

Lessons from AIMC4 for cost-effective, fabric-first, low-energy housing

Part 3: Technical development of the designs

Adam Tilford and Christopher Gaze

This Information Paper is Part 3 in a series of four papers about the AIMC4 applied research project, which was created to research, develop and pioneer the volume production of low-carbon homes for the future that would achieve Level 4 (energy) of the Code for Sustainable Homes without the use of renewable energy.

Part 1 introduces the AIMC4 project and describes the process of translating its objectives into innovative solutions to meet the project targets. Part 2 covers the supply chain development phase of the project. Part 4 focuses on understanding value for the end user and making the construction process as efficient as possible.

Part 3 focuses on the development of the technical specification for the 17 homes built by the developer partners, from drawing up specific criteria for the materials and products required (including interaction between products), through to the final as-built specification. The key technology types that make up the fabric-first approach are discussed, including the main superstructure systems, windows and external doors, space heating, hot water, ventilation systems, airtightness products and lighting and controls.

This series of Information Papers seeks to draw together the AIMC4 story in one place as a reference point for industry, government and other stakeholders. The lessons learned cover issues that are relevant to the volume production of low-energy homes, which will be important for all builders and developers as regulations develop in the future.

Introduction

Technical development of fabric-first solutions to achieve the target AIMC4 energy performance started in early 2010 with



Figure 1: Stewart Milne Group's Portlethen site homes

the modelling of several house types, each chosen to represent typical designs used by the three developer partners. The Standard Assessment Procedure (SAP 2009)^[1] was used to model the AIMC4 homes. The target specification of Level 4 of the Code for Sustainable Homes^[2] requires a 25% reduction in CO₂ emissions relative to Part L of the Building Regulations 2010 (England and Wales)^[3].

This initial modelling provided an indicative specification that was used to inform the project team of the types of materials and products that would be required to build energy-efficient fabric-first AIMC4 houses. The following technical issues were identified as critical:

- level of insulation (U-values) – including zero U-value party walls
- degree of thermal bridging (ψ -values)
- air permeability
- efficiency of space and water heating system, and hot water storage
- control of heating system
- efficiency of artificial lighting
- solar gain
- overheating
- ventilation strategy.

Having identified these critical areas, the AIMC4 consortium enlisted the help of the industry's supply chain (including potential new suppliers), involving over 300 companies in a process designed to maximise their potential contribution to addressing these issues in the most cost-effective way possible. Central to this aspect of AIMC4 was a series of 'sandpit' events designed to enable suppliers to showcase their products and capabilities in a creative way, and to facilitate collaboration, in order to bring new ideas to the attention of the project team. This was an innovative process not previously seen by the housebuilding industry (see Part 2).

The consortium received valuable input from numerous suppliers, and was able to identify a range of products and materials that could assist in developing a robust fabric housing specification. The developers then identified the sites on which AIMC4 houses would be built (Figure 2), and the house types that the AIMC4 specification would be applied to.

The sites chosen were in different regions and subject to a range of different planning requirements, thus delivering a key AIMC4 objective – that the solutions could be delivered anywhere, and in keeping with the local vernacular. The five AIMC4 sites ranged geographically from Aberdeen to Epsom, including one in a conservation area. All five of the planning authorities granted the variations necessary to deliver AIMC4 under delegated powers, ie the changes were not considered significantly different from the original consent.

The developers collectively chose to use a wide range of fabric and services solutions, which had the potential to become part of mainstream specifications for future Code Level 4 (energy) houses. Fabric specifications were also chosen to ensure that a range of construction methods were covered, ie masonry, timber and structural insulated panel systems (SIPs).

A more detailed specification for each house is shown in Table 1.

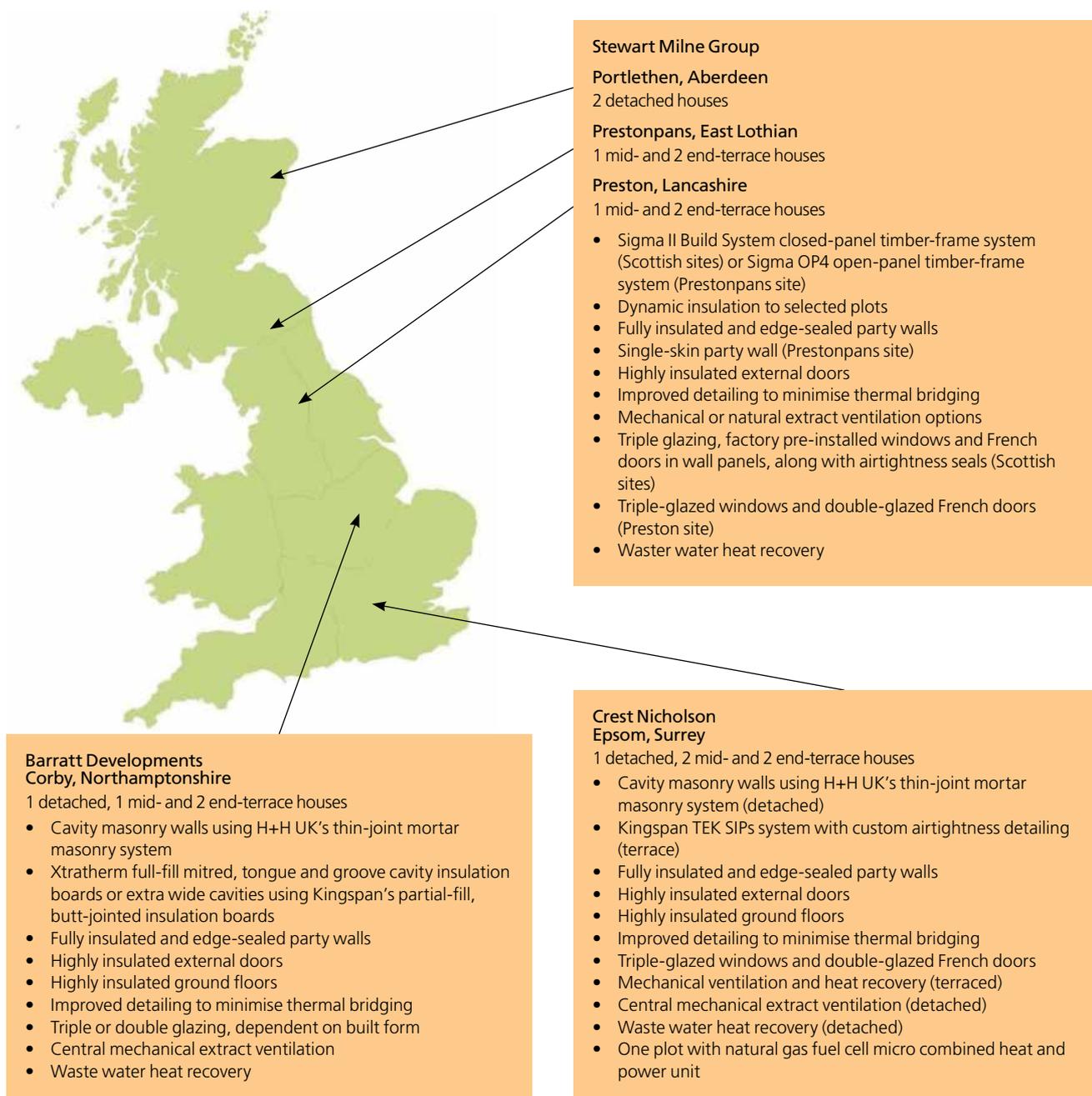


Figure 2: Overview of AIMC4 sites

Table 1: House design specifications

House type	Primary U-values (W/m ² K)								y-value	Airtightness (m ³ /h.m ² @ 50 Pa)	Window g-value	WWHR	Ventilation	FGHR
	Wall	Roof	Floor	Party wall	Front door	Window	French door	y-value						
Barratt Developments														
Lincoln detached thin-joint (plot 162)	0.15	0.10	0.12	N/A	1.3	DG 1.2	DG 1.15	0.032	4	0.50	Yes	MEV	Yes	
Tiverton end-terrace thin-joint (plot 163)	0.15	0.10	0.12	0	1.3	TG 0.8	DG 1.15	0.040	4	0.39	Yes	MEV	Inbuilt	
Tiverton mid-terrace thin-joint (plot 164)	0.15	0.10	0.12	0	1.3	TG 0.8	DG 1.15	0.045	4	0.39	Yes	MEV	Yes	
York attached thin-joint (plot 165)	0.15	0.10	0.12	0	1.3	DG 1.2	DG 1.15	0.040	4	0.50	Yes	MEV	Inbuilt	
Crest Nicholson														
Detached thin-joint (plot 157)	0.15	0.09	0.13	N/A	1.1	TG 0.83	DG 1.3	0.025	4	0.49	Yes	MEV	No	
End-terrace SIPs (plots 158 and 161)	0.15	0.10, 0.15	0.12	0	1.1	TG 0.83	DG 1.3	0.039	3	0.49	No	MVHR	No	
Mid-terrace SIPs (plots 159 and 160)	0.15	0.10, 0.15	0.11	0	1.1	TG 0.83	DG 1.3	0.045	3	0.49	No	MVHR	Yes	
Stewart Milne Group														
Portlethen detached closed-panel (plot 325)	0.15	0.10	0.14	N/A	0.9	TG 0.8	TG 0.8	0.032	4	0.41	Yes	MEV	No	
Portlethen detached dynamic insulation (plot 326)	0.16*	0.08	0.12	N/A	0.9	TG 0.8	TG 0.8	0.034	3	0.41	Yes	MEV	No	
Prestonpans end-terrace dynamic insulation (plot 67)	0.15*	0.10	0.10	0	0.9	TG 0.8	TG 0.8	0.049	3	0.41	Yes	MEV	Yes	
Prestonpans mid-terrace closed-panel (plot 68)	0.15	0.08	0.09	0	0.9	TG 0.8	TG 0.8	0.066	2	0.41	No	MVHR	Yes	
Prestonpans end-terrace closed-panel (plot 69)	0.15	0.10	0.10	0	0.9	TG 0.8	TG 0.8	0.046	4	0.41	Yes	MEV	Yes	
Preston end-terrace open-panel (plot 1)	0.12	0.07	0.08	0	1.0	TG 0.8	N/A	0.060	3.5	0.41	Yes	IEF	Yes	
Preston mid-terrace open-panel (plot 2)	0.12	0.07	0.08	0	0.8	TG 0.8	N/A	0.070	4	0.41	Yes	IEF	Yes	
Preston end-terrace open-panel (plot 3)	0.12	0.07	0.08	0	1.0	TG 0.8	N/A	0.060	4.4	0.41	Yes	IEF	Yes	

* Dynamic U-value. WWHR – Waste water heat recovery. FGHR – Flue gas heat recovery. DG – Double glazed. MEV – Whole-house mechanical extract ventilation (without heat recovery). TG – Triple glazed. MVHR – Mechanical ventilation with heat recovery (balanced whole-house ventilation). IEF – Intermittent extract fans and trickle vents (natural ventilation). N/A – Not applicable.

Key technologies

Superstructure

The aim at the beginning of the project was to find a variety of solutions so that AIMC4 homes could be built using a range of construction methods. The technical and supply chain development processes resulted in three different approaches being selected.

The introduction of the concept of the zero U-value party wall was new at the time that the design work took place. SAP 2009 modelling showed that it was essential. This was a significant challenge to the project and one that required the use of new systems.

The designs also required great attention to be given to linear thermal bridging. Liaison with the suppliers was critical for this, particularly in the case of offsite systems. All the detailing was reviewed for buildability.

Timber frame

Stewart Milne Timber Systems provided the timber systems for the eight houses built by Stewart Milne Group. Of these, five were built using a closed-panel system known as the Sigma II Build System (Figure 3). Two adopted dynamic insulation, three used the normal Sigma II Build System insulation of expanded polystyrene (EPS) beads and three utilised the Sigma OP4 open-panel timber-frame system, which was insulated on site.

The three terraced houses at Prestonpans adopted the Stewart Milne Timber Systems single-skin party wall (SSPW). The SSPW is fully insulated and edge sealed off site to provide a wall that exceeds the requirements of the Building Regulations but is thinner than a conventional two-leaf timber system solution.

On the Stewart Milne Group site in Preston, Lancashire, the Sigma OP4 open-panel timber-frame system was used with rigid polyurethane (PU) insulation and a dedicated service zone behind the plasterboard in order to achieve the U-values required.

The normal Sigma II Build System comprises wall panels and floor cassettes based on engineered timber C-stud structural elements enclosed on both sides with oriented strand board

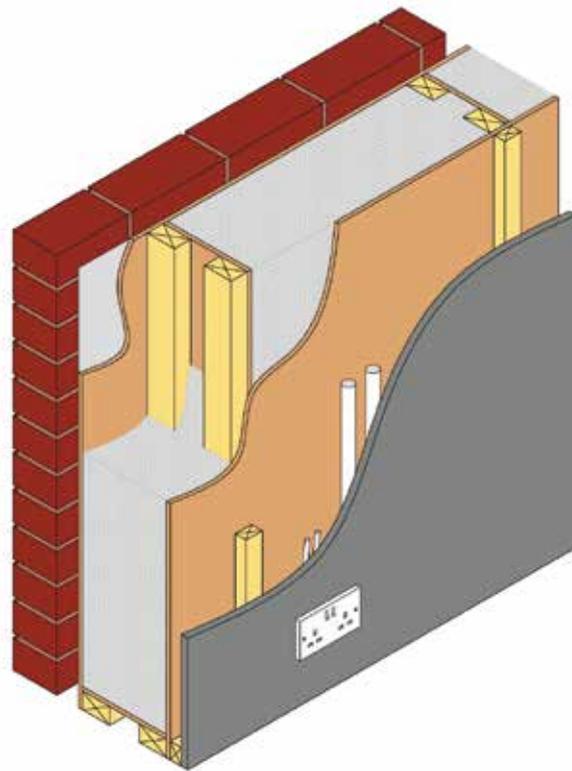
Box 1: Standard Assessment Procedure (SAP)

The Standard Assessment Procedure (SAP) was used to model the AIMC4 homes. SAP is an annual heat balance model based on ISO 13790:2008 (*Energy performance of buildings – Calculation of energy use for space heating and cooling*)^[4]. Outputs include the SAP rating, which is an energy cost index, specific energy use (kWh per m² of floor area) and specific CO₂ emissions (kg CO₂ per m² of floor area). To demonstrate compliance with Part L of the Building Regulations, SAP modelling is used to calculate the CO₂ emissions from both the dwelling being assessed (determining the dwelling emission rate, DER) and a hypothetical dwelling of identical geometry but specified to backstop elemental performance values (determining the target emission rate, TER). The level of improvement in the DER relative to the TER may show either that a design meets the requirements of the Building Regulations or that it exceeds these requirements by a percentage figure.

(OSB). The panels are fully filled with bonded high-performance EPS insulation beads containing graphite. Intermediate floors are constructed using floor cassettes. Walls are finished internally with plasterboard on battens to provide a service void for electrical heating and plumbing services. There is an option of ceiling cassettes, which aid airtightness, speed up weathertightness, give safe access to any ventilation equipment in the roof space and provide scope for storage and a future room in the roof. Externally the houses are given a facade of brick or reconstituted stone.

An alternative version of the Sigma II Build System employing Energyflo dynamic insulation was trialled in houses on Stewart Milne's AIMC4 sites in Portlethen and Prestonpans, where dynamic insulation panels replaced a portion of the conventional insulation in some full-height sections of wall panels. The remainder of each panel (such as areas below windows) was filled with conventional insulation.

Dynamic insulation aims to recapture the heat flowing out through the insulation material and reintroduce that heat into the dwelling. It comprises EPS panels into which a number of channels have been formed, through which air may flow. At the base of the wall the air channels in the insulation are open to the external cavity, which is ventilated conventionally. The tops of the dynamic insulation panels are connected via ducts or vents to the inside of the dwelling.



Key features of the Sigma II Build System

- Fully insulated off site
- Service cavity pre-fitted
- Improved fire and weather protection during build
- Airtightness detailing and seals built into panels
- Floor cassettes for speed and ease of service installation
- Principal service penetrations pre-formed
- Factory-fitted windows and doors
- Optional insulated ceiling/roof cassettes

Figure 3: Section through Sigma II Build System panel

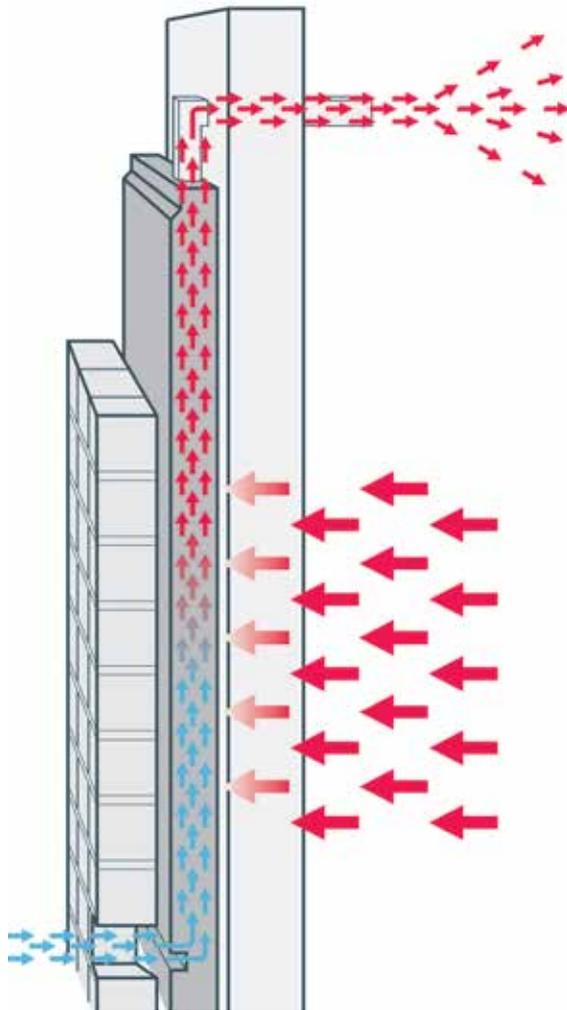


Figure 4: Schematic of dynamic insulation
(Courtesy of Energyflo)

Dynamic insulation (Figure 4) requires a continuously running mechanical ventilation system. Several options are possible, and the Stewart Milne Group AIMC4 homes used a central MEV system that creates a slight negative pressure in the house, thus drawing cool, fresh air from outside through the channels in the dynamic insulation and into the home. As the air passes through the channels in the insulation, it is warmed by the heat that would otherwise have been conducted out through the wall and lost to the external environment. Heat loss through the wall is reduced, and the insulation can be assigned a 'dynamic' U-value, which is lower than that assigned for a 'static' insulation of the same material and thickness. The use of dynamic insulation also allowed the stud size to be maintained at the standard depth of 140 mm.

Thin-joint masonry

Thin-joint masonry (Figure 5) was used to construct five of the AIMC4 houses: those built by Barratt Developments and the detached house built by Crest Nicholson. The system used was provided by H+H UK using their aerated autoclaved concrete (aircrete) blocks. The blocks are manufactured using up to 80% of recycled material (pulverised-fuel ash, which is an industrial by-product), and 99% of the raw materials used are sourced within the UK. Such constructions achieve the highest environmental rating from *The green guide to specification*^[5].

The blocks are manufactured to a tight dimensional tolerance, enabling thinner joints (2–3 mm compared with conventional 10 mm), and can be produced in larger formats than the traditional block size of 440 mm by 215 mm. The blocks are bonded using H+H UK's Celfix, a specialist cementitious thin-layer mortar designed for thin-joint construction. The mortar is applied using a scoop to maintain a consistent joint thickness and it remains workable within the bucket for several hours. However, with an initial bond time of some 15 minutes, storey-height panels can be achieved in one lift and structurally loaded within 1–2 hours. There is no mortar 'swimming' and this allows continuous block laying. The masonry was laid on site by bricklayers trained in the use of the system.



Key features of thin-joint masonry

- Allows block layering to storey height in one day, providing a faster weathertight shell
- Construction of inner leaf independently of outer leaf provides weathertight shell more quickly than conventional cavity wall construction and allows inspection of insulation
- Reduction in quantity of mortar required
- Early installation of floors and roofs
- Early installation of internal block walls and first-fix trades
- Reduction of site wastage
- Improved airtightness
- Post fixing of cavity ties enables outer leaf to be built simultaneously with the first fix internally
- Can be deployed in colder weather than traditional mortar

Figure 5: Using thin-joint masonry

The system gives a number of quality and productivity benefits over conventional masonry. The inner leaf can be constructed before the outer leaf, enabling faster weathertightness of the structure compared with conventional masonry and removing coursing issues as the cavity wall ties are installed as the outer leaf is built. The blocks can be laid more quickly due to their increased size (whilst still being sufficiently light to handle), and entire storey-height sections can be constructed in one day. Since construction of the outer leaf can be carried out simultaneously with the first fix internally, significant time savings can be achieved. The blocks are cut on site using mechanical saws to provide an accurate build. As a result, there is a reduction in site wastage. Since the materials are available using the traditional supply chain route, there are no associated lead times with the system.

Another benefit is the ability to inspect the insulation in the cavity before the outer leaf is installed. This generally provides cleaner cavities and ensures that any cavity insulation is in place and without gaps before the outer skin of brickwork is constructed.

Heat loss owing to direct U-values and linear thermal bridging is reduced due to the low thermal conductivity of aircrete relative to other forms of masonry and as a result of the reduced proportion of the wall area that consists of mortar. Using the thin-joint system can contribute to achieving low design air permeability rates by improving airtightness.

Polyisocyanurate (PIR) foam boards (which are similar in form to PU foam boards) were used to insulate the masonry cavity walls of the houses built by Crest Nicholson and Barratt Developments.

Two types of PIR product were used. The first was a partial-fill cavity wall insulation used by Barratt Developments on a terrace of three houses. In order to improve the U-value to achieve the level of energy performance required to meet Code Level 4, wider-than-conventional cavities were used to accommodate a greater thickness of insulation whilst maintaining a residual cavity.

The second PIR product was an innovative rigid board trialled by Barratt Developments and Crest Nicholson on their detached house types. The product is a full-fill PIR cavity insulation board with a moulded (not expanded) polystyrene face. It has a total thickness of 125 mm (including nibs) designed for fully filling 125 mm cavity walls. The polystyrene face sheds any water entering the cavity and therefore a residual cavity need not be maintained, thus enabling a thinner overall wall construction at any given U-value (compared with insulation boards, which require a 50 mm residual cavity to be maintained). The boards incorporate factory-precision pre-cut mitred corners and engineered tongue and groove joints to ensure correct installation and continuity of the insulation layer, avoiding the thermal bypass issues associated with poorly installed butt-jointed insulation boards.

Structural insulated panels

SIPs were used to construct a terrace of four houses by Crest Nicholson. The Kingspan TEK system was selected (Figure 6). This is based on composite panels comprising 15 mm OSB3 outer skins that are adhesively bonded to a PU foam core. The system differs from panellised timber frame, due principally to the limited requirement for any structural timber elements within the PU core. This largely eliminates regular thermal



Key features of Kingspan TEK structural insulated panels

- Insulation integrated into structural element, resulting in potentially thinner constructions
- Minimised regular thermal bridging compared with standard or panellised timber frame
- Improved airtightness due to panel jointing detail
- Offsite panellised construction could enable faster build times
- Factory production is material-efficient and minimises site waste

Figure 6: Structural insulated panels
(Courtesy of Kingspan)

bridges (the studwork) present in other panellised forms of construction, but studs are still needed around apertures and at joints. The panels are sufficiently strong and rigid to provide structural strength as well as the thermal envelope of the building.

SIPs are manufactured in a factory to each site's design requirements and delivered to site pre-cut and ready for assembly, with window and door openings pre-prepared. This minimises site waste and facilitates speedier construction than traditional masonry housebuilding. Wall U-values of 0.2 W/m² K may be achieved by the system alone, and on the Crest Nicholson AIMC4 homes this was further improved by lining with extra insulation. The SIP structure was given a brick outer leaf with brick slips applied to dormer cheeks to give a traditional finish virtually indistinguishable from the neighbouring masonry plots, and in keeping with the original planning requirements for the homes.



Figure 7: Floor insulation system used by Barratt Developments and Crest Nicholson (Courtesy of Springvale)

Floor insulation

Barratt Developments and Crest Nicholson used beam and block suspended concrete floor systems (Figure 7). The space around the reinforced concrete beams is in-filled with EPS insulation, which is moulded to wrap under each beam, forming a continuous layer of insulation under the beams and fully filling the space between the beams. A structural concrete topping is then applied, creating the finished floor.

Stewart Milne took a different approach to creating highly insulated floors, which was based on ground-bearing and suspended slabs with PU foam and EPS insulation used under the slab and at the slab edges. The slabs had a 'powerfloat' finish.

Roof insulation

Roof insulation for the masonry and open-panel timber-frame houses was mineral fibre. However, the energy performance demanded of the AIMC4 homes dictated a slightly thicker layer than generally used for homes complying with the 2010 Building Regulations. The terraced homes by Crest Nicholson incorporated a 'room in the roof', so have roofs constructed from the same SIPs panels as the walls, and with the same type of additional internal insulation. The closed-panel timber-frame houses by Stewart Milne included factory-insulated ceiling cassettes to aid prompt weather- and airtightness. Trussed rafter roofs were constructed over these cassettes.

Windows and doors

Various PVC-U window and door options have been used by the three AIMC4 developers, who considered several attributes of the frame and glazing in deciding on their chosen specifications. Both double- and triple-glazed sealed units have been used, in some cases depending on the built form. Improvements in wall U-values can mean that detached houses may only need double glazing to achieve the required overall 25% improvement in

performance over the Building Regulations 2010 (England and Wales), whilst mid-terraces need to have triple-glazed sealed units to achieve the same percentage improvement. However, this raised questions for the developers with regard to the market positioning of their homes, eg the purchaser of a detached house may question why a mid-terrace home has been provided with triple-glazing when the more expensive detached home has not. Therefore the specification of windows considered customer as well as technical concerns, with Stewart Milne and Crest Nicholson choosing to apply triple glazing to all house windows.

Most French doors installed were double glazed, as triple-glazed units are very heavy and difficult to handle. However, Stewart Milne factory-fitted triple-glazed French doors into wall panels when supplying its closed-panel system.

In addition to the glazing U-value, which indicated the ability of the window to retain heat in the building, the g-value was also considered. The g-value indicates the proportion of solar thermal radiation that is transmitted into the home. A higher g-value means the window allows greater solar gain, which can reduce heating demand in a well-insulated building but in the summer may increase the duration of periods when the home becomes too hot. Therefore different g-values were modelled in SAP 2009 to minimise both the heating requirement and the risk of overheating, with the results for overheating checked in a dynamic model.

The windows were a focus for collaboration between suppliers and developers in some Design for Assembly (lean design) workshops, in order to develop more efficient procedures for installation and improved quality in terms of airtightness. The principles of these workshops are described in more detail in Part 4 of this Information Paper series. Stewart Milne introduced an innovative means of factory-installing windows using a sliding bracket fixed to the timber-frame wall panels, along with integrated seals. This allows the wall panels to be flat-stacked during transportation. The windows were then slid into their final position after the frame of the house had been constructed. These brackets were made from high-strength plastic with low thermal conductivity, thereby minimising the thermal bridge at this particular component junction. In one of the detached houses all the windows and doors were moved into position and fixed in place in 24 minutes.

Crest Nicholson also had to ensure sufficient strength of cavity closers to support the triple-glazed windows as on the masonry plots these were installed before the outer leaf was constructed.

Hot water

The energy requirement for heating water in houses to achieve Code Level 4 energy performance varies from approximately 50% to 150% of the energy used for space heating. This depends on the built form, with more exposed forms (detached houses) having a relatively greater space heating demand than less exposed forms (mid-terraces). So the energy used for domestic hot water provision in AIMC4 houses had to be minimised. As the aim of the project was to achieve Code Level 4 energy performance without the use of renewable energy technologies, this ruled out solar-thermal water heating, which is currently the most popular means of reducing the energy used for domestic hot water provision.

Hot water cylinders need to be highly insulated to minimise standing losses. AIMC4 challenged the industry to drive down the standing losses of their cylinders and new products were produced.

Waste water heat recovery

Innovative waste water heat recovery (WWHR) technology was also installed in a number of AIMC4 houses. WWHR systems reduce the energy required to heat domestic hot water. Some of the heat energy content of the waste water from showers (and other uses of hot water) is recovered as it is discharged through the soil stack and used to pre-heat the cold water supply to the shower and hot water cylinder or combination boiler.

Several different WWHR suppliers were used in the AIMC4 houses. Figure 8 illustrates one such product, which comprises copper mains cold water pipes coiled around a central section of copper soil pipe. The potential loss of pressure in the potable water supply is overcome by wrapping several parallel pipes around the central soil pipe. Heat transfer from the soil pipe to potable water is maximised by using a square cross-section pipe to form the coils, and relies on the falling film phenomenon, whereby the waste water clings to the inner face of the soil pipe. All systems used in the AIMC4 project were tested in accordance with SAP Appendix Q and were WRAS (Water Regulations Advisory Scheme) approved.

The technology requires no change in occupant behaviour and is passive, requiring no scheduled maintenance of filters, motors or moving parts in the vertical configuration.

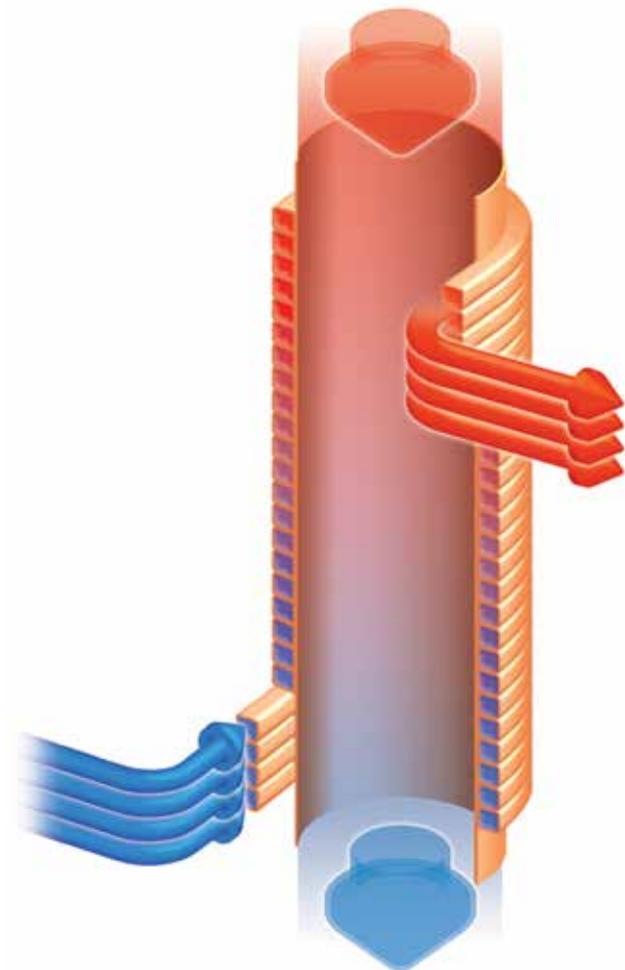


Figure 8: Schematic of waste water heat recovery unit (Courtesy of Powerpipe)

Ventilation and airtightness

AIMC4 houses had specified levels of airtightness that the volume developers considered replicable, ie mostly between 3 and 5 m³/(h.m²) @ 50 Pa.

In order to achieve these airtightness levels, a number of sophisticated tapes and seals were trialled, along with more conventional sealing products. There are varying opinions among the consortium developer partners over whether the most sophisticated products are necessary, especially at the higher end of these air leakage specifications. Such products may, however, give better results in the longer term.

A level of airtightness of between 3 and 5 m³/(h.m²) @ 50 Pa is one at which the specification of the ventilation system becomes important to safeguard indoor air quality and protect the building and its occupants from excessive humidity and associated issues. Various systems have been used by the AIMC4 consortium.

From a homeowner viewpoint, natural ventilation or MEV requires the least attention. Stewart Milne designed the homes at Preston, Lancashire, to benefit from natural ventilation using trickle vents in the windows with use of intermittent extract fans in kitchens and bathrooms.

Most of the other homes used continuously running centralised MEV together with trickle vents in the windows. Some were also fitted with humidity sensors to boost the speed of the central MEV system when cooking, showering or bathing is taking place.

Mechanical ventilation with heat recovery (MVHR) was used on the Crest Nicholson terraced houses (Figure 9) and in one of the Stewart Milne Sigma II houses in Prestonpans. The relatively low airtightness in both cases (3 m³/(h.m²) @ 50 Pa or less) was ideal for the application of MVHR. The units were supplied with a bypass to ensure that warm air is not drawn into the homes during the summer months.



Figure 9: MVHR system installed in a Crest Nicholson home

Lighting and heating controls

Low-energy lighting was specified throughout all the AIMC4 houses, and generally this is in the form of compact fluorescent lamps. However, Crest Nicholson worked with an AIMC4 supplier to specify LED lighting in all kitchens and bathrooms.

Householders' interaction with their homes and how they control the various systems provided is a critical factor that affects the operational energy use. Heating and ventilation controls were therefore chosen with great care, as were various other aspects affecting people's control of their environment, such as window furniture. Input was sought from end users in a series of consumer focus groups. This resulted in the rejection of various options such as windows with three handles, which consumers did not find intuitive to use, and certain controls with insufficiently clear user interfaces. Again, an AIMC4 supplier rose to the challenge and provided a more intuitive touch screen for the heating zone-control interface.

Results

All of the houses built as part of the AIMC4 project contain a range of innovative solutions that maximise the thermal performance of the building fabric or services. This has enabled Code for Sustainable Homes Level 4 energy performance and CO₂ emission reduction targets to be achieved without the need for renewable energy technologies. It is also worth noting that all dwellings met and surpassed the proposed 2016 (or 2013) Fabric Energy Efficiency Standards (FEES). The headline facts about the houses, including the SAP ratings for the homes (as built), are shown in Table 2. It is intended that a further paper will be written on the as-built performance.

The consortium regards it as a considerable achievement that the technical solutions applied, whilst innovative, are generally an evolution of existing technologies or construction methods (the exception being the dynamic insulation); these homes are not radically different from current solutions favoured by developers, and therefore provide a range of robust, low-risk technical solutions to Code Level 4 energy performance.

However, these homes are much more than the sum of their parts. The technical performance, cost reduction and build quality elements of the AIMC4 project goals were delivered as a result of the integrated design and collaboration between developers and suppliers, starting from the very beginning of the project and continuing through the design process and on site – the whole representing a synergistic, innovative and successful outcome.

Lessons learned

The key lessons learned from the technical development of the project are:

- At this level of performance party walls must be 'zero U-value'.
- A U-value of around 0.15 appears optimal for masonry and SIP solutions when weighing up cost and buildability.
- Obtaining good thermal bridging solutions is a cost-effective way of achieving good fabric.
- For site installation, triple-glazed windows and double-glazed French doors should be the new standard.
- For most houses the service solution appears to be either an MVHR unit or a WWHR unit with an MEV unit.
- The timber-frame option used at Preston had an improved U-value for the walls. This gave Stewart Milne Group the option of designing out MEV and allowed the more conventional ventilation solution of intermittent fans in kitchens and bathrooms to be used.

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Table 2: Headline facts of AIMC4 homes

Summary	<ul style="list-style-type: none"> • 17 exemplar homes – delivered and sold • A wide range of house designs, sizes and locations, with different fabric and product solutions • A wealth of innovative products and designs • A fabric-first approach – deliverable everywhere • Planning variation granted under devolved powers at all five sites • A welcome for the low-carbon homes of the future 		
Developer	Barratt Developments plc	Crest Nicholson plc	Stewart Milne Group
Site	Meridian Park, Corby, Northants In a market town	Noble Park, Epsom, Surrey In a conservation area	Leathen Meadows, Portlethen, Aberdeen Near the 'granite city' Athena Grange, Prestonpans, East Lothian Near stately Edinburgh Adelphi Road, Preston, Lancashire By a housing association (Community Gateway Association)
The designs of AIMC4			
Type and number of homes (Figures 10–14)	<ul style="list-style-type: none"> • One detached 4-bed home • Two 2-bedroom terraced homes with steps and staggers • One 3-bedroom terraced home 	<ul style="list-style-type: none"> • One 4-bedroom detached home • Four 4-bedroom townhouses 	<ul style="list-style-type: none"> • Two 5-bedroom detached homes • Three 2- and 3-bedroom terraced homes • Three 2-bedroom terraced homes
Fabric	<ul style="list-style-type: none"> • H+H UK thin-joint masonry 	<ul style="list-style-type: none"> • H+H UK thin-joint masonry (detached home) • Structural insulated panels (Kingspan TEK) (townhouses) 	<ul style="list-style-type: none"> • Sigma II Build System (Portlethen) • Dynamic insulated timber frame (Prestonpans) • Sigma OP4 open-panel timber frame (Preston)
Ventilation strategy	<ul style="list-style-type: none"> • MEV 	<ul style="list-style-type: none"> • MEV (detached home) • MVHR (townhouses) 	<ul style="list-style-type: none"> • MEV (Prestonpans and Portlethen) • MVHR (Prestonpans) • Natural (Preston)
Airtightness (m³/(h.m²) @ 50 Pa)	<ul style="list-style-type: none"> • 3.3–3.7 	<ul style="list-style-type: none"> • 3.2 (detached home) • 1.5–2.3 (townhouse) 	<ul style="list-style-type: none"> • 2.4–4 (Portlethen and Prestonpans) • 3–4.1 (Preston)
Performance	<ul style="list-style-type: none"> • Code 4: EN1 • FEES: Pass • Energy performance: B • SAP rating (2009): 85–89% • Airtightness (actual): 1.6–4.1 • Scoring: 86–88 • DER/TER: 25–34% • Heat loss parameter: 0.52–1.08 • £/year lighting, heating and hot water: one-third of UK average (DECC) 		



Figure 10: Barratt Developments' completed AIMC4 homes



Figure 12: Stewart Milne Group's Portlethen site homes



Figure 11: Crest Nicholson's completed AIMC4 homes



Figure 13: Stewart Milne Group's Prestonpans site homes



Figure 14: Stewart Milne Group's Preston site homes

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Driving Innovation

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BRE, Garston, Watford WD25 9XX
Tel 01923 664000, Email enquiries@bre.co.uk, www.bre.co.uk

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