

Developing future energy performance standards for UK housing: The St. Nicholas Court project – Part 2

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Abstract

This paper and Part 1 which appeared in the last issue, set out the results of a housing field trial designed to evaluate the impact of an enhanced energy performance standard for dwellings. The project was designed to inform the next review of Part L of the Building Regulations for England and Wales, which, following the publication of the UK government's white paper on energy policy (DTI, 2003), is expected in 2005. The project reported explores the implications of an enhanced standard in the context of timber frame construction. Although for programming reasons it was necessary to terminate the research project at the end of the design phase, the results suggest that the standard investigated is well within the capacity of the industry but it was clear that the whole supply chain will need to take a positive approach to the development of new solutions. The secret to a smooth and cost optimised transition is for the necessary development work to begin immediately, not when regulation changes. AMEND

Keywords: housing, energy, performance, conservation, regulation, timber frame, case study.

Introduction

The seeds of this project were contained in a report commissioned by the Joseph Rowntree Foundation at the start of the review of Part L in 1998 (Lowe and Bell 1998)¹. In this report the authors argued for the 1998 review to set out a programme of improvements that looked at least ten years ahead with firm proposals for 2000 and an outline standard for 2005 that could be subjected to field testing during the intervening quinquennium². The St Nicholas Court Project was set up to carry out such a field trial with particular reference to the design, construction and performance of timber framed dwellings. A companion project involving masonry housing (Lowe and Bell 2002) is currently underway involving the construction, by commercial developers, of some 600 dwellings on a site in the Northwest of England. The energy performance standard adopted for both studies (EPS08³ - Lowe and Bell, 2001) is modelled on proposals made by Lowe and Bell (1998) together with those set out by the DETR⁴ in June 2000 for a possible review in the second half of the present decade (DETR, 2000). The overall goal of the project was, therefore, to support such a review through an enhanced body of qualitative and quantitative evidence on options and impacts.

The St Nicholas Court Development involved the design and construction of a group of 18 low energy and affordable semi-detached 2 & 3 bedroom dwellings for the York Housing Association on a brown field site in York as part of a larger speculative

housing development.⁵ The research project was established in two stages. Initial funding was provided by the Joseph Rowntree Foundation in the spring of 1999. This ensured the involvement of the research team from the outset of the development process. Additional funding was provided from late 2000 by the Housing Corporation and by the DETR through the *Partners in Innovation* programme, responsibility for which now lies with the Department of Trade and Industry (DTI).

The project implementation plan defined the aims of the project as follows:

...to make it possible for both DETR and the house-building industry to consider a wider range of options in a possible 2005 review of Parts L, F and J of the Building Regulations, as they affect dwellings. To this end, the project seeks to:

- *comprehensively evaluate the impact of enhanced energy performance standards designed for possible incorporation into a 2005 amendment to the Building Regulations, in the context of a development of [approximately] 20 houses to be built for York Housing Association by Wates Construction Ltd; and to*
- *communicate and disseminate the results of this evaluation effectively to all stakeholders.*

The enhanced performance standards referred to here have been designed to achieve significant reductions in CO₂ emissions from new dwellings compared with dwellings built to current regulations [ADL95]. The project will explore impacts and experiences arising from the application of the improved standards, on all participants in the procurement process, including client, architect, contractor, site workforce and building control officers. These impacts and experiences will be evaluated together with costs and performance of the dwellings in-use. (Lowe and Bell, 2000a)

The research project was originally divided into five phases – project definition, design, construction, occupation, and communication and dissemination. Delays in site acquisition initially allowed the design phase to be extended, but ultimately forced the abandonment of the construction and occupation phases, and the scaling down of the communication and dissemination phase. Despite the delays, the development itself is now expected to go ahead, with construction starting in mid-2003. Sadly, it has not been possible to resume the research project. However many of the lessons learned are informing Government thinking and are contributing to the companion masonry project⁶ which is expected to begin construction towards the end of 2003.

The Purpose of this paper is to summarise the results from the design phase of the St Nicholas Court project and to discuss their implications for regulators, housing developers and the house building industry in general. Detailed results and discussion are contained in the final project report, Lowe, Bell and Roberts (2003). **Part 1 of the paper concluded with a discussion of cost issues and this paper concentrates on technological and design issues as well as considering likely future developments.**

Impacts on Construction technology

One of the functions of the project was to assess the extent to which the adoption of EPS08 would require (or at least precipitate) shifts in the technology of timber frame construction. Throughout discussions prior to the introduction of ADL02, the timber frame industry expressed considerable confidence in their ability to accommodate lower U values with little or no change in standard construction techniques. Despite this confidence, we consider it likely that a combination of further reductions in U value and the parallel agenda of rationalising construction will ultimately lead to significant change. The impacts are discussed below.

Wall and roof construction

The approach to construction adopted at St Nicholas Court, an externally insulated frame, has the property of retaining the structural efficiency, simplicity and familiarity of existing frame technology and reducing thermal bridging at openings, junctions and structural elements with the use of an external insulation layer. Its disadvantage is the need to use a more expensive and (some would argue) a less environmentally acceptable insulating material.

Increasing the thickness of overcladding to 100 mm would enable this construction to deliver U values as low as $0.2 \text{ W/m}^2\text{K}$ – though this may lead to practical problems due to the length of fixings that would be needed. Longer term requirements for lower U values, together with wider concerns about material use and the drive towards pre-fabrication and rationalisation are likely to stimulate interest in other forms of timber frame construction. There is increasing recognition that I-beam construction has considerable technical potential particularly as the experience on this project would suggest that cost barriers are reducing. However in our view, the most significant potential change in timber frame construction would be a shift to pre-fabricated structural insulated panels.

The emphasis in EPS08 on thermal bridging and airtightness together with the increasing need for controlled ventilation systems will impact on roof construction. In this project, the acceptance of the technical and living space merits of warm roof construction together with work on costs suggest that trussed rafter construction is likely to face considerable competition from I-beam structures.

Windows

The target of a U value of $1.3 \text{ W/m}^2\text{K}$ is, as intended, on the margin of what is achievable in double glazed windows with high performance low emissivity coatings, inert gas fills (argon or krypton) and insulated edge spacers (warm edge technology). In our view, the EPS08 performance standard therefore represents a tough but achievable target for windows for 2008. However, given the intention of the UK Government to bring forward to 2005 the date of the next review of Part L (see the white paper on UK energy policy – DTI, 2003), the revised time scale, may not leave enough time for much of the UK window industry to respond. Nevertheless the inclusion of the target in EPS08 has stimulated one European manufacturer to offer a revised specification that achieves the target with a double glazed window. This supports the view that a strategic and long-term approach to the development of Part L could be a major driver of innovation in the construction industry. The EPS08 performance target is of course readily achieved with triple glazed windows (which

are offered in the UK by a number of Scandinavian manufacturers, often with little price differential compared with double glazed windows), and surpassed by a factor of 1.6 by so-called passive house windows⁷. The question of whether raising minimum performance standards for windows will protect or harm the UK window industry is an important one. Our view is that, without pressure from regulation, the UK industry will continue to stagnate, leaving it increasingly vulnerable to competition from highly engineered, high performance, mass-produced products from the continent.

As noted above, the key areas for technical improvement are edge spacers, improved coatings, inert gas filling of sealed units and improved frame designs. Warm edge technology is now 20 years old and is ripe for introduction throughout the UK and Northern Europe. It is surprising that sealed unit manufacturers have been so reluctant to introduce it. Nevertheless, a number of warm edge spacers are now available which are drop-in replacements for aluminium or steel. It would appear justifiable for the ODPM to signal window performance standards for 2005 which would require the use of warm edge in all windows. In our view, inert gas filling of sealed units comes into the same category, if not by 2005 then certainly by 2008.

The question of frame materials and designs is potentially contentious, but there is now a wealth of framing technologies that can achieve very low heat loss. ADL02 provided (on the basis of a somewhat dubious technical argument) for a higher U value target for metal framed windows. Our position is that technical limitations of any particular framing material should not be used as a reason for limiting the requirements of Part L, provided these are signalled sufficiently far in advance. In the longer run, the division of the window industry into metal, plastic and wood framed appears artificial. We would expect hybrid constructions (for example aluminium-clad timber and timber-insulant sandwiches), in which each material is used to best effect, to take a much larger proportion of the market by the end of the decade. Regulation needs to reflect not just current technological constraints but also current technological opportunities.

Airtightness

Conclusions on the technological impact of the airtightness standard must remain tentative since the dwellings have not yet been constructed and airtightness details have not been fully developed. However, the issues received considerable attention during the design process from which we are able to make a number of observations.

- There is a general lack, in the UK, of established technological solutions aimed at the level of airtightness set out in EPS08 and this meant that the design team were, to a large extent working from scratch.
- Understanding of the demands of airtightness design was relatively low at the beginning of the project and, although this improved considerably during the design phase final construction details remained sketchy.
- Initial discussions of airtightness design often centred on junction design and the problems of wrapping complicated junctions with an air barrier. However this contrasted with later debates concerning the design of whole elements aimed at simplifying the construction to avoid complicated details. The discussion of the

roof construction and of balloon frame versus platform frame were examples of attempts to reduce the complexity of junction details at eaves and first floor.

Heating and ventilation

The levels of airtightness envisaged on this project (set, initially at 3m/h but later relaxed to 5m/h) would require a continuously operating whole house ventilation system. Mechanical systems were chosen with half of the dwellings based on MEV and half MVHR. The prospect of a reduced heating system was also explored together with an integrated ventilation and space heating system. As in the case of airtightness, conclusions about performance must remain tentative since monitoring and testing of working systems was not possible. However we are able to reach the following conclusions about the impact of EPS08:

- An exploration of the feasibility of integrating space heating with a heat recovery ventilation system led to the conclusion that the insulation and airtightness standards contained in EPS08 would not drive the heating load low enough in the St. Nicholas Court dwellings to make this a technically viable option. However further reductions in heat loss could make such an approach viable and enable significant cost reductions.
- The St Nicholas Court design team did however accept that the EPS08 standard, in combination with MVHR, would enable radiators to be omitted in upstairs bedrooms and avoid the need for radiators in downstairs rooms to be sited on external walls. Given the general reluctance of house builders to countenance such measures hitherto, this represents a significant step forward. The design team was however not convinced that this conclusion would be valid for dwellings with MEV, or by implication, passive stack ventilation (PSV)⁸.
- Desk studies undertaken in support of the design process did not support the contention that temperatures in highly insulated dwellings would be difficult to control due to dynamic interactions between the envelope and heating system⁹. Indeed it appears that such interactions will be less significant in highly insulated dwellings due to the lower operating temperatures and thermal mass of the heating system. These theoretical results are consistent with measurements and anecdotal reports of high levels of thermal comfort from the occupants of energy efficient dwellings.

Impacts on the design team and design processes

Given the pivotal position of regulation in any building design process, the project sought to assess the extent to which the design team could absorb (and design in accordance with) the prototype standard. Our observations in this area are as follows:

- At a conceptual level, the team had little difficulty in absorbing what was required. However at a more detailed level, designing to EPS08 required a considerable amount of work by the design team and significant input from the research team.

- In the key areas of thermal bridging and airtightness, initial awareness of their significance was low. However raising awareness was relatively straightforward as the research team were able to tap into existing understanding of the principles involved. To put it another way, team members knew about thermal bridging and airtightness but did not realise how important they were or the implications for detailed design – the devil was in the detail.
- The design of individual elements and associated details was enhanced considerably by feedback from the research team on thermal performance. This was provided partly through quantitative assessments (mainly thermal bridging calculations) and qualitative reviews of proposals.
- Although the team grasped the requirements very quickly, they did not develop a significant independent ability to use thermal bridging calculation techniques, relying instead on the research team to provide results that could be applied in a modified SAP spreadsheet. This was partly the result of the way the roles and relationships developed and partly a general reluctance (or lack of time) to learn how to use the new calculation software.
- Given the lack of enthusiasm for detailed calculation, it is likely that there will be a need to develop simplified standard approaches that enable calculation to be avoided. It would be possible to provide a number of levels ranging from full calculation to a prescriptive approach incorporating different factors of safety depending on the level of variability produced by each method. The development, as part of this project, of a thermal bridging catalogue interfaced to a modified SAP spreadsheet showed considerable promise.

Implications for training and professional development

The St Nicholas Court Project has enabled us to identify a number of areas of training and professional development that would be needed to minimise the transient effects of the introduction of EPS08 or a similar standard. The most important of these relate to thermal bridging and airtightness. Our conclusions in this area are as follows:

- As one would expect, conventional seminars and workshops played an important part. All of those involved in the design phase of the St Nicholas Court Project appear to have benefited from the workshops that were provided by the research team.
- There was widespread recognition that the open workshop style adopted and the participation of the research team resulted in extensive knowledge development. Working on a real project conceptualised the learning and, with its natural feedback cycles, provided the impetus and focus necessary for much deeper-seated learning than is possible through conventional seminars. This experience will be difficult to replicate but training workshops based on cycles of participation and feedback using realistic project simulations could form an important part of CPD programmes during any regulatory transition period.

- The natural role of building control authorities, as guardian, supporter and explainer of standards and underlying concepts could enhance the informal dissemination of understanding. However, this would require building control staff to receive extensive training well in advance of any change. In line with our conclusions on a participatory workshop style, such training should be based around “dummy” or “dry-run” assessments of realistic submissions.

Methodological and research management issues

The action research approach, in conjunction with partnering in the supply chain, appears to be an effective approach to organising and carrying out projects aimed at evaluating the impacts of new performance requirements on the procurement process and for exploring innovative approaches to construction.

The St Nicholas Court Project has demonstrated that a combination of conventional empirical costing methods and an engineering-based approach, in the context of field trials of improved standards, can yield worthwhile results. The main difficulties with this approach are the long time-scales and uncertainties associated with housing field trials. This project, like many previous trials, shows the vulnerability of research projects which are piggy-backed onto live construction projects. An approach based on desk studies and laboratory investigations and undertaken in collaboration with the upstream supply industry may offer a useful complement to full-scale field trials. Desk studies cannot, however, replace such field trials entirely. The logical implication of this is that funding bodies may need to consider funding a number of field trials, in parallel, to provide reasonable assurance that some at least will run to completion. One further limitation on the St Nicholas Court Project has been the size of the associated development. With the exception of our partners, Oregon and Baxi, this has not been big enough to engage the attention of the upstream supply industry¹⁰.

Directions for future work

The publication of the white paper *Our Energy Future* (DTI, 2003) has prompted us to stray a little further from the direct lessons of the St Nicholas Court Project than is conventional for a research paper of this nature. We feel, however, that the pivotal nature of the White Paper makes a more speculative and wide ranging discussion unavoidable.

The St Nicholas Court Project has revealed a number of areas where further work is needed, both to establish the scientific basis for energy efficient housing, and to stimulate the processes of technical innovation that will allow general implementation of standards of performance similar to those of EPS08 in the second half of this decade.

Ventilation requirements and indoor air quality

The development of performance-based ventilation standards for dwellings is one of the most important tasks that remains to be undertaken in the UK. In EPS08 we have illustrated a possible model, but consider that further work is needed to develop both the conceptual and empirical foundations of such standards in the UK context.

Further work on the interactions between continuous ventilation systems, built form and background infiltration is necessary. A clearer conceptualisation of these interactions in terms of airflow path and ventilation efficiency is needed. This is likely to become more important due to the (welcome) resurgence of interest in compact dwelling forms and urban living. External noise and pollution, particularly in urban areas, are important additional factors in this area.

Paucity of information on the actual performance of the main types of ventilation system in occupied dwellings is a major problem for the development of performance based ventilation standards. More information is needed on actual air flow rates, indoor air quality and long term reliability achieved by different ventilation systems. The Warm Front project (Oreszczyn, 2003) has begun to develop an epidemiological approach to these questions in the context of existing housing. In our view a similar approach, at a similar scale, is needed in new housing.

Heating and ventilating systems

More work is needed to commercialise mechanical ventilation systems – both single point extract systems and MVHR - in the UK. In particular, it is important to ensure the availability of electricity efficient systems using electronically commutated DC motors and efficient fans. The developing European market will ultimately ensure that such equipment is widely available in the UK, but there is a need to develop the UK technology and skills base to ensure that new products can be successfully integrated into the UK construction industry, and that they can be correctly specified, installed, commissioned and maintained. It is also important that the UK avoid the mistake of successfully commercialising obsolete technology.

Support systems for the care and maintenance of ventilation technologies need to be developed and commercialised. Such support systems need to be integrated or combined with existing support systems, such as those for gas servicing, in order to deliver support at marginal cost.

By comparison with overseas standards, existing design standards for mechanical ventilation are brief and do not deal comprehensively with design (this is related to the absence of performance-based standards for ventilation) and commissioning. The development of existing standards for mechanical ventilation is an important task.

The condensing boiler represents the thermodynamic end of the line for the gas boiler – with efficiencies now in the low 90s, there is nowhere left to go¹¹. Work remains to be done to drive down costs and improve reliability and also to demonstrate and market test dwellings with reduced heating systems. But future developments in gas technology will probably be in the areas of micro-CHP and fuel cells. It is, however, clear from our work both at St Nicholas Court and at Brookside Farm that the construction industry finds it very difficult to contemplate either approach. The alternatives of block heating and district heating, which get favourable references throughout the EU Directive on Energy Performance of Buildings (European Commission, 2003), appear to be even less feasible in the current UK context. The integration of these technologies into the UK construction industry will be a major, probably decade-long, task.

Parenthetically, the UK gas condensing boiler market has been poorly served by the relatively sedate rate of progress of energy efficiency regulations through the 80s and 90s, and by stop-start subsidy programmes whose main effect may well have been to act more as a means of price support for manufacturers than a significant market stimulus. As the White Paper notes, the more strategic approach taken in the Netherlands has led to a market penetration of 75% for condensing boilers compared to 12% in the UK (DTI, 2003, p. 35). The logical next step for Part L – a level of performance predicated on the use of condensing boilers – could, therefore lead to an increased level of imports from the Continent. The lesson here is that an ideological pre-disposition to view regulation as a burden on industry rather than as a stimulus to technological development and innovation, can be unhelpful in the long run.

There is a strategic need to develop and commercialise sources of heat that further reduce the demand for gas, including heat pumps and solar DHW, particularly in the context of all-electric houses¹². The design of heat pump systems and their implications for the electricity system, depend heavily on the relative magnitudes of demands for space and water heat. Implementation of EPS08 and the prospect of the convergence of regulatory requirements for gas and electrically heated dwellings would begin to create a market for such systems. Once again, the UK industry lags behind its continental counterparts. Heat pump systems intended for very low space heating requirements have been under active development for some ten years in Germany, stimulated by the Passivhaus programme.

Moving to heat distribution, as we noted earlier, EPS08 has come close to the point of enabling the convergence of heating and ventilation systems in housing. Such a development would represent a strategic reorientation for the UK domestic heating industry. The advantages of such systems would be the elimination of wet distribution systems and the ease with which heat recovery can be integrated into such systems. Work is needed to develop design solutions for the elegant integration of ductwork and fan and heat exchanger units into dwellings and to demonstrate the commercial viability and market acceptability of these systems in appropriate dwelling types. Work is also needed on the building of the capacity to effectively install and maintain the newly developed systems.

Construction systems

It has been obvious for a quarter of a century that timber I-beam technology is of strategic importance to the development of energy efficient, low environmental impact housing. The failure until very recently to commercialise this technology or to develop a UK production capacity has been nothing short of astonishing. The point here is not to dwell on past omissions but to argue that in certain areas, the state has a role in picking and supporting winners.

Looking forward, the next major strategic step in timber frame construction appears to be the development of pre-fabricated, pre-insulated structural timber panels, making use of I-beam technology to minimise thermal bridging and use of timber. As the Passivhaus programme has shown, this technology supports the development of hybrid masonry-timber construction as well as pure timber frame. Such a development would indeed signal that sustainability issues had been successfully embedded in the industry's wider agenda for reform. There is also a need to support the development and adaptation of more conventional, near-term construction systems

such as the overlaid timber frame chosen for the St Nicholas Court development. Developments in this context could be as simple as placing structural sheathing on the inside rather than the outside of the timber frame to provide a more durable air barrier on the inside of the construction.

Recent UK developments in foundation systems for timber framed dwellings appear to have focused on innovative structural solutions – such as pile-and-beam systems – which offer relatively little in terms of thermal insulation or airtightness. There is a need to demonstrate a wider range of systems including the use of reinforced concrete rafts poured directly into foamed plastic formwork¹³. This approach appears to go further than any other to minimising thermal bridging at the edges of floor slabs, and has the advantage of facilitating the removal of the entire construction from the site at the end of the building's life. It can also be used as a foundation system for externally insulated masonry dwellings.

Windows and doors

The demonstration and market testing of high performance windows (doubles and triples) incorporating warm edge technologies, advanced low emissivity coatings and inert gas fillings is of strategic importance. We would recommend the use of competitions – the Golden Carrot approach – to stimulate the window industry to bring high performance windows to the UK market. We would suggest that such competitions be **used** to promote both windows meeting the EPS08 performance target and windows meeting the Passivhausfenster standard (U=0.8). The use of market transformation mechanisms such as window energy rating¹⁴ have a major part to play in this context as will the integration of window energy rating into SAP.

Monitoring and feedback

Energy use in buildings is affected by trends in construction, in user behaviour, in energy prices and in technology generally, that can only be captured retrospectively by energy models. Examples include trends towards smaller households, changes in attitudes to cooking and entertainment. Within the construction industry itself, trends towards the industrialisation and rationalisation of the construction process – embodied in *Rethinking Construction* (Construction Industry Taskforce, 1998) – are likely to affect actual energy use significantly, by changing the relationship between notional and actual U values, air leakage, thermal inertia and so on. Innovation in the construction industry requires empirical information on actual in-use performance, if it is to achieve the objectives of raising building performance and reducing environmental impact.

There is therefore a need for a measurement programme that is capable of detecting long term trends in energy use in the whole stock, based on stratified random samples of existing dwellings and a measurement programme aimed at detecting trends in the performance of new homes. This would require point-of-completion and in-use performance data from significant numbers of new dwellings, based on stratified random samples and measured on a rolling, cohort-by-cohort basis. Measurements in both new and existing dwellings would include such things as internal temperatures, annual gas and electricity use, appliance ownership and energy ratings, envelope and heating system characteristics and patterns of occupancy and use. It would also be useful to measure dwelling heat loss by the co-heating method in small numbers of

new and existing dwellings to ensure that the theoretical models we use (such as U value calculations) do not lose touch with reality.

We would suggest that both programmes be sustained for a minimum of ten years. These two additions would extend the function of the measurement programme beyond the estimation of effects of individual measures or packages of measures to the provision of time series data on the energy related performance of the entire housing stock and on new build. Together with information on construction costs, they would make it possible to track changes in performance under combined impacts of technological innovation, changes in procurement systems and the development of the regulatory environment. Such a tracking function would be essential to the design and implementation of policy capable of achieving the carbon emission goals set out in the White Paper¹⁵.

End Piece – 2008 and beyond

The development and evaluation of EPS08 or similar standards is a short-term goal. That, in this project at least, we have been able to move relatively painlessly towards this goal is due to the fact that the technology to achieve it has been demonstrated repeatedly in the UK over the past twenty years. There is now an urgent need to begin to conceptualise and demonstrate a performance standard to follow EPS08. Such a standard, which would need to be consistent with the demanding sustainability goals of the White Paper, would bring together many of the proposals that we have made in this paper. It would help to provide the construction and up-stream industries and the research community with long-term performance goals well into the next decade. In reviewing the performance impact of EPS08 above we tentatively put forward the concept of the “one-tonne house” as a possible medium-term goal. While this has the advantage of simplicity, and possibly also of market appeal, more work would be needed to develop it into a robust standard. In our opinion, the German Passivhaus standard (www.passivehouse.com) may well provide an appropriate model for a long term UK energy performance standard.

Notes

¹ Material from this report was also published as part of a series of Journal articles in Structural Survey, See Bell and Lowe (2000), Lowe and Bell (2000b) and Bell and Lowe (2001)

² The review eventually resulted in the current 2002 Approved Documents L1 and L2.

³ Throughout the project the standard has been continually refined and clarified and the latest version is referenced here. In addition, the expected implementation programme for a part L review changed early in the course of the project from 2005 to 2008 but has recently reverted to 2005 following the publication of the UK Government’s white paper on energy policy (DTI 2003).

⁴ Department of the Environment, Transport and the Regions. Following UK Government reorganisation the this department no longer exists. The building regulation function now resides with the Office of the Deputy Prime Minister (ODPM).

⁵ Initial plans for the development were for some 24 dwellings, but following negotiations with the commercial developers the number was reduced to 18.

⁶ Lowe and Bell (2002) - Partners In Innovation Contract CI 39/3/663

⁷ A brief web search reveals at least a dozen manufacturers of Passivhausfenster (superwindows with U values of 0.8 W/m²K or less) in Germany, Austria and Switzerland. Unlike windows of Scandinavian origin these are not currently marketed in the UK.

⁸ MEV and PSV both lead to ventilation heat loads under windows. Efficient MVHR in an airtight envelope eliminates as much as 75% of this heat loss.

⁹ This was a concern voiced very early in the process based on the fear that the thermal inertia in the heating system would lead to large temperature overshoots.

¹⁰ The companion Brookside Farm Project (Lowe and Bell, 2002) at 6-700 houses over 4 years, does appear to have crossed this threshold.

¹¹ This does not undermine the case for extending the use of condensing boilers throughout the UK housing sector. The performance advantage of condensing compared with conventional boilers is significant.

¹² In the short term, heat pumps with CoPs in the region of 3 offer only marginal reductions in CO₂ emissions compared with gas-fired condensing boilers. In the long term, one can envisage an electricity system based on the most efficient current fossil-fired technology (gas-fired combined cycle generation) or other options currently under development, together with high levels of renewables leading to a carbon coefficient for electricity close to that for delivered natural gas. Against such a supply background, heat pumps would reduce both carbon emissions and the consumption of natural gas by a factor of 3 or more compared with gas fired condensing boilers.

¹³ This approach is exemplified by the “Houses Without Heating”, designed by Hans Eek and built in Göteborg in southern Sweden (Eek, 2001).

¹⁴ The British Fenestration Rating Council (BFRC) scheme is the most comprehensive currently available in the UK.

¹⁵ The White Paper (DTI, 2003) accepts, as its strategic target, the Royal Commission on Environmental Pollution’s assertion that a 60% reduction in carbon emissions will be required by 2050 in order to restrain climate change to manageable levels (RCEP 2000).

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