Innovate UK

Building Performance Evaluation Programme: Findings from domestic projects

Making reality match design

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Innovate UK

Content

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Executive summary

Homes must perform well for the benefit of residents and the environment. However, they rarely live up to their designers original aspirations. This report explores the reasons – and examines the best design strategies for low-carbon properties. The goal is to ensure designers and developers use the best approaches for building low-carbon homes.

Meeting demanding standards

This report looked at data from a subset of 76 homes in the Innovate UK's Building Performance Evaluation Programme (BPE). The homes are part of leading-edge developments where low-carbon design was a priority. Various homes did not initially meet demanding standards for building fabric and system efficiencies – despite carefully specifying, designing and building the properties.

Achieving expected airtightness

Airtightness was an exception. Every home achieved better than the minimum airtightness standards in the Building Regulations, with a mean of 4.2 m^3/hr per m^2@50Pa. However, some projects had aimed to do even better – and one third did not achieve their expected airtightness.

Overcoming heat loss

Passive House designs focus more on insulation and airtightness than conventional construction techniques. Consequently, they achieve the best heat-loss coefficients and thermal performance. However, the heat-loss coefficient is only as good as the weakest link in a thermal envelope. Thermal bridges, incomplete insulation or gaps in the air barrier result in a higher heat-loss coefficient. So to stay comfortable, residents use more energy and create more CO_2 emissions.

Considering new technologies

The projects encountered major teething problems with some new technologies, including solar water heaters, heat-recovery ventilation, automatic blinds and heating controls. In most cases, difficulties with these technologies harmed carbon performance. This is partly inevitable when people start using new technologies – but largely due to installers inexperience setting up unfamiliar systems in different homes.

Designers and developers should take care when using innovative systems, unless they know the installers have used them in similar ways before. It is vital that the individual installer – not just the company – has hands-on experience of the technology, or a mentor who can guide them.

Unnecessarily complex controls

Controls are a problem. Heating, lighting and renewable energy system controls are often too complicated for people to use confidently. Residents can be wary of using their controls, which can result in using more energy and emitting more CO_2.

Focusing on handover

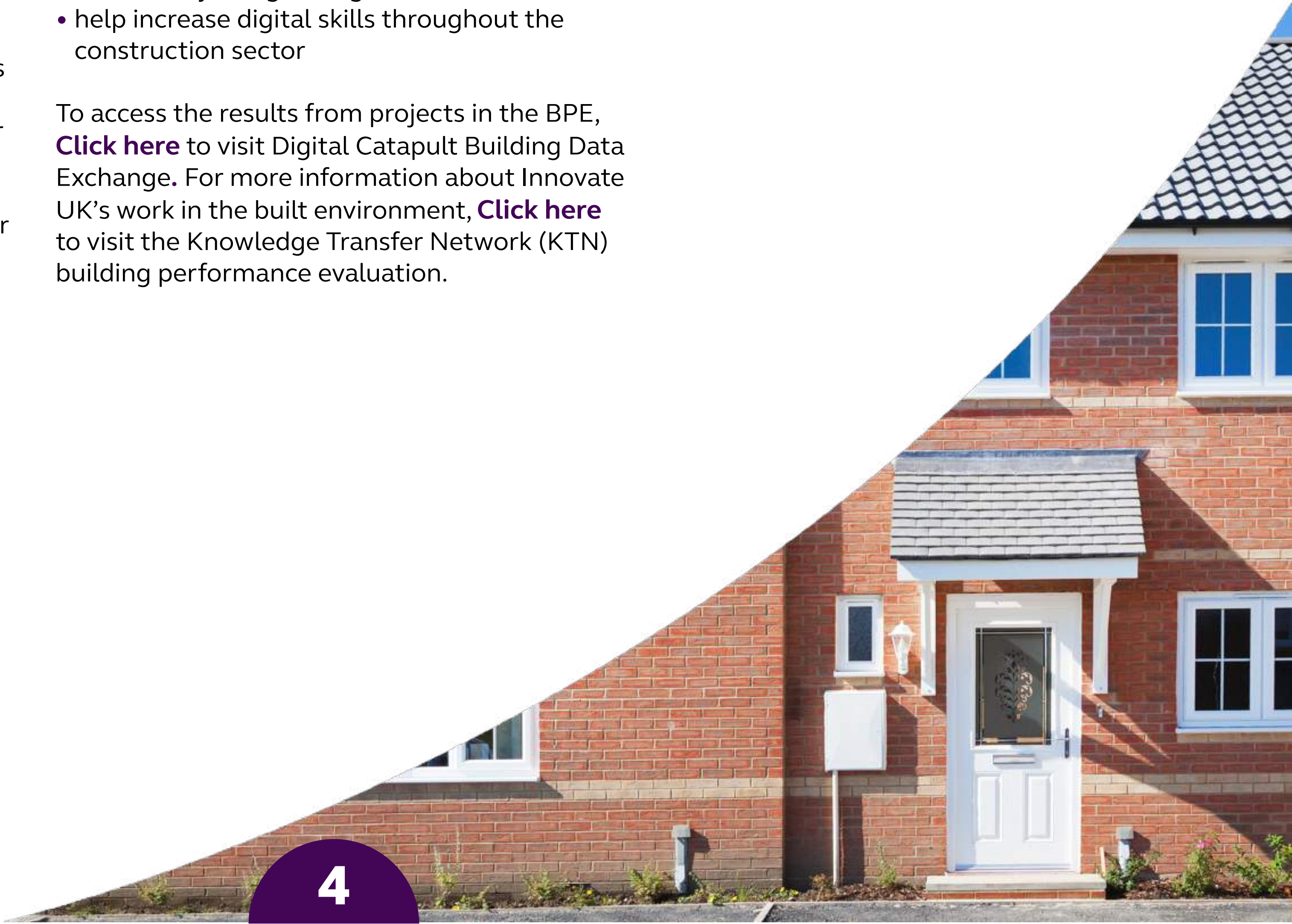
Developers often neglect handover and commissioning when rushing to finish projects and pass homes to residents. However, both stages are essential for homes to achieve their design targets for energy. Companies should consider using the increasingly popular 'Soft Landings' protocol, which brings together best practice at every stage of a building project.

Unlocking better buildings

Innovate UK has joined forces with the Digital Catapult Centre to launch the Building Data Exchange which will:

- give designers, developers and policymakers access to the data and lessons required to make buildings more efficient
- provide the sector with more opportunities to innovate by using the right data
- help increase digital skills throughout the construction sector

To access the results from projects in the BPE, **Click here** to visit Digital Catapult Building Data Exchange**.** For more information about Innovate UK's work in the built environment, **Click here** to visit the Knowledge Transfer Network (KTN) building performance evaluation.



Introduction

The UK is legally bound to reduce greenhouse gases by 80% by 2050. Building better low-carbon homes will help the UK achieve this challenging goal. Now, more than ever, we need to know which carbon-cutting approaches are best, and which are failing to hit the mark. This report recommends to designers and developers the approaches they could use.

Differences of opinion

Will biomass heating solve the low-carbon conundrum? Or is the Passive House standard the answer? Or should we listen to those who advocate passive solar solutions, without complex mechanical ventilation? Almost every designer and developer in the UK has their own strategy for cutting carbon emissions from homes. However, there is little consensus about the best way to cut operational carbon emissions. Project teams typically claim their ideas are best but it is rare to find independent scrutiny of actual carbon performance when residents are living in their homes.

Our focus areas

This study looked at 76 homes, chosen from 59 monitoring projects that Innovate UK funded through its £8 million Building Performance Evaluation programme.

The study focused on:

- projects that had reliable energy data
- building fabric and systems
- design strategies and technologies that successfully reduced energy use and carbon emissions, and those that did not

Some sections of this report cite figures for fewer than 76 homes. This is because complete data was not available in some circumstances. However, the report includes data from as many homes as possible.

Project summaries

This section summarises the housing projects examined.

Choosing the right approach

The projects in this study used many materials, construction methods, and energy systems. Designers and construction teams can choose which approach to use. However, the client paying for the project has the final say. Corporate clients, like developers and housing associations, build most of the UK's new homes but rarely occupy their new properties. So residents are often not involved in the homes' design. However, in this study, every client was at least sympathetic towards – and usually enthusiastic about – cutting energy use and carbon emissions.

Three different approaches

There are at least three different approaches to achieving very low energy use:

1. **Traditional housing design with renewable energy systems** – such as biomass heating, large photovoltaic (PV) arrays, solar water heating, and air source heat pumps (ASHP).
2. **Passive House design** – mechanical ventilation with heat recovery (MVHR) with excellent insulation and airtightness.
3. **Passive solar** – large south-facing windows and small north-facing windows, typically with natural ventilation and exceptional insulation.

The first two are well-represented in the BPE; however, there are a few examples of the third.

The study analysed data for as many of the following homes as possible. However, there were slight differences in the information project teams provided, so the sample sizes vary.

Properties

Aberfawr Terrace near Caerphilly comprises thirteen homes, with nine flats and four houses. All the homes are electric-only, with exhaust air heat pumps providing heating. Some have solar electric panels. The measured heat pump coefficients of performance varied from 0.4 to 2.1 – which were much lower than the manufacturer's estimate. Airtightness was also not as good as the design target, and deteriorated over time. One of two monitored homes used more energy than design estimates; the other less.

Avante Homes are designed to be affordable, sustainable and low density. They are built using a structurally insulated panel system (SIPS). The designer aimed for high levels of airtightness and construction efficiency. MVHR supplements a natural stack ventilation system using glazed lanterns. Thermal mass in the ceilings provides a buffer against overheating. The buildings achieved a slightly better fabric heat-loss value than predicted by the Standard Assessment Procedure (SAP).

Properties

Birchway Eco Community are built using modular construction, and designed to be energy efficient with good insulation and airtightness. The energy strategy includes a community biomass heating system (wood pellets) that supplies individually metered space heating and hot water; and PV panels on the buildings' south and west-facing roofs.

Bloom Court in Livingstone, Scotland, consists of six 1.5-storey houses intended for older people. The homes are built with timber frames and breathable, rendered wood-fibre walls, with hemp insulation. They achieved better-than-expected airtightness of 4 m^3/hr per m^2@50Pa (much better than the Building Regulations require). The homes are well liked, but there is inadequate ventilation in bathrooms, which have no windows so rely on extractor fans. The homes are quite warm all year, but there are significant variations in energy use between households.

Bryan House shows affordable housing can also be energy efficient. The project chose innovative construction methods, with a lightweight steel-frame construction and pre-insulated panels. The aim was to deliver high standards of insulation, U-values and airtightness for maximum energy efficiency. The development has a communal heat pump and a PV array with a peak output of 5.9kW. All homes achieved maximum credits for Heat Loss Parameter (combining insulation and airtightness) under the Code for Sustainable Homes.

Camden Passivhaus is a single property in London, built to meet outstanding standards of insulation and airtightness. It has a pre-fabricated timber frame and insulated wall panels. It uses heat-recovery ventilation, and automatic blinds to reduce summer overheating. Onsite personnel experienced difficulties achieving the demanding Passive House standards, however, they ultimately reached the targets. The house now illustrates exemplary low energy use for space and water heating.

Properties

Centenary Quay buildings were designed to maximise thermal efficiency with target U-values from 0.15 (floors and roof) to 0.18 W/m^{2}K (walls). The target U-value of the windows was 1.6 W/m^{2}k, but achieved 1.2 W/m^{2}K. The development incorporates a site-wide district heating network. This uses combined heat and power (CHP), and is served by two energy centres. Each home has mechanical ventilation and a heat interface unit linked to the CHP network.

Community in a Cube is a residential development in Middlesbrough. It has an efficient thermal envelope, sustainable and breathable construction materials, and low-energy lights and appliances throughout. A communal biomass boiler supplies hot water and space heating. It also aimed to use a private wire to supply electricity from renewable sources. A dedicated energy services company maintains and operates the energy systems.

Cross Street, Gainsborough, comprises four new build houses and three refurbished homes. Walls use structurally insulated panels (SIPs), and there are triple-glazed windows. Heating is from gas boilers, with heat-recovery ventilation (this had incomplete commissioning and residents used it 'incorrectly'). The homes have solar electric panels and rainwater harvesting, and aim for Code Level 5. Airtightness was good but deteriorated over time. Two homes overheated in summer.

Dormary Court homes are constructed using the hempcrete system (a hemp and lime composite product) built around a timber frame. It has a high thermal inertia and is breathable. The designers estimated it has negative embodied energy and low U-values (a 300mm wall has a target U-value of 0.2W/m^{2}K). The bungalow also includes MVHR, roof-mounted PV, and a high-efficiency gas-condensing boiler.

Properties

Dormont Park in Dumfriesshire features houses built in a rural setting to Passive House standards. Each house faces south, with south-facing main living spaces, which allow large glazing areas for solar gain. The site is not on mains gas. As the estate has plenty of timber, the houses include a wood burner with a traditional chimney. The constructed U-values are very low. Measured energy use for space heating was well below the Passive House standard of 15kWh/m^2/y for three homes, but significantly higher for the fourth.

Dungannon Passivehaus, Northern Ireland, are designed to meet the Passive House standard. Windows are triple glazed and have a U-value of no more than 0.8 W/m^2.K. Small LPG gas boilers heat the homes. The heat is transferred through the MVHR. Solar thermal panels meet a proportion of the hot-water demand.

Future Works (Larch), Ebbw Vale, is a timber-clad home in South Wales. It has exemplary U-values (less than 0.1 W/m^{2}K for walls, roof and floor) and airtightness. It has a relatively high glazing ratio – 55% on the south side – and automatic blinds. Like other Passive House buildings, it has heat-recovery ventilation. Monitoring revealed exceptionally low energy bills and very good thermal comfort.

Future Works (Lime), Ebbw Vale, is a rendered two-bedroom house, in South Wales. Like Larch House, it meets the Passive House standard, and has heat-recovery ventilation, and exceptional insulation and airtightness. However, it has much less glazing, no automatic blinds, and a little less insulation. This meant it cost around 10% less to build than the Larch House. It has achieved class-leading energy performance.

Properties

Green Street has three-storey terraces with high-specification insulation (0.13 W/m^2K for walls) and airtightness (3 m^3/hr per m^2@50Pa). The houses have openable windows and a heat-recovery ventilation system. All houses benefit from a PV array providing up to 1.5 KWp. A gas-fired condensing combination boiler and wet radiator system provides heating and hot water. To control solar, each property has electric user-operated external blinds.

High Density Apartments, Andre Street in London, is a four-storey block of 23 apartments. It uses a novel system of heat pumps drawing energy from exhaust air. The heat pumps, linked to underfloor heating, did not deliver heat as fast as residents wanted. Poor commissioning also meant that underfloor heating distributed heat unevenly, with some hot and cold rooms. Un-closable wall vents also led to draughts and poor thermal comfort. Energy use for heating was 40% higher than expected.

Houghton-le-Spring, Sunderland, comprises 28 bungalows, built to Passive House standards, with super insulation (including triple-glazed windows), excellent airtightness, and heat-recovery ventilation. Eighteen also have solar water heaters, and five have PV arrays, to meet the Code for Sustainable Homes Level 5. The study revealed that airtightness had deteriorated six months after completion. Plug-in appliances and cooking accounted for 87% of electricity use. Studying one home also pointed to an overheating risk.

Knight's Place uses carefully scaled windows to allow good daylight and solar gain. This, together with the buildings' super-insulated envelope and high airtightness (less than 0.6 m^3/hr per m^2@50Pa), enables them to achieve space-heating requirements of less than 15 kWh/m^2/y. One solar panel per flat provides 1,200 kWh of water heating, or around 60% of average hot water requirements. A heat-recovery ventilation system was installed in each flat to provide ventilation and heating.

Properties

Low Carbon Apartments West Yorkshire comprises 13 flats for people aged over 55. It aimed to achieve Code for Sustainable Homes Level 4 (25% less energy than usual building regulations). The flats use district heating from two GSHPs, distributed by underfloor heating. They also feature rainwater harvesting. There were problems with the heat pumps, but residents are happy with their homes. Energy use was 10% to 25% higher than design estimates.

Lyndhurst Crescent, Swindon, is an affordable housing development of 13 council houses. The homes met the Code for Sustainable Homes Level 5, partly by using solar thermal and solar electric panels, with exhaust air heat pumps. Construction saw hempcrete cast into a timber frame. Airtightness fell short of an ambitious target for the two homes studied. They also both suffered from unbalanced mechanical ventilation. Occupants reported poor control over heating and high bills.

One Brighton is a mixed-use development comprising residential blocks with office and community space below. The buildings have an efficient thermal envelope, and use sustainable construction materials and low-energy appliances. A biomass boiler and PV array provide heat. The PV array is estimated to generate up to 7,600 kWh/year. A community energy services company manages the energy.

Passivhaus at Wimbish, comprises 14 flats and houses in Suffolk. It succeeded in providing low running costs. Residents say they pay just £30 a quarter for heating, and each property's heating bills are only a fraction of the UK norm. Like other Passive Houses, it has super insulation, excellent airtightness, heat-recovery ventilation, and triple glazing. The homes are comfortable. However, the air is sometimes a little dry, and the homes can be warmer than residents want in summer.

Properties

Plummerswood is the first Passivhaus Standard Certified home in Scotland. It was designed on ecological design principles to create a healthy, comfortable, energy-efficient home. The home aims to only use mechanical systems when necessary – and ensure that they supplement, not replace, natural systems. The prefabricated superstructure was constructed onsite using an innovative glue-less mass timber technique called 'brettstapel'.

Rotherham Estate This development of 24 two-to four-bedroom homes included two designed to Code for Sustainable Homes Level 5, with solar electric and solar thermal systems. They have ASHPs and complex heating controls, and some of the heating systems were larger than necessary, resulting in wasted energy and overheating. Airtightness was found to degrade over time, which partly contributed to carbon emissions for the Code 5 homes being double the expected emissions.

Rowan House social housing flats have a heavyweight block and beam construction. The historic conservation setting restricted design options. Meeting Passive House standards required super-insulated envelopes. Airtightness of less than 0.6 m^3/hr per m^2@50Pa helped the buildings achieve space heating at less than 15 kWh/m^2/y. One solar panel per flat should provide 1200kWh of water heating, or around 60% of average hot-water requirements.

Scotland's Housing Expo comprises several very different but innovative houses designed to high standards of energy efficiency and low-carbon technology. Most are of timber construction and use high levels of insulation, passive ventilation and solar heating. Each is designed by a different Scottish architect.

Properties

Thames Valley Houses in Feltham comprise 10 council houses with timber frames and brick cladding. The homes have gas boilers with heat-recovery ventilation, including a summer bypass mode. They also have solar electric panels. Airtightness (6 m^3/hr per m^2@50Pa) was not as good as the design target, but better than Building Regulations require. The study found that residents set thermostats close to 30°C and regulated temperature by opening windows – undermining energy performance.

Tigh-na-Claddach Affordable Housing in Scotland has one Passive House and two Code Level 4 homes, all built using timber frame. They have exceptional insulation, and excellent airtightness. They are off the gas grid, so use electric heating – the Passive House uses an air-to-air heat pump and heat-recovery ventilation, along with solar water heating. All three of these technologies had problems, but were replaced. Now the solar water heating provides nearly two-fifths of the hot water. All three homes use much less energy than the UK standard.

The Quarries housing for over 55's in Edinburgh comprises 58 units with communal facilities. The development provides independent housing for people aged over 55. The homes were well insulated with airtight construction. They use heat-recovery ventilation. The development also tries to recycle heat collected in sun-trap walkways. Solar PV panels supply 'free' electricity to the communal area.

Annual energy use

Measured energy use in the homes ranged from 4,373 to 42,706 kWh (for electricity and heating fuel) – a factor of nearly ten between the lowest and highest.

A wide variation

The highest electricity-consuming home used more than 21 times as much electricity as the lowest – and 68 times as much heating fuel (see table 1). The homes' design and construction are not the only reasons for this. Occupant numbers particularly affect electricity and energy use for hot water. Some households also own and use more electrical appliances than others.

A positive achievement

The low-end figures represent a positive achievement, considering Ofgem's 'typical' consumption figures are 3,200 kWh a year for electricity and 13,500 kWh a year for gas[1].

Eight of the homes used a tiny amount of heating fuel for space and water heating – less than 2,000 kWh a year. And 24 of them used a tiny amount of grid electricity – again, less than 2,000 kWh a year (with extra electricity coming from homes' own PV panels). In short:

- 49 of the projects used less electricity than Ofgem's electricity benchmark
- 29 used more than Ofgem's electricity benchmark
- 55 of the non-electric heating homes used less than Ofgem's thermal energy benchmark
- only 7 of the non-electric heating homes used more than Ofgem's thermal energy benchmark.

[1]Ofgem (2013) New Typical Domestic Consumption Values. London: Ofgem. ['Medium' figures quoted.]

All figures kWh/year	Highest	Lowest	Average (mean)
Electricity*	8,528	657	3,281
Heating fuel (with outlier)**	29,786	440	6,258
Heating fuel (outlier removed)	20,240	440	5,890
Biomass***	3,398	496	1,448

Table 1: Energy use by fuel – highest and lowest consumption

* Excluding electrically heated homes.
** One home has very high gas use for CHP. Data shown with and without this outlier – see above.
*** Only the seven homes with biomass heating.

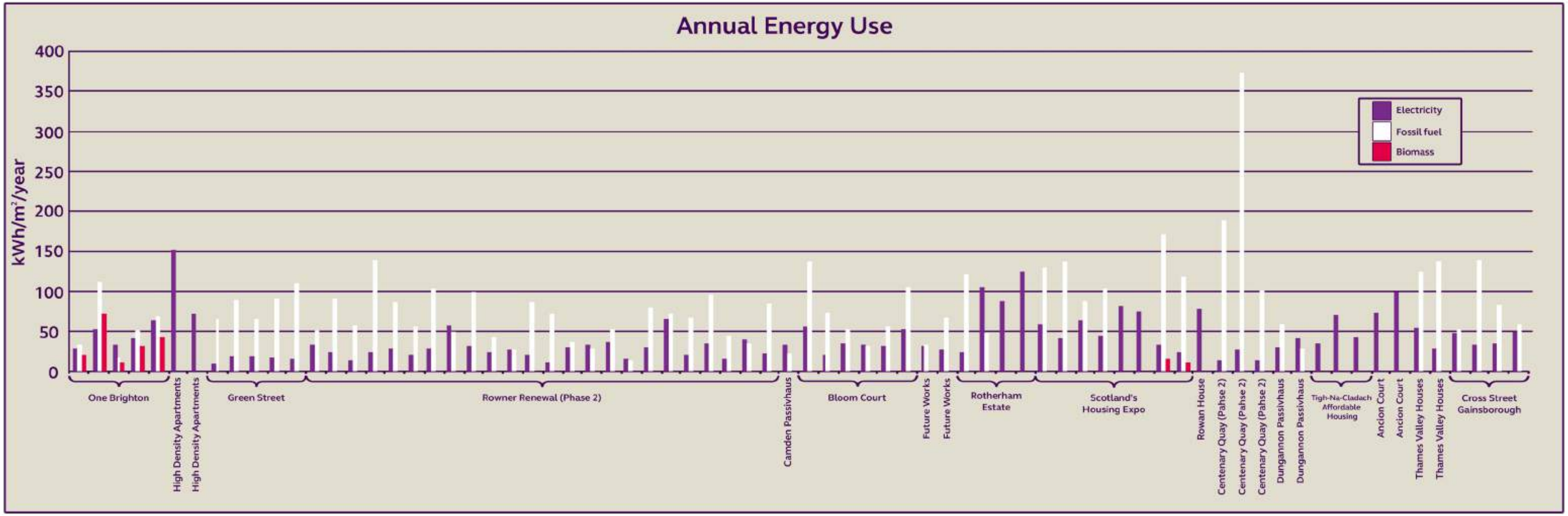


Fig 1. Some of these homes use tiny amounts of energy. The one very high gas use at Centenary Quay is partly to run CHP – some of the gas is used to generate electricity exported to the grid.

Explaining a high figure

The one high heating fuel figure of 29,786 kWh a year is an outlier (an observation that is abnormally distant from other values). It applies to one of the homes on the Centenary Quay estate. It has CHP, which uses gas to generate heat and electricity. The home exports some of this electricity through the grid to other households. This partly explains the unusually high gas use.

Considering factors other than temperature

The number of residents typically has less effect on energy use for heating than energy use for appliances and water heating. The way homes are built is also not always the decisive factor. Some households prefer high internal temperatures in winter (approaching 30°C average in the living room and bedrooms), while others prefer much cooler conditions (down to 20.6°C average in the living room and bedrooms).

All of the homes are warm compared to the UK mean winter internal temperature of 17.7°C. [2] It would be expected that homes kept warmer in winter use more energy, on average. However, there is little evidence of that here (see fig. 2). Other factors appear to be more significant than temperature alone.

[2]Palmer J, Cooper I (2014) UK Housing Energy Fact File 2013. London: DECC.

Examining the figures

Different projects excelled in different areas. The following figures are positive, considering the high thermal comfort the homes deliver:

- Many of the Rowner Renewal homes had exceptionally low electricity use (below 30 kWh/m^2 a year, or in one case, only 14 kWh/m^2).
- Some of the One Brighton units, and some of those at Green Street, also had low grid electricity use – well under 30 kWh/m^2.
- The Camden Passivhaus had exceptionally low fuel use for space and water heating – just 22.9 kWh/m^2 a year.
- One of the One Brighton units; one of the homes at Rowner Renewal; and Dungannon Passivhaus also performed well for thermal energy – with measured thermal energy use below 30 kWh/m^2 a year.

Recommendations

1. Adopting Passive House principles can achieve very low energy use for space heating. Long-term low heating bills can repay the extra effort and attention needed onsite.
2. Construction has a limited effect on electricity use. However, the use of low-power fittings, including lights, can reduce demand. Efficient construction provides a much bigger scope for savings in space heating.
3. High-density flats can achieve exceptionally low demand for thermal energy, especially when combined with onsite renewables like PV and solar thermal.

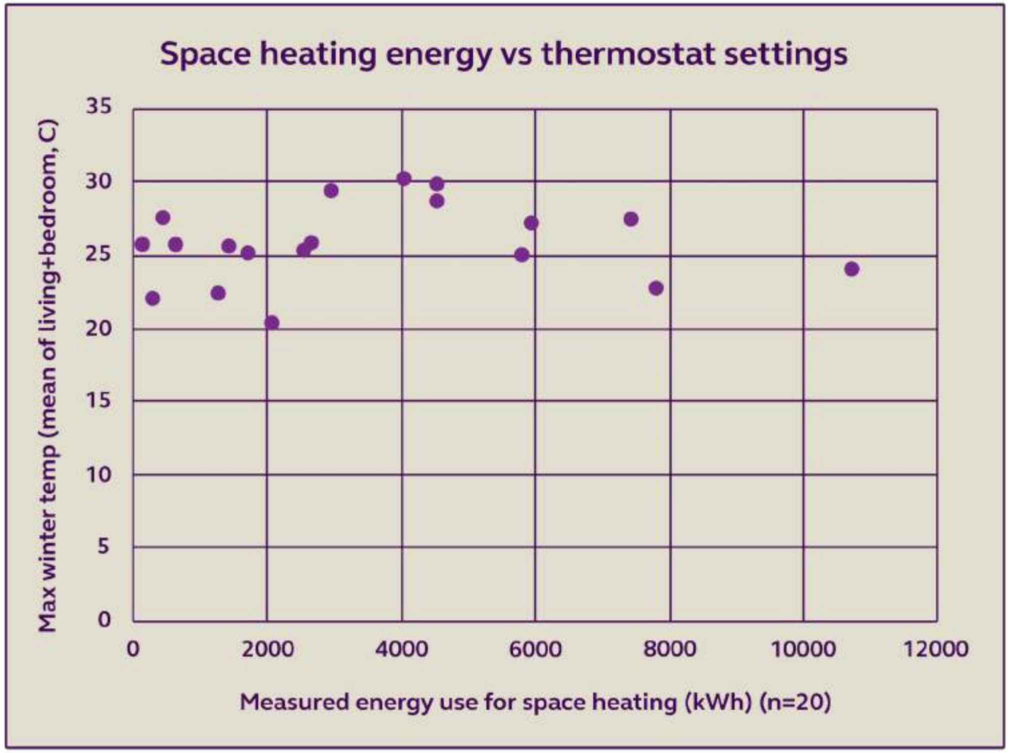


Fig 2. There is no correlation between maximum winter temperature and energy use. This suggests that other factors – including the duration of heating – are more important than peak internal temperature. One outlier, recorded at 35°C, has been removed from this graph.

Eight of the homes used a tiny amount of heating fuel for space and water heating… and 24 of them used a tiny amount of electricity.

The performance gap

This study provides strong evidence that carbon emissions from new homes are two or three times higher than design estimates.

Estimating use and emissions

UK Building Regulations require new homes to estimate energy use and carbon emissions, using standard assumptions. The Standard Assessment Procedure (SAP) creates these estimates. Designers and developers must submit SAP calculations with their planning applications.

SAP includes assumptions about how residents will use heating (thermostat settings and hours of use), lighting and hot water. It also include estimates of energy and carbon savings from low and zero-carbon technologies, if they will be installed. However, the SAP figures do not estimate energy use for appliances and cooking, which have little to do with how homes are designed and built.

SAP provides a way to compare energy and carbon performance between homes at the design stage. It does not provide an accurate estimate, because it is impossible to know beforehand how residents will use energy systems.

The gap between estimates and reality

It is expected that SAP energy use and CO_2 estimates would be lower than the actual figures. This is because actual energy use includes appliances and cooking, and so-called 'regulated' energy.

For most of the projects, SAP predictions of CO2 varied from 8 to 23 $kgCO_2/m^2$ a year. Some were predicted to have 'negative' emissions – four at Cross St, Gainsborough; and the two Welsh Passive Houses at Future Works.

Higher emissions in the first year

However, in the first year of monitoring, usually straight after homes were handed to residents (dates varied between projects), actual carbon emissions were much higher, mostly varying from 20 to 50 $kgCO_2/m^2$ a year (see fig. 3). Two homes had far higher actual carbon emissions in the first year. This was as much as 88 $kgCO_2/m^2$ a year in one of the Rotherham Estate houses.

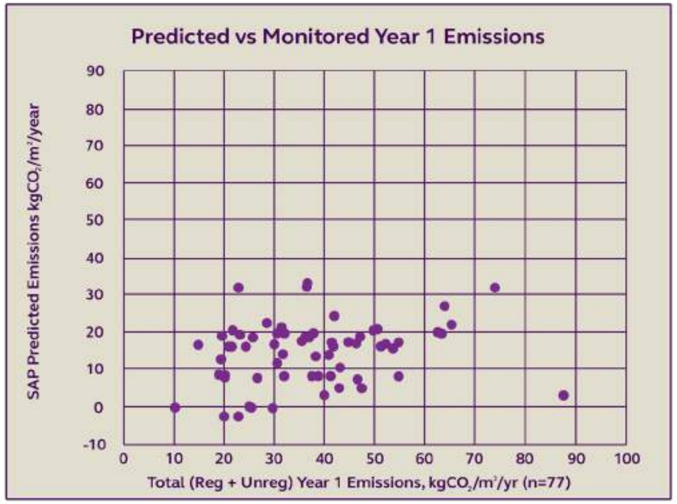
The house spans 114m^2; has a heat pump, solar water heating, PV and heat-recovery ventilation; and recorded problems with the solar water heating. Its result, at the time of monitoring, is 29 times more than the design estimate for regulated energy.

Reducing emissions in the second year

In the second year of monitoring, some of the very high carbon emissions were reduced. This is common, as energy system teething problems are overcome. However, some of the middle-ranking emitters increased emissions. Actual emissions mostly ranged from 16 to 55 $kgCO_2/m^2$ a year – a wider range than the first year. Despite this, average emissions fell overall from 36.2 to 34.3 $kgCO_2/m^2$ a year.

There was scarcely any link between the SAP estimate of CO_2 emissions for space and water heating, lighting and ventilation, and actual total emissions. This is surprising, as it is common for heating and lighting to make up 80% of total energy use in individual homes.

The average SAP estimate for regulated emissions across all homes with this data was 14.1 $kgCO_2/m^2$ a year. The average total carbon emissions for both years was 35.3 – more than 2.5 times higher than the design estimate. It is a little misleading to call this a 'performance gap', as the actual emissions include energy use from cooking and appliances. However, even allowing for this, the evidence highlights much higher actual carbon emissions than design-stage estimates.



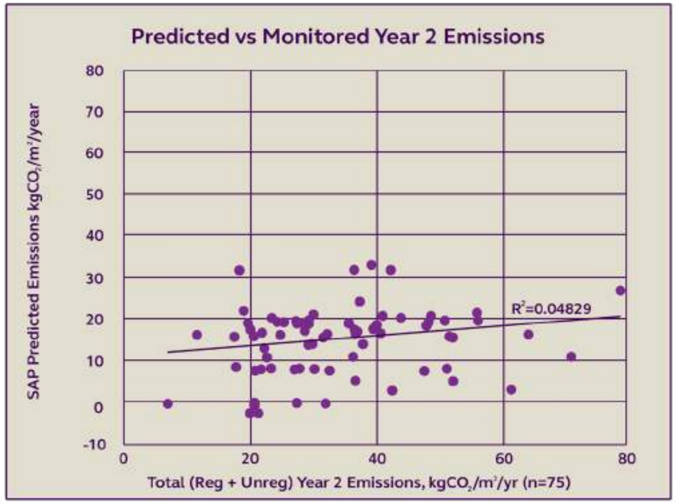


Fig 3a. and 3b. The SAP figures here are the 'Dwelling Emission Rate'. The carbon intensities used were gas 0.194, electricity 0.55, and biomass 0.025 $kgCO_2/kWh$.

Recommendations

1. It should not be assumed that actual carbon emissions link in any way to emission estimates needed for planning consents (also used in EPCs).
2. Teething problems in the first year can increase CO_2 emissions – sometimes quite considerably. There is no guarantee that such problems will be spotted and fixed, unless there is a performance evaluation and intervention.
3. To achieve low-carbon emissions, low-carbon heating – such as biomass heating and heat pumps – needs to be carefully designed, installed, maintained and used.

Fabric

The study revealed a gap between design aspirations and the actual performance of building fabric.

Testing thermal performance

A blend of thermal imaging and airtightness testing can show weaknesses in building fabric's thermal performance. Both tests are useful. However, the study found that thermal imaging was better at finding small internal air-leakage pathways. Using these tests as building progresses is useful for detecting problems early. However, in the long term, design practices and construction skills must change to prevent these problems.

Reviewing and assessing

Before changing designs, projects should always review the implications and assess how they might affect the building's performance. For example, the Avante project changed the cladding and roofing materials once the building was on site, which harmed the building fabric's performance. Designers and developers must have a clear process that identifies desired performance characteristics – and requires the changes to comply with the output specification.

Integrating innovative designs

To avoid detailing problems later, innovative designs must integrate fully with services from an early stage. Designers and developers need to 'road test' elements such as large windows and lanterns, making sure they are accessible and usable. The study found this to be a weakness on the Avante project.

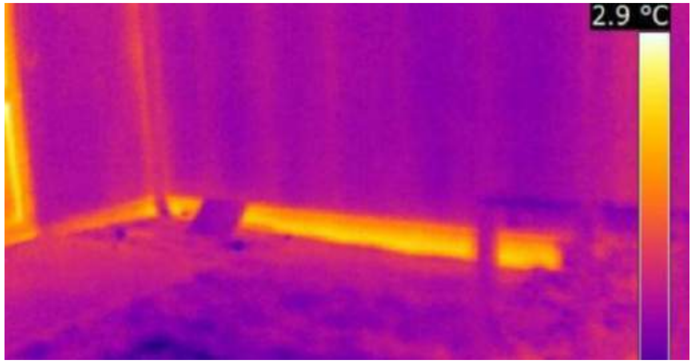


Image 1: Thermal image suggests there may be heat loss through the brick plinth at The Quarries.

To avoid detailing problems later, innovative designs must integrate fully with services from an early stage.

Coordinating construction

If using prefabricated elements, designers and developers need to carefully coordinate the construction process. This will help avoid unnecessary site amendments. Teams should also cross-check detailing before going onsite.

The importance of good drawings

Clear, well-referenced and updated drawings that also show design changes could alleviate many of the problems. Good drawings are vital for architects to communicate their complex and innovative low-carbon design ideas to contractors.

Recommendations

1. Testing throughout the design process will prevent and detect detailing, which could cause heat loss. All relevant parties should fully understand changes to design, and how they might affect building performance.
2. A clear process should be established to ensure any onsite design changes do not affect the building fabric performance.
3. Prefabricated elements should be coordinated and checked to minimise onsite disruptions and alterations.
4. Clear and up-to-date drawings should be used, especially for points vulnerable to heat loss, such as plinths and window-frame junctions. Work should be done as detailed.

Project	Problem	Cause	Solution
The Quarries	Detailing issues in many components which cause minor heat loss, e.g. wall plinths Ductwork losing heat outside the building envelope Changes to the design resulted in overheating in the access corridors	Insulation insufficient or missing – work not done to designers' specifications Not fully insulated beyond roof penetration Fire regulation/value-engineering compliance forced design changes, which limited ventilation	Check work adheres to architects' design Ensure continuous insulation of ductwork Consider designing for fire regulations at an early stage, so the design is not compromised
Community in a Cube	Trickle vents installed despite being unnecessary, due to the presence of MVHR	Unknown – possibly lack of understanding of Part F of the Building Regulations	Check construction details more rigorously as projects progress – and use clear drawings
Avante Homes	Discrepancies between design and building e.g. late substitutions of roofing and cladding materials Restricted flow in ductwork, resulting in increased fan power	Lack of coordination between the design and site teams Flexible ductwork used, which has a higher air resistance	Better communication between architects and site team about detailing and specifying fabric Use rigid ductwork where possible
Dungannon Passivhaus	Errors in fitting insulation	Human error	Check and rectify carefully; attention to detail on site; use factory-made panels
Future Works	Possible heat loss around plinth area	Contractors may not have carried out detailing as specified in drawings	Check work is done as specified
Centenary Quay	Damage to floor fabric during construction meant it had to be replaced	Ground workers accidentally punctured pipe, which leaked steam	Rigorous commissioning of building; better on-site supervision – especially around vulnerable components

Table 2: Problems caused by poor detailing experienced by select projects.

Co-heating tests

A co-heating test is a tried-and-tested way to assess a home's 'heat-loss coefficient' – which summarises its overall thermal performance.

What is a heat-loss coefficient?

A heat-loss coefficient (HLC) is a measure of the whole building fabric's insulation value. It summarises the combined effect of construction materials, insulation and glazing U-values, and airtightness. It is also a parameter in SAP.

Measuring the HLC

The HLC can be measured directly with a 'co-heating test', which uses electric fan heaters and fans to bring a home up to a stable, even temperature (typically 25°C). The technique requires the home to be empty, with no other internal gains. This allows the test user to precisely measure the energy input needed to maintain a fixed temperature difference compared to outside.

Calculating the average

The design HLCs from SAP in 12 projects where data was present ranged from 37.2 W/K for one of the Passive House projects to 135 W/K for a more traditional construction. The average SAP HLC across these projects is 83.6 W/K.

Optimism among designers

This compares to measured HLCs ranging from 41 to 221 W/K, and a mean of 98.8 W/K. In nine out of thirteen cases, the SAP design estimate was better than the measured HLC. This suggests designers are optimistic when assessing the true heat loss from their designs. Four cases also achieved better-than-expected HLCs, including the Camden Passivhaus, which was significantly better than designs suggested.

Recommendations

1. A co-heating test on a prototype property should be considered. This will help enable more accurate overall thermal performance measurements. It also help roll out many homes using consistent construction.
2. Passive House designs, which focus more on insulation and airtightness than conventional construction techniques, should be considered. The properties achieve the best HLCs and thermal performance.
3. An HLC is only as good as the weakest link in a thermal envelope. Thermal bridges, incomplete insulation and gaps in the air barrier result in higher HLCs.

Project	Heat-loss coefficient (W/K)			Test by
	Design SAP	As-built SAP	Measured	
Future Works (Lime House), Wales	37.2 (PHPP)	101	41+/-8 or 45+/-2 [1]	Welsh School of Architecture
Rowner Renewal	52.8	-	91.6	BSRIA
Future Works (Larch House), Wales	57.6 (PHPP)	102	60+/-14 or 62+/-4 [1]	Welsh School of Architecture
Camden Passivhaus	63.6 (PHPP)	-	35+/-15 [2]	UCL
Andre Street plot 6	68.9	68.9	76.4	Gastec
Andre Street plot 14	71.2	71.2	77.8	Gastec
Lyndhurst Crescent, plot 6	86	-	116	BSRIA
Lyndhurst Crescent, plot 7	86	-	150	BSRIA
Stawell	110.53	97.40	105.17	Oxford Brookes
Ratby	122.05	-	140.3	Oswald Consulting
Avante Homes	134.0 [3]	133.8 [4]	121.6	Oxford Brookes
Dormary Court	134.9	-	220.6	Leeds Met

Table 3: Co-heating test results compared to SAP calculated figures

[1] WSA performed an unusual 'Siviour' analysis as part of its co-heating test. WSA said this helped minimise the effect of solar gains on the results. The first figure is the usual regression HLC. The second figure is from the Siviour analysis.

[2] It was warm and sunny during this test, which meant it was impossible to maintain 25°C continuously. This led to less accurate results, and UCL recommended a second co-heating test.

[3] Using the original SAP calculation, which had MVHR on; not the revised SAP calculation, with MVHR off, which cited an HLC of 118.45 W/K. Oxford Brookes subsequently re-calculated this as 113.65 without MVHR.

[4] Oxford Brookes re-calculated the as-built HLC at 127.7 W/K.

Air-permeability testing

Many homes achieved airtightness test results that would have been unheard of just 15 years ago. However, some still failed to meet their goals.

What is air permeability?

Air permeability is a measure of how much air enters or leaves a building per square metre of envelope, when pressurised up to a differential of 50 Pascals (Pa) between inside and outside. This simulates the effect of strong wind. A pressure test involves using a large fan, taped in place of the front door (a 'blower door'), and temporarily sealing ventilation paths.

Calculating the average

The design air permeability for 69 projects in the study ranged from 0.34 to 10 m^3/hr per m^2@50Pa, with an average target permeability of 4.61 m^3/hr per m^2@50Pa. Forty of the projects had design targets of less than half – that is, twice as good as – the minimum requirement of Part L of the Building Regulations (10 m^3/hr per m^2@50Pa).

Decreasing airtightness over time

Most of the projects calculated air permeability several times. Table 4 shows the earliest results – typically from around completion – alongside the most recent ones, to see if airtightness deteriorated over time. In fact, most projects became less airtight over time.

In fact, most projects became less airtight over time. However, most stayed comfortably within Part L's airtightness requirements; and the average recent permeability was 4.24 m^3/hr per m^2@50Pa (across the projects, for pressurisation and depressurisation).

Larch House on the Future Works site in South Wales achieved an exceptional 0.26 m^3/hr per m^2@50Pa almost 4 years after it was completed. Nevertheless, the data shows that when designing heating and ventilation systems, designers and developers should consider how building performance changes over time.

Failing to meet expectations

While most homes achieved better air permeability than the design estimates, almost a third did not meet airtightness expectations. The major implication for Part L of the Building Regulations is that most new homes are still not achieving the heat-loss coefficients and airtightness results submitted to Building Control in planning applications.

In this study, more than a third of such homes were more than 50% over the expected heat-loss coefficient. Additionally, many airtightness targets are not ambitious. Almost a quarter of these projects did not aim to do any better than the minimum Building Regulations requirements.

Recommendations

1. Airtightness problems should be avoided from the start rather than plugging gaps with sealant after construction is complete.
2. The air barrier should be monitored through design and onsite, and shown clearly on drawings – especially for junctions – and ideally in a different colour.
3. Wet construction typically achieves better airtightness than plasterboard.
4. Appointing an onsite airtightness champion with the authority to intervene when needed should be considered.

Project	House Type	Ventilation	Air permeability (m^3/hr per m^2@50Pa)					Test dates
			Design	Depressurisation		Pressurisation		
				Earlier	Later	Earlier	Later	
Future Works (Lime House)	House	MVHR	0.34	0.40	0.49	0.29	0.44	2010 and 2014
Knight's Place, 1	Flat	MVHR	0.41	0.30	0.74	-	-	2011 and 2013
Knight's Place, 2	Flat	MVHR	0.46	0.39	1.16	-	-	2011 and 2013
Tigh-Na-Cladach Affordable Housing, 1	House	MVHR	0.50	1.15	0.59	0.76	0.57	2013 and 2014
Rowan House, 1	Flat	MVHR	0.50	0.33	0.95	-	-	2010 and 2013
Rowan House, 2	Flat	MVHR	0.50	0.55	1.10	-	-	2010 and 2013
Camden Passivhaus	House	MVHR	0.54	-	-	0.53	0.71	2011 and 2013
Future Works (Larch House)	House	MVHR	0.56	0.26	0.27	0.22	0.25	2010 and 2014
Dormont Park, DA12[2]	House	MVHR	0.6	2.42	2.23	-	2.08	2012 and 2014
Dormont Park, DB12[2]	House	MVHR	0.6	2.72	2.06	-	1.87	2012 and 2014
Dormont Park, DA22[2]	House	MVHR	0.6	2.14	1.93	-	1.83	2012 and 2014
Dormont Park, DB22[2]	House	MVHR	0.6	2.41	1.85	-	1.82	2012 and 2014
Dungannon Passivhaus, 2	House	MVHR	0.66	-	-	0.69	1.47	2012
Plummerswood	House	MVHR	0.79	Avg 0.50	Avg 0.69	-	-	2010 and 2013
Dormary Court, Bungalow	Bungalow	MVHR	2.00	4.32	4.92	4.63	4.87	2011 and 2014
Lyndhurst Crescent, 1	House	MVHR	2.00	Avg 5.36	Avg 6.35	-	-	2013 and 2014
Dormary Court, House	House	MVHR	2.00	7.25	6.12	7.81	7.89	2011 and 2014
Lyndhurst Crescent, 2	House	MVHR	2.00	Avg 15.77	Avg 16.48	-	-	2013 and 2014

Table 4: Comparison of airtightness test results

Project	House Type	Ventilation	Air permeability (m³/hr per m²@50Pa)[2]					Test dates
			Design	Depressurisation		Pressurisation		
				Earlier	Later	Earlier	Later	
Cross St, 1	House	MVHR	3.00	2.65	3.30	2.53	3.46	2012 and 2014
Cross St, 2	House	MVHR	3.00	2.66	3.63	1.90	3.67	2012 and 2014
Green Street, 1	House	MVHR	3.00	-	-	2.92	3.87	2011 and 2012
Green Street, 2	House	MVHR	3.00	-	-	-	3.87	2012
Rotherham Estate, 1	House	MVHR	3.00	5.16	5.32	5.57	5.64	2012 and 2014
Green Street, 5	House	MVHR	3.00	-	-	2.97	5.62	2011 and 2012
Thames Valley Housing, 1	House	Mixed Mode	3.00	Avg 5.86	Avg 6.01	-	-	2013 and 2014
Thames Valley Housing, 2	House	Mixed Mode	3.00	Avg 5.97	Avg 6.17	-	-	2013 and 2014
Green Street, 6	House	MVHR	3.00	-	-	-	7.07	2012
Green Street, 7	House	MVHR	3.00	-	-	2.92	-	2011
Green Street, 8	Flat	MVHR	3.00	-	-	2.98	-	2011 and 2012
Rowner Renewal, B1	Flat	MVHR	4.00	-	-	3.99	4.73	2011 and 2013
Rowner Renewal, B2	Flat	MVHR	4.00	-	-	3.33	4.95	2011 and 2013
Rowner Renewal, C1	Flat	MVHR	4.00	-	-	-	4.98	2013
Rowner Renewal, C2	Flat	MVHR	4.00	-	-	3.70	5.23	2011 and 2013
Rowner Renewal, C3	Flat	MVHR	4.00	-	-	3.73	5.44	2011 and 2013
Rowner Renewal, B3	Flat	MVHR	4.00	-	-	3.95	5.49	2011 and 2013
Rowner Renewal, C4	Flat	MVHR	4.00	-	-	3.84	5.90	2011 and 2013

Table 4: Comparison of airtightness test results

Project	House Type	Ventilation	Air permeability (m^3/hr per m^2@50Pa)[2]					Test dates
			Design	Depressurisation		Pressurisation		
				Earlier	Later	Earlier	Later	
Rowner Renewal, B4	Flat	MVHR	4.00	-	-	-	5.95	2013
High Density Apartments, 1	Flat	MVHR	5.00	2.76	2.52	2.71	2.86	2011 and 2012
Aberfawr Terrace, 1	Flat	MVHR	5.00	Avg 2.90	Avg 3.72	-	-	2010 and 2014
Aberfawr Terrace, 2	Flat	MVHR	5.00	Avg 4.80	Avg 8.08	-	-	2010 and 2014
Low Carbon Apartments, 1	Flat	Natural	5.00	4.75	4.80	-	-	2012 and 2014
Low Carbon Apartments, 2	Flat	Natural	5.00	5.35	-	-	-	2012 and 2014
Low Carbon Apartments, 2	Flat	MVHR	5.00	5.72	5.35	5.73	5.41	2011 and 2012
Rotherham Estate, 2	House	MVHR	5.00	7.60	-	7.95	-	2012
One Brighton, 1	Flat	MVHR	5.00	4.17	-	-	-	2009
One Brighton, 2	Flat	MVHR	5.00	4.17	-	-	-	2009
One Brighton, 3	Flat	MVHR	5.00	4.69	-	-	-	2009
One Brighton, 4	Flat	MVHR	5.00	4.69	-	-	-	2010
One Brighton, 5	Flat	MVHR	5.00	4.84	-	-	-	2009
Centenary Quay	House	Natural	6.00	Avg 7.53	Avg 7.15	-	Avg 7.88	2011 and 2013
Tigh-Na-Cladach Affordable Housing, 2	House	MVHR	10.00	4.31	3.07	3.76	2.89	2013 and 2014
Tigh-Na-Cladach Affordable Housing, 3	House	MVHR	10.00	4.44	3.41	4.14	3.32	2013 and 2014
Scotland's Housing Expo, A1	House	Natural	10.00	3.82	3.50	-	3.63	2012 and 2014
Bloom Court, 1	House	Natural	10.00	3.71	Avg 3.99	-	Avg 3.98	2012 and 2014
Scotland's Housing Expo, A2	House	Natural	10.00	4.21	4.20	-	4.41	2012 and 2014
Scotland's Housing Expo, C2	Flat	Mech	10.00	5.93	5.47	-	5.34	2012 and 2014

Table 4: Comparison of airtightness test results

Project	House Type	Ventilation	Air permeability (m^3/hr per m^2@50Pa)[2]					Test dates
			Design	Depressurisation		Pressurisation		
				Earlier	Later	Earlier	Later	
Scotland's Housing Expo, B2	House	Natural	10.00	5.82	5.73	-	5.35	2012 and 2014
Scotland's Housing Expo, D1	Flat	Natural	10.00	5.71	6.06	-	6.06	2012 and 2014
Scotland's Housing Expo, D2	Flat	Natural	10.00	4.53	6.64	-	6.34	2012 and 2014
Bloom Court, 2	House	Natural	10.00		-	-	-	2012

Table 4: Comparison of airtightness test results

[1] Naturally ventilated dwellings usually have intermittent mechanical extraction from kitchens and bathrooms. 'MVHR' is mechanical ventilation with heat recovery, also known as heat-recovery ventilation. Mechanical ventilation is recommended for dwellings with airtightness below 5 m^3/h per m^2@50Pa.

[2] The airtightness targets for passive house projects is expressed differently from the Building Regulations minimum requirements for airtightness - as 'air changes per hour', not m^3/h per m^2'. Design targets for Passive House dwellings Design targets for passive house dwellings are hard to convert directly to an airtightness figure, because this depends on the area of the building envelope. However, a target of 0.6 ach@50Pa is likely to be at or below around 1 m^3/h per m^2@50Pa.

The Passive House projects have far better airtightness than other schemes. This undoubtedly contributes to their lower energy use for space heating.

Most projects' airtightness deteriorates over time, sometimes by more than one third. So the 'as constructed' airtightness is unlikely to endure several years after people move in.

Energy systems

Low-carbon homes often have complex systems that provide heating, hot water, electric services – and a bigger risk of things going wrong.

Integrating new technologies

Most of the homes studied – 65 out of 76 – have complicated and innovative technologies that collect, store, provide and control energy. Designers should consider how these technologies integrate within buildings, and contractors must install them properly onsite.

Allow for technologies in designs

Homes often need more space for these technologies – such as for the plant, ductwork and vents – than for conventional energy systems. Sometimes, homes also need extra storage space, for example, for biomass fuels. Designers must allow for this and design these technologies into the building.

Mechanical ventilation systems illustrate this well. Buildings must be detailed correctly so that complex ventilation systems can function effectively. Contractors need to know that even small changes can harm the whole system. For example, there must be small air gaps under internal doors. For Avante Homes and in Future Works, there were either no gaps or thick carpeting.

Maintaining ventilation systems

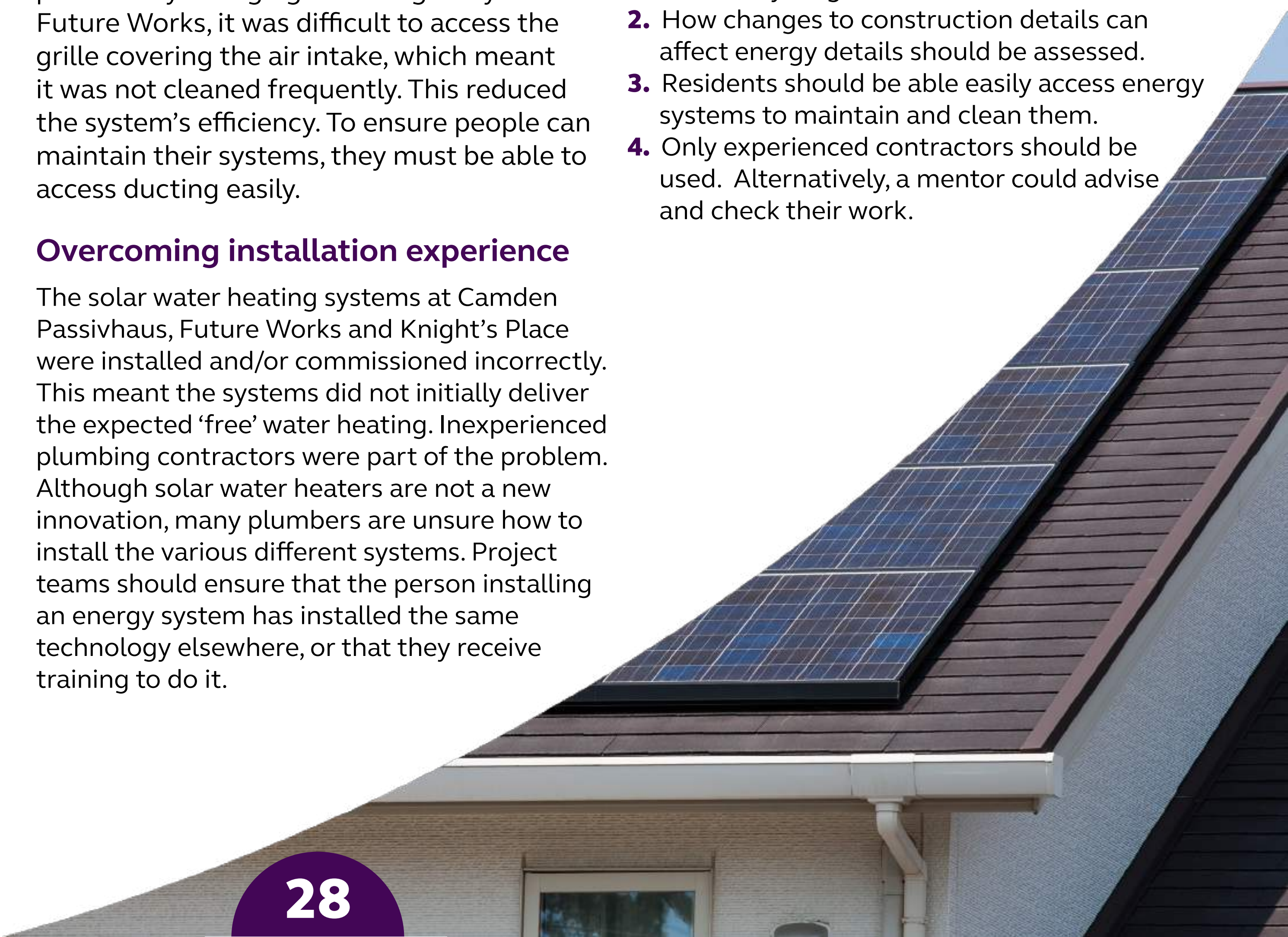
Maintaining ventilation systems is essential, particularly changing filters regularly. At Future Works, it was difficult to access the grille covering the air intake, which meant it was not cleaned frequently. This reduced the system's efficiency. To ensure people can maintain their systems, they must be able to access ducting easily.

Overcoming installation experience

The solar water heating systems at Camden Passivhaus, Future Works and Knight's Place were installed and/or commissioned incorrectly. This meant the systems did not initially deliver the expected 'free' water heating. Inexperienced plumbing contractors were part of the problem. Although solar water heaters are not a new innovation, many plumbers are unsure how to install the various different systems. Project teams should ensure that the person installing an energy system has installed the same technology elsewhere, or that they receive training to do it.

Recommendations

1. Energy systems should be included in designs at an early stage.
2. How changes to construction details can affect energy details should be assessed.
3. Residents should be able easily access energy systems to maintain and clean them.
4. Only experienced contractors should be used. Alternatively, a mentor could advise and check their work.



Project	Problem	Cause	Solution
Centenary Quay	Radiators oversized	Unknown, possibly to comply with expected norms in British heating systems	Check that contractors install the specified size of radiators, and designers match radiator size to true heat loss
Andre Street	Heating using underfloor systems appeared to use much more energy than electric fan heaters	Complex but related to the additional ventilation produced by the 'NIBE' system – and compounded by the large thermal mass of floor, especially when heated by a small heat pump	Further investigation required
	Electric sub-meters labelled incorrectly, so two flats effectively swapped meters	Incorrect labelling	Checks before handover
Avante Homes	Some doors have insufficient air gaps at the bottom to allow for cross ventilation	Human error	Checking designs implemented accurately on site; effective communication
Ebbw Vale	Insect screens for ventilation system became badly blocked	Screens not accessible for replacement and cleaning	Screens removed, and accessible pre-filters now filter insects and debris
	Door undercuts too small for the ventilation system	Carpets installed which were not specified originally	Ensure contractors understand importance of ventilation under doors when making changes
Camden Passive House	Solar water heating pump control error and installation errors	Contractor error that did not come to light until building was handed over	Ensure installers are competent and experienced

Table 5: Problems with energy systems experienced by select projects

Project teams should ensure that the person installing an energy system has installed the same technology elsewhere.

Heat-recovery ventilation

Heat-recovery ventilation systems are becoming commonplace, particularly in airtight homes and Passive Houses, where they are a requirement. However, the study showed that many were insufficiently commissioned.

Considering installations from every angle

Many installations were not thought through from every angle. For example, ductwork was routed in awkward voids and fan units sited in inappropriate locations. In such cases, the systems' airflows underperform. This is caused by too much resistance in the system, inadequate commissioning, or both.

Increasing resistance and noise

Many projects decided to use flexible ductwork, or to introduce additional bends, tees and reducers, for example. This significantly increased the system resistance beyond its allowed static pressure. Additionally, this can cause more sound to escape from the system. In at least three homes, residents switched off their systems to stop the noise.

Ensuring expert installation

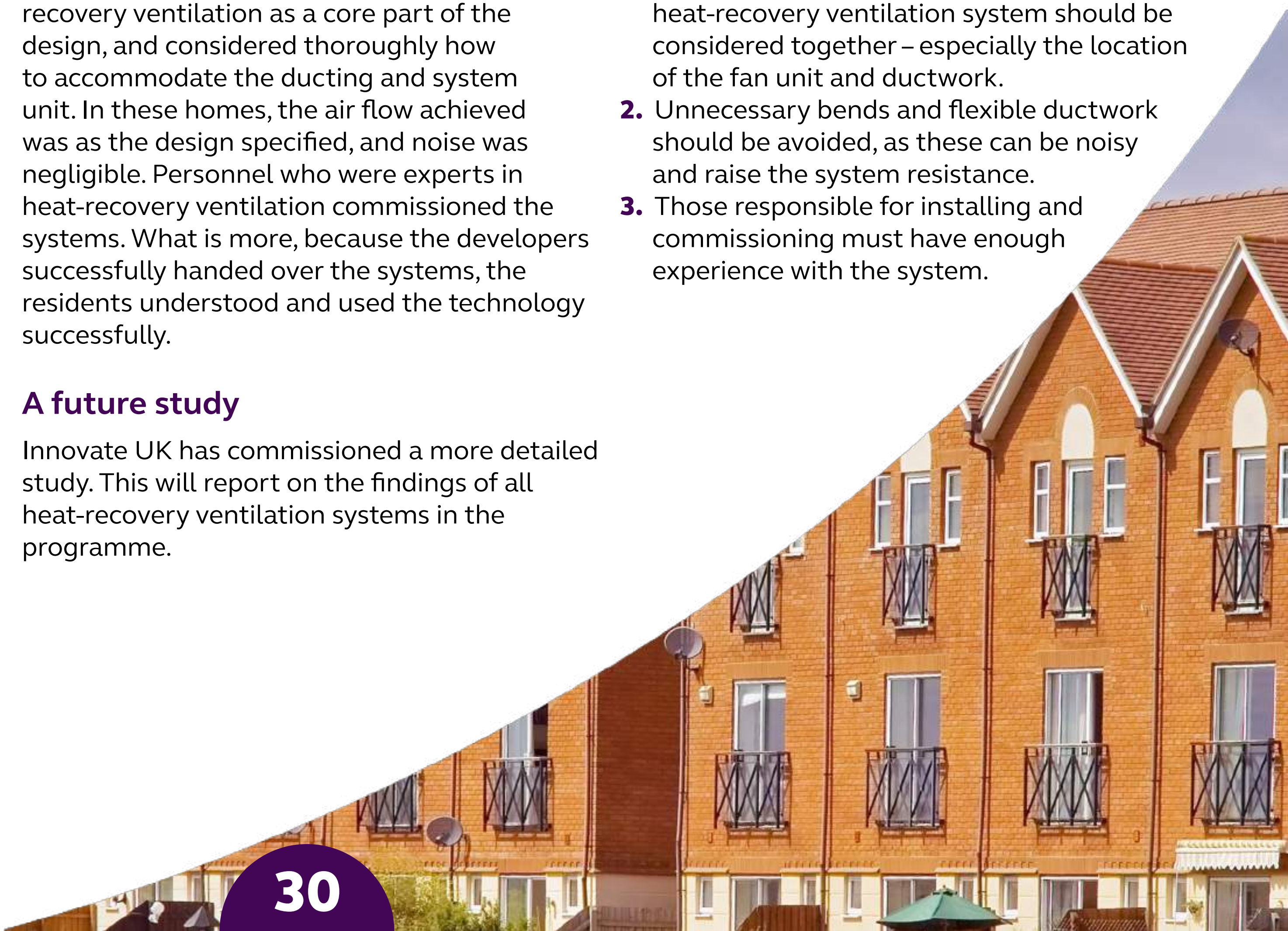
More positively, a few projects saw heat-recovery ventilation as a core part of the design, and considered thoroughly how to accommodate the ducting and system unit. In these homes, the air flow achieved was as the design specified, and noise was negligible. Personnel who were experts in heat-recovery ventilation commissioned the systems. What is more, because the developers successfully handed over the systems, the residents understood and used the technology successfully.

A future study

Innovate UK has commissioned a more detailed study. This will report on the findings of all heat-recovery ventilation systems in the programme.

Recommendations

1. To ensure seamless design, all parts of the heat-recovery ventilation system should be considered together – especially the location of the fan unit and ductwork.
2. Unnecessary bends and flexible ductwork should be avoided, as these can be noisy and raise the system resistance.
3. Those responsible for installing and commissioning must have enough experience with the system.



Controls

Low-carbon energy systems will only perform well if residents know how and why they work.

Explaining systems to residents

The study found that developers had not explained low-carbon energy systems well enough to residents when handing over properties to them. Low-carbon technologies, such as community biomass boilers and heat-recovery ventilation systems, are unfamiliar to most people, and have unclear benefits. Some Birchway Eco Community residents did not understand what the heat-recovery ventilation system aimed to do, seeing it as a waste of electricity and a source of dust. Some said they had turned it off at the distribution unit. Simply explaining how and why systems work would help solve this.

Fitting simple controls

Designers should avoid using complex controls, and allow residents to manage their heating from one unit. Dungannon Passivhaus properties had two thermostats, which residents needed to set at different temperatures, when one would have been easier to use and understand. Similarly, the Bicester Homes development has thermostats in every room. Conversely, Future Works' heating controls just have an on/off button and an "up/down arrow to change temperature.

This digital controller should help avoid the common belief that a rotary thermostat is a type of 'tap', where higher settings correlate to more power. In truth, thermostats do not affect power – they only affect whether the heating is on or off.

Avoiding automatic controls

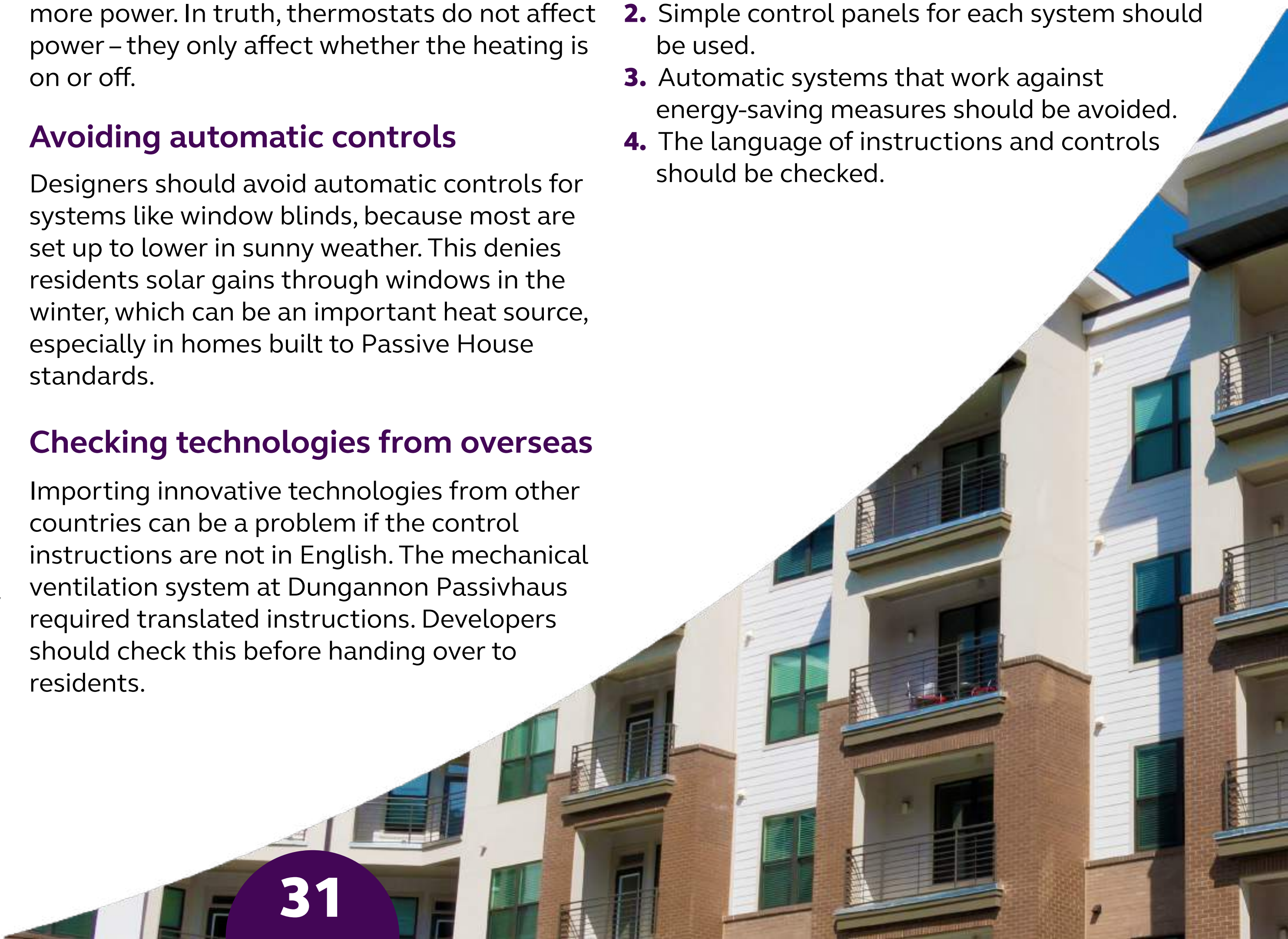
Designers should avoid automatic controls for systems like window blinds, because most are set up to lower in sunny weather. This denies residents solar gains through windows in the winter, which can be an important heat source, especially in homes built to Passive House standards.

Checking technologies from overseas

Importing innovative technologies from other countries can be a problem if the control instructions are not in English. The mechanical ventilation system at Dungannon Passivhaus required translated instructions. Developers should check this before handing over to residents.

Recommendations

1. When handing over, residents must receive clear explanations about how and why systems work.
2. Simple control panels for each system should be used.
3. Automatic systems that work against energy-saving measures should be avoided.
4. The language of instructions and controls should be checked.



Project	Problem	Cause	Solution
Dungannon Passivhaus	Heating controls are unnecessarily complex MVHR systems controls are in German	Two thermostats installed which need to be set at different temperatures System imported and instructions only in German	One control which sets both temperatures automatically Translate instructions
Low Carbon Apartments	Residents found heating controls difficult to use	System takes a long time to respond	Give better instructions to residents
Future Works	Blinds lower to cut out sunshine all year round, reducing winter solar gains	This is standard for automatic blinds	Simple up/down controls would be more effective
Birchway Eco Community	Problems with heating controls Some residents felt they had no control over cooling	Immersion heaters would not turn off, resulting in high bills Lack of understanding	Correct installation and maintenance Better explanation and handover
Avante Homes	Controls were not easily accessible (too high to reach, in an airing cupboard)	Not enough thought given to how to access controls	Position controls in better locations

Table 6: Problems with controls experienced by select projects

Low-carbon technologies, such as community biomass boilers and heat-recovery ventilation systems, are unfamiliar to most people, and have unclear benefits.

Handover

When handing over, developers should help residents adapt to new and unfamiliar technologies in their homes.

Supporting and advising residents

Developers should do more than simply give residents written information, such as occupant handbooks and manufacturers' literature. They need to support and advise residents face to face, in line with their requirements. To help residents behave in ways that support a low-carbon philosophy, developers should also explain how systems work together. Ideally, designers should prepare this guidance early in the design stage. Considering users early in plans means residents are more likely to receive systems that they find easy to use and access.

Advising on other low-carbon approaches

Developers should explain other ways of saving energy and cutting emissions, such as where to recycle, transport options and water-efficiency measures.

Asking residents to perform tasks

Demonstrations are useful but it is better for developers to return and ask residents to perform tasks themselves, for example, to show how they would clean the air filters.
This confirms that residents have understood the guidance. In this example, filters need much attention. A lack of instructions about how to change air filters was a common problem at Avante Homes and the Camden Passivhaus.

Staying in touch

Developers should stay in touch with residents for some time after they move in. A good example of this is the Soft Landings protocol, which Bere Architects adopted at the Camden Passivhaus and Future Works.

Soft Landings - bringing everything together

Soft Landings is a complete process that brings together best practice at every stage of a project. It sits alongside any procurement process, reinforcing five areas:

1. Inception and briefing.
2. Managing expectations during design and delivery.
3. Preparing for handover.
4. Initial aftercare in the four to six weeks after handover.
5. Extended aftercare, monitoring and feedback over the first three years of occupancy.

Educating housing staff

In social housing for more vulnerable people it is important to properly educate housing staff who liaise direct with residents.

If they understand systems such as MVHR, they can feel confident about advising tenants. Staff who are used to liaising with occupants are best placed to advise them on their systems.

Recommendations

1. Preparing guidance early will help ensure systems are easy to use and access.
2. Residents should be advised in person, and given handover documents.
3. Instructions should be tailored instructions to residents' needs.
4. Instructions should cover a wide range of topics.
5. Residents should be asked to show they understand the guidance.
6. Best practice should be adopted, such as the Soft Landings approach.

Project	Problem	Cause	Solution
High Density Apartments	Ambiguous wording and descriptions of technology	Insufficient time and resources invested in handover	Agree terminology, explain it in the handbook, and use consistently throughout
Avante Homes	Manuals for appliances and technology not easy to understand Misconception about what the MVHR does No demonstration of how to clean the air filters	Documents did not account for users' needs Home demonstrators did not adequately explain or understand the technology	Provide clearly written manuals that everyone can understand. Consider using visual/diagrammatic guides Ensure that those handing over are well-versed in the technologies and how to use them Include filter changing in the handover process
Bryan House	Information presentation and format could be more succinct Demonstration tour focused on heating and ventilation, but should also address other issues	 Occupants had already been living there for a while – the developer assumed they knew the basics	Write clear and well-presented handover documents Cover other energy-saving concepts such as water efficiency, recycling, maintenance issues and transport options
Camden Passivhaus	More information required on how to change air filters		Include this in the handover material
The Quarries	In-house staff were not familiar enough with the technology to explain it to the residents	Staff not briefed well enough or included effectively in the handover	Ensure staff understand the systems

Table 7: Problems with handover experienced by select projects

Demonstrations are useful but it is better for developers to return and ask residents to perform tasks themselves.

Procurement

In the UK, low-carbon buildings are a relatively new development. The industry is also still establishing best practice for contracts and project management. The study found that onsite problems stemmed from gaps in responsibility and weak communication, which often resulted from the contract.

Contractor preference for design and build

Contractors tend to view design and build contracts positively because they are involved early in the design. The main contractor at The Quarries felt that this helped balance their sustainability and commercial ambitions.

Architects and traditional contracts

Conversely, most architects prefer traditional contracts, where they have more contact with the client and see the project through to the end. Architects argue that this helps ensure clients do not water down or cut design ideas due to costs.

Passive House challenges

Passive House standards – which feature at Camden, Dormont Estate, Dungannon, Knight's Place, Rowan House and Future Works – pose problems for contracts and project management. Currently, very few contractors have experience of this type of work, which requires meticulous detailing and execution. Mechanical and electrical design costs can also be much higher for Passive House work. If contractors do not anticipate this, they risk under-pricing.

Appointing competent and diligent site managers

A competent and diligent site manager is essential, especially on Passive House projects. At Future Works, this helped reduce problems with contract ambiguities. Site managers need to supervise more often and deal with more paperwork to achieve Passive House certification.

Feedback between designers and contractors

It is important that the design team and contractors establish a good feedback arrangement. This will ensure the right people review unavoidable changes before implementing them. The Avante Homes project considered that its feedback arrangement was inadequate, and took significant steps to address this. To avoid confusion, projects also need a clear audit trail for changes to working drawings.

Recommendations

1. Contract choices should be considered carefully. There are pros and cons, for example, innovative designs typically require designers and contractors to collaborate closely.
2. For Passive House projects, contractor with previous experience of meeting the standard should be chosen.
3. Additional M&E costs for Passive Houses should be considered.
4. Competent and diligent site managers should be appointed.
5. Good communication between contractor and designers should be established, including a formal feedback arrangement and drawing audit trail.

Project	Problem	Cause	Solution
The Quarries	Challenge of achieving design within the funding regime	Tight budget	Balancing cost savings and design; allowing more time to deal with aspects that are new to the project team; and being prepared to compromise
Dungannon Passivhaus	Concern that airtightness may not achieve Passive House standards, as it was the first of its type in Northern Ireland	Importance of achieving Passive House certification	Contractor agreed to a retention – which was only payable if airtightness was acceptable; target airtightness was achieved
	Mechanical and electrical details vary from house to house, due to contractors making changes	Mechanical and electrical details left to contractor	Use a traditional contract where architect is involved to monitor site work and substitutions
Future Works	Ambiguous contract arrangement meant that the architect could not issue instructions to rectify work that did not comply with the specification	The contractor was technically answerable to the United Welsh Housing Association, not the architect	Diligent site manager ensured work was performed satisfactorily
Camden Passivhaus	Contractor had no previous experience of Passive House work	In the UK, there are very few contractors experienced in Passive House projects	Ensure either that contractors have worked on Passive House projects before, or that they have been suitably trained; ideally involve a mentor
Avante Homes	Architects only employed until the end of the design process	Design and build contract	Architect was involved at every stage and able to review changes once onsite – traditional form of contract
	Contractors changed roofing and cladding materials, which harmed performance	No clear audit trail for drawing alterations once onsite	Ensure formalised and complete accounts of specification and drawing changes

Table 8: Problems arising from procurement methods experienced by select projects

Overheating

As home insulation and airtightness improves, there is a rising risk of overheating in summer.

Architects and traditional contracts

The study examined summer temperatures in 67 homes with temperature loggers. Every home's peak summer temperature was over 25°C. However, in some homes, the period with temperatures over 25°C was short and only occurred in the daytime. Just under half of the properties (32) had temperatures above 28°C, which most people feel is uncomfortably hot. However, these hot periods were very short – less than 0.6% of the time, on average, over the summer (May to August).

A Passive House home on the Dormont Park estate exceeded 28°C for 9% of the summer, and exceeded 25°C for around a fifth of the summer. This may be due to the two residents leaving windows closed for much of the time.

Inconclusive evidence of overheating in high SAP homes

The study explored why some homes are more vulnerable to overheating than others. It assessed whether thermally efficient homes (shown by high SAP ratings) faced a higher risk of overheating. The results were inconclusive, despite analysing summer temperatures relating to house type, construction materials, airtightness, geographic region (north-south and east-west), and SAP rating. The BPE's data did not draw robust conclusions, due to uncertainty about window-opening routines and when people were or were not at home.

The benefit of external shading

One conclusion, although based on a small sample, was that homes with external shading including movable blinds were less likely to become uncomfortably hot (rise above 28°C) in summer.

Recommendations

1. Although better insulation and airtightness may increase peak summer temperatures, evidence suggests that window-opening routines are more important.
2. External shading can be considered to overcome concerns summer overheating.

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