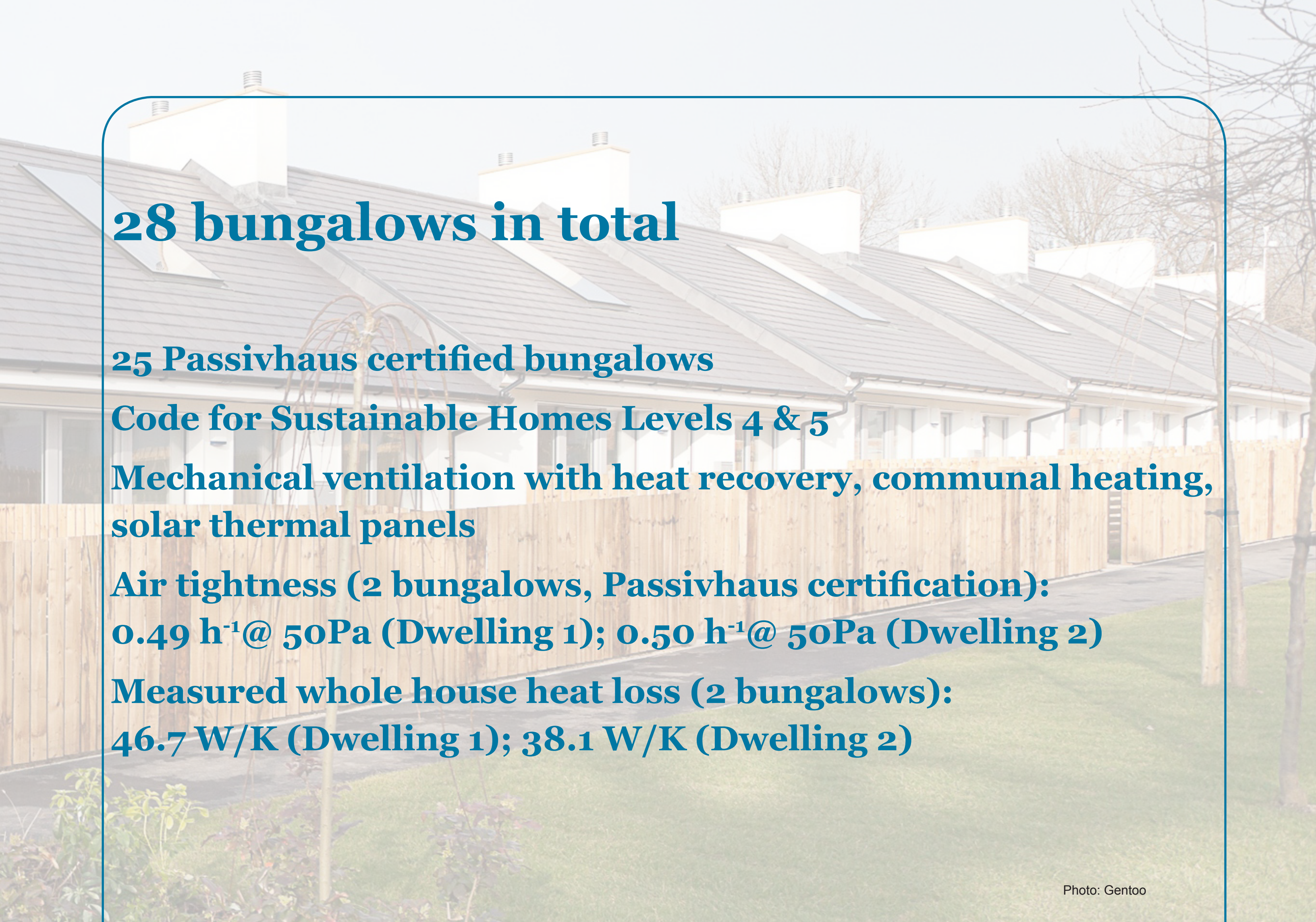
CASE STUDY

RACECOURSE

Building Performance Evaluation


Photo: Gentoo

The project reported here is part of the Technology Strategy Board's Building Performance Evaluation programme and acknowledgement is made of the financial support provided by that programme. Specific results and their interpretation remain the responsibility of the project team.



28 bungalows in total

25 Passivhaus certified bungalows

Code for Sustainable Homes Levels 4 & 5

Mechanical ventilation with heat recovery, communal heating, solar thermal panels

Air tightness (2 bungalows, Passivhaus certification):
0.49 h^{-1}@ 50Pa (Dwelling 1); 0.50 h^{-1}@ 50Pa (Dwelling 2)

Measured whole house heat loss (2 bungalows):
46.7 W/K (Dwelling 1); 38.1 W/K (Dwelling 2)

Photo: Gentoo

Evaluation Team

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Introduction

Racecourse is a development of 28 bungalows for housing senior people, located in a council estate in Houghton-le-Spring, Sunderland, and built in 2011. The area is part of a Citywide Renewal Plan aiming to replace older housing stock with around 4,000 high quality homes. Of the 28 bungalows, 25 are terraced (8 end-terrace and 17 mid-terrace) and three are detached. The terraced bungalows are designed to Passivhaus standards and either level 4 or 5 of the Code for Sustainable Homes. The detached units are designed for mobility impaired tenants, and although they have been built to the same fabric and services' standards as the terraced dwellings, due to their more challenging dwelling form, they are not designed to be Passivhaus certified.

Bunaglows at Racecourse

This case study examines two Passivhaus bungalows: one mid-terrace and one end-terrace. These bungalows were completed in November 2011. The evaluation of these dwellings was conducted under the Technology Strategy Board's (TSB) Building Performance Evaluation programme. The purpose of this programme is to assemble data from different new buildings so that conclusions about the effectiveness of different various design types and construction and operational practices can be drawn, with the aim to improve the whole sector.

To determine the effectiveness of the design and delivery strategy at the Racecourse, real fabric performance indicators were tested to compare these results with anticipated performance. The project team followed the TSB protocols for fabric and services testing, conducting the following examinations:

- Thermographic survey
- In-situ u-value tests
- Airtightness tests
- Coheating test
- Services commissioning checks
- Design and Construction review
- Occupant induction review

Additionally the BUS survey was used to capture occupant perceptions about their dwellings.

The results from this evaluation are positive. As-built, the dwellings achieve Passivhaus standards. The building fabric has exceptionally low heat loss and air permeability, the building services have been commissioned correctly and the occupants are generally happy with their homes.

Design and Construction

The predicted fabric and services performance figures are listed below in Table 1.

Table 1. Design Targets

Whole house heat loss (Leeds Met calculation)	43.4 W/K (Dwelling 1) 36.6 W/K (Dwelling 2)
Air permeability (design SAP)	0.6 $m^3h^{-1}m^{-2}$@ 50Pa
Air tightness (design Passivhaus)	0.6 h^{-1} @ 50Pa
U-value: roof (as-built SAP)	0.08 W/m^2K
U-value: walls (as-built SAP)	0.10 W/m^2K
U-value: ground floor (as-built SAP)	0.08 W/m^2K
U-value: windows and doors (as-built SAP)	0.70-0.90 W/m^2K
Y value (as-built SAP)	0.02 W/m^2K
MVHR heat exchanger efficiency (SAP Appendix Q)	85%
MVHR fan Specific Fan Power (SAP Appendix Q)	0.5 W/l/s

Building Fabric

Each bungalow has a total floor area of $66m^2$, comprising an open-plan living and kitchen area, a mezzanine which functions as a plant room and loft space, and two bedrooms.

The external walls were built using pre-fabricated timber-frame cassettes filled with 300mm insulation. Walls were then externally clad with 15mm bitroc and either brick or render. Internally, the external walls have a 47mm insulated service void lined with 25mm plasterboard. The walls have a designed U-value of 0.095 W/m^2K.

The ground floor is reinforced concrete slab-on-ground construction, with 300mm insulation above the slab and then a 50mm screed, with a designed U-value of 0.083 W/m^2K.

The roof is constructed using pre-fabricated timber-frame cassettes filled with 450mm of insulation and clad in clay roof tiles, with a designed U-value of 0.082 W/m^2K.

All windows are triple glazed, low-e krypton filled units with warm edge spacers and thermally broken frames. Designed U-values are between 0.72 and 0.95 W/m^2K, depending on size. The doors are aluminium faced composite (aluminium/insulation/timber) with thermally broken frames, with designed U-values between 0.70 and 0.86 W/m^2K, depending on the size.

A detailed strategy for achieving the air leakage target of ≤ 0.6 h^{-1} @ 50Pa was developed and carried out. This involved the following:

- A properly designed and properly executed primary air barrier.
- Formally adopt the airtightness target and communicate this well.
- Plans and details annotated to include information on airtightness.
- Inclusion of airtightness testing into the programme to allow the dwelling to be pressure tested at various different stages of construction.
- A well communicated construction strategy and training programme for on-site personnel.

Building Services

A whole house MVHR system has been installed in the loft space of each bungalow. The installed unit has a SAP Appendix Q heat exchanger efficiency of 85% and a specific fan power of 0.5 W/l/s. It is controlled with a remote keypad in the drying cupboard, and push-to-make boost switches in the hall and kitchen. The intake and exhaust ductwork is insulated with two layers of closed cell insulation sheet to avoid condensation and degradation in energy performance, giving a total insulation thickness of 50mm. Supply ductwork to the rooms is insulated with 50mm mineral fibre.

MVHR installation

70°C primary hot water to the heat emitters in each of the bungalows is supplied from a gas-fired condensing communal boiler, located in a small boiler room on the East end of the terrace, via a highly insulated communal heat main. Billing is provided utilising a heat meter in each dwelling.

As a conventional wet, central heating system is not required because the space heating demand for each dwelling is very low (being built to Passivhaus standards), space heating is provided via a small, low temperature hot water heater battery installed in the MVHR ductwork. In addition to the heater battery, a heated towel radiator is provided in the bathroom and a small radiator has been installed in the drying cupboard.

Control to the heater battery in the MVHR system is provided with room thermostat in the living room and also a return temperature thermostat, regulating the temperature of the heater coil to avoid overheating the ventilation air. Although time control is provided, the heat output of the space heating system is low so it is recommended that the heating be run continuously throughout the day to maintain adequate temperatures. Thus, the 24 hour programmer has been purposely located in the drying cupboard to try to discourage its use.

The small radiator in the drying cupboard is controlled with a manually operated touchstat which incorporates a boost setting. The towel radiator is controlled by both the room thermostat and also by a manually operated timed boost switch located in the hall.

The domestic hot water system utilises twin coil hot water cylinders in the mezzanine plant area of each bungalow, with heat input from the communal heat main and the solar hot water system. 3m^2 roof-mounted collectors have been installed on the South-facing roof slope of each bungalow.

Domestic hot water cylinder

Design and Construction Experiences

Design Challenges

The Project Architect identified the following issues encountered during design that they would not look to replicate, or would look to do differently in the future:

- The form factor of a bungalow is disadvantageous in Passivhaus design due to the high surface area to volume ratio. This results in additional heat losses that have to be compensated by increased performance specifications. A more efficient form factor, such as a two or three storey dwelling enables lower performance specifications to be used, and consequently can result in a reduction in capital costs.
- Locating the plant space on the mezzanine floor is not the preferred option for building maintenance, for example, changing filters in the MVHR system.
- The Project Architect understands that homes with staircases offer the opportunity for greater exercise and can help to reduce the incidence of osteoporosis. As the dwellings were designed to be occupied by elderly residents, multi-story dwellings may be better for occupant health.
- Newer Passivhaus certified MVHR units would be used as they offer higher heat recovery efficiencies and also incorporate an automated, rather than manually operated summer bypass which could help reduce overheating.
- OSB would be used as the primary air barrier rather than a membrane, as this would have reduced the risk of damage from construction activities.
- The Project Architect was concerned the occupants would not be able to comprehend the inter-relationship between space heating and ventilation (the all-air-heating system) and believes separate heating and ventilation systems are better for usability.

Construction Challenges

The main changes and challenges encountered during construction and how they were managed are discussed in this section.

Throughout construction the project architect and contractor worked closely to ensure that airtightness targets were fulfilled, the designs were buildable, and the project met quality assurance measures. Additionally the Passivhaus designers held knowledge transfer events for the services installation engineers, who then briefed the maintenance engineers on maintenance requirements.

A number of strategies were used to reduce the risk of thermal bypass within the timber-frame cassettes. For example, the specification stated that tuck ends should be avoided, and the insulation thickness was specified to be 10% greater than the available cavity to achieve a tight but even compression; this became known as an 'over-stuff'. The project architect also trained and briefed the timber-frame contractor to make them aware of the importance of the over-stuff.

Two air tightness details were refined during construction; one adjacent to the sole plate, and one at the internal step along the party wall. The design intent had been to use 15mm OSB with taped joints as the air barrier. The timber frame contractor proposed using a membrane instead, as they had experience with this. The client and contractor consented to the change despite reservations from the project architect. At the end of the project, the site manager confirmed that the membrane was fragile and susceptible to repeated damage. Resource had to be dedicated to fixing tears in the air barrier membrane to avoid air leakage points.

Air barrier membrane with tear

The first timber-frame manufacturer became insolvent and extra time was required for re-tender and the design/development of a new timber-frame cassette system. Although prefabrication can reduce on-site construction time, the extended design time of specialist timber-framing undermines this.

The timber-frame manufacturer that ultimately supplied the pre-fabricated cassettes introduced additional structure into these cassettes to allow for them to be craned on site. This change of design resulted in the timber fraction increasing. While this did not affect Passivhaus certification, it did impact on the U-value of the roof, which increased from 0.08 to 0.082 W/m^2K.

Additionally, there were procurement problems with the doors. The supplier provided doors that were 100mm wider than in the construction drawings. The timber-frame system had to then be redesigned so that the wide doors could be accommodated. The roof insulation also needed to be upgraded to offset additional heat loss from the doors in order to maintain Passivhaus Standard requirements.

Construction Review

The evaluation team visited the site during construction, noting anything that could impact fabric performance and airtightness. The first observation took place after the superstructure had been completed, but prior to the internal partitions being erected. The external windows and doors had not been installed at this stage, so the dwellings were not wind and watertight. As only a limited number of site visits were possible during construction, the following observations only represent a snapshot in time, and therefore may not be representative of what was finally built.

- Gaps were observed between the sole plate and the DPC. Grout was subsequently applied on the inside to seal the gap between the bottom rail of the timber-frame cassette and the ground floor. If these gaps were not grouted effectively, or shrinkage occurred between the DPC, the grout and the timber-frame, there is a possibility that air leakage may occur.
- There were a number of tears in the foil faced membrane used as an air barrier. If these were not properly repaired, air leakage could occur. On a later site visit, it was

noted that the contractor had paid close attention to taping-up damaged areas of air barrier membrane. The contractor had also ensured continuity of the air barrier membrane around openings, such as windows.

- At external/internal stud wall junctions a black vulcanised rubber strip was attached to the internal face of the timber-frame cassette and the ground floor. This strip minimises potential damage to the internal air barrier membrane and enables continuity of the air barrier.
- Construction debris was found in the open section of the timber-frame cassettes at the sills of all openings. If not cleaned out prior to the installation of the mineral wool insulation, it may result in additional thermal bridging around the openings.
- Once mineral wool had been installed into the open sections of the timber-frame cassettes, it was not protected from the elements and became saturated prior to the installation of the OSB sheeting, sill and jamb boards. It is not known if this insulation was replaced or dried out prior to the boards being installed. If still damp, the thermal performance of the insulation will have been degraded.

Sealed services penetrations

- The contractor had taken care to use the appropriate gaskets, grommets and sealing putty to seal any services that penetrated through the air barrier membrane. However, no attempt had been made to seal where some services penetrated the external layer of bitroc on the outside wall, which may result in wind washing.
- After the superstructure had been completed the dwellings were not wind and watertight, and were exposed to the elements. The structure became saturated and significant amounts of standing water were present inside. If the dwellings were not fully dried out prior to completion, this is likely to have contributed to the high levels of construction moisture recorded during the Coheating test.
- The external leaf of brickwork on the gable end of Dwelling 1 did not run parallel to the timber-frame cassette. The cavity was non-existent at one end of the gable wall and 50mm at the other. It is not known if this was rectified prior to the completion of the gable wall.

If not addressed, the issues highlighted above could have had adverse effects on measured performance. However, pressurization test results and Coheating data suggests that these issues were either rectified later on in construction or had little effect on performance. Both dwellings achieved high levels of airtightness (0.49 and 0.50 h^{-1} at 50Pa for Dwellings 1 and 2, respectively) and a heat loss coefficient close to that of the predicted heat loss coefficient.

Building Fabric Evaluation

To evaluate the real building fabric performance, air pressuring testing, a Coheating test and in-situ U-value tests were performed on the two studied bungalows.

Coheating Test

The coheating test was undertaken on one end-terraced (Dwelling 1) and the adjacent mid-terraced (Dwelling 2) bungalow between the 11th November and the 21st December 2011, in accordance with the TSB adopted protocol developed by Leeds Met. This protocol has now been updated[1].

Beginning with pre-coheating pressurisation tests on the 8th and 9th of November 2011, the coheating test equipment was then in-

1 http://www.leedsmet.ac.uk/as/cebe/projects/iea_annex58/whole_house_heat_loss_test_method(coheating).pdf

stalled and both dwellings were then gradually heated.

Access to Dwelling 3 (adjacent to Dwelling 2) could not be controlled throughout the Coheating test, with this dwelling used as the site welfare facilities and the site manager's office, and it was only possible to provide heat input into the space immediately adjacent to the party wall of Dwelling 2 - the open plan living/kitchen area. This made it difficult to control the mean internal temperature within this space. The heat loss coefficient figure for Dwelling 2 therefore should be treated with a degree of caution, as it is likely there some heat loss into Dwelling 3.

During the coheating test it was not always possible to maintain all of the rooms at 25°C, particularly in the small South-facing bedrooms, where the temperature rose above 25°C for short periods. This highlights the difficulty with undertaking coheating tests in highly insulated, airtight dwellings that have small South-facing rooms with a high proportion of glazed area.

High relative humidity was measured in both dwellings throughout the test period, suggesting that there was still some residual moisture within the building fabric. A slight reduction in mean moisture content at the end of the test indicated that the building fabric had dried somewhat. However, this drop was small, and is likely to have had a minimal impact on heat loss through the building fabric.

During the coheating test water was found around the MVHR units (which had been electrically isolated), with a considerable amount of standing water found in the frost protection unit on the air intake duct. This was subsequently brought to the attention of the assistant site manager, and the water was siphoned away.

The reason for the accumulation of water in the frost protection units is thought to be attributable to warm, moisture laden air from within the dwellings entering the MVHR system ductwork, with air being driven through the unit to the outside. This poses a potential complication for undertaking coheating tests in dwellings which have high internal humidity, are airtight and have an MVHR system installed. In these instances, it may be more effective to seal the MVHR system at the intake and exhaust connections to the main unit rather than at the internal supply and extract grilles.

The measured and predicted heat loss coefficient for both dwellings are very close to one another, with the difference in heat loss coefficient being within the range of the error associated with the test, as shown in Table 2 below.

Table 2. Predicted and Measured Heat Loss Coefficients

House	Heat loss coefficient (W/K)		
	Predicted	Measured	Difference
Dwelling 1	43.4	46.7	+7%
Dwelling 2	36.6	38.1	+4%

In context, the measured and predicted whole house heat loss for both dwellings represent the two best performing dwellings out of a sample of 21 other new build coheating tests undertaken by Centre of the Built Environment at Leeds Met over the last decade. It is also important to note that bungalows have a much greater exposed envelope area, and resultant heat loss than other dwelling forms of equivalent floor area.

In-situ U-value Test

A number of heat flux plates were located throughout Dwellings 1 and 2 (20 were used in Dwelling 1 and 10 in Dwelling 2) to obtain in-situ measurements of the U-values of various elements of the building fabric. Measurements from the heat flux plates were taken at one minute intervals throughout the coheating test. Figures obtained from the heat flux plates were undertaken on a small area of each of the building elements, so are only indicative - they may not necessarily be representative of the building U-values as a whole. Also note that intended U-values decreased during the design process so measured U-values are compared to the values found within the final, as-built SAP worksheet.

U-values for the external wall in Dwelling 1 ranged from 0.08 to 0.23 W/m^{2}K, with a mean of 0.12 W/m^{2}K. This compares well with the design value of 0.10 W/m^{2}K. U-values for the ground floor in Dwelling 1 varied from 0.07

to 0.18 W/m^{2}K, with a mean of 0.10 W/m^{2}K, which again compares well with the design value of 0.08 W/m^{2}K. For the ceiling, measured U-values in Dwelling 1 measurements ranged from 0.09 to 0.20 W/m^{2}K, with a mean of 0.13 W/m^{2}K, which is slightly higher than the design value of 0.08 W/m^{2}K.

U-values for the centre-pane of a North facing window in Dwelling 1 varied ranged from 0.56 to 0.78 W/m^{2}K, with a mean of 0.68 W/m^{2}K, which is lower than the design value of 0.80 W/m^{2}K. Heat flux was also measured through the window reveal - U-values varied from 0.17 to 0.36 W/m^{2}K, with a mean of 0.23 W/m^{2}K.

Heat flux plates were also located at the eaves/wall junction in Dwelling 2. U-values for the wall at the eaves/wall junction varied from 0.08 to 0.47 W/m^{2}K, with a mean of 0.21 W/m^{2}K, while for the ceiling at this junction U-values ranged from 0.07 to 0.31 W/m^{2}K, with a mean of 0.18 W/m^{2}K.

A very small amount of positive heat flux was measured from all of the heat flux plates located on the partition wall in both dwellings, indicating that the party wall is acting as a heat loss mechanism. In dwelling 1, the U-value for the party wall ranged from just under zero to 0.04 W/m^{2}K, with a mean of 0.02 W/m^{2}K, while in Dwelling 2, U-values ran from under zero to 0.09 W/m^{2}K, with a mean of 0.02 W/m^{2}K.

Air Pressure Testing

Air pressurisation tests and leakage identification was undertaken on the two studied bungalows. The bungalows form part of a terrace of 7 properties, with the primary air barrier around the entire terrace as a whole, rather than around each individual bungalow. Tests were conducted twice: before the Coheating test (after Practical Completion), and immediately after the Coheating test. This second test was performed to see whether the Coheating test had any impact on airtightness.

Although very tight by UK standards, the figures obtained for both dwellings (0.89 and 1.31 m^{3}h^{-1}m^{-2}@ 50Pa) are higher than the designed tightness of 0.6 m^{3}h^{-1}m^{-2}@ 50Pa found on the SAP worksheets. The results showed no increase in air permeability as a result of the Coheating test conditions.

Only very small areas of air leakage were detected (mostly around service penetrations) using the hand-held smoke generator. These were identified as follows:

- Around the communal heat pipework party wall penetrations located in the loft space.
- Via holes in the plasterboard dry-lining in the loft space, created for cabling within the service void.
- At the threshold corners of the external doors and French doors.
- Around the occupant alarm trunking.
- Around the bracket support for the pipe hangers in the loft space.

Pressure equalisation tests were also performed on Dwellings 1 and 2 to determine the extent inter-dwelling air leakage. Results suggest that there was some small air leakage between dwellings.

In addition to the tests undertaken by Leeds Met, an external contractor tested Dwellings 1 and 2 on completion of the primary air barrier and at Practical Completion. Both of these tests were undertaken using the Passivhaus pressure testing methodology. These results showed both dwellings achieving the required air leakage target of ≤ 0.6 h^{-1} @ 50Pa (0.49 h^{-1}@ 50Pa for Dwelling 1, 0.50 h^{-1}@ 50Pa for Dwelling 2).

The external contractor also tested both dwellings for Building Regulations compliance purposes in accordance with ATTMA Technical Standard L1 (ATTMA, 2010). A comparison of these results with the tests undertaken by Leeds Met shows the Leeds Met tests to be higher. The reason for this may be because the Leeds Met tests were undertaken almost two weeks after the external contractor tests, and during this time a number of holes had been made in the plasterboard lining to enable access to cables located within the service void.

Real Performance

The table below compares the design targets with the measured values for the fabric tested bungalows. Overall the dwellings, as constructed, are very airtight and well insulated, and perform close to the design targets.

Table 2. Closing the Performance Gap

	Predicted	Measured [Leeds Met]
Whole house heat loss coefficient	43.4 W/K (Dwelling 1) 36.6 W/K (Dwelling 2) [Leeds Met calc]	46.7 W/K (Dwelling 1) 38.1 W/K (Dwelling 2)
Air permeability	0.6 $m^3h^{-1}m^{-2}$@ 50Pa [design SAP]	0.89 $m^3h^{-1}m^{-2}$@ 50Pa (Dwelling 1) 1.31 $m^3h^{-1}m^{-2}$@ 50Pa (Dwelling 2)
Air tightness	≤ 0.6 h^{-1} @ 50Pa [design PH]	0.49 h^{-1}@ 50Pa (Dwelling 1) 0.50 h^{-1}@ 50Pa (Dwelling 2) [extenal contractor tested for PH certification]
Ground floor	0.08 W/m^2K [as-built SAP]	0.07-0.18 W/m^2K 0.10 W/m^2K [mean]
Wall	0.10 W/m^2K [as-built SAP]	0.08-0.23 W/m^2K 0.12 W/m^2K [mean]
Roof	0.08 W/m^2K [as-built SAP]	0.09-0.20 W/m^2K 0.13 W/m^2K [mean]
Window (centre-pane)	0.80 W/m^2K [as-built SAP]	0.56-0.78 W/m^2K 0.68 W/m^2K [mean]

Building Services Evaluation

MVHR

The Leeds Met research team undertook flow rate measurements on Dwellings 1 and 2 in January 2012. The measurements indicated the following:

- Whole house supply and extract rates were balanced.
- The units satisfied Part F 2006 requirements.
- In the living area and the kitchen, higher readings were measured by the Leeds Met team than the external contractor. This may be due to measurement error, as the flow hood the Leeds Met team used may not have been large enough in relation to the diffuser.
- The total measured supply and extract flow rates are higher than the design rates, in some cases by almost 50%.

It was determined that the greater air flows were most likely because the 7 factory pre-set speed settings of the MVHR units could not be changed on-site, with all the units installed on the development are of the same type. The manufacturer based fan speeds on design flow rates and potential occupancy levels, thus supplying one unit that could provide flow rates for all the different dwelling sizes. However in practice, the first three of four pre-set speed settings all resulted in the same measured total flow rate, irrespective of the terminal settings.

Inspection of the MVHR installation suggested that the MVHR units were installed well and according to specification. The ductwork visible in the loft was also installed to a very high standard, with considerable care taken with insulation (in accordance with the services specification). The supply grilles to each room were also individually adjusted to meet the particular room requirements.

Heating System

The space heating systems for the examined dwellings were commissioned in November 2012. This comprised completing a commissioning checklist covering the overall system, the controls, the central heating mode and the boiler.

Observations of the installed space heating system indicated that the specified system, including the communal boiler and distribution pump, space heating systems in the dwellings, and the majority of the exposed pipes in the loft space were properly insulated (missing sections were predominately around pipe supports and some fittings).

The hot water heating systems for examined dwellings were commissioned in May 2012. Commissioning comprised completing a site inspection record which looked at the solar collector installed on the roof, the connections and the control systems. The inspection found the following:

- In both dwellings the drain cocks were not at the lowest points in the system.
- The pressure in the expansion vessel was too high in Dwelling 1.
- In Dwelling 2 there was an error light on the control system, a panel sensor was damaged, fluid circulation could not be tested due to the sensor error, and the system and expansion vessel pressure were both too high.

Remedial works were subsequently undertaken to reduce the pressure in the expansion vessels and system and replace/repair the sensor connections.

Occupant Engagement

The information given to occupants when they moved into the properties was evaluated as part of this study, as was the occupant induction.

Occupant Guides

The main document provided to the occupants is a 10 page booklet titled “A Quick Guide to your PassivHaus Home”. This provides information on how this Passivhaus differs from more traditional buildings, and the advantages of this. This guide also provides details on services that the occupants may be unfamiliar with, such as the MVHR.

The guide was generally found to be informative, factual, and for the most part uses language and presentation that is accessible to a non-technical audience. In the future, a glossary may be helpful when technical language cannot be avoided.

Several “door hangers” were placed on the handles of rooms containing potentially unfamiliar control units. These are short guides with a description and picture of the controls. Occupants were also supplied with an Occupant Pack which contains all essential information on the services and appliances, including manuals, certifications and guarantees. Emergency contact details are also contained within this.

The Occupant Pack was found to not be well presented, but it is an essential feature of the home, containing all of the necessary manuals and certificates. The Occupant Pack would greatly benefit from some ordering to assist the user in finding information.

Induction

Induction, or occupant handover, is the process by which new occupants are walked around the dwelling by a member of the buildings team and introduced to the various systems and appliances. Following induction, Gentoo provides further support should occupants have any issues or have any more questions.

Although it was not possible for the research team to view an induction, the process was demonstrated to Leeds Met in a role play format. The walkthrough process on the whole was found to be excellent; the information given was thorough and accurate. Care was taken to ensure the occupant was happy with all of the services demonstrated, and contact details were given should any issues arise. The occupant was also informed about maintenance and management of the various services, such as changing air filters in the MVHR system.

Occupant Perceptions

It was observed that occupants were not opening their windows, which has potentially led to overheating. This was traced back to earlier advice given to the occupants asking them to avoid opening their windows, as this would reduce the effectiveness of the MVHR heat recovery, in addition to the potential security risk of leaving their windows open at night. This advice is also found in the PassivHaus booklet. It should be noted that intermittent opening of windows should not have an adverse impact on the operation of the MVHR system, unless the windows are left open for an extended period of time.

BUS Questionnaire

The BUS questionnaire gauges occupant satisfaction with their dwelling and helps to inform the research team about occupant issues, which can then be cross referenced with measured data to ascertain potential reasons for poor performance.

27 BUS questionnaires were distributed to residents, of which 21 were completed and returned. On the whole, occupants were satisfied with their dwellings, and had positive feedback for the majority of the questionnaire categories. There were some exceptions, however - these are highlighted below:

- Occupants found the air quality in the properties to be too still during both summer and winter, with additional concerns about air being excessively humid in summer. Possible reasons for this could be incorrect use of the MVHR system and windows. Confusion around window usage had been highlighted from occupant feedback, with occupants previously being advised to keep the windows closed to improve MVHR efficiency (and for security) and interpreted this as an instruction to not open windows at all.
- Residents found the indoor temperature too hot, both in summer and winter. This may be due to a combination of factors such as incorrect MVHR operation, the large South-facing glazed façade, leaving windows closed and thermostats not set at an appropriate level or not functioning correctly.
- Some residents felt that the low energy pendant light bulbs were too dim.
- Tenants highlighted that the electricity bill was larger than expected. However, this may be due to a general increase in electricity prices.

Key Observations

1. Fabric tests showed both dwellings to be very airtight by UK standards, with measured U-values close to the design U-values, and no significant areas of unexpected heat loss.
2. The coheating tests showed very little difference between the measured and the predicted heat loss coefficient of both dwellings, with any difference observed being well within the range of the measurement error of the test.
3. Coheating tests can be difficult in dwellings that are highly insulated and airtight, and have small South-facing rooms in which a large proportion of the external envelope is glazed.
4. Building services appear to have generally been installed to a high standard and commissioned correctly.
5. The design and construction team experienced a number of challenges during the construction process, the majority of which were completely out of their control. For instance, two timber-frame manufacturers ceased trading during the project, and there were difficulties sourcing a number of the building products. Despite these challenges, the dwellings were constructed pretty much as intended.
6. The Project Architect identified aspects of this design that they would not replicate in future, including: bungalows to Passivhaus standard (due to their form factor); the mezzanine plant room (not ideal for maintenance purposes); and the complexity of the building services.
7. Feedback from the client and tenants has identified potential overheating in some homes. This is thought to be a result of occupants keeping windows closed during summer, which has been traced back to early guidance concerning the MVHR given to occupants.
8. Occupant guides and the walkthrough were found to be of a high standard, providing sufficient guidance for occupants to understand and enjoy their homes.
9. Overall the residents feel the dwellings are of high quality, enjoy living in them and are happy with their performance. The key area of concern for occupants is overheating, which hopefully will be lessened now that they have been properly instructed on the use of their windows, however night time purge may not be possible due to the security risk.

Key Lessons

1. Careful design alongside the appropriate quality control systems, such as those required to attain Passivhaus Certification, can help deliver dwellings that begin to bridge the Performance Gap.
2. When undertaking a coheating test in an airtight dwelling with high internal humidity and an MVHR system, it may be more appropriate to seal the MVHR system at the intake and exhaust connections to the main unit, instead of at the individual supply and extract grilles to the individual rooms, to prevent the accumulation of water in the MVHR units.
3. There is no standardised method of commissioning particular building services; the development of a standardised method would enable comparability between dwellings.
4. The high surface area to volume ratio of a bungalow is disadvantageous in Passivhaus design. This results in additional heat losses that have to be compensated by increased performance specifications. A more efficient form factor enables lower performance specifications to be used, and can result in reduced capital costs.

The Technology Strategy Board is a business-led executive non-departmental public body, established by the Government. Its role is to promote and support research into, and development and exploitation of, technology and innovation for the benefit of UK business, in order to increase economic growth and improve the quality of life. It is sponsored by the Department for Business, Innovation and Skills (BIS). T: 01793 442700 www.innovateuk.org