

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

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Introduction

The St Nicholas Court Project was set up to explore the implications of an enhanced energy performance standard for new housing with particular reference to the design, construction and performance of timber framed dwellings. The energy performance standard, EPS08¹, (Lowe and Bell 2001) is modelled on proposals made by the DETR² in June 2000 for a possible review of Part L of the Building Regulations in the second half of the present decade. The overall goal of the project was to support the next revision of Part L through an enhanced body of qualitative and quantitative evidence on options and impacts.

The seeds of the project were contained in a report commissioned by Joseph Rowntree Foundation at the start of the review of ~~Part L~~ in 1998 (Lowe and Bell 1998)³. 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 (see site plan, figure 1).⁴ 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).

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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 ~~[approximately]~~ 20*

¹ 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).

² 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).

³ 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 (2000) and Bell and Lowe (2001)

⁴ Initial plans for the development were for some 24 dwellings, but following negotiations with the commercial developers the number was reduced to 18.

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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, 2000)

[insert Figure 1]

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 a companion project⁵ involving the construction, by commercial developers, of some 600 masonry dwellings on a site in the Northwest of England.

The Purpose of this paper is to summarise the results from the design phase of the 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).

The Partnership

The design and development of the project based on a partnering approach that included all key players in the development process. Table 1 sets out the organisations who made a direct contribution throughout the design phase. Plans were also in place to expand the team, as construction got under weigh, to include all sub contractors.

[Insert Table 1]

Summary of the Energy Performance Standard (EPS08)

The St Nicholas Court Project was conceived from the outset as revolving round a clearly defined energy performance standard, used in place of the then ~~current version~~ of Part L (Approved Document L, 1995 - ADL95). The first version of the *Energy*

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⁵ Lowe and Bell (2002) - Partners In Innovation Contract CI 39/3/663

and Ventilation Performance Standard, written in 1999, was based on an expansion and revision of the proposals for 2005 contained in Lowe and Bell (1998). The opportunity was taken to review the elemental U values that had been proposed in 1998, to provide a much clearer indication of the relationship between three compliance modes - elemental, target or mean U value and carbon index and to define, more precisely and procedurally in terms of the raft of British, European and International standards that had by then emerged, what was meant by U value. The opportunity was also taken to begin to explore approaches for integrating other developments – such as the British Fenestration Rating Council (BFRC) window energy rating system – into the standard, and to outline a possible format for the ventilation provisions of Part F in order to ensure compatibility with the proposals for Part L.

The elemental requirements of EPS08 are presented in Table 2. The U values in table 2 are defined as whole element values. They include contributions to total heat loss from all linear thermal bridges. U values calculated on this basis are more difficult to achieve than those calculated according to procedures laid out in the current Part L Approved Document. Crudely, a wall with a U value of 0.25 W/m²K calculated according to EPS08 requires 10-15% more thermal insulation than one calculated according to ADL02. The precise amount depends on the care taken to reduce thermal bridging, both within the wall, and at junctions between it and other elements of the building thermal envelope.

[insert table 2]

Research methodology

The research project was conducted using an action research approach. The appeal of action research stemmed, to paraphrase Greenwood et al (1993), from the fact that it:

- addresses real-life problems;
- is change-oriented;
- emphasises a participatory approach in which participants and researchers generate knowledge and understanding through collaborative processes in which all participant's contributions are valued;
- is an eclectic approach that embraces ideas, knowledge and theory from any source that is able to contribute to the goal of addressing the research problem;
- does not insist on classical experimental methods as the only way of establishing truth, particularly in the social domain;
- maintains the validity of meanings negotiated by free agents in the course of undertaking and reflecting upon a shared task.

This approach worked well with the partnering approach to design and construction, which was laid down as a requirement, from the outset, in York Housing Association's Innovations Brief (Gilham 1999). This in turn drew on the Egan Report, *Rethinking Construction* (Construction Industry Task force 1998).

The key features of the research process were:

- the acceptance by all partners of the performance standard EPS08, which defined the performance target to which the dwellings and their sub-systems were ultimately designed.
- reflection on and evaluation of the design process and the performance standard throughout the design process and through a series of group and individual interviews conducted by the research team.

The research team participated throughout the design process and were considered to be an integral part of the design team. They provided technical support through a series of formal and informal meetings, workshops, demonstrations, email exchanges and working papers. The data set consisted of formal minutes of design and project team meetings, minutes and notes of informal meetings, relevant correspondence, research notes and material such as flip charts sheets produced during meetings and a series of open-ended interviews with individual team members conducted towards the end of the design process in October and November 2000. All formal minutes, interview transcripts and, wherever possible, informal notes were circulated to support the processes of individual and collective reflection. In many cases, meetings were tape-recorded and, in a small number of cases, video recorded to provide additional material for subsequent reflection.

Although in most cases the research team proposed workshops, the ultimate decision to hold a major workshop on any particular subject was taken by the team as a whole. The whole process of design was managed and punctuated by a series of Design Team meetings, involving essentially all those with a professional interest in the design and construction of the St Nicholas Court project (see table 1).

The design process

York Housing Association's decision to adopt the partnering approach was perhaps the most important determinant of the design process. As a result of this decision, upstream suppliers – in particular Oregon and Baxi - were involved from the start of the design process. Within the design team, the primary role of the architect was as an information broker. Within this structure, the prototype standard provided a very clear focus for the design process and was used, in place of ADL95, to assess emerging design solutions. The research team acted partly as the guardian of the standard and partly as a facilitator of training and provider of technical support. The atmosphere within the design team was characterised by open debate and a positive attitude to the achievement of the standard. This atmosphere was the result of clarity of purpose, reinforced by the client, and the partnering approach.

Early design discussions focused on conceptual reorientation as the design team grappled with the changes required by the new standard. Thermal bridging, airtightness and the need for a whole house ventilation system were key areas to be addressed. Initial attempts at solutions for the dwelling envelope tended to seek the achievement of the required U values using conventional approaches that did not take account of thermal bridging and with little appreciation of the implications for airtightness. This was to be expected and these early attempts provided an essential starting point for raising awareness of the practical significance of these issues. The conceptual principles involved were grasped very quickly - in the case of the wall

design bridging through the studs and at openings and junctions was illustrated at a single meeting, leading to a rapid redesign (from a conventional frame using 189 x 38mm studs to an externally insulated frame using standard 89 x 38mm studs). The resulting solution remained largely unchanged through subsequent design iterations. Airtightness was addressed in a general way by raising awareness of the importance of continuity of the primary air barrier, and of the need to minimise service penetrations. Practical impacts of this on the design included the choice of roof construction, the decision to use a combi-boiler, the incorporation of a polythene vapour barrier in the wall construction and the provision of a service-space between it and the plasterboard.

Considerable effort was centred on the design of the roof. Initially, a low pitch, trussed rafter roof with insulation at ceiling level was designed. This was challenged both by the research team and ventilation designer/supplier and an I-beam warm roof was proposed. Despite an acceptance that such a solution was technically superior and provided an opportunity for additional living space, it was rejected on cost grounds. Considerable effort was then put into making the trussed rafter solution work, a process that promised to produce some complicated details. The delay in the project programme coupled with the client's desire to realise the benefits of additional habitable volume resulted in a review of this decision and the adoption of the warm roof design.

The issue of the roof design illustrates the problems that are likely to arise when standards begin to push the boundaries of conventional technology. Although the trussed rafter solution could be made to work, it is likely that improved performance standards will progressively erode the advantages of this form of construction. We would expect the technical and environmental merits of I-beam construction coupled with evidence of falling costs to make this an increasingly common choice for timber frame construction in the future.

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The proposed airtightness standard requires the design of a whole house ventilation system. Early hopes that the levels of insulation envisaged by EPS08 would enable heating and ventilation systems to be combined, proved infeasible and separate systems were designed. However improved insulation enabled a reduction in the size of the heating systems, particularly in dwellings ventilated using MVHR where the omission of bedroom radiators was considered to be a viable option.

The training support facilitated by the research team ranged from formal seminars and workshop discussions to the provision of feedback as design solutions emerged. The two approaches proved to be complimentary with the seminars covering a wide range of principles that were reinforced by discussion during design development. Although it would be prohibitively expensive to replicate this approach in full, there are lessons that can be learned. The implications for training are discussed later in this paper.

The proposed requirements for the comprehensive treatment of thermal bridging require efficient mechanisms for accounting for thermal bridges. In this project the calculations were done by the research team and the resulting values provided to the design team through a modified SAP⁶ spreadsheet. This was designed to simulate an

⁶ The UK Government's Standard Assessment Procedure for the energy rating of dwellings

approach based on a catalogue of pre-calculated values or on certified values provided by suppliers for standard construction details. This approach demonstrated considerable promise with the architect reporting that the modified SAP spreadsheet was easy to use. However any system that relied on designers to use thermal modelling software to calculate their own values, is unlikely to meet with widespread success.

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The design solution

The design solution is illustrated in the plans and section for the 3 bedroom, 5 person house type shown in figures 2 and 3. An analysis of the design indicates that it will meet and, in some respects, exceed the requirements of the EPS08 performance standard.

[insert figures 2 and 3]

Wall construction: The construction of the proposed St Nicholas Court dwellings is shown in Figure 4. The most obvious change is to the wall construction, which is to consist of conventional 89mm studwork clad externally with 40 mm of rigid polyurethane insulation. This construction:

- significantly reduces thermal bridging through studwork and at junctions
- makes the overall thermal performance less sensitive to detailed design of the timber frame
- achieves the required whole wall U value of approximately 0.25 W/m²K.

An alternative construction using timber I beams in place of conventional studwork was considered, but was rejected mainly on grounds of cost⁷, practicality and lack of familiarity on the part of the timber frame supplier.

[Insert figure 4]

Roof construction: Two roof constructions were developed for the scheme – a cold roof variant using a conventional timber truss structure and a warm roof variant using an I-beam structure with 200 mm of insulant (mineral or cellulose fibre). The costing exercise also explored the option of a warm roof design using conventional 150mm rafters, over-clad with approximately 50 mm of rigid insulation board. This option was estimated to be more expensive than the I-beam option.

Ground floor construction: The U value requirement for the ground floor was to be met through a modest increase in insulation thickness coupled with improved edge detailing. The method chosen was a beam-and-block construction, insulated with

⁷ The question of cost was an interesting one. The initial proposals from the Partnering Contractor acknowledged the technical superiority of a timber I-beam solution but put the additional cost at over £3,000 per dwelling. This was very influential in the decision to use a more conventional design. Work on I-beams carried out for the roof design some 3 years later suggested that this cost is likely to be much lower, but the wall design has yet to be revisited.

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approximately 60 mm of polyurethane insulation. Incremental reductions in ground floor U value can be achieved, without qualitative changes in construction, by increasing the thickness of the insulation board.

Windows: Windows are to be double glazed in softwood timber frames from a UK supplier. Sealed units are to incorporate a high performance low emissivity coating and argon filled gas space. Currently it is not intended to use insulating glazing spacers. The resulting window U value is estimated to be in excess of 1.6 W/m²K – failing to meet the elemental requirement of EPS08 and falling just outside the acceptable range for trade-off. Clearly further design iterations will need to be carried out with the manufacture to seek to achieve the required values. Work with a second, European manufacturer, undertaken as part of the companion Brookside Farm project (Lowe and Bell 2002), has led to the development of a specification for a double glazed window in a softwood timber frame which does achieve the elemental target U value of 1.3 W/m²K. The key differences between this window specification and that envisaged for the St. Nicholas Court dwellings was the inclusion of insulated edge spacers to in the glazing unit and the adoption of a lower timber frame profile giving a lower frame U value. The absence of certified window performance data made it significantly more difficult for the St Nicholas Court design team to confirm window performance claims and generally impeded the process of window selection.

Impacts on performance

The primary impact of EPS08 is to reduce energy use and CO₂ emissions for space heating from new dwellings. The predicted impact of the elemental performance requirements on CO₂ emissions and carbon index for the 3 bedroom 5 person semi-detached house type (floor area 98m²) is shown in Figures 5 and 6. The predicted reduction attributable to space heating is of the order of 50% compared with ADL02 and around 70% compared with ADL95. Overall reductions in carbon emissions for space and water heating and ventilation amount to some 40% against ADL02 and just under 55% against ADL95. Total CO₂ emissions (1.58 tonnes - including an estimate for emissions attributable to lights and appliances) are within sight of the psychologically significant one tonne mark, raising the rather appealing prospect of the development of a “one-tonne house”. The carbon index (figure 6) for this dwelling rises from 6.06 to 8.91. Figures 5 and 6 also demonstrate a slight improvement over EPS08 from the final design with total emissions, including lights and appliances, of 1.41 t/a and a carbon index of 9.33. This illustrates the rather obvious expectation that if the standard represents a minimum hurdle some dwellings will clear it by a significant margin. Given the rigorous application of a revised Part L, coupled with the constraints imposed by real-world design and specification, one would expect most designs to exceed the standard.

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[Insert figure 5]

[Insert figure 6]

There are reasons for believing that this picture is conservative. The most important of these is that, in our view, ADL02 is likely to lead to a wider range of performance

than EPS08. This is due to the fact that, unlike EPS08, ADL02 does not explicitly allow for structural and geometric thermal bridges nor does it require the airtightness requirement to be verified through testing. This is likely to mean that average energy consumption and CO₂ emissions from dwellings built to ADL02 will be significantly higher than indicated in figures 4 and 5. However, given the fact that, at the time of writing, very few dwellings have been built to ADL02, statistically reliable data on the impacts on energy use and other parameters is not available and this makes it difficult to be certain on this point.

The impact of EPS08 on gas consumption is important, given that UK domestic gas production has now peaked and most if not all UK natural gas will need to be imported within 20 years (Cheshire 2001). EPS08 reduces gas consumption by approximately 33% compared with ADL02 and by approximately 54% compared with ADL95.

The main impact of EPS08 is on space heating, although improved boiler efficiency and an assumed reduction in losses from hot water distribution and storage also lead to a reduction in water heating. In two storey houses built to EPS08, space heating is likely to use less energy than water heating. In compact dwelling types – for example flats – water heating may exceed space heating by a factor of 5 or more.

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Related to the declining importance of space heating are the reduction in the length of the heating season and the increase in the temperature that is likely to be achieved in un-heated dwellings. The balance temperature of houses built to EPS08 will be in the region of 10°C, giving a heating season length of approximately 6 months. The “free temperature rise” in such houses will be around 9°C, sufficient to maintain a heating season mean internal temperature of around 15°C and of perhaps 12°C even in January⁸. While we have not reached a point where space heating is unnecessary in conventional dwellings, it is clear that very modest inputs of space heat will be enough to eliminate the physical effects associated with fuel poverty⁹. Minimum temperatures in compact dwelling types such as flats may be as much as four degrees higher still.

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A reduced demand for space heating in principle reduces the rating of space heating systems and allows their geometry to be simplified. Radiators can be smaller and fewer and can be positioned with more flexibility. In practice, given the paucity of data on the performance of heating systems in highly insulated dwellings, design teams tend to be reluctant to omit radiators. However, the the St Nicholas Court design team and the client were able to agree to a reduction in the number of radiators in dwellings with heat recovery ventilation (MVHR).

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Costs and cost effectiveness

⁸ Older readers will remember a time, not so long ago, when the heating season average temperature in Scottish houses was reported to be around 13°C.

⁹ The difference between air and surface temperatures in these dwellings will be tiny, essentially eliminating surface condensation.

The termination of the research project at the end of the design phase has restricted the cost assessment to design estimates. The lack of actual construction costs means that conclusions in this area must remain tentative. The cost increase stems from 5 areas - ground floor, walls, roof, windows & doors and services.

The overall picture of impacts of EPS08 on costs is complex and indeed was the final aspect of the project to be fully understood. In the 3 bed 5 person dwelling (warm roof design), the change in standard from 1995 to 2002 adds just over £1,470 to cost. The step from 2002 to EPS08 adds a further sum, either £1,130 or £1,900¹⁰ depending on whether the cost of the internal service-space is taken into account¹¹. In percentage terms, the 2002 standard adds some 2.6% to construction cost. EPS08 adds a further 1.9% if the cost of the service space is not counted, rising to 3.3% if it is.

Annual energy cost savings of just under £70 were calculated for the shift from 1995 to 2002 and a further £50 from 2002 to 2008. If the value of the carbon saved is added, the figures increase to £93 and £67 respectively. Simple pay back times (based on energy cost savings) are:

1995 → 2002 22 years

2002 → EPS08 23 years (excluding cost of services space) to 39 years

Although these payback times are relatively long compared, for example, with the payback rates expected in manufacturing industry, they straddle the **range of payback times** (25 to 30 years) expected in similar social housing developments.

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The discount rate currently recommended for long-term investment in such areas as building regulations is 3% (HM Treasury 2002). The economic benefit of moving to EPS08 from ADL02, expressed as an average annual equivalent saving over a 60 year life, and including the value of carbon saved¹², ranges from +£26 to -£2, depending on whether the cost of the service space is included or not. The corresponding internal rate of return, including the shadow price of carbon, is between 2.9% and 6.0%. A rate that can be compared with the 3% test discount rate proposed in the latest edition of the Treasury Green Book (HM Treasury 2002). The tentative conclusion that can be drawn is that, at current energy prices and median estimates of the shadow cost of carbon emissions, EPS08 is likely to represent a cost effective approach.

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Although we were able to arrive at reasonable cost estimates we were acutely aware of a number of issues relating to what are inherent uncertainties in costs and the way they are developed during the design stage. Three key issues emerged:

- Costs are largely *design* rather than *standard* dependent - put another way, cost is, almost self evidently, sensitive to design choices. In fact one can never be sure that

¹⁰ For an alternative design that adopted a cold roof the range was from £960 to £1600.

¹¹ It is not clear that the whole cost of the services space should be set against the airtightness standard. As well as reducing the risk of air leakage through service penetrations of the air barrier the services space was provided in the final design to enable flexibility of services routing. It could be argued that this space is a matter of good design rather than compliance with any given airtightness standard.

¹² The cost of carbon (£93.84/te(C)/a) was derived from the recommendations of Clarkson and Deyes (2002) published by the UK Treasury. A more detailed discussion is contained in the final project report (Lowe et.al. 2003)

the cheapest options have been arrived at since there may always be a more cost effective solution that has not been thought of. The standard merely acts as spur to the development of other solutions. Indeed there are situations where the standard can force design choices that reduce costs. In any case the cost estimates for meeting EPS08 at St. Nicholas Court suggest that the standard is not so challenging that the additional costs became a dominant feature of the predicted overall cost.

- In all cases where cost iterations beyond what would be normal practice for a small housing scheme were undertaken, cost estimates have fallen – the harder we looked, the smaller they got. Although it is yet to be formally documented, this effect appears even more clearly in the companion Brookside Farm Project (Lowe and Bell 2002) where initial estimates of over-cost have consistently fallen as review cycles have proceeded and quantity surveyors have become more familiar with the changes in construction and removed uncertainties associated with the sourcing of new materials and components.
- Industry procedures for producing budget costs in the context of novel projects appear likely to overestimate costs of improved standards: cost differences in individual elements are small; construction details and building services systems are often not fully resolved until designs move to site¹³; up-stream suppliers upon whom cost estimates are based are often unsure of their own costs for supplying to currently non-standard specifications; and, finally, potentially beneficial synergisms between individual measures are unlikely to be captured without multiple iterations, an open book partnership approach and significantly higher overall costs in the design-phase.

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These conclusions relate to a series of more general observations. Network effects and economies of scale are major determinants of costs and cost dynamics within the construction industry over the long run. These effects, which in principle operate at all levels in the procurement process, could be seen at work in the St Nicholas Court Project¹⁴. Formally, the construction industry consists of a series of sub-systems. Uncertainties about costs associated with new performance standards are present within each of these sub-systems. Complete information about cost is rarely passed across boundaries between sub-systems. Loss of information at sub-system boundaries involves replacing relatively complex internal cost models with simplified models or constants. Coupled with this loss of information, where costs are for non-standard specifications, costing becomes defensive to ensure that downside risks are low¹⁵. The ability of such a process accurately to reflect the marginal changes involved in a change in energy standard is weak.

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The implication of all of the above is that predictions of the costs of implementing improved performance standards nationwide, in advance of such a change, are likely to be systematically over-estimated by conventional costing approaches. This

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¹³ Our more experienced and care-worn readers may accuse us of unjustified optimism at this point.

¹⁴ One of the best analyses of the impact of network effects on innovation may be found in de Almeida's study of the French market in electric motors (de Almeida, 1998).

¹⁵ It is, of course, prudent to seek a fail-safe cost direction and at budget and design stages a QS will seek to maintain an amount of "bunce" to cover unforeseen contingencies. In general, the larger the uncertainty the larger one would expect the "bunce" to be.

tendency to over-estimate in the face of uncertainty is understandable, but unless it is allowed for at strategic and policy making levels, it is likely to inhibit the development of both energy performance standards and the technology required to support them. The St Nicholas Court Project has enabled us to observe shifts in cost estimates consistent with this picture. For example, the over-cost for an I-beam warm roof fell from an initial value of approximately £2,000 per dwelling to something close to zero as the design was firmed up and more definitive cost estimates were obtained. Our current view is that it is likely that costs associated with the EPS08 standard will continue to fall.

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It is necessary to utter a final word of caution on costs and cost effectiveness. The project was not able to cover the construction phase of the St Nicholas Court development, or the performance of the dwellings in use. While we hope that projects currently in the pipeline will shed light on the measured cost and performance of dwellings constructed to EPS 08, our conclusions must at this stage remain tentative.

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 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 W/m²K – 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 W/m²K 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 windows¹⁶. 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.

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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.

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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.

¹⁶ 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.

Airtightness

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

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- 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 verses 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 ly 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:

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- 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)¹⁷.

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¹⁷ 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.

- 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 system¹⁸. 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 occupants of energy efficient dwellings.

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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.

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¹⁸ 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.

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.

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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

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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 problems 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, entirely replace such field trials. 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 industry¹⁹.

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 (reference – phone Tadj) 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,

¹⁹ The companion Brookside Farm Project (Lowe and Bell 2002) at 6-700 houses over 4 years, does appear to have crossed this threshold.

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.

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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 go²⁰. 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). 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.

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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 houses²¹. The design of heat pump systems and their

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²⁰ 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.

²¹ 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.

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 formwork²². 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

²² This approach is exemplified by the “Houses Without Heating”, designed by Hans Eek and built in Göteborg in southern Sweden (Eek 2001).

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 rating²³ 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

²³ The British Fenestration Rating Council (BFRC) scheme is the most comprehensive currently available in the UK.

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 Paper²⁴.

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.

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²⁴ 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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¶ Acknowledgements¶
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Table 1 The Design Team	
Organisation	Role
York Housing Association	Client
Constructive Individuals	Architect
RWS Partnership	Quantity Surveyor
Wates Construction Ltd	Partnering Contractor
Oregon Timber	Timber Frame Supplier
Baxi Air Management	Heating and Ventilation Supplier
LEDA	Planning Supervisor (Health & Safety)
York Building Control	Building Control Authority

Table2: EPS08 elemental performance requirements	
exposed walls	0.25 W/m ² K
roofs	0.16 W/m ² K
floors	0.22 W/m ² K
windows, outer doors & rooflights (no more than 25% of gross floor area)	1.3 W/m ² K (or window energy rating ≥ 70)
air permeability at 50 Pa	5 m/h
maximum carbon intensity for space and water heating	70 kg/GJ

Figure 1: Layout of houses at St Nicholas Court (original scheme layout)

Figure 2 Floor plans –3 bedroom 5 person house type

Figure 3 Elevation and section – 3 bedroom 5 person house type

Figure 4: Construction section through 3-bed 5-person house at St Nicholas Court.

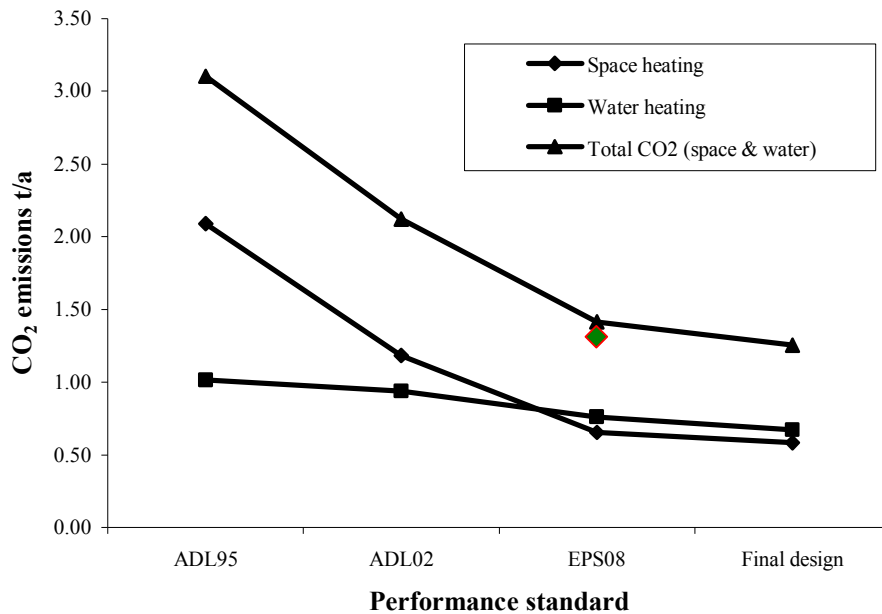


Figure 5: Comparisons of carbon emissions for the 3 bedroom, 5 person house type (floor area 98m²).

Could I suggest that the final design is not a member of the same time series as the other three points. ADL95, ADL02 and EPS08 define the lower bound for energy performance (upper bound for energy use). “Final design” is a real-world approximation to EPS08 arrived at under conditions of limited design time and grainy up-stream markets (not all physically possible construction variants are achievable in practice). I suggest that “final design” should therefore be shown as a separate point in the same column as EPS08. In the above graph, it looks as though there is only room for the “total CO₂” point (which I’ve added in the most garish possible combination of colours). Figure 6, below, would not be a problem.

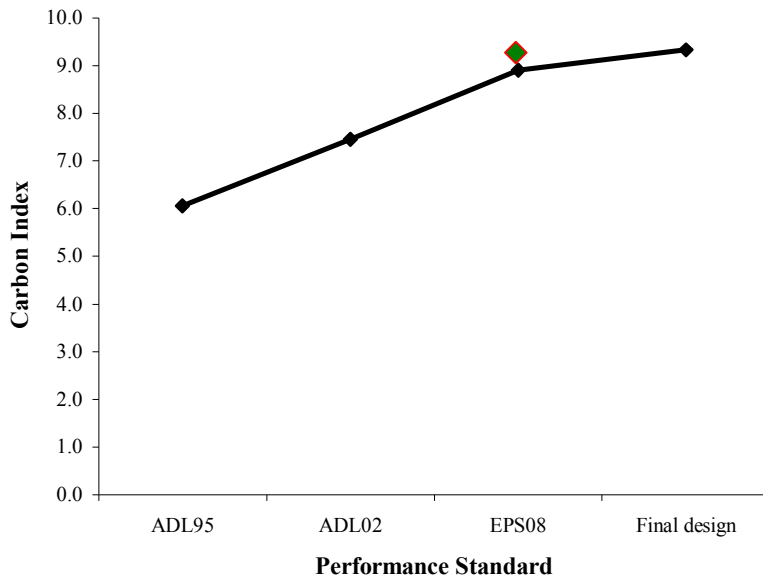


Figure 6: Comparison of carbon index for the 3 bedroom, 5 person house type (floor area 98m²).

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