.

Further options are opened up if a building generates or stores electricity onsite. Schemes are becoming available that allow small generators to sell excess electricity to a service provider or possibly over a peer-to-peer network. In this case, the offset would be the carbon emissions associated with the mains electricity replaced by the onsite renewables.

A building without onsite generation capacity can use a similar approach by purchasing and distributing renewable energy from a third party that can confirm that it is more carbon efficient than mains electricity.[24]

Polluter pays

Carbon funds offer opportunities to invest in renewable technologies or carbon sequestration and quantify how much carbon a given investment offsets, allowing calculation of how much investment is needed to bring a given building to net-zero (Figure 3).

Different carbon funds apply different approaches to reducing greenhouse gasses, and some funds are more reputable than others. Treehugger's website provides an annually updated list of reputable carbon funds.[25]

Box 5: Electric vehicles

The transport sector accounts for 28% of the UK's greenhouse gas emissions, which is more than any other sector of the economy. Electric vehicles are currently rare but with sales of petrol and diesel-powered vehicles due to be banned by 2030,[26] electric vehicles will become progressively more common over the next decade.

As most chargepoints for electric vehicles are in buildings, the distinction between energy used by the transport sector and the building sector will become increasingly blurred. The blurring is a matter of policy in the UK where, at the time of writing, the government is consulting on regulations that will mandate minimum numbers of chargepoints for different types of buildings.[31]

One consequence is that at any given time, there will be a significant battery capacity connected to the grid which can be used to meet periods of high demand. The approach is typified by the 'Powerloop' [27] scheme currently offered by Octopus Energy in South East England and East Anglia. Powerloop covers both provision of electricity to a building and the lease of an electric car, offering rebates on energy bills if the car battery is made available at certain times of day.

From the perspective of bringing a building to net-zero, electric vehicles offer a way to offset the building's greenhouse gas emissions. However, it is also possible that their battery capacity will reduce the discrepancy in energy prices between high and low demand periods which may reduce the potential returns on energy storage systems that exploit those differences.

Disclosure

Atamate shares the UK Green Building Council's position that a building's carbon budget should be reported, disclosed and publicly verified:

> *Disclosure should be made through any publicly accessible information, such as an organisation's annual sustainability report or clearly presented on a website. This form of public disclosure is intended for building developer, owner or occupier to 'show their working' on how they have achieved net-zero carbon. This information should be the subject of third-party auditing to avoid self-made claims.*[6]

Measuring the aspects of the carbon budget across its lifespan involves the following elements:

- Measurement should be carried out directly wherever possible but is only likely to be possible with operational carbon emissions and some types of offset.
- Estimation of carbon emissions to date, including operational carbon emissions where direct measurements are not available and embodied carbon.
- Projection of carbon emissions in the future, including the demolition and disposal of the building.

The UK Green Building Council provide templates for the reporting of carbon emissions associated with construction and operations that can be adapted for all aspects of the building's carbon emissions.

The reporting should incorporate a regular update schedule to take account of fluctuations in factors such as changes in emissions associated with mains electricity, maintenance-associated increases in embodied carbon and changes in any factor that may impact the carbon emissions associated with demolition and disposal.

The road to net-zero lies through reducing a building's carbon emissions as far as possible and making up the difference with offsets. A rigorous approach to disclosure allows an organisation to demonstrate the distance it has travelled down that road.

The Atamate approach

The Atamate Building Operating System (atBOS) can drive all stages of the Atamate energy hierarchy. It is designed to be flexible enough to operate in any type of building with any type of service (Figure 10). It is designed to monitor a building in considerably more detail than the building management systems (BMS) installed in most large buildings, although it can operate alongside them.

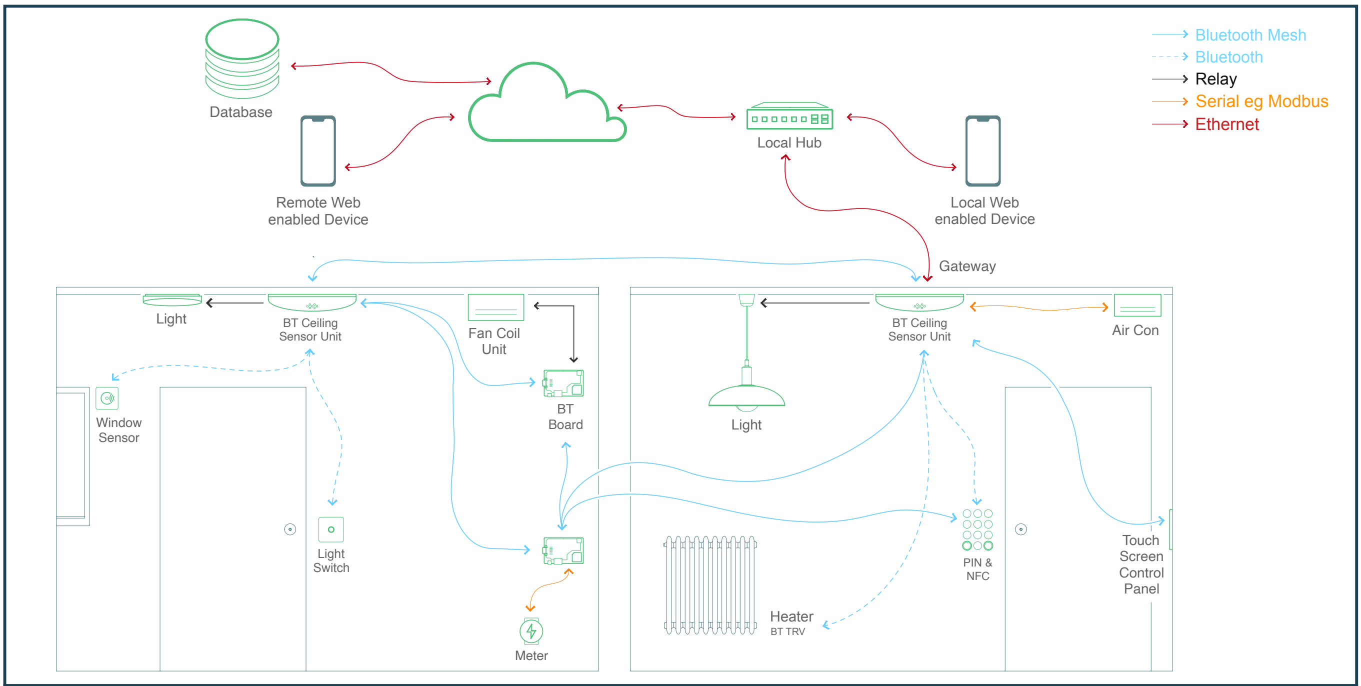

Figure 10: The Atamate Building Operating System (atBOS).

How atBOS can be applied to each step is described below.

Stage ① : Understand the building

Atamate's sensor network does the 'seeing' that is the keystone of the see-think-do framework. Central to the network is the ceiling sensor unit[28] (Figure 11) which collects data on the following:

- Indoor temperature (air and surface temperature).
- Air quality (carbon dioxide, humidity and volatile organic compounds).
- Noise and vibration.
- Ambient light.
- Room occupancy.

Ceiling sensors are powered by lighting circuits and communicate using the Bluetooth wireless protocol, enabling them to be fitted to an existing building without needing extensive cabling. A further function of the ceiling sensors is to support a Bluetooth network that encompasses the entire building. Each unit functions as a network node, meaning that data from a sensor may be relayed to the hub via several other sensors.

Relaying messages saves on energy costs by allowing communication across a large building without the need for signals more powerful than is needed to reach the nearest node.

At the centre of the network is the hub which collates the data and passes it into storage in the cloud, ensuring it is backed up against hardware failures.

Atamate's software tools allow the data to be analysed for the 'think' in see-think-do. For example, combining data on the temperature in a room, the heating and cooling services in that room and data from the external sensors can be used to calculate how much energy the heating or air conditioning is required to maintain that room at a given temperature.

However, energy use needs to be considered in the context of a building's behaviour and the needs of its occupants. Comparing energy use before and after the changes are introduced allows their impact on carbon emissions to be measured as well as allowing the approach to be refined if necessary.

Figure 11: Ceiling sensor unit.

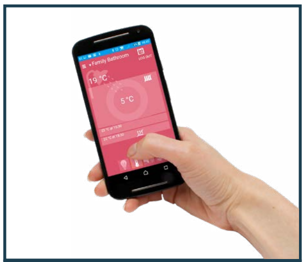

Figure 12: atBOS user interface.

Stage ② : Simple wins

Reducing demand usually involves automating services. Using the same technology that controls the Atamate sensor network, atBOS controls services through actuators that may have a cabled connection to a sensor unit or may be a Bluetooth node in its own right.

The Atamate platform can control any type of building service in any type of building. However, full automation is not always the best option. Any extension of the platform should be based on a cost/benefit analysis which may reveal that some services are worth automating while others are not.

The services that are automated can be controlled through the Atamate user interface, which can be accessed from any internet-enabled device and offers several ways to control services:

- Direct control allows a service to be switched on or off by an authorised user who has access to the interface (Figure 12).
- Occupancy control activates a service only when someone is in a room and switches it off when the last person leaves a room. This is often used for lighting, air conditioning and fast response heaters such as infra-red (Figure 13).
- Calendar controls switch services on or off at preset times, which allows a heating system to be engaged so that it heats a building before the staff come to work or heats a room that needs to be pre-booked.

Comparing energy use before and after the changes are introduced allows their impact on carbon emissions to be measured as well as allowing the approach to be refined if necessary.

Stage ③ : Upgrade the building

The same data that informs simple wins also shows where a service upgrade would be worthwhile. In addition, the sensor network can provide some data on the building fabric, partly by comparing indoor and outdoor temperatures (see Box 4: Calculating the heat loss coefficient) and partly by using pressure data to estimate whether there is enough infiltration across the building fabric to warrant more detailed investigation.

Once the upgrade has been completed, the sensor network is still in place and able to evaluate the effect of the upgrade on energy expenditure and carbon emissions.
Comparing that data with a model of the building based on data collected before the upgrade allows the impact of the upgrade to be quantified.

Stage ④ : Utilise local energy sources

Any system for onsite generation or storage can be controlled by atBOS although how that works will depend on the system in place and the circumstances.

Some examples are:

- Photovoltaic arrays usually supply some but not all of a building's energy demand so atBOS balances the supply to use all the solar energy available and make up the difference from the mains.
- Solar thermal cells produce an output that is dependent on the weather so atBOS reviews the time and local weather reports to anticipate their likely output, deciding whether mains energy is only needed to keep a water tank at a minimum temperature until there is ample solar heat later in the day or to heat it using only mains energy when a cold day is predicted.
- Storage options can deliver substantial savings if they are paired with a flexible electricity tariff so atBOS can be set to only draw electricity from the mains when the tariff is low enough to make it worthwhile.

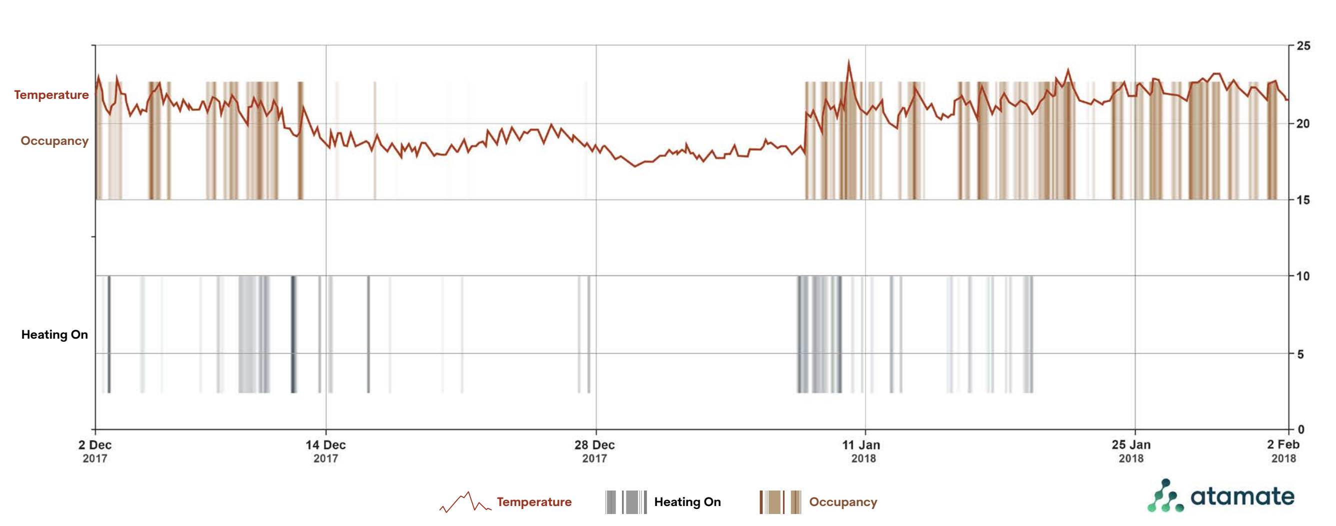

Figure 13: Occupancy-based electrical heating under atBOS controls in a single bedroom, showing the temperature dropping during a prolonged absence for the Christmas holidays but rapidly returning to the 21°C setpoint when the occupant returned.[32]

Disclosure

In all cases, atBOS keeps a record of what energy has been drawn from and where, meeting the World Green Building Council requirement for a building's carbon budget to be based on measurements. The data can then be used to calculate any necessary offsets and can also be used to produce any necessary reports.

Footnotes

[1] DBEIS (2019). UK becomes first major economy to pass net zero emissions law.
https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law
(accessed on 02 February 2021).

[2] Global Alliance for Buildings and Construction (2019) *2019 Global Status Report for Buildings and Construction.* UNEP, Nairobi. 41pp.
https://www.worldgbc.org/news-media/2019-global-status-report-buildings-and-construction

[3] MHCLG (2021) *The Future Buildings Standard.* Crown Copyright, London. 183pp.
https://www.gov.uk/government/consultations/the-future-buildings-standard

[4] MHCLG (2021). *The Future Homes Standard: 2019 Consultation on changes to Part L (conservation of fuel and power) and Part F (ventilation) of the Building Regulations for new dwellings.* Crown Copyright, London. 114pp.
https://www.gov.uk/government/consultations/the-future-homes-standard-changes-to-part-l-and-part-f-of-the-building-regulations-for-new-dwellings

[5] *Energy Transitions Commission (2019) Mission Possible sectoral focus: building heating.* Energy Transitions Commission, London. 34pp.
https://www.energy-transitions.org/publications/mission-possible-sectoral-focus-building-heating/

[6] UKGBC (2019) *Net Zero Carbon Buildings: A Framework Definition.* UK Green Building Council, London. 25pp.
https://www.ukgbc.org/ukgbc-work/net-zero-carbon-buildings-a-framework-definition/

[7] RICS (2017) *Whole life carbon assessment for the built environment, 1st edition.* Royal Institution of Chartered Surveyors (RICS), London. 41pp.
https://www.rics.org/uk/upholding-professional-standards/sector-standards/building-surveying/whole-life-carbon-assessment-for-the-built-environment/

[8] ICE (2015). Embodied Energy and Carbon.
https://www.ice.org.uk/knowledge-and-resources/briefing-sheet/embodied-energy-and-carbon
(accessed on 02 February 2021).

[9] Atamate (2021) *Atamate Guide to Energy Metering.* Atamate, Oxford. 18pp.
https://www.atamate.com/guide-to-metering

[10] Atamate (2018). How much will a smart meter reduce my home energy bill?
https://www.atamate.com/atamate-blog/how-much-will-a-smart-meter-reduce-my-home-energy-bill
(accessed on 02 February 2021).

[11] DBEIS (2018) *Clean Growth - Transforming Heating.* UK government, London. 136pp.
https://www.gov.uk/government/publications/heat-decarbonisation-overview-of-current-evidence-base

[12] WHO (2010) *WHO guidelines for indoor air quality: selected pollutants.* WHO, Geneva. 484pp.
https://apps.who.int/iris/handle/10665/260127

[13] *DBEIS (2020) 2018 UK Greenhouse Gas Emissions, Final figures.* UK government, London. 41pp.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/862887/2018_Final_greenhouse_gas_emissions_statistical_release.pdf

[14] Carbon Brief (2020). Analysis: UK low-carbon electricity generation stalls in 2019.
https://www.carbonbrief.org/analysis-uk-low-carbon-electricity-generation-stalls-in-2019
(accessed on 02 February 2021).

[15] DBEIS (2020). *Powering our Net Zero Future.* Queen's Printer and Controller of HMSO 2020, London. 170pp.
https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future

[16] CCC (2017) *Energy prices and bills - impacts of meeting carbon budgets.* Committee on Climate Change, London. 119pp.
https://www.theccc.org.uk/publication/energy-prices-and-bills-report-2017/

Footnotes

[17] BRE (2019) *SAP 10.1.* BRE Garston, Watford. 180pp.
https://www.bregroup.com/wp-content/uploads/2019/10/SAP-10.1-01-10-2019.pdf

[18] Beshir, MY & Ramsey, JD (1981). Comparison between male and female subjective estimates of thermal effects and sensations. *Applied Ergonomics* 12:29-33.
https://www.sciencedirect.com/science/article/pii/0003687081900910

[19] Atamate (2020). Future Homes 1: Atamate Calls For an Outcome-based Approach.
https://www.atamate.com/atamate-blog/future-homes-1-atamate-calls-for-an-outcome-based-approach (accessed on 23 February 2021).

[20] HSE (2013) *Legionnaires' disease. The control of legionella bacteria in water systems.* Crown Copyright, London. 28pp.
https://www.hse.gov.uk/pubns/books/l8.htm

[21] Energy Technologies Institute (2015) *Smart Systems and Heat Decarbonising Heat for UK Homes.* Energy Technologies Institute, Birmingham. 44pp.
https://www.eti.co.uk/insights/heat-insight-decarbonising-heat-for-uk-homes

[22] Sarbu, I & Sebarchievici, C (2018). A Comprehensive Review of Thermal Energy Storage. *Sustainability* 10:191
https://www.mdpi.com/2071-1050/10/1/191

[23] Clements, S & Ruf, L (2020) *UK Energy Storage Lab Project.* Element Energy, Warwick. 13pp.
http://www.element-energy.co.uk/wordpress/wp-content/uploads/2020/01/UKESL-Non-technical-Public-Report_2020.pdf

[24] Burrows, VK & Adams, M (2019) *WorldGBC Net Zero Carbon Buildings Commitment.* World Green Building Council, London. 49pp.
https://www.worldgbc.org/resources-further-guidance

[25] Treehugger (2020). The 6 Best Carbon Offset Programs of 2021.
https://www.treehugger.com/best-carbon-offset-programs-5076458 (accessed on 02 February 2021).

[26] DoT, OLEV, DBEIS, Sharma, A & Shapps, G (2020). Government takes historic step towards net-zero with end of sale of new petrol and diesel cars by 2030.
https://www.gov.uk/government/news/government-takes-historic-step-towards-net-zero-with-end-of-sale-of-new-petrol-and-diesel-cars-by-2030 (accessed on 23 February 2021).

[27] Octopus Electric Vehicles (2021). Powerloop.
https://www.octopusev.com/powerloop (accessed on 02 February 2021).

[28] Atamate (2021). Hardware datasheet: Mesh-3 ceiling sensor.
https://f.hubspotusercontent20.net/hubfs/4763425/Devices%20datasheets/DEC162DataSheet_CeilingSensor.pdf (accessed on 02 February 2021).

[29] U.S. Green Building Council (2017). Top four benefits of installing solar panels on your home.
https://www.usgbc.org/articles/top-four-benefits-installing-solar-panels-your-home (accessed on 08 March 2021).

[30] The Eco Experts (2020). Solar Thermal Panels: Everything You Need to Know.
https://www.theecoexperts.co.uk/solar-panels/thermal (accessed on 08 March 2021).

[31] Department of Transport (2019) *Electric Vehicle Charging in Residential and Non-Residential Buildings.* Crown copyright 2018, London. 50pp.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/818810/electric-vehicle-charging-in-residential-and-non-residential-buildings.pdf

[32] Kelly, KA, Sassi, P & Miles, J (2019). In-use Energy Performance Study Of Automated Smart Homes. *SDAR* Journal of Sustainable Design & Applied Research 7*: Article 2.
https://arrow.dit.ie/sdar/vol7/iss1/2/

About Us

Atamate is a dynamic Oxford-based smart building software company started in 2007. We aim to reduce the environmental impact of buildings in the UK and around the world while reducing both capital and running costs of properties.

Collaborations with top-class universities such as Oxford University, Oxford Brookes, Loughborough as well as publishing academic papers withthe Chartered Institute of Building Services Engineers (CIBSE) means that we are always on the cutting edge of our field.

Contact us

Please get in touch to see how Atamate can benefit your next project.

Email: info@atamate.com

Visit: www.atamate.com

Call: 01865 920 101

Atamate Ltd,
Old House,
The Ridings,
Oxford
OX3 8TB, UK.

Registered in Wales, no. 07130716

atamate