atamate

Atamate guide to apartment building services

June 2022

This white paper presents the Atamate template for the services of a newly built apartment block which we anticipate will be the best option in the majority of cases. The template is for each apartment's services to be self-contained. All services are automated and powered directly by mains electricity supplemented by an exhaust-air heat pump.

In recent years, updates to the building regulations have emphasised energy performance, primarily to minimise a building's carbon footprint. In particular, Part L of the UK building regulations[1] mandates that new buildings and renovations should be designed to minimise the heating requirement with high-quality fabric, defined by being well insulated and with minimal air leakage.

In June 2022, the new Part O regulations[2] on overheating came into force, mandating mitigation of summer overheating and placing cooling in the summer on the same regulatory basis as heating in the winter.

Improving carbon efficiency requires moving away from natural gas, which currently powers the space and water heating of 85% of British homes[3]. Current policy is for all new buildings to be 'zero carbon ready' by 2025[4], meaning they will not be connected to the gas mains and all their services will be powered by electricity.

The transition from gas to electrical power is essential to cutting the carbon emissions from the domestic sector (Box 1) but there is a fundamental problem to overcome: a kWh of electrical power is considerably more expensive than a kWh of natural gas power.

Before the dramatic rise in gas prices in 2021, a unit of electrical energy was five times more expensive than the equivalent unit of energy provided by gas (Table 1). At the time of writing, energy prices are in flux but there is no reason to expect gas prices to rise to the level of electricity in the foreseeable future. Simply replacing gas boilers with electric would lead to a massive rise in energy bills and exacerbate fuel poverty, which is already so commonplace that more than one household in eight cannot afford adequate heating[5].

Table 1. Cost and carbon emissions associated with natural gas and electricity consumption in the UK in 2021.

	Mains gas	Mains electricity
Cost (£/kWh)[5]	0.028	0.144
Carbin emissions (kg CO_2e/kWh)[6]	0.21	0.136

Transitioning the domestic sector from gas to electricity requires a complete rethink of building services. The ideal solution depends on the building, which is why the Atamate view is that every development project requires a comparison of all available options at the design phase.

In the large majority of cases, we expect the lowest cost and carbon emissions to be delivered by applying what we call the Atamate template, which is an approach to electric building services that can be adapted to most apartment blocks.

Recent years have seen dramatic changes in apartment block design, partly to meet new requirements and partly to incorporate new technologies.

The major differences between the Atamate template and conventional service layouts are:

- Replacing the gas-powered combination (combi) boiler, which conventional buildings use for space and water heating, with electric alternatives.
- The warming climate makes cooling a higher priority than it was at the time most existing buildings were designed.

Box 1: Reasons to replace gas with electricity

Greenhouse gas production: Natural gas produces carbon dioxide at the point of combustion and because the combustion is disseminated between boilers and cookers in individual homes, offering no practical way to sequester that carbon. Electricity, on the other hand, can be produced by renewable generation methods like wind and solar power. At the time of writing, around 40% of Britain's electricity is still provided by gas-fired power stations[5] although the electricity mix is decarbonising as it transitions to renewables, mostly provided by wind and solar power[8].

Indoor air pollution: Burning natural gas produces nitrous oxides which degrade indoor air quality and although only a very poorly designed ventilation system would allow them to build up to toxic levels, electric power does not produce indoor pollutants in the first place.

Price stability: Energy suppliers buy natural gas on the global market, which leaves both suppliers and consumers at the mercy of its price fluctuations. For instance, the 2021 price shock saw prices quadruple in a little over six months[9] because of a coal shortage in China[10] and a dispute between Russia and the European Union[11]. The latter dispute was exacerbated by Russia's 2022 invasion of Ukraine, which drove gas prices even higher[12]. At the time of writing, prices show no sign of stabilising and even if the international gas market recovers from its current disruption, there will still be a long-term trend of rising gas prices because some of the world's largest economies are transitioning their electricity generation from coal to gas, increasing global demand in the coming years[13]. At the same time, British electricity generation is transitioning away from its current dependence on gas[14] and toward renewables generated domestically, offering consumers the option of insulating themselves from the vicissitudes of the international gas market.

- The Atamate template is compatible with modern building materials like timberframe which have the advantages of low cost, low carbon footprint and the ability to be manufactured offsite[15] but have the disadvantage of lower thermal capacity than traditional materials like bricks and concrete.

The Atamate template aligns closely with the principles for electrification of buildings laid out by the Chartered Institute for Building Engineers (CIBSE)[16]. Central to the Atamate template is the Atamate building operating system (atBOS), which continually monitors the building so that energy is used where it is required and nowhere else.

The building as a dynamic entity

The Atamate approach is based on what we call the four C's of building service design (Box 2), which lay out the considerations underpinning the design of a building's services. Our view is that the installation and running costs of all options should be compared at the design stage of a new building, although we are confident that the Atamate template will emerge as the preferred option in all but a few cases.

The purpose of modelling a building is to build a picture of its behaviour as a dynamic entity (Figure 1). The behaviour of an apartment block arises through the interaction of three elements:

Overview of the Atamate template

Fabric: The materials that make up the building envelope form the interface between the external and internal environment.

Occupants: People inside the building affect the internal environment both metabolically, by producing heat and carbon dioxide, and behaviourally, through their use of appliances and services, so a model must take account of how long they spend in their apartments and what they do in there.

Services: Various systems are needed to maintain a comfortable internal environment, all of which consume energy and many of which interact with each other's operation.

The fabric is the least dynamic of the three elements and also the most constrained by regulation. For all new builds and renovations, Part L of the UK building regulations1 mandate high-quality fabric, defined by high levels of insulation and minimal air leakage.

Even without high-quality building fabric, apartment blocks tend to retain heat simply because they are large buildings. Their size gives them a low form factor, meaning the total area of the building envelope is low in comparison to their total floor area. Moreover, most apartment blocks have several internal walls between the centre and the envelope, which further enhance heat retention by impeding airflow.

The high heat retention keeps the heating demands relatively low even in the winter. In the summer, the same high heat retention can cause a building to become uncomfortably hot unless a cooling system is incorporated into the design.

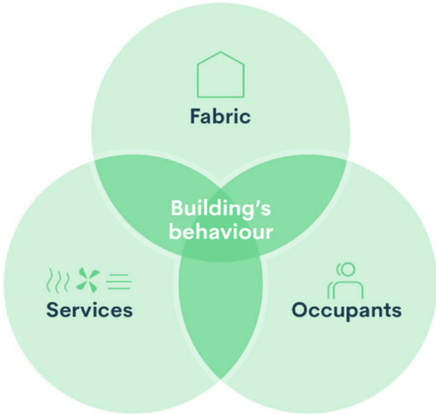

Figure 1: The elements of a building's behaviour.

Services for individual apartments

The Atamate template treats each apartment's services as self-contained. By separating the apartments, only six connections are required for each, which minimises installation and maintenance costs:

- Power cable
- Coldwater pipe
- Wastewater pipe
- TV/internet cable
- Fire alarm cable
- Sprinkler supply

The fewer pipes and cables entering an apartment, the more compatible the service layout is with offsite construction techniques[15] and the fewer fire dampers are required.

Another advantage of each apartment's services being self-contained is to simplify billing. A meter on the power cable and another on the coldwater pipe record the utilities use for each apartment, enabling bills to be allocated as fairly and transparently as required by the relevant regulations[17].

Box 2: Atamate's four C's of design

Comfort: A digital model should assume that a comfortable indoor environment is a fixed factor and optimise the other three C's around it. A comfortable indoor environment is defined by a comfortable temperature, high-quality air and hot water being available on demand

Cost: Projections of the building service costs include both the installation costs borne by the developer and the bills paid by the occupants.

Carbon: Carbon calculations should encompass a lifecycle analysis of carbon emissions associated with the entire building, including the manufacturing, construction, operation and disposal of the building's components and any upgrades it is likely to undergo within its lifespan. A projection should incorporate the projected changes in grid carbon factors as electricity generation moves from fossil fuels to renewables.

Convenience: In an apartment block, convenience mostly applies to the building management responsible for maintenance and ongoing regulatory compliance. Some service approaches require more ongoing management than others, which raise costs if outside staff need to be brought in.

Automation using atBOS

Placing all building services under atBOS control is the single most important factor in meeting the requirements of the four C's. In keeping with those requirements, the fittings required by the Atamate template require little space and are unobtrusive, minimising their impact on the interior design (Figure 2).

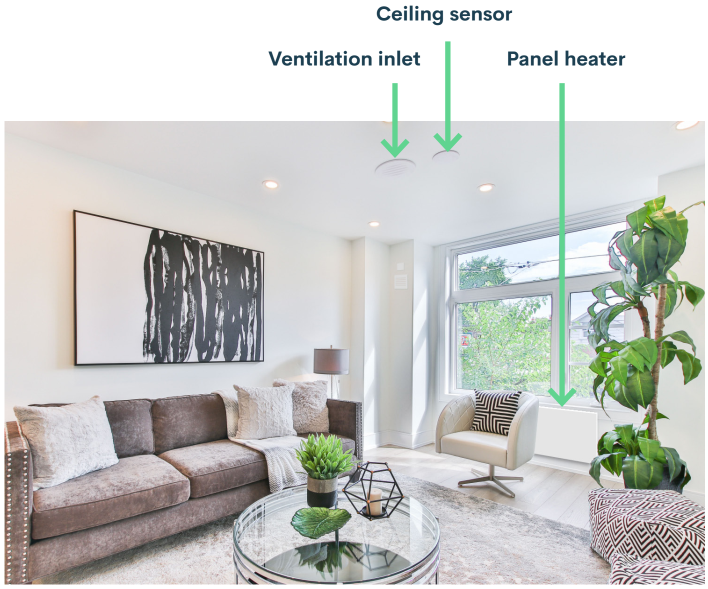

Figure 2: A room in an apartment with services according to the Atamate template.

The Atamate template is operated by atBOS

The atBOS is based on a sensor network that continuously monitors the indoor environment. The basic unit is a ceiling sensor unit (Figure 3) installed in every room, which collects data on:

- Temperature.
- Indoor air quality (carbon dioxide, humidity & volatile organic compounds).
- Noise & vibration.
- Ambient light.
- Passive infra-red (PIR) movement sensor.

Figure 3: The Atamate ceiling sensor unit

Other sensors are used where required, such as to detect whether a window is opened or closed, to measure the temperature of the hot water tank or the pressure in the water pipes. All sensors transmit data to a central hub whose software compares each parameter to a predefined acceptable range. If the readings fall outside the acceptable range, the hub operates the necessary services.

If the parameter is related to the indoor environment, the action usually involves activating a service such as by heating or cooling a room that is outside the comfort temperature or ventilating a room where air quality has fallen below the acceptable range. Other parameters are concerned with facilitating maintenance, triggering alerts when problems are detected. For instance, anomalously high humidity under a bath may indicate a leak in a place where no one would notice it until it caused enough damage to draw attention to itself. Early detection enables the pipe to be repaired when the pipe is still the only thing that needs repairing.

All the data from sensors, meters and service usage is stored on a cloud server, although the hub also stores data locally so internet outages do not affect atBOS functionality.

Bluetooth mesh runs the atBOS network

The various sensors, meters, services and any other devices controlled by atBOS are connected to the hub through a wireless network. Using wireless enables atBOS to operate with very little control and data cabling, and also makes it easy to connect other devices if required at a later date.The atBOS network uses the Bluetooth mesh protocol[18], selected for the following reasons:

Security: Bluetooth uses bank-level encryption, making the network extremely difficult to hack.

Range: Every node on the network can relay messages as well as send or receive them. As long as every node is within range of other nodes, atBOS can communicate across a network of effectively unlimited size using low power signals. Repeaters can be used to bridge gaps where necessary.

Redundancy: In practice, very few installations have any nodes that are only within range of one other node. There are multiple pathways between each node and the hub, which means that the failure of any single node does not affect the signalling across the network.

Interoperability: Bluetooth code is open source, making it easy to interface with other wired or wireless operating systems if a developer requires a service that uses them. Current installations include interfaces with Modbus, DMX and BacNet protocols and many others can be added if required.

Extended functionality

The biggest differences between conventional approaches and the Atamate template lie in the services that fall under the HVAC categories: heating, ventilation and air conditioning. They are also the services that have the most direct impact on comfort and account for most of an apartment's energy consumption. They are covered in detail in the sections below.

However, atBOS was designed from the outset to be flexible enough to operate any building service so, in any given installation, atBOS can be tailored to the services required for that installation. Similarly, data from each sensor may be used for multiple purposes. Examples include but are not limited to:

Lighting: Placing the lighting under atBOS controls enables it to switch it on or off according to whether or not a room is occupied, and atBOS also has the functionality to pre-programme lighting scenes that vary the hue or intensity of a room's lighting.

Entry control: A camera and intercom over the door can be accessed via a smartphone, which can allow a building manager to admit maintenance staff without being onsite. Alternatively, the main entrance and doors to individual apartments may be controlled by smartphone-based near field communication or keypads, allowing codes to be issued to maintenance staff that allows access only to the areas they need to access and are revoked when no longer needed.

Security: If a door is forced or movement is detected at a time or place where no one should be, atBOS can respond with outdoor intruder lighting, alerts to residents or alarms.

Noise measurements: The ceiling sensor contains a microphone that measures decibel levels, but cannot record. As noise is a frequent source of dispute among residents of apartment blocks, an accurate measure of the noise as experienced in each room of each apartment can be valuable information to reach a resolution.

Window opening: Motorising a window can make it easier for an elderly or otherwise impaired person to open and close it. Where windows are not motorised, sensors can detect when they are open and switch off any heating or cooling to save energy.

Sound systems: Third-party sound systems can be controlled by atBOS, allowing control of speakers throughout the apartment.

atBOS operation

The entire system is controlled through a graphical interface that may be accessed by any internet-enabled device (Box 3). The principle underlying control is that an apartment's occupants define the indoor environment they find comfortable and atBOS uses the apartment's services to maintain that environment in the most energy-efficient way.

The controls are based on the following parameters:

Setpoint control: Ceiling sensors continually monitor the indoor environment in every room and compare the parameters with setpoints that can be set by zone and calendar. The setpoints define a comfort range that atBOS will use the services to keep an occupied zone within (Table 2).

Table 2: Suggested comfort ranges used by atBOS for heating and ventilation control.

Parameter	Comfort range
Temperature	20–25°C (68–77°F).
Carbon dioxide	Below 800ppm
Relative humidity	40–60%

Zonal control: The system divides the building into zones, each of which usually corresponds to a single room. Having this level of granularity enables occupants to define how they want each zone to behave, for example by defining a different comfort temperature for bedrooms and living rooms. Combined with occupancy control, energy is saved by not applying heat or extracting warm air where it is not necessary.

Occupancy control: Ceiling sensors detect whether anyone is in a zone by movement, carbon dioxide and noise level. Placing fast-response temperature control or ventilation under occupancy control ensures that energy is only used in occupied zones.

Calendar control: Certain parameters may be set according to date or time. For example, the setpoint temperature of an occupied bedroom may be lower during the night, when the occupant is likely to be asleep under a duvet, than during the day when they are likely to be more active. Alternatively, in buildings with slow-response central heating whose occupants arrive home from work at a predictable time, the heating may be set to come on in advance of that time to heat the apartment before they arrive.

Box 3: controlling atBOS

Overall control of an atBOS installation is through the user interface (UI), a graphical interface that can be accessed through any internet-enabled device (Figure 4). It enables users to set the controls for any of the services such as by defining a zone's comfort range or setting which services are dependent on occupancy or calendar controls. The UI also allows users to directly control services.

For every installation, a designated owner has complete control while other users have as much or as little control as specified by the owner. For example, parents may allow their children full control of the services in their own bedrooms but nowhere else, or a landlord may give maintenance staff control restricted to the services they need to work on for a designated time period.

The UI is also how the owner accesses the data that atBOS collects from its sensors and services. For example, a landlord may use meter data to allocate bills within a property or a homeowner may want to confirm the quality of the air in their home.

Not everyone is comfortable using a graphical interface so a typical installation incorporates conventional switches for certain services such as lights and motorised windows. There are also certain types of controls designed specifically for atBOS that make control easier:

Atamate HAZE: a type of dimmer switch with additional modes that can control additional lighting, audio, shading and motorised windows (Figure 5).

Faceplate heating control: a switch that controls the panel heater in the room, allowing it to be switched on and off and also incorporating a 'boost' function that raises the temperature above the setpoint programmed into the UI for a predefined length of time.

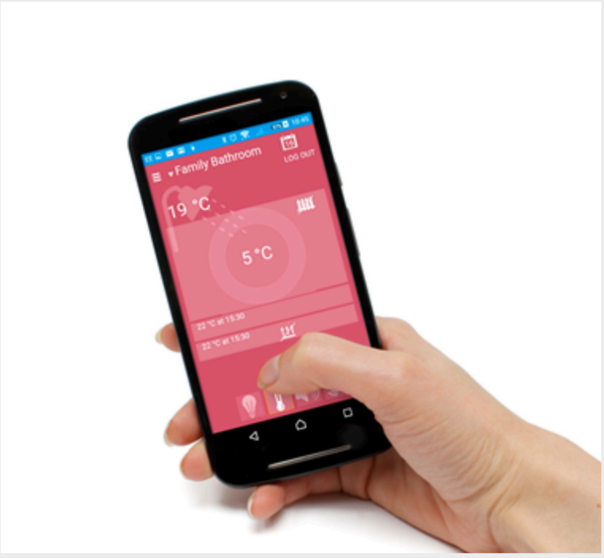

Figure 4: atBOS User interface screen on a smartphone.

Figure 5: Atamate HAZE multi-purpose switch

Space heating

The basic unit of space heating is an electric panel heater installed in every room (Figure 2).

Most existing apartment blocks use gas-powered 'wet' central heating but when the government's zero-carbon ready requirement[4] comes into force in 2025, gas power will no longer be an option for new buildings. The requirement to use electricity, with its higher cost per unit energy, is a matter of concern for many developers but our view is that electric panel heaters are already the better option for apartment blocks constructed with high-quality fabric.

That's because energy cost is not the only consideration. Modern building fabric keeps the heating demand so low that a modern apartment does not need wet central heating, which has inherent inefficiencies as well as its substantial capital and maintenance costs (Table 3).

Table 3: major points of comparison between wet central heating and electric panel heaters.

	Wet central heating	Panel heaters
Power source	gas, electricity augmented with air-source heat pump or district heating.	Electricity
Energy conversion	Converts energy to hot water that distributes heat around the building.	Directly converts energy to heat in the room
Response time	Slow: high thermal capacity of water requires warm-up time.	Fast: electricity heats the room directly.
Internal gains	Heat energy is lost from pipework as it is distributed.	Heat energy is only produced at source
Installation	Requires extensive pipework to connect a plant to radiators and underfloor heaters.	Panel heaters are plugged in directly to the mains although, in a large building, a large anticipated heat requirement may require additional electricity infrastructure.
Maintenance	The plant, pipework, radiators and underfloor heating require ongoing maintenance.	If a panel heater fails, it can be scrapped and replaced.
Regulatory requirements	Gas heating systems require annual checks.	Electric systems require checks every five years.

Efficiency through fast response

Wet central heating uses water as a distribution medium, which is key to both its efficiencies and its inefficiencies depending on the context in which it is used.

In a building that requires continuous heating, water's high thermal capacity enables it to carry a considerable amount of heat from the plant where the heat is generated to the radiators and underfloor heaters that conduct it into the rooms of a building. However, apartment blocks rarely require continuous heating, especially if they are constructed with high-quality fabric.

There is an inherent inefficiency in needing an intermediate step between heat energy being generated and being conducted into a room. In a large apartment block, a substantial amount of heat energy can be lost between a central plant and the apartments where it is required.

A further inefficiency derives from the high thermal capacity that makes water the distribution medium of choice. Any wet central heating system contains a large volume of water and the larger the building, the larger the volume. When heating is required, it takes some time to heat that water to the required temperature so to respond to heating requirements quickly, many apartment blocks keep the water heated to a minimum temperature. Hence wet central heating consumes energy even when no space heating is required.

The heating response time is affected not only by the thermal capacity of water but also by the thermal capacity of the building fabric which, in a conventional concrete apartment block, can be substantial. If a room requires heating, the air temperature will see little change until the building material reaches the required temperature. Most modern building materials have much lower thermal capacities than concrete, which enables the use of fast response space heating.

When a room reaches the required temperature, the radiators and underfloor heating can take as long to cool down as they took to warm up. Wet central heating's slow response times often lead to room temperatures fluctuating around the thermostat setpoint, with the room spending more time being uncomfortably warm or uncomfortably cool than at the designated comfortable temperature. Modern building fabric tends to lead to more time being spent on the uncomfortably warm side of the setpoint temperature simply because it retains heat so well.

Electric panel heaters avoid the inefficiencies of wet central heating by delivering heat energy directly to where it is needed. For apartments that only require intermit heating, avoiding the inefficiencies inherent to distribution goes some way to balancing the cost differences between electricity and gas. They also deliver better comfort because a panel heater can quickly heat a room to the comfort temperature and switch off as soon as that temperature is reached.

The potential efficiencies of panel heaters depend on their being switched on only when and where they are needed, which requires automation. Most people will not remember to switch a heater on and off every time they enter or leave a room but if they preset the required zonal, calendar and occupancy controls, they don't have to. They can leave atBOS to direct energy to where it is needed and nowhere else, which is only possible with fast-response electric heating.

Installation and maintenance

Another advantage of electric panel heaters over wet central heating is that they are considerably easier to install and maintain, which is reflected in lower embodied carbon and capital costs.

Panel heaters are cheap to manufacture, and installation is a simple matter of mounting and connecting them. By contrast, installing the pipework, radiators and underfloor heating of a wet central heating system requires considerably more material, time and skills.

Once a building is occupied, the electrics need to be tested every five years[19], which is less of a regulatory burden than the annual checks needed for gas appliances[20]. If a panel heater fails, it is much cheaper to replace it than to diagnose and repair a fault in a wet central heating system.

A new apartment block is likely to require some upgrading of the local electricity distribution infrastructure, which is usually more expensive than a connection to the gas main. The zero-carbon ready requirement[4] will require new buildings to use electric space heating which will inevitably increase the upgrade costs for developers used to installing gas-powered heating. Maximising the efficiency of electric space heating will minimise the building's overall requirement and limit the cost of the required upgrades.

Water heating & ventilation

Because the space heating requirements of a modern apartment block are so low, domestic hot water is usually the largest source of energy consumption (Figure 6).

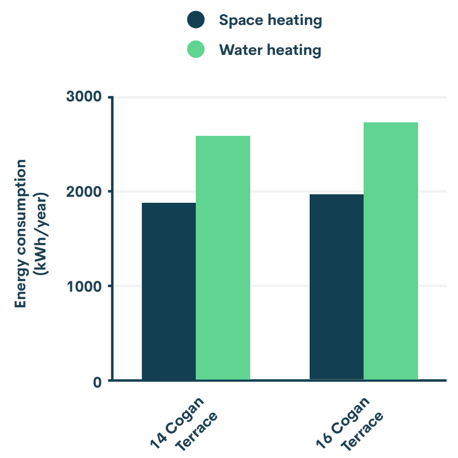

Figure 6: Annual energy demand for space and domestic hot water derived from post-occupancy evaluation of two terrace houses, 14 & 16 Cogan Terrace in Cardiff, each rented to seven people divided between three apartments fitted with services according to the Atamate template.

Without wet central heating, the Atamate template removes the combination (combi) boiler that, in most existing apartment blocks, provides space heating from the same source as the water heating. The Atamate template inverts that approach by using a heat pump to recover the energy used for space heating from the ventilation exhaust into a hot water tank in each apartment. The exhaust-air heat pump links the ventilation and hot water systems so closely that they are effectively a single building service.

The exhaust-air heat pump

Augmenting electric water heating with air-source heat pumps is often suggested as a way to increase the cost-efficiency of electric water heating (Box 4). However, the limitation of any heat pump is that the lower the temperature of the source medium, the less efficiently the heat pump operates.

Because the typical comfort temperature is 20–25°C (68–77°F), the air vented through the exhaust vent is warmer than the outside air for most of the year. Field trials of air-source heat pumps in Britain have shown that across a year, their coefficient of performance (CoP) is usually in the region of 250–300%[21], meaning that the energy they deliver is 250–300% of the energy they draw from the mains.

In our experience, using air that has already been heated makes a considerable difference, allowing the exhaust air heat pump to operate with a CoP of around 350%. The exhaust-air heat pump usually provides almost all of the required water heating, with the rest supplied directly from the mains.

At the time of writing, 350% still falls short of the 400–500% that would be needed to bring electricity to cost parity with gas even if the heat pump provided all the hot water heating requirements. However, there are other savings associated with the Atamate template as described below.

Demand controlled ventilation

The principle underlying the ventilation system is the use of occupancy and zonal control to ensure that the occupants always have good air quality without ventilating rooms that do not need ventilating.

Airflow is driven by a two-speed extractor fan (Box 5) that draws outdoor air through damper-controlled inlets in rooms like bedrooms and living rooms that usually have the highest air quality. It then passes to the kitchens and bathrooms, which are likely to be the sources of humidity and unpleasant smells and from there to the exhaust duct (Figure 7).

If the trigger was low air quality in an occupied bedroom or living room, the only inlets that are opened are those in the room that requires ventilating. The air in other zones is left undisturbed so no further heating is required. If the trigger is air quality falling below the setpoint in the bathroom or kitchen, an inlet is opened in whichever bedroom or living room has the lowest air quality at the time.

Tank technology

The unavoidably high energy demand of heating water lends itself to technological improvements to limit it. Next-generation hot water tanks like those made by Mixergy[22] use two approaches that minimise the energy needed to provide hot water when a tap is turned on:

Stratification: Rather than heating the whole volume of the hot water tank to temperature, stratification makes use of the fact that the warmer water in a tank rises to the top. The heating element is placed at the top of the tank and heats water to the 60°C (140°F) required to kill the Legionnaire's disease bacterium[23]. Water at the bottom of the tank is much cooler and there is a stratification of temperature in between so that when water is piped from the top, the warm water below it is pushed to the top and can be quickly heated to the required temperature.

Machine learning: A machine learning algorithm optimises the tank's energy use by adapting to the hot water requirements in a given home. For example, it may heat only the top layer of the tank to 60°C for most of the night but half an hour before the apartment's occupants wake up, it may heat much more of the volume so it is ready for everyone's morning showers. By only heating water to 60°C immediately before it is used, it minimises the amount of standing hot water that wastes heat energy as internal gains rather than contributing to the occupants' comfort.

The Mixergy tank's controls are restricted to the tank but we anticipate that it will be a feature of the next generation of building automation systems.

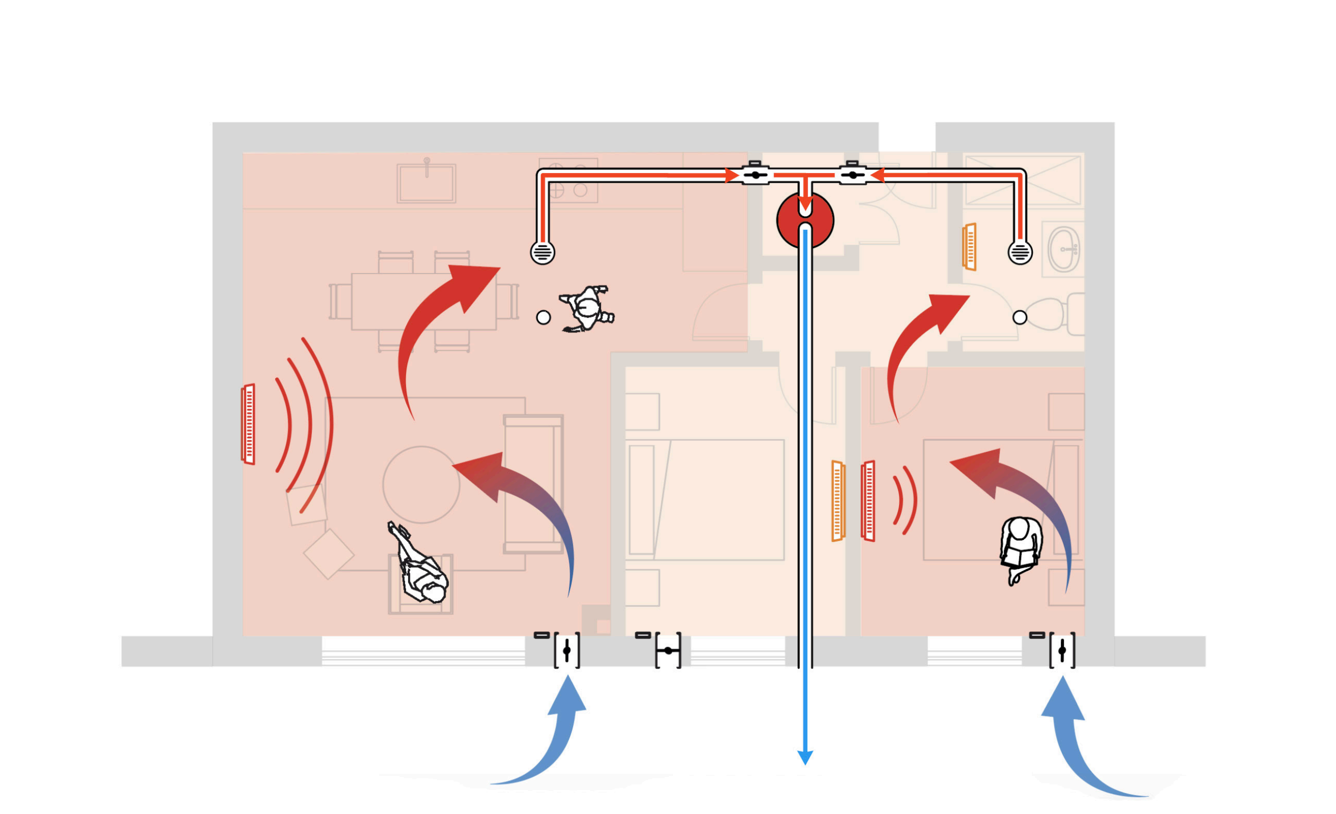

Figure 7: Schematic of airflow through an apartment laid out according to the Atamate template. Outside air enters through damper-controlled vents in the occupied bedroom and living room where electric heaters warm it to the comfort temperature. It then passes to the bathroom and kitchen where it is drawn into ducts that pass through the exhaust-air heat pump, which extracts the heat energy into the hot-water tank, and out through the exhaust vent.

Atamate template vs heat pumps

In recent years, air-source heat pumps (ASHPs) have often been promoted to level the cost of electricity up to equivalence with gas. They have received so much attention that when the government announced a subsidy for gas boiler replacement in October 2021[24], the BBC reported it as a subsidy for installing heat pumps[25] even though the wording of the announcement made it clear that the subsidy was available for any low-carbon alternative.

An ASHP extracts heat energy from outside air, multiplying the energy it draws from the mains by a coefficient of performance (CoP). Field trials of ASHPs[21] in Britain have shown a very broad range of CoPs, ranging from 200% to 450%. Hence the best performing ASHPs augmented mains electricity almost enough to deliver energy at a similar cost to mains gas. However, most installations delivered CoPs in the range of 250–300% and a realistic projection of the CoP for a given installation should not be based on the best possible outcome but the most likely.

Compared to the Atamate template, the ASHP has several disadvantages including:

- The ASHP delivers space heating through a wet central heating system, incurring the inefficiencies described above.
- The ASHP provides hot water by functioning as a single plant, leading to the problem of internal gains inherent to hot water distribution.
- As well as the capital costs associated with wet central heating, the heat pumps themselves are expensive to install and maintain.
- A heat pump large enough to power an apartment block takes up a substantial amount of space.
- A large heat pump is likely to be noisy, requiring it to be sited to minimise disturbance to residents of both the apartment block it supplies and anyone else who lives nearby.

To justify the greater costs and complications, ASHPs would need to deliver substantially better energy efficiency than any other option. However, when we compared the real-world energy usage of apartment services based on the Atamate template with a projection of the same apartments using an ASHP-based mechanical ventilation and heat recovery as recommended by the Passivhaus Trust[26], we found that the greater capital costs would have delivered a negligible improvement in energy efficiency[27]:

- Atamate template using figures derived from the standard assessment procedure (SAP 2012[28]) discounted by 34% to reflect the discrepancy between SAP calculations and the lower energy demand derived from post-occupancy evaluation of a newly built apartment using the Atamate template[29].
- The SAP 2012 projection for an identical apartment using an air-source heat pump to power mechanical ventilation and heat recovery, based on a Mitsubishi Ecodan Monobloc[30] as a typical ASHP.

The energy demand from the ASHP option was no lower than from the Atamate template (Figure 8). By opting for the Atamate template over an ASHP, the designer of the apartment used for the post-occupancy evaluation had delivered both financial savings and lower embodied carbon.

Urban areas often have waste heat sources, such as wastewater treatment plants or buildings like datacentres that require continuous cooling, which offer the prospect of a higher CoP than the conventional ASHP approach of using outdoor air. Moving the extracted heat from its source to a home requires a heat network, which uses water as a distribution medium to pump heat energy around a district or a building. Recent innovations have allowed heat networks to use disseminated power sources rather than being dependent on a central powerplant[31], allowing them to use such waste heat sources. However, the infrastructure needed for a heat network is complex, involving high installation and maintenance costs.

The costs and efficiencies of heat networks are likely to vary considerably from one situation to another, depending on the power and heat sources available, the size of the network and whether or not it is serving buildings with poor enough fabric to require wet central heating. Comparison with other options is always necessary at the design stage of a development.

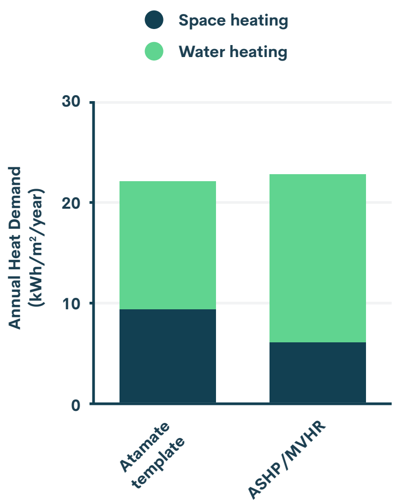

Figure 8: Comparison of heating energy demand options in a newly built apartment. Atamate template uses SAP[9] figures discounted according to post-occupancy evaluation of Cogan Terrace. ASHP/MVHR is based on using SAP[9] figures to model an identical apartment fitted with air-source heat pump with mechanical ventilation and heat recovery[25].

Box 4: The two-speed extractor fan

An apartment's extractor fan must be able to achieve the minimum ventilation rate mandated by Part F of the UK building regulations[32], which may be as high as 60l/s for the kitchen of an apartment that uses intermittent ventilation. However, such high ventilation rates are very rarely needed so the Atamate template uses a two-speed extractor fan which effectively has three modes:

High-speed mode is usually used when warm air is required by the exhaust-air heat pump but it may also be used if air quality in an occupied zone is particularly poor.

Low-speed is engaged if air quality in an occupied zone falls outside the comfort range for as long as it takes to return it to the comfort zone.

Fan off is allowable if air quality in all occupied zones is within the comfort range and the hot water does not require heating.

Combining an automated fan with continuous building monitoring avoids the need for the fan to be operated continuously, as required by a mechanical ventilation with heat recovery system, and using a two-speed fan avoids the energy requirement and mechanical wear of running the fan faster than required.

Cooling

While an apartment block's high heat retention keeps the heating requirement low in the winter, many existing apartment blocks become uncomfortably hot during the summer. At present, one in five British homes regularly overheats to the point where it affects the wellbeing of its occupants[33]. As the warming climate makes heatwaves more frequent[34], the problem will become more common during the lifespan of any building constructed today.

Many older apartment blocks are built out of concrete, which has a high enough thermal mass to stabilise the internal temperature during the summer. During the hottest part of the day, the building fabric absorbs the heat energy into the fabric and releases it at night, when the outside air is cooler. In recent years, concrete has been replaced with materials that have a lower carbon footprint and are compatible with offsite construction, but those materials have a lower thermal mass.

Because of the warming climate and changes in building construction, large buildings like apartment blocks require cooling to be among their service priorities.

The overheating problem

Our experience has been that the need to mitigate overheating has often been overlooked in building design. It has always been considered good practice but that has placed it at a lower priority than heating efficiency, which is mandated by Part L of the UK building regulations. Consequently, many new builds have been designed around heat retention, which minimises the heating requirements in the winter but exacerbates overheating in the summer.

As of June 2022, the newly drafted Part O[2] of the building regulations gives mitigation of overheating the same regulatory priority as heating efficiency, and revisions to Part L require the energy efficiency of active cooling systems like air conditioning to be considered alongside heating efficiency.

Part O allows for certain buildings to meet their cooling requirements purely by opening windows but most apartment blocks will require the dynamic thermal modelling approach which uses CIBSE's TM59[35] methodology.

Key requirements are:

- Overheating is broadly defined as a zone in which temperature exceeds 26°C (79°F) for 3% of the time it is occupied throughout the year, although there are more specific stipulations that depend on the building design[36].
- Mitigation measures should be designed to maximise the contribution of passive cooling with minimal energy required for active cooling.

The Part O regulations only apply to building work initiated after they come into force and are not applied retrospectively. However, overheating is a significant problem in many existing apartment blocks for the following reasons:

Disputes: Overheating is a common cause of disputes between tenants and landlords. If a building frequently breaches the TM59 definition of overheating, tenants could argue that the building is managed in a way that is detrimental to their health and the landlord is negligent.

Air-conditioning requirements: If a building overheats often enough to be uncomfortable, the residents are incentivised to retrofit mechanical air-conditioning. Apart from incurring a substantial installation cost, the energy consumed by the aircon system will substantially increase the building's energy consumption and defeat the object of any design to minimise heating energy requirements.

Minimising internal gains

In apartment blocks that distribute hot water from a central plant, either for wet central heating or domestic hot water, internal gains from pipework are often a major contributor to overheating. The small diameter of a pipe gives it a high surface area in relation to its volume, which makes it an efficient conductor of the heat it contains to the outside air. Insulating the pipes can reduce heat loss but not completely prevent it and the lost heat is at best a waste of energy and at worst a cause of overheating, especially as pipes usually run through central corridors where it must pass through apartments before it can escape the building.

Applying the Atamate template avoids the need for a central plant with its extensive pipework. However, that does not completely avoid internal gains associated with hot water. Some hot water still needs to be piped around each apartment and during the summer, the lost heat will combine with heat produced by appliances and high external temperatures to make the apartments uncomfortably hot without some sort of cooling measures.

Passive cooling

The most energy-efficient approaches to cooling are those that do not require continuous operation of an electrical device. Some such approaches can be designed into the building while others are made possible with a building control system like atBOS. The most commonly used options are:

Brise-soleil: South-facing windows are covered by horizontal shades that provide shadows when the sun is high in the air during summer, minimising solar gains and uncomfortable glare. In winter, the lower sun can shine directly through the windows, maximising natural light and solar gains when an apartment will need heating (Figure 9). A brise-soleil may be a purpose-built structure or its function may be fulfilled by balconies designed around the position of the sun.

Figure 9: Buildings fitted with brise-soleil of different designs.

Automated blinds or curtains: Double or triple-glazed windows may be fitted with automated blinds or curtains under atBOS control. When the sun is shining directly through the windows into an unoccupied room, atBOS closes them. When the room is occupied, the curtain may be manually controlled by switches or through the atBOS interface.

Passive approaches to ventilation use little or no energy and they are usually sufficient to meet the TM59 requirement of keeping the temperature below 26°C for most of the mild British summer. During a heatwave, some apartments may require mechanical approaches.

Air conditioning

Mechanical air conditioning is expensive to install and operate, and much of the reason for designing to avoid overheating is to limit the need for it. However, the combination of the warming climate and the high heat retention of apartment blocks makes it inevitable that more apartment blocks will require aircon in the coming decades. There are two situations in which aircon is likely to be unavoidable:

- In large apartments with few occupants, the hot water tank is simply not a large enough heat sink for the exhaust-air heat pump approach to provide adequate cooling.

- When existing apartments need to be renovated (Box 6) because the warming climate causes them to overheat more often, an aircon system may emerge as a better option if the exhaust-air heat pump approach would require complete replacement of the ventilation and hot water system.

Modern aircon systems are effectively two-way air-to-air heat pumps that can heat as well as cool so if one is fitted, it would replace the panel heaters as the source of space heating. Whether in heating or cooling mode, aircon changes a room's temperature fast enough to be operated using the same fast-response principle as panel heaters, using occupancy-based, calendar and zonal controls to avoid cooling rooms where it is not needed.

Box 5: Retrofitting atBOS in existing buildings

The Atamate template is intended primarily for new buildings but because it is intended to be flexible, it can also add substantial value when upgrading an existing building to meet modern standards.

Because the Atamate approach to design is based around a building's behaviour (Figure 1), the first stage of designing a renovation is to install the sensor network. Sensor data is then used to build a detailed picture of the building's physics and service usage patterns, which the designer can then use to plan the upgrade.

Understanding the building is the first part of the four-stage Atamate energy hierarchy (Figure 11), which outlines our preferred approach to upgrades. The over-arching principle is that financial expenditures and increases in embodied carbon must be justified by future savings and cuts in carbon emissions. Because service upgrades tend to incur the highest costs, it is often more cost-effective to optimise existing services than to replace them.

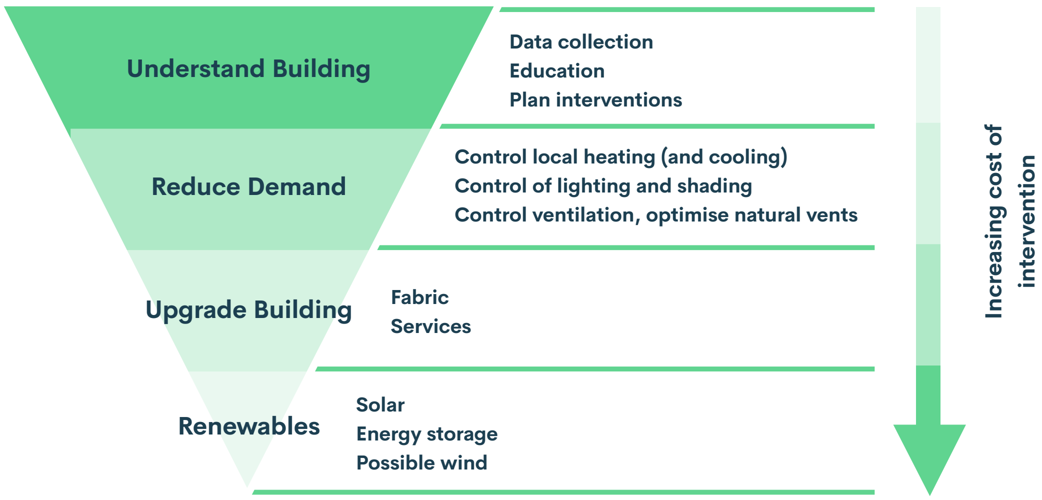

Figure 10: The Atamate energy hierarchy, a template for renovating an existing building for better energy performance.

In apartment blocks, optimisation often means improving rather than replacing a building-wide wet central heating system. Placing such a system under atBOS control often offers significant savings, such as by using thermostatic radiator valves to introduce zonal control and by the same integration with other services to avoid wastage as would be used in the Atamate template.

With the government planning to phase out gas boilers completely by 2050[24], we anticipate that the best option for some apartments will be to retain the wet heating system but to convert it to electrical power, possibly augmented by a heat pump.

The disadvantages of a building-wide wet heating system can be at least partially offset by the high thermal retention of a single large water tank, as it can be used as an energy store. The atBOS can use low-cost electricity or electricity generated onsite as much as possible and although such upgrades are never likely to reach the energy efficiency of a newly built apartment block using the Atamate template, atBOS can at least make the retrofit as efficient as possible.

Future directions

While a building designed today must be designed for the world of today, its lifespan will be measured in decades during which time there will be changes in both the way electricity is generated and produced and in the service technologies available for it to power

Because atBOS was designed from the outset to be flexible, Atamate will be able to upgrade it to incorporate whatever new technology the future brings. The innovations described below are those that we anticipate becoming important in the next ten years but we do not expect this list to be comprehensive and we fully expect to have to incorporate innovations that we are not yet aware of which is why flexibility has always been a design priority for atBOS.

Cooling with the exhaust-air heat pump

A paradox of an apartment block in a heatwave is that it may have cooling and heating requirements simultaneously. Cooling is required to keep the indoor environment comfortable, but the hot water tank still requires heating.

At present, most service layouts involve separate devices operating independently to fulfil both those requirements. One of Atamate's ongoing developments aims to turn that paradox into an opportunity, improving an apartment's energy efficiency by integrating cooling with the already integrated ventilation and hot water services.

The simplest approach is that during a heatwave, outdoor air might be ducted directly through the exhaust-air heat pump and vented into the rooms. One definition of a heatwave is that the outdoor air is above the comfort temperature and if that air is warmer than the indoor air, it will deliver a higher CoP and more efficient water heating. The exhaust air would be a source of outdoor-quality cool air.

Because there are many heat sources inside an apartment, there are likely to be times when the indoor air is above the comfort temperature while the outdoor air is below it, which will require a more complex approach. Outdoor air could still be drawn into the apartment and passed out through the exhaust-air heat pump as in the current Atamate template (Figure 8) but some of the exhaust air could be recirculated back into the apartment.

Such an approach would need atBOS to balance the indoor air quality with the cooling requirement by venting as much of the 6°C (43°F) exhaust air into the apartment as needed to cool it to the comfort temperature and no more. The quality of air coming out of the exhaust-air heat pump is higher than the quality of air going in because cooling it condenses out much of the water vapour, removing many noxious smells and lowering its humidity.

Cooling with the exhaust-air heat pump would require substantially more ducting than the current Atamate template but the capital and maintenance costs may be worthwhile if the alternative is mechanical air conditioning.

Onsite generation

At present, the most likely source of onsite energy is photovoltaic cells which may be placed on the roof of an apartment block. Most apartment blocks have small roof areas but any solar energy collected means less electricity that needs to be bought from a supplier.

It may be used to power communal areas, such as corridor lighting or lifts. Alternatively, it could be distributed among the apartments to power appliances such as fridges, freezers and washing machines that may be operated even when the apartments are empty.

Rooftop wind power is not a mature technology at the time of writing but may become viable within the next decade. If so, it would complement photovoltaic cells because windspeed is highest in the winter when solar power is limited by the short day length, and because wind power is available during the night.

Optimising energy consumption

Energy suppliers buy electricity at wholesale prices driven by demand fluctuations across the 24h period, being lowest at night when demand is lowest. Some suppliers offer contracts that charge lower retail prices to the consumer at night. An Economy 7 or Economy 10 tariff charges lower electricity prices for the 7 or 10 hours of lowest demand, albeit at the cost of higher prices for the remainder of the day. Few consumers can make use of Economy tariffs for the same reason that they exist at all: we don't use much electricity when we're asleep.

As the national grid becomes more dependent on renewable sources, supply fluctuations will become less regular. Solar power gives a predictable diurnal cycle as power output but much of renewable energy is from wind power, which is entirely dependent on when the wind is blowing.

The near future will also bring changes in demand, leading to a summer peak in domestic energy demand between 5pm and 7pm, driven by people returning from work, plugging in their electric vehicles and turning on their aircon to cool apartments that have been overheating all day[37].

All of those changes will break the current pattern of a diurnal fluctuation in energy prices. If suppliers offer tariffs that pass on the differences to consumers, there is likely to be a certain amount of variation between suppliers depending on the generation mix that they source their electricity from.

Future versions of atBOS will be able to adjust the supply and demand of an apartment block to keep prices as low as possible. On the demand side, atBOS will monitor the prices offered by different suppliers and purchase electricity from wherever is cheapest at the time.

Demand can be regulated by scheduling energy usage based on the time of day and the weather forecast, which will enable it to predict the availability of wind power. Possible approaches include:

- Electric vehicle charging could be delayed to avoid the high-demand period in the evening and scheduled for the lower demand period late at night.
- Most people use very little hot water during the night and then shower in the morning. In a hot water tank that uses stratification, atBOS can ensure there is always a small amount of hot water available during the night and then heat a larger volume for when it is needed.
- In an apartment cooled by aircon, it may be worth running it during a summer day even if an apartment is empty, making use of the peak availability of solar power to lower the anticipated 5pm–7pm peak in domestic usage.

Other approaches to optimising energy pricing may emerge with new building service technologies.

Energy storage

An extension of optimising energy use is to store electricity when it is at its cheapest. The simplest approach to energy storage is to use the hot water tanks as a thermal energy store. Such an approach would involve a calculation of the losses through internal gains, especially if they would require active cooling to avoid overheating, but stratification technology makes the approach more viable as atBOS would be able to precisely calculate how much energy it would be worth storing.

Another approach is to use electrical energy storage systems (EESS). Options are limited by the charge/discharge ratio of the batteries currently on the market, which is so poor that the potential savings in cost and carbon emissions will not offset their installation cost and embodied carbon. However, it is possible that better batteries may become available, or that the gap between maximum and minimum electricity prices may become wide enough that even an inefficient battery would deliver savings.

A recent project by Warwick University and Element Energy suggested another solution: using batteries recovered from electric vehicles[38]. They anticipate that by 2030, large numbers of electric vehicles will have reached the end of their lifespan but their batteries will still have a capacity of at least 65%. Such reused batteries will be far cheaper than brand new batteries and because reusing an existing battery extends its lifespan, they carry far less embodied carbon than if they were manufactured for the sole purpose of being used in the building.

Another EESS is the batteries of electric vehicles connected to the building's chargepoints. Octopus Energy is already pioneering such an approach in the UK with the 'Powerloop'[39] that combines domestic electricity supply with the lease of an electric vehicle, offering discounts to customers that make the vehicle battery available for balancing electricity supply. The same approach could be applied within an apartment block, allowing vehicle owners the option of making their vehicles available as an energy store while specifying when they need them fully charged.

Machine learning

The current generation of atBOS depends on its users defining the parameters it is intended to work to but much of Atamate's research and development efforts are directed toward machine learning, which will allow the next generation of atBOS to optimise itself to the building it is installed in.

It will achieve that by comparing the responses to the services it engages with the subsequent changes in the indoor environment detected by the sensors. For example, switching on a heater in one room will take a certain amount of time to heat that room to setpoint temperature but some heat will also leak into adjacent rooms. In collaboration with Oxford University's Department of Computer Science, Atamate is developing an algorithm that assesses the effect of every space heater on every room[40], enabling it to calculate the most efficient way to follow an instruction to heat a given room to a given setpoint.

Ultimately, Atamate aims to apply the same approach to all building services and also to incorporate its experience of how services are used, learning all three elements of a building's behaviour: the fabric, services and occupants (Figure 1). Combining data on how energy is used in the building with weather forecasts, which predict the availability of wind and solar power, and energy storage will enable atBOS to extend its current role of maximising usage efficiency to include maximising cost efficiency.

Summary

We have designed the Atamate template to be the most cost-effective and carbon-efficient approach to an apartment block's building services, and it has the further advantage of being compliant with any regulatory changes likely to come into force during a building's lifespan.

The key elements are:

- Each apartment's services are self-contained.
- All services are powered by mains electricity.
- All services are automated under atBOS control.

Placing atBOS at the core of the template future proofs an apartment block because atBOS will be continuously upgraded to incorporate changes in electricity distribution and demand and to allow new technologies to be retrofitted as they become available.

Footnotes

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