PROJECT 80 – ECO DRIVE HANDSWORTH

FUTURE HOMES STANDARD CASE STUDY

Interim Report July 2023

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1. EXECUTIVE SUMMARY

The UK has set a legally binding target to bring all its greenhouse gas emissions to net zero by 2050. In 2019, the government announced plans to develop a Future Homes Standard aimed to ensure that all new homes built from 2025 will produce 75-80% less carbon emissions than homes built under 2013 regulations. Midland Heart, working with the Building Alliance, decided to make the Eco Drive development near Birmingham a demonstrator that would be designed and built to the anticipated 2025 regulations. The goal of the demonstrator was to show how the standard could be achieved cost effectively without unintended consequences. The scheme of two-, three- and four-bedroom homes, used standard house layouts, and was adapted from the original 2013 Building Regulations design to meet the notional 2025 Future Homes Standard. Birmingham City University (BCU) was brought onboard to capture a case study of the development, to undertake detailed monitoring, and to engage with the occupants to record their experiences and lessons. A team of Midland Heart, designers, contractor, subcontractors, materials suppliers, specialists and BCU was set up to deliver the project in a collaborative and learning approach.

The target for the Eco Drive project was to deliver an 80% reduction in CO_2 emissions, from the 2013 designs, by increasing insulation in walls, enhancing the window specification, increasing the levels of airtightness, employing planned ventilation approaches, and using heat pumps and photovoltaic (PV) systems. The 12 homes were given three different variations of solution involving two types of space and water heat pump, and a water heating only heat pump with electric radiators. All used traditional brick and block construction because it is the most common construction form in the UK. Four were built to a much higher low-energy specification, and all were given 2.2 kW of PV panels, beyond the standard, to help the occupants with rising energy costs. Work commenced on site in March 2021 and was completed in May 2022.

The construction contractor overcame all the development issues including electrical utility supply, brickwork insulation and local conditions which caused programme modifications. The overall project was delivered with a 15% uplift in cost against the project designed to 2013 Building Regulations.

2-bed house

Uniquely, this project provides granular energy and environmental data. It also provides feedback from occupants on their experiences of using heat pump and ventilation equipment. Monitored data were analysed visually in graphs at both a daily period using minute data and over monthly periods. These data showed how equipment operated, how the houses responded, and how the occupants' lifestyles affected operations. This monitoring of energy use and environmental conditions showed that heat pumps could provide very comfortable conditions even in very cold periods. The series of interviews with the occupants showed the tremendous success of the project; in particular, the occupants found the added comfort a pleasure after their previous poor housing conditions. Total volatile organic compounds (TVOC) and fine particles (PM 2.5) increases were related to cooking activity, which in some homes could be for six hours a day. These parameters subsided when cooking stopped showing that ventilation was successful. The daily pattern of heating showed high energy use in most houses and lifestyles often put pressure on the environmental conditions. However, the houses, which had heat pumps and PV, worked to their design performance targets and have achieved an estimated 70% reduction in carbon production against the use of the same house with a gas boiler; this percentage will rise as the electricity grid is decarbonised.

The lessons learnt suggest that the occupant lifestyle is a key factor in achieving the Future Homes Standard targets and more needs to be done to assist them in understanding heat pumps, controls, ventilation and building performance. The heat pump operation needs to be explained in an explicit strategy and there is an opportunity for those maintaining the equipment to provide an annual refresher to occupants to improve in-use performance. Similarly, a ventilation strategy needs to be properly produced and explained with the identification of possible problems when floor, door and windows are modified. The supply chain required to achieve the Future Homes Standard needs to be expanded and trained because the complexity of the changes cannot be understood without experience; this supply chain needs to include maintenance as an essential service. There needs to be a more comprehensive monitoring of equipment and house environments to better understand operations but also to feedback to occupants about how their lifestyles influence the performance of their houses.

The Eco Drive project has demonstrated that it is possible to create homes to the 2025 regulation that are traditionally built and can contribute to substantial carbon reduction.

3-bed house

2. INTRODUCTION

Eco Drive is a development of 12 houses built for Midland Heart Housing Association ('Midland Heart') in Handsworth, Birmingham. It is part of Midland Heart's future homes development programme, known as Project 80, which involves building homes to cut carbon emissions by 80%. The programme seeks to test high specification designs that are buildable and affordable, providing future-proofed homes and better living conditions.

Eco Drive started in 2016, and over the next five years plans evolved from building a modest infill development of 7 houses to an enlarged site with 12 houses. Designs for the houses were updated in 2021 after the government announced it would update building regulations requiring new homes to substantively reduce carbon and energy use from 2025. The Eco Drive project houses had originally been designed to the 2013 building regulations using Midland Heart's standard house layouts. The houses were redesigned to conform to the anticipated 2025 Future Homes Standard. The development invited Birmingham City University to join the project to develop a case study from the work, monitor its development, and engage with residents to record their experiences and share the lessons learned.

This approach was considered an excellent test of the Future Home Standard because it:

- eliminated fossil fuel heating and improved energy efficiency through higher fabric standards;
- employed traditional contextual design using standard layouts rather than being purposely designed as a demonstration project;
- used traditional brick and block masonry, which is the most common form of construction;
- involved a size of housing development that enabled all parties involved, including developers designers, contractors, subcontractors, and materials suppliers to work together and learn;
- could be built relatively quickly in order to provide lessons that inform future developments; and
- involved a strong partnership between Midland Heart, Building Alliance and Birmingham City University that would produce reliable and robust evidence immediately and over the long-term.

In 2018, the heating and powering of homes accounted for 22% of all greenhouse gas emitted in the UK. In 2019, the government set a legally binding target for the country to produce net zero emissions by 2050 and announced plans for a Future Homes Standard aimed to ensure that all new homes built from 2025 produce 75-80% less carbon emissions than homes built under 2013 regulations[$].

These changes will be implemented using more efficient building fabrics, including insulation and structural materials; higher-specification windows to reduce heat loss; lower air permeability; and the adoption of low-carbon heating systems using heat pumps. The government updated Part L of the existing building regulations to lift minimum energy performance targets for buildings; Part F, which introduces new ventilation standards; Part O for overheating mitigation; and requirements were introduced that photographic evidence should be collected during construction to provide quality assurance of energy efficiency assessments. In 2021, the government introduced an interim uplift in regulations requiring new homes produce 31% less emissions from 2022 to support the wider implementation of the Future Homes Standard from 2025.

[$] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/956094/Government_response_to_Future_Homes_Standard_consultation.pdf

The target for the Eco Drive project was an 80% reduction in emissions. The data from the project has shown that this can be achieved by increasing insulation in walls, enhancing the window specification, increasing the levels of airtightness, employing planned ventilation approaches, and using heat pumps and PV systems. The scheme was designed with three different ways of meeting the Standard including 4 houses with lower air permeability and MVHR to test the capabilities to achieve this. All 12 homes were given 2.2KW of PV panels to help the occupants with rising future energy costs.

PROJECT HIGHLIGHTS:

- 12 homes, 3 different solutions successfully delivered
- Adapted conventional house types and masonry construction.
- Designed to 80-90% reduction in carbon from 2013 regulations
- 70% carbon reduction with heat pump and PV over gas
- Heat pumps deliver over 20ºC even when outside -7ºC .
- Monitored and Occupant Interviews over 1 year since occupation
- Scheme 15% more expensive overall but early adoption and variety cost
- Small reduction in bills
- Occupants delighted with comfort
- Learning: Occupants, Heat Pumps, Controls, Supply Chain

3. METHODOLOGY

The study into the Eco Drive project sought to understand the impact of designing and building new homes that meet the government's Future Homes Standard. Although the novel approaches to building and installation used in this project are not unique, having been used separately on previous developments, the implementation on this project was considered somewhat exceptional and so unfamiliar to most of the parties involved.

To ensure the changes required were successfully implemented at scale, the research sought to understand how all the project's partners adapted their approach to designing and constructing the development. Regular collaboration meetings were held involving all parties including manufacturers. The research was divided into different tasks to gather relevant data from the project so that a proper study and analysis could be conducted to compare the quality that was specified with the quality that was achieved. The tasks undertaken to achieve these aims are listed below.

DESIGN AND CONSTRUCTION

In order to appraise the home development processes, including assessment of the design, construction, commissioning, handover and cost, the research team:

- conducted observation and inquiries on site during the build to understand any difficulties that needed to be overcome and gather feedback on how people felt about working differently;
- attended collaboration meetings;
- interviewed designers, contractors, subcontractors and manufacturers about their developing understanding and use of their knowledge;
- conducted an analytical cost study using data provided by the main contractor; and
- projected the economic and capacity impact on the industry.

BUILDING PERFORMANCE

Physical tests were conducted to evaluate fabric performance. These included:

- air-tightness tests; and
- thermal variation assessments using thermal imaging cameras

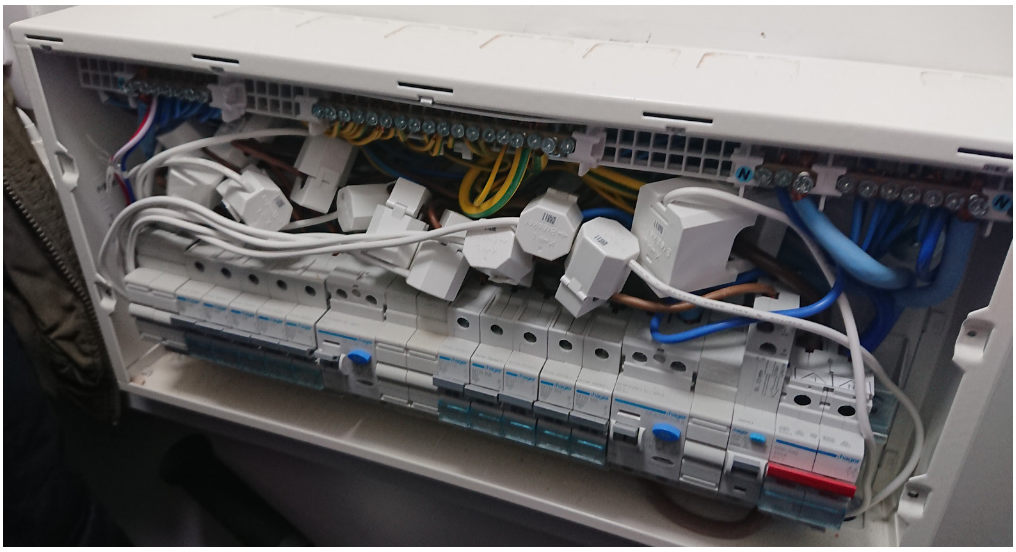
OCCUPATION

Uniquely, the study has gathered real-life occupant usage data for houses designed and built to the Future Homes Standard. An evidenced route of how improvements can be made in practice has also been provided. Occupants and their lifestyle choices are all very different so cannot be standardised. Their activities continually change thus disturb the integrity of measurements. Before conducting the research, ethics approval and permission from the residents was sought. To gather measurements related to occupant behaviour:

- occupants agreed to be interviewed and fill out diaries to help researchers understand their usage patterns, experience, and learning requirements,
- weather data was gathered to establish the context of energy use, environmental conditions and solar contribution;
- indoor air quality (Temperature, Humidity, PM2.5, TVOC, CO_2, Formaldehyde) was measured to establish property occupancy dynamics, living temperatures and ventilation effects; and
- individual electric circuits were monitored to establish property occupancy dynamics, energy usage, the PV input, and the contribution of other electricity usages.

Off the shelf equipment was used for this monitoring. WiFi connectivity and cloud storage was used so that the method could be reproduced easily across the widest range of properties. As much as possible, data was verified through comparisons with meter readings and occupant experience. Several experiments were conducted to check the data (e.g. equipment being switched off and on) and to check the operation of the house (e.g, cooking with windows open and closed). This provided further insight into the measurements and the response of the houses.

The evidence presented in this report focuses on five properties for which the data was verified and most complete. The occupants of these five homes were extremely accommodating. They took part in four formal interviews since they moved into their new homes and observational data was gathered during other visits to the property while their monitoring equipment was updated. One of the four interviews was conducted at the beginning of their occupancy to establish their past housing experiences and their expectations for their new homes. The second and third interviews were conducted each side of winter to see how lifestyles and operation of the equipment developed. The fourth interview determined the overall experience of the occupants, and how they felt about the environment within their homes. Many of the occupants provided access to their energy bills which helped validate monitoring data. All 12 houses will continue to be monitored to improve research datasets.



Top left: Air Quality Sensor, Top right: Weather Station, Bottom: Electricity Circuit Sensors

4. DESIGN

The Eco Drive project development was designed by Oakley Architects who obtained initial planning permission for a smaller, conventional project of 7 houses on brownfield land. As opportunities for more land became available this changed to 12 houses (see Figure 1) and then in 2019 the development was selected by Midland Heart to be its Future Homes demonstrator. Thus, the Eco Drive project development was not designed as a typical demonstrator project but was adapted from existing plans for 2 two-bedroom houses, 8 three-bedroomed houses, and 2 four-bedroom houses. The target was to build homes that met the top-end target of the government's coming 2025 Future Homes Standard by producing 80% less carbon emissions. This adaptive approach gives the demonstrator project more relevance and provides a greater opportunity for lessons to be learnt including how a traditional architectural design and a traditional masonry form of construction can be adapted to meet the challenges of climate change.

Figure 1: Site Plan

The design is based around a detailed standard specification from Midland Heart. This followed National Development Space Standards but also had separated kitchens and straight flights of stairs. The internal arrangements were dictated by the narrow frontage with small footprints requiring a need to extend vertically. The design respected the context by using brick facades and the heights were dictated by the need for continuity with the existing street frontage (see elevation in Figures 2 and 3). The original designs conformed to the 2013 Building Regulations and were costed by the contractor; however, after becoming a demonstration project, the houses were redesigned, adding more storage space for services, and costed to the anticipated 2025 regulations. The final design was very close to a standard house type.

The collaborative team that developed the design specification to meet the 2025 standard and achieve an 80% reduction in carbon (see detailed specifications in Table 1) included: Midland Heart, the contractor (Tricas Construction), Birmingham City University, and specialist suppliers and manufactures who helped to detail the enhanced fabrics and reduce thermal bridging and air leakage.

Table 1: Detailed specification of each house type

Element	Type 1	Type 2	Type 3
Floor	75mm screed, 150mm Xtratherm Thin-R, 150 beam and block floor	75mm screed, 150mm Xtratherm Thin-R, 150 beam and block floor	75mm screed, 150mm Xtratherm Thin-R, 150 beam and block floor
External wall	Ibstock facing brick, 150mm Cavity Therm, H+H aircrete block, airtight polymer spray, plasterboard on dabs and skim	Ibstock facing brick, 150mm Cavity Therm, H+H aircrete block, airtight polymer spray, plasterboard on dabs and skim	Ibstock facing brick, 150mm Cavity Therm, Besblock Star Performer, plasterboard on dabs and skim
Roof	150mm Xtratherm Thin-R between rafters, 90 mm Xtraththerm Thin-R below rafters, two layers of plasterboard on dabs and skim	400mm Knauf Earthwool Loftroll 40	150mm Xtratherm Thin-R between rafters, 90 mm Xtraththerm Thin-R below rafters, two layers of plasterboard on dabs and skim
Window	Munster double glazed unit, 1.2W/m2K with 0.45 G-value	Munster double glazed unit, 1.2W/m2K with 0.37 G-value	Munster double glazed unit, 1.2W/m2K with 0.45 G-value
Door	Munster GRP front door, and rear glazed doors	Munster GRP front door, and rear glazed doors	Munster GRP front door, and rear glazed doors
Lintel	Thermally Broken Hytherm	Thermally Broken Hytherm	Thermally Broken Hytherm
Cavity closer	Xtratherm Safe-R Close-R	Xtratherm Safe-R Close-R	Xtratherm Safe-R Close-R
Heating	Baxi Assure 7kW ASHP, Baxi Assure 210L unvented cylinder, Stelrad Vita compact radiators	GlenDimplex panel heaters and 200L Edel hot water heat pump	Vaillant Arotherm 5kW, Vaillant uniSTOR 200L, Stelrad Vita compact radiators
Ventilation	MVHR Envirovent energiSava 250	MVHR Envirovent energiSava 250	Envirovent Filterless Infinity extractor fan
PV	Q.Peak duo g9 cell, 2.2kW	Q.Peak duo g9 cell, 2.2kW	Q.Peak duo g9 cell, 2.2kW
Wastewater heat recovery	Showersave QB1-21	Showersave QB1-21	Showersave QB1-21

As three house types were available, the decision was taken to trial three different systems to test a range of technologies to meet the standard. Types 1 and 2 took a different approach in terms of airtightness and ventilation. Type 1 is a four-bedroom unit and was designed to include Baxi space and water heating heat pump , lower air permeability and heat recovery (MVHR) systems. Type 2 is a two-bed unit with minimal space load so was designed to include a water-only heat pump and efficient, Dimplex electric panel radiators, lower air permeability and heat recovery (MVHR) systems. Type 3 is a three-bed unit and was designed to include a Vaillant space and water-heating heat pump. The ventilation in Type 3 was spot mechanical extract fans in the kitchen and bathrooms with a low background rate and humidity or pull cord activated boost. All 12 homes were given 2.2KW of PV panels, beyond the standard, to help the occupants with rising future energy costs.

Figure 2: Elevation of 4 bed house

Figure 3: Elevation of two- and three-bed houses

ENERGY PERFORMANCE CALCULATIONS

In developing the low energy design, the Standard Assessment Procedure (SAP) was used although in 2019 the software had not been updated to reflect the 2025 standard. The homes were modelled in SAP 2013 to meet a pass in terms of Dwelling Fabric Energy Efficiency (DFEE) and Dwelling Emission Rate (DER). Then in the beta version of SAP 10 they were re-run in order to improve the specification to get an 80% CO_2 reduction in DER compared to the SAP2013 version and a circa 30% improvement in the DFEE. However, in order to meet the 80% reduction in SAP2013, Waste Water Heat Recovery and PV were added. The work for this was done collaboratively with assistance from the Besblock block manufacturer. A new SAP has now been introduced which makes this tool work more easily with the 2025 regulations. The design performance estimates are provided in table 2. Also included in table 2 are Passivhaus targets for comparison. This shows that U-values (that is the rate of transfer of heat through a structure) achieved for the floor, roof and walls are better than indicative Passivhaus values, but not for openings such as windows and doors.

Element/Specifications	Indicative FHS specification	Type 1	Type 2	Type 3	Passivhaus
Floor U-value - W/(m$^{2.K}$)	0.11	0.11	0.11	0.11	0.15
External wall U-value - W/(m$^{2.K}$)	0.15	0.13	0.13	0.13	0.15
Roof U-value W/(m$^{2.K}$)	0.11	0.1	0.1	0.1	0.15
Window U-value W/(m$^{2.K}$)	0.8	1.2	1.2	1.2	0.8
Door U-value W/(m$^{2.K}$)	1.0	1.2	1.2	1.2	0.8
Air permeability (m^3/h/m^2)	5.0	1.5	1.5	5	0.6
Heating appliance	Low-carbon heating e.g. (heat pump)	ASHP)	HWHP)	ASHP)	-
Ventilation	Natural (with extract fans)	MVHR	MVHR	Natural (with extract fans)	MVHR
PV	None	Yes	Yes	Yes	-
Wastewater heat recovery	No	Yes	Yes	Yes	-
Y-value	0.05	0.028	0.0274	0.028	0.01
Design CO_2		**85%**	**80%**	**90%**	

Table 2 Design performance of each house type

INSULATION AND AIR PERMEABILITY

One of the key fabric changes to the 2025 regulations is the requirement for using thicker walls to accommodate extra insulation. Given the site's arrangement of plots, this thickness could not be expanded much without reducing site density, or house space. So, a 352mm wall with a fully filled cavity was chosen. To achieve the overall U-values the insulation installed was high performance XtraTherm with a PIR core. The fire aspects of this were fully considered. At the same time, construction details were provided to reduce cold bridging and air leakage at joints. Polymer wall spray was used to create low permeability in Type 1 and Type 2 houses. This was experimental but the results have proved successful.

As well as thicker walls, space needed to be found for the installation of a hot water cylinder as the new standards do not allow the use of the fossil-fuelled combi boiler that was specified in the original design. In the Type 2 properties, the cylinder and hot water heat pump were in a single unit. The accommodation of the cylinder can be challenging on tighter plots as occupant storage space has to be reduced. The siting of the heat pump in the garden was a pragmatic decision that meant long pipe runs, which was not ideal.

WINDOWS, VENTILATION, AND SOLAR POWER

The initial window specification was for triple glazing, however practical considerations dictated that enhanced double glazing was the simpler solution with the losses in performance balanced out by tighter criteria on other elements including the walls and roof. This decision was reached by assessing cost, availability, ease of maintenance, weight, wall aperture position, frame size, light transmission, and the ease of providing opening windows.

The accommodation of the MVHR did not turn out to be problematic as the ductwork was easily placed within the space formed by the I-Joists with allowed holes. It was determined that the most suitable place for the heat exchange unit was in the roof space and maintenance access was provided. The system had supply and exhaust terminations in the roof ridge.

The PV panels were considered a useful addition to help residents offset the costs of using electrical heating but they were not at the time a requirement of the Future Homes Standard. The design was subcontracted to ensure that it met certification requirements. The controls and inverter were placed in the roof space and maintenance access was provided.

DESIGNS MEET AND SURPASS THE FUTURE HOME STANDARD

The design performance of the different solutions led to an estimated reduction of 85% in carbon emissions for Type 1 houses, 80% for Type 2 houses, and 90% for Type 3 houses, against 2013 standard. This established that the key objective of the project, to reach or surpass the specifications of the Future Homes Standard, was met using traditional construction with no gas connection.

4-bed house

5. CONSTRUCTION

Midland Heart is a professional client and has long-term relationships with designers and contractors enabling them to undertake complex and out of the ordinary work. Although, this project was tendered as a design and build job, there was extensive discussion and negotiation to reach a final specification. The contractor Tricas was a partner in the Eco Drive project and contributed expertise and problem solving. It also employed the architect during the construction to help make changes and choices of materials. The site had normal in-fill problems of access but also the ground conditions involved a sloping site and the need for deeper than average foundations. There was also the need for pumped sewer provision. These aspects determined the phasing of the construction. Tricas had experience with low energy buildings and placed an experienced site manager in charge supported by an informed contracts manager. The programme schedule was tight and encountered delays related to provision of electric utility, dormer windows and sewage storage tank, but it was delivered to the satisfaction of Midland Heart at the end of May 2022.

COLLABORATION

Tricas subcontracted the main work packages but collaborated with its supplier and manufacturers throughout the supply chain. The decision to use two different fabric solutions (aerated and concrete blocks) with low U-values, different levels of air tightness, three heating systems and various ventilation solutions added to the construction complexity. The entire project team, including Building Control, worked together in a spirit of openness and cooperation. Monthly project review meetings were held in a mutual determination to deliver a first-class development and share the lessons learnt. The value-add and knowledge of the suppliers was used fully to ensure the best use of materials and systems, as well as calculating the critical junction details required to meet the new standard. The academic team were involved from the beginning to collect case study material and to develop a comprehensive monitoring strategy.

SUBCONTRACT PACKAGES

The Eco Drive project highlighted the critical role of subcontractors in meeting the new standard. This required subcontractors to work with new materials and to a greater accuracy in more complex details. These changes disturbed workflows and increased the risk that future work undertaken by subcontractors could damage prior contractors' work.

The provision of fully filled cavities in the brick and block construction caused the brickwork subcontractor several challenges. This included the order of placing facing bricks, the cleaning of mortar from behind these bricks, the placing of solid insulation, and the detailing around windows. These problems were overcome by the site teams who worked closely with the manufacturers, and all parties are confident that this problem can be avoided in future through R&D and training.

The mechanical and electrical (M&E) services were subcontracted to a local company who were tasked with installing some systems with which they had no previous experience. There is evidence of a skills gap in this fast-emerging area. There was some difficulty finding technicians to complete the work which caused delays. The heat pump manufacturers provided valuable advice and assisted on site. The ventilation systems were designed by the manufacturers and installed by the subcontractor. The PV system was installed by a subcontractor to the M&E contractor which led to disconnects and required further coordination.

The application of polymer spray to reduce air permeability in four of the houses was carried out by a specialist subcontractor. This was accomplished successfully but required the houses not to have others working at the same time, adding organisational complexity.

Homes built to the Future Homes Standard are more complex than those built to the current standards. The Eco Drive project had some problems with commissioning. The hand over and commissioning process needs much greater attention to detail, and a robust formal process needs to be designed and implemented to ensure the intended design matches the actual performance.A great deal of effort was put into explaining the operation of the homes to occupants. This included open days, webinars, subcontractor and manufacturer visits.

KEY STAGE PHOTOGRAPHY

The Future Homes Standard requires that key stage construction photographs be taken and stored in perpetuity. A smart phone app provided by Captego was used to fulfil this task. Photographs were taken throughout the project but it is recommended that subcontractors should be involved in the future. Considerations need to be given as to where photographs will be stored, for how long, and who should have access to them. The software package performed well but there are opportunities for further development of this and other software solutions.

SITE VISITS

The Eco Drive project is a trailblazer for the Future Homes Standard so attracted a great deal of interest. There were usually high number of site visits including from politicians, civil servants, local government officers, leading home builders, SME homebuilders, housing associations, students, and academics. Tricas managed this high level of intrusion well, ensuring the safety of visitors and providing in progress commentary on the progression of the project.

Top left: Site Construction, Top right: Polymer Spray, Bottom left: Installation Eco Drive PV, Bottom right: Corner Detail

6. COST

The subcontract package cost data for the whole scheme was prepared by the main contractor in an elemental breakdown with extra information provided on the cost of the build changes and on the cost of the installed equipment. This elemental breakdown was then reverse engineered into a standard New Rules of Measurement (NRM) format so that the cost of the individual variations of house type, heating, ventilation, and permeability could be estimated; the cost effectiveness reviewed; a 'what-if' analysis conducted; and an industry economic impact performed. According to the construction contract with Tricas, the estimated final project cost for the 12 plots is £2,169,373. If the homes had been built to 2013 standards, Tricas estimated the cost would be £1,885,759.99. It is expected that the increased cost of building to the incoming regulations will be lower for larger projects that make use of the lessons learned during the Eco Drive project.

COST OF ADDITIONAL ITEMS TO MEET THE FUTURE HOMES STANDARD

An analysis of the additional costs of building to the expected Future Homes Standard is shown in Table 3. The overall additional cost is about 15% higher. The additional costs are mainly due to the better insulation for walls and roof; the higher-specification windows needed to achieve lower U-values; alternative services costs for heating and ventilation; and the provision of PV panels.

Table 3: A breakdown of the additional cost of items used to build 12 houses that meet/exceed the incoming 2025 Future Home Standards

Additional items required to meet/ exceed the 2025 Future Homes Standard	Additional Cost (£)	% Increase in costs (as compared with works to meet 2013 building regulations)
Installation of rigid insulation	29,121.47	+26%
Non-permeable block used in house Types 1a/1b/2a/2b	4,970.05	+24%
Polymer spray for air tightness used in house Types 1a/1b/2a/2b	11,750.00	New cost
Xtratherm insulation	34,340.00	+382%
Uplift in 'U' value & 'G' value to SAP and future homes glazing	25,588.99	+60%
Larger trusses due to weight of PV panels	6,924.82	+41%
Air source heat pumps/heating/ wastewater heat recovery	78,227.51	+64%
PV panels	44,208.00	New cost
MVHR used in house Types 1a/1b/2a/2b	6,900.00	New cost
Savings made by avoiding the use of natural gas services/appliances	-13,200.00	-100%
Higher kVA pull from site	33,917.59	+257%
Full calculations and understanding of the Future Homes Standard / Overheating regulations / SAPS etc (due to being early adopter)	20,864.58	+1242%
Total cost:	**283,613.01**	**+15%**

COST OF BUILDING ELEMENTS USED TO MEET THE FUTURE HOME STANDARD

An analysis of the cost of building elements is shown in Table 4. The data are categorised according to the relevant elements classified in RICS New Rules of Measurement (NRM). The major cost contributors are the elements for the building envelope and services. The additional designer's fee is attributed to the extra tests conducted for demonstration purposes and is likely not a recurring cost for projects meeting the Future Homes Standard. Given that the gross internal area (GIA) for the 12 houses is 1311.53 m², the unit cost for construction per square meter under the new standard is £1,654 compared to £1,438 to meet the existing regulations.

Table 4: A breakdown of the cost of building elements used to build 12 houses that meet/exceed the incoming 2025 Future Home Standards versus existing regulations

Element	Future Homes Standard Assigned Cost (£)	Current Regulations Assigned Cost (£)	% increase in costs
Roof	109,251.10	81,722.28	+34%
External Walls	285,538.76	225,961.24	+26%
Windows and external doors	62,307.51	36,757.08	+70%
Services	317,460.31	167,407.21	+90%
Gas	-	13,200.00	
Water	9,708.81	9,708.81	
Electrical	47,117.59	13,200.00	
Mechanical	200,683.91	122,456.40	
PV panels	44,208.00	-	
EV car charging points	3,090.00	3,090.00	
External lighting (private)	5,752.00	5,752.00	
MVHR to certain plots	6,900.00	-	
Designer's fee	84,360.61	63,496.03	+33%
Total cost:	**2,169,373.00**	**1,885,759.99**	
Cost per m² of the gross internal area (GIA)	**1,654**	**1,438**	
% difference:	+15%		

ESTIMATED COSTS FOR INDIVIDUAL PLOTS

Tricas has not prepared a breakdown of costs for individual plots so an estimate has been prepared using the elemental estimating method (see Table 5). This involved apportioning the cost of the quantity of building elements for individual plots while accounting for their particular specifications. For instance, MVHR units are only installed in house Types 1a/1b/2a/2b.

Table 5: A breakdown of the apportioned cost per m^2 of the gross internal area (GIA) for individual plots built in the Eco Drive project to meet/exceed the incoming 2025 Future Home Standards

Plot	**Estimated cost per m2GIA (£)**	**% increase**
Type 1a/1b	1724	+20%
Type 2a/2b	1970	+37%
Type 3 terraced	1573	+9%
Type 3 semi-detached	1612	+12%
Overall:	**1,654**	**+15%**

It is important to note that the above costs are from initial estimates but not final agreed costs and are subject to changes because of variations, cost fluctuations, and loss and expenses. Further investigation is required to understand how the particulars of future projects including economies of scale impact costs. The above estimates and breakdowns provide a preliminary indication of the additional costs of meeting the new Future Homes Standard.

7. BUILDING PERFORMANCE TESTING

Levels of airtightness and heat loss play a key role in the efficiency of homes. While the government's Future Homes Standard does not include more stringent requirements for house builders to increase airtightness, the project exceeded the indicative specification in Type 1 and Type 2 houses. This meant making them more airtight with the aim of reducing total heat loss. Increased levels of airtightness required the use of mechanical ventilation to ensure adequate air exchange rates and good indoor air quality. The results of tests conducted on the Eco Drive project's 12 houses ahead of the residents moving in are presented below.

AIR-TIGHTNESS TEST

Two air permeability targets were set: a stricter target of 1.5 $m^3/h/m^2$ for type 1 and type 2 houses; and 5 $m^3/h/m^2$ for type 3 houses, which is in line with the indicative Future Homes Standard. Types 1 and 2 units were designed with airtightness closer to the Passivhaus standard (0.6 $m^3/h/m^2$). These houses were mechanically ventilated, and a polymer spray was used to increase air-tightness levels. Due to this increased airtightness, MVHR was installed in Type 1 and Type 2 houses to ensure continuous background ventilation. All the Type 1 and 2 houses met the Future Homes Standard target but not the project's stricter target due to air leakages around windows and doors. The target for Type 3 houses was 5 $m^3/h/m^2$. They were designed as naturally ventilated homes. The ventilation in Type 3 houses included spot mechanical extract fans in kitchen and bathrooms with a low background rate and humidity or pull cord-activated boost. All type 3 houses met the project's air permeability target (see Table 6).

Table 6: Air permeability test results for the 12 Eco Drive project houses.

		House types* and their air permeability test results											
Indicative Future Home Standard specification for air permeability ($m^3/h/m^2$ @50Pa)	Project target ($m^3/h/m^2$ @50Pa)	1a	1b	2a	2b	3a	3b	3c	3d	3e	3f	3g	3h
5	1.5	2.46	2.43	2.98	2.58								
5	5					4.79	4.86	4.99	4.51	4.60	4.55	4.59	4.63

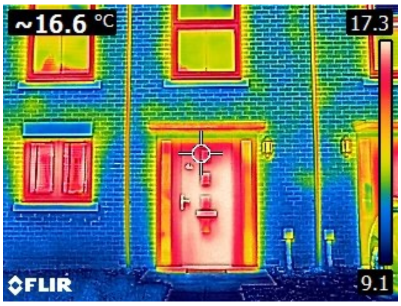
*Numbers 1, 2 and 3 correspond to the house type. Letters correspond to the specific houses.

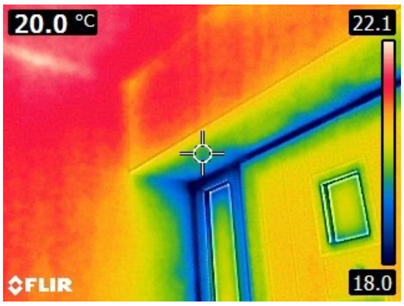
Insulated wall construction

Polymer spray for increasing airtightness

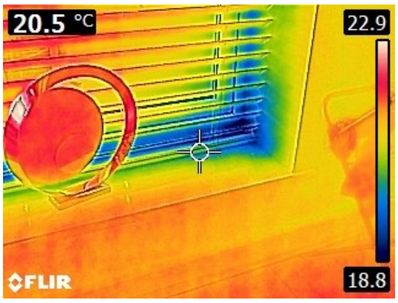
HEAT LOSS

To test for heat loss, internal and external thermal images of the houses were taken using an FLIR thermal camera in March 2023. Figures 4 to 7 show some heat loss around doors and window frames, which can explain why Type 1 and Type 2 houses did not meet the project's air permeability target. However, as shown in the pictures, the temperature difference between internal surfaces and the window and door junctions with the walls is not significant (around 4ºC) so condensation is unlikely to occur with normal user behaviour patterns as humidity would need to be very high to reach the required dew point temperature.



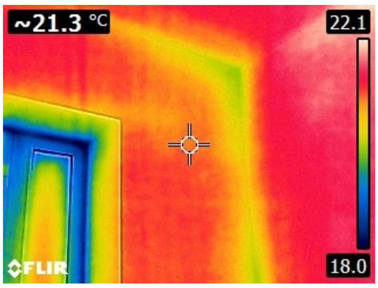


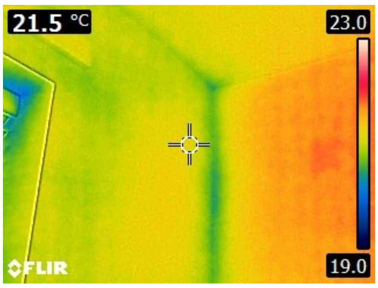
Figures 4 and 5: Temperatures shown are at the target point.



Figures 6 and 7: Thermal images of the exterior and interior view of a first-floor window.

Internal thermal images of the junctions were also taken, which showed minimal temperature difference between the walls and the corners (1-2 ºC) and therefore no thermal bridging heat losses (see Figures 8 and 9). The small temperature difference might be explained by the internal airflow being unable to reach the corners, therefore showing a slightly lower temperature. The design value for thermal bridging heat losses (y-value) at the junctions were 0.028 (lower than the 0.05 indicative value for the Future Homes Standard). Thermal images confirm that good detail design and execution led to a reduction in thermal bridges and therefore, an increase in indoor thermal comfort.





Figures 8 and 9: Thermal images of the interior view of junctions

8. ENERGY AND ENVIRONMENTAL PERFORMANCE

The performance study of the buildings-in-use focused on energy use and environmental parameters. This in-use performance is presented at two levels: single day operations and activities, and monthly averages and totals. A selection of this data is given below.

8.A DAILY COMPARISON

The electricity usage and environmental conditions for a Type 1 and a Type 3 house during 15/12/22 are given in Figure 10. The Type 1 house was designed with lower air permeability than the Type 3 house and included MVHR. The weather on this day was very cold, dropping to -7ºC and over 90% relative humidity, with a small amount of sunshine rising to 260 W/m^2. High comfort temperatures were maintained in both houses throughout the day and night with little variation.

HEAT PUMP USE

In both houses the heat pump was on continually. The heat pumps provided both space and water heating although a significant amount (around 85%) is for space heating. The smaller Type 3 house consumed 36.6 kWh and the larger Type 1 house consumed 43.58 kWh. The Type 1 house had off periods through the day whereas the Type 3 house had off periods in the evening when the outside temperature was warmer. The data gathered shows both heat pumps were cycling. The indoor temperatures were a relatively steady 20ºC in both properties and did not vary even when the heat pump was not supplying heat. The lower levels of electricity usage of the heat pump correspond to space heating and the upper levels to water heating where the heat pump must work harder to achieve higher temperatures. Though not presented here, this trend is clearer in data collected for spring months. In both houses water heating is supplemented by an immersion heater consuming 1.1 kWh in the Type 3 house and 8.411 kWh in the Type 1 house. The occupant control of the immersion heater is being investigated further to understand how this use could be avoided.

PHOTOVOLTAICS AND ENERGY CONSUMPTION

The figures for total consumption of electricity at each house are calculated by adding the electricity imported from the mains plus the electricity generated by the PV panels minus the unused photovoltaic power that was exported to the mains. On 5/12/22, the total consumption for the Type 3 house amounted to 52.05 kWh and 63.56 kWh for the Type 1 house. The 2.2 kW of PV panels provided 0.524 kWh in the Type 3 house and 0.240 kWh in the Type 1 house. Panels in the Type 3 house provided 0.524 kWh and 0.240 kWh in the Type 1 house. This difference is due to the different orientation of the homes in relation to the sun. The total solar radiation for the day was 0.217 kWh/m^2 over seven hours. As a contrast, on 10/5/23 the panels provided 6.68 kWh in the Type 3 house and 8.52 kWh in the Type 1 house corresponding to 33% and 57% of consumption respectively when total solar radiation for the day was 3.311 kWh/m^2 over 14 hours.

THE IMPACT OF COOKING AND ENVIRONMENTAL CONDITIONS

Cooking and the use of kitchen equipment accounted for some of the largest consumptions of electricity in both properties. This amounted to 5.96 kWh (or 11.4%) in the Type 3 house and 4.89 kWh (7.6%) in the Type 1 house. In both cases the additional cooking appliances consumed more than the cooker and this is a pattern repeated in other properties. The usage pattern involved higher usages over periods of about 30 minutes duration at different times through the day. MVHR in the Type 1 house consumed only 0.367 kWh on the 15/12/22.

Cooking activity was responsible for increases in both TVOC and PM 2.5. The kitchen in both properties is enclosed with doors to the hallway. Both households made considerable use of the hob for frying food or used an air fryer and this resulted in high peaks of pollutants. In both cases these high TVOC and PM 2.5 levels subsided once cooking has stopped, which demonstrated the adequacy of the ventilation. The pollutants did not spread to other rooms because of the ability to close the kitchen doors. Concentrations of CO_2 reached high levels during the day in the Type 3 house and during evening and night in the Type 1 house. These fluctuations are a result of occupant behaviour patterns in terms of room usage, door opening and window opening. The influence of MVHR on CO_2 was not detectable but the environmental conditions were adequately maintained outside of cooking activities. The humidity levels in the houses were found to be at normal levels so condensation is unlikely to occur. This was confirmed during interviews with occupants conducted in March 2023, who expressed satisfaction with the houses because they were not showing signs of damp and mould after living in them for almost a year.

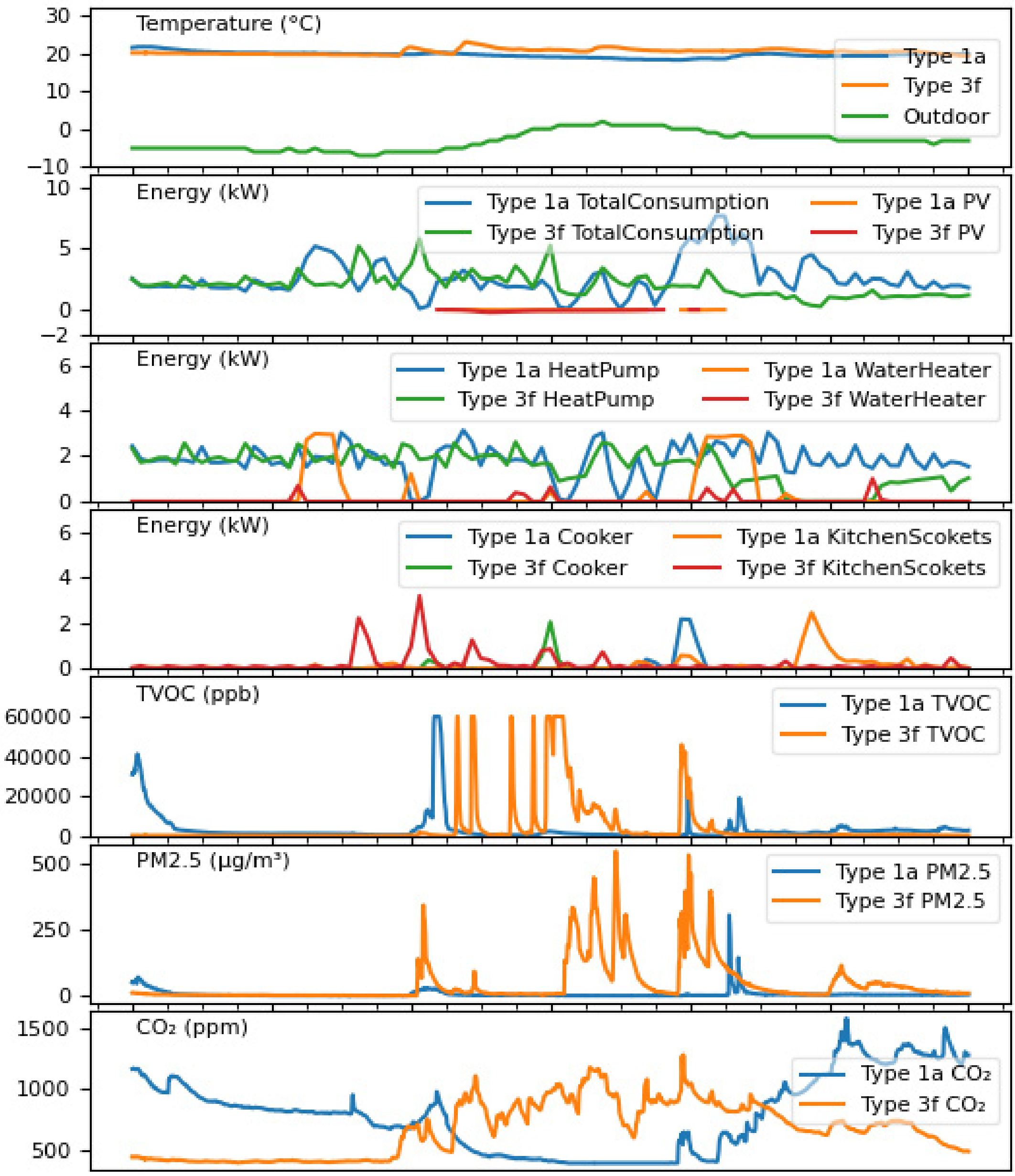


Figure 10. Environmental conditions on 15/12/22 for house Types 1a and 3f

8.B MONTHLY COMPARISON

The graphs in Figure 11 and table 7 compare the operation of 3 of the three-bedroom homes between October 2022 and April 2023. It is evident that each month the PV panels deliver about the same quantity of energy to each property. This is not surprising given that these houses all have the same orientation. The three households have occupancy of four or five people. The variation in their energy use is mostly due to lifestyle though the Type 3e house is mid terrace so had less fabric heat loss. The monthly figures for electricity consumption at each house were calculated by adding the electricity imported from the mains plus the electricity generated by the PV panels minus the unused PV power that was exported to the mains.

The Type 3e household had the lowest consumption of 416 kWh in October when the average difference between the inside and outside temperature was 10.5°C. Its consumption peaked at 788 kWh in December when the average difference between the inside and outside temperature was 17.3°C. The heat pump is the major energy usage in all homes. The Type 3e household had the lowest heat pump use compared to the other two properties. Its heat pump consumed 137.1kWh in October and 563.5 kWh in December. This represents a heat and hot water input of 5.60 kWh/day in October and 20.09 kWh/day in December.

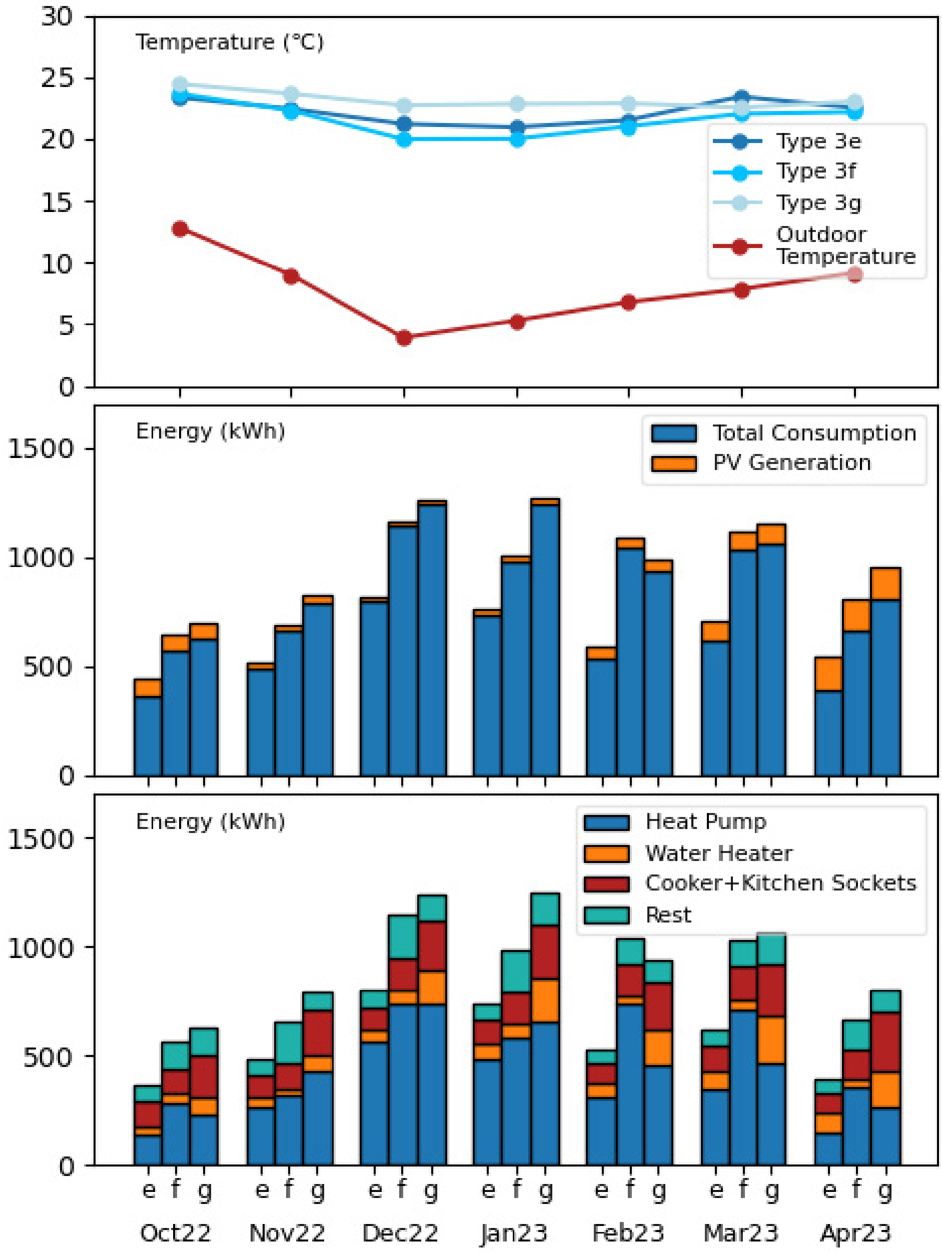


Figure 11: Operation of house types 3e, 3f and 3g

Table 7: Monthly energy usage in three Type 3 houses

				Type 3e	2 adults, 3 children		Type 3g	2 adults, 2 children		Type 3g	1 adult 3 children	
	days	Average outside temp	solar radiation	total consumption	average inside temp	space and water usage	total consumption	average inside temp	space and water usage	total consumption	average inside temp	space and water usage
Month		degC	kW/m2	kWh	deg C	kWh	kWh	degC	kWh	kWh	degC	kWh
Oct 22	31	12.81	206.893	416.54	23.30	173.49	683.59	23.62	331.21	713.40	24.40	314.35
Nov 22	30	8.99	76.933	501.58	22.40	309.44	740.76	22.26	352.73	834.94	23.62	502.21
Dec 22	31	3.89	49.819	788.24	21.19	622.70	1252.13	19.97	801.38	1271.17	22.68	891.88
Jan 23	31	5.29	75.386	745.64	20.93	557.51	1033.37	20.00	653.14	1252.97	22.79	855.11
Feb 23	28	6.77	139.168	571.56	21.50	378.10	1080.44	21.00	776.85	1010.35	22.85	619.74
Mar 23	31	7.83	336.485	690.65	23.38	428.75	1109.98	22.00	762.13	1133.22	22.50	681.15
Apr 23	30	9.12	1102.574	529.72	22.50	236.26	790.55	22.15	396.28	960.26	23.00	432.50

ESTIMATED SAVINGS FOR HEATING COSTS AND CARBON EMISSIONS

The data collected does not allow a direct calculation of the cost and operational carbon impact of building homes to the Future Homes Standard, however, an indicative estimate can be produced (see Table 8). The footnote explains the calculation.

This gives a space and water load of 14.88kWh/day in October and 69.16kWh/day in December provided by electricity usage of 5.60 kWh/day in October and 20.09 kWh/day in December. However, because of the PV panels, the actual imported electricity is only 4.08 kWh/day in October and 19.52 kWh/day in December at a cost (assuming electricity at 33.2p/kWh) of £1.35/day and £6.48/day respectively. If this was supplied by gas boiler, it would consume 17.51 kWh/day of gas in the October and 81.37 kWh/day in December at a cost of £1.80/day and £8.38/day respectively, slightly larger than the electricity cost. The carbon equivalent of this usage is 1.30Kg/day for electricity and 3.22 Kg/day for gas in October and 4.68 Kg/day for electricity and 14.98 Kg/day for gas in December. Thus the Eco Drive households are achieving up to a 70% monthly carbon reduction against gas heating and a small saving in heating cost.

Table 8 Estimation of the cost of heating savings and reduction in carbon for the Eco Drive project Type 3e household built to the Future Homes Standard

		Unit	Oct 22 (31 days)	Nov 22 (30 days)	Dec 22 (31 days)	Jan 23 (31 days)	Feb 23 (28 days)	Mar 23 (31 days)	Apr 23 (30 days)
Type 3e	heat pump consumption	kWh	137.12	267.13	563.48	481.10	315.12	348.49	144.66
	immersion consumption	kWh	36.38	42.31	59.22	76.42	62.99	80.25	91.59
	PV used	kWh	46.98	24.26	17.41	26.65	44.37	66.03	82.94
	estimated fraction heat pump in space mode	%	55.00	65.00	85.00	80.00	75.00	70.00	55.00
	estimated space load @Cop 4	kWh	301.65	694.54	1915.84	1539.52	945.35	975.79	318.26
	estimated heat pump water load @CoP 2	kWh	123.40	186.99	169.05	192.44	157.56	209.10	130.20
	total space and water load	kWh	461.44	923.84	2144.11	1808.37	1165.89	1265.13	540.05
	estimated gas consumption @85%	kWh	542.87	1086.87	2522.48	2127.50	1371.64	1488.39	635.35
	gas cost@10.3p/kWh	£/day	1.80	3.73	8.38	7.07	5.05	4.95	2.18
	Eco Drive Future home cost @33.2p/kWh	£/day	1.35	3.16	6.48	5.69	3.96	3.88	1.70
	No PV Future Home cost @33.2p/kWh	£/day	1.86	3.42	6.67	5.97	4.48	4.59	2.61
	gas carbon @.184Kg/kWh	£/day	3.22	6.67	14.97	12.63	9.01	8.83	3.90
	eco drive carbon @ 0.233Kg/kWh	kg/day	0.95	2.21	4.55	3.99	2.78	2.73	1.19
	eco drive % carbon reduction	kg/day	70	67	70	68	69	69	69

Calculation of gas equivalent usage

Monitoring of the electrical input into the heat pump system showed that during the coldest month of December 15% of its use was for heating water and 85% for heating space. This varied each month as shown in Table 8.2. The heat pump operated with a different coefficient of performance (CoP) in each of these modes. It has been assumed that its space heating CoP is 4.0 and its water heating CoP is 2.0. These are determined by outside temperature, required flow temperature, and load. The electricity input into the heat pump was then factored by the space/water breakdown at the different CoPs to give heat load plus the extra immersion usage for water heating. It has been assumed that gas boiler is 85% efficient.

The calculation of energy costs used the price guarantee of 33.2p/kWh for electricity and 10.3p/kWh for gas.

The calculation of carbon usage used a carbon emission factor of 0.23314 kg/kWh for electricity and 0.18387 kg/kWh for gas. This is based on the UK government's GHG Conversion Factors for Company Reporting (2020) - DEFRA

9. USER EXPERIENCE

Occupants agreed to fill out diaries and be interviewed by researchers to provide insights on the experience of living in homes built to the Future Homes Standard. User experience was positive across all households.

HEALTH AND THERMAL COMFORT

All occupants said they were *"happy with their new homes"* and *"were happy with the [thermal comfort]"*. In addition to their perception of the buildings' performance levels, they also said they were excited about living in homes that were built to future standards that help to combat climate change.

> *"It is an eco-friendly house, and we hope it will bring down our energy cost and for health reasons as well. Also, it has new technology, including PV panels and electric car charging. We also like the area."*

All occupants who had issues in their previous homes were relieved by the absence of mould. The occupants of one household had history of respiratory conditions including asthma. During the second set of interviews, they disclosed that none of the family members had experienced the 'recurring issue of asthma' since moving into their new home. She was confident that the new home was the cause for this positive change.

All households reported they were very happy with the level of thermal comfort. One household member said that they could walk around the house in "normal clothes" even when the house was not being heated because it was not as cold as their previous house.

Households that included smokers reported that they have modified their habits since moving into their new home with all but one household now smoking outdoors. Although not stated directly, it is assumed that the occupants have started smoking outdoors due to the 'newness' of the homes and the fear of recreating the old conditions of their previous homes. Furthermore, the occupants said they are aware of the airtightness levels of their new homes and said it would be more difficult to remove the fumes and resultant smell of cigarette smoke.

HEATING CONTROLS

Even with manuals, webinars and visits, some occupants said they were not fully conversant with the space heating controls, especially when it came to heat pumps. They said they were unsure about the most efficient settings to use to ensure space heating is most effective both for their thermal comfort and implications for energy costs.

> *"I need to understand the system better. If there was an app or system, we could know the exact amount [of heating] we are using."*

Some had managed to improve their user settings through *"trial and error"* and had become confident in the months they had lived there. However, some other households were still in doubt and reported that they were turning up the thermostat to an extremely high temperature to put their heat pumps into overdrive to initiate the space heating. This is not an effective way of heating the space as the practice serves as a 'boost' system which traditionally is an expensive technique of heating homes. A bespoke and more effective user manual or app for houses built to the Future Homes Standard would have helped residents avoid these inefficient and ineffective practices.

An anomaly was detected in one household: an excessive spike in energy usage during the nights. When the householder was interviewed and shown their data, they revealed that they sometimes used portable space heaters in their home. This was a common practice by their teenage sons who did not want to turn on the heating for the whole house so resorted to using portable heaters that had been provided by the landlord of their previous house. As inspection of the heaters confirmed their energy consumption rate was the cause of the irregular spikes in the data. The sons said they thought it was a more efficient use of energy as they were only heating one room in the house, but it turned out they had mistakenly and drastically increased their household energy usage. Unfortunately, the occupants had not noticed this as they had not received an energy bill breakdown from their energy providers.

VENTILATION AND INDOOR ENVIRONMENTAL QUALITY

Several households reported opening their windows all day. One of the occupants mentioned that they did that because *"they liked fresh air"*. This is an effective approach to remove stale air and improve ventilation. However, some of the homes that did so were designed with MVHR and as such, opening the windows for background ventilation was a redundant practice as it reduced the efficiency of the heating and ventilation systems and the potential energy savings.

They reported that the practice of opening windows stems from the experience of living in their previous houses which were poorly insulated and insufficiently ventilated, which often produced mould. As highlighted above, some households disclosed that they had not experienced any respiratory related issues including asthma since moving into the new homes. They stated that they could "feel the freshness in the air when they breathe" an indication of the absence of the odour propagated by mould spores.

A lack of understanding among residents about how their mechanical ventilation systems work also created problems with the internal flows required for the systems to work optimally. The homes were handed over without floor coverings except in kitchens and bathrooms. Many households chose to install laminate flooring in living areas and corridors but this covered the recommended gaps underneath the wet room doors. Most of the occupants were interviewed admitted closing the kitchen and bathroom doors at night. The lack of internal air flow due to not having kept the recommended 10mm gap at the bottom of doors was very evident from the data monitored, as pollutants such as CO_2 wouldn´t decay totally during the night until doors and windows were opened again in the morning.

> *"I´ll open [the windows] every morning and they stay open most of the day. In the winter, they are open in the morning for like an hour maybe, and then I would close them."*

Households reported that they had noticed solar heat gains during summer. One occupant said their new home was excessively hot during the heatwave of the summer of 2022 , with outside temperatures about 30ºC. She said: *"We had to use fans and cool down with ice lollies"*. Furthermore, they reported that the sun-facing sides of the buildings were extremely hot, and the windows and mechanical ventilation systems were not sufficiently avoiding and removing the temperature gains.

Cooking methods were identified as a source of pollutants arising in kitchens. Most households reported using traditional ovens, air fryers and toasters. Culturally-influenced cooking patterns and the ingredients used also increased the level of pollutants around the house. These pollutants included fine particulate matter and volatile organic compounds. For example, frying foods with vegetable oil was a common practice in most households and significantly increased fine particulate matter and volatile organic compounds.

Data from air quality sensors revealed that the spike in pollutants in the kitchens during cooking was followed by a quick decay. This is likely related to the effectiveness of the ventilation systems coupled with conventional ventilation practices mentioned by residents including the opening of windows and doors while cooking.

LEARNING NEEDS

Residents need help understanding their new homes and must take responsibility for adapting their behaviours to achieve the greater efficiencies that the Future Homes Standard should unlock.

Some householders said they believed that their new homes require minimal effort to attain sustainable levels of performance. Others admitted that despite knowing it was essential they had not modified their lifestyles to take advantage of the efficiencies capable in their new homes. The following quote from an occupant summed up views expressed by other householders: *"[I know I have to make changes but] Old habits die hard"*. Understandably, residents are aware that they have some level of responsibility, but more effort is required.

10. LESSONS LEARNT AND RECOMMENDATIONS

The Eco Drive project has demonstrated that it is possible to create homes to the 2025 regulation that are traditionally built and can contribute to substantial carbon reduction. There is no need for exceptional design or construction. Costs are greater but justified against the lower carbon emissions produced and lower energy used. The improved internal environment can be regarded as an extra benefit.

INVOLVING OCCUPANTS

The evidence gathered in this study shows that occupants and their behaviours are key to low carbon living. Occupants enjoy homes built to the Future Homes Standard as they can more easily provide for their needs and enhance their comfort. Future homes are much more complex for occupants such that their lifestyles and previous experience may contribute to poor performance. There is evidence that occupants start living at higher temperatures in future homes, resulting in higher energy use than expected. Occupants can apply inappropriate settings to their systems and use expensive, ancillary forms of heating due to their lack of understanding of how controls work. Heat pumps equipment and controls are difficult to understand by occupants and outside their experience. The move to automation is unlikely to be successful as occupants operate homes to their knowledge and concerns. Expectations and habits dictate how occupants behave, and this is difficult to change.

Occupants cannot be expected to understand everything when they move into a home and facilities for progressive learning and revision needs to be provided. Information Technology (IT) offers the opportunity for better explanation, and learning. Opportunities include links to videos, manuals, and user groups. IT also offers opportunities to provide feedback to occupants on their living conditions, energy use and lifestyles. Monitoring can be used to provide occupants with information to help them achieve low carbon living and better living conditions. Occupants need to understand buildings, equipment (including when things are not working so that they can request maintenance), and the influence of their behaviour (particularly living temperatures, cooking, washing and ventilation) to ensure good performance of future homes and healthy indoor environments.

Recommendations:

- Occupants need to be provided with more information about their home, its equipment and the influence of their lifestyle to bring about low carbon living.
- The handover to occupants needs to be carefully managed over an extended period.
- Heat equipment, controls, ventilation and buildings must be designed to be understandable and operable by occupants.

HEAT PUMP STRATEGY WITH MAINTENANCE

Although heat pumps have been around for many years, these are a new technology in mass housing. There is still a lack of knowledge in the industry about the installation, use and maintenance of these systems. The fact that different heat pumps operate slightly differently and involve different connections and controls is not widely appreciated. For example, the way that heat pumps work with immersion heaters and how different heat pumps accommodate frost protection and legionaries' disease can be confusing. A heating and hot water operation strategy needs to be formally presented to make it understandable to contractors, maintenance people and occupants so that the design expectations are successfully met throughout long-term operation.

The location of the external unit is important to ensure its effective operation. Consideration needs to be given of its impact on occupants' use of space and aesthetics, its length of primary pipe runs to the inside and to the domestic hot water cylinder, its accessibility for maintenance, and that noise and vibration affects occupants. Security considerations are also critical, such as protection of external units, electrical isolation, and primary circuit isolation from children, accidental damage, vandalism, and theft.

Ensuring the installation of insulation and protection of external pipework is important to achieve the designed performance. This should include insulation within the penetration of the walls to reduce heat loss in the primary circuit. Similarly, internal pipework should be insulated to reduce the overheating impact of heat loss from the primary and secondary pipe runs.

Recommendations:

- The location and installation of the external unit needs to be thought about carefully at the initial house design stage. This needs to include security considerations.
- Extra attention needs to be paid to the installation of insulation and protection of external and internal pipework.
- There would be a benefit if heat pumps were more standardised (or at least presented in a standardised manner) so that knowledge and understanding by all industry parties could be increased.
- Controls need to be more user-friendly and the implications of different occupant strategies needs evaluating and accommodating particularly the desire to have intermittent operation.
- Effective commissioning and on-going maintenance are essential.

ENVELOPE DESIGN AND CONSTRUCTION

Homes built to the Future Homes Standard have thicker walls and need a location to install the heat pump. This needs to be accounted for during design in relation to plots and plot densities but also for planning and viability issues particularly for infill sites. There is some difficulty in placing of very low U-value insulation (which allow smaller thickness) during construction and the fire resistance needs to be considered as part of the decision. Fully-filled cavities using solid insulation, that are required for the lowest U-values, can make bricklaying challenging and the conventional order of construction may need changing.

The decision on double or triple glazing is not just about U-value, but involves purchase cost, weight of glazing units and availability, as sophisticated glazing coatings and more complex and non-standard formats may not be immediately available. This also makes maintenance more challenging. Triple-glazed units are much heavier and require more substantive frames, mechanical on-site handling and more expert handling. The decision on glazing needs to include:

- The location of the window in the wall aperture in relation to load bearing structure and reveal details including insulation;
- Ease of openings and light penetration. Windows are important for light and ventilation thus ease of opening and progressively larger opening windows for ventilation need to be considered. It can be the case that triple glazing requires larger frames which can also make openings more difficult and reduce light levels;
- The security and noise attenuation aspects of the windows, both generally and when open for ventilation; and
- Maintenance after breakage, as part of the aftercare strategy.

Recommendations:

- The wall compositions need to be viewed as a whole for low U-values, low air permeability and fire resistance. Bricklaying and wall tie requirements need to be considered for different insulation types, wall compositions and thicknesses.
- Good buildable junction details need to be available to ensure air tightness and minimise cold bridging (e.g. around windows (reveals), where cavity insulation joins; where there are corners and where there are wall penetrations) to assist designers, energy assessors and small- and medium-sized home builders.
- The decision on glazing should not be based solely on thermal performance. It needs to include considerations around weight, availability, ease of opening, light penetration, security and maintenance.
- Quality control of installations for insulation and structure is extremely important and needs to be part of contracts recognising difficulties of wall composition.

VENTILATION STRATEGY AND OVERHEATING

In future homes that are more sealed and have higher insulation, ventilation is a critical facility for ensuring good air quality and avoiding overheating. This involves ventilation systems, window location, window design and occupant understanding. Ventilation system control needs to be properly set and understood by residents and is particularly important during cooking and high occupancy periods. For more airtight properties, MVHR regularises some of this but makes gaps under internal doors more important to ensure internal airflow. Also, if ventilation strategy is not properly understood, occupants might open windows for background ventilation, reducing performance of ventilation and heating systems. Expectations and habits dictate how occupants behave, and this is difficult to change.

Our study did not find any marked difference in indoor air quality and energy use between houses with higher levels of airtightness (with an MVHR system) and those with normal permeability and point mechanical extract with natural ventilation; this will be investigated further.

In more sealed and higher insulated homes, overheating is a growing risk especially with warming due to climate change. There is evidence of some houses overheated during some days in summer where external temperatures were very high. External shading solutions seem to be the most cost-effective way of reducing overheating, but their design and installation might have some implications in terms of aesthetics, planning, construction, and maintenance. Also, in future homes it is important to insulate all hot water pipework throughout a house and in cylinder cupboards. Again, occupant lifestyles can provide additional heat sources which can contribute to overheating.

Recommendations:

- A ventilation operation strategy needs to be formally presented to make it understandable to contractors, maintenance people and occupants so that the design expectations are successfully met throughout long-term operation.
- Occupants need to be assisted to understand their role in achieving healthy air and ventilation, and how their lifestyle choices involving cooking, internal humidity sources and other contaminant sources such as candles and cleaning products affects the air quality.
- Ventilation systems need to have test certification to ensure compliance with Part F of the building regulations.
- The ventilation pathways, in particular under door gaps, into and through rooms, need to be understood by door and flooring fitters, as well as occupants. The implications of the need of these gaps for ventilation and fire safety need to be understood to avoid unintended consequences.
- The provision of external shading solutions might be suitable passive solutions to overheating but the implications of their use needs considering in regards to aesthetics, planning, construction and maintenance.
- Window openings need to be suitable for varying ventilation in different conditions. More understanding of ventilation-in-use backed up by research is required.

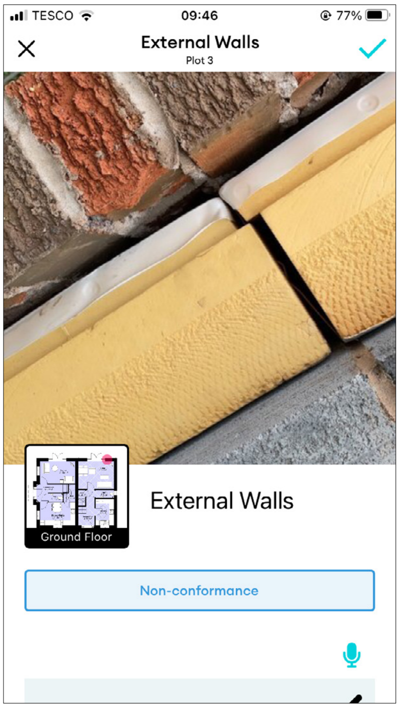
SUPPLY CHAINS AND MANUFACTURING

Future homes are much more complex, so it is important that the industry encourages collaboration between designers, constructors, and manufacturers to correctly produce homes and overcome problems. Problems and failures experienced by occupants can be amplified and disturb the development of future homes and promote false messages.

The requirement for photographic recording of as-built detail was found to assist the provision of quality but needs to be used positively with the supply chain. There is a need for fuller training of contractors and operatives to ensure good detail and build quality. Design needs to be understandable to make it easier for operatives to produce quality. At the moment, specialist capacity is limited, and less experienced subcontractors may not deliver quality work. This is due to a mixture of their abilities in installation design, the variety of heating and ventilation options, as well as installation.

Recommendations:

- Companies and the industry need to work together to achieve designed performance both in the supply of equipment but also in installation and maintenance. Contracts need to encourage and reward this and not destroy participation.
- Industry, manufacturers, and public agencies need to work together to develop experienced capacity by investing in training and supporting more attractive working conditions.
- Methods of achieving quality on site need to be developed to ensure performance. Commissioning needs to be properly conducted and certification provided.
- Electrical utility providers need to be involved early in planning as the added electrical load in future homes may cause delays to the programme.



Captego Non conformance report

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PERFORMANCE AND CONDITION REPORTING

Future homes are designed to reduce energy use and carbon production, create more resilient homes, and bring about more healthy indoor environments. This comes at a cost (approximately 11% more for the Future Homes Standard houses plus PV) yet provides added value. The main increase in build costs is in the provision of equipment associated with the heat pump. The use of heat pumps reduces operational carbon by over 50% and reduces operational cost but not significantly because gas is a third of the price of electricity. The incorporation of PV panels helps to alleviate higher costs of electricity and risks of future disruption. A 2.2 kW array was found to provide 4% of total consumption in January, 28% in April and 70% in June. The variation in energy use across households is markedly different and lifestyle is the key variable in reducing energy and carbon use in these future homes; it was not apparent that the houses with extra insulation and lower air permeability produced significant improvement

The rebound effect was evident in that the occupants took the opportunity to live at higher temperatures (the three-bedroom future homes can save about 120 kWh per month by living at 1ºC lower temperature), making real time monitoring and feedback available to occupants, critical to potentially their behaviour. As regards the indoor environment, all the houses adequately ventilated pollutants from cooking and because of being able to close kitchen doors this pollution did not circulate into the house. Again, cooking lifestyles vary enormously, and cultural differences contribute to stressing the indoor environment. Cooking can be responsible for 20% of winter energy consumption and involve multiple sessions during a 24-hour period. The research found that many households use cooking appliances in addition to installed cookers. It was also found that lifestyle practices involving candles, cleaning products and air scents contribute to higher TVOCs and PM 2.5.

Recommendations:

- The increased value of future homes with regards to reduced energy consumption and increased comfort needs to be emphasised, in relation to increased build costs.
- Achieving significant reductions in energy use depends on the lifestyles of occupants. Occupants need to understand heating and ventilation strategies, and equipment controls.
- Future homes are more complex. To avoid unintended consequences, real-time monitoring of energy and indoor conditions is needed to ensure low carbon and healthy environments. This monitoring will also facilitate commissioning, ongoing performance re-setting, and maintenance requirements. It can also be the basis of feedback to occupants as a route to behaviour change.
- Home occupiers need clear and concise information such as that provided to car drivers to influence behavioural change and ensure the continued effectiveness of the home.
- Maintenance is a key consideration and its provision needs to be part of the delivery.

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Midland Heart
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Envirovent
Glen Dimplex
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Munster
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Building Alliance

Hawk
Thornton Firkin
Captego

The Eco Drive project has demonstrated that it is possible to create homes to the 2025 regulation that are traditionally built and can contribute to substantial carbon reduction.

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