TEMPLE AVENUE PROJECT

ENERGY EFFICIENT NEW HOMES FOR THE 21ST CENTURY

54&69

JOSEPH ROWNTREE FOUNDATION

JOSEPH ROWNTREE HOUSING TRUST

FOREWORD

Nigel Ingram

Director of Development and Asset Management,

Joseph Rowntree Housing Trust

In little more than four years time zero carbon should become the standard for all new homes. The definition has not been finalised and successive governments have been charged with relaxing the zero carbon standard. However, the Coalition has committed its support to an approach based on carbon reductions that are achieved in real life, rather than those predicted by models (HM Treasury 2011, p. 117). This is an entirely new challenge to the housebuilding industry, which has previously demonstrated Building Regulations compliance through carbon emission calculations submitted during the design stage.

Housebuilding is becoming increasingly complex but some simple truths will always apply: designing the building fabric correctly must be the highest priority. Getting the fabric right will save energy for the whole life of the dwelling. It is also essential for the efficient use of low and zero carbon technologies, which will still be necessary ingredients for the carbon compliance element of the zero carbon mix. This publication examines the low carbon journey of 54 & 69 Temple Avenue, York. We hope that it will be a useful reference for policy makers, housing professionals and everyone in the industry who is gearing up to deliver consistent 'as-built' performance.

FINDINGS FOR INDUSTRY

Many processes and cultures within the housebuilding industry and its supply chain need to change if zero carbon housing is to become a reality in 2016

Procurement - Housing providers need to be more committed to the energy and carbon performance of homes and to ensuring that claims made by designers, contractors, developers and suppliers are supported by robust evidence.

Design - Design processes should be improved to:

- Increase the robustness of detailed design and thermal calculations;
- Consider 'as-built' performance, including tolerances in all calculations;
- Take into account the construction sequence.

Construction - Construction processes need to be improved so that:

- Construction sequence and operations are planned in more detail and include in-production testing;
- On-site briefings ensure that everyone involved is sufficiently aware of the issues to do their job well;
- Changes during construction are closely controlled to make certain that performance is not compromised;
- The specification, installation and commissioning of mechanical ventilation and other services is more robust, so that the expected efficiencies are realised.

The supply chain - Information provided by suppliers should reflect 'as-built' rather than laboratory performance.

OVERVIEW

Although a number of high profile demonstration low carbon houses have been built, there is little verifiable evidence that these homes will deliver the performance that their designers intended. The housebuilding industry as a whole suffers from a lack of measured data. Consequently there has been little impartial analysis of the processes and techniques that the industry will have to adopt in the design, procurement, construction and commissioning of projects to deliver 'as-built' standards of carbon compliance.

The Joseph Rowntree Foundation (JRF) and the Joseph Rowntree Housing Trust (JRHT) have a history of conducting rigorous post-construction and post-occupancy testing and evaluation of low carbon housing. A pilot project in 2007 - Elm Tree Mews - was one of the first to evaluate both the fabric performance and the efficiency of low carbon technologies in houses that aspired to higher levels of energy performance than the Building Regulations required. It revealed a number of issues that arise when innovative and relatively unfamiliar technologies are used in conjunction with modern methods of construction.

The Temple Avenue Project (TAP) in York described here, and in the sister publication 'Temple Avenue Project: 67', represents JRF and JRHT's next Action Research step, learning lessons from the 2007 pilot project and applying them to prototype house designs and construction techniques, which will be used in Phase One of JRHT's new community in Derwenthorpe. As at Elm Tree Mews, Leeds Metropolitan University, Centre for the Built Environment (Leeds Met) undertook a substantial programme of design and construction observation and involvement, as well as testing and evaluation. This report is underpinned by Leeds Met's detailed technical findings (Miles-Shenton et al. 2012). It identifies some areas where the houses did not perform as well as we had intended, but this is an essential part of prototyping, leading to a repeatable solution suitable for volume housebuilding.

In the latter part of this booklet we describe the 2009/10 lessons learned from TAP and how these will be applied to Derwenthorpe, which is currently being constructed. The TAP houses deliver some of the best post construction results that have been recorded but there is still the issue of whether the lessons can be transferred to mainstream practice (Miles-Shenton et al. 2012, pp. 19-20). In Phase One of Derwenthorpe JRHT has teamed up with David Wilson Homes, part of the Barratt Developments group, to help ensure that the next stage in the evolution of Derwenthorpe can help inform the housebuilding industry as a whole.

PART 1.1

INTRODUCTION TO THE 54 & 69 PROJECT

HOW TO USE THIS BOOKLET

We hope that this booklet will appeal to a wide audience. The following conventions have been adopted to highlight some of the important messages:

Key points are located at the top of pages and can be read independently;

The discursive text below expands upon the key points;

Text against a purple background gives further explanation of the technical information.

Did the prototypes perform as well as the designers predicted? Can their performance be replicated by volume housebuilders? Can tomorrow's homes deliver 'as-built' levels of carbon compliance?

The Temple Avenue Project (TAP) houses are prototypes for replication and, as such, they test techniques that are suitable for volume delivery, economically and consistently. The emphasis is different from a money-is-no-object demonstration project as there must be a focus on cost-effectiveness and usability.

The two prototype dwellings were constructed between July and December 2009 and contain some technological innovation. One prototype, Number 54, was built using thin joint masonry construction and the other, Number 69, using a Structural Insulated Panel System (SIPS).

The houses have similar ventilation and energy strategies, including high levels of insulation and airtightness and an energy recovery ventilation system, Mechanical Ventilation with Heat Recovery (MVHR). The project tests the efficacy of these measures and also their reliability.

Heat loss from a house (described as whole-house heat loss) is a combination of conduction, convection and radiation through the dwelling fabric (fabric heat loss) and via air leakage (background ventilation heat loss).

In order to minimise heat loss it is necessary to improve the insulating effect (U-value) of each element of the fabric and airtightness. Good practice construction establishes continuous insulating and air barrier layers. It also addresses other construction issues that can increase heat loss, minimising thermal bridging (instances of extreme fabric heat loss) and thermal bypass (the movement of unheated outside air within cavities in the construction, which has bypassed the insulation layer) and avoiding out-of-sequence work, which can prevent other work stages from being completed properly, or damage work that has already been done.

Reduced running costs and carbon emissions

Overleaf. Architect's impression of Derwenthorpe and location of Numbers 54 & 69

Computer generated image

1. Photovoltaic panels
2. Thin joint masonry wall construction
3. SIPS wall and roof construction
4. High-performance double-glazed timber windows
5. Double-height space collects heat from the winter sun
6. Robust detailing to reduce heat and air loss
7. Secure cycle storage
8. Rain water harvesting for WC flushing and washing machines
9. Sustainably sourced materials

Building prototypes provided the opportunity to test two modern methods of construction (MMC) and the installation of an energy recovery ventilation system. It was also possible to compare estimations with measured or 'as-built' performance.

The prototypes allowed the team to make an objective assessment of the buildability and performance of two modern construction types and to monitor the installation and commissioning of the MVHR system. JRHT also learned useful lessons about the supply chain and communication between suppliers, designers and constructors.

MMC potentially offer improved thermal performance and faster build times. Thin joint masonry (blockwork) differs from traditional blockwork construction by using a thin layer of expoxy resin in lieu of traditional mortar. The resin sets more rapidly giving earlier stability to the construction. The system also uses driven wall ties allowing the blockwork and outer leaf to be constructed separately. Thin joint systems claim to achieve better quality, faster build times and improved airtightness.

SIPS (Structural Insulated Panel Systems) consist of a rigid core of insulation sandwiched between two timber boards, offering superior insulation, structural strength and airtightness over traditional construction. SIPS are also lightweight, making them quick to erect. Both construction types allow in-production air permeability testing to be carried out before the building is complete, while repairs can still easily be made.

MVHR is a continuous mechanical supply and extract ventilation system. It is a balanced whole house strategy where stale air is removed from wet rooms at a constant rate and fresh air is supplied to all habitable rooms mechanically. In the ventilation unit, heat is recovered from the outgoing air via a heat exchanger and is used to pre-heat the incoming air, reducing heat loss due to ventilation.

1.2 INTRODUCTION TO THE OBSERVATION AND TESTING

Leeds Metropolitan University, Centre for the Built Environment (Leeds Met) observed the construction process, reviewing detailed design and carrying out forensic visual and thermographic inspections on-site.

Researchers from Leeds Met made over twenty site visits from August to October 2009, using a variety of testing and observational techniques.

Thermograms display surface temperatures in a range of colours. Thermograms of heated buildings can show comparative heat loss through different elements of the building envelope and thermal weaknesses. However, skilled interpretation is needed as the displayed variations in surface temperature are also affected by a surface being in shade or in sunlight, or being wet or dry, or differences in infra-red emissivities of materials.

Air pressurisation testing measures the air permeability of the building envelope to determine airtightness. During pressurisation air leaks are more obvious and are found using smoke detection. During depressurisation air infiltration is more obvious. Thermograms

Leeds Met also extensively tested the prototypes' performance at critical stages of construction and when completed. The evaluation included coheating tests - a lengthy procedure limited to the winter period - pressurisation tests and considerable use of heat flux sensors.

showing cooler air being drawn in highlight particular areas for concern. Testing the house under pressuristation and depressurisation gives a clearer understanding of ventilation losses.

Coheating testing measures whole-house heat loss (a combination of fabric heat loss and ventilation heat loss). A coheating test involves heating the inside of the dwelling using electric fan heaters to an elevated internal temperature (typically 25°C) over a period of time (typically one to three weeks). The electrical energy required to maintain the internal temperature each day is recorded giving the daily heat input in watts. The daily heat input is plotted against the daily difference in temperature between the inside and outside of the dwelling to give the heat loss coefficient in W/K. In order to obtain a sufficient temperature difference (generally ten degrees Kelvin or more), the coheating test should be carried out in the winter months, usually between October/November and March/April. The house must be unoccupied and undisturbed throughout the test period to ensure accurate results. Once collected, the data is adjusted to compensate for solar gains (Wingfield et al. 2010).

Heat flux sensors measure the rate of heat loss through a material at a specific point giving an indicative U-value for a building element.

Opposite. Thermogram taken during coheating testing showing air and heat leakage around windows, roof windows and the perimeter of the balcony door

Heat flux sensors measuring the rate of heat flux during coheating testing

2.1 ENVIRONMENTALLY SUSTAINABLE DESIGN

FEATURES

- BEST ORIENTATION FOR SOLAR GAINS
- HIGHLY INSULATED AND AIRTIGHT FABRIC
- MODERN METHODS OF CONSTRUCTION
- HIGH-PERFORMANCE WINDOWS
- PHOTOVOLTAIC PANELS
- MVHR

The JRHT design team's sustainable strategy delivers energy efficient and comfortable homes with a lower demand for energy and water, resulting in reduced carbon emissions and running costs.

The houses have been carefully oriented, with larger windows and a sunspace to the south to maximise solar gains. The sunspaces act as environmental buffers throughout the year: collecting solar energy in the winter and helping to cool the houses in the summer, making use of the stack effect and secure summer ventilation. They also provide a degree of privacy to south facing living rooms that occur close to the street.

The homes have similar ventilation and energy strategies; including airtight construction, high levels of insulation and MVHR. As a result the houses provide internal environments with good air quality and comfortable temperatures throughout the year, with minimal fuel costs. Both houses have high quality double glazing and on Number 54 the windows also have background ventilators - so ventilation can, in theory, be provided by natural means, or by extract only, if the MVHR system is removed.

'A' rated white goods and low water consumption sanitary fittings have been installed throughout to limit water and energy consumption. Collected rainwater provides water for WC flushing and washing machines. Light fittings are dedicated to accommodate 100 per cent energy efficient fixtures.

The homes allow for connection into the proposed future communal heating centre, which will provide all space heating and hot water using a biomass boiler. Photovoltaic (PV) panels on the south facing roofs generate electricity that can be fed back into the national grid when not required in the dwelling.

Recycling bins within the kitchen and secure external storage provide residents with space to compost and recycle, and keep bicycles.

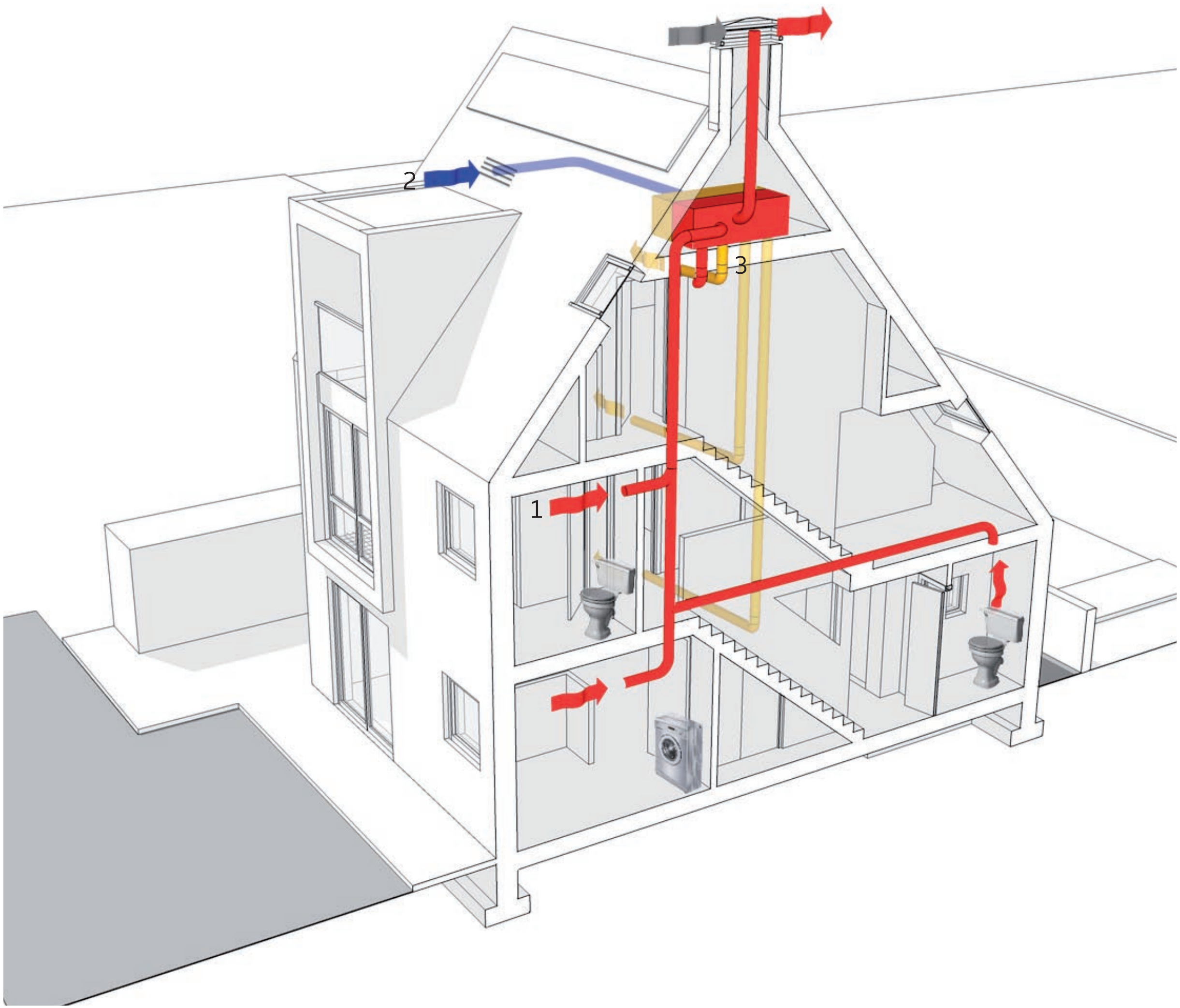
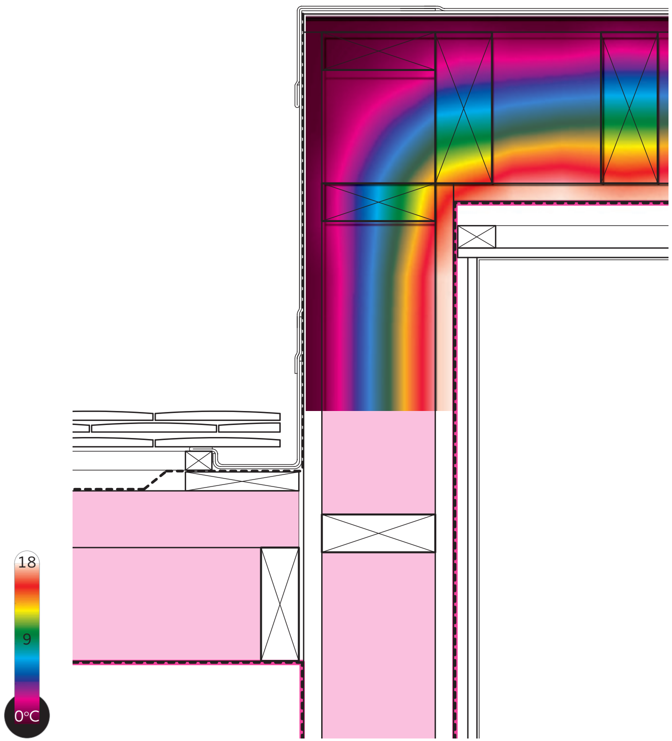


Diagram of MVHR system

1. Warm stale air extract from wet rooms
2. High-level cool fresh air intake
3. Heat recovery, tempered fresh air supply to all habitable rooms

To account for heat loss accurately the architects used heat transfer models to test each detail as it was being developed. This made it possible to enter more accurate inputs for geometric thermal bridging into SAP (the Government's national Standard Assessment Procedure).



With help from the designer, contractor, supplier and researcher, it was possible to enter precise inputs into SAP, rather than relying on the calculation tool's 'default' or estimated values.

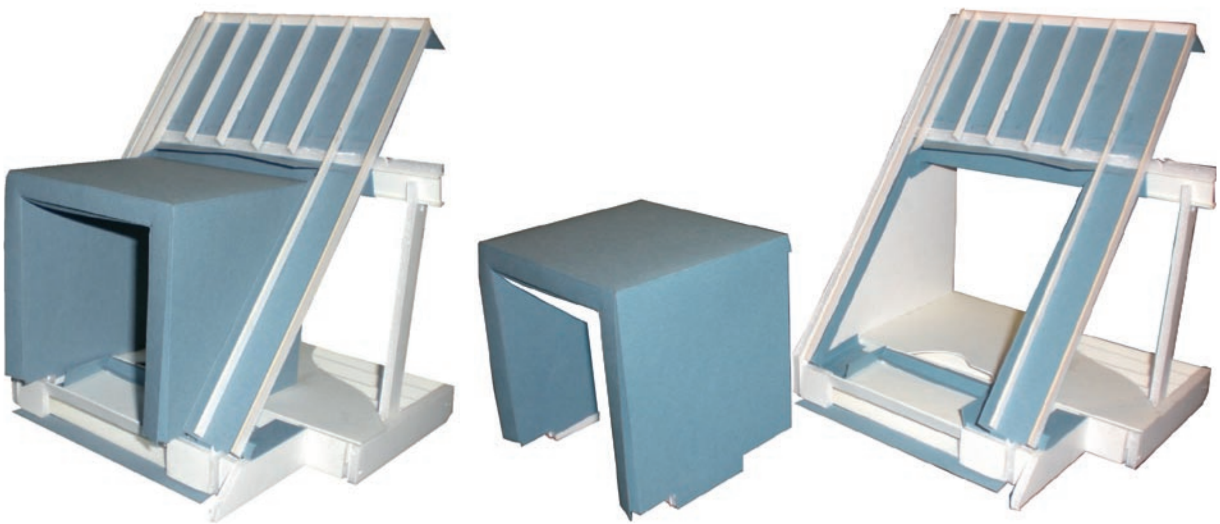
The architects, who are a multidisciplinary practice of architects and environmental consultants, undertook heat transfer analysis of each construction detail. The SIPS manufacturer provided calculations of the actual timber content in the home, accounting for all of the extra trimming around the windows, doors and support positions. The research team from Leeds Met also passed on invaluable technical advice. This helped the JRHT team to build a more accurate picture of the expected performance of the prototypes within the limitations of thermal performance calculations and the SAP model.

Many of the project partners 'raised their game' knowing that the homes would be forensically scrutinised and tested.

In addition to detailed construction drawings showing the line of thermal insulation and the airtightness barrier, the architects constructed physical cardboard models of the roof and dormer window construction. The models were used to discuss the location of the airtightness barrier in workshops with the contractor and research team.

Opposite. Detailed section of the dormer window and analysis of thermal transmittance using 'Therm' model to account for the effects of the complex roof profile

Cardboard model of the dormer window constructed to test the buildability of the proposed position of the airtightness layer



2.2

DESIGN STAGE PERFORMANCE PREDICTIONS

NO. 54 EPC
PREDICTED FUEL COSTS PER YEAR
DECEMBER 2009

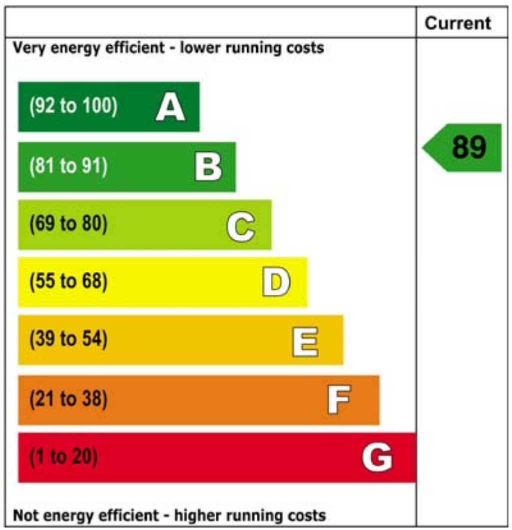
HEATING =	£270
HOT WATER =	£121
LIGHTING =	£73

AVERAGE U-VALUE
THERMAL TRANSMITTANCE
W/m^2K

WALLS =	0.17
ROOF =	0.15
FLOOR =	0.15

Design stage calculations estimated that the homes would achieve Code for Sustainable Homes Level 4 - the intended target for the Part L 2013 standard - with Dwelling Emission Rates (DER) of 12.35 and 12.59 $kgCO_2/m^2/year$.

PREDICTED ENERGY EFFICIENCY RATING



The Energy Efficiency Rating which appears on the EPC (Energy Performance Certificate) is a measure of the overall efficiency of a home. The higher the rating (on a scale of 0-100), the more energy efficient the home is and the lower the fuel bills are likely to be.

Energy efficiency and estimates of fuel cost were calculated using SAP. The calculation is based on the energy costs associated with space heating, water heating, ventilation and lighting, less cost savings from energy generation technologies. It is adjusted for floor area so that it is essentially independent of dwelling size. The calculation does not account for the individual characteristics of the household occupying the dwelling.

The designers used SAP2005 v9.81.

NO. 69 EPC
PREDICTED FUEL COSTS PER YEAR
DECEMBER 2009

HEATING	=	£271
HOT WATER	=	£122
LIGHTING	=	£75

AVERAGE U-VALUE
THERMAL TRANSMITTANCE
W/m²K

WALLS	=	0.15
ROOF	=	0.15
FLOOR	=	0.16

Although every effort was made to enter accurate information into the SAP calculation, currently thermal performance inputs and SAP's fixed defaults do not account for the realities of building on-site.

The SAP calculation uses information provided by manufacturers and designers for the performance of building components, insulation and services. This information tends to be based on laboratory testing and 'notional' constructions that do not reflect the realities of building on-site or the variability of workmanship and weather. Over-optimistic assumptions in the design predictions will increase the discrepancy between designed and 'as-built' performance.

The mechanisms for heat loss through different paths in the construction and by ventilation also need to be understood. In a very well insulated dwelling a much higher proportion of heat is lost through thermal bridges. Heat loss through thermal bridges will also increase if the dwelling is a complicated shape.

Thermal bridges or cold bridges are weak instances in the building envelope where heat loss is worse than through the main building elements. In a well insulated building thermal bridges can account for more than 30 per cent of all heat loss.

Linear non-repeating thermal bridges that include items such as cills, lintels and jambs typically span between the inner and outer skins of a wall. Geometric thermal bridges occur at junctions between building elements, for instance, between walls and a roof, and at changes of geometry, for example, a corner in a wall or at a hip in a roof.

It is not possible to avoid all thermal bridging, but the effect can be lessened by careful detailing. It is more difficult to avoid thermal bridging caused by poor workmanship, as even if thermal imaging cameras are used to detect the problem, it will often be too late to avoid costly remedial works.

3.1 NUMBER 54 OBSERVATIONS

The 54 and 69 project was set up as a learning process and modifications took place as construction progressed. Some of the construction systems were not familiar and in many cases the work was out of sequence as far as the typical sequence of trades and fixes is concerned.

Thin joint blockwork construction using hammer-driven cavity wall ties allows the blockwork, insulation and airtightness barrier to be completed before the external facing brickwork is built. This approach allowed the team to make a thorough visual inspection of the insulation and airtightness barrier and to carry out in-production air pressurisation testing while repairs could still be made.

Fixing the wall insulation in full sheets was quick and effective - joints were minimised and successfully taped. Tape bonded well to the foil face of the boards, but not so securely to the exposed foam. There were difficulties fitting the below ground cavity wall insulation. Gaps remained around the underfloor vents at the front and rear of the house. Mortar build up displaced the cavity insulation, resulting in gaps between the inner leaf blockwork and the insulation boards.

Maintaining the continuity of the roof airtightness membrane caused considerable time and effort, suggesting that a simpler roof construction should be used for the main project.

Opposite. Photographs taken during construction showing how accurately the insulation was installed

Following construction numerous thin cracks appeared in the blockwork. Although the cracks are typical of the construction drying out and are not a structural concern, they may compromise airtightness should further cracking occur after parging.

The contractor's cost-saving choice to substitute roof trusses for the designed cut roof meant that it was not possible to fix large areas of the air barrier membrane as shown in the sectional drawings. Instead, it was necessary to make numerous cuts, folds and joints in the air barrier to work around the trussed rafters.

Taping and joining the air barrier membrane to itself and other substrates, in particular to the unparged blockwork, caused problems. It was also difficult to adhere the tape when there was nothing firm behind the membrane.

Sequencing problems occurred when some of the first fix installations were undertaken prior to parging. Working around internal partition walls and other installations may have compromised airtightness. Corners where slight cracking in the blockwork had occurred could not be accessed for parging as soil pipes and MVHR ducting had already been installed.

The MVHR ducting displaced roof insulation in a number of instances and required additional penetrations through the air barrier, probably compromising the thermal performance of the roof. These problems did not occur at Number 69 as all ducting ran through floor voids or service risers.

NUMBER 54 PERFORMANCE

MEASURED AIRTIGHTNESS =
$m^3/(h.m^2)$@50Pa

4.17

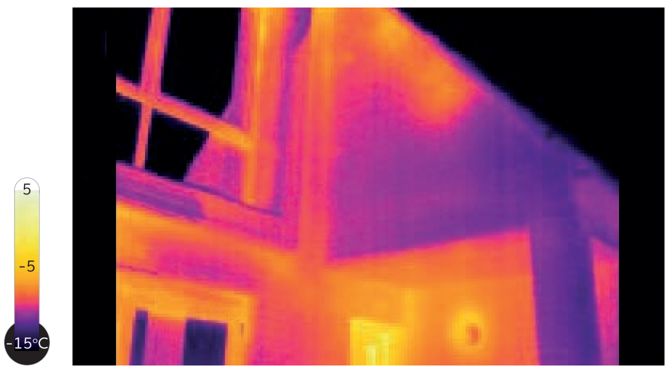
PREDICTED HEAT LOSS =
W/K

124.0

MEASURED HEAT LOSS =
W/K

149.5

Number 54 illustrates the benefit of carrying out in-production pressurisation testing at air barrier completion when the air barrier is still accessible, allowing repairs to be made, as opposed to compliance testing at completion.



Pressurisation tests were carried out at several construction stages. The test undertaken when the air barrier was complete identified significant air leakage through the roof membrane. Following this discovery substantial additional sealing to the membrane was undertaken, to achieve the final airtightness of 4.17 $m^3/(h.m^2)$@50Pa.

The research team recorded only a slight deterioration in airtightness as a result of shrinking and drying during the coheating tests. This indicates that the measured airtightness relies on a robust primary air barrier rather than secondary sealing, such as decoration, and suggests lasting performance.

Although the wall insulation was well fitted, air movement between the insulation and blockwork was observed at junctions, openings and penetrations. Thermal imaging during

Number 54 was predicted to have a heat loss of 124.0 W/K, but the coheating test recorded a loss of 149.5 W/K. However, Number 54 delivered the closest results to the design value target for masonry dwellings tested to date by Leeds Met.

Opposite. Thermogram showing air and heat leakage above the front door and canopy

depressurisation revealed significant cold air infiltration above the front door and canopy.

Heat flux measurements taken during the coheating test indicate variations from design U-values. Measurements in the middle of the ground floor slab were as predicted, but increased U-values at the slab perimeter reflect construction observations of discontinuity of insulation and thermal bridging at this junction. Designed U-values for walls were found to be an optimum rather than average value due to the far greater than predicted effect of air movement at edges and openings. However, measurements of the windows closely matched the manufacturer's claimed U-values. In the roof measured U-values were surprisingly lower than the design values. This could be explained by some form of heat recovery from warm air in the roof structure voids.

The coheating test results for Number 54 were more greatly affected by variations in wind speed and direction than Number 69. This will have been due to the poorer airtightness, but may also have been a result of its more exposed orientation to severe weather from the north and northeast.

Measurement of the MVHR system flow rates found significant commissioning errors. The manufacturer had to return to site three times to re-examine and recommission the systems in both prototypes. "This raises serious questions over the commissioning process, and without the independent checks being carried out... both prototypes would not have been providing either the energy efficiency assumed in the design calculations or even the trickle supply and boost extraction warranted by Part F of the Building Regulations" (Miles-Shenton et al. 2012, p. 26).

3.3 NUMBER 69 OBSERVATIONS

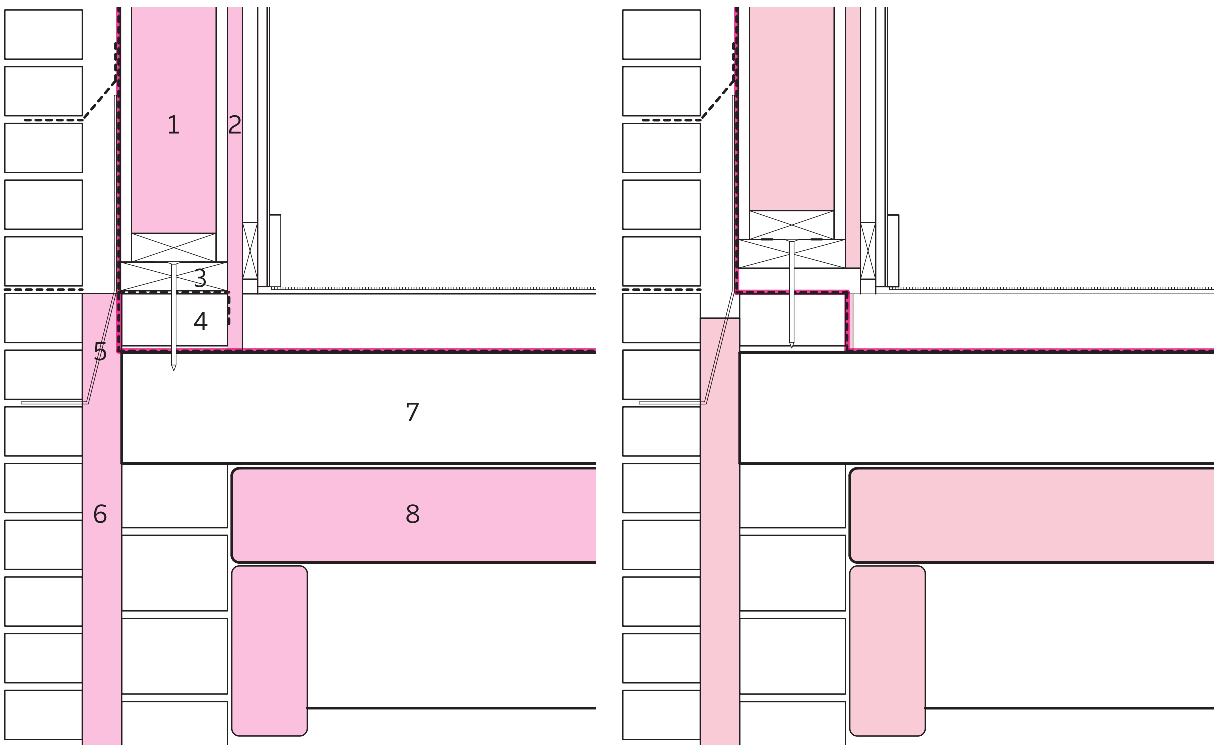
Constant contact between the designers and contractors was possible throughout the prototype building process and can be regarded as one of the successes of the project.

Similarly to Number 54, there were difficulties fitting the below ground wall insulation. Again, gaps remained around the underfloor vents at the front and rear of the house.

A number of the SIPS panels were damaged as they were unloaded during delivery. Although the contractor repaired the damage on-site, their performance may have been compromised. The breather membrane was not trimmed back sufficiently to allow the window frames to be sealed to the wall panels. Instead, the frames were taped to the breather membrane, resulting in air leakage at openings.

Construction issues are likely to have caused thermal bridging at the ground floor slab perimeter. Variations in the ground floor slab and the blockwork course resulted in a gap of up to 30 mm in some places between the wall soleplate and the floor. This gap was filled with injectable grout; however, the grouting was undertaken after the internal wall insulation had been installed, making the job more difficult to perform successfully. Although the drawings showed continuous internal wall insulation down to the slab, the construction sequence, where the screed was laid before the wall was built, resulted in a break in the insulation. In addition, the below ground cavity wall insulation boards were often trimmed short of the top of the slab.

There were a number of construction problems regarding the detailing at the slab perimeter and the soleplate, which are likely to have compromised the thermal performance of the ground floor slab perimeter.



Opposite. Gap below the soleplate

Left. Detailed construction drawing showing the ground floor slab perimeter as it was designed

Right. Altered construction drawing showing the same detail 'as-built'

1. SIPS
2. 20 mm thick insulation
3. Soleplate
4. Blockwork course
5. Holding down strap
6. Below ground full fill rigid insulation
7. Concrete beam
8. Insulating aerated concrete infill block

3.4

NUMBER 69 PERFORMANCE

MEASURED AIRTIGHTNESS =
$m^3/(h.m^2)$@50Pa

2.42

PREDICTED HEAT LOSS =
W/K

120.1

MEASURED HEAT LOSS =
W/K

132.9

Pressurisation testing of Number 69 recorded an airtightness of 2.42 $m^3/(h.m^2)$@50Pa.

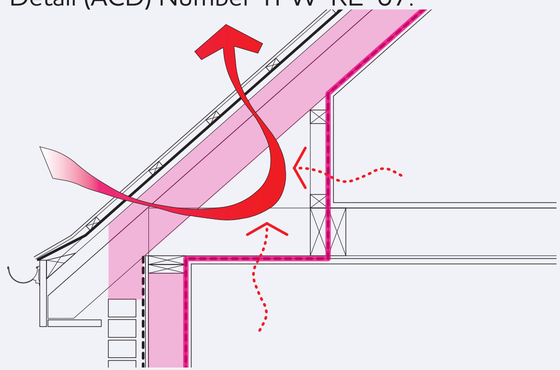
Leakage detection revealed that most of the air leakage was at openings and around the ground floor perimeter. Similarly to Number 54, the slight deterioration in airtightness during the coheating test indicates that the measured airtightness relies on a robust primary air barrier rather than secondary sealing, pointing to good long-term performance.

Heat flux measurements taken during the coheating test found variations from design U-values. Similar results to Number 54 found that the centre of the ground floor slab performed as predicted, but performance worsened at the edges, predicted U-values for the walls were the most favourable rather than an average, and the windows performed as predicted.

The same errors in commissioning the MVHR system were discovered in both prototypes.

Number 69 was predicted to have a total heat loss of 120.1 W/K, but the coheating test recorded a total heat loss of 132.9 W/K – an increase of 12.7 W/K. However, Number 69 was equal to the best performing timber framed new build houses tested to date by Leeds Met.

Thermal bypass is the movement of unheated outside air within voids in the construction, particularly, in party wall cavities, underfloor voids and lofts, resulting in increased heat loss. The drawing below is Accredited Construction Detail (ACD) Number TFW-RE-07.



It shows a potential thermal bypass in a loft at the eaves. In this situation it is particularly important to ensure that the airtightness barrier follows the line of the insulation to avoid creating a cavity between the two.

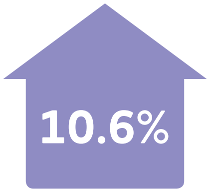
Opposite. Thermogram showing lack of thermal bridging and cold air infiltration around the window – NB the glazing cannot be assessed as it is reflecting the internal surfaces of the room

Left. Construction photograph showing a potential thermal weakness in the roof space, which could easily have gone unnoticed, occurring where an uninsulated duct carrying unheated supply air runs on the warm side of the insulation

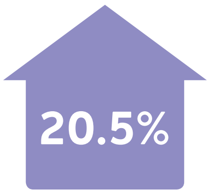
4.1

HOW SUCCESSFUL WERE THE PROTOTYPES?

NO. 69
SIPS (STRUCTURAL INSULATED PANEL SYSTEM)



NO. 54
THIN JOINT MASONRY



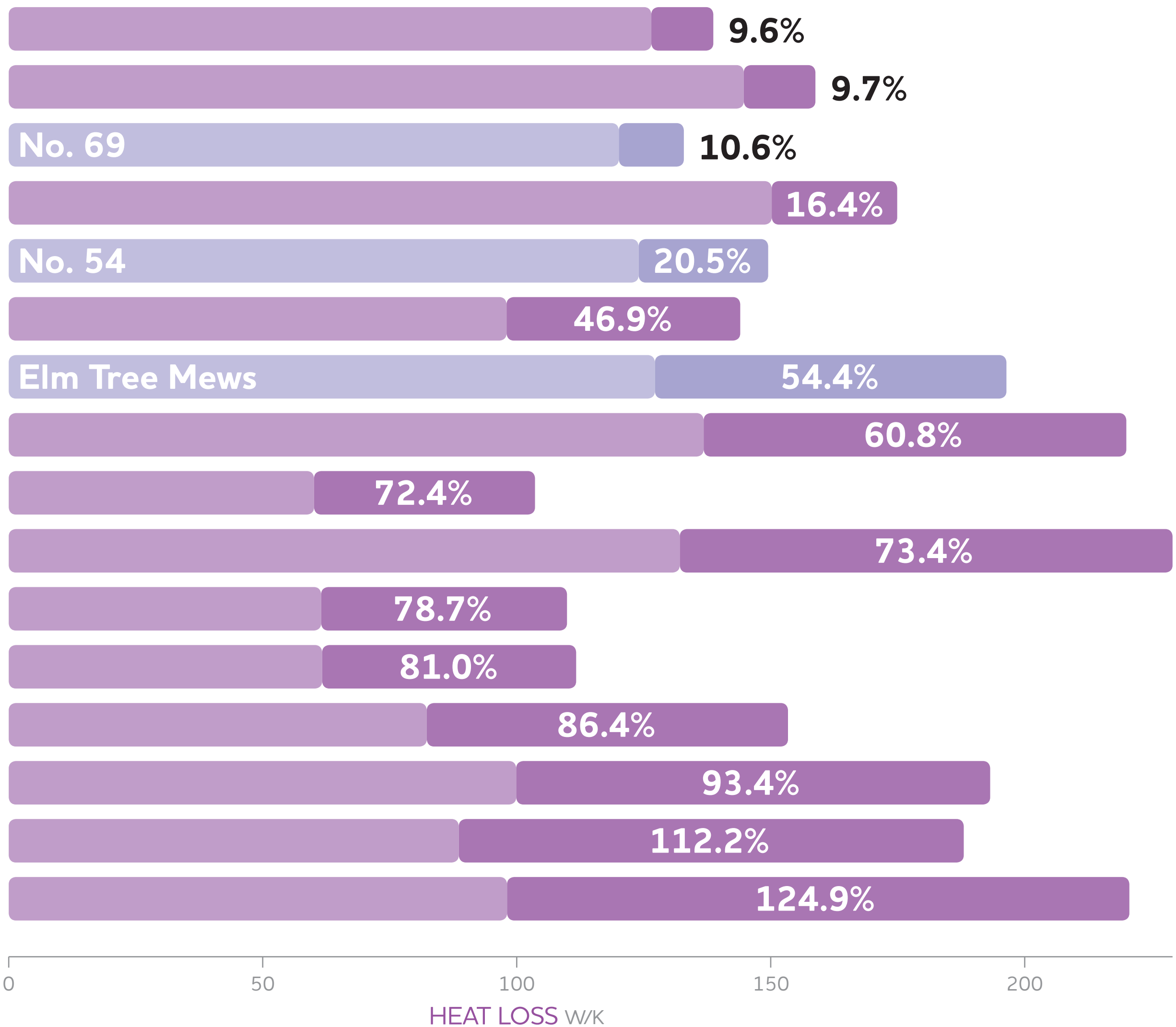
Neither house performed as well as predicted. Measured heat losses revealed a 10.6 per cent increase over the design value for Number 69, and a 20.5 per cent increase for Number 54. However, these increases are amongst the lowest recorded by Leeds Met in coheating tests on new build dwellings.

The pressurisation test results achieved show that the target airtightness of 3 $m^3/(h.m^2)$@50Pa is achievable in both forms of construction. The level of airtightness through the wall construction was very similar in both prototypes. There was air leakage through the roof membrane and window trickle vents in Number 54, but it performed better than Number 69 around openings and at the ground floor perimeter.

Number 69 was predicted to have a total heat loss of 120.1 W/K, but when tested recorded a heat loss of 132.9 W/K - 10.6 per cent higher than was expected. Heat loss for Number 54 was measured to be 149.5 W/K - 20.5 per cent higher than the predicted value of 124.0 W/K.

When the measured heat losses are compared with a recalculated prediction using a ventilation heat loss derived from the measured air permeability, the percentage increase over the predicted value for Number 54 reduced from 20.5 per cent to 15.6 per cent. This is a better indication of the thermal performance of the building fabric.

These increases are due to a number of factors. There may be inaccuracies in the predicted heat loss, calculated by SAP. In well-insulated, airtight dwellings, heat loss through thermal bridging becomes increasingly important. Although difficult, thermal bridging calculations should be undertaken to ensure that accurate inputs are used, rather than relying on default values in SAP. However, it is extremely unlikely that elements built in the field will achieve their design values, due to construction faults and modifications, sequencing problems and the other uncertainties of building on a construction site: tolerances, deflections, weather and inconsistent workmanship.



Increase in 'as-built' heat losses (shown by the darker colours) as a percentage of predicted values

This diagram is adapted from Leeds Met's technical report (Miles-Shenton et al. 2012, p. 19). The sample of sixteen dwellings is measured using Leeds Met's coheating test method. All of the houses have a greater measured heat loss than predicted. Numbers 69 and 54 have the third and fifth smallest increases out of the sixteen dwellings. The smallest increases were recorded for two timber-frame dwellings built as part of a development of eight houses to 2006 standards. The sample comprises a mix of house types and sizes and direct comparisons between the absolute heat losses should not be attempted.

4.2 LESSONS FOR THE FUTURE

Feedback and learning – One of the key findings of the Elm Tree Mews project was the need for a much sharper focus on the process of design and construction, starting with the information provided by suppliers and manufacturers and extending right through the construction process to the commissioning and hand over. Guidance provided by suppliers should reflect the as-built performance rather than laboratory or notional performance; designers need to improve the robustness of details and the thoroughness of thermal calculations; and construction needs to be planned and co-ordinated to ensure that predicted performance is achieved. The development at 54 & 69 demonstrates that with improved attention to many of these issues high levels of energy and carbon performance can be achieved. However, improvements must be made to education and training throughout the industry underpinned by the use of in-production testing and post-construction testing to support the feedback and learning.

Housing providers need to take more interest in the actual energy and carbon performance of homes – The actual performance of a dwelling will have an impact on decisions, such as sizing boilers and district heating systems, but will be even more important for consumers who, in buying or renting a low or zero carbon home, are seeking to shield themselves from the uncertainties of rising fuel prices.

Construction operations and sequences need to be planned in more detail – Design drawings need to communicate the sequence of construction as well as the overall relationship of the construction elements. Architects do not normally include this information on drawings and proper planning requires the input from both builders and designers. The installation of services and ventilation systems must also be considered in this planning process to avoid the breach or displacement of insulation and airtightness membranes. To plan the operations correctly the design information must also be available and understandable. The use of three-dimensional drawings and models prompted useful discussions at TAP especially regarding the complexity of the roof. However, the final trussed roof structure included many secondary pieces of framing timber that were not drawn by the supplier, complicating the installation of the airtightness membrane.

Briefings are needed to ensure that everyone involved is sufficiently aware of the issues in order to do their job well – The architects attempted to minimise penetrations through the air barrier and building fabric; however, a number of penetrations appeared to be made as a result of ad-hoc decisions by the services installers. The use of dedicated services zones behind walls and at ceiling level could help to protect the airtightness barrier. Although thermal elements may have been installed correctly they are easily damaged or displaced by subsequent trades, who might not fully understand the consequences of their actions. The design intent needs to be communicated to all those in the supply chain who could potentially affect the air barrier or create a thermal bridge. In Phase One of Derwenthorpe site briefings and 'toolbox talks' have been instigated.

Changes during construction need to be closely controlled – Working the air barrier around the trussed rafters at Number 54 took considerable time and effort. This could have been avoided by using the original roof designed by the architects. Alternatively a composite panel building system or SIPS could have been used. However, the use of in-production air pressurisation testing at the completion of the air barrier allowed the team to evaluate the impact of the substitution and make informed decisions about the roof construction for the first phase of Derwenthorpe.

The specification, installation and commissioning of mechanical ventilation needs to be more robust – "The debacle surrounding the commissioning of the MVHR system is a serious concern" (Miles-Shenton et al. 2012, p. 30). Recent performance assessments by Leeds Met have uncovered similar problems in commissioning at the Elm Tree Mews and Stamford Brook projects (Bell et al. 2010; Wingfield et al. 2008). This points to the unfamiliarity of consultants and contractors with mechanical ventilation, 'Approved

Document F' and the 'Domestic Ventilation Compliance Guide'.

Designers, contractors and suppliers can learn from prototyping to increase the robustness of detailed design – The process of building and rigorously testing prototypes provides lessons for both modern construction techniques. The procurement process must allow the learning from prototyping to be transferred to volume building.

Thin Joint Masonry:

- Air movement detected between the blockwork and the insulation could be minimised by fixing the insulation using a continuous adhesive capable of accommodating the unevenness of the masonry – similar to the procedure used for external wall insulation.
- Leakage around openings appeared to result from gaps around the specified rigid cavity closures. A flush fitting cavity closer bonded to the blockwork would prevent air movement. The contractor's suggestion to partly trim back the insulation and butt it against the window/door frame would negate the need for cavity closer, but relies on craftsmanship to achieve airtightness.
- Using joist hangers instead of building in the joists would prevent awkward sealing and potential air leakage around the intermediate floor joists, which are subject to differential shrinkage and have the potential to cause a failure in the sealing of the joint with the blockwork joist pocket.

SIPS:

- Paying more attention to levelling the ground floor slab and blockwork course would have avoided gaps between the slab and SIPS and improved thermal performance at the slab perimeter.
- The joints between SIPS and between the SIPS and the soleplate could be improved by using a spline or connector piece providing a seal through the depth of the wall, instead of relying on expanding foam.
- The 20 mm thick internal insulation could be moved to the outer face of the SIPS subject to dew point analysis, eliminating sequencing problems at the ground floor slab perimeter

and minimising thermal bridging at external corners, internal wall junctions and intermediate floor perimeters.

- In both prototypes the straps used to secure the window/door frames caused thermal bridges and contributed to airtightness problems. Securing the frames with a plywood (or similar material) box would improve performance at openings.

Lessons from prototyping are already influencing suppliers – Since the construction of Number 69, the SIPS manufacturer has developed a unique cassette joint sealed with expanding urethane to join the panels. This gasket is now a standard component in their system, showing the value of a prototyping process to the development of the housebuilding industry.

Bottom. The first phase of JRHT's 540-home sustainable community in Derwenthorpe on the periphery of York is under construction - the roofs use technology tested in the SIPS prototype and the walls are thin joint blockwork

Overleaf. Architect's impression of the second phase of Derwenthorpe

4.3 PROJECT SUMMARY

TAP PROTOTYPES	54 TEMPLE AVENUE	69 TEMPLE AVENUE
ESTIMATED FUEL COSTS PER YEAR (DECEMBER 2009) £/yr HEATING HOT WATER LIGHTING	 270 121 73	 271 122 75
SAP BAND A-G	B	B
SAP SCORE 0-100	89	89
ESTIMATED CARBON DIOXIDE EMISSIONS PER YEAR $kgCO_2/yr$	1600	1600
DWELLING EMISSION RATE (DER) $kgCO_2/m^2/yr$	12.59	12.35
PREDICTED HEAT LOSS W/K	123.97	120.14
PREDICTED HEAT LOSS PARAMETER W/m^2K	0.83	0.78
MEASURED AIRTIGHTNESS $m^3/(h.m^2)@50Pa$	4.17	2.42
MEASURED HEAT LOSS W/K	149.47	132.86
MEASURED HEAT LOSS PARAMETER W/m^2K	0.98	0.86

5.0 CONCLUSIONS

- The SIPS prototype, Number 69, achieved the lower measured heat loss and the better airtightness. However, up to eaves level both houses performed similarly.
- The performance of the masonry prototype, Number 54, was undermined by the substitution of trussed rafters that disrupted the continuity of the roof membrane.
- Neither house performed as well as predicted. Measured heat losses revealed a 10.6 per cent increase over the design value for the SIPS prototype and a 20.5 per cent increase for the masonry prototype.
- This gap between measured ('as-built') and predicted ('as-designed') values is known as 'the performance gap'.
- Inputs used in the SAP calculation tool, such as U-values, thermal bridging values and efficiencies of building services, can be based on manufacturers' data, which is tested in laboratory conditions and does not account for the realities of building on-site, variability in workmanship and the effects of the weather.
- Given the nature of the inputs, it is highly unlikely that the designed performance will ever be achieved in the majority of cases in mainstream construction. Bearing this in mind, appropriate tolerances or confidence

factors should be included in all calculations.

- Thin joint masonry requires laying techniques that are unfamiliar to traditional bricklayers. Number 54 benefitted from having a construction team that were experienced with thin joint technology.
- To achieve the U-values of the notional design an additional layer of insulation was added to the inside of the SIPS which undermined the inherent simplicity of the panelised construction.
- The weaknesses in the SIPS were largely confined to junctions at the soleplate and between the panels. Provided that these received due attention on-site the system offers a very robust thermal solution.
- "If the commissioning of the MVHR system is typical of the commissioning processes of other systems, the performance of services should not be taken at face value" (Miles-Shenton et al. 2012, p. 31). Ideally MVHR specification, installation and commissioning should be independently checked.
- Although the SIPS prototype performed slightly better, it is currently more expensive and the cost benefit was marginal. For Phase One of Derwenthorpe a hybrid construction of thin joint masonry walls and SIPS roofs was chosen.

SPECIALIST TERMS

Accredited Construction Details (ACDs): Are Government approved typical details for masonry, steel and timber constructions addressing the continuity of thermal and airtightness layers, available at: http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/bcassociateddocuments9/acd.

Air permeability: Is the unintended leakage of air through gaps and cracks in the external envelope of a building.

Air pressurisation testing: Measures the air permeability of the building envelope to determine airtightness, which is expressed as the volume of air leakage per hour per square metre of external building envelope ($m^3/h.m^2$) at a tested pressure of 50 pascals (Pa).

'As-built' performance: Describes performance measured post-construction.

Coheating testing: Measures whole-house heat loss (a combination of fabric heat loss and ventilation heat loss). A coheating test involves heating the inside of the dwelling using electric fan heaters to an elevated internal temperature over a period of time, typically one to three weeks. In order to obtain a sufficient temperature difference (generally ten degrees Kelvin or more), the coheating test should be carried out in the winter months, usually between October/November and March/April.

Construction sequence: Describes the order in which elements of a building are constructed. Out of sequence work can prevent other work stages from being completed properly or damage work that has already been completed, with serious consequences for the airtightness and thermal performance of the building envelope.

Cut roof: This is the traditional method of constructing a roof involving cutting the timber on-site and building up the roof using rafters, ridge boards, joists and purlins, etc. The rafters are a single piece of timber spanning from the wall plate to the ridge.

Dwelling Emission Rate (DER): Is a measure of carbon dioxide emissions arising from energy use in homes calculated by SAP. It is expressed in kilograms of carbon dioxide per square metre of floor area per year and takes into account energy used for space heating, hot water, fixed internal lighting and fans and pumps. To demonstrate compliance with Approved Document Part L1A, 2010 edition, the DER of a dwelling must be no greater than its corresponding Target Emission Rate (TER).

Heat flux sensors: Measure the rate of heat loss through a material at a specific point giving an indicative U-value for a building element.

Heat loss parameter: Is a building's heat loss (fabric heat loss and ventilation heat loss combined) per unit floor area. The heat loss parameter is comparable with other buildings.

Mechanical ventilation: Is a system of fans and ducts used to extract stale air and bring fresh air into a building. Mechanical ventilation can include the recovery of waste heat from the outgoing air, which is used to pre-heat the incoming air - Mechanical Ventilation with Heat Recovery (MVHR).

Natural ventilation: The supply of fresh air to spaces within the home through windows, trickle ventilators, air bricks, etc. Removal of air may take place by natural or mechanical means.

Parging: Is a thin coat of plaster or mortar used to finish the surface of a masonry wall.

SAP (Standard Assessment Procedure): Is the Government's nationwide approved method for calculating energy efficiency and carbon emissions from homes to demonstrate compliance with Building Regulations.

Solar gains: Are the build up of heat within a building due to direct sunlight.

Target Emission Rate (TER): Is the benchmark emission rate, calculated by SAP, for a particular home expressed in kilograms of carbon dioxide per square metre of floor area. The calculation is based on a notional dwelling of the same size and shape as the proposed dwelling.

Thermal bridging: Are weak instances in the building envelope where heat loss is greater than through the main building elements. There are four types of thermal bridge:

1. **Repeating thermal bridges** follow a regular pattern and are evenly distributed over an area of a thermal element. Typical examples include: timber studwork and I-beams in timber frame construction and mortar joints in an insulating blockwork inner leaf. They are accounted for in U-value calculations;
2. **Non-repeating or linear thermal bridges** are intermittent and occur at a specific point in the construction. They are often caused by discontinuities in the thermal envelope. They typically occur around windows and doors and where internal walls or floors penetrate the thermal envelope;

3. **Point thermal bridges** are created by a small cross section element that has high conductivity and penetrates the thermal envelope. Typical examples include: wall ties, insulation fixing screws and fixing brackets;
4. **Geometric thermal bridges** are a result of the geometry (or shape) of the thermal envelope. They can be two-dimensional (where two planes intersect) or three-dimensional (where three or more planes intersect). They occur at junctions between building elements, such as between the walls and roof, and at changes of geometry, for example, a corner in a wall or a hip in a roof.

Overall thermal bridging should be calculated by the SAP assessor.

Thermograms: Display surface temperatures in a range of colours. With skilled interpretation, thermograms of heated buildings can show comparative heat loss through different elements of the building envelope and thermal weaknesses.

Thermal bypass: Thermal bypass is the movement of unheated outside air within voids in the construction, particularly, in party wall cavities, underfloor voids and lofts, resulting in increased heat loss.

Thermal performance: Each 'element' of the building envelope - a wall, a roof, a floor, a window or a door - has a role to play in minimising heat loss. The insulating effect of each of these elements is measured by its U-value.

Truss roof: A roof made up of factory-made trusses which are delivered to site complete and just erected.

Toolbox talks: Are short practical presentations to the workforce on a single aspect of construction or health and safety.

U-value: Is the calculated rate at which heat is lost per unit area of a building element expressed in W/m^2K; the lower the U-value, the better an element's thermal performance.

Zero carbon: Although the precise definition has yet to be agreed it is likely to combine three components: fabric efficiency, on-site carbon compliance and off-site 'allowable solutions'. Despite its apparent complexity it is hoped that this hierarchy of measures will provide flexibility to the housebuilder and to ensure that all houses regardless of type and location can cost-effectively comply.

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CLIENT: **Joseph Rowntree Housing Trust**

ARCHITECT: **Richards Partington Architects**

MECHANICAL AND ELECTRICAL ENGINEER: **Arup**

STRUCTURAL ENGINEER: **Alan Wood & Partners**

CONTRACTOR: **Strata (Mansell)**

CODE FOR SUSTAINABLE HOMES ASSESSOR: **Richards Partington Architects**

BUILDING PERFORMANCE ASSESSOR: **Leeds Metropolitan University**

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Joseph Rowntree Foundation (Head Office)
The Homestead, 40 Water End, York
YO30 6WP, UK
tel: +44 (0)1904 629241
email: info@jrf.org.uk

This information can be provided in other languages and formats (such as large print, Braille or audio) from the Communications Department at JRF
Tel: 01904 615905 Email: info@jrf.org.uk

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