# Developing Future UK Energy Performance Standards

## St Nicholas Court Project

## Final Report





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April 2003

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Participatory Action Research requires partners. This project would have been impossible without the active involvement of Jenny Brierley, John Gilham and Ron Bailey of York Housing Association, Phil Bixby of Constructive Individuals, Phil Hughes, Graham Cooper, Phil Askin and John Corke of Wates Construction, Robin Dodyk of Oregon Timber, Brian Stace of RWS Partnership, Chris Palmer, Martin Searle and Barry Turner, of Baxi Air Management, John Fowler, Phil Parker and Mike Collins of City of York Building Control and James Haigh of LEDA.

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Neil Smith of NHBC, Ben Cartwright of CITB, Dr Vic Crisp of BRECSU (now at the Carbon Trust) and the late Martin Rowbotham of Hastoe Housing Association Ltd served on the Project Advisory Group. Roger Stephens of BRE and David Olivier of Energy Advisory Associates, with support from the Design Advice Service, participated in technical workshops on airtightness and energy efficient dwelling design.

It does not diminish the contribution of any of the above to affirm that the responsibility for any remaining errors or omissions in this report lies with the authors and that the contents of this report do not necessarily reflect the views or policies of the project’s funders or partners.

# Contents

# Executive Summary

**Introduction**
The St Nicholas Court Project was set up to explore the implications of an enhanced energy performance standard for new housing for the design, construction and performance of timber framed dwellings. The energy performance standard, EPS08, is modelled on proposals made by the DETR 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 – *Towards Sustainable Housing* - commissioned by Joseph Rowntree Foundation at the start of the last review of this part of the Building Regulations. The project itself has been based on the St Nicholas Court Development which involves the design and construction of a group of 18 low energy and affordable dwellings on a brown field site in York (see site plan below). 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 DTI).

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 will now go ahead, with construction starting in mid-2003.

**The Partnership**
The St Nicholas Court Project was based on a partnership that included all those involved in the design process. The following organisations contributed directly throughout the design phase:

York Housing Association
Constructive Individuals
RWS Partnership
Wates Construction Ltd
Oregon Timber
Baxi Air Management
City of York Council
LEDA

Support for the project's advisory group was also provided by NHBC, CITB, BRECSU and the Hastoe Housing Association Ltd.


Figure 0.1: Layout of houses at St Nicholas Court

**Summary of 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 (ADL95). The first version of the *Energy and Ventilation Performance Standard*, written in 1999, was based on an expansion and revision of the proposals for 2005 contained in *Towards Sustainable Housing*. 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 CEN 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 contemporary developments – such as the BFRC window energy rating system – into the standard, and to outline a possible format for the ventilation provisions of Part F which would be consistent with the proposals for Part L.

The elemental requirements of EPS08 are presented in Table 0.1 below:

| Table 0.1: 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<br>(no more than 25% of gross floor area) | 1.3 W/m$^2$K<br>(or window energy rating ≥ 70) |
| air permeability at 50 Pa | 5 m/h |
| maximum carbon intensity for space and water heating | 70 kg/GJ |

U values in the above table 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/m$^2$K 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.

The predicted impact of these elemental performance requirements on $CO_2$ emissions and carbon index is shown in Figures 0.2 and 0.3 below:

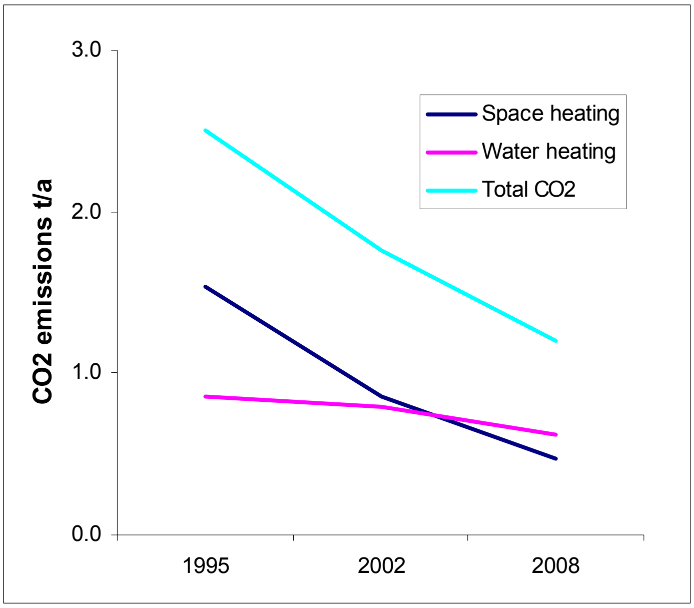


Figure 0.2: Comparisons of carbon emissions under ADL95, ADL02 and EPS08, for an 80m$^2$ gas heated semi-detached dwelling.

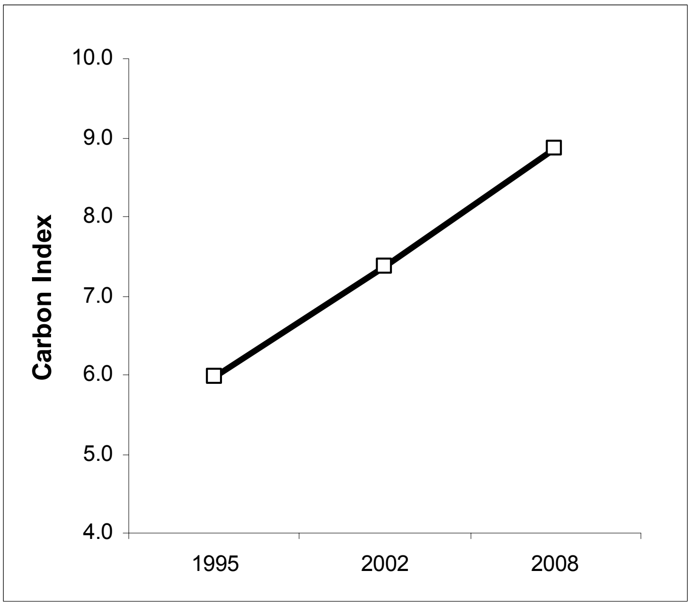


Figure 0.3: Comparisons of carbon index under ADL95, ADL02 and EPS08, for an 80m$^2$ gas heated semi-detached dwelling.

In brief, EPS08 is expected to reduce $CO_2$ emissions and gas consumption for a typical 80 m$^2$ semi-detached dwelling by approximately one third compared with ADL02 and by more than one half compared with ADL95. At this level of performance, annual energy requirement for domestic hot water is greater than for space heating.

## 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 provided technical support to the design team though a series of workshops, informal meetings, demonstrations, email exchanges and working papers. Wherever possible, exchanges between partners were minuted and minutes circulated to support 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 workshops were proposed by the research team, 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 design and construction of the St Nicholas Court project: client, architect, main contractor, up-stream suppliers, building services engineer.

## 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, up-stream 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 information broker. Within this structure, the prototype standard provided a very clear focus for the design process and was used, in place of ADL95, continuously 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 the 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. The resulting solution, an 89 mm stud externally insulated frame, 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, improved performance standards appear progressively to erode the advantages of this form of construction. The technical and environmental merits of I-beam construction coupled with evidence of falling costs are likely to make this an increasingly common choice for timber frame construction.

The proposed airtightness standard requires the adoption of a continuous 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 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. As far as possible, training programmes should be participatory and based on "real" cases with design and feedback cycles built into the process. The role of building control staff as a dissemination tool should be exploited much more than in the past, backed up by investment in building control training, again, based on a participatory approach.

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 SAP spreadsheet. This was designed to simulate an 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 the use by designers of thermal modelling software to calculate their own values, is unlikely to meet with widespread success.

**The design solution**

It appears that the design that emerged from this process will meet the U value and airtightness requirements of the EPS08 performance standard with relatively minor modifications. The specifications of the main elements of the dwellings are:

Wall construction: The construction of the proposed St Nicholas Court dwellings is shown in Figure 0.4. 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 $W/m^2K$.

An alternative construction using timber I beams in place of conventional studwork was considered, but was rejected mainly on grounds of practicality and lack of familiarity on the part of the timber frame supplier. Cost was an important secondary factor in this decision.

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 found to be more expensive than the I-beam option.

Ground floor construction: The U value requirement for the ground floor is to be met through a modest increase in insulation thickness coupled with improved edge detailing. The method chosen is beam-and-block construction, insulated with 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 $W/m^2K$ – 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, has led to the development of a specification for a double glazed window in a softwood timber frame which appears to achieve the elemental target U value of 1.3 $W/m^2K$. The absence of certified window performance data made it significantly more difficult to confirm window performance claims and impeded the process of window selection.

**Costs and cost effectiveness**

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.

In the 3 bed 5 person dwelling (warm roof - as designed), 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 £1,900 depending on whether the cost of the internal service-space is taken into account[1]. 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

The discount rate currently recommended for long term investment in such areas as building regulations is 3%. 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 saved, ranges from +£26 to -£2, depending on whether the cost of the service space is included or not. The former case comfortably passes the economic test and the latter is on the margin.

Our general observations and analysis of costs in this project lead us to the conclusion that the uncertainties that exist during the design phase of any project are likely to impact much more on estimates of cost for novel constructions and untried standards of performance than on those that are well tried and tested. This leads to the general conclusion that the costs of achieving improved standards are likely to be over estimated. Empirical evidence for this is provided by the trajectory of over-cost for an I-beam warm roof, which fell from an initial value of approximately £2,000 per dwelling reduced to something close to zero as the design was firmed up and more definitive cost estimates were obtained. This tendency to over-estimate in the face of uncertainty is understandable, but unless it is allowed for, it may have the unfortunate effect of inhibiting the development of both housing energy standards and the technology required to support them.

[1] 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.

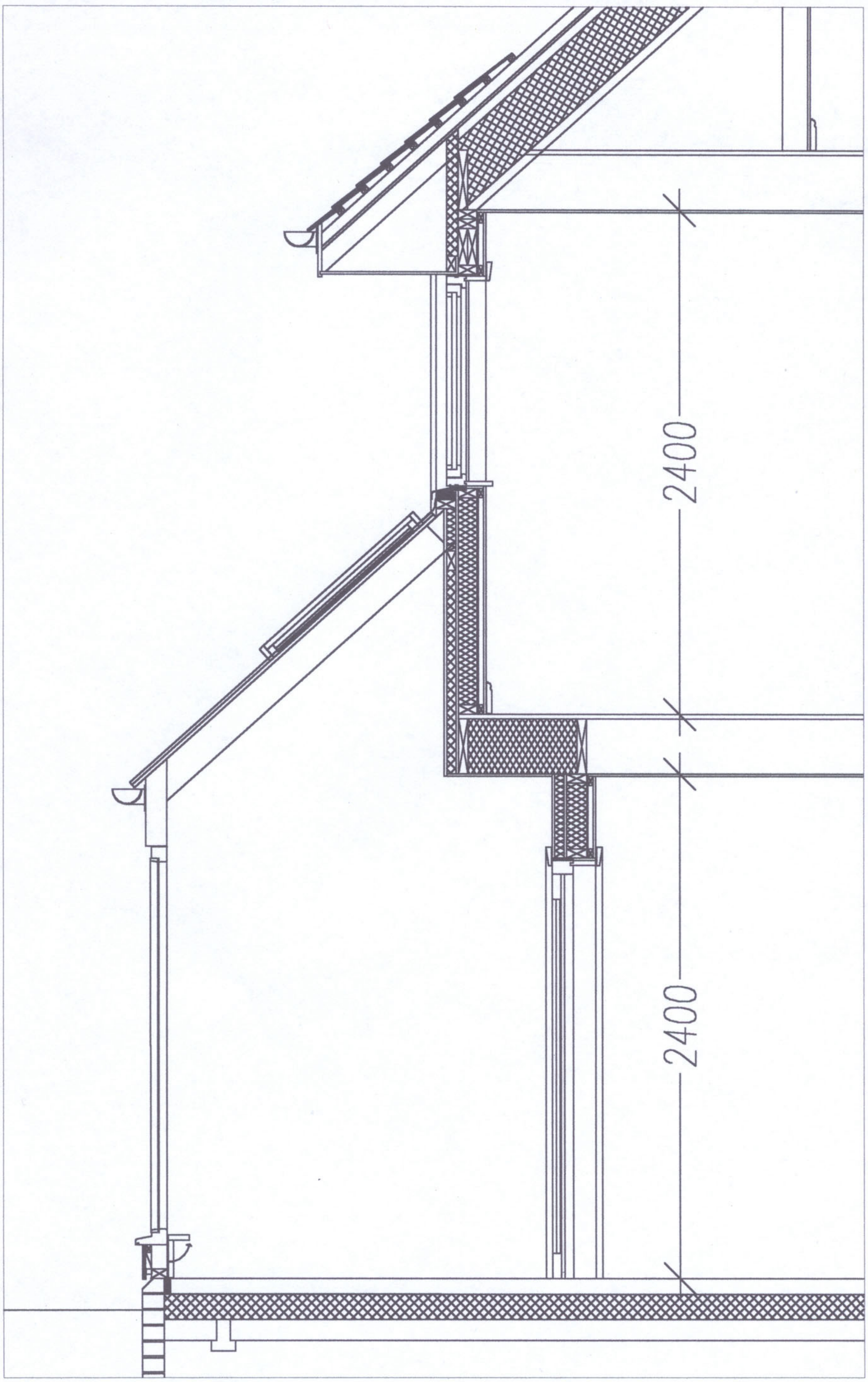


Figure 0.4: Construction section through 3-bed 5-person house at St Nicholas Court.

**Principal conclusions and recommendations**

The wide-ranging discussion contained in the full report is summarised here, with key recommendations emphasised.

**(i)** It appears that with the exception of windows, the envelope requirements of EPS08 are relatively straightforward to meet in timber-framed housing. The standard appears to be economic when tested against current Treasury guidelines, provided that account is taken of the value of carbon saved by the improved standard.

**(ii)** With the support of the research team, the design team found the thermal bridging and airtightness requirements of the standard conceptually straightforward. However few, if any, of the design team or York Building Control achieved familiarity with the quantification of thermal bridging. *This suggests that a prescriptive standard, based on the current Robust Details approach, would be an important part of the implementation of EPS08 or similar standards. There is a need to extend Robust Details to include numerical information on thermal bridging, and a need to ensure that this information is interfaced to a modified version of SAP.*

**(iii)** The approach taken by the project to training appears to have been effective. The key features were a workshop-based approach, with use of graphical techniques and on-site demonstrations, in the context of real design problems. Training was facilitated by the partnering approach. Training of this nature is needed throughout the supply chain and in organisations responsible for building control.

**(iv)** Absence of reliable information on air leakage led to uncertainty in a number of areas – e.g. as to whether a services void on the inside of the timber frame would be needed to achieve the air leakage target of 5 m/h at 50 Pa. *The introduction of mandatory pressurisation testing of a proportion of new dwellings may be the most effective way to ensure the rapid diffusion of knowledge about air tightness and the rapid generation of a large database of experience on both effective and ineffective design and construction solutions.*

**(v)** For double glazed windows with current framing systems, the performance target of 1.3 $W/m^2K$ or a window energy rating of 70 is, as intended, on the margin of what is achievable. However, a number of continental manufacturers can achieve this performance with triple glazed windows at modest over-costs, and the Passivhaus window standard – a whole window U value of 0.8 - exceeds the EPS08 U value requirement by a factor of 1.6. The key areas for technical improvement are edge spacers, improved coatings, inert gas filling of sealed units and improved frame designs. *It would appear justifiable for the ODPM to signal window performance standards for 2005 that 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. We view the commercialisation of a range of high performance windows with these features as urgent and of strategic importance. There is also a need to demonstrate and commercialise a range of superwindows with performance at the level of the Passivhaus standard*

**(vi)** The development of performance-based ventilation standards for dwellings is a key task. We have developed 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. *More work is needed to commercialise a wider range of continuous ventilation systems, particularly single point extraction systems (MEV) and balanced heat recovery ventilation (MVHR).*

**(vii)** *There is a powerful case for requiring, from 2005, the use of condensing boilers wherever gas is used for heating*. However, the thermal performance of the condensing boiler has essentially reached its physical limit. *There is therefore a pressing need to define and commercialise a range of successor technologies to the condensing boiler*. These are likely to include some or all of (micro-) CHP, fuel cells, district heating and heat pumps supplemented with solar hot water heating. It is clear from our work both at St Nicholas Court and at Brookside Farm that the integration of any of these technologies into the UK construction industry will be a major, probably decade-long, task.

**(viii)** 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 measurement programmes capable of detecting long-term trends in energy use in the whole stock, and in the performance of new homes*. This would require performance data from significant numbers of existing and new dwellings, based on stratified random samples and measured on a rolling, cohort-by-cohort basis.

**(ix)** The St Nicholas Court project has helped us to identify a number of areas of technology in which the UK lags behind developments elsewhere. These include condensing boilers, high performance windows and construction systems. We suspect that a significant contribution to this situation was made by the view, which prevailed through the 1980s and much of the 1990s, that regulation is a burden on industry. It appears that under certain conditions the opposite may be the case, and that a challenging regulatory environment can become a stimulus to innovation.

**(x)** Finally, *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 *Our Energy Future*, would bring together many of the proposals that we have made in this report. 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. The German Passivhaus standard (www.passivehouse.com) may well provide an appropriate model for a long-term UK energy performance standard.

# Chapter 1 Introduction

The purpose of this report is to document the methods, results and conclusions of the St Nicholas Court Project. The overall aim of the project was to make it possible to expand the range of options considered in the next review of Part L of the Building Regulations, by providing a comprehensive evaluation of the impact of an enhanced energy performance standard (Lowe & Bell, 1998a) on a real housing development. The standard itself was first outlined in 1998 by Lowe and Bell in *Towards Sustainable Housing: Building Regulation for the 21st Century* - a report commissioned by Joseph Rowntree Foundation (Lowe & Bell, 1998b).

The St Nicholas Court Project emerged from a series of discussions between Leeds Metropolitan University, Julie Cowans of the Joseph Rowntree Foundation and Jenny Brierley and John Gilham of York Housing Association in the middle of 1998. York Housing Association had at this stage decided to build approximately twenty low energy and affordable dwellings on a brown-field site in York. It quickly became apparent that this project offered an opportunity to evaluate proposals in *Towards Sustainable Housing* for an enhanced energy performance standard for new housing.

The project architect, Phil Bixby, was appointed at the beginning of 1999. Initial discussions involving Bixby and Lowe and Bell from LMU took place early in 1999. The decision to build the St Nicholas Court dwellings in timber was taken at this stage. Initial funding for the research project was secured from Joseph Rowntree Foundation in the spring of 1999. The Project Definition Phase involving discussions with the design team began in earnest in May of 1999. An initial bid for Partners in Innovation funding based on the proposed development was made in September 1999 and a full bid was made in January 2000.

The design process, conducted through a series of meetings and supported by workshops, occupied the eighteen months from the beginning of 2000 to the middle of 2001. This was the most intensive period of activity in the life of the Project. This period was prolonged by delays in the acquisition of the site for the development. These delays, which began early in 2001, were initially used as an opportunity for further exploration of issues thrown up earlier in the design phase and ultimately for a complete redesign of the dwellings. This unexpected iteration significantly enriched the understanding that emerged from the design phase but ultimately made it necessary to abandon the original aim of tracking the construction phase and evaluating the performance of the dwellings in use. The decision to truncate the research project was taken, with regret, early in 2002.

The proof of any dwelling design process lies in the performance of the dwellings in use. The St Nicholas Court Project cannot pretend to be conclusive and it would indeed have been unfortunate if that were the end of the story. Fortunately the research team was presented, in mid-2001, with the opportunity to undertake a companion project - the Brookside Farm Project - looking at the implications of EPS08 for masonry housing. It is hoped that many of the questions that have been left unanswered by the St Nicholas Court Project will be answered by Brookside Farm.

# Chapter 2 Research methodology and project implementation – an overview

## 2.0 Introduction

The objective of this chapter is to provide an overview of the methodology of the St Nicholas Court Project. Detailed descriptions of methods used in particular phases of the project will be presented in other chapters.

Any discussion of methodology has to begin with a clearly defined research problem. The fundamental research problem for the St Nicholas Court Project was to evaluate an improved energy performance standard for new UK housing by applying it to a real development project.

Any proposal to implement an improved energy performance standard in the domestic sector faces a number of obstacles. It is necessary to demonstrate to the house construction industry and to Government that the costs of the proposed standard are proportionate to the social and environmental objectives; that the standard can be understood and implemented at all levels in the construction industry; that buildability problems could be overcome; and that implementation is unlikely to lead to a significant net increase in the incidence of building failures. It is necessary to understand the training and professional development needs of actors throughout the house construction industry, and of the building control community. Finally, it is essential to demonstrate that occupants like dwellings built to such standards, and that health, comfort and safety are not compromised.

As noted in Chapter 1, the St Nicholas Court Project aimed to address all of these issues. The Project Team, adopting an Action Research approach, set out to develop an intimate understanding of the attitudes of the major stakeholders in the procurement process and the way in which these attitudes developed and changed with exposure to the sorts of technical standards proposed, in the context of a real housing scheme.

## 2.1 The choice of the Action Research approach

Action research is an approach that has been developed over the last five decades, in settings that range from the first world industrial corporations to the villages of the Third World[2]. The term "Action Research" was coined by Kurt Lewin (1946) who undertook research into problems of minority communities and into the effects of workers' participation in the 1940s. The wide range of settings has been complemented by an equally wide range of objectives – from projects aimed at achieving "reforms and incremental change in relatively well-organised and tightly coupled systems in politically open societies in developed countries" to projects

[2] The first author owes his own introduction to the principles and history of Action Research to Dr Lai-fong Chiu, now senior research fellow at the Nuffield Institute for Health, University of Leeds.

aimed at "politically empowering and liberating relatively powerless, disenfranchised groups" in developing countries (Elden & Chisholm 1993, see also Grundy 1988). The classic examples of the former are the work of Whyte, Greenwood and others on the development of manufacturing at the Xerox Corporation, and the work of Whyte, Greenwood, Gonzalez and others with the Mondragon industrial co-operatives. Both are summarised in Greenwood et al (1993). Classic examples of the latter are provided by the work of Freire (1985). Clearly, the St Nicholas Court Project sits at the former end of this spectrum.

The appeal of action research in the present context stemmed, to paraphrase Greenwood et al (1993), from the fact:

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

Specifically, the approach appeared to be consistent with the partnering approach to procurement that was laid down as a requirement from the outset of the process in York Housing Association's Innovations Brief (Gilham 1999), which in turn drew directly on *Rethinking Construction* (Construction Industry Task force 1998).

Finally, the approach appeared to be the only possible way:

- of enabling stakeholders in the procurement process to develop considered views on the impact of an enhanced energy performance standard, through the process of designing and building dwellings to that standard;
- of providing a framework and a process through which the development of those views could be documented and evaluated;
- of allowing the research team to participate in and provide technical support throughout the design phase (and, had it taken place, the construction phase) thus ensuring that the other members of the team would not simply be left to sink or swim as they came to terms with the enhanced energy performance standard[3].

[3] An informal undertaking, using precisely this form of words, was given by Lowe and Bell to the other members of the Design Team on a number of occasions during the project definition phase (see below).

This last point in our view is crucial. The construction industry has to negotiate changes in the building regulations approximately every 5 years. Such changes are normally negotiated publicly over a period of 2 or 3 years, are presaged by consultation documents and draft approved documents and are underpinned by a wealth of supporting material provided by BRE, BRECSU, CITB, NHBC and others to ensure that, by and large, disasters are avoided. In the case of the 2002 revision to Part L, the industry has had a period of approaching 4 years to adjust to the new requirements[4]. For the St Nicholas Court partners in the context of EPS08 (a detailed description of which appears in Chapter 3), none of this has been true. To have attempted to implement a non-participatory research approach - insisting on clear distinctions between researchers and researched - would have led, in our view to any or all of:

- unacceptably high risk of technical failure;
- unrealistically high costs;
- defensive and sub-optimal designs; and
- unremittingly negative views from many of those involved on the difficulties imposed by the proposed standard.

Technical support was delivered through a series of workshops, informal meetings, demonstrations, email exchanges and working papers. Wherever possible, such exchanges were minuted and minutes circulated to support 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 the research team proposed workshops in most cases, 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 design and construction of the St Nicholas Court project: client, architect, main contractor, up-stream suppliers, building services engineer. These meetings were business-like, multi-disciplinary and non-hierarchical and were generally characterised by vigorous and respectful exchanges. Meetings involving smaller sub-groups were held between Design Team meetings, normally at the request of individual members of the Design Team. Technical questions arising from the energy performance standard were discussed at most of these meetings.

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To have done otherwise would have been ethically unconscionable, in addition to ensuring that the results of the project were of little subsequent interest.

[4] Those companies who became aware of the likely direction of the Part L review in 1998 and who were able to "bank" sufficient building control approvals under the 1995 document to carry them into the second quarter of 2003, will have had a lead time of approximately five years to adapt to ADL02.

## 2.2 The project programme

The St Nicholas Court Project was divided from the outset into five main phases, each of which contained a series of sub-tasks. These are set out, with their original timings, as follows:

1. Project definition phase – May 1999 to October 1999
   Drafting and review of enhanced energy performance standard (covering parts L, J and F of building regulations).
2. Design phase –September 1999 to February 2000
   Qualitative evaluation of process based on recordings of Design Team meetings, focus group interview with Design Team, supplemented by individual interviews with planning and building control officers.

   Preliminary cost analysis of dwellings to EPS08 standard and to 1995 and proposed 2000 Building Regulations.

   Qualitative analysis of previous schemes built by YHA to determine major changes in practice.

   Technical support for design process, including seminars on airtightness and pressurisation testing, heating and ventilation systems for low energy houses, techniques for minimisation of thermal bridging.

   Submission of final designs for Building Control approval, evaluation of Building Control process.
3. Construction phase - March 2000 to December 2000
4. Occupation phase – January 2001 to May 2002
5. Communication and dissemination phase – January 2001 to November 2002

For the reasons discussed in the introduction, the design phase of the project has been significantly extended and the construction and occupation phases have been aborted. As will be discussed later, the original intention to include construction and occupation in the research project were essential in two key respects:

- to secure the full co-operation of four companies and the personal commitment of more than a dozen busy professionals; and

- as a guarantee of the validity of the results of the project, the fact that participants were committed to build St Nicholas Court as a commercial project provided a powerful incentive for honesty and frankness throughout the design process. (The pragmatist philosopher, Dewey, refers to insights derived through research in such real-world situations as "warranted assertions").

The main reasons for terminating the project at the end of the design phase were the financial strain placed on LMU by the prolonged and, at the time of writing, still indefinite delay in construction and, more importantly, the difficulty in keeping the rest of the team together. By the beginning of 2002, several individuals who had made major contributions through the design process had moved to other jobs and were no longer available to the project. Continuity between the design and construction phases appeared to us to be essential to the success of the research project.

Despite the loss of the latter phases of the project, the prolongation of the design phase has provided significant added value in allowing one major redesign of the dwellings to be undertaken, incorporating the insights gained from evaluation of the initial design.

## 2.3 Outputs and strands of evaluation

The principal outputs from the project are a comprehensive evaluation of the impacts of enhanced domestic energy performance standards on all participants in the design and building control process. These include the client, architect, contractor, team, principal up-stream suppliers and building control officers. Context for this evaluation is provided by detailed assessments of the costs and predicted energy performance of the dwellings.

The results of this work will provide the DETR and the housing industry with guidance in the following areas:

1. The expected additional costs involved in achieving enhanced energy and environmental performance, and the extent to which they may be contained by: rationalisation of construction techniques; management and procurement processes; and overall dwelling design, within the constraints of prevailing construction techniques and aesthetic values.

2. Predicted energy performance of dwellings constructed to the requirements of the enhanced standards.

3. The development of attitudes to the substantive and procedural aspects of the enhanced standards among building designers, the construction workforce, planning and building control officers and within the housing association, over the life of the project.

Evaluation has been both quantitative and qualitative. Qualitative evaluation has been based on participant observation, focus groups and individual interviews. Quantitative evaluation has been based on predictions of cost and energy performance. The principal issues for evaluation are the predicted costs of achieving the enhanced energy performance standard, the costs of achieving it and the impact of the proposed standards on all participants in the design process. The following bulleted paragraphs describe the main areas of investigation and associated methods in more detail:

- **Technical impact** – This has been assessed through comparison of the St Nicholas Court Development with previous and current[5] practice and assessments of the

[5] Given the fact that during the writing process the industry was only just beginning to design to the 2002 regulations, it was difficult to be certain about modifications to construction and design. In view of this it has been necessary to estimate, with advice from appropriate members of the design team, the construction most likely to have been adopted.

effects of these changes on dwelling performance. Analysis has focused on predicted changes in elemental U values, extent of thermal bridging, design responses to airtightness requirements, measures to ensure indoor air quality and measures to reduce the capital costs of heating and ventilation systems. This analysis has been undertaken using a SAP-based energy calculation tool to estimate energy and $CO_2$ emissions from the completed dwellings, finite element simulation to estimate elemental U values and use of the admittance method to predict impacts on thermal comfort.

- **Economic impact** - the economic costs of the changes incorporated in the proposed standards, including the possible ameliorating effects of technical rationalisation and process improvement, have been assessed using conventional quantity surveying methods based on data from the design of the field trial dwellings and from previous housing schemes with which the team were familiar.

  The economic costing exercise has been supplemented by an analysis of the reductions in carbon dioxide emissions that we predict will be achieved by the standard. This in turn has enabled us to estimate the economic cost of carbon saved by the standard and to compare this with current estimates of the wider economic cost of carbon emissions.

- **Impact of enhanced standards on the Design Team** – This has been investigated through participant observation of the design and procurement process, which has enabled direct observation of both the process of adaptation of construction methods and detailed design and the process of the Design Team's adaptation of their models and theories of dwelling energy performance. Raw data from this process has been collected through tape recordings, written notes and minutes of Design Team meetings and workshops and through individual and focus group interviews with Design Team members. Interviews have been conducted throughout the design phase of the project. The purpose of these interviews was to establish and document the reasoning behind particular technical decisions and to gain insight into the development of the views of the Design Team on the proposed regulatory framework and its implications for design and construction. An important practical outcome of qualitative work with this group and other participants has been the identification of training and professional development requirements that would be likely to arise from the adoption of the proposed standards.

- **Impact on Building Control** - The impact of the proposed regulatory framework on Building Control has been tested by having the Building Control Department of York City Council assess the development for compliance under the proposed standards. This exercise has been supported and shadowed by the Project Team and monitored through interviews with Building Control Officers responsible. It has required the Project Team to document the enhanced standards to the necessary level of detail. The quality of these documents and the nature of the provisions that they contain have been central to the research project. In order to ensure that they provided a suitable basis for this project, initial versions were circulated to project partners and to the DETR and reviewed at a 1 day workshop in October 1999.

## 2.4 Dissemination

Dissemination was an integral part of the original work plan. The results of this project have been disseminated through interim reports and through the CeBE website: http://www.lmu.ac.uk/cebe/projects/energy.htm.

A CD-ROM containing graphical and other information on the project, including working drawings and photographs, is available from: m.burton@lmu.ac.uk

The project originally included a structured dissemination process using existing channels for provision of information, training and CPD to the construction industry. The objective was to use the project to identify strategic gaps in existing provision and to begin to develop products to fill these gaps, in collaboration with and through the programmes of organisations such as DETR Building Regulations Division (which played an active part in formulating the project), BRECSU, CITB and NHBC. The loss of the Construction and Occupation phases of the project has meant that this has been curtailed, but we intend to pursue the strategy in the context of the Brookside Farm Project.

# Chapter 3 The dwelling energy and ventilation standard

## 3.1 History of the standard

The origins of the St Nicholas Court Project go back a study of options for the end-of-millennium review of Part L of the Building Regulations undertaken by LMU for Joseph Rowntree Foundation in 1997, at the outset of the most recent review of Part L of the Building Regulations[6]. This work, published as *Towards Sustainable Housing: Building Regulation for the 21st Century* (Lowe & Bell 1998b) included outline proposals for the development of Part L in two stages. The first, intended for possible introduction in 2000, aimed to achieve a reduction in excess of 60% in carbon emissions from space heating in a typical UK dwelling. The second was aimed at a subsequent review of Part L in or around 2005. This aimed to achieve a reduction in excess of 80% in carbon emissions from space heating. The relationship between the requirements of the 1995 Part L and what were subsequently referred to as the 2000 and 2005 standards is illustrated below in Figure 3.1.

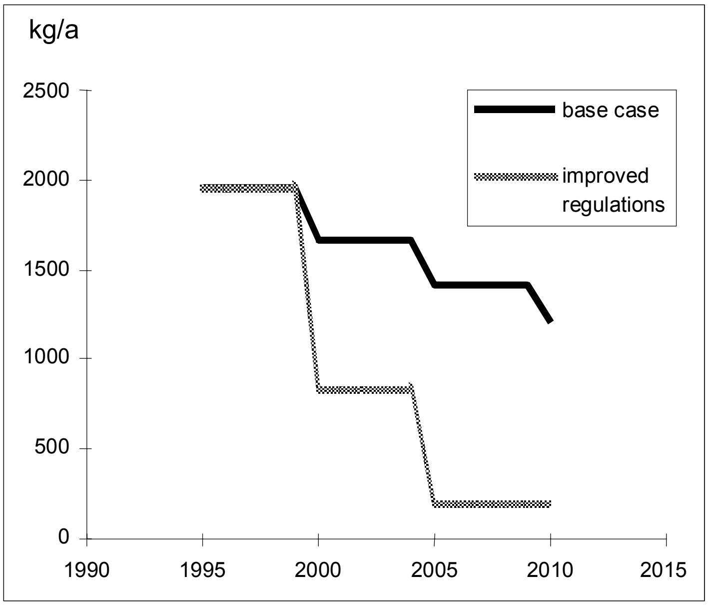


Figure 3.1: Relationship of $CO_2$ emissions for space heating from reviews of Part L.

As noted in the previous chapter, the methodology of the St Nicholas Court Project was conceived from the outset as revolving round a clearly defined energy performance standard. The initial step, undertaken in 1999, was based on an expansion and revision of the proposals for 2005 contained in *Towards Sustainable*

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[6] The request from the Joseph Rowntree Foundation for such a study can itself be traced back to the Labour Party's pre-election commitment to a 20% reduction in UK $CO_2$ emissions by 2010. Following the election, it became clear, within the DETR, that such a commitment would be difficult to achieve without a more rapid rate of technological progress in all fields, including that of new construction.

*Housing*. 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 CEN 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 contemporary developments – such as the BFRC window energy rating system – into the standard, and to outline a possible format for the ventilation provisions of Part F which would be consistent with the proposals for Part L.

The following year, 2000, saw the publication by the DETR of a Consultation Paper on its proposals for amending Part L. This document included a section on possible future amendments of the energy efficiency provisions – a step that had been strongly recommended in *Towards Sustainable Housing* and that had found a measure of support in the 1998 public consultation process on Part L. These proposals, summarised below, were with the exception of the requirements for window performance, close to those presented by the Centre for Built Environment. A decision was therefore taken in March 2000, in consultation with the DETR, to adopt the opaque elemental U values and air leakage limit proposed in the Consultation Document for the St Nicholas Court Project. The amended energy performance standard was published as *Dwelling Energy Performance Standards for 2008: Prototype standards for energy and ventilation performance* (Lowe & Bell 2001a)[7]. This document is also on the CeBE website.

| Table 3.1: Summary of *indicative* long term fabric performance standards for Part L. (DETR 2000:180) | |
|---|---|
| roof | 0.16 $W/m^2K$ |
| external walls | 0.25 $W/m^2K$ |
| ground floors | 0.22 $W/m^2K$ |
| windows, doors and rooflights | 1.8 $W/m^2K$ |
| air leakage at 50 Pa | 5 m/h |

## 3.2 Structural innovations in EPS08.

As noted above, the main objectives of EPS08 were:

- to define a level of energy performance capable of achieving significant reductions in $CO_2$ emissions, and which was consistent with the thinking on possible future amendments of Part L set out in the 2000 Consultation Document;
- to explore possibilities for simplification of the structure of Part L;
- to explore the implications of developments such as the BFRC Window Energy Rating System for Part L.

[7] This in turn was abbreviated to EPS08. This title reflected the fact that the review of Part L, that had been started in 1998, took longer to complete than had originally been expected and, as a consequence, the next major review of Part L was not expected until 2008 at the earliest. The publication of the white paper *Our Energy Future* has once again brought the date of the next review forward to 2005.

The two main structural innovations in EPS08 concern the relationships between the three numerical compliance modes – elemental, target U value and carbon index. In the first of these innovations, compliance under the elemental and target U value modes requires the dwelling's heating system(s) to achieve a minimum level of performance. This is expressed in the form of a maximum *annual mean carbon intensity for space and water heating*. The advantages of this form are that it:

- treats all heating systems in an identical manner – there is no need for the regulations to make specific reference refer to gas, oil, electric or any other class of heating system;
- encompasses future categories of heating system – for example, heat pumps – without further modification;
- extends the scope of the elemental compliance mode – in ADL02 this cannot be used with electric heating systems;
- provides a clearly defined incentive for the development of low carbon heating systems[8].

The simplest approach to implementing the carbon intensity concept would be through modifications and extensions to the SEDBUK system for domestic boilers.

The second structural change is to move all trade-offs other than those between elements within the target U value mode, into the carbon index compliance mode. Thus, trade-offs between heating system, ventilation system and envelope performance are evaluated using a single comprehensive SAP-based energy calculation tool. This simplifies the elemental and target U value modes and makes it easier to ensure consistency between the requirements of all three numerical compliance modes.

## 3.3 Elemental and envelope performance targets in EPS08

The first point to note about EPS08 is that is intended to comply with BS EN ISO 6946: 1997, BS EN ISO 10211-1: 1995, and BS EN ISO 14683: 1999[9]. These standards require the effects of all major linear thermal bridges to be taken into account in the estimation of building heat loss. One implication of doing this is that we have the choice either of making the concept of the elemental U value more complex so that it can accommodate all linear components of heat loss, or of abandoning it as a basis for specifying the performance standard.

[8] This incentive impacts equally on heating appliances and energy supply systems. Thus, one possible response to framing Part L in this way would be for developers and energy supply companies to collaborate to ensure the supply of low carbon energy carriers (renewable electricity, district heating, biogas…) for space and water heating in new developments.
[9] This is consistent with the statement in the 2000 Consultation Document that:
"We think that from Stage 2, [the linear thermal transmittance] concept (as described in BS EN ISO 14683) could beneficially be used to quantify the effects of thermal bridges." (DETR 2000:180).

Mathematically, the heat loss from a building can be expressed as[10]:

$$c_f = \Sigma A_i . U_i + \Sigma l_j . \Psi_j \qquad \text{(W/K)}$$

where:

$U_i$ represent heat losses averaged over plane elements of the building
$\Psi_j$ represent linear thermal bridges that have not been included in $U_i$
$c_f$ is the fabric heat loss coefficient, including all linear thermal bridges

The point here is that the choice of where we account for any particular linear thermal bridge or class of thermal bridges is arbitrary. The options include:

- accounting for all thermal bridges in the $\Sigma l_j . \Psi_j$ sum;
- accounting only for junctions between construction elements in the $\Sigma l_j . \Psi_j$ sum;
- rolling all linear thermal bridges into the U values and omitting the $\Sigma l_j . \Psi_j$ sum completely - in this formulation, all U values become “whole element U values”.

The advantage of expressing regulatory constraints on envelope performance in terms of whole element U values, is that the concept is likely to appear familiar to most members of the UK construction community, who will be therefore feel able to relate proposals for future U values to their past experience. This advantage can, however, also be a disadvantage. Because whole element U values represent and emerge from a more rigorous approach to the problem of defining building heat loss than the industry has hitherto been used to, an intuitive understanding of the practical implications of, say, a whole wall U value of 0.25, may well be misleading.

At a conceptual level, the notion of elemental U values is complicated by the fact that major linear thermal transmission components relate to the junctions between different types of element – from junctions between wall and roof, wall and ground floor, wall and window, external wall and party wall. While it is straightforward to partition linear thermal transmission values between adjacent elements using standard 2-D tools such as THERM, the $\Psi$ values for such junctions are actually shared properties of the adjacent elements. Changing the construction on one side of the junction changes both the $\Psi$ value for the whole junction, and the contributions to the $\Psi$ value from each side of the junction. The accounting process wants to deal with separate contributions to fabric heat loss from separate construction elements, but the underlying physics wants to treat the whole envelope as a single continuous entity.

One possible response to the perceived artificiality of whole element U values is to express regulatory constraints on envelope performance in terms of the fabric heat loss coefficient, $c_f$ - or, and this amounts to the same thing, the mean U value. The relationship between these two concepts is:

$$U_{mean} = c_f / \Sigma A$$

[10] For completeness, we should also include point thermal transmittances, $\Sigma \alpha_k$ in the above. In practice, the additional heat losses represented by point thermal transmittances are small and, except for wall ties, are generally not important enough to be worth including.

In this formulation, $U_{mean}$ is the U value, including all linear thermal bridges, averaged over the whole surface area of the building, $\Sigma A$ (which, by convention, we measure over the inside surface of the thermal envelope). Part L of the Building Regulations currently requires $U_{mean}$ to be less than the target U value. This in turn is calculated straightforwardly from the elemental U values, and assumptions about dwelling geometry and glazing ratio[11]. The problem with the target U value approach from the viewpoint of a discussion of possible future standards, is that the target U value is not a single value, but a variable that depends on dwelling form. Moreover, the calculation of target U value involves notional elemental U values.

In drafting EPS08, we took the view that, for all their problems, whole element U values are a helpful way of sub-dividing and thinking about building heat loss. The same view appears to have been taken by the DETR. The maximum whole element U values in EPS08 are shown in Table 3.2:

| Table 3.2: EPS08 maximum elemental U values and leakage rate. | |
|---|---|
| exposed walls | 0.25 |
| roofs | 0.16 |
| floors | 0.22 |
| windows, outer doors & rooflights<br>(no more than 25% of gross floor area) | 1.3<br>(or window energy rating ≥ 70) |
| air permeability at 50 Pa | 5 m/h |

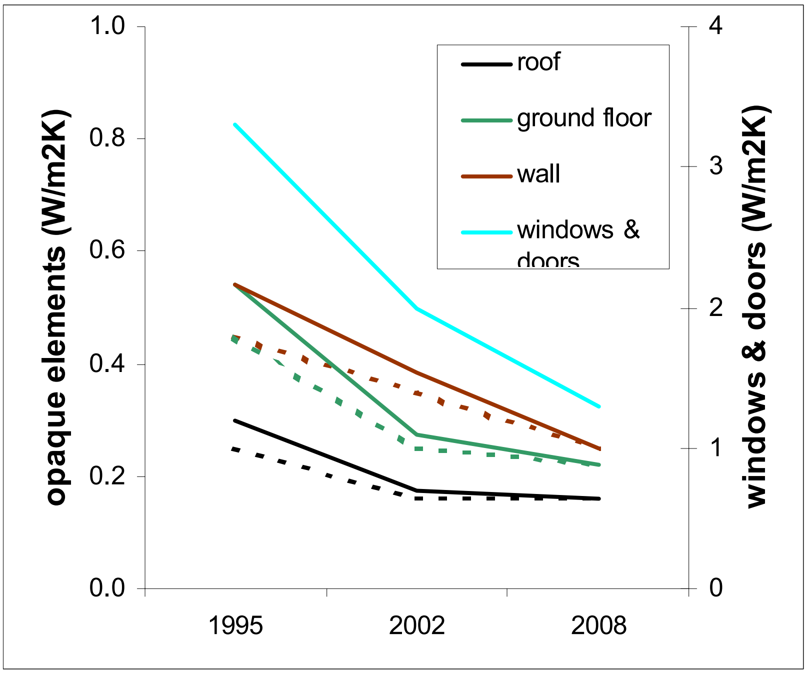
The only departure here from the proposals contained in the 2000 Consultation Document is in the treatment of windows and doors. The authors took the view that the DETR's proposed U value of 1.8 did not take sufficient account of developments in window technology over the last twenty years, or of the profound impact of high performance windows on comfort, energy use and the design of heating and ventilating systems. The value of 1.3 $W/m^2K$ was selected as being achievable, with care, with well-designed double-glazed windows, while being relatively easy to achieve with triple-glazed windows. The former would require high performance low-emissivity coatings, argon or krypton-filled gas spaces and warm-edge technology in well-designed window frames[12]. The inclusion of window energy rating as an alternative to specification of window U values provides designers with the option of trading off heat loss against solar gain, both at the level of the window and, through the carbon rating method, at the level of the whole dwelling. The latter option is dealt with at greater length in section 3.6 below.

Comparisons between the limiting elemental U values in ADL95, ADL02 and EPS08 have to take account of the different treatments of thermal bridges in the different standards. As a result of this, the U value for any given major structural element – a wall, roof or ground floor – will be in the order of 10-15% higher than that calculated according to ADL02 and 20-25% higher than that calculated according to ADL95.

[11] A more elegant and general formulation of this is: $U_{mean} = \dfrac{\iint \Phi(\Delta T)\,.\,ds}{\Delta T\,.\iint ds}$
where $\Phi(\Delta T)$ is the heat flux at each point on the building thermal envelope, for a temperature difference across the envelope of $\Delta T$.

[12] The performance of timber windows incorporating these features has been explored in an earlier working paper (Roberts & Lowe 2002). A major european window manufacturer has now indicated that it can supply double glazed windows with a whole window U value of 1.3 $W/m^2K$.

The approximate relationships between elemental U values specified by ADL95, ADL02 and EPS08 are illustrated in Figures 3.2 and 3.3 below. The dotted lines show the relationships between the numerical values of the limiting U values, with no account taken for different treatments of thermal bridging. The logarithmic axis in Figure 3.3 makes it easier to compare the proportional changes involved.




Figures 3.2 Comparisons of limiting elemental U values in ADL95, ADL02 and EPS08, including the effects of linear thermal bridging (the dotted lines exclude these effects).

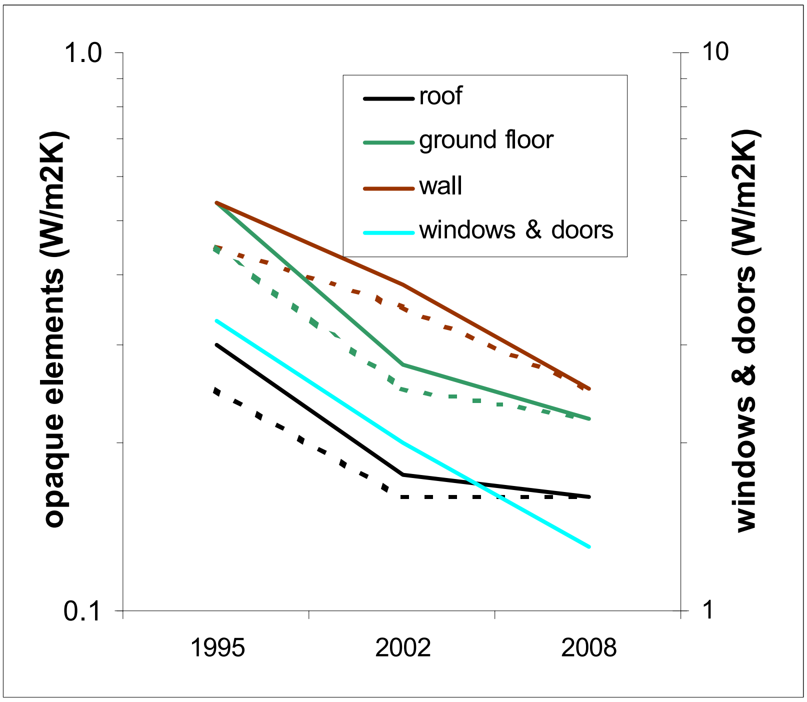



Figure 3.3 Comparisons of limiting elemental U values in ADL95, ADL02 and EPS08, including the effects of linear thermal bridging(the dotted lines exclude these

effects). The logarithmic scale means that equal proportional changes correspond to equal vertical displacements.

The final point to note in this section is the constraint on envelope air leakage. The original proposal in *Towards Sustainable Housing* was for a maximum value of 3 m/h at 50 Pa. Following discussions with the DETR, this was changed to 5 m/h at 50 Pa to bring it in to line with the Consultation Document. EPS08 defines leakage rate in terms of the total envelope area of the dwelling, including "those elements shared with adjacent dwellings (party walls, and floors between separate dwellings)", an approach subsequently adopted by CEN (EN 13829:2000).

For most dwellings, this represents a relaxation of the standard originally proposed. The assumption in EPS08 is that compliance would be confirmed by testing a proportion – perhaps 10% - of dwellings constructed in each separate development. A more detailed discussion of possible approaches to mandatory pressurisation testing is contained in Lowe et al. (2000). One of the implications of a mandatory standard discussed in that paper is that the mean air leakage rate of all new dwellings will be significantly below the regulatory maximum – by how much, depends on the failure rate that the construction industry decides to accept. This in turn depends both on the rate at which knowledge about the means for achieving air tightness diffuses through the industry, and on the penalties for test failure. The approach taken by Lowe et al. suggests that to achieve a failure rate of 10% against a 5 m/h limit, mean air leakage rate would need to be just over 3 m/h. An leakage target at this level is low enough to begin to reveal the energy and carbon benefits of MVHR (Lowe 2000).

## 3.4 Modifications to SAP in EPS08

The letter and spirit of the changes introduced in EPS08 would require corresponding changes in SAP. The demands of the project required us to produce a modified version of SAP in which we prototyped these changes. The main changes relate to treatment of air leakage and ventilation, the handling of the performance of ventilation systems, and solar gain and window energy rating. In the rest of this section, we present a brief summary of these changes.

## 3.5 Treatment of air leakage and ventilation

SAP 9.70 currently contains a model of ventilation based on the 1/20 rule of thumb:

$$n_{background} = (1 - 0.075 \,.\, \text{shelter factor}) \,.\, q_{50}/20$$

in which: $q_{50}$ is the air permeability at 50 Pa (m/h)
$n_{background}$ is the heating season background mean air change rate (ac/h)

For naturally ventilated dwellings, this background air change rate is modified by window opening behaviour:

$$n_{effective} = 0.5 \,.\, (1 + n_{background}^2)$$

while for dwellings with balanced MVHR systems:

$$n_{effective} = n_{background} + 0.17$$

The figure of 0.17 in the above equation is derived from the contribution to ventilation heat loss of an MVHR system supplying 0.5 ac/h of ventilation with a heat recovery efficiency, $\eta_T$, of 66%:

$$0.17 = 0.5 \,.\, (1 - \eta_T)$$

We propose in the first place to retain most of the above[13]. But there are three specific limitations in the approach that we feel need to be addressed. The first is that SAP 9.70 makes no explicit mention of continuous whole house mechanical extract ventilation (MEV). As it happens, the choice of natural ventilation model in SAP 9.70 appears to represent a reasonable fit to the performance of MEV systems. All that would be needed to would be to make it clear that equations 23 and 24 in SAP 9.70 apply to MEV systems (and probably to PSV systems) as well, and to account for the electricity used by the continuously operating fans in MEV systems.

The second is that while a heat recovery efficiency of 66% is likely to be representative of a significant proportion of MVHR systems in the UK, it does not represent the effective upper limit of performance. Restricting the heat recovery efficiency of MVHR to a single prescribed figure provides no incentive to those manufacturers who achieve, or, given the incentive, could achieve higher performance. Indeed, without a system for certifying the performance of MVHR systems, there is no incentive even to meet this prescribed level of performance. The second problem is with respect to electricity consumption. SAP 9.70 assumes that all whole-house mechanical ventilation systems consume an additional 0.004 GJ/a of electricity per $m^3$ of dwelling volume. The problem with this is that it does not differentiate between MEV and MVHR systems, and takes not account of wide range of performance of both types of system.

We therefore propose that the heat recovery performance of MVHR systems be made explicit. Ultimately this could be done through a system similar to SEDBUK. We also propose that the electricity consumption of all continuously operating ventilation systems be based explicitly on specific fan power (ratio of fan power to air flow rate, with units of W/l/s or, more simply, J/l). Tabulated generic values for specific fan power could, in the first place, be based on factors such as motor type (shaded pole, electronically commutated DC) and duct type (flexible, rigid rectangular section, rigid circular section). But a better long-term option would be an independently certified rating system for mechanical ventilation systems, backed by empirical measurements from sample installations.

[13] The SAP 9.70 approach is not consistent with the EPS08 recommendations for ventilation air flow rates, but these are at a relatively early stage of development.

## 3.6 Window energy rating and solar gains.

The main problem with this section of SAP 9.70 is that it does not make window solar performance explicit. This is a significant drawback, which will be come even more significant if window U values are further reduced in the next revision of Part L[14]. It turns out that overcoming this problem simultaneously simplifies the structure of SAP, and makes it possible to integrate the BFRC window energy rating system into the tool in an elegant and physically straightforward way. The current approach in SAP 9.70 is based on tabulated values of solar flux at the inside surfaces of a variety of glazing systems. In the proposed modification, the whole of this table would be replaced by a table of unobstructed external solar fluxes on vertical and horizontal surfaces. The current version of this table contains 7 times as much data and, in any future review of Part L, would need to be further extended to account for technical developments in glazing.

Table 3.3 Proposed modifications to tabulated solar radiation data in SAP 9.70.

*Taken from: SAP 9.70 Table 6 (revised) –UK heating season mean unobstructed solar fluxes on vertical and horizontal surfaces*

| Window orientation | Flux (W/m2) |
|---|---|
| N | 27.8 |
| NE/NW | 33.0 |
| E/W | 47.2 |
| SE/SW | 63.2 |
| S | 70.3 |
| Horizontal | 73.2 |

Radiation data are approximate values for the East Pennines region.

Section 6 of the SAP sheet would need to be modified along the following lines:

[14] The reason for this is that one way to achieve low U values with double glazing is to use very low emissivity coatings. Unfortunately, many of these also have low solar transmission. More careful consideration of the trade-off between heat loss and solar gain, the task for which the BFRC window energy rating system was designed, will therefore be needed in the future.

Table 3.4 Proposed modifications to solar gains section of SAP 9.70.

6. Solar gains

| ORIENTATION | Access factor (table 6a) | | Area ($m^2$) | | window solar factor | | solar flux (table 6) ($W/m^2$) | | Gains (W) | |
|---|---|---|---|---|---|---|---|---|---|---|
| North | | x | | x | | x | | = | | (56) |
| NE/NW | | x | | x | | x | | = | | (57) |
| E/W | | x | | x | | x | | = | | (58) |
| SE/SW | | x | | x | | x | | = | | (59) |
| South | | x | | x | | x | | = | | (60) |
| Roof-lights | | x | | x | | x | | = | | (61) |
| Total solar gain | [56]+…+[61] | | | | | | | = | | (62) |

*Note: window solar factors to be taken from BFRC Certified Products Directory or table of generic values*

The major change here is the insertion of an additional column representing window solar factor into the calculation for solar gains on each façade (lumping together of façades with equal levels of solar gain (East and West, NE and NW etc.) is an additional minor simplification). In CEN terminology, solar factor, g, is the ratio of the solar flux on the outside of the glazing system to heat flux at the inside surface (BS EN 410: 1998). As defined by CEN, solar factor is a property of the glazing system, not of the whole window. We have adopted the term “window solar factor” to refer to the analogous property of the whole window[15].

The final modification to SAP would be the extension of Table 6b to include generic window solar factor and window energy rating data. This would be used, by default, for windows that were not BFRC rated. Reference to an externally validated database of certified window performance data would, in principle, allow further simplifications to be made to Table 6b and would remove the need for regular updates to SAP itself to take account of on-going developments in the UK window market.

## 3.7 Ventilation requirements in EPS08

It must be stated at the outset that the proposals for ventilation in EPS08 are not as detailed or as thoroughly thought through as those for energy performance. It was nevertheless essential for the St Nicholas Court Project that we formulate a set of proposals that would deal with the implications of the airtightness standard in EPS08, and would ensure a combination of energy efficiency, safety and satisfactory indoor air quality.

[15] In North America the term “solar heat gain coefficient” is used for the same concept.

The primary objectives of the proposals made in EPS08 were:

- to indicate how a performance-based alternative to the current Part F might be developed

- to ensure "that buildings are constructed so as to ensure satisfactory indoor air quality in normal use, while at the same time limiting energy use for space heating. This standard, together with the associated prototype standard relating to energy performance […] will ensure that buildings in normal use will be adequately ventilated, free from condensation and mould, and in the case of dwellings, that excessive summertime temperatures can be avoided."

As with thermal performance, proposals for ventilation can be divided into structural and substantive proposals.

The most important structural proposal in EPS08 is that Part F should be based on the objective of providing a defined quantity of fresh air per occupant at design occupancy in a manner that limits over-ventilation under adverse weather conditions. This was operationalised through a requirement for means to provide a flow rate of 5 l/s/occupant at design occupancy, based on the quantity of fresh air needed to ensure that internal $CO_2$ concentration did not substantially exceed 1000 ppmv as a result of emissions from sedentary occupants[16]. This criterion was supplemented by room-by-room requirements for air supply. These requirements were based on the current Canadian standard for mechanical ventilation systems CSA-F326-M91 (CSA, 1998), with the exception of the extract rate for kitchens which was taken from the current Danish Building Regulations (Anon 1995).

Other innovations set out in this section of EPS08 were:

- requirements for supplementary means of ventilation to allow dwellings to be ventilated despite failure of the primary means of ventilation;

- explicit linking of the provisions for rapid ventilation to the summer condition

- a general requirement for ventilation systems to be designed and constructed to allow proper and safe cleaning and maintenance of ducts, fans and filters;

- a requirement to provide measuring points to allow easy measurement of air flow and power consumption during commissioning and maintenance.

[16] A typical person emits 0.2 l/minute of $CO_2$ while at rest. A fresh air supply of 5 l/s will provide a dilution ratio of 1500, and therefore an excess of 1 part in 1500, or 667 ppmv above the background concentration. The latter is currently around 370 ppm, which means that 5 l/s per person of fresh air will limit internal $CO_2$ concentrations to about 1060 ppmv.

## 3.8 Critique of ventilation provisions

A number of criticisms can be levelled at the ventilation provisions laid out in EPS08. The first is that, based on the relationship between occupancy and gross floor area assumed in SAP, the 5 l/s/p overall requirement leads to a design air change rate of approximately 0.22-0.25 ac/h. In practice this requirement is completely subsumed by the room-by-room requirement. Conversely, the room-by-room requirements lead to ventilation requirements that appear unnecessarily high. As noted above, these requirements were based on the current Canadian standard for mechanical ventilation.

The Canadian approach is a comprehensive one, dealing with a range of systems and establishing control, installation, commissioning and verification requirements. The principles of CSA-F326-M91, as laid out in an extensive commentary in its Appendix B, are:

- to ensure a continuous ventilation capacity of at least 7.5 l/s per occupant to account for biogenic contaminants, and of at least 0.3 ac/h to account for non-biogenic contaminants[17];
- to attempt to provide 5 l/s per person of continuous ventilation to bedrooms
- to ensure adequate extraction, either continuous or an intermittent, from kitchens, bathrooms[18] and w/cs;
- to ensure that the continuous operation of the ventilation system does not increase the pressure in the dwelling by more than 10 Pa, to avoid interstitial condensation;
- to ensure that the ventilation system and other appliances cannot de-pressurise the dwelling by more than 10 Pa to avoid problems with radon and back-draughting of combustion appliances (the de-pressurisation limit is 5 Pa where combustion appliances are uncertified).

The main problem with attempting to apply CSA-F326-M91 to the UK is that typical UK dwellings are significantly smaller than Canadian dwellings. Direct application of CSA-F326-M91 therefore tends to lead to ventilation capacities that are higher than the 0.5-0.7 ac/h recommended by BRE Digest 398 for UK dwellings and, arguably, higher than necessary. Figure 3.4 and Table 3.5 show the ventilation capacities and overall air change rate resulting from application of the Canadian Standard to three dwelling types:

<u>type 1:</u> (80-100 $m^2$): 3 bedrooms, living room, dining room, kitchen, bathroom, w/c

<u>type 2:</u> (60-80 $m^2$) 2 bedrooms, living room, kitchen/dining room, bathroom, w/c

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[17] The commentary notes that, “ASHRAE Standards 62-1981 and 62-1989, Ventilation for Acceptable Air Quality, strongly influenced the ventilation air requirements of this Standard.” The Canadian standard makes no allowance for air leakage in determining ventilation capacities. Dwellings are assumed to be airtight.

[18] In North American English, the term “bathroom” includes “w/c”.

<u>type 3:</u> (40-60 $m^2$) 1 bedroom, living room, kitchen, bathroom

| Table 3.5. Ventilation capacities for UK house types according to CSA-F326-M91 | |
|---|---|
| type 1 (3 bedroom) | 45 l/s |
| type 2 (2 bedroom) | 40 l/s |
| type 3 (1 bedroom) | 25 l/s |

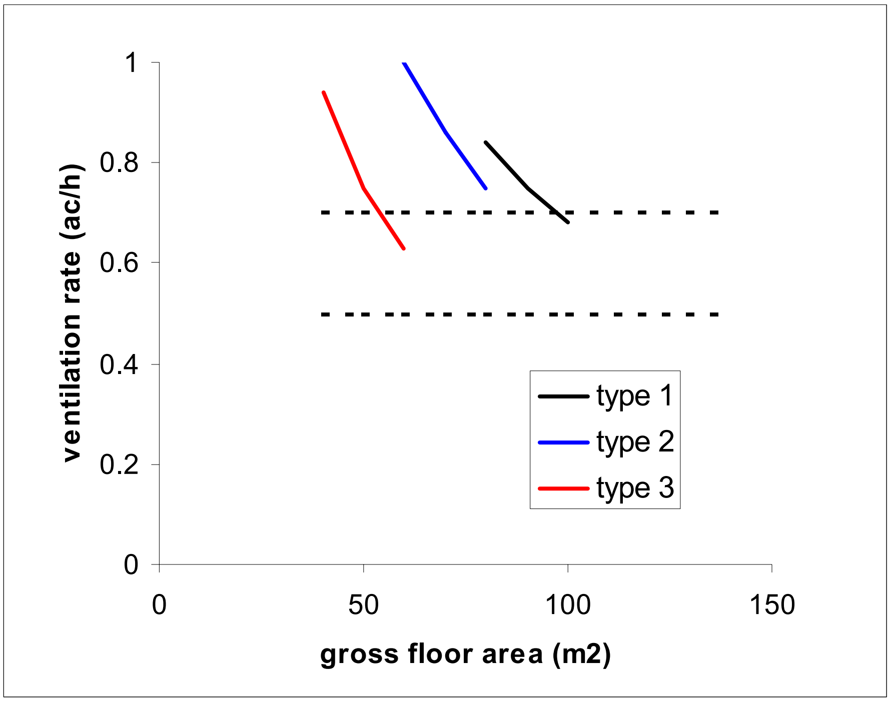


Figure 3.4. Ventilation capacities for UK house types according to CSA-F326-M91. Dashed lines show range of air change rates currently recommended by Digest 398.

There are grounds for suggesting that the 5 l/s/occupant requirement for air supply to individual rooms (10 l/s/person in main bedrooms) leads to an overall dwelling ventilation rate that is unnecessarily high. These include:

<u>Impact of movement of air and people between rooms</u>. Peak occupancy of any particular room will tend to be higher than the peak occupancy of the dwelling as a whole. Movement of air and/or people between rooms may make it possible to base ventilation requirements on the air supply ventilation rate to the whole dwelling and therefore to lower ventilation requirements for individual rooms. Movement of people between rooms is more likely to occur during the daytime than at night and primarily affects living and dining rooms. Significant recirculation of air between rooms depends on doors between rooms being kept open, a condition that, again, may be more likely during the day than at night.

<u>Lower metabolic rates for sleepers.</u> $CO_2$ emissions are lower for sleeping people than for people at rest. It may therefore be possible to reduce ventilation rates in bedrooms. The possible impact of room-by-room ventilation requirements based on multiples of 4 l/s/occupant of fresh air rather than the 5 l/s/person assumed in CSA F326 would lead to whole house ventilation rates more in line with existing UK guidance – see

Figure 3.5 – while satisfying the requirement of ASHRAE 62 under most conditions. Figure 3.6 shows the relationship between asymptotic $CO_2$ concentration and air supply rate for a sleeping man, based Nishi's equation relating $CO_2$ production rate and metabolic rate (ASHRAE 1993). Current Swedish Building Regulations, to which our attention was drawn following the circulation of the first draft of this report, adopt a very similar conceptual approach to that of the CSA and require the supply of 4 l/s/person to "rooms or parts of rooms for sleep and rest" (Boverket 2001).

Allowance for natural infiltration. Uncontrolled natural infiltration is likely to be significant in UK dwellings for some time to come, despite proposals to require more airtight construction backed by pressurisation testing. The question is whether uncontrolled infiltration can be used to justify a reduction in air supplied by the dwelling's primary ventilation system. The position taken by the Canadian standard is that it cannot, but this may reflect the relative air tightness of Canadian dwellings. The technical arguments appear to relate to the efficacy with which uncontrolled air flow supports indoor air quality. The problems with uncontrolled infiltration relate to its variability in time, to its impact on ventilation efficiency (related in turn to flow path of air through the dwelling) and to the variability of air leakage rates in the dwelling stock. It would appear reasonable to assume that uncontrolled natural infiltration is less effective than controlled ventilation but better than nothing. The fact that air leakage rates are, and are likely to remain, unknown in the majority of new dwellings[19] would necessitate a fairly conservative allowance for uncontrolled infiltration. Moreover the relationship between air leakage and heating season mean infiltration rate – the 1/20 rule of thumb - is statistical and is affected by built form. A conservative approach might perhaps be to apply a 1/40 conversion to the 90$^{th}$ percentile air leakage rate, giving an allowance for uncontrolled infiltration of less than 0.1 ac/h.

Arbitrariness of $CO_2$ limits. Concentrations of $CO_2$ in indoor air in the range 1000 – 1100 ppm are not in themselves harmful. Standards, e.g. ASHRAE's Standard 62-1999, that establish $CO_2$ limits for indoor air, use $CO_2$ as a proxy for a soup of other biogenic indoor contaminants. $CO_2$ is appropriate for this purpose as its concentration is reasonably high in absolute terms and is relatively easy to measure. Effects of other indoor air contaminants can be controlled in a variety of ways other than ventilation. For example, the effects of water vapour at any given absolute humidity are reduced by energy efficiency measures whose effect is to raise air and surface temperatures. The question of the level at which $CO_2$ limits should be set is therefore a complex one and somewhat higher limits may be ultimately be acceptable. Upward revision of $CO_2$ limits is however constrained by the limit for narcosis, which is around 2000 ppm for long term exposure.

Despite these criticisms, the basic notion of a performance-based ventilation standard, which places clear constraints on ventilation flow rates based on explicit models of occupancy and indoor air quality, appears logical[20]. The CSA approach accounts for the likelihood that for any given house type, smaller dwellings are likely to be more densely occupied and therefore to require higher air change rates than larger

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[19] Not even the most enthusiastic of proponents of mandatory pressurisation testing have proposed testing every new dwelling.
[20] An exploratory meeting with members of the Residential Ventilation Association was held at Leeds Metropolitan University on 7$^{th}$ November 2002.

dwellings. It also ensures that bedrooms, which are in most cases the most intensively occupied rooms in the dwelling, are adequately ventilated.

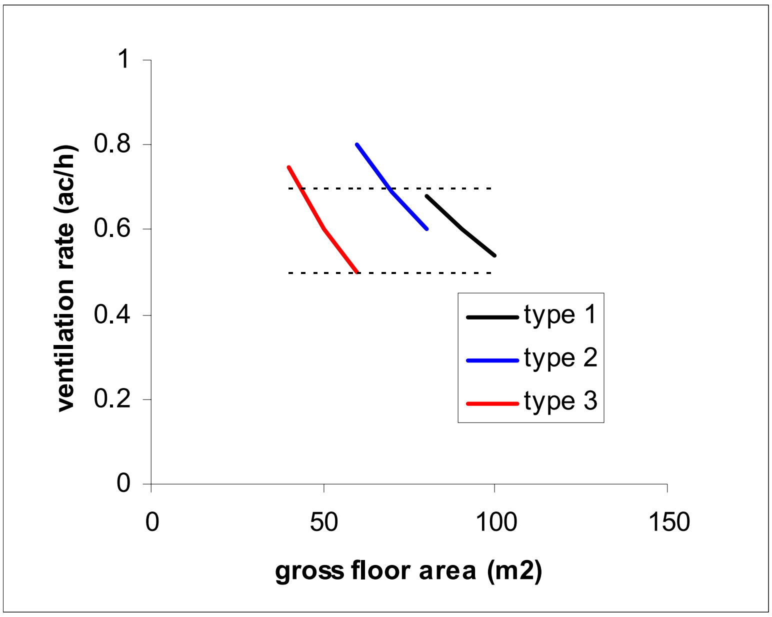


Figure 3.5 Ventilation capacities for UK house types according to CSA-F326-M91, but with basic ventilation requirement reduced to 4 l/s/p. Dashed lines show the range of air change rates currently recommended by Digest 398.

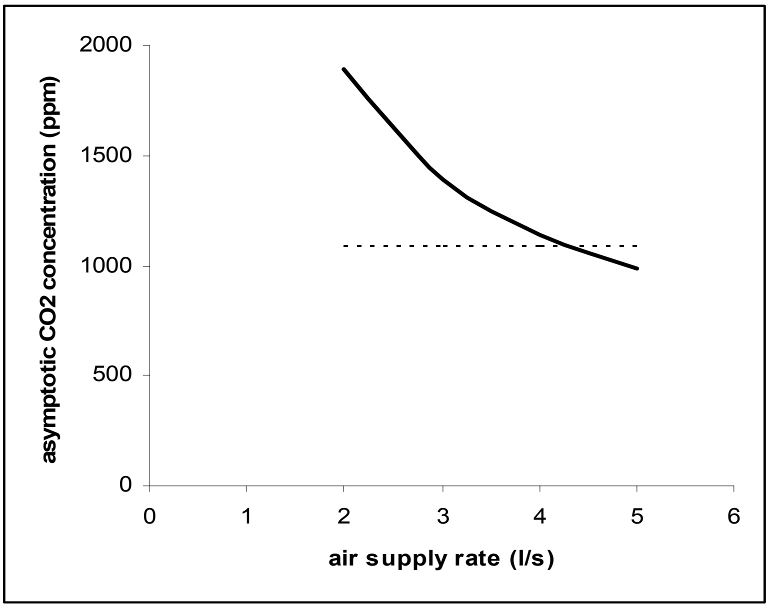


Figure 3.6 Asymptotic $CO_2$ concentration in bedroom occupied by single sleeping man. Dotted line shows ASHRAE Standard 62 limit (700 ppm above background).

Although the proposals contained in EPS08 were originally framed with mechanical ventilation in mind, there is no reason in principle why they cannot be adapted to other approaches. In the case of passive stack ventilation, it may be necessary to relax the requirements so that systems that were not capable satisfying them for 100% of the time would still be deemed adequate. Discussion would be needed to determine what levels of under-ventilation would be acceptable. A thorough approach might focus both on the proportion of time spent below any given ventilation rate (the ventilation exceedance curve) and on the length of any given period of under-ventilation. This conceptual framework could also embrace the actual in-use performance of mechanical systems.

### 3.9 Comparison of projected energy use and $CO_2$ emissions – ADL95 / ADL02 / EPS08

The purpose of this section is to compare energy use and carbon emissions from dwellings according to three energy standards: EPS08, the current standard, ADL02 and the previous standard, ADL95. A discussion of the impact of electric space and water heating is also presented. All of this work is based on a parametric energy and Carbon Index calculator, which is in turn based on SAP 9.70.

The relationships between the three energy standards are shown in figures 3.7 and 3.8. A number of conclusions are immediately apparent from these figures:

- Emissions from the base case dwelling (an 80 $m^2$ semi-detached house) with gas heating, are roughly 1.2 t($CO_2$)/a. This represents more than a 70% reduction compared with the current mean emission rate for the UK housing stock.

- the overall impact of EPS08 is almost exactly to halve the carbon emissions of the base case dwelling under ADL95: the step from ADL95 to ADL02 accounts for a 30% reduction, and the step from ADL02 to EPS08 for a further 30%;

- the preceding point suggests that, in proportional terms, the magnitude of the task that would face industry following the adoption of a standard similar to EPS08 would be similar to that currently faced as a result of the introduction of ADL02.

- ADL02 and EPS08 both affect space heating much more strongly than water heating - energy use in new housing in the UK is currently undergoing a transition, from domination by space heating to domination by water heating;

- ADL02 and EPS08 each produces an increase of about 1.5 Carbon Index points.

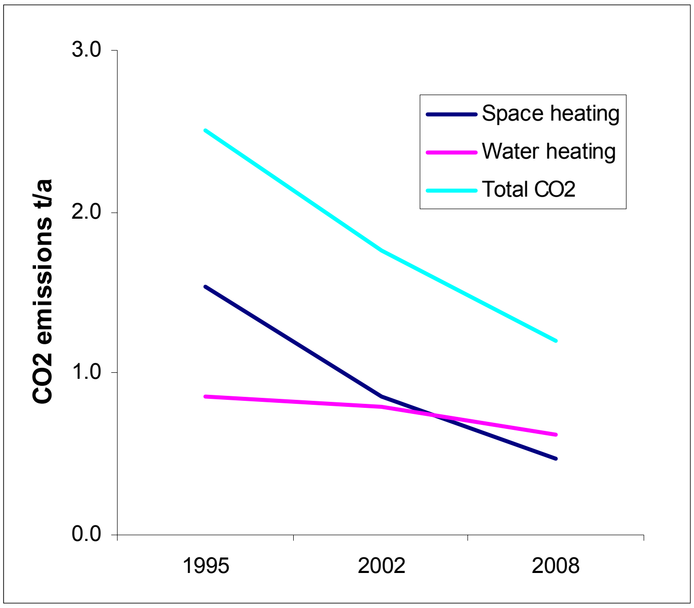


Figure 3.7 Comparisons of carbon emissions under ADL95, ADL02 and EPS08, for an 80 m$^2$ gas heated semi-detached dwelling.

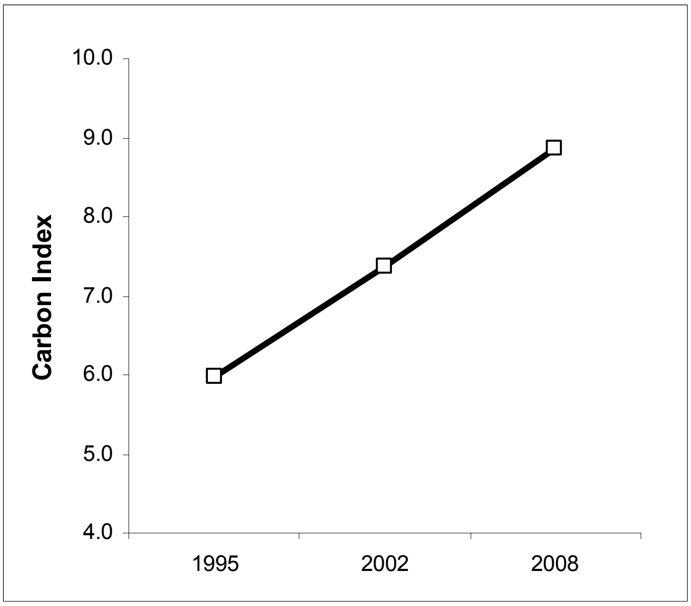


Figure 3.8 Comparisons of carbon index under ADL95, ADL02 and EPS08, for an 80 m$^2$ gas heated semi-detached dwelling.

If we were to use the performance of the base case dwelling, with gas heating and satisfying the elemental requirements of EPS08, as a basis for establishing an overall Carbon Index limit for all dwelling types, Figure 3.8 suggests that the resulting limit would be around 8.8. This is lower than the value of 9.1 suggested previously (Lowe & Bell 1998a), due to a change in the formula for converting carbon emissions to carbon index.

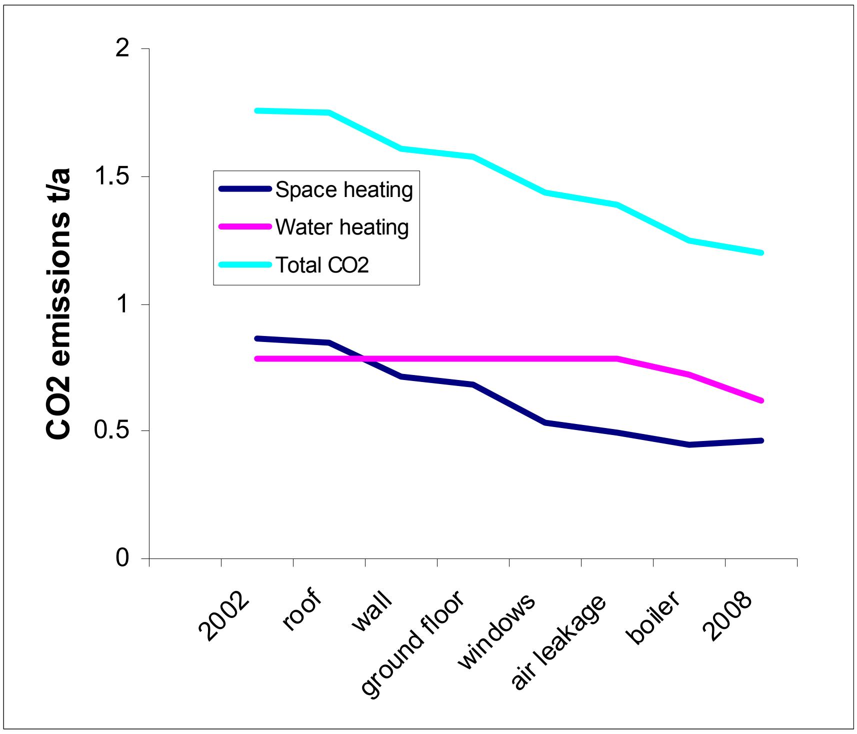


Figure 3.9 Breakdown of carbon emissions reductions by individual measures.

Figure 3.9 shows how the overall reductions in carbon emissions illustrated above, relate to improvements in elemental U values, air leakage and heating system efficiency. The three most important steps in the transition from ADL02 to EPS08 are improvements in wall and window U values and boiler efficiency.

The final area explored in this section is the effect on carbon emissions of using electricity for space and water heating. The carbon intensities for gas and electricity used in SAP 9.70 are:

mains gas 54 kg($CO_2$)/GJ
mains electricity 115 kg($CO_2$)/GJ

The difference, slightly more than a factor of two, means that taking into account boiler efficiency, electrically heated dwellings emit slightly less than twice as much $CO_2$ as gas heated dwellings. Emissions from the base case dwelling, an 80 $m^2$ semi-detached two storey house, heated electrically, are roughly 2.1 t ($CO_2$)/a compared with 1.2 t ($CO_2$)/a when heated with gas.

The original proposal put forward in *Towards Sustainable Housing* was that from 2005 onwards, carbon emission targets for new housing would be set irrespective of the energy carrier or heating system. This was justified on the grounds that the 7 years that were available between the time of writing (mid 1998) and the target date of 2005 was thought to be long enough to allow the development and commercialisation of a wide range of technical options for reducing carbon emissions in electrically heated dwellings, provided that the need for such technologies was signalled clearly in the 2000 review process.

Technical options for reducing carbon emissions from electrically heated dwellings can be grouped under two broad headings: alternatives to resistance heating (such as heat pumps and solar hot water systems), and improved fabric performance. The St Nicholas Court project provided an opportunity to re-examine the potential of such measures. Figures 3.10 and 3.11 show the cumulative effects on carbon emissions and carbon index from the base case dwelling, of applying the following measures:

- replacement of MEV with efficient MVHR (specific fan power 1 J/l, heat recovery efficiency 85%);
- reduction of envelope air leakage from 5 to 3 m/h;
- reduction of elemental U values by a factor of 0.85 (ADL02 requires a reduction in U values of approximately 0.86 for electrically heated dwellings);
- addition of solar water heating with a 2 $m^2$ collector area;
- increasing the area of solar collector from 2 to 5 $m^2$.

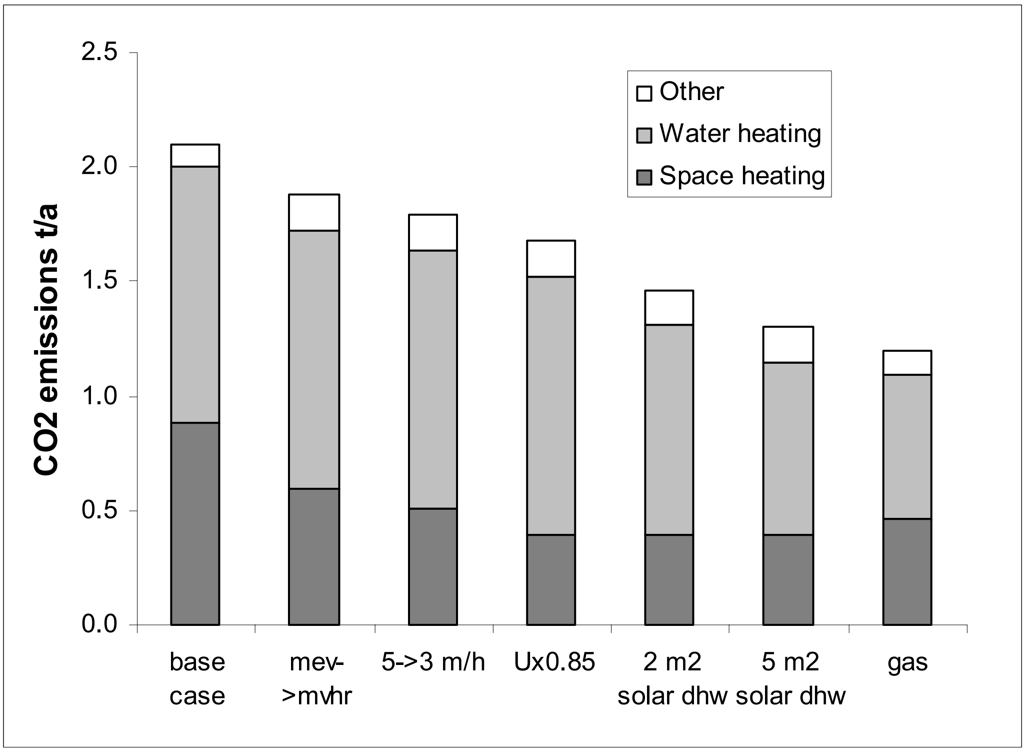


Figure 3.10 Technical measures for reducing carbon emissions from an electrically heated dwelling.

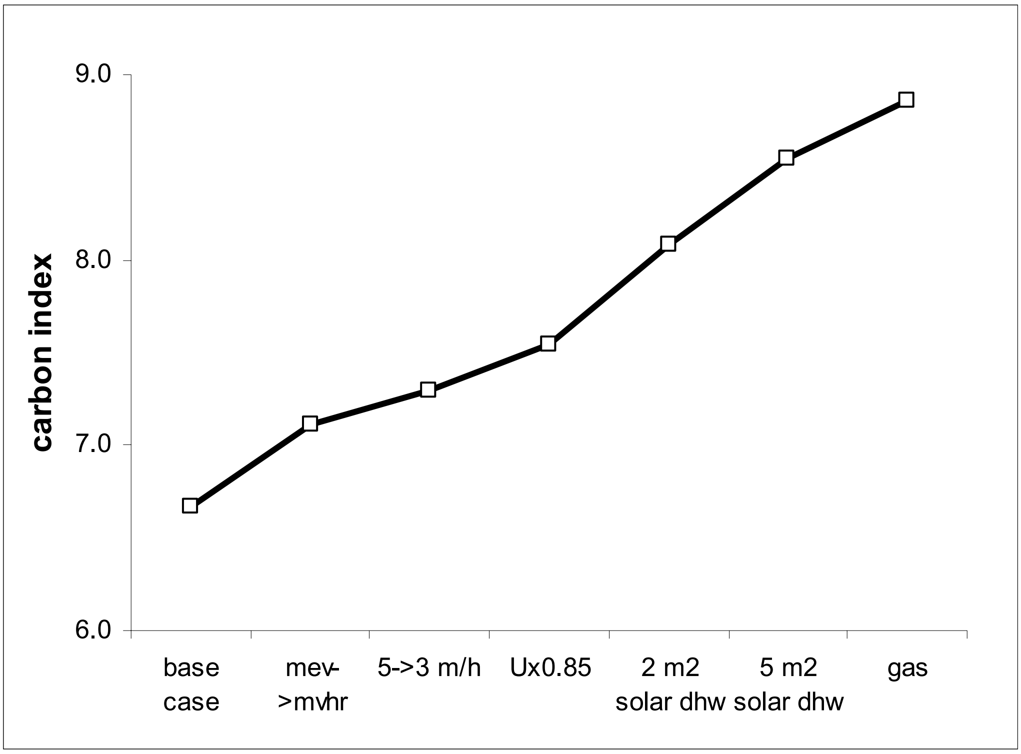


Figure 3.11 Technical measures for reducing carbon emissions from an electrically heated dwelling.

These two figures suggest that it is technically feasible to reduce the carbon emissions from electric resistance heated dwellings to within 10% of those from gas heated dwellings. The implications of figures 3.10 and 3.11 are that:

- the gap between the carbon emissions of electrically heated and gas heated dwellings can be substantially closed through a series of technical measures;
- in the case of semi-detached dwellings, the measures considered result in carbon emissions attributable for space heating being lower in the case of electric heating than gas heating.

This analysis is however, based on a traditional semi-detached dwelling. The demand for electric heating is likely to be greatest in more compact dwelling types, particularly flats, in which it may be impractical to provide a gas supply. The impact of dwelling form on carbon emissions from electrically heated dwellings is shown in figures 3.12 and 3.13. Carbon emissions have been calculated based on the EPS08 elemental requirements, but with the addition of thicker insulation on the hot water cylinder (70 mm instead of 35 mm), heat recovery ventilation instead of mechanical extract and reduced air leakage (from 5 to 3 m/h at 50 Pa). These measures are likely to be micro-economically justifiable in electrically heated dwellings, and probably represent a minimum set of additional measures that could be expected to be required, in such dwellings, by the next major revision of Part L.

Figures 3.12 and 3.13 show that carbon emissions for the most compact dwelling form – a mid-floor, mid-block flat – are just 20% higher than those for a conventional gas heated semi. For such dwellings, space heating accounts for just 12% of total carbon emissions, not including lights, cooking and electrical appliances – the environmental impact of water heating is nearly 7 times larger. The domination of total emissions by water heating means that the addition of a solar water heating system of just over 2 $m^2$ is sufficient to achieve a carbon index limit of 8.8. The peak space heating loads of such dwellings are correspondingly small – in the example under discussion, less than 1 kW (approximately one dinner party). Such loads can plausibly be supplied by MVHR systems with supplementary heating delivering air at temperatures of less than 40°C. This approach has been pioneered in a number of recent single person housing schemes – for example in the CASPAR scheme in Leeds (Powell et al 2000). It is also a strategic component in the German Passivhaus standard, which, by requiring significantly higher envelope performance than EPS08, is able to extend it to all dwelling types (Feist 1998). The most important advantage of this approach is the complete elimination of wet central heating from the dwelling.

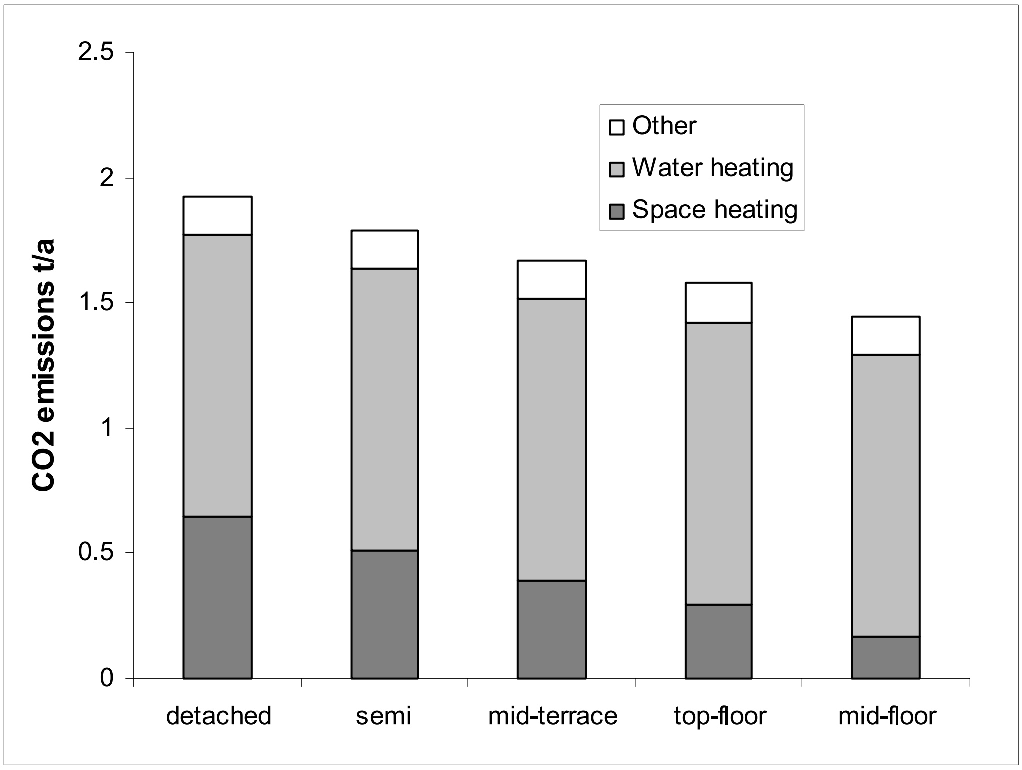


Figure 3.12 Impact of built form on carbon emissions from electrically heated dwellings.

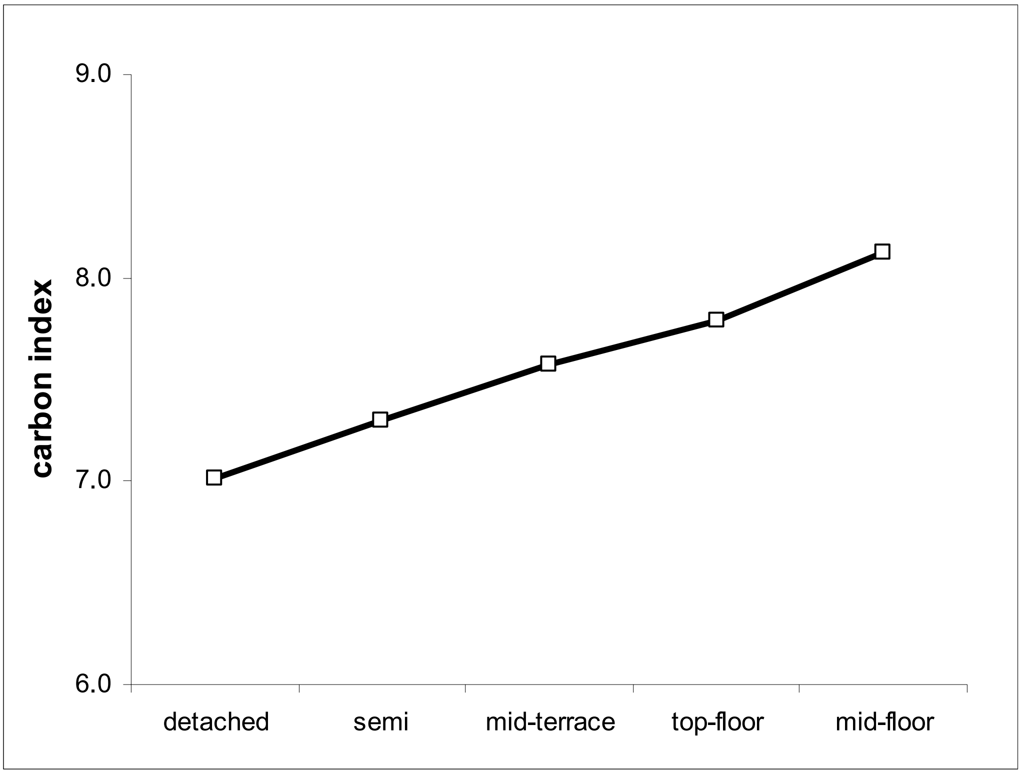


Figure 3.13 Impact of built form on carbon emissions from electrically heated dwellings

The technical option that is not included in this analysis is heating based on heat pumps. There is comparatively little practical experience of heat pumps in the UK, and currently little likelihood of rapid development in the face of declining energy prices. Nevertheless, heat pump coefficients of performance (COP) in the region of 3 allow the achievement, without any additional measures, of carbon indexes in excess of 11 in semi-detached houses and lower annual $CO_2$ emissions from all classes of electrically heated than from gas heated dwellings. Combined with electricity efficient lights and appliances, this would allow total $CO_2$ emissions from new dwellings to be reduced to below 2 t/a. The successful commercialisation of heat pumps in the UK housing market, probably beginning with the most compact dwelling types, would represent a strategic transformation of the domestic energy sector. Such a transformation would raise a number of issues – for example, its impact on the electricity supply system, particularly on peak load, would need to be studied in some detail. But it would make it possible to simplify Part L by setting a single Carbon Index target for all types of housing, irrespective of energy carrier used for heating.

It is clear that the development and commercialisation of alternatives to electric resistance heating has proceeded more slowly in the UK than we thought likely in 1998. On the other hand, carbon intensity of electricity has continued to fall - the value given in SAP 9.70 is 20% lower than in previous versions. Thus the gap that needs to be closed between the environmental performance of electric and gas-heated dwellings is smaller now than ever.

At the time of writing, we are probably still in a transitional situation that requires separate Carbon Index targets for gas and electrically heated dwellings. If heat pumps are not expected to be widely commercially available by 2008, a plausible carbon index target for electrically heated dwellings might be in the region of 7.5 – requiring, in typical low-rise housing, a combination of:

- high performance MVHR (specific fan power 1 J/l, heat recovery efficiency 85%);
- reduction of envelope air leakage from 5 to 3 m/h;
- reduction of elemental U values by about 15% compared to those applicable in gas heated dwellings.

Such a target would place significant but not impossible pressure on housing developers. It would provide a significant incentive for solar hot water heating and heat recovery ventilation in mainstream housing, and would produce a technical environment that would encourage the replacement of wet central heating systems in many dwellings by supplementary heating delivered by balanced mechanical ventilation systems. It would provide a rationale for the development, by the construction industry, of construction techniques capable of meeting insulation requirements following a further review of Part L in the early part of the next decade. Finally, it would provide a significant incentive for the commercialisation of heat pumps for water and space heating in new dwellings.

# Chapter 4 Design solution and predicted technical performance

## 4.0 Introduction

This chapter describes the final house design that is shortly to be built at St Nicholas Court, York. It was the intention to make post-construction tests on the houses as well as monitoring the energy performance in detail over the first twelve-month period of occupation. We would have run co-heating tests on 2 houses and air pressurisation tests on at least ten and possibly all. We would also have commissioned an infrared survey of the dwellings. The co-heating test would have measured actual envelope performance and the air pressurisation test would have measured the actual airtightness of the dwelling. In lieu of the actual energy performance data, predicted data are presented which were calculated using an energy performance spreadsheet (Parametric Domestic Energy Model, see Appendix 2) based on SAP 2001. This BREDEM-based energy performance tool allows the incorporation of thermal bridging data and other energy performance refinements[21]. Thermal bridging was calculated using Thermal modelling software (Therm 2.1a) which estimated the additional heat losses at construction junctions[22]. The energy performance spreadsheet was used to provide a detailed energy assessment of one of the three house types to be built at St Nicholas Court: a 3-bed semi-detached).

The following definitions of terms have been used throughout:

*building thermal envelope*: the elements of construction that separate the internal heated space from the external environment.

*exposed building element*: a major part of the building thermal envelope, normally bounded by other elements and normally planar, through which heat flows from inside to outside (typically, roof, wall, ground floor, window and door).

*centre-element U value*: based on one dimensional heat flow through the centre of an exposed plane element.

*whole element U value*: based on the total heat flux through an exposed plane element, measured at the internal surface and including all additional thermal bridging heat losses through construction and junctions associated with that element. In practice, estimates of whole element U values presented in this document omit point or 3-D contributions.

*mean U value*: based on the total heat flux through the entire building thermal envelope, measured at the internal surface and including all additional thermal

[21] The SAP worksheet used was version 9.70 as described in the ADL02. The worksheet was checked using SAP examples supplied by the BRE.
[22] Thermal performance of junctions was calculated using Therm 2.1 (LBNL). Kobra Eurokobra version 2.1 (Physibel) was used to verify these thermal bridging values. The Wärmebrücken-Atlas (Hauser and Stiegel, 1992) was used to crosscheck the values and an example is shown in Appendix 6.

bridging heat losses through construction and junctions in the envelope. As with whole element U values (see previous), estimates of mean U values presented in this document omit point or 3-D contributions.

In order to put the energy performance of the final house design into perspective, the basic house type was modified in the Parametric Domestic Energy Model in order to comply with each of three standards: ADL95, ADL02 and EPS08 (the proposed energy performance standard for 2008). Certain non-standard thicknesses of building material were used for modelling purposes to allow U value requirements to be met precisely. For example, a non-standard 78×39mm stud was used in an insulated stud wall to give the wall a particular U value but, in practice, the next size available commercially would be 89×39mm. The modifications to building fabric maintained the same room sizes and standard of accommodation. A comparison was also made between warm and cold roofs and other studies evaluated window and ventilation performance. The heating system was evaluated using the carbon intensity.

## 4.1 Technical description of dwelling designs, including construction, heating & ventilation systems

The St Nicholas Court dwellings will be timber-framed and timber-clad and have been designed to be highly insulated with low thermal bridging losses. The roof will be constructed of I-beams, which allows the roof space to be part of the heated envelope of the dwelling giving extra habitable space. I-beam roof construction makes more efficient use of timber. Additional benefits through simplification of roof construction are better control of air-tightness; lower thermal bridging; and space to locate MVHR equipment and ductwork without incurring heat loss. The details of the air barrier have followed a strategic approach to air-tightness to provide assurance that the air-tightness target of 3 m/h at 50 Pa could be attained (the final version of EPS08 requires 5 m/h or less but in the initial version the target was 3 m/h.). All houses will have a condensing combination boiler and no hot water storage. Half of the houses are to have radiators to ground floor, landing and bathroom only and a MVHR ventilation system. A paper is included in Appendix 1 which gives full details of the argument that was developed for omitting radiators from bedrooms while maintaining thermal comfort. The remainder of the dwellings will utilise extract-only ventilation and will be equipped with radiators throughout.

An energy performance calculation was performed for the houses as designed for the St Nicholas Court scheme. Some items exceeded the EPS08 requirements. This performance relates directly to the costing exercise in Chapter 5. Detailed qualitative and quantitative descriptions of the house elements are found in Table 4.1 (U value specifications for the comparison of energy performance of the standards are found later in Table 4.4).

| Table 4.1: Constructions and estimated whole element U values for the 3 bed house type at St Nicholas Court | | |
|---|---|---|
| Element/sub-system | Qualitative technical description | Quantitative description |
| External walls | 12mm sheathing ply on 44×89 studs with 5mm hardboard internal lining, factory filled cellulose insulation ($\lambda$= 0.035 W/mK).<br><br>44mm rigid urethane insulation board ($\lambda$= 0.026 W/mK) applied externally to timber frame.<br><br>Red cedar/rough sawn softwood cladding. | U = 0.257 $W/m^2K$ Including thermal bridging through stud-work (EPS08 requires elemental U = 0.25 $W/m^2K$) |
| Roof | Warm roof with sleeping shelf: 300 mm timber I-beam panels, constructed off-site, post-insulated with 300 mm sprayed cellulose fibre ($\lambda$= 0.035 W/mK) | U = 0.127 $W/m^2K$ Including bridging through I-beams (EPS08 requires elemental U = 0.15 $W/m^2K$) |
| Ground floor | Beam and block<br>75mm reinforced screed on 75mm EPS ($\lambda$= 0.037 W/mK). | U = 0.201 $W/m^2K$ Including thermal bridging at edges (EPS08 requires elemental U = 0.22 $W/m^2K$) |
| Windows | 20mm argon filled gap, low-e ($\varepsilon$ = 0.08), warm edge, in untreated timber frames. Frame fractions minimised by rationalisation of design - all windows are single light designs. | U = 1.3 $W/m^2K$ or DWER 70 |
| Air barrier | concrete screed in ground floor, polyethylene vapour barrier in walls protected by a service void, strategy for roof to be decided. | air leakage ≤ 3 m/h at 50 Pa |
| Heating systems | condensing combination boilers, radiators to ground floor, landing and bathroom only in houses with MVHR, radiators to all ground and first floor rooms in houses with extract-only ventilation (see below) | carbon coefficient of space and water heating ≤ 70 kg/GJ |
| Ventilation systems | either:<br>• multi-point extract only systems, or<br>• whole house MVHR | |

## 4.2 Predicted energy performance of St Nicholas Court final house design.

U values
The predicted whole element U values for the three-bed semi are shown in Table 4.1. The whole wall U value is calculated to be 0.257 $W/m^2K$. This is slightly higher than the EPS08 elemental value of 0.25 $W/m^2K$. Similarly, the ground floor was calculated to be 0.201 $W/m^2K$, better than the requirement of 0.22 $W/m^2K$. The whole roof U value is also expected to be better (0.127 $W/m^2K$) than the elemental value in EPS08 (0.15 $W/m^2K$).

SAP
The three-bed semi with MVHR[23] achieved a SAP rating[24] of 108.5. The same house with extract-only ventilation achieved a SAP rating of 111.3. The difference in ratings reflects the additional electricity used to operate the MVHR unit.

Space and water heating cost
Predicted total annual running costs (gas and electricity) for space and water heating were £150.06 for the MVHR and £142.33 for the extract-only ventilation options. The difference in cost is due to electricity used by the additional MVHR fan.

Total $CO_2$
Total $CO_2$ emissions for the three-bed semi MVHR were 1.33 tons/annum. With the extract-only option, the carbon released was slightly higher at 1.41 tons/annum.

Carbon index
The three-bed semi with MVHR is calculated to achieve a carbon index of 9.6, exceeding 8.8, the revised requirement of EPS08 using the carbon index method of compliance[25]. With extract-only ventilation, the carbon index was slightly lower at 9.3. Although the MVHR system used slightly more electricity, its better carbon rating is due to the energy saved in the heat exchanger.

Fabric heat loss
The predicted fabric heat loss for the three-bed semi was 62.7 W/K.

The performance is summarised in Table 4.2.

Table 4.2: Summary of performance of final house design under two medium performance ventilation options.

| | MVHR | MEV |
|---|---|---|
| SAP rating | 108.5 | 111.3 |
| Running costs (£/a) | 150.06 | 142.33 |
| Total CO2 emissions (t/a) | 1.33 | 1.41 |
| Carbon index | 9.6 | 9.3 |
| Fabric heat loss (W/K) | 62.7 | 62.7 |

[23] In this report we refer to three categories of ventilation system performance: ‘low’, ‘medium’ and ‘high’, which are defined in section 4.9. For the purposes of the present exercise, the performance of MEV and MVHR ventilation systems was assumed to be ‘medium’.
[24] The LMU energy performance spreadsheet does not arbitrarily truncate the SAP or Carbon Indices.
[25] As noted in Chapter 3, the equation for Carbon Index presented in SAP 9.7 is different from that given in the earlier Part L Consultation Paper (DETR 2000). The effect of the difference is to reduce the value of the Carbon Index corresponding to a given level of $CO_2$ emissions by 0.4 points.

One of the more interesting conclusions from the above table is that, under the stated conditions, MVHR outperforms MEV on carbon emissions but not on economic cost. This apparent discrepancy is due to the fact that the economic costs of gas and electricity (p/kWh) differ by a factor of approximately 5, while the carbon intensities differ by only a factor of 2. This means that MVHR needs to achieve a coefficient of performance of between 5 and 10 to enable the economic value of heat saved to exceed that of additional electricity used, but only 2-4 to enable the reduction in carbon emissions from space heating to exceed the increase in carbon emissions due to additional fan energy.

Comparisons between MVHR and MEV are complex. As noted elsewhere in this report, envelope airtightness and electrical efficiency both tend to increase the relative advantage of MVHR, as does the possibility that carbon intensity of electricity will fall in the future due to an increased proportion of renewable energy in the mix of electricity production. It is also possible that average indoor air quality would be superior in MVHR houses, since the air supplied by an MVHR system is in addition to natural infiltration, whereas air supplied by an MEV system tends to displace natural infiltration. Moreover MVHR provides greater control over air flow paths in dwellings, which should translate into higher ventilation efficiency. Finally, it is likely that thermal comfort will be higher in houses with MVHR than in houses with MEV, since with MVHR fresh air is unlikely to enter the dwelling at temperatures much less than 15°C while, with MEV, air enters the dwelling at outside temperature. Disadvantages of MVHR include greater complexity, higher maintenance costs and the risk that fouling of filters and supply ducts will lead to reduced air quality.

Many of the factors involved in the comparison would require empirical case studies in occupied dwellings to resolve. It is therefore unfortunate that the occupation phase of the St Nicholas Court project has been abandoned. At the time of writing, the complexity of the picture is such that neither ventilation option appears clearly preferable.

## 4.3 Scheme drawings: elevations, floor plans, section and site plan

The flank elevation and the North and South elevations are shown below in Figures 4.1 and 4.2, respectively. A floor plan is shown in Figure 4.3 and a section through the dwelling is shown in Figure 4.4. Finally, the site layout is shown in Figure 4.5.

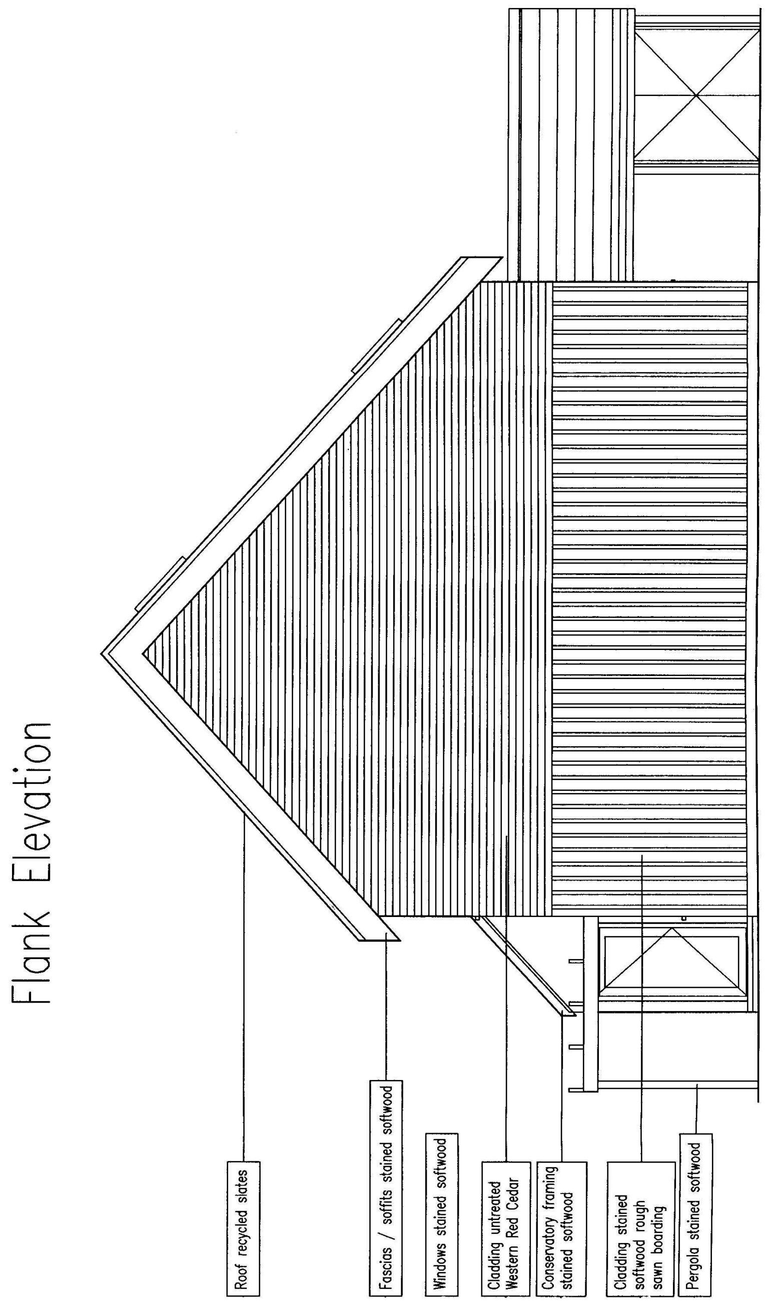


Figure 4.1: St Nicholas Court dwelling - flank elevation.

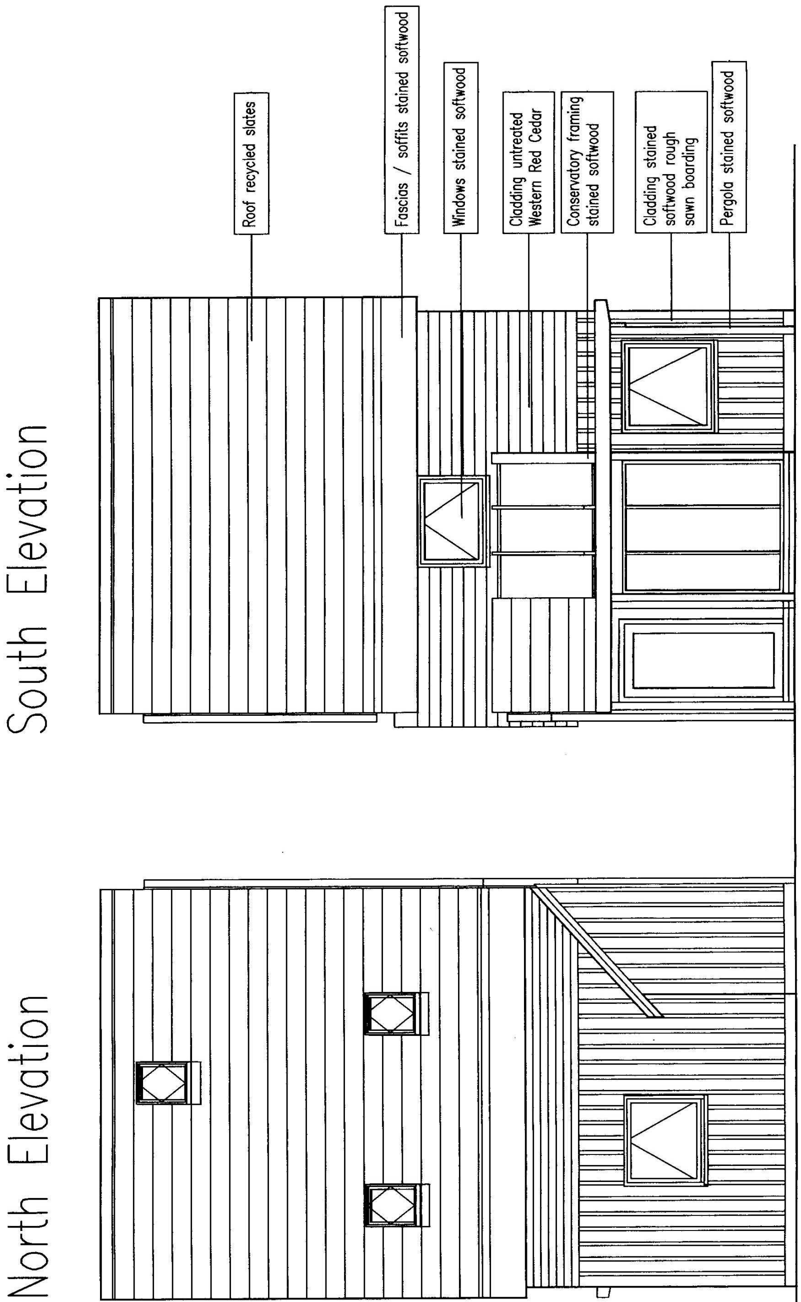


Figure 4.2: St Nicholas Court dwelling - North & South elevations.


Figure 4.3: St Nicholas Court dwelling - floor plans.

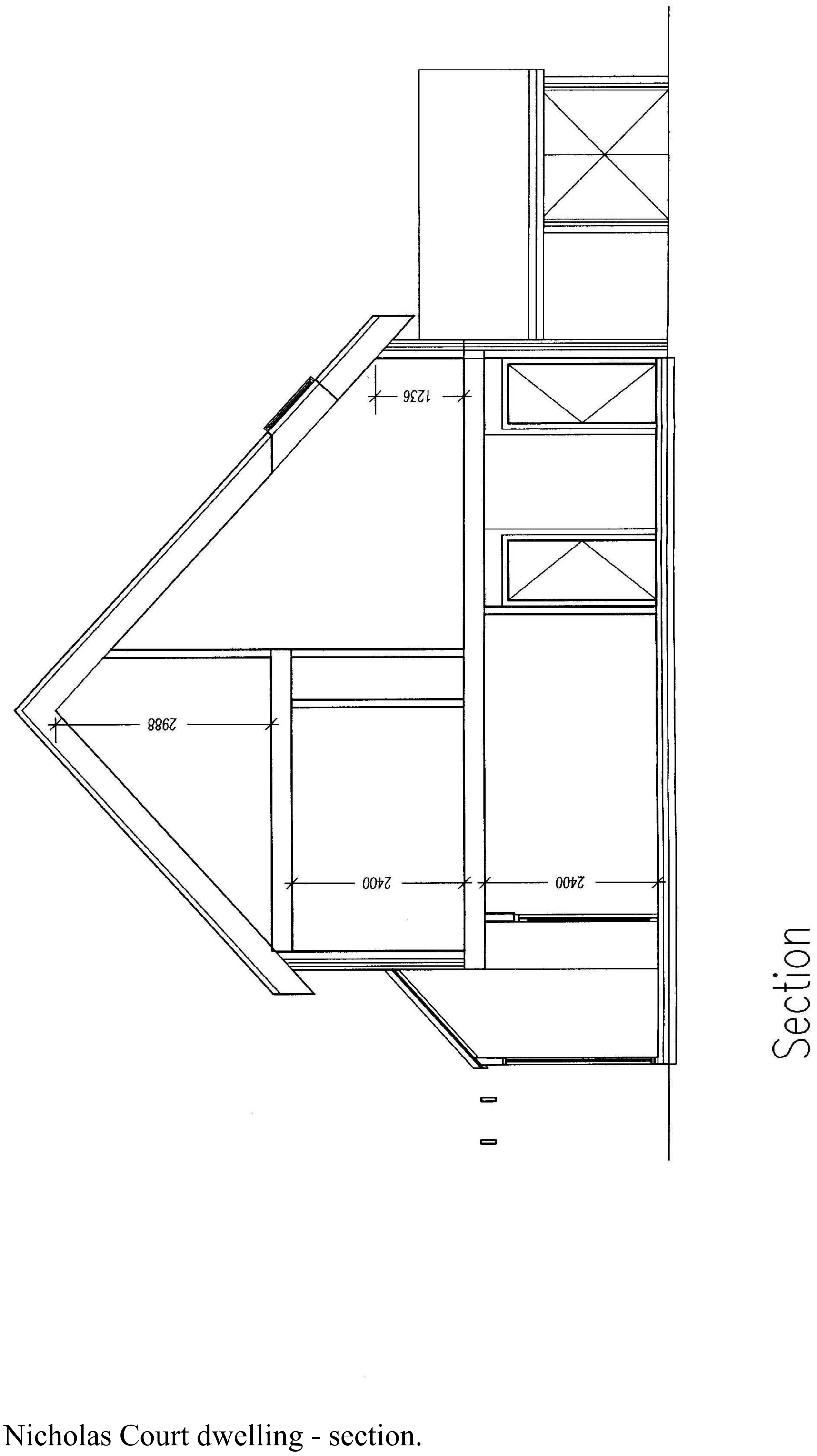


Figure 4.4: St Nicholas Court dwelling - section.


Figure 4.5: St Nicholas Court site plan.

## 4.4 Assumptions used in the comparison between standards

A comparison of EPS08 with the current ADL (2002) and with ADL95 was made in order to put the proposed changes for 2008 into historical context. Energy performance of the dwellings built to each of the standards was estimated. The comparisons were made using the following assumptions (for convenience, the section numbers follow those of the SAP sheet):

<u>SAP, Section 1. Overall dwelling dimensions</u>
The overall (internal) dwelling dimensions are based on the 3 bed 5 person house designed for the St Nicholas Court scheme in York (as shown previously in section 4.3).

<u>SAP, Section 2. Ventilation rate</u>
Energy performance was calculated for the ADL95 and ADL02 using local extract fans in wet rooms and trickle vents; the EPS08 had extract-only whole house mechanical extract ventilation (MEV); the final house design had either MVHR or extract-only.

<u>Airtightness</u>
ADL95 does not specify an airtightness standard to be achieved, only recommends sealing possible air leakage routes (limiting infiltration section 1.25 to 1.26). UK housing stock airtightness data supplied by the BRE (Stephen 88) was used to give an estimate of the actual air leakage rate of houses built to ADL95.

ADL02 (see limiting air leakage section 1.33 to 1.35) first introduced the notion of an airtightness target of $10m^3/hour/m^2$ at 50 Pa [in other words, 10 $m^3/h$], to be tested by air pressurisation, but with the alternative of using the guidance given in Robust Details (DTLR 2001) as proof of compliance. It was assumed here that the ADL02 house achieved 10 $m^3/h$.

EPS08 specifies that a sample of dwellings be pressure-tested to ensure compliance with the limiting value of $5m^3/h$ at 50Pa. The St Nicholas Court houses were assumed to exceed this target with a pressure test result expected of $3m^3/h$ at 50Pa. The air leakage rates chosen for each standard are summarised in Table 4.3:

Table 4.3: Assumed airtightness values

| Standard | Measured or assumed Q ($m^3/hour/m^2$ @ 50 Pa) |
|---|---|
| ADL95 *Data taken from Stephen (1988, Figure 4.2)* | 13.1 |
| ADL02 *see section 1.35, ADL02* | 10 |
| EPS08 | 5 |
| Expected air leakage for final house design | 3 |

SAP, Section 3. Heat losses and heat loss parameters

The constructions and the corresponding elemental U values used for the three standards are based on typical details of the time and are shown in Table 4.4.

Table 4.4: U value specifications for the 3 bed house type at St Nicholas Court

*Note: certain non-standard sizes of building materials listed in this table have been used for thermal modelling purposes only. For example, a 78×38mm stud is not commercially available and the next size up (89×38mm) would be used in practice. The implication of this is that actual U values may, in some cases, be better than the elemental maxima.*

| | ADL95 (based on typical details used at the time) | ADL02 (based on typical details used currently) | EPS08 (based on details designed for the St Nicholas Court scheme) |
|---|---|---|---|
| Ground floor<br><br>P/A ratio:<br>3 bed = 0.57 | U = 0.35 W/m$^2$K<br><br>Beam and block<br><br>22mm above-slab EPS insulation ($\lambda$= 0.037 W/mK). | U = 0.25 W/m$^2$K<br><br>Beam and block<br><br>60mm above-slab EPS insulation ($\lambda$= 0.037 W/mK). | U = 0.22 W/m$^2$K<br><br>Beam and block Reinforced screed on 62mm EPS insulation ($\lambda$= 0.037 W/mK). |
| External walls | U = 0.45 W/m$^2$K<br><br>Standard timber frame technology 78×38 stud frame filled with mineral fibre insulation ($\lambda$= 0.035 W/mK)<br><br>Red cedar/rough sawn softwood cladding. | U = 0.35 W/m$^2$K<br><br>110×38 stud filled with mineral fibre insulation ($\lambda$= 0.035 W/mK)<br><br>Red cedar/rough sawn softwood cladding. | U = 0.25 W/m$^2$K<br><br>12mm sheathing ply on 44×89 studs with 5mm hardboard internal lining, factory filled cellulose insulation ($\lambda$= 0.035 W/mK).<br><br>50mm rigid urethane insulation board ($\lambda$= 0.026 W/mK) applied externally to timber frame.<br><br>Red cedar/rough sawn softwood cladding. |
| Roof (warm) | U = 0.25 W/m$^2$K<br><br>**Warm** roof with sleeping shelf. 150mm rafters with 119mm mineral fibre insulation ($\lambda$= 0.035 W/mK) between. | U = 0.2 W/m$^2$K<br><br>**Warm** roof with sleeping shelf. 150mm mineral fibre ($\lambda$= 0.035 W/mK) fully filled rafters with additional 38mm rigid urethane insulation board ($\lambda$= 0.026 W/mK)on top of rafters. | U = 0.15 W/m$^2$K<br><br>**Warm** roof with sleeping shelf. 300mm **I**-beam roof with 224mm cellulose insulation ($\lambda$= 0.035 W/mK) between. |
| Windows, Timber double glazed | U = 3.3 W/m$^2$K<br><br>12mm air gap plain glass | U = 2.2 W/m$^2$K<br><br>e.g., 12mm air gap, low-e 0.15 | U = 1.3 W/m$^2$K or DWER 70<br>e.g., 20mm argon filled gap, low-e 0.8 |
| Doors (glazing same as windows) | U = 3.3 W/m$^2$K | U = 2.2 W/m$^2$K | U = 1.3 W/m$^2$K |

SAP, Section 4. Water heating requirements

| Table 4.5: water heating parameters | | | | |
|---|---|---|---|---|
| | ADL95 | ADL02 | EPS08 | Final house design |
| Hot water storage (l) | 120 | 120 | 120 | 0 |
| Cylinder insulation thickness (mm) | 35 | 35 | 70 | N/A |
| Primary circuit loss (table 3) | 2.2 | 2.2 | 1.3 | N/A |
| Heater efficiency (%) | 72 | 78 | 85 | 90.7 |

SAP, Section 5. Internal gains

| Table 4.6: additional internal gains (from Table 5 of SAP 2002) | | | | |
|---|---|---|---|---|
| | ADL95 | ADL02 | EPS08 | Final house design |
| Central heating pump (W) | 10 | 10 | 10 | 10 |

SAP, Section 6. Solar gains
The house type was assumed to take good advantage of solar gains through glazing: 6.82m$^2$ to the South and 1.09m$^2$ to the North. Rooflights: 2.28m$^2$ facing [north or south].

SAP, Section 9. Space heating requirement

| Table 4.7: Space heating parameters | | | | |
|---|---|---|---|---|
| | ADL95 | ADL02 | EPS08 | Final house design |
| Boiler type | Typical gas-fired wet systems using a non-condensing boiler | Typical gas-fired wet systems using a non-condensing boiler | Condensing boiler | Condensing combi boiler |
| Efficiency of main heating system (%) | 72 | 78 | 85 | 90.7 |
| Electricity (GJ/a) for... ...central heating pump | 0.47 | 0.47 | 0.47 | 0.47 |
| ...fan assisted flue | 0.16 | 0.16 | 0.16 | 0.16 |
| ...cont. mech. ventilation | 0.83 | 0.83 | 0.83 | 0.83 |

It is worth noting that for any given heating system, heat-to-power ratio rather than energy use per annum will be constant. Thus, dwellings with lower total heat consumption will require less electricity for the central heating pump. It would be worth incorporating this effect into future versions of SAP.

SAP, Section 10. Fuel costs
Fuel costs as given in SAP 2002 document for all standards. This means that no adjustment for inflation is necessary.

<u>SAP, Section 12. Carbon index</u>
A carbon index for each standard was calculated using the procedure given in the Standard Assessment Procedure, 2002.

## 4.5 Discussion of thermal bridging issues

The construction industry is familiar with the concept of the U value as a method of calculating heat loss through one-dimensional plane elements. EPS08 requires that additional thermal bridging heat losses to be incorporated into the whole element U value calculation. Therefore, in order to make a fair comparison of envelope performance across the standards, a procedure was used to apportion the relevant additional heat losses from details (typical at the time of regulation) into the relevant whole element U values of each standard. The way that each standard has treated thermal bridging is as follows:

ADL95 states that thermal bridging should be limited, but only around openings: lintels, jambs and sills. When using details **similar** to those shown in 'Diagram 3', additional heat loss is ignored in the calculation of elemental U value. The details shown are masonry details, so standard timber frame details that were typical of the time were supplied by a timber frame manufacturer , Oregon Timber, and used in the assessment.

ADL02 extended the concept of limiting thermal bridging to include openings and junctions. Two compliance routes are available: either to use designs as shown in Robust Details OR to demonstrate by calculation (using BRE Information paper IP 17/01) that building performance is at least as good. Again, no additional heat loss is included in U value calculation or in the carbon index method of compliance.

EPS08 is the only standard that requires all linear thermal bridging heat loss to be calculated and included in the elemental (or mean) whole element U value. As thermal bridging has been treated differently in the three standards, it was therefore necessary to perform this set of comparisons between the three standards in order to compare like-for like.

## 4.6 Incorporating thermal bridging heat losses into the dwelling mean U value and into individual whole element U values

Two ways were considered to include bridging in the dwelling mean U value. In the first, as used by the architect in the building regulation submission, the overall fabric heat loss was simply a combination of mean U value and additional thermal bridging heat loss from all the junctions in the building.

In the second method, as presented here, individual whole element U values were made up of the plane element U value added to the thermal bridging through the junctions connected to that element. Bridging through wall junctions such as heads and sills were added to the wall U value. Where a junction straddled two plane elements, each plane element was attributed with a proportion of the thermal bridging through that junction. For example, at eaves, some of the bridging was added to the wall U value and some was added to the roof U value. When all the additions were made, the whole element U values were found to be higher than centre element U values.

## 4.7 Heat flow modelling

'Therm 2.1a' computer modelling software by LBNL was used to predict the magnitude of heat loss at junctions. For the 95 standard, typical details of the time were supplied by Oregon Timber and modelled in Therm. For the 2002 standard, relevant details found in the Robust Details were used. For the EPS08 standard, the details designed by the architect of the St Nicholas Court scheme were modelled. The lengths of the 2-d junctions remained the same for all three standards.

Following the notation used in BS EN ISO 14638:1999, $\psi$ (psi) values were calculated from:

$$\psi = L^{2D} - \Sigma U_i w_i$$

where:

$L^{2D}$ is the thermal coupling coefficient obtained from a 2-D calculation of the junction

$U_i$ is the 1-D U value of the i-th component forming the junction

$w_i$ is the width, measured perpendicular to the main axis of the junction, of the i-th component forming the junction

A timber fraction of 10% was assumed for $U_{wall}$ (the un-bridged wall U value) This assumption was based on work done by Bell & Overend (2001) who found that a realistic figure for stud proportion in timber framed walls is between 8% and 13%, depending on house type. Timbers at sole plates, headers, openings and floor junctions were not included in this timber fraction as they form part of the structure at junctions where thermal bridging occurs and are therefore already counted in the $\psi$ values.

## 4.8 Predicted results of comparison of three standards

The results of the comparison of the three standards taking thermal bridging into account in the whole element U value calculation are presented in Table 4.8 and Figures 4.6 to 4.9, below. Also included in each are data for the final house design for reference purposes.

Table 4.8: Summary of whole element U values achieved (W/m$^2$K)

| | ADL95 | ADL02 | EPS08 | Final house design |
|---|---|---|---|---|
| Uroof (warm) | 0.368 | 0.226 | 0.160 | 0.127 |
| Uwall | 0.507 | 0.403 | 0.250 | 0.257 |
| Uground floor | 0.492 | 0.269 | 0.220 | 0.201 |
| Uwindows | 3.30 | 2.00 | 1.30 | 1.30 * |

** This value was unconfirmed at time of writing, see section 4.8*

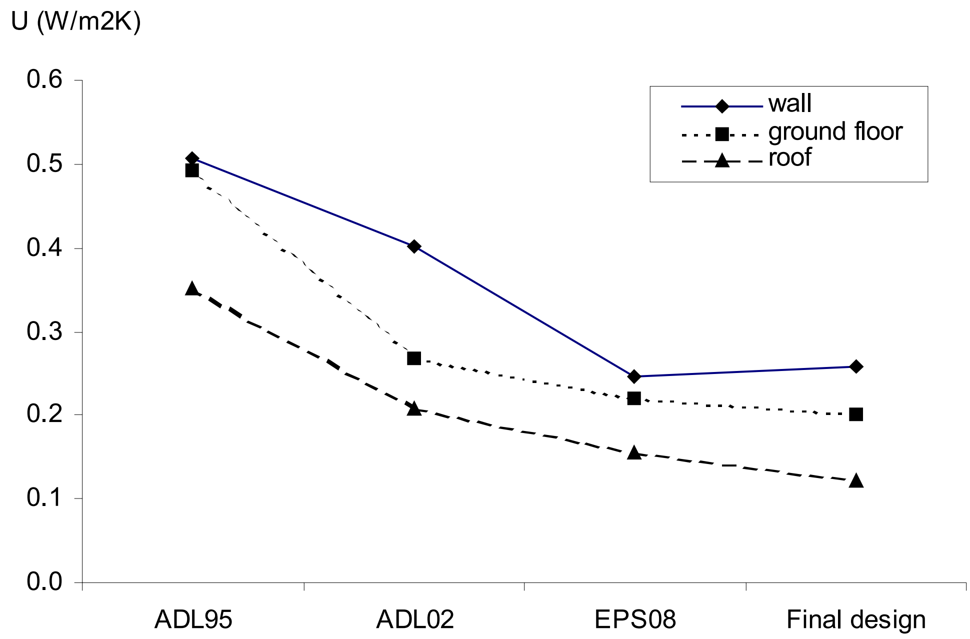


Figure 4.6: Whole element U values (warm roof house).

Whole element U values shown in Figure 4.6 can be seen to have largely followed a similar historical downward trend instigated by previous standards. The wall requirement has changed more than the roof and the ground floor less so. In the case of the floor and the roof, the final house design meets the requirements comfortably while the whole wall U value of 0.2569 W/m$^2$K just fails to meet the requirement of 0.25 W/m$^2$K.

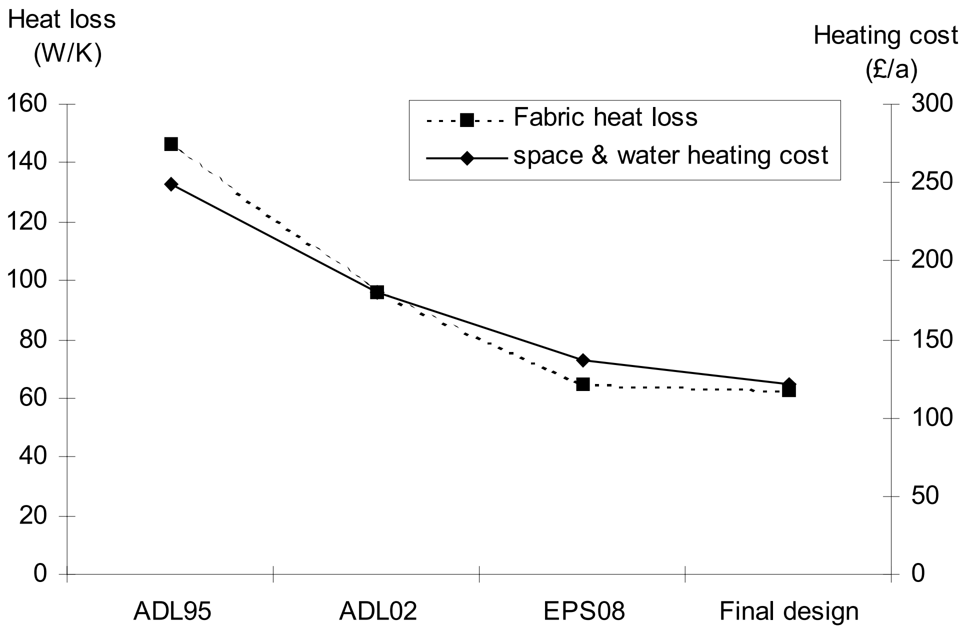


Figure 4.7: Predicted fabric heat loss & heating cost (warm roof house).

Figure 4.7 shows that, as fabric heat loss is lower, so too is the heating cost. The cost of space and water heating for houses built to EPS08 is approximately half that of the same house built to 1995 standards. Reasons why the final house design has substantially lower heating costs than the EPS08 house and yet with only a slightly lower fabric heat loss include the higher efficiency boiler and a more airtight construction.

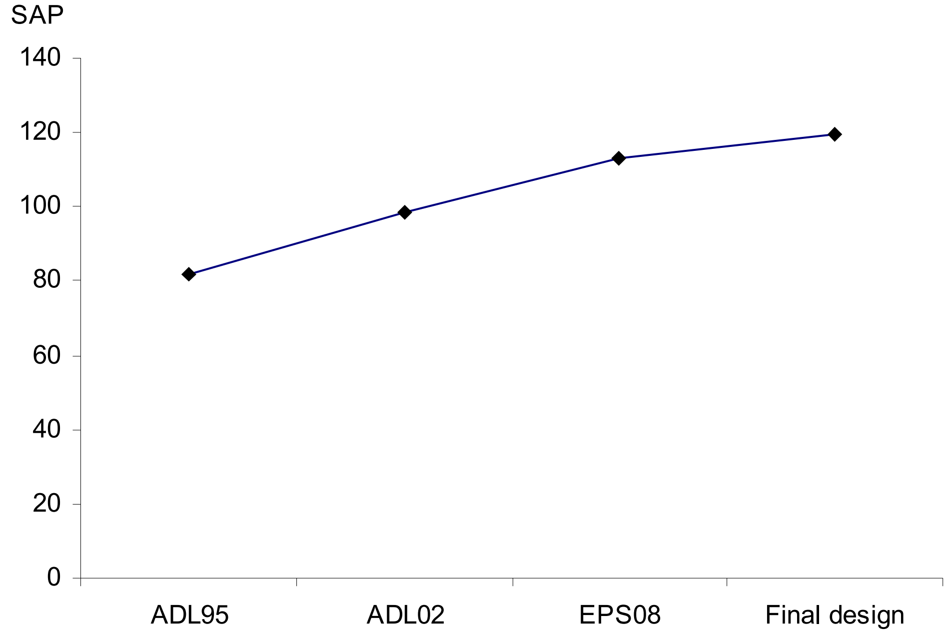


Figure 4.8: SAP rating (warm roof house).

SAP ratings for the three standards were 78.6, 92.9 and 107.3, as shown in Figure 4.8. The final house design attained a SAP of 111.3.

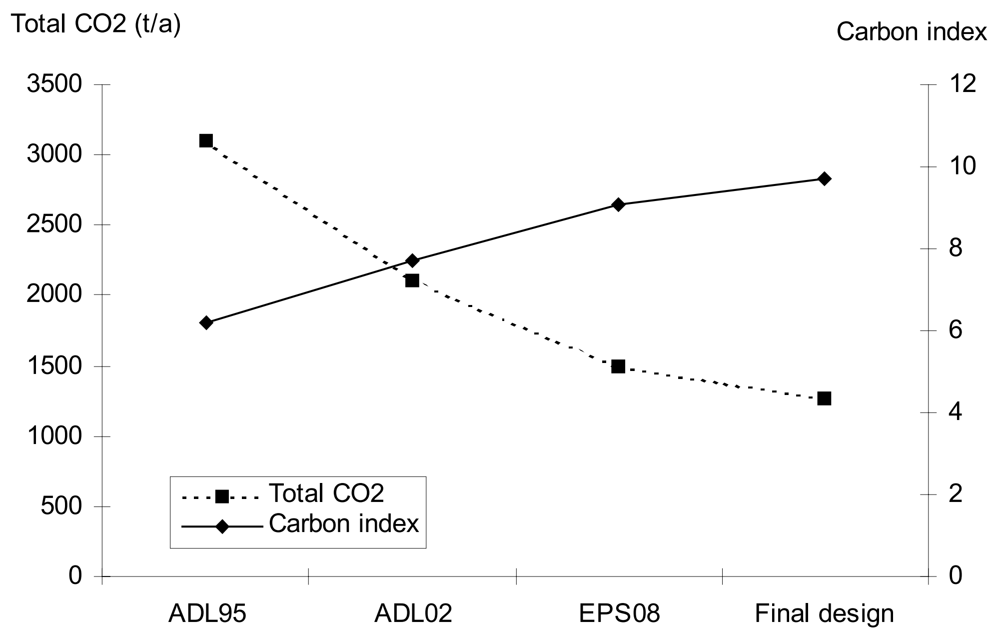


Figure 4.9: Carbon emissions and carbon index (warm roof house).

Figure 4.9 shows carbon emissions falling, as each successive standard has required improved thermal performance of the fabric (and therefore a lower heating requirement). The graph demonstrates that houses built to EPS08 produce less than half the carbon emissions from houses built to the 1995 standard (the standard in force at the time of drafting EPS08). The final house design goes further still and shows that carbon emission reductions of 57% are possible compared with ADL95 These carbon emission and carbon index values are comparable to other work done on a smaller house type, see Figures 3.6 and 3.7.

## 4.9 Overall effect of including thermal bridging into the calculation of U value

Table 4.9 summarises key indicators that show the main effects that including thermal bridging into the whole element U value calculation has on building performance.

Table 4.9: Summary of changes due to thermal bridging for the final house design built to EPS08:

| | Energy and environmental performance: | | |
|---|---|---|---|
| | Without thermal bridging | With thermal bridging | % difference |
| $CO_2$ emissions (t/a) | 1.38 | 1.41 | 2.1 |
| Carbon Index | 9.4 | 9.3 | -1.1 |
| Mean U (W/m2K) | 0.2643 | 0.2828 | 6.5 |
| Fabric heat loss(W/K) | 58.65 | 62.7 | 6.5 |
| SAP | 112.4 | 111.3 | -1.0 |

The additional whole house heat loss due to thermal bridging is calculated to be 8.6, 7.4 and 4.4 W/K for the ADL95, ADL02 and EPS08 standards, respectively. This shows that the design of the junction details has followed a trend of continual improvement. However, this trend may not continue indefinitely. The EPS08 value of 4.4 W/K may be near the limit that can be achieved as some bridging is caused by geometric effects and cannot be ameliorated (the exterior surface area of a building is always larger than the interior surface area). Also, as these dwellings are timber-framed, timber members are required in most junctions for structural purposes and further reductions in thermal bridging here will be difficult using traditional timber frame technology. I-beam technology appears to provide opportunities for improvements in this area.

Interestingly, as one-dimensional plane element U values become lower, the proportion of heat loss due to thermal bridging using the same junction details becomes higher[26]. However, this effect was offset in this comparison of standards as details improved thermally at the same time that elements did. The inclusion of thermal bridging into the total fabric heat loss made corresponding reductions in the SAP value and the Carbon Index of the order of 2% for ADL95, 1.5% for ADL02 and 1% for EPS08 (SAP and CI are non-linear functions).

[26] A simple dimensional argument shows that as the thickness of insulation in elements meeting at a junction increases, so the 1-D U values of the elements fall, but the $\psi$ value of the junction remains constant.

## 4.10 Plane whole element U values

When designing a wall, a ground floor or a roof, what is the expected magnitude of the bridging component of the whole elemental U value of each? In other words, how much smaller does the plane element U value have to be to allow room for the additional thermal bridging component to bring the whole element U value to the requirement? Each house could be different, depending on the performance of the construction details and the amount of them. However, a possible rule of thumb from this work appears to be 13% for walls, 8% for ground floors and 7% for roofs. In other words, if the plane elements achieve U values of 0.23, 0.19 and 0.11 $W/m^2K$, respectively, then the thermal bridging additions will increase those values to the required 0.25, 0.22, 0.16 $W/m^2K$ whole element U values. These guidelines apply to timber frame construction very generally, and to this particular house type in particular. Further work on a range of house types is needed.

## 4.11 Importance of thermal bridging

Although the heat loss due to bridging may appear small it is worth remembering that the heat loss through ADL95 details was more than twice that of the (thermally improved) EPS08 details. Also, the St Nicholas Court final house design was intended to have minimal junction lengths. Other buildings with irregular floor plans, decorative gables, porches and other (thermally poor) additions could very well have much more junction length. Both these factors together could increase thermal bridging heat loss by a substantial degree. This underlines the importance of including thermal bridging heat loss in the procedures for calculating heat loss.

This study has only attempted to model 2-D thermal bridges where two plane elements meet (for example, the edge where the front wall meets the side wall). The team is aware that 3-D bridges also occur where three plane elements meet (for example, the corner where the ground floor meets the front wall and a side wall). Three-dimensional modelling was beyond the scope of this investigation. However, the research team believes that the heat loss through three-dimensional junctions is much smaller than that through two-dimensional junctions. An example of this difference is illustrated in Figure 4.10.

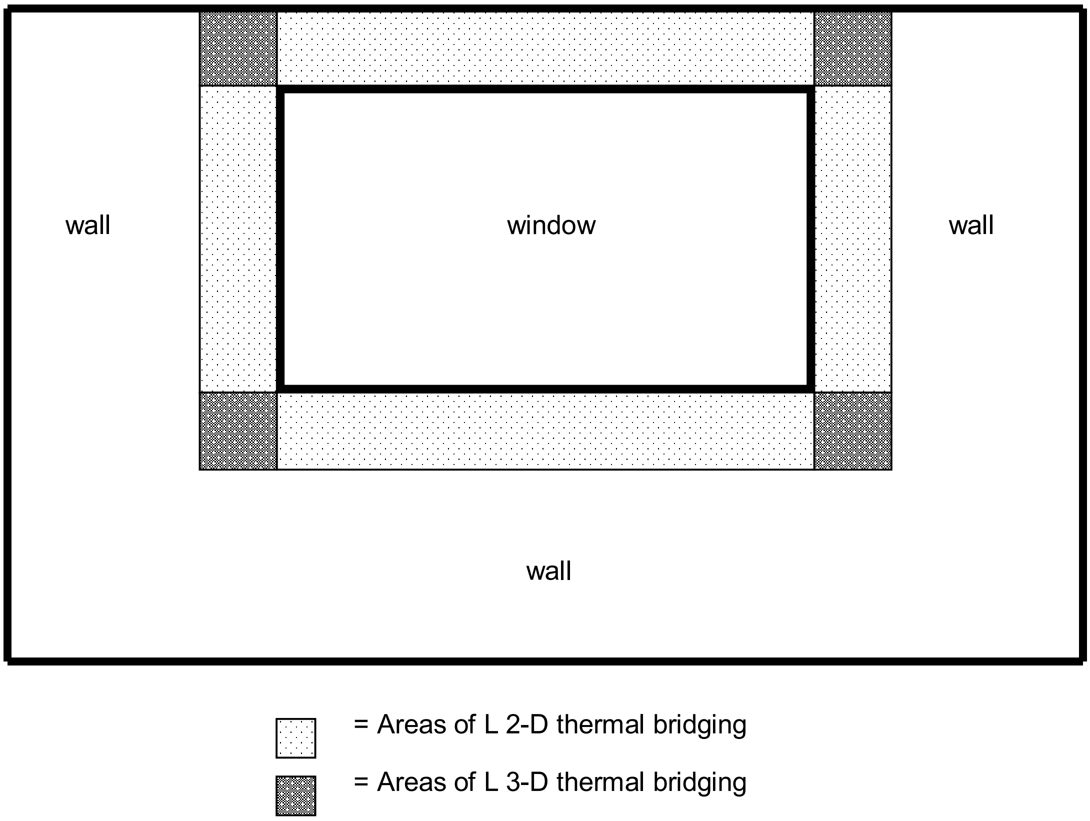


Figure 4.10: Relative areas of 2D and 3D thermal bridging around a window opening.

Figure 4.10 shows a window in a wall. Above, below and at the sides of the window frame (shaded light) are wall areas where 2-D thermal bridging has been modelled and included in the whole wall U value. Beyond the corners of the window frame (shaded dark) are areas where 3-D thermal bridging occurs. Omitting the 3-D elements in this way leads to a small underestimation of the total heat loss.

## 4.12 Comparison between standards using low-pitched cold roof

In addition to the warm roof with habitable space shown above, another comparison was made between the three standards using a cold low-pitched roof option using construction methods described in Table 4.10. For this comparison it was assumed that the eaves were at first floor ceiling level.

| Table 4.10: Cold low pitched roof option (no habitable roof space) | | | |
|---|---|---|---|
| *Note: as explained in Table 4.4, non-standard thicknesses of building materials have been used for modelling purposes only.* | | | |
| | ADL95 | ADL02 | EPS08 |
| Cold low-pitched roof | Low-pitched ($25^0$) cold roof using standard trusses.<br><br>100mm mineral wool insulation between and 53mm over joists. | Low-pitched ($25^0$) cold roof using standard trusses.<br><br>100mm mineral wool insulation between and 132mm over joists. | Low-pitched ($25^0$) cold roof using dropped chord trusses.<br><br>100mm mineral wool insulation between and 139mm over joists. |

The EPS08 house was modelled with dropped chord trusses to allow a continuation of the loft insulation to provide better thermal performance at eaves. In this way, thermal bridging for the roof of the EPS08 house was half that of the ADL02 cold roof. The whole element U values for walls, ground floor and windows were the same as previously in the warm roof comparison.

With this cold roof construction, insulation was laid between, and on top of, joists at the upper floor ceiling level. This has two consequences: as there is no habitable roof space, the standard of accommodation is less in a cold roof house. The corollary of this is that there is a smaller space-heating requirement. In short, the cost of heating is lower but only at the detriment of the habitable roof space.

| Table 4.11: Whole element U value requirements for warm and cold roofs ($W/m^2K$) | | | |
|---|---|---|---|
| | ADL95 | ADL02 | EPS08 |
| Uroof warm | 0.35 | 0.20 | 0.16 |
| Uroof cold | 0.25 | 0.16 | 0.16 |

Table 4.11 demonstrates that, in earlier standards, separate U value targets were specified for warm and cold roofs whereas the EPS08 requires the same value for each.

The results of the comparison of energy and environmental performance with a cold roof construction is presented in Figures 10 to 13, below.

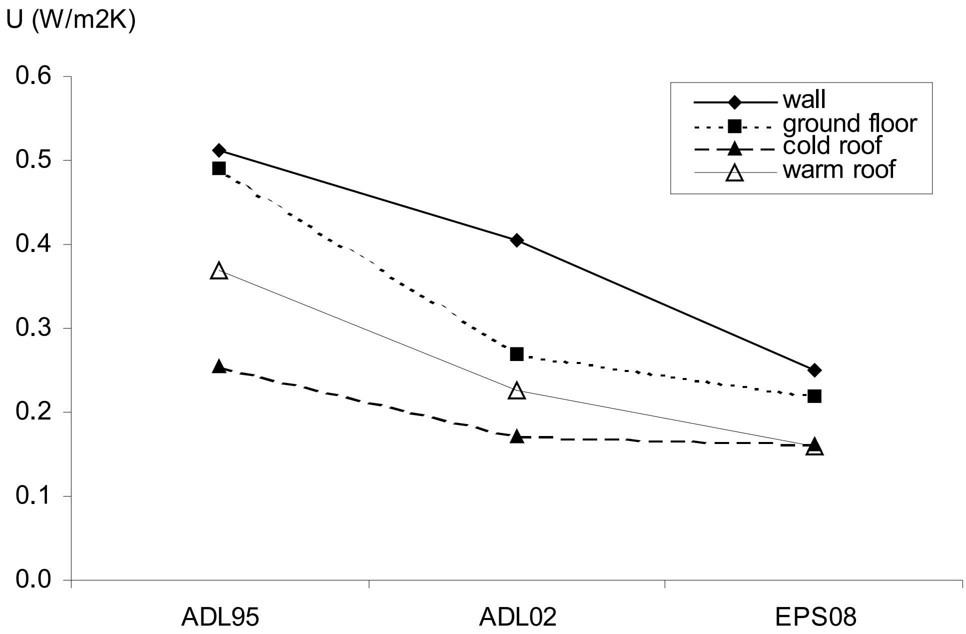


Figure 4.11: Elemental U values including linear thermal bridging.

Elemental U value requirements for houses with cold roofs are shown in Figure 4.11. Also shown are the requirements for a warm roof. All roofs are required to meet 0.16 $W/m^2K$ in EPS08.

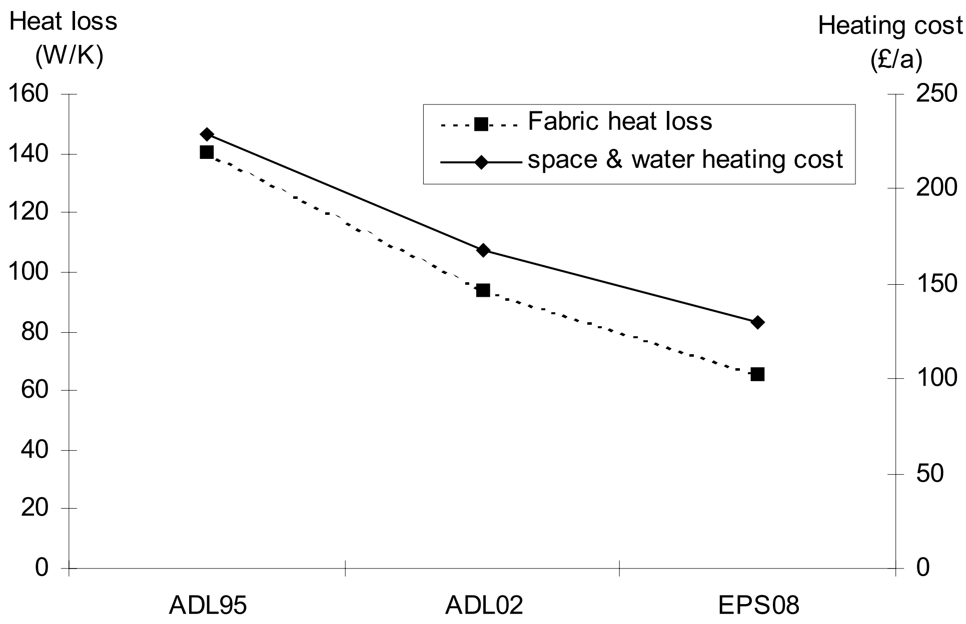


Figure 4.12: Predicted fabric heat loss & heating cost (cold roof house).

The fabric heat loss was almost the same as for the warm roof houses and the space and water heating cost only 5% lower.

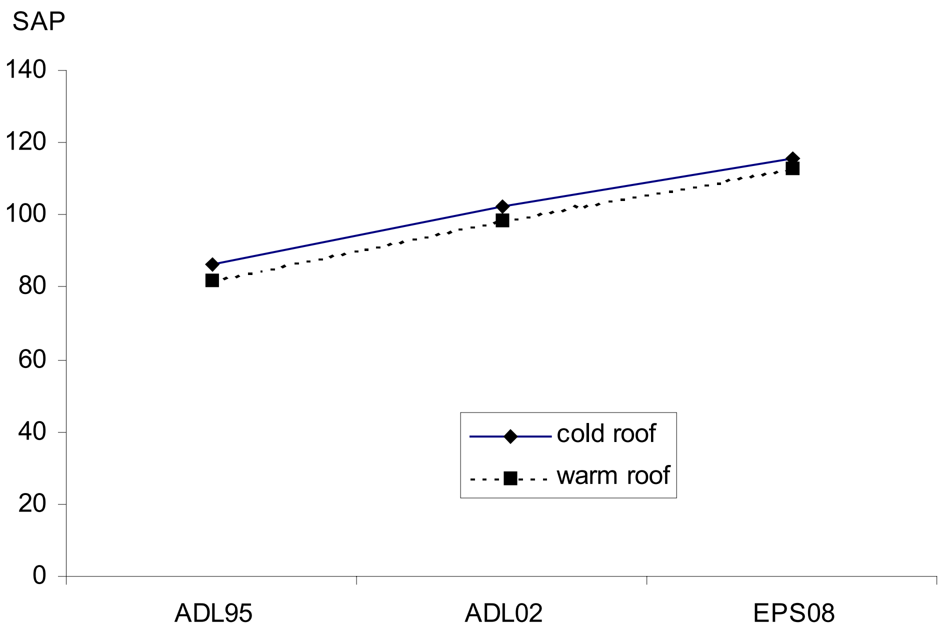


Figure 4.13: SAP ratings for warm roof and cold roof houses.

Figure 4.13 shows the SAP ratings achieved by the three standards for warm roof houses and for cold roof houses. The cold roof SAPs are slightly higher than the warm roof equivalents due to the way that the SAP algorithm incorporates gross floor area and heated volume. The larger gross floor area in the warm roof design offsets most of the higher energy consumption.

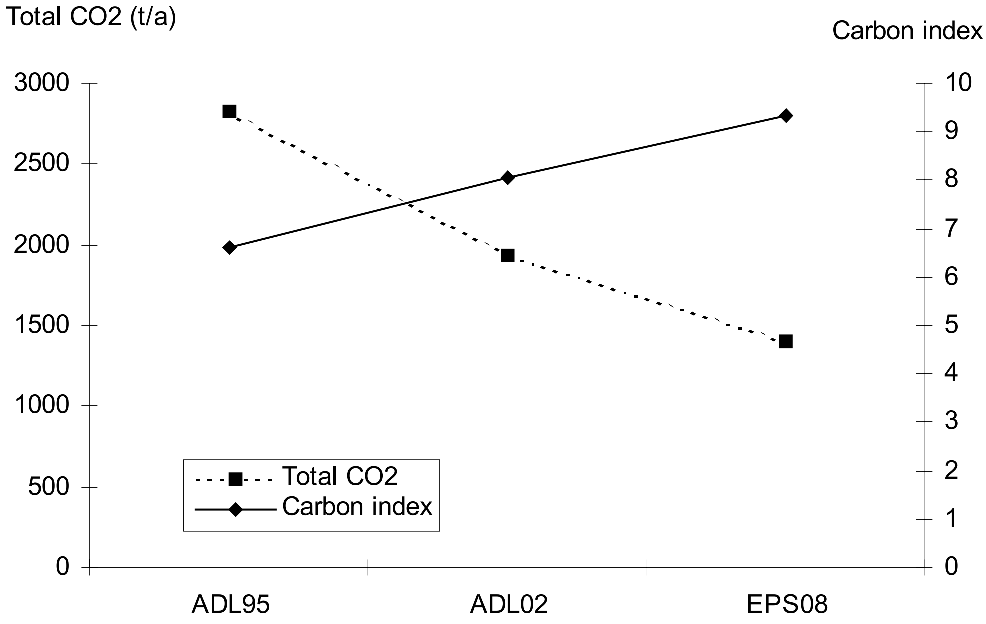


Figure 4.14: Carbon emissions and carbon index (cold roof house).

Carbon emissions were lower in the cold roof houses: 1.58 t/a (warm roof house) down to 1.44 t/a (cold roof house). However, this did not translate into an improved carbon index which went down from 8.9 to 8.6. This is because the increased floor area in the warm roof design offset the additional carbon emissions. The implication is that the warm roof design provides additional floor area in a carbon-efficient way.

## 4.13 Anticipated window performance

A study was made (Roberts & Lowe, 2002) which explored the actual and potential performance of double-glazed timber windows to see whether they were capable of meeting the EPS08 (whole window U value no higher than 1.3 W/m$^2$K or a domestic window energy rating (DWER) of 70 or better). A brief synopsis of the work follows and full details are given on the CeBE website.

The starting point for the work was a high performance timber-framed window that incorporates an intermediate low emissivity coating, an argon-filled gas space and a standard aluminium spacer to achieve a whole window U value of 1.66 W/m$^2$K and a domestic window energy rating of 68.1. The exercise shows that it is possible to achieve the DWER target, defined above, by adopting warm edge technology (in this case, Superspacer), an intermediate emissivity coating ($\varepsilon$=0.083) and replacing argon with krypton in the gas space of the insulating glazing unit. However, meeting the U value target appears more difficult, even with a very low emissivity coating ($\varepsilon$=0.026).

The substantive conclusion from this study is that the proposed window standard is near the limit of what can be achieved with double glazed timber-framed windows using existing frame and glazing technologies. However, this paper represents a first foray into this territory. It is based on only one frame type and a small number of glazing systems - all North American. Considerably more work would be needed to provide a comprehensive overview of the likely impact of window energy rating and the proposed performance standard on windows in the UK market.

There are a number of options for increasing the performance of timber double glazed windows further. We have shown that adding a 2-stage seal to the sill section achieves a small improvement (≈1.5%). Future work could explore the practicalities of using very wide glazing cavities which appear to give better overall performance despite poorer centre pane U values. Significant improvements would require the re-design of the timber frame profile to reduce its U value. Such options would be available in the medium-to-long term but have not been explored here.

This exercise has confirmed that the enhanced energy performance standard proposed by LMU can be met with timber windows of both BFRC standard sizes, with a combination of Superspacer, optimised low emissivity coatings and krypton-filled gas spaces. The standard is a demanding one for such windows and designs with higher frame fractions - for example, multi-light windows or windows with decorative glazing bars - may not meet the standard. However, it appears that the glass products used in this analysis may have been optimised by manufacturers for a mixed or cooling dominant climate characteristic of much of continental North America rather than for the heating-dominant climates of northern Europe. Use of glass products optimised for heating-dominant climates might well result in improved solar transmission and energy ratings, and lift more of the window variants examined in this study, above the DWER 70 threshold. The absence of entries from major European manufacturers from the LBNL glazing products database is a severe limitation on the work that can currently be carried out.

Despite its limitations, this study represents a first step to a full understanding of the impacts of the BFRC's window energy rating system and LMU's enhanced energy performance standard on the UK window market. The work now needs to be extended to other framing materials (including uPVC, aluminium, steel and pultruded fibreglass) and to include a comprehensive range of frame sections, glazing systems and window configurations for each material.

### 4.14 Ventilation issues – review of expected ventilation and thermal performance of MEV and MVHR systems

As different models of MVHR and MEV equipment exhibit different performance characteristics, an attempt was made to create three performance categories in the Parametric Domestic Energy Model (these could be included in future versions of SAP). Specific fan power and efficiency were used to define categories of 'low' 'medium' and 'high' system performance, as shown in Table 4.12.

| Table 4.12 Ventilation system performance default data. | | | |
|---|---|---|---|
| | Performance category | | |
| | Low | Medium | High |
| MVHR efficiency | 0.66 | 0.75 | 0.85 |
| MVHR specific fan power | 2 | 1.5 | 1 |
| extract-only specific fan power | 0.8 | 0.6 | 0.4 |

The two ventilation strategies were compared at 'low' 'medium' and 'high' system performance using the final house design. Then a study was made of the effect of increased airtightness on MVHR performance. Here, airtightness was incrementally improved from 3 m/h (the final house design house) to 2.5, 2.0, 1.5, 1.0 and 0.5 m/h.

## 4.15 Results of ventilation strategy comparison

Results of the comparison of MVHR and MEV are shown in Figures 4.14 to 4.19.

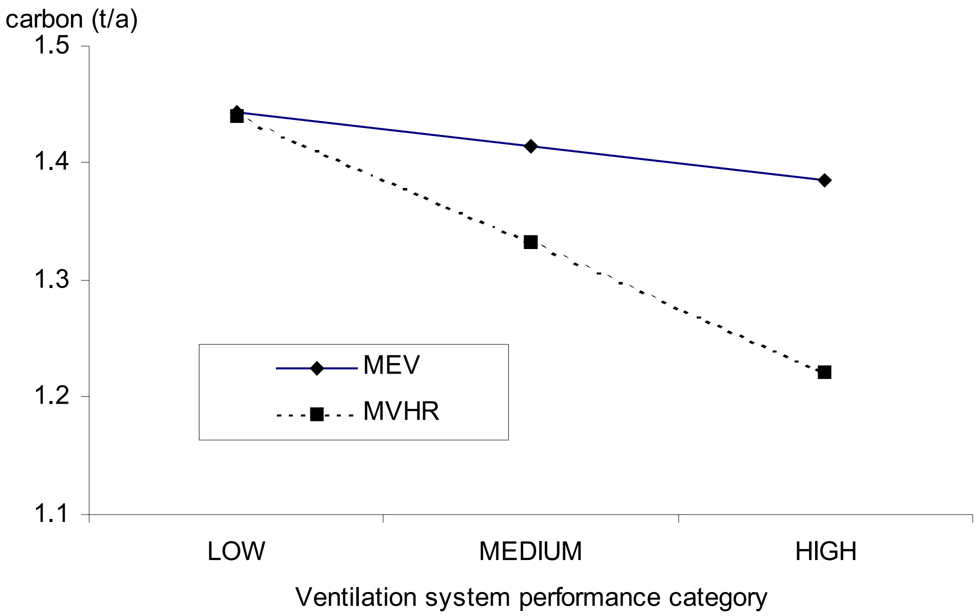


Figure 4.15: Carbon emissions using MEV and MVHR ventilation strategies operating at three levels of system performance.

At 'low' performance, both ventilation strategies give the same carbon emissions of 1.44 t/a, see Figure 4.15. Higher performing MEV gives slightly reduced emissions but a 'high' MVHR gives much greater reductions in carbon, from 1.44 to 1.22 t/a.

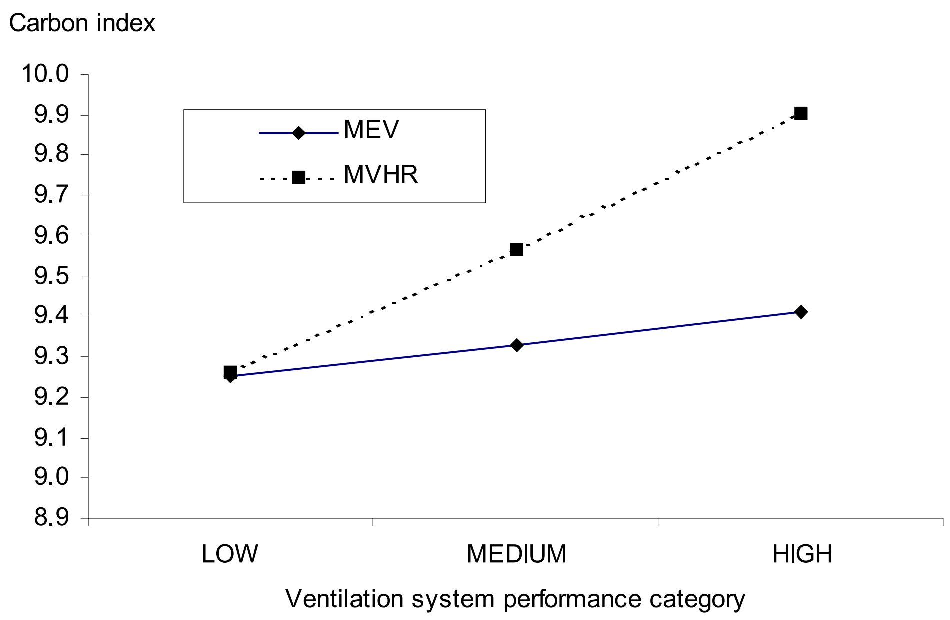


Figure 4.16: Carbon index using MEV and MVHR ventilation strategies operating at three levels of system performance.

As shown in Figure 4.16, the carbon index is higher in all MVHR performance categories and rises by 6.5% from the ‘low’ to the ‘high’ category. The corresponding change with MEV is only 2.1%

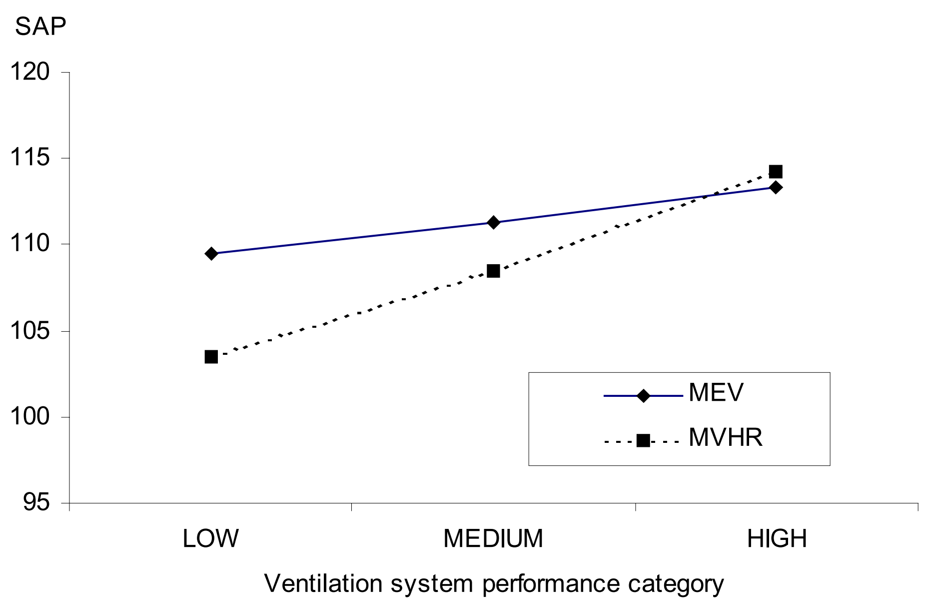


Figure 4.17: SAP rating using MEV and MVHR ventilation strategies operating at three levels of system performance.

MEV achieves a higher SAP rating than MVHR at ‘low’ and ‘medium’ performance categories but MVHR attains a higher SAP of 114.3 when in the ‘high’ category, as shown in Figure 4.17.

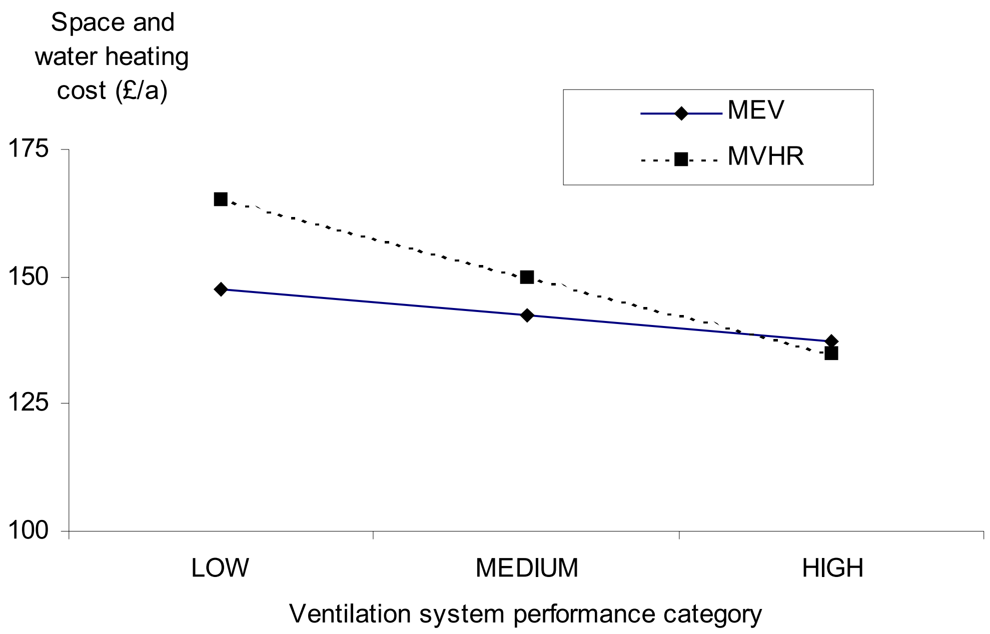


Figure 4.18: Space and water heating costs using MEV and MVHR ventilation strategies operating at three levels of system performance.

Although the heating cost of MVHR is £17.67 higher than MEV in the ‘low’ system performance category, the cost of using MVHR falls more quickly as performance increases and at the ‘high’ category, MVHR costs less than MEV.

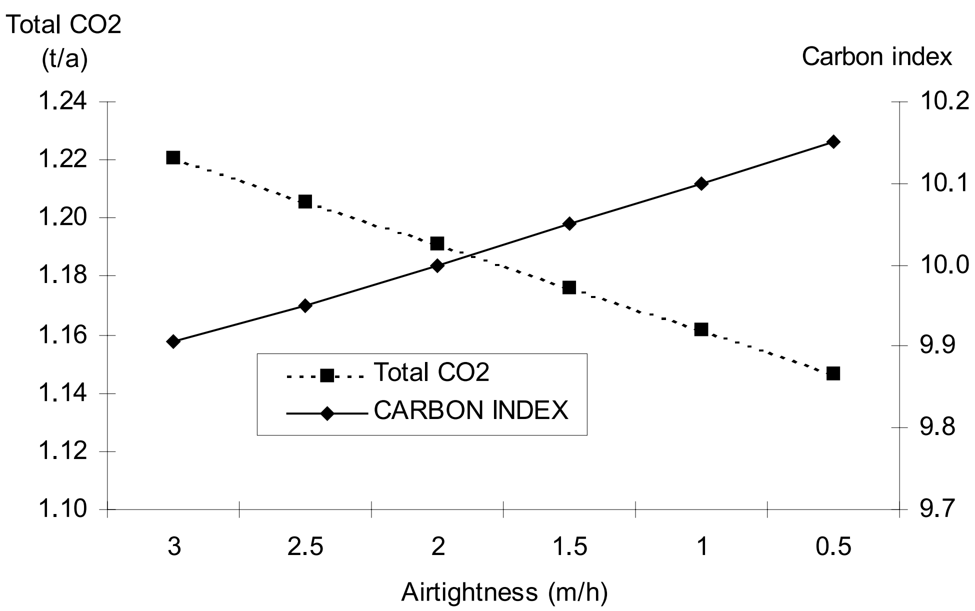


Figure 4.19: Carbon emissions and Carbon Index using ‘high’ performing MVHR at different airtightness standards.

Carbon emissions reduce and the Carbon Index rises as airtightness is reduced to values below 3 m/h, as shown in Figure 4.19. A Carbon Index of 10.15 was achieved at 0.5 m/h.

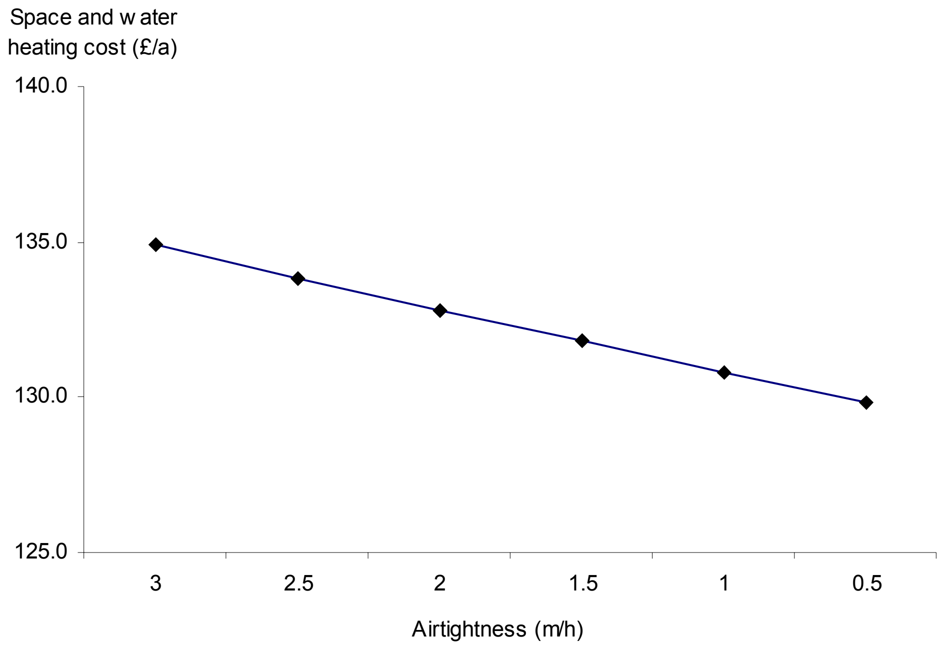


Figure 4.20: Space and water heating cost using ‘high’ performing MVHR at different airtightness standards.

Figure 4.20 shows that increasing airtightness to values below 3m/h can further reduce the heating cost from £135 to £129.80.

## 4.16 Additional benefits of MVHR

Many of the benefits of MVHR may be qualitative and therefore beyond the scope of this spreadsheet –based comparison. Improved air quality, lower humidity and lower dust mite populations are believed to be major benefits to the householder.

As part of the final house design for St Nicholas Court, it was calculated that, with MVHR, it was possible to omit radiators in bedrooms and place downstairs radiators near core walls thereby simplifying the pipework runs (full report in Appendix 1). Construction cost savings at this scale can be seen to easily outweigh any additional running costs. The partnering approach to the design of St Nicholas Court has allowed many discussions of this nature to occur with the result that the designer and the client have confidence in innovative methods of construction. In the past, it seems, doubt, not data has been the barrier to change.

## 4.17 Carbon intensity of heating

The carbon intensity of heating for the final house design was 60 which meets the EPS08 target of less than 70 and was calculated from:

$$c_h = c_d/\eta = 54 / 0.907 = 60$$

where:

$c_h$ = carbon intensity of useful heat ($kg(CO_2)/GJ$)
$c_d$ = carbon intensity of delivered energy ($kg(CO_2)/GJ$)
$\eta$ = thermal efficiency or coefficient of performance of heating system

It should be noted that this does not include parasitic electrical losses from, mainly, the fan energy and central heating pump. Inclusion of these losses would raise the carbon intensity for these boilers to perhaps 64 ($kg(CO_2)/GJ$) – still within the EPS08 limit.

## 4.18 Summary of main findings:

- The cost of space and water heating for the St Nicholas Court houses built to EPS08 is approximately half that of the same house built to 1995 standards. This is consistent with the predictions for a smaller generic house type presented in Chapter 3.

- Houses built to EPS08 produce less than half the carbon emissions from houses built to the 1995 standard. The final house design goes further still and shows that carbon emission reductions of 57% are possible compared with ADL95. Once again, this is consistent with the generic predictions of Chapter 3.

- Fabric heat loss for the ADL95-compliant envelope was more than twice that of the EPS08-compliant envelope.

- Inclusion of thermal bridging at junctions between building elements increased the total fabric heat loss of the dwelling by approximately 6.5%. This figure is in addition to thermal bridging within elements (for example through wall studs and rafters).

- Further reductions in thermal bridging may be difficult using traditional timber frame technology. It may be possible to reduce losses through the junction of ground floors and walls, for example by casting floor slabs directly onto thermal insulation.

- I-beam technology appears to offer opportunities to rationalise and simplify the design and construction of dwellings and to make it easier to reduce thermal bridging and air leakage. The proposed use of timber I-beams in the roof at St Nicholas Court makes it possible to bring all building services into the heated volume of the building and essentially to eliminate heat losses from the mechanical ventilation system.

- Inclusion of thermal bridging at junctions with other elements increases whole element U values of walls, ground floors and roofs from 0.23, 0.19 and 0.11 $W/m^2K$, to the EPS08 elemental maxima of 0.25, 0.22 and 0.16 $W/m^2K$

respectively. Similar ratios may be expected for other buildings of similar timber-framed construction. Different ratios may be expected to apply to other forms of construction.

- Consideration of thermal bridging within the design process appears to have resulted in significant reductions in heat loss at certain junctions. For example, thermal bridging for the roof of the EPS08 house, using dropped-chord trusses which allow undiminished thickness of insulation at eaves, was half that of the ADL02 cold roof which used traditional trusses.

- Carbon emissions were lower in the cold roof houses: 1.58 t/a (warm roof house) down to 1.44 t/a (cold roof house). However, this did not translate into an improved carbon index, which went down from 8.9 to 8.6. This is because the increased floor area in the warm roof design offset the additional carbon emissions. The implication is that the warm roof design provides additional floor area in a carbon-efficient way.

- The proposed window standard is near the limit of what can be achieved with double glazed timber-framed windows using existing frame and glazing technologies. The main area of improvement still to be incorporated into windows is warm edge spacer technology.

- ‘Low performance’ MVHR and MEV give the very similar carbon emissions. Although ‘high performance’ versions of both types of ventilation system showed reduced emissions, the reduction in the case of MVHR was significantly greater.

- A move from ‘low’ to ‘high performance’ MEV system is predicted to raise the carbon index by 0.1. The corresponding change in the case of MVHR increased the carbon index by 0.6.

- MEV is predicted to outperform MVHR in terms of running cost and SAP rating at ‘low’ and ‘medium’ system performance. The differences between SAP and Carbon Index come about because the prices of gas and electricity differ more than the carbon intensities of these two energy carriers. The consequences of this are particularly noticeable in the case of technologies that trade-off increased electricity use against reduced demand for heating.

- As airtightness is increased below 3m/h, further reductions in carbon are possible in the case of dwellings with MVHR. A reduction in leakage from 3m/h to 0.5 m/h raised carbon index from 9.9 to 10.2 and reduced annual running costs by just over £5 per annum.

- The first order energy and cost benefits of MVHR over MEV are modest. Second order benefits of MVHR may well ultimately be more important. These have elsewhere been found to include improved air quality, lower humidity and lower dust mite populations. In the case of the St Nicholas Court dwellings, the design team was convinced that, with MVHR, it was possible to omit radiators in bedrooms and place downstairs radiators near core walls thereby simplifying the pipework runs.

# Chapter 5 Cost assessment

## 5.0 Introduction

The cost assessment presented in this chapter seeks to make a series of comparisons between construction costs based on the application of the 1995, 2002 and 2008 standards to the St Nicholas scheme. The assessment is based on the final design of the two main house types as set out in Chapter 4[27]. The termination of the research project at the end of the design stage precludes the use of actual construction costs and the estimates used in this chapter have been prepared from data supplied by the project quantity surveyor based on costing data gathered during the design phase. Costs for the 1995 and 2002 alternatives have been based on the same data, modified as necessary to reflect the differences in construction and material quantities. In the case of the final roof design (I-beam warm roof), the material cost data was obtained from an I-beam manufacturer following a detailed structural design. With the exception of the I-beam roof, the base date for costs is September 2001. Costings are based on the construction specifications set out in Chapter 4. In view of the extensive discussion surrounding the design of the roof (see Chapter 6) the cost assessment included an assessment of cold roof and warm roof design options[28].

As indicated above, the costs on which this chapter is based are broad estimates done primarily for budget assessment purposes and as such are limited. At the time of preparation, final detail design remains uncertain and the costs contain a significant number of assumptions as to detailed construction. One of the most important areas of uncertainty is the cost impact of the airtightness standard and the elimination of thermal bridging. Although the costs can take into account the inclusion of such things as air barriers (a design feature that is, to a large extent, a matter of good practice and included in almost all timber frame design in the UK whatever the standard), the cost of ensuring that they are installed effectively cannot be reliably estimated. In theory, with a fully trained workforce, the additional cost should be very small but the lack of a construction phase in this project means that there is no data on which to base an assessment. For example, the final design included a 50mm services space to the internal face of the envelope. This approach was adopted in order to reduce the potential for air barriers to be breached and to provide for flexibility of service routing and to facilitate alterations during the life of the dwelling. This cost has been included in the 2008 standard and discussed in section 5.4. The picture is further compounded by the impact of the compliance method used in design. It would be possible, using the trade-off method, to avoid a large increase in wall construction cost by allowing the wall U-value to increase and to be compensated elsewhere by an element such as the roof (cold construction) where insulation costs are relatively low and/or by reducing expensive window area. Such an approach would have a

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[27] The scheme consists of two, 2 ½ storey house types (2 and 3 bedroom) and two single storey bungalows for the disabled. As in Chapter 4, this chapter will focus on the costs of the 3 bedroom, 5 person type since this is thought to be more representative of the housing stock as a whole.

[28] The initial scheme design proposed a trussed rafter (25°pitch) cold roof. Cold roof costs in this chapter are based on this roof type applied to the floor plans in the final design. Chapter 6 describes the design process that led to the change from cold to warm roof design.

disproportionate impact on costs, since limiting U-values in the 1995 and 2002 standards are much less restrictive than in the 2008 prototype. In this report, costs are based on elemental U-values that meet the elemental standard. Given the above uncertainties, any conclusions drawn on costs must be considered tentative and treated with caution. However the overall picture presented is indicative of the likely scale of the cost impact of the different standards as applied to the dwellings designed for the St. Nicholas Court Scheme.

## 5.1 Results

Tables 5.1 and 5.2 set out the cost assessment for each house type broken down into the different cost elements. Since the design process involved considerable debate about the relative merits of warm roof and cold roof designs, the tables include costs for both. The house types are identical in form and the cost differential (some 10%) is a reflection of floor area variation. In view of this, the analysis is based almost entirely on the 3 bedroom, 5 person house type. In addition, the cost of the sleeping shelf accommodation (about £1,100) has been excluded since this represents the cost of additional accommodation and does not have a bearing on the impact of the different standards.

Table 5.1: Cost analysis: 3 Bedroom 5 person house type – (floor area 98 $m^2$ ).

| | 1995 standard | | 2002 standard | | 2008 standard | |
|---|---|---|---|---|---|---|
| | Cost | % of Total | Cost | % of Total | Cost | % of Total |
| **Base case - warm roof** | | | | | | |
| Substructure & GF | 6,587 | 11.66 | 6,787 | 11.64 | 6,996 | 11.69% |
| Ext. Walls & frame | 9,701 | 17.17 | 10,194 | 17.49 | 10751 | 17.96% |
| Roof | 7,076 | 12.53 | 7,527 | 12.99 | 7,692 | 12.85% |
| Upper floors | 3,060 | 5.42 | 3,060 | 5.25 | 3,060 | 5.11% |
| Windows & ext. doors | 3,892 | 6.89 | 4,221 | 7.24 | 4,308 | 7.20% |
| Internal walls & linings | 5,607 | 9.93 | 5,607 | 9.62 | 6,380 | 10.66% |
| Internal doors | 1,985 | 3.51 | 1,985 | 3.40 | 1,985 | 3.32% |
| Finishes | 2,936 | 5.20 | 2,936 | 5.04 | 2,936 | 4.90% |
| Sanitary | 1,593 | 2.82 | 1,593 | 2.73 | 1,593 | 2.66% |
| Fittings | 2,423 | 4.29 | 2,423 | 4.16 | 2,423 | 4.05% |
| Services[1] | 5,776 | 10.22 | 5,776 | 9.91 | 5,884 | 9.83% |
| Preliminaries | 5,857 | 10.37 | 5,857 | 10.05 | 5,857 | 9.78% |
| Total (warm roof) | 56,493 | 100.00 | 57,966 | 100.00 | 59,865 | 100.00 |
| | | | | | | |
| **Cold roof option** | | | | | | |
| Roof | 6,768 | 12.11 | 6,953 | 12.18 | 6,953 | 11.85 |
| Internal walls & linings | 5,297 | 9.48 | 5,297 | 9.28 | 5,948 | 10.13 |
| Other elements | 43,810 | 78.41 | 44,832 | 78.54 | 45,793 | 78.02 |
| Total (cold roof) | 55,875 | 100.00 | 57,082 | 100.00 | 58,694 | 100.00 |
| Difference | -618 | | -884 | | -1,171 | |

| Table 5.2: Cost analysis: 2 Bedroom 4 person house type – (floor area 79 $m^2$ ). | | | | | | |
|---|---|---|---|---|---|---|
| | 1995 standard | | 2002 standard | | 2008 standard | |
| | Cost | % of Total | Cost | % of Total | Cost | % of Total |
| **Base case - warm roof** | | | | | | |
| Substructure & GF | 6,214 | 12.06 | 6,385 | 12.02 | 6,566 | 11.99 |
| Ext. Walls & frame | 9,176 | 17.81 | 9,642 | 18.15 | 10,169 | 18.57 |
| Roof | 6,260 | 12.15 | 6,628 | 12.55 | 6,768 | 12.36 |
| Upper floors | 2,661 | 5.16 | 2,661 | 5.01 | 2,661 | 4.86 |
| Windows & ext. doors | 3,369 | 6.54 | 3,648 | 6.87 | 3,897 | 7.11 |
| Internal walls & linings | 4,824 | 9.36 | 4,824 | 9.08 | 5,522 | 10.08 |
| Internal doors | 1,850 | 3.59 | 1,850 | 3.48 | 1,850 | 3.38 |
| Finishes | 2,648 | 5.14 | 2,648 | 4.99 | 2,648 | 4.83 |
| Sanitary[1] | 1,593 | 3.09 | 1,593 | 3.00 | 1,593 | 2.91 |
| Fittings | 2,423 | 4.70 | 2,423 | 4.56 | 2,423 | 4.42 |
| Services | 4,656 | 9.04 | 4,656 | 8.77 | 4,821 | 8.80 |
| Preliminaries | 5,857 | 11.37 | 5,857 | 11.03 | 5,857 | 10.69 |
| TOTAL (warm roof) | 51,531 | 100.00 | 52,815 | 100.00 | 54,775 | 100.00 |
| | | | | | | |
| **Cold roof option** | | | | | | |
| Roof | 6,022 | 11.81 | 6,168 | 11.85 | 6,168 | 11.47 |
| Internal walls & linings | 4,529 | 8.88 | 4,529 | 8.70 | 5,110 | 9.50 |
| Other elements | 40,447 | 79.31 | 41,363 | 79.45 | 42,485 | 79.02 |
| TOTAL (cold roof) | 50,998 | 100.00 | 52,060 | 100.00 | 53,763 | 100.00 |
| Difference | -533 | | -755 | | -1,012 | |

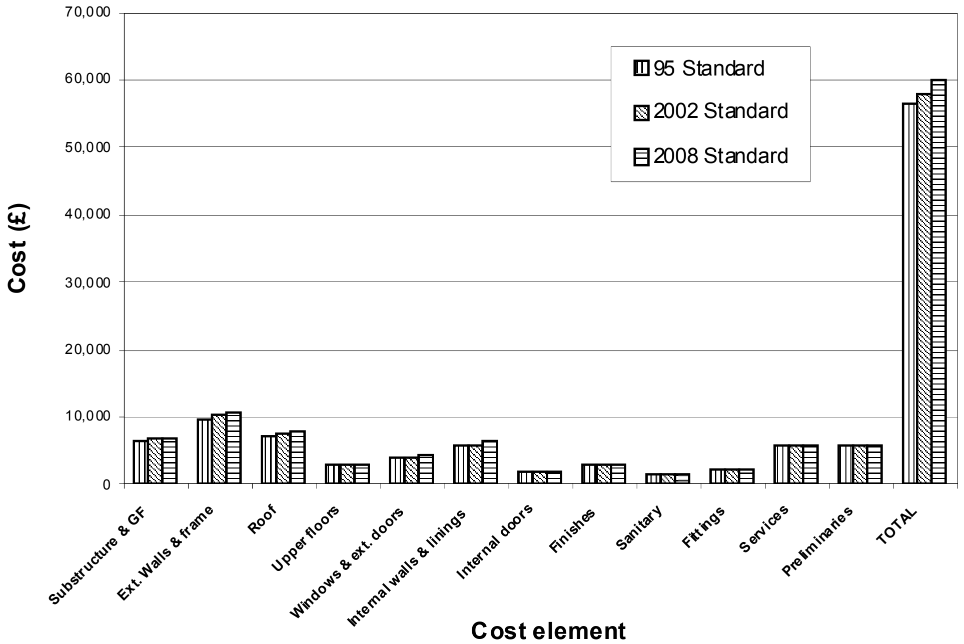



Figure 5.1: 3Bed 5Person house: cost variation by standard (warm roof design).

Figure 5.1 illustrates the overall cost picture for the 3 Bed house type (warm roof) and shows a difference in total cost of £3,372 as between the 1995 and 2008 standards. This represents an increase of just under 6% on the 1995 cost. The change in total cost is slightly lower in the 2002 case than for the 2008 standard with an increase of 2.6% (£1,473) from 1995 to 2002. The change from 2002 to 2008 adds a further £1,899 (3.4 percentage points). The cost impacts are concentrated in six areas and the relative change in each area is illustrated in Figure 5.2. The following sub sections discuss the behaviour of the cost variations in each of these areas.

## 5.2 Sub structure and ground floor

The progression of substructure costs is almost entirely due to the increased insulation thickness. For the 3 bedroom house type the cost increases by about £200 (3%) for each increment in standard, resulting in an overall increase to 2008 of about 6%.

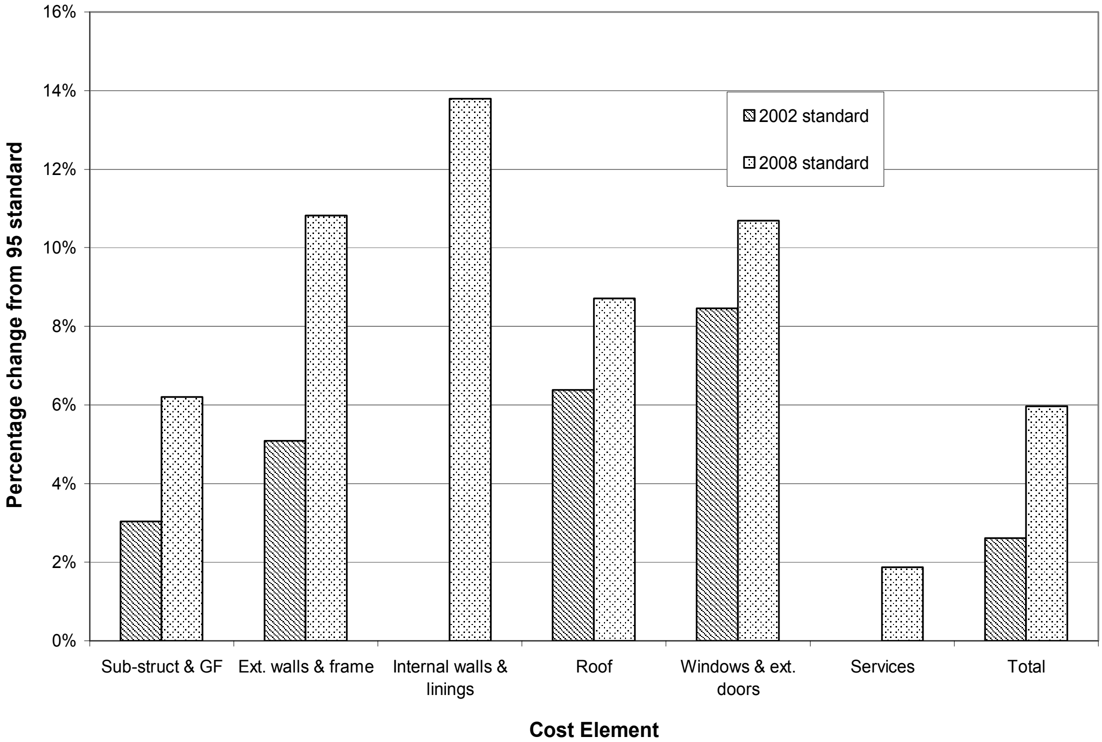



Figure 5.2: 3 bed 5 person house, percentage cost variation for key elements.

## 5.3 External walls

In common with substructure, the cost picture for external walls presents an even progression with a 5% (£493) increase as a result of the 2002 standard and a further £557 (5.8 percentage points) to achieve the 2008 standard. However the total extra cost of the 2008 standard (£1,050) represents the second largest percentage increase of any cost area at 10.8% and the largest absolute increase. In fact this increase accounts for just under a third (31%) of the total additional cost of the 2008 standard.

Unlike the substructure, which required no change in basic construction, both constructional and material changes were required to the walls in order to meet the different standards. In the case of the 2002 standard two construction variants were assumed. One using a standard 140 × 38 mm stud with mineral fibre insulation between and one using a 89 × 38 mm stud with 22mm of expanded polystyrene insulation fixed across the outside of the studs[29]. The latter specification was used to derive the costs in Tables 5.1 and 5.2 since this resulted in the lowest cost by a margin of £146. The cost increase for the 2008 standard is the result of the need for a rigid insulation board of increased thickness (from 22mm to 40mm) and, a change in material from expanded polystyrene to the more expensive rigid urethane (see construction details in Chapter 4). The significance of the cost of the external insulation raises a question as to the cost effectiveness of the construction chosen in comparison with other approaches. As discussed in Chapter 6 the wall design was driven by concerns over thermal bridging and the need to avoid excessive wall thickness and the use of large section (189mm) timber. Although a more radical solution using timber I-beams was discussed it was thought, at the time, to be prohibitively expensive[30]. However recent experience with the cost of I-beams for the warm roof (see below) suggest that this may no longer be the case. The insulation costs for the over-clad solution amount to about £14/m$^2$. If the required insulation levels could be achieved with the use of mineral fibre this would fall to about £8/m$^2$. In order to be more cost effective, an I-beam solution would have to add more than £6/m$^2$ to the structure cost of the wall panels. Evidence from the detailed cost estimates for the I-beam roof suggests that the additional cost of an I-beam wall could well be less than the £6/m$^2$ breakeven point indicated above. Clearly, more detailed work is required to clarify the position but the above assessment would suggest that a much more radical approach to the production of well insulated timber frame walls may result in costs that are somewhat lower than has been accepted, hitherto.

## 5.4 Internal walls and linings

The additional cost of £773 for internal walls and linings, an increase of just under 14% on the 1995 and 2002 standard, is the second largest absolute increase. The whole of this extra cost is attributable to the decision to provide a services space between external wall structure and the internal plasterboard lining. The inclusion of this cost raises important questions about the interplay between design decisions and the standards themselves. The provision of the services space was justified on the grounds of future service flexibility as well as a means of ensuring the integrity of the air barrier. It is arguable that a clear space for services is good construction practice and as such should be treated as a matter of "good detailed design" rather than a difference of standard. However the lack of airtightness testing in 1995 and 2002 enables house builders to avoid the issue and continue the rather hit-and-miss approach of taping and sealing service penetrations for electric and other services, a practice that is known to lead to significant quality problems and dwellings with high leakage rates.

[29] Quite apart from the apparent cost advantages, this form of construction would result in less timber, reduce the need for the use of large section mature timber and reduce the extent of thermal bridging across the insulation.
[30] The extra cost quoted in the proposals submitted by the partnering contractor was £3200 per dwelling (see Chapter 6, Figure 2).

If one were to accept that a “tape and seal” approach is a reliable way of achieving the required level of airtightness (5m/h) then the services space becomes a function of design (for flexibility and future modification reasons) rather than a function of regulatory standard. Such an approach would result in no additional cost in this area. The net effect would be a reduction of £773 to give an extra total cost of only £2599 for the 2008 standard, representing some 4.6% increase on 1995 costs.

## 5.5 Roof

Warm roof costs display a larger increase from 1995 to 2002 (£451 – 6.4%) than between 2002 and 2008 ( a further £165 – 2.3 percentage points). This is not surprising given the U value difference of 0.15 $W/m^2K$ between the 1995 and 2002 standard (from 0.35 to 0.2) and 0.04 between 2002 and 2008 (from 0.2 to 0.16). In the case of the cold roof 2002 and 2008 elemental U values are identical. Cold roof costs across the board are lower but not by as much as is often imagined.

The roof costs illustrate the importance of detailed design in achieving any given standard. The assumed warm roof specification for 2002 (over-clad 150mm traditional rafter roof) was chosen initially for costing purposes because it was considered to be the solution most likely to be adopted in response to the 2002 regulation. It was however surprising to discover that in this case it was more expensive than the I-beam solution used for 2008 compliance. In view of this, an I-beam solution, using just enough mineral fibre insulation (200mm) to achieve the required U value was used in the cost analysis for Tables 5.1 and 5.2. Table 5.4 shows the cost breakdown for the key elements in each construction and includes both the traditional rafter and I-beam options for the 2002 standard (U=0.2 $W/m^2K$). Although the cost of the I-beam structure is about £300 higher than the costs of a traditional rafter construction, the cost of the external cladding insulation (rigid urethane) adds some £790. In this case it is clear that, despite initial concerns over the cost of timber I-Beams they are likely to prove to be a cost effective solution for both current and future standards.

Table 5.4: Roof cost analysis.

| Element | 1995 | 2002 (trad rafter) | 2002 (I-Beam) | 2008 | 2008 Cold roof[1] |
|---|---|---|---|---|---|
| | £ | £ | £ | £ | £ |
| Structure | 1,059 | 1,047 | 1,345 | 1,345 | 1,619 |
| Insulation | 495 | 1,293 | 661 | 826 | 556 |
| Cladding flashings & roof drainage | 5,521 | 5,521 | 5,521 | 5,521 | 4,778 |
| Total | 7,075 | 7,861 | 7,527 | 7,692 | 6,953 |

*Notes:*
*1. The cost of the cold roof design includes an amount of £568 to cover the cost of additional wall area required in order to ensure adequate room heights on the first floor.*

As discussed in Chapter 6 the design process included considerable debate about the relative merits of warm and cold roof constructions. During design discussions throughout 2000, cost was a major factor. The prevailing cost view at the time was that the cost of a warm I-Beam construction was considerably higher than an equivalent cold roof design. So dominant was the cost argument that it took the combined arguments of increased amenity (a sleeping shelf in the main bedroom) and technical merit (ease of maintaining airtightness and avoiding thermal bridging) coupled with a redesign involving cost savings elsewhere to overcome the perceived cost difficulty. The cost argument appears to have been based on the initial budget costings in 1999 which suggested an extra cost of some £2,000 per dwelling. However the more detailed I-Beam roof costing done for this report would suggest a considerable reduction in costs as the availability and application of I-beams (mainly for internal floors) within the UK construction industry has increased. The costs in Table 5.4 suggest that in the case of the St. Nicholas Court dwellings the costs of an I-Beam roof structure may be less than a trussed rafter roof. The lower overall cost for the cold roof is due to a reduction in the quantity of insulation required, a reduced area of internal lining (insulation and lining to a horizontal loft rather than in the slope) and a reduced area of roof covering, resulting from a lower pitch (25° as opposed to 45°).

Cost reductions for the cold roof design were relatively modest across all standards with differences between 1% and 2% of total build costs (£618 -1995 standard, £884 - 2002 and £1,171 - 2008). Given the considerable technical and amenity benefits of warm roof construction this is a relatively small price to pay.

## 5.6 Windows and Doors

In line with other areas the costs for windows and doors tend to show a larger increase from 1995 to 2002 (8.5%) than from 2002 to 2008 (an additional 2.2 percentage points). This reflects the change from double glazed units using plain glass to Low-E units and then to super low-E, argon filled units. Since, at the time the costing was carried out, the window specification was the least well developed, these costs should be treated with extreme caution. As discussed in Chapter 4, analysis of glazing design relating to the 2008 standard (Roberts and Lowe 2002, see Appendix 3) suggests that a U-value of 1.3 $W/m^2K$ would be difficult, but not impossible, to achieve with double glazing. A combination of argon fill, insulating edge spacer and intermediate low-E coating ($\varepsilon = 0.083$) could achieve a U value below the limiting value of 1.56 contained in EPS08 and come very close to the required DWER of 70. Careful design work by the window supplier to the Brookside Farm project has resulted in certified values of U = 1.3 $W/m^2K$ and DWER = 70.7 for a CEN standard fixed light window (1231 × 1480). The need for painstaking design and, possibly, the use of krypton fills as well as warm edge technology may result in cost increases in the short term but as optimised products are developed this would be expected to come down.

## 5.7 Services

Services costs for the 2008 standard are based on the installation of a mechanical extract ventilation system (MEV). However, the scheme design anticipated the installation of both MEV and mechanical ventilation with heat recovery (MVHR). Table 5.5 shows the relevant costs of each system within the context of total services cost and the different standards. The costing suggests that the 2008 standard would have only marginal cost impact over the 1995 standard where MEV ventilation was specified. In this case the extra cost of the MEV system (£586) has been accommodated by a reduction in the scale of the central heating system. The higher insulation and airtightness standards together with post construction airtightness testing provided the heating designer with the necessary confidence to close-size the heating system[31]. Not only are radiators smaller but, in the case of the MVHR system, it was considered unnecessary to site radiators on outside walls. This resulted in a much more compact distribution system. In the case of the MVHR dwellings it was also decided to dispense with radiators in bedrooms, relying instead on a landing radiator and a heated towel rail in the bathroom. However, confidence in this approach was not total and distribution pipe stubs were to be installed to enable the system to be extended if required (see Chapter 6). The reduction in radiators accounted for the £220 difference between the heating systems in the 2008 MVHR and MEV dwellings.

Table 5.5: Service cost break-down.

| Element | 1995 | 2002 | 2008 (MEV) | 2008 (MVHR) |
|---|---|---|---|---|
| | £ | £ | £ | £ |
| Space & water heating | 2128 | 2128 | 1650 | 1433 |
| Ventilation[1] | 0 | 0 | 586 | 1275 |
| Other (ex. waste water & drainage) | 3648 | 3648 | 3648 | 3648 |
| Total | 5776 | 5776 | 5884 | 6356 |

*Notes:*
*1. Costs of extract fans for 95 and 02 standards are included in the cost of space and water heating*

The efficiency demands of the 2002 standard are not large enough to require the installation of a condensing boiler and the cost differential is estimated to be zero. Unlike the 2008 assumptions, those in the 2002 case do not include for any reduction in the heat distribution system since, in our view, the 2002 standards are unlikely to enable significant cost saving to be realised in this way. In order for this to happen, not only would it be necessary for standards to be higher (particularly the airtightness standard) but there must be a high level of confidence in the fit between nominal performance and realised performance. Since the 2002 requirements do not include the post construction testing of airtightness, and significant thermal bridging remains (robust details, notwithstanding) it would be a brave heating designer who would specify a significantly reduced system or to leave radiators out of bedrooms.

## 5.8 Cost effectiveness

The relationship between the marginal capital cost and energy and $CO_2$ savings for the 2002 and 2008 standards is explored in Table 5.6. All data relate to the 3 bedroom, 5 person house type. The capital construction cost information is taken from the figures in this chapter and the energy and $CO_2$ data is taken from the assessments in Chapter 4. Two alternatives are presented for the 2008 standard depending on whether the cost of providing an internal services space is included (high cost) or excluded (low cost). The inclusion, or not, of this feature is a definitional question and is discussed in section 5.4 above.

[31] During the design phase the heating and ventilation supplier remarked on more than one occasion that in the past attempts to close size heating systems have run into problems because of uncertainties in heat loss estimates, particularly the impact of thermal bridges and control of airtightness. Commenting on this project he indicated that it is the only one they have been involved with that sought to address these issues explicitly and therefore provided greater confidence in a close sized design.

| Table 5.6: Cost effectiveness analysis – 3Bed 5Person house. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Warm roof | | | | Cold roof | | | |
| Standard | 1995 | 2002 | 2008[1] high cost | 2008[1] low cost | 1995 | 2002 | 2008[1] high cost | 2008[1] low cost |
| | | | | | | | | |
| total capital cost | 56493 | 57966 | 59865 | 59092 | 55875 | 57082 | 58694 | 58043 |
| Additional capital cost (£/a) | - | 1473 | 1899 | 1126 | - | 1207 | 1612 | 961 |
| Annual equivalent of capital cost[2] | | 53.22 | 68.62 | 40.69 | | 43.61 | 58.25 | 34.72 |
| | | | | | | | | |
| Energy cost - space & water heating (£/a) | 270.59 | 202.38 | 153.45 | 153.45 | 248.69 | 186.50 | 142.09 | 142.09 |
| Energy cost saving (£/a) | - | 68.21 | 48.94 | 48.94 | - | 62.20 | 44.41 | 44.41 |
| | | | | | | | | |
| Carbon emissions - space & water heating (t/a) | 3.27 | 2.28 | 1.58 | 1.58 | 2.98 | 2.08 | 1.44 | 1.44 |
| Carbon dioxide saving (t/a) | | 0.98 | 0.71 | 0.71 | | 0.90 | 0.64 | 0.64 |
| Carbon dioxide cost saving @ £93.84/t (C)[3] | | 25.20 | 18.08 | 18.08 | | 22.98 | 16.41 | 16.41 |
| | | | | | | | | |
| Simple payback period (energy only) | - | 21.6 | 38.8 | 23.0 | | 19.4 | 36.3 | 21.6 |
| Net annual equivalent (energy only) | | 14.98 | -19.68 | 8.25 | | 18.58 | -13.84 | 9.69 |
| Net annual equivalent (energy & carbon) | | 40.19 | -1.60 | 26.34 | | 41.57 | 2.57 | 26.10 |

*Notes:*
*1. The capital and energy cost assessment for the 2008 standard is based on a dwelling with MEV ventilation*
*2. Life =60 years and I=3%*
*3. The cost of carbon is taken from a recent government review of the economic costs of carbon emissions (Clarkson and Deyes, 2002) carried out for the treasury and DEFRA. The cost for $CO_2$ is obtained by applying a factor of 12/44.*

From an inspection of the table, the following observations can be made:

- Simple payback periods, based on energy savings alone, range from 19 to 39 years depending on the standard, the inclusion of services space cost and the roof form adopted. The 2002 and the low cost 2008 standard pay back times are in line with the overall pay back times expected on investment in new social housing. It is not uncommon for the total payback times on social housing developments to be in the region of 25 to 30 years and in the case of the St Nicholas court development the relevant payback time for the whole scheme is 27 years. However the high cost view of the 2008 standard presents a much less favourable pay back time.

- The application of discounting to the capital cost in the form of an annual equivalent cost of capital over 60 years at a discount rate of 3% provides a direct comparison between annual cost savings and the initial capital investment in the higher standards[32]. This analysis demonstrates that over the nominal life of the

[32] The use of 3% is taken from Treasury recommendations (The Treasury Green Book) for long term investment in relation to such areas as building regulations policy and 60 years has been adopted based on standard practice in the assessment of housing policy over the last 50 years or so. The annual equivalent is sometimes referred to as amortisation and, in this case provides a more convenient and understandable basis for comparison than the use of present values.

dwellings the energy savings in the 2002 case are greater than the amortised capital cost by some £15 to £18 and in the case of the 2008 standard the net annual equivalent value ranges from -£20 to +£10 depending, principally, on the view taken about capital costs. The breakeven capital cost increase from 2002 to 2008 (on an energy cost only basis) is in the region of £1350 (a reduction from the high cost point of some £450).

- Taking the cost of carbon into account[33] net annual equivalents are positive, with the exception of the high cost 2008 warm roof case. Values range from -£1.60 to just over +£40 with the 2002 and low cost 2008 cases producing relatively high positive values but with much more marginal values in the case of the high cost 2008 scenario.

As is common in most cost effectiveness assessments, the conclusions that can be drawn are sensitive to a number of key input and calculation factors. The analysis is clearly sensitive to the cost estimates used. In the 2008 case cost effectiveness would depend on being able to reduce any additional cost (over the cost of the 2002 standard) to somewhere in the region of £1,350 on an energy cost only basis or £1,850 if the cost of carbon were taken into account. Both of these “break even” figures lie within the range defined by the high and low cost estimates presented in Table 5.6.

On the assumption that the costs for 2008 provide a “best estimate” of the likely range of cost increase, we can assess the internal rate of return against which we can compare the values used in Table 5.6. At the high cost end of the spectrum, represented by the high cost 2008 warm roof case, the internal rate of return is 2.9% and at the low cost end (low cost 2008, cold roof) the internal rate of return is 6.0% both of which are based on the median value for the cost of carbon (see footnote, below). The sensitivity of the cost of carbon has been assessed by looking at the impact of a doubling and halving of the value used in the initial assessment. At double the initial cost (£187.68) the net annual equivalent value for the 2008 standard ranges from about +£18 to +£44. The equivalent range resulting from a halving of the cost of carbon (£46.92 ) is from -£11 to +£18.

This analysis suggests that, on the costs and savings presented here, the cost effectiveness of the 2002 changes would appear to be high with a positive net annual equivalent under all assumptions while the cost effectiveness of the 2008 standards is less so and much more sensitive to input variation, within the expected cost range. Be that as it may, in comparison with the 1995 standard the 2008 (high cost) case displays a positive value even with a halving of the cost of carbon. Despite the complexity of the above analysis, it must be remembered that the level of uncertainty in the construction cost estimates themselves means that firm conclusions on cost

[33] The cost of carbon has been derived from the recommendations of Clarkson and Deyes (2002). The recommended figure is £70/tC (at 2000 prices) plus a £1 per year real increase to account for the increasing damage costs over time. The figure used in table 5.6 has a base value of £72.78/tC (updated to 2001 prices - (70+1)x1.025) to which has been added the discounted annual equivalent value of the £1 per annum real increase over the nominal life of the investment. The application of the real cost increase term means that the cost of carbon will vary with discount rate. Clarkson and Deyes suggest that the figure be used as a median value with an upper boundary of double and a lower boundary of half the median value. This has been done in the discussion of sensitivity.

effectiveness must remain tentative. Issues of uncertainty are discussed in the next section.

## 5.9 Discussion

Throughout this analysis we have been keenly aware of the level of cost uncertainty that exists during the design phase of most building projects. This is particularly true when a scheme is out of the ordinary. Budget costs, by their very nature, are the result of a compromise between the cost of acquiring accurate information, the time available to acquire it and the consequences of inaccuracy. Since design decisions are significantly influenced by cost arguments, the reliability of the cost information is crucial. The problem for any scheme that is pushing the boundaries of performance is that the costing information on novel construction is likely to be much less certain than that available for well tried and tested solutions. One of the consequences of unfamiliarity is a tendency to play safe and to cover the risk uncertainty brings by adding a premium. In a situation where cost is critically important (and the St. Nicholas scheme was no different in this respect than other social housing schemes) it is, perhaps, not surprising that, the cost expectations for novel construction forms will be significantly more conservative than in the case of more familiar technologies[34].

Throughout the analysis of scheme costs the research team sought to address some of these uncertainties. Two areas in particular where addressed, the roof and the wall construction. In the case of the roof, a detailed design and cost quotation was sought from a timber I-beam manufacture with the result that an extra-over cost quoted at £2,000 per dwelling during the design process faded away. So much so that the costs returned by the I-beam manufacturer resulted in a lower estimate for the I-beam structure than one based on trussed rafters[35]. Similarly, an I-beam solution to meet the 2002 standard resulted in a lower cost than that estimated for a more traditional over-clad rafter design. In the case of the 2008 wall design the uncertainties revolved around the cost of the external insulation. Information from an insulation supplier resulted in a reduction in the all-in-rate for the external insulation of between £4 and £5 per m$^2$, the effect of which was to reduce the wall over-cost by about £500, some 15% of the total over-cost on the 2008 standard. Although it is our contention that the cost of the higher standard is likely to be inflated in the circumstances discussed, this need not be so in all cases. For example, we are not completely convinced that the heating system costs in the 2008 standard (reflecting cost savings on radiators and pipe runs) will be reduced to quite the extent suggested above.

To what extent the cost shifts are a result of real cost changes in the market place over the last 3 or 4 years or a lack of accurate information at the time the design was being developed is not possible to determine. However in markets that are in the process of maturing, as in the case of timber I-beams and, during the 1990s, condensing boilers, it is likely that increasing market penetration will bring costs reductions and that at some point that fall may well become rapid. Our experience with roof costs suggest

[34] 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.
[35] In practice, it is possible that, faced with this information, a lower price for a trussed rafter roof would be forthcoming.

that I-beam structures may have reached this point. During the project we also came across anecdotal evidence of price reductions in the case of condensing boiler installations. In one of the cost plans, the project QS provided an estimate of a condensing boiler system based on previous comparable social housing schemes with which he was familiar. This resulted in an additional cost of some £486. However, recent enquiries with suppliers suggest that the cost difference between condensing and non-condensing boiler units lies somewhere between £150 and £200 depending on the model chosen. Current estimates prepared for the St Nicholas Court project's sister project (Brookside Farm PII reference - CI39/3/663) involving some 600 speculatively built dwellings, suggest a cost difference of only £90, reflecting the bulk buying power of a large housing developer. Even at the top end of the cost range the differential is less than half the £486 included in the original cost figures. This demonstrates both the extent of cost movement in the last 3 or 4 years, driven, at least in part, by the 2002 requirements, and the extent of the cost variability in the market place.

To a significant degree the uncertainties expressed about costs reflect the fact that the research project had to be terminated prematurely. The open book nature if the partnering arrangement would have provided much more accurate up-to-date costing information and site observations would have helped to clarify labour requirements for unfamiliar construction details. What we have been able to report in this project is the nature of the problem and the gap in the information base that needs to be filled if accurate costing information is to be provided for the assessment of performance standards, particularly where these are likely to require some technological change.

The lack of such information also has an inhibiting effect on designers and reduces their propensity to seek new technological solutions, this, in turn inhibits the development of the technology itself. In short, faced with cost uncertainty a prudent designer would find it safer to stick to what he or she knows[36]. It is undoubtedly true that improving regulation will help to push designers into new solutions, and that eventually the familiarity with costs and other practical issues will provide the sort of information required but such a process is, potentially, slow and painful and likely to lead to the sort of resistance to regulatory change that is often observed. In the face of concerns about climate change, ways must be found to speed up the process and make it less difficult. Improving cost information would play a small but significant part in doing this. One of the research responsibilities of industry and government must be to improve the information base. Doing this will require a much more focused approach using a combination of laboratory and field work designed to provide reliable cost information for effective design decision making and the framing of workable standards.

[36] This is part of a wider network effect in which all members of the design and construction team borrow off and are informed by each other. Such networks can inhibit or discourage the development of new solutions depending on the nature and quality of the information passed around. Information networks that rapidly disseminated well informed material on cost, performance and reliability would help to speed up the process of low carbon and environmental design.

# Chapter 6 The design process: developing the solution

## 6.0 Introduction

In this chapter we seek to tell the story of the way the design solution was developed and the influence of the performance standard on design decisions and the way they were made. Although separated for the purposes of discussion and description, it is a story that is inextricably bound to the development of the design team and their understanding of the design issues raised by the prototype standard. This complementary story is told in the next chapter. In tracking the design process the research team made use of the following qualitative data sources.

- Design documentation such as the Client's "innovations" brief, the Architect's outline solution, the Partnering Contractor's initial detailed design proposals and working papers prepared by team members during the design phase. Where appropriate, individual documents are referred to in the text and included as an appendix.

- Minutes of design and project team meetings, backed up by tape recordings.

- Relevant correspondence.

- Notes made by the research team together with materials such as flip chart sheets produced during meetings.

- Open-ended interviews with individual team members undertaken towards the end of the design process between October and December 2000.

## 6.1 Scheme inception

The Client's decision to develop a sustainable housing scheme was based on a desire to address environmental issues and on the conviction that such a scheme could bring considerable benefits to their tenants in terms of reduced running costs and greater comfort. The initial phase of the design process (autumn 1998 to spring 1999) was spent defining the problem. In essence, this phase consisted of translating the vague idea of a sustainable housing scheme into a set of performance requirements that could be used as a starting point for the development of the scheme design and, in refined form, as evaluative criteria. In providing operational form to ideas on sustainability the Association laid considerable emphasis on the need to ensure that such a scheme was practicable and remained within the reach of the normal financial provisions of grant-aided social housing. There was also a concern that the scheme should not be driven by the technology but by the needs of the users. As the chief executive at the time remarked: *"These have got to be houses that tenants want to live in, enjoy living in, are comfortable in, can afford to live in and want to continue being there long-term"* The emphasis on practicability in financial and user terms put a high value on the reliability of performance as well as the standard of sustainability and, to some extent, acted as a constraint on the nature and type of technology adopted. It also placed considerable responsibility on the design team to ensure that design decisions did not involve significant risk of failure.

During this phase the Association sought the advice of the LMU research team on an appropriate energy performance standard that represented a significant step forward in performance but ran little risk of outstripping the ability of the industry to deliver a workable scheme that met the requirements of tenants. During these discussions it became clear that the standard proposed by Lowe and Bell (1998a) for UK building regulation post 2005 provided a suitable starting point. It was also clear that the emphasis on practicability as well as sustainability provided an ideal context in which to evaluate the extent to which the proposed standard could form the basis of post 2005 regulation. The Association were extremely receptive to the research project. Not only did it fit in with the specific objectives for the scheme it also addressed their desire for wider dissemination and for the scheme to influence housing standards at a national level.

> *"I was actually very encouraged when [LMU] linked the research on this with a piece of work which will have some kind of national impact. ..... If we can contribute in some way to that happening, whether to incorporate some of what we are doing, or even the reverse, say some of this is not going to be deliverable on a bigger scale, that is worthwhile as far as I am concerned." (interview with the Association's CE)*

In addition to seeking appropriate energy performance standards a wider sustainability performance standard was also being sought dealing with such issues as car usage the design of surface water drainage and landscaping. These were developed with the aid of the scheme architect and the local environmental group responsible for the construction of the Environmental Community Centre on the adjacent St Nicholas Fields site. Overall performance targets were developed and together with the energy performance standard formed the basis for scheme design and for planning and funding submissions. The full set of performance targets together with the background to the scheme and the procurement approach are set out in the "Innovations" brief (Appendix 6), written by the Association as part of the funding submission to the Housing Corporation.

At the time procurement decisions were being made the Egan report (Construction Industry Task Force, 1998) was published and the Housing Corporation was encouraging Housing Associations to consider the adoption of the partnering recommendations. Following their own assessment of partnering, the Association took the view that the innovative nature of the scheme required the type of open and integrated approach to design and construction on which partnering is based.

> *"…we feel quite strongly that some of the procurement methods outlined in the Egan Report are tailor-made to deliver the sort of sustainable housing scheme that we have been planning." (Gilham 1999)*

In particular, it was seen as a way of enabling a much wider and thorough discussion of the environmental and energy design issues as well as the practical issues associated with buildability. In selecting this approach, the client sought to foster a collective commitment to the objectives it had set for the scheme and, as discussed elsewhere, there is strong support for the view that these hopes were, indeed, fulfilled during the design phase.

## 6.2 Outline design and design team assembly

One of the most important decisions in the early phases was the selection of the scheme architect. This was done on the basis of previous experience. Prior to the project, the Association had begun to work with a local architect on a self build scheme (Holgate Park) that had a reasonably strong focus on improved energy performance. This experience, together with the architect's local reputation for his interest in green issues, persuaded the association to make the appointment. The appointment was made at a very early stage and enabled the architect to have a considerable involvement in the setting of overall performance standards. During the summer and autumn of 1998 the funding application was prepared and the project team expanded with the addition of the quantity surveyor and planning supervisor.

At this time the outline design was prepared and following grant approval early in 1999 was refined. This original site layout and initial dwelling design proposals are included in Appendix 10. The outline design sought to maximise passive solar gains through appropriate dwelling orientation and the design of a two storey sun-space. The super structure design was based on a conventional well insulated timber frame with brick and timber external cladding and a low pitch trussed rafter roof with insulation at ceiling level.

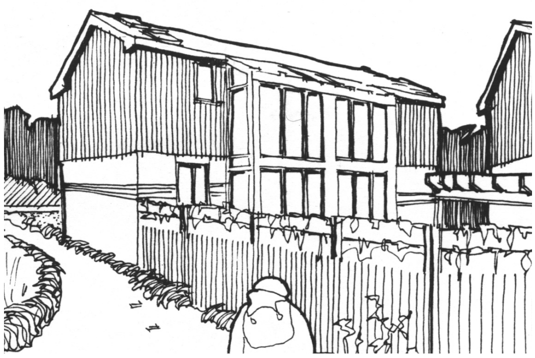
| | |
|---|---|
|  |  |
| Outline design (Bixby, 1999) | Holgate Park self-build scheme |

Figure 6.1: Comparison of the outline design and the Holgate Park self-build scheme

The decision to adopt timber frame construction was taken very early, prior to the selection of the constructing partner and before the involvement of the research team. As with most design projects the initial design decisions set the boundaries within which the remainder of the design work was carried out. The choice of timber frame was influenced by the perceived sustainability of timber and the fact that timber framed construction lends itself to prefabrication (a strong theme of the Egan report). It was also the form of construction used in the self-build scheme and was the predominant form with which the architect was familiar. In fact the influence of the self build scheme would appear to be very strong not only on the choice of construction (the self-build scheme was based on a 140mm thick traditional timber frame with brick and timber cladding) but also on the form of the dwellings, particularly the use of a two storey sun-space. This influence is clear from Figure 6.1 which compares the completed self build dwellings with the initial design for the St Nicholas Court scheme.

Selection of the partnering contractor took place in the spring and early summer of 1999 and involved a three stage process beginning with a trawl for expressions of interest and proceeding through two rounds of interview and presentation. The selection was made by the Association with the assistance of the architect, quantity surveyor and planning supervisor. During the final stage a shortlist of two contractors were asked to make detailed proposals for meeting the performance objectives and it was these, together with the outline design, that the team began work on in the late summer and autumn of 1999. Although the process for selecting the partnering contractor provided an opportunity for submissions to propose a radical redesign, the outline scheme remained unchanged until modifications were made to the roof form and scale of the sun space much later in the design process. The successful contractor took the view that as partnering contractor they were required to develop what was already on the table and add their practical knowledge and their experience of partnering. The proposals also involved a number of key suppliers, notably the timber frame manufacturer.

> *"We went through the thought process of considering a total redesign and discussed it with our architect. In the end I rang [the client] and told them I was confused about what I should be doing. It turned out that they wanted us to add our buildability and our knowledge of partnering…" (contractor interview).*

By the beginning of August 1999 the core team was complete and work began on the development of the scheme. Following the selection of the contractor, the design framework became fixed and there was a tacit acceptance that from this point the design problem was primarily one of making the outline design work in detail and, as discussed in the design issues section below, radical changes to construction form were hard to accommodate. Design is, fundamentally, a convergent process and the need to fix the boundaries of design problems at each stage is an essential part of managing the production of a solution, however the impact of early design decisions on the remainder of the process and on actual performance is considerable. In this case it would appear, from external observation, that the design of the dwellings on the Holgate Park self-build scheme provided a blueprint for the St. Nicholas Court dwellings, the problem was to work out how best to modify the blueprint so that the required performance was achieved. The issues that emerged during this process are discussed in the following sections.

## 6.3 Research team input and training

Research team involvement in the early phase was small[37] and consisted of a number of general discussions on matters of principle and the provision of copies of *Towards Sustainable Housing* (Lowe and Bell 1998b). This contained the principal requirements for envelope performance (mainly elemental U values) and an outline of the way heating was to be treated. The information was also available to contractors as part of the selection process. In order to provide a much more realistic trial of the standard, as a prototype for future regulation and to ensure that the design team had sufficient detail against which to measure design decisions, a prototype approved document (Lowe and Bell, 2001a) was presented in draft form at a meeting of all project partners in November 1999. This document was then treated by all participants as if it were an approved document. As indicated in Chapter 2, the research team played an active part in all design meetings from August 1999 onwards and provided detailed design advice and feedback on proposals so as to ensure adherence to the prototype standard. The nature of the input and its influence on detailed design is indicated in the discussion of each design issue.

The process was further informed by two one day seminars (facilitated by the research team and external consultants) on energy efficient design. The first of these seminars was conducted under the aegis of the Design Advisory Service who provided the services of an energy consultant. This meeting took place in October 1999 and was led by David Olivier (Energy Design Associates) with support from the research team. The seminar raised a number of important issues, many of which were to surface on more than one occasion during design development. Details of the seminar are included in Appendix 7 and the main topic areas covered are set out below.

- Thermal bridging - the nature of the problem, critical points in the design and possible solutions.

- Airtightness – the impact of airtightness, the principles of airtight timber frame construction and possible solutions and implications for the design of the ventilation strategy.

- Dwelling form – in particular the impact on heat loss of the ground floor WC addition (see plan in Appendix 10).

- The roof form – the particular, detailed design problems created by the adoption of a cold roof design (mainly in terms of increased risk of thermal bridging and difficulties in ensuring an airtight envelope). This issue was to become a particularly difficult one throughout most of the detailed design phase.

- Heating and ventilation strategy – the need for conventional (reduced) space heating system and the possibility of a comparison of MVHR and extract only on the scheme.

[37] Funding and staffing requirements prevented a formal start to the research project until December 1999, however, in practical terms, research team involvement in the design process was evident from the beginning of August 1999. At this point the partnering contractor had been appointed and the detailed design of the scheme was about to begin.

- User issues – general discussion of principles.
- Life cycle costing – general principles in the context of the scheme.

The Second seminar, which took place in June 2000, dealt with the problem of airtightness and was conducted by Roger Stephen (then of the Building Research Establishment) with support from the research team. The seminar began with a pressure test on one of the Association's dwellings, a test that provided a graphic illustration of air leakage issues both in terms of the extent of the problem (the dwelling tested was extremely leaky) and, with the aid of a smoke generator, typical air leakage paths. The seminar stressed the interplay between the overall design, particularly the general arrangement of walls, floors and roof, the design of construction details and the ease with which the design could be realised on site. In commenting on the general arrangement drawings Roger Stephen drew attention to the following issues (comments relate to Appendix 5):

- The design of the first floor overhang into the sun space provided a potential discontinuity of the air barrier as the main wall was stepped back at this point.
- The junction between the sleeping shelf, external wall and roof presents a three way junction that may make it difficult to ensure continuity of the air-barrier.
- The use of plasterboard as an air barrier on party walls, especially since any service penetrations of the plasterboard layer (planned or unplanned) will communicate with cavities in the party walls and are likely to bypass air-barriers in external walls. This particular problem was also discussed during the seminar the previous October.

Feedback from the seminar was extremely positive with all members of the design team finding both the pressure test (only one member had witnessed a pressure test before the seminar) and the seminar extremely useful and informative. In fact the seminar was highlighted in one of the design team interviews some months later as a "revelation":

> *"One particularly outstanding piece of knowledge was how leaky building are. I thought that air-tightness day was a revelation." (partnering contractor interview)*

## 6.4 Wall design

The design of the wall construction was resolved, in principle, at the first design meeting in August 1999. The starting point was the submission of proposals made by the partnering contractor during the selection process. Two options were discussed in the submission:

- a timber frame using I-beam technology; and
- a conventional timber frame using 189mm × 38mm timber studs

The submission recognised the significant advantages of the more innovative I-beam solution and acknowledged that this was, probably, the most appropriate technical solution. However the I-beam frame was rejected on cost grounds with the extra

£62,000 (£3,100 per dwelling) to be used "to greater effect within other elements" (see Figure 6.2).

SECTION 3 Construction Proposals

**Frame**

The methods of timber frame construction that we have considered are as follows:

- Fillcrete TRADIS' System, which incorporates the Masonite Beam, Warmcell insulation and Panelvent board.
- Traditional timber frame.

The TRADIS System, in our opinion, offers the following advantages over the traditional timber frame:

a) Reduced requirement of timber quantities in the production of the structural beam. The Masonite Beam typically offers a saving of 40 — 65% of the volume of timber when compared to a timber stud of the same overall dimension.

b) The timber used in the manufacture of the Masonite Beam originates from smaller, younger trees. This has the advantage of assisting more efficient forest management, further improving sustainability.

c) The web of the Masonite Beam is manufactured from waste and other forest thinnings.

d) The Masonite Beam is stronger and therefore spans and centers may be increased to reduce material quantities.

e) The Masonite Beam is less susceptible to twisting and warping and is more dimensional stable than timber.

f) .The Panelvent board does not require an external breathing paper, thus being less susceptible to site damage.

*However, it is our opinion that, at the present time, **the cost of this system is prohibitive**, in excess of £62,000.00 more expensive overall and this budget may be used to grater effect within other elements.*

The **Oregon Timber Frame** however offers many benefits and meets or exceeds the project's requirements in all respects, whilst maintaining a high degree of cost effectiveness.

The combination of a 189mm wide stud in the frame and Warmcell 500 insulation filling the cavity within the frame will provide a u-value in excess of the proposed UK Building Regulations 2005 requirements for walls of 0.25.

The timber used in the structural frame comes from managed, sustainable forests, both from Northern Europe and the United Kingdom. The timber is treated with water based preservatives which are solvent free and contain no lindane or metal based biocides.

The structural frame is prefabricated in composite panels and incorporates the Warmcell insulation, which is installed under factory conditions.

*(Extract from the Partnering contractor's proposals – June 1999.)*

Figure 6.2: Extract on timber frame proposals – part of the Partnering Contractor's initial submission.

The key issues in the design of the proposed timber frame were thermal bridging through timber studs and at junction details and ensuring an adequate standard of airtightness. In this section we concentrate on the thermal bridging issues.

Airtightness is addressed in a later section. The initial proposals were presented as providing a U value "in excess of" (below) the required 0.25 W/m$^2$K (see Figure 6.2). Indeed, if calculated on the basis of the examples in the 1995 Regulations Approved Document L, a U value of 0.19 could be claimed for this construction and even if the slightly more stringent 2002 Approved Document) were used a U value of 0.22 would result[38]. However, typical junction details, which were provided at the first detail design meeting in August 1999, displayed extensive thermal bridging at most junctions. Figure 6.3 shows a detail of a wall - floor junction (with a window below) which was typical of the standard timber frame details presented. It was clear that if the additional bridging caused by the large amount of through timber at junctions was taken into account, as required by the prototype standard, the overall wall U value would have been considerably higher than the limiting value[39].

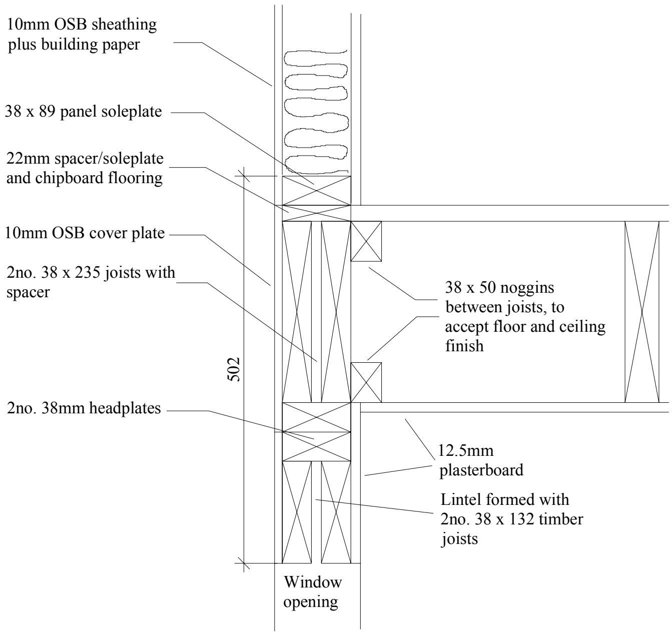



Figure 6.3 Typical first floor and window head detail. (source: Bell & Overend 2001)

It was clear that the principle of including all linear thermal bridges as well as the quasi-homogeneous bridging through repeating studs and ties had not been applied in the calculation of the U value[40]. It was also clear that the implications of this approach for the design of junction and opening details had not been appreciated. The research team were able to demonstrate the nature and extent of this problem with the use of two-dimensional heat flow simulations and an information pack containing various

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[38] The difference is accounted for by a change in the method of accounting for homogeneous thermal bridging (mainly the timber studs) and the fraction of timber assumed to be in the main insulation layer. The example in ADL95 implies a nominal value of about 7%, the ADL1-02 example more than doubles this fraction to15%. In practice values can be much higher than this. In one study (Bell and Overend 2001), timber fractions (including timber at junctions and openings) of between 30% and 40% were observed.

[39] The extent and impact of bridging in typical timber frame construction under ADL95 and ADL1-02 (robust details) is discussed in Chapter 4.

[40] U value calculation is dealt with in the Prototype standard, Appendix A).

examples of low energy schemes from Europe and North America, much of which was reinforced at the DAS seminar about six weeks later.

The ensuing discussion lead to the principle of a wall design based on 89mm × 38mm studs with cellulose fibre insulation between and clad on the external face with rigid urethane insulation (see Chapter 4) giving the following perceived advantages over the original proposal:

- greater structural efficiency, using less timber;
- studs would not have to be cut from high quality, large section mature timber, much of which would not be available from UK sources;
- the impact of quasi-homogeneous thermal bridging would be significantly reduced by the continuous layer of external insulation; and
- thermal bridging at junctions and openings would be easier to eliminate or reduce.

Thermal bridging simulations[41] on typical junction and opening details carried out during detailed design work demonstrated that this approach was reasonably successful with additional heat loss amounting to about 8% of the total fabric heat loss and a wall U value (based on the sharing of bridging effects at junctions between adjoining elements) of around 0.22 W/m$^2$K compared with an elemental standard of 0.25 W/m$^2$K. The average envelope U value was some 6% to 11% below the target of 0.35 W/m$^2$K depending on assumptions made about window U values and (crucially) areas. Had the design progressed to construction stage it is expected that thermal bridging could be reduced even further with another iteration of detailed design.

Although this issue was resolved with relative ease (about an hour's discussion), it is interesting that the problems identified did not precipitate a reconsideration of the I-beam solution. The possibility was raised very briefly but immediately discounted on cost grounds and the discussion returned to the modification of the initial (traditional) solution. Cost was clearly the critical barrier to the more innovative solution despite the fact that everyone recognised its potential and the likelihood that, in a more mature market, the cost would be competitive. However by this time other influences were also at work. To all intents and purposes the choice of a traditional frame had changed the design context in that it provided another fixed point in the solution convergence process, a point reinforced by the identification and inclusion of the timber frame supplier who, although familiar with the I-beam concept was not in a position to produce a complete construction system. The modified conventional solution was relatively obvious, easy to apply and (in the context of this project) appeared to provide the most cost effective solution. The fact that it compromised to some extent the client's desire to use a low embodied energy insulation material (recycled cellulose fibre) was an inevitable and acceptable compromise. Throughout the remainder of the design process the form of wall construction became a fixed point of reference. Other issues, particularly the design of the roof, were not resolved with the same degree of ease.

[41] Using THERM (2.1a) a 2D finite element thermal simulation programme developed by the Windows and Daylighting Group, Lawrence Berkeley National Laboratory, University of California USA.

## 6.5 Roof design

The story of the roof design is primarily one of a choice between a conventional shallow pitch cold roof design using trussed rafters and a more radical design which provided a warm roof using I-beams and possibly an increased roof pitch capable of providing additional living space. Given the influence of the Holgate Park self-build scheme (which incorporated a warm roof using traditional rafters) it seems surprising that the warm roof option was not part of the outline design. Comments by the architect suggested that since initial client requirements did not include a 2½ storey option, as in the case of the self-build scheme, the additional expense of a warm roof was thought to be difficult to justify. It is also interesting to note that the roof form was not discussed at all in the contractor's detailed design proposals. Although the contractor outlined a proposal to make use of reclaimed slates for the roof covering (having located a local source) the trussed rafter cold roof design would appear to have been taken as given.

The discussion continued from August 1999 to the redesign of the dwellings in the spring of 2000. The key technical design issues that emerged are set out below:

- Cost- This was the main concern throughout the debate. The extra construction cost was estimated to be around £24,000 (£1,200 per dwelling) and the argument was constantly reiterated that this would make it difficult to achieve other aspects of the scheme. However the additional cost was almost always treated at the elemental level within the context of the outline design and second order cost/value issues such as the loss of living or storage space because of the need to house air handling equipment within the heated envelope or the need for a deeper first floor ceiling space for duct runs were no fully considered. These issues are discussed in more detail in section 6.10.

- Thermal bridging – The difficulties of avoiding thermal bridging in a trussed rafter cold roof, particularly at the roof/wall junction, were expressed by the research team on a number of occasions.

- Airtightness – The research team and the heating and ventilation supplier raised the problems of achieving the airtightness standard were there was a significant risk of breaching the air barrier. The proposed design involved services located in the loft space with the attendant difficulties of sealing around service penetrations (heating and ventilation services and light fittings) and maintaining those seals over the life of the dwelling.

- Heating and ventilation equipment location – Given the problems of space allocation, initial proposals involved the use of the loft space for the location of ventilation equipment and duct work (at one point there was even a proposal to place the heating boiler and hot water cylinder in the loft). This was considered to be particularly problematic because of the need for a substantial thickness of insulation (300mm or more) around the equipment and duct work.

Underlying this technical debate was a reappraisal by the client of the value for tenants of additional space in the roof. This was inspired by the 2½ storey (sleeping shelf) arrangement designed for the Holgate Park scheme which was nearing completion during the autumn of 1999. In October 1999 the client requested that the 2½ storey option should be investigated, however, two months later, following an investigation the idea was abandoned on cost grounds. The idea of a warm roof remained under consideration but based on the external insulation of a trussed rafter roof.

> *"It was agreed not to pursue the room-in-the roof option further. [X] to contact [Y] to work up details for 'conventional' warm roof" (minutes of project meeting 3/12/99)*

The other underlying pressure was that of time. The construction start date (March 2000) was edging closer and the need to finalise the design had become extremely urgent.

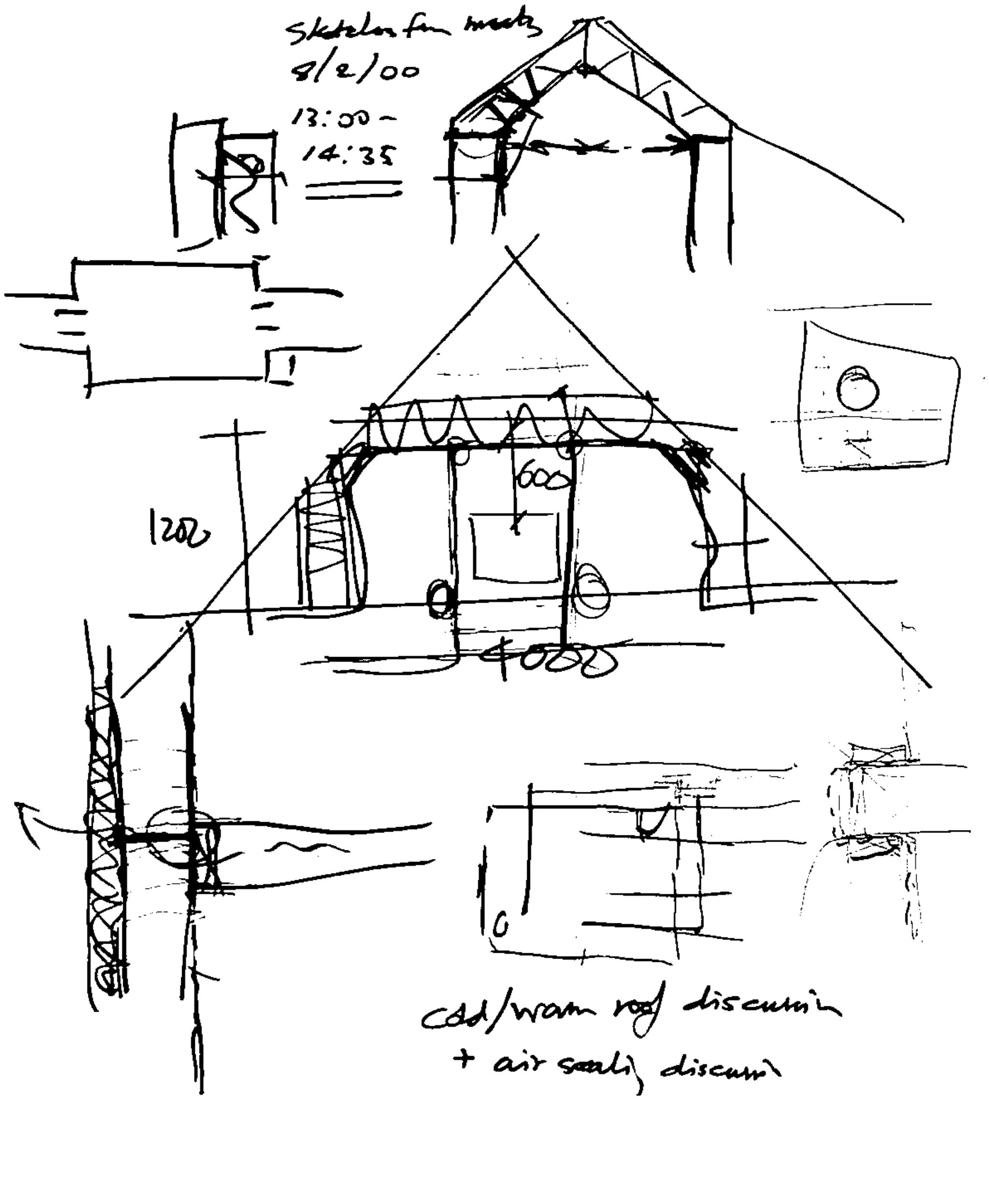


Figure 6.4: Flip chart from design meeting of 8 February 2000 relating to the discussion on the difficulties of air sealing and the housing of H&V equipment in the roof space.

By February 2000 the roof design issue had, apparently, reached a critical stage and, at a design meeting in February 2000, a final decision was made to abandon the warm roof and seek to locate all H&V services within the thermal envelope. Figure 6.4 shows a flipchart sheet from the meeting and illustrates the level of detailed discussion that took place as the team sought to reconcile the requirements of maintaining a continuous air barrier, avoiding thermal bridging and creating a warm service space all within the confines of low pitch, trussed rafter construction. The progressive modifications to the trussed rafter starting point resulted in more and more complexity until it was clear that an alternative location for the H&V equipment would be required so that detailed design could concentrate on issues of air-sealing and bridge free insulation. The process is captured in a reflective note made by a member of the research team immediately after the meeting and reproduced in Figure 6.5.

1. The starting point and starting assumptions determined the direction of the discussion (inevitably). Ideas were explored based on modifications of the trussed rafter solution. At one point the solution got quite complex (the attic truss solution) - almost out weighing the I beam solution (although no costs could be determined) and certainly producing detailing and quality problems because of its complexity.
2. The attic truss solution [see central sketch on the flipchart in Figure 5] was a modification of an existing solution to a related problem - i.e. that of getting a room in the roof using trussed rafters. The familiarity (around the table) with this class of solution seems to have been an important driving force in its initial acceptance and development. After all, we needed a small room in the roof to put the ventilation unit in.
3. The solution was refined until it was pointed out that the insulation problems and air sealing problems would be difficult to resolve. In any case it still left unresolved the problems of duct runs in the loft. It was not until later that it was realised that if duct outlets had to run in the un-insulated part of the loft space and at right angles to the ceiling joists the amount of insulation over the ducts would be reduced to only 100mm of cellulose insulation instead of the 200mm when run parallel to the ceiling joists…… It is interesting how once set up as "the general solution" [in this case the trussed rafter] there is a reluctance to let it go and each criticism or problem is met with a modification to the basic idea until someone says "Hey! we have created Frankenstein's monster out of bits and pieces" !…… The point is that the modifications progressively change the idea until it bears only scant resemblance to the original.

Figure 6.5: Reflective research note following the roof design meeting February 2000.

As in the case of the wall construction, there was broad agreement that a warm I-beam roof had many technical advantages but the projected costs, at that point in the process, presented an insurmountable barrier. It is ironic, perhaps, that within a few weeks of resolving the roof design, external circumstances, in the form of a land acquisition delay, presented the client and architect with the opportunity to revisit dwelling design in a more fundamental way than hitherto[42]. The client was very keen to use this opportunity to return to the issue of roof space accommodation.

[42] The first documentary evidence of the review of dwelling design came in an email from the architect dated 20 March 2000, some 6 weeks after the critical design meeting in February that confirmed the use of the cold roof design.

> *"I was quite pleased when we made a decision about having usable roof spaces- it wasn't the original decision but we re-visited it…. the delay meant that Phil could re-look at that, the roof, and get the useful roof spaces in. …… maybe this is making a virtue out of a necessity, but the delays have meant that we could re-look at some of the technology." (Interview with the association's CE)*

The design that emerged (see Chapter 4) was the result of a complex interplay (indeed alliance) between various user, technological and pragmatic factors. It is clear that without the delay the desire for habitable roof space would not have returned to the design agenda and the warm roof design would not have been established. At the same time the need to accommodate the perceived elemental cost increase precipitated a search for cost savings, savings that were to be found by simplifying built form. This simplification sought to reduce overall surface area by incorporating the ground floor WC and shower into the main body of the dwelling (with a small increase in dwelling footprint) and reducing the height of the sun space to a single story. In addition to producing the necessary cost savings the modifications also addressed a number of energy and comfort performance concerns relating to summer overheating, surface area and detailed design of the thermal envelope, issues that are taken up in the next section (section 6.6). Some of the strategic issues relating to the impact of the performance standard on the design of the roof and, to a lesser extent, other elements are discussed in sections 6.7 to 6.10, below.

## 6.6 Design of built form

As indicated in section 6.5 (roof design) two principal concerns were expressed about the built form of the original dwelling design (see Appendix 10 – original design drawings). The first concerned the overheating potential raised by the lightweight nature of the construction coupled with the presence of a two storey sun space. The second related to the ground floor plan, which included a single storey extension housing an entrance lobby and WC.

The problem of overheating was raised formally at the design meeting in August 1999 at which the criticality of thermal mass, and solar access were demonstrated by the research team with the aid of a simple Excel model to predict peak summertime temperatures using the admittance method. This demonstration, together with advice provided at the DAS meeting in October 1999 and by the research team at other design meetings at that time, lead to the redesign of the ground floor construction (from suspended timber to suspended concrete) and an increase in the thickness of plasterboard internal finish in an attempt to increase thermal mass. The design of external shading took the form of a pergola at first floor level to shade ground floor windows and an extension to the roof line to provide summer shading to the sun-space. Although the problem appeared to have been dealt with successfully, and with relative ease, by the end of October 1999 (it does not receive a mention in design or project minutes after this date) the prospect of summer overheating remained a background concern within the research team.

As indicated in section 6.5 above, the delay in construction and review of design decisions in March and April 2000 lead to the reduction in the size of the sun-space. From the point of view of overheating this decision significantly reduced the risk since it concentrated solar gain on the thermally massive ground floor and enabled the extension of the single storey pergola to provide external shading[43]. The design of the conservatory appears to have been driven by both cost and overheating considerations. Although the first note on the decision to revisit the design (email of 20 March) referred exclusively to the reduction of overheating risk, there was an inevitable cost reduction and subsequent discussions suggested that this was at least as important as overheating concerns.

Concerns about the single storey WC/lobby space were raised informally by the research team in the summer of 1999 and also raised by the consultant at the DAS meeting on October 1999. The principal problems included:

- an increased surface area to volume ratio leading to an increased overall heat loss;
- air sealing difficulties at the junction with the main house and within the single storey structure; and
- difficulties (and increased costs) associated with the provision of heating and ventilation services to the WC.

Despite a recognition that the above problems existed there was a tacit acceptance during this phase that pragmatic considerations prevented a redesign of the dwellings. As in other areas, the process of solution convergence, fixed at the time of outline design and unchallenged until the detail design phase, prevented any change which required major change to layout or form. The delay in the programme enabled the removal of what could be interpreted, at least in part, as a self imposed constraint and the dwelling was redesigned to incorporate the WC and lobby within the main dwelling envelope.

## 6.7 Floor design

As already observed, initial construction proposals in the summer of 1999 included a suspended ground floor and, although the proposal is silent on the design of the first floor, the implied construction was a suspended timber first floor installed by the timber frame supplier[44]. The concerns over thermal mass expressed at the August 1999 design meeting were taken on board and by the design meeting of 1 October the idea of improving the thermal mass using a beam and block suspended concrete floor with EPS insulation and a substantial screed was the proposed construction. The decision was generally agreed and remained unchanged, despite a discussion of alternative concrete floor options at the DAS seminar a few days later.

[43] The design drawings, as submitted for building regulations approval, provide external shading to the vertical glazing of the sunspace but no shading is provided to the sloping roof glazing. Had the scheme been constructed it is likely that a further detailed design iteration would have picked this up and some internal or external devices would have been specified.

[44] The budget costing and main text in the contractor proposal document refer to the first floor and timber frame together as part of the superstructure timber frame system.

*"Ground floor proposal is for a concrete beam and block floor with insulation and screed. Polystyrene likely insulation material because no feasible alternative. Aim is to provide thermal mass to reduce temperature swings." (minute of design meeting 1/10/99)*

The design of the first floor construction was driven by the needs of the proposed heating and ventilation systems. The use of composite (timber top and bottom flange with a lattice of galvanised steel) floor joists provided considerable flexibility for ventilation duct layouts and had the added advantages of providing a more rigid floor structure and, because of increased spans, allowed flexibility of internal layout. The only detailed design issue was the floor wall junction and the potential for air-sealing and thermal bridging. Thermal bridging calculations suggest that the junction has the lowest $\Psi$ value (0.0108 W/mK) of all linear thermal bridges in the structure adding some 0.3 W/K (less than 5%) to the total thermal bridging heat loss.

## 6.8 Window design

For cost reasons the design team wished to achieve the required elemental whole window U value of 1.3 W/m$^2$K using double glazed units in timber frames. Work by the research team (Roberts & Lowe, 2002) on the effectiveness of this approach suggests that, in many window configurations, this will be difficult but not impossible to achieve. It is clear, however, that with careful window specification (low E coatings, inert gas fill and warm edge construction) the prototype standard limiting value of 1.56 W/m$^2$K is readily achievable. If this were the case, the proposed dwelling designs would satisfy the prototype standard, using the Target U Value Method.

The main problem during design was the capacity of the design team to check manufacturer's claims. The first manufacturer considered claimed to be able to meet a whole window U value $\equiv$ 1.3 W/m$^2$K but the work by Roberts and Lowe (2002) would suggest that this is unlikely for the specification envisaged. In order to verify the claims of the proposed window manufacturer an independent consultant was employed to provide window energy ratings (which include a whole window U value) for a typical window design. The results of this analysis demonstrated that the standard product proposed had a U value of 1.62 W/m$^2$K (*cf*. required value $\leq$ 1.3 W/m$^2$K with a limiting value $\leq$ 1.56 W/m$^2$K) and a domestic window energy rating of 67.5 (*cf*. required value 70). The windows fail on both counts and do not meet limiting value when the Target U Value or Carbon Rating methods are used. Clearly further design iterations will need to be carried out with the manufacture to seek to achieve the required values. Subsequent design work by a prospective window supplier to the Brookside farm project (PII project CI 39/3/663) has demonstrated the achievement of a U-value of 1.3 W/m$^2$K and a DWER of 70.7 for double glazed units in timber frames using warm edge technology, low-E and argon fills.

## 6.9 Airtightness

So far in this chapter we have focused on the design of individual elements and airtightness has been referred to in that context. The purpose of this section is to review how the airtightness requirements were treated in a more general way. The issue was referred to in a rather oblique way in the contractor's construction proposals. The proposals included a vapour check (to control interstitial condensation) behind an internal cladding sheet and an internal service void *"to prevent any breech of the integrity of the timber frame"* by service penetrations. However it is interesting that, despite the requirement for a stringent airtightness standard, the issue was not addressed specifically. In fact the rather oblique and vague references suggested an element of uncertainty in the early stages of the project.

The problems of maintaining a continuous air barrier featured in most of the early meetings and was a major item of discussion at the DAS seminar in October 1999 as well as the airtightness seminar in June 2000 following the redesign of the dwellings. The lower section of the flipchart (Figure 4) from the meeting on roof design illustrates some of the discussion that took place. Having concluded the discussion of the roof, attention turned to maintaining airtightness at the junction of wall panels and the first floor. Sketch 1 in Figure 6 depicts a rather complex solution involving an air barrier wrapped round the first floor structure while sketch 2 in Figure 6 suggests a structural solution in which the first floor is "hung" inside the wall structure (balloon frame), thus simplifying the problem of maintaining the air-barrier and minimising thermal bridging.

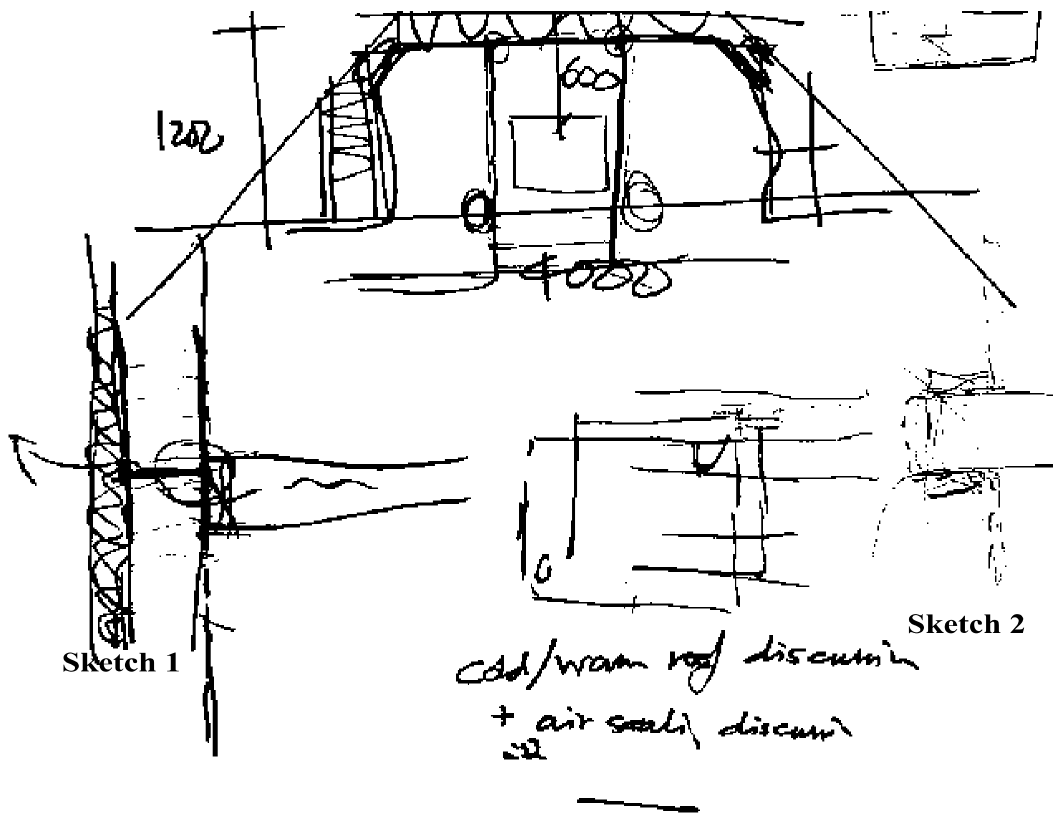


Figure 6: Airtightness sketches.

A qualitative analysis of design drawings suggests that although the general principles have been absorbed, many of the details lack sufficient detail to give a high degree of confidence that they will remain airtight. For example the first floor junction remains problematic as do the areas identified at the airtightness seminar. The lack of detail is largely due to the fact that the project remains in limbo until acquisition delays are resolved and the timber frame manufacturer is not in a position, for contractual reasons, to produce all panel and junction details. However, even if highly detailed drawings of every junction were available, a level of detail that is achieved in very few (if any) building regulations submissions, qualitative judgements about the level of airtightness achieved would be very difficult for building control authorities to make (this issue is discussed later in more detail in Chapter 9). If site quality control problems are added, the checking of performance at design stage becomes impossible and the logic of post construction testing and remediation is unavoidable. In fact it is arguable that the only way each designer and contractor could develop their own robust details and quality control systems would be through rigorous post construction testing.

## 6.10 Heating and Ventilation systems design

In order to realise savings on the space heating system as a result of higher insulation standards and to achieve economies throughout the heating and ventilation system the possibility of a fully integrated ventilation and heating system based on an efficient mechanical ventilation system with heat recovery (MVHR) were explored at a very early stage. This proposal was considered during the summer of 1999 and first recorded at a project meeting on 1 October 1999 *"Proposal is to install a controlled ventilation system, which doubles up as a heating system….." (minutes of 1/10/99).* However it soon became apparent that the heating load was not low enough to enable such a system to deliver the required performance and only a few days later, at the DAS meeting on 6 Oct, the proposal had been rejected and a reduced wet system (for example the omission of radiators in bedrooms) with a condensing boiler was under consideration.

The notion of a reduced heating system was approached with some caution by the client who was concerned about the poor image of partial heating in social housing and the reaction of tenants[45]. However, work by the research team in December 1999 (see Appendix 1) suggested that under steady state conditions radiators in bedrooms would be unnecessary in dwellings with heat recovery ventilation as long as there was a radiator in the bathroom. The research team also recommended the location of a radiator on the landing to reduce the risk of a draft caused by a convective loop in the stair well. Although the same heating strategy may be viable for dwellings with MEV systems, it was felt that there was a significant danger of air movement through trickle vents and other gaps in the external envelope reducing bedroom comfort levels unless radiators were provided. In the MVHR dwellings, the association was prepared to accept the reduced heating system on the understanding that pipe-work was installed that would enable the fitting of radiators in the future if that was thought to be necessary. The fact that physical monitoring would record actual temperatures and that tenant surveys would be undertaken during monitoring work was an additional factor in the decision.

At a technical level some concern was raised about the stability of temperatures. The argument was that the thermal inertia of a wet system would become more significant

[45] It is worth remembering that there remains a strong social housing folk memory relating to the disastrous failure of partial heating in poorly insulated council housing following the recommendation of the Parker-Morris report (Parker-Morris 1960).

as dwelling heat loss fell. An investigation by the research team (see Appendix 8) demonstrated, on the basis of a simplified thermal model that the opposite was likely to be the case, that the lower design heat loss would allow reduced radiator sizes and/or water temperatures and therefore reduce the thermal inertia of the heating system. As a result the tendency of room temperatures to overshoot would fall as the dwelling became better insulated.

The view taken by the whole team was that the airtightness standard required the installation of a reliable whole house ventilation system and a decision was taken very early to adopt a mechanical system. In order to provide a comparison of system performance a decision was also taken to install an extract only ventilation system in half the houses and balanced system with heat recovery in the remaining half. Following this decision the principal issues hinged around the problems of accommodating the equipment and ducts within the thermal envelope and, as indicated in previous sections, the implications for the design of the dwelling superstructure.

### 6.11 The Building Regulations submission

The building regulations submission was made in April 2001 and assessed under the regulations then in force. Approval was given in May. A subsequent exercise was carried out with the Building Control authority in August and September 2002 in which they were asked to consider the submission against the prototype standard. This exercise was designed to stimulate comments on the practical difficulties of working with the standard, particularly compliance checking and the implications for training, and other support requirements. The results of this exercise are discussed in Chapter 9. In this section we seek to identify a number of issues relating to the preparation of the submission and the support provided by the research team during this process.

It is apparent from the rest of this chapter that the research team were active in all areas of design and to that extent made a significant contribution to what was submitted. The contribution took the form of clarifying general principles and, through detailed comment on proposals providing feedback on the application of those principles. However the architect remained responsible for the form and content of the submission, which consisted of a SAP spreadsheet for each house type together with general arrangement drawings, indicative details and a general specification of construction for each element. Detailed structural matters were reserved until timber frame panel drawings and calculations were available.[46]

In the majority of areas the architect was able to use the traditional methods of specification and drawings but the proposed definition and calculation of U values (see annex A of the prototype standard) presented a problem that required the development of a new design tool. The principal difficulty was the calculation of linear thermal bridges and their incorporation into overall envelope U values. The prototype standard requires that where thermal bridges are not amenable to

[46] Because of the land acquisition delay the client was unable to approve a firm order to the timber frame manufacturer and they in turn were reluctant to spend resources on the level of detailed structural design that would be needed. This problems also accounts, to some extent, for the lack of airtightness detailing referred to in Chapter 5.

calculation as repeating thermal bridges using the methods specified in BS EN ISO 6946:1997 they should be *"estimated using a linear transmission coefficient* [ Ψ ] *taken from an approved encyclopaedia of thermal bridges or alternatively, they may be calculated by 2 dimensional simulation using methods described in BS EN ISO 10211-2:2001"*. At present a catalogue of thermal bridges suitable for use in the UK is not available and calculation would have to be undertaken using a suitable finite element simulation programme.

Given the relative complexity and time consuming nature of the calculation process for the different bridges that can occur in a typical design, it is unrealistic to expect designers and building control officers to use this approach. A catalogue approach is much more likely however and it was this approach the research team attempted to simulate.

The research team calculated linear transmission coefficients for each detail provided by the architect and these were presented to him as if they had been selected from a catalogue. The next step was to enable their incorporation into the calculation of envelope U values and to ensure that they were incorporated in to the SAP calculation. This was done by modifying the SAP spreadsheet to include a thermal bridging calculator which combined data on elemental areas from the existing dimensional input to SAP (supplemented as necessary), together with partial U values calculated according to BS EN ISO 6946:1997 and linear bridge lengths and Ψ values derived from a database on a separate sheet within the Excel workbook, containing the values calculated for the St. Nicholas fields project.[47] The submitted SAP spreadsheet contained both partial U values and Ψ values as well as the final U value so that the different values could be amenable to verification by a building control officer checking the submitted construction against his or her catalogue and partial U value calculations.

The architect reported that he found the calculator and modified SAP spreadsheet very easy to apply and the Building Control Authority felt that the information provided was sufficiently comprehensive to give them a high degree of confidence in the final values.

In broad terms the solution that was developed displayed a mixture of modified conventional timber frame construction coupled with a more innovative roof form. In this chapter we have focused our attention on the solution but just as important for the objectives of the research project is an understanding of the development of the design team and their perceptions of the process. This is discussed in the following chapter and in Chapter 8 we discuss some of the strategic issues the design process raises for the development of regulation and the technological and professional developments the construction industry may need to embrace if it is to play its part in tackling the problem of climate change.

[47] In a fully developed system such a database could be web-based in the same way as the SEDBUK data base for heating boilers.

# Chapter 7 The design process: development of the design team

## 7.0 Introduction

In Chapter 6 we concentrated on the issues involved in the development of the design solution. In this chapter we focus on the development of the design team. We have adopted the term design team to describe everyone involved in the project, as opposed to the alternative epithet "project". This is quite deliberate since the choice of a procurement route that wholeheartedly embraced partnering meant that, although the architect was formally responsible to the client for design, everyone in the team contributed to and took responsibility for design decisions. What emerged was a truly interdisciplinary team dedicated to a successful outcome. This chapter takes its data from the same sources as used in Chapter 6 but places greater emphasis on the set of design team interviews undertaken, towards the end of the design phase, in November 2000.

The general aim of the interviews was to seek to understand the impact of the prototype standard on the people and processes needed to design and construct schemes that meet them. In the context of the original design proposal the interviews carried out in November 2000 were to be the first in a series of similar interviews planned to capture the construction and occupation phases. The curtailment of the project meant that only the design phase interviews were possible. The interviews were qualitative and explorative in nature and Figure 7.1 sets out how the overall aim was broken down into more detailed objectives. Appendix 4 contains the full interview schedule. The design team consisted of a core of ten individuals (excluding the research team[48]) with a small number of other people from the organisations involved who provided comments or specific pieces of advice, usually through a core team member or by attendance at one or two design meetings. The core team consisted of the Client (2 members – Chief Executive and Development Manager) the Architect, Project Quantity Surveyor (PQS), the Planning Supervisor (a formal health and safety role), the partnering contractor (3 members, Director, proposed Site Manager and Quantity Surveyor (CQS)), the timber frame subcontractor/supplier and the heating and ventilation subcontractor/supplier. All ten members were interviewed and, for each interviewee, the interviews sought to gain insights along the following dimensions:

- personal background of team members and their involvement in the project;
- change in general views and attitudes about the project and the standard (interest, attitude & motivation);
- development of knowledge skills and understanding; and
- perceptions of the design process and the partnering approach.

[48] Although, for the purposes of clarity, the involvement of the research team throughout the process will be discussed separately towards the end of the chapter it should not be forgotten that they were an integral part of the design team.

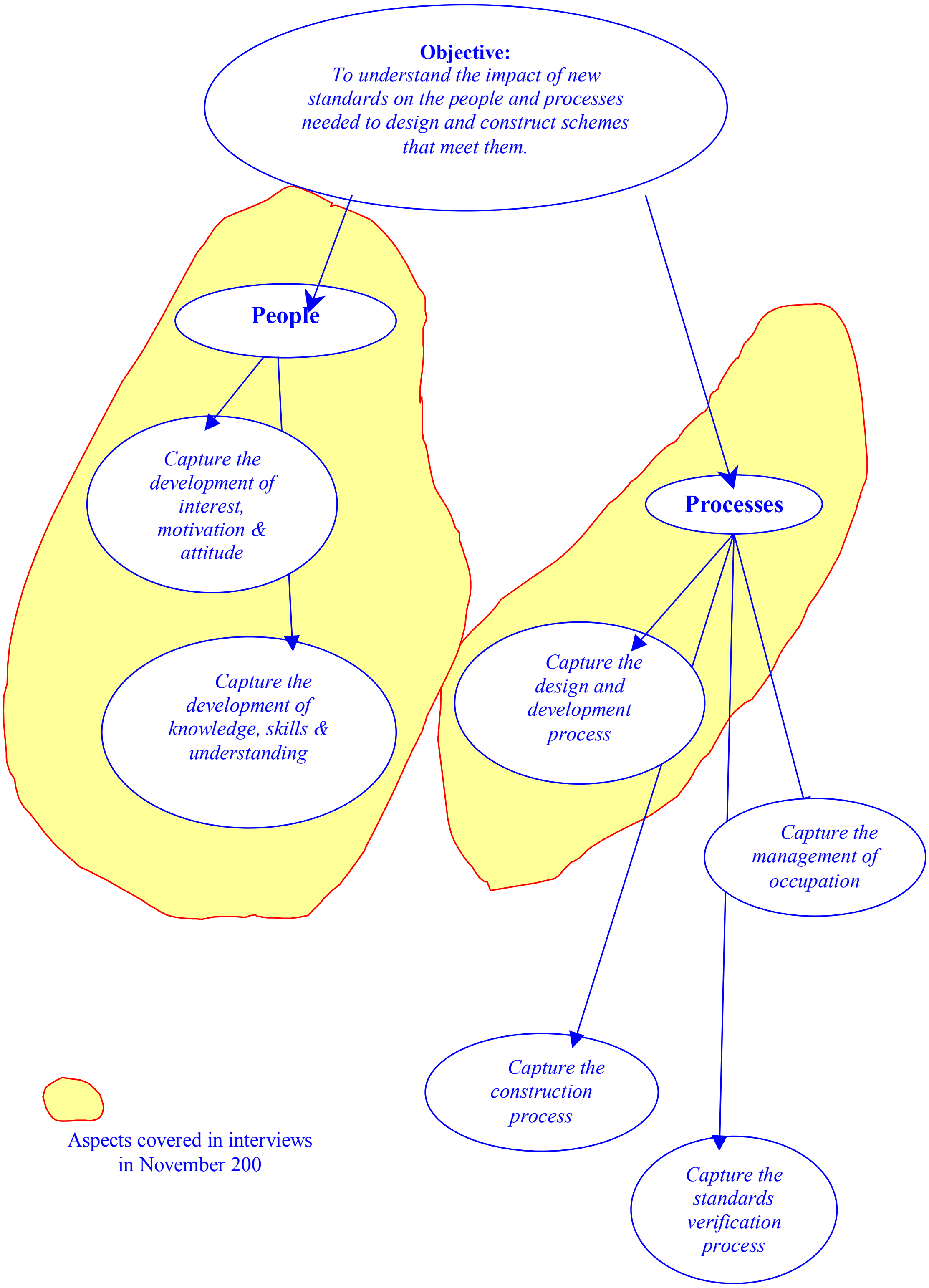


Figure 7.1: Interview objectives

The main themes that emerged are discussed in the remaining sections of this chapter.

## 7.1 Team member background

As one would expect, the backgrounds of team members ranged from those with a relatively high level of knowledge of energy and environmental issues to those who came to the project with very little knowledge. Officers of the association had some general experience of energy efficient housing, most notably the chief executive who had been involved in a housing scheme in Sheffield (Vale & Vale, 1992) but with little technical knowledge. The architect, project quantity surveyor (PQS) and the planning supervisor all had good background experience based on their involvement in previous schemes that sought to address energy and environmental issues. As indicated in Chapter 6, it was they, along with the client and the St. Nicholas Fields environmental group, who conceived and developed the initial ideas that lead to the involvement of the research team and the selection of the partnering contractor. The contractor's team came to the project with a traditional contracting background and had relatively little knowledge of energy efficient housing and even less direct experience[1]. However, in another region, the company had experience of building housing to standards set by the INTEGER group[2] and this experience was called on in the development of the submission made during the selection process. The specialist subcontractors/suppliers brought specific skills and experience in their own areas coupled with some experience of product development aimed at increased energy efficiency. The timber frame manufacturer had designed and supplied timber frames for a number of projects (including INTEGER housing in Wiltshire and the midlands) in which increased levels of insulation were required and the heating & ventilation system supplier was actively engaged in the development of products with a strong energy and environmental focus.

Whatever the level of knowledge and experience all members (with one exception) displayed a strong personal interest in the energy and environmental dimension. It is also noticeable that, whatever the level of understanding of the specific issues relating to thermal bridging and airtightness, the non-client (technical) members of the team possessed a shared understanding of the general concepts. A factor that enabled them to communicate effectively at a technical level and to assimilate rapidly the detailed problems even if finding a solution was not always easy.

The background experience and understanding of partnering was generally low across all members of the team. The contractor, however, had experience within their national organisation and this was used to assist in the development of a number of key instruments such as a partnering agreement, a dispute resolution procedure and a success matrix, which was used to monitor the partnering dimension. The development of the partnering approach was an important factor for a number of team members. For the client it formed, alongside the sustainability standard, a condition of Housing Corporation[3] funding and gave them a head start in pursuing the notion of Egan compliance (Construction Industry Task Force, 1998) that was to become a very important part of government policy in the distribution of funds for social housing and

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[1] It is interesting to note that the contracting company had constructed, almost 30 years ago, a dwelling that remains one of the most energy efficient dwellings in the UK – the Wates House at Macchynlleth (Olivier & Willoughby, 1996) Yet this aspect of company history (perhaps not surprisingly) came as a total surprise to the team when mentioned at one of the early meetings.

[2] http://www.integerproject.co.uk/

[3] http://www.housingcorp.gov.uk/

other publicly funded projects. For the contractor it fitted the company's strategic plan and was to be its first partnering project in the region. For the team as a whole it was seen as an important part of the process of extending energy standards in mainstream housing. The commitment to making the partnering arrangements work was considerable and enabled the project to move ahead even when acquisition problems placed the whole project in some doubt.

The early part of the interviews asked interviewees to reflect on their initial perceptions of the regulations[4] prior to the commencement of the project. Views ranged from the feeling that they were "fairly strict" to "woefully inadequate" with two team members having no particularly strong view since they did not see it as their role to comment on standards. However, since the majority of the team had had some experience of building to higher standards it was inevitable that the predominant view was towards the "woefully inadequate" end of the spectrum.

## 7.2 Change in views and attitudes

Given that the majority of the team brought very positive attitudes and commitment to the energy and environmental objectives of the project, change was not expected to be great. In general, attitudes simply became more positive and beliefs about both the importance and feasibility of achieving higher energy and environmental standards were strengthened. The experience also seems to have impacted on the confidence of at least one member of the team to develop other sustainable schemes. The following comments present a flavour of the responses received:

> *"My feeling of the importance of taking some kind of action, whatever is within our power to do, is even more strong now than it was before…. if anything I have become more convinced that this is something that is not just worthwhile doing but it's actually necessary for us to do. I think I've become more aware that doing one demonstration scheme, however fascinating it is …. is only a start, really."*

> *"My objectives haven't changed at all. I'm even more convinced that we've got to do even more to push further. So if anything,……. I don't feel it goes far enough.*

> *"[My views about the energy and environmental objectives have]* not *[changed]* in *terms of their importance, because I went into it believing that it was important. What has changed has been my understanding of the detail of how you achieve that, and that's been good. It's also equipped me with sufficient experience and conviction to push hard to get one or two other sustainable housing projects …… which I don't think I'd have had the resources to go for if it hadn't been for this one. But in terms of my attitudes and understanding of energy efficiency it's more in terms of the way it's implemented rather than my belief in it…"*

The client reported that the scheme was influencing their own thinking and interest and that this was having an impact on the rest of the organisation and was impacting on thinking with respect to applications in other aspects of their work.

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[4] The 1995 regulations (ADL95)

> *"I think that's increased [interest in the impact of housing on the environment] and now suddenly I find myself reading things that I would have skipped over, even trying to understand what the building regulations part L actually say"*

> *"Even looking at our own stock there are more things that we can do and I suppose that's something I've become much more aware of. We've got to turn our attention to doing that."*

> *"Yes, [I think the views of the organisation have changed]. I think it's partly because we are involved in the project and that involvement has given us the impetus to develop an environmental policy.."*

> *"I think doing this for new build has made us think about how we do refurbishment and major repairs and that's already come through in at least one major window renewal contract where we went explicitly for a very high specification of timber window from sustainable sources and high quality double-glazing….Yes, it's changing our thinking."*

Although it is clear that the team displayed positive attitudes throughout the design there remained some concerns, principally from the constructors, about the extent to which the objectives could be achieved using current construction processes. And, by implication, whether "traditional tradesmen" would be able to respond to achieve the requirements on site.

> *"I think the environmental objectives are laudable and fully supportable but I think they need to be pegged back from where they are…I think they need refining a bit. On this scheme, what we are trying to do is achieve much tighter standards with current practices. One of my favourite sayings is, 'If you do what you always do you end up with what you always get'. We've got these targets but we're not doing anything radically different in the way that we are building it - we are going to build it on site with traditional tradesmen and materials - so we'll probably get somewhere near what we want but there will have to be an evolution of processes as a result of these tighter targets."*

Unfortunately the need to truncate the research project will leave this very important question (one which most of the team would echo) hanging in the air for the present.

Concerns were also expressed about controlling cost and ensuring that enthusiasm for energy considerations do not avoid the cost dimension.

> *"It worries me that we might have a breakdown when we firm up the design and find we can't afford it. So we need to learn and develop a mechanism where in every conversation the cost is just as important as the energy factors and the buildability."*

Not every member of the team saw the scheme in terms of the environmental and energy standards. For one member in particular the benefits of the scheme lay in the potential for non-environmental added-value.

*"I have to be absolutely honest and say, perhaps, I am not very environmentally friendly as a person and I wouldn't say I have become more environmentally friendly since we started. Whilst I say that, it's more[about] money for me. ….but I've considered the possibility of installing a heat recovery system in my house, for more than one reason because of the humidity benefits it gives you, which cuts down dust mite and that type of thing, … I get [a] dust allergy, so it would be a great benefit to me and that would have a knock on effect on energy consumption in the house. So it would save money, it would cut down the dust mites and it would also have a benefit on the environment."*

As would be expected, initial views about the building regulations strengthened among those who thought them poor to start with. Among those who thought them to be reasonably stringent before the project perceptions had undoubtedly changed.

*"I used to teach a CIOB building regs module at the building college so I was quite familiar with them in terms of the standards, I've seen them get harder and harder on insulation values and I thought they were fairly strict. I think now that they weren't, they were incredibly lax".*

Even where the view remained neutral, the mood seems to have swung to wondering.

*"I said earlier we are a bit apathetic on them: we don't really have a view on what they are or what effect it has and I think we are a little bit detached from it but I would say from the direct involvement in this, you wonder why we can't do more."*

Although it is clear from the responses that interest, attitudes and motivations are very positive throughout the team and have been generally strengthened during the design process, there is a noticeable difference between the views expressed by constructor team members and the rest. On the whole, the constructors seem to be less inclined to criticise the current regulations and more likely to raise concerns about the achievability of the prototype standard. Although, for most team members both the energy & environmental and partnering aspects of the scheme were important motivating factors the constructor members were more likely than others to mention partnering as a key issue.

### 7.3 Knowledge, skills and understanding

The operation of any change to regulations will require an understanding of the extent and nature of learning that needs to take place within the construction community. The interviews sought to identify the extent to which knowledge, skills and understanding had been enhanced and to pinpoint specific areas of learning. As with the development of views and attitudes the extent of acknowledged learning varied depending on each individual's starting point. The analysis of the interview transcripts suggests that team members fell into four broad groups with respect to existing understandings:

- Those (client advisors) who started with a good grasp of the general principles of energy efficient housing.

- Those (construction advisors) who had very little knowledge of either detail or the general principles of energy efficient housing but who had a sound technical knowledge of building construction and current regulations relating to energy efficiency requirements.

- Those (supply chain) who had very detailed product knowledge and a broad understanding of its potential application in energy efficient housing.

- Those (client) who had little technical knowledge but had a broad understanding of the performance requirements and some of the principles behind achieving them.

Among the first group there was a strong sense that although they considered themselves to be experienced in the design of energy efficient housing, they had learned a great deal at the detailed level about the application of the principles. In particular about the way the detailed design and construction of housing can influence in a significant way energy and environmental performance. Although there was an existing awareness of thermal bridging and airtightness the project had clarified these issues and the design approaches that need to be adopted to ensure a good solution.

> *"I've got more detailed knowledge. I might have had some ideas or some background information previously, but with the aid of [the research team] it's certainly increased my knowledge of the detail.*

> *"……there has been an understanding about air-tightness as an issue which I wouldn't necessarily have given as much weight to before about issues like simplifying the building envelope which I wouldn't have had as high on my list of priorities as before, and the design of the houses has changed along the way to reflect that kind of shift in understanding".*

The learning within the supply chain group also tended to be at the level of detailed application of their product/system in the context of energy efficient housing and having to look at familiar problems in a different way.

> *"I've learnt quite a lot about the detail of achieving air-tightness. The demonstration ... in York was beneficial……. I'd been to pressure testing before but never seen a demonstration that was as clear."*

> *"The air-tightness and looking at it in a different way. Forcing myself to look at different ways…"*

For the construction group the learning was more extensive and followed two distinct phases the first was the preparation of their initial submission to the client during the selection process in which a considerable amount of work was done on both energy efficiency design issues and on the wider environmental objectives. Much of this acquired by talking to others in the company who had experience of energy efficiency projects and to potential suppliers. The second phase took place during detailed design and resulted in an increased detailed understanding of the application of the principles developed during preparation of the initial submission. The first phase was seen by some to be the most extensive.

> *"I would say the biggest learning process was when we put the initial proposals together and just by doing the research which we did …. going from, I would say, 5% knowledge to what was probably 50-60% knowledge, I think we gained a hell of a lot information during that time. We came to realise that to work within the parameters that we had been given…..in the brief, it required more than just finding a highly-insulating material and that was something as a concept I have never considered before."*

As with other team members the principal areas of detail in the second phase related to airtightness, thermal bridging and the need for thermal mass.

> *"One particularly outstanding piece of knowledge was how leaky buildings are. I thought that air-tightness day was a revelation. Some of the input from LMU, such as energy saving considerations - I've learnt a lot."*

> *"I've become so aware of cold bridging. I was impressed by the degree to which it has been addressed on this scheme - the amount of thermal bridges that I wasn't aware of"*

> *"…the elimination of thermal bridging, the thermal mass requirement - we were going to use a timber suspended floor and didn't understand the principles of something to catch the heat - that was good knowledge. The airtightness, the environmental side of things was all knowledge that I gained."*

Interviewees not only commented on what was learned but on where material came from and how it was learned. The research team input was commented on by almost all and features in a number of the extracts above. The DAS and airtightness seminars were also mentioned as important sources of advice.

> *"Particular useful events along the way have been having [the research team's] involvement in the Design Team meetings"*

> *"…the input that [the research team have] put into the scheme about energy efficiency, the input [from the DAS seminar] and the input that was coming from [timber frame supplier] and from doing visits to [other schemes]has all been fuel for me … look at the construction methods, look at what problems we might encounter. Talking with the contractor about the buildability aspects of it.....*

> *...other key decisions to do with detail design have been to do with the work which [the research team] have done on thermal bridging and what effect that has and how it becomes significant in well-insulated buildings and how we might address that, so that's been important.*

However, for some, the project had stimulated their own enquiry into some issues or made them more receptive to material that they would otherwise not have noticed or recognised as relevant.

> *"Some of the things that if I haven't picked up directly through this project, because we are doing it, they've leapt out at me from other sources. It's a sort of*

> *stimulus to see what other people are doing and learn from other people and bring that knowledge to this project as well…",*

All team members acknowledged that there had been a considerable amount of mutual learning (as illustrated in one of the extracts above) and were able also to indicate what knowledge they had brought to the team. In fact it was noticeable that by the end of the design process some team members were quite happy to get involved in issues outside their specific area of expertise as well as accepting that others would do the same. How the material entered the arena was also commented upon. A great deal of information appeared to have been absorbed through talking and consulting both within and outside the team. The constructor team's approach to building its knowledge base prior to making their initial submission is a particular case in point and the workshop style within the design process, enhanced by a good atmosphere created by the partnering approach, received particular comment.

> *"I think what has helped has been the kind of workshop-style approach to the design process. I hope we've all learned something, but I know I have, in terms of my understanding about the way buildings work and way the factors influence the energy efficiency."*

To what extent the degree of learning on this project was different from that experienced on any other project involving something out of the ordinary is difficult to say but judging by the comments on the extent of learning, it is likely that this process has been much more focused on the development of the knowledge base of the whole team ( as opposed to specific individuals) than in a more typical housing design process.

## 7.4 Managing the design process: Partnering

We have already indicated the importance of partnering as a key objective of the client and the contractor, both of whom were keen to develop their experience of this aspect of the "Rethinking Construction" agenda (Construction Industry Task Force, 1998). In this section we seek to report on the partnering experience and the influence it had on the way the design of the St Nicholas Court scheme developed.

Roles within the team were established along broadly traditional lines but the relationships that developed were not. The contractor was chosen relatively early in the process but, as observed in Chapter 6, by the time the contractor was invited to make proposals, boundaries had already been drawn around the class of solution that was to be pursued. The contractor selection process, although bearing a superficial resemblance to a traditional pre-tender/tender process was not at all traditional. The way the process was carried out seemed to set the tone for the development of the project and the success, so far, of the partnering approach. The effect of the early involvement of the contractor, particularly the requirement for explicit design proposals based on an explicit energy and environmental standard, was to ensure that he had a stake in the design solution from the beginning. So much so, that it was possible to detect in the first one or two design meetings, a concerned reaction to criticism, born out of a commitment to the design and research work already carried out. However the basis of the relationships were such that, if anything, the discussions that ensued tended to strengthen, rather than weaken, relationships within the team.

*"I remember when we were first taken on we had some meetings where we went through the design, ……[the research team] put their thoughts in. I seem to remember they ripped the thing to bits! Bear in mind that we did a lot of research but we knew we weren't perfect. So from that we developed the design and I was involved in a lot of the buildability side of things. We had a good relationship with [the Architect]and we came up with what I thought was a good solution"*

The general experience, as evidenced by the views of team members and the direct experience of the research team, was very positive. Almost all team members remarked on the co-operative atmosphere in all aspects of design development and pointed out the contrast with their experience on conventional contracts. Even when design issues looked like getting difficult, problems were treated as the property of the whole team with no retrenchment into traditional positions. To what extent the experience was also a function of the smallness of the team, the nature of the personalities involved, the fact that it was the subject of an action research project and/or a whole host of other factors is not possible to say. It is certainly true that not all partnering experiences are good ones and that the way they are set up and managed is crucial to success. Similarly not all conventional contracts result in difficult and adversarial experiences. As Domberger et. al. point out, *"partnering is, essentially a collection of good management principles, many of which could be incorporated into traditional contracts"* (Domberger et. al. 1997). However the experiences of the participants in the St Nicholas court project reinforce the view that the partnering approach provided the team with the necessary flexibility to deal with uncertainty and to engage in a level of communication commensurate with the degree of learning required to produce a satisfactory solution.

The positive benefit derived from the involvement early in the process of the constructor and others in the supply chain was a key element in the comments made. For the constructor putting their knowledge to good use and being listened to were important issues.

*"The biggest difference has been the early involvement and the fact that people actually listened to your point of view……..We've got a lot of knowledge and a lot of experience to offer and it is enlightening to see that people on this project listen to what we have got to say.*

*"Early involvement in the design has been refreshing"*

The designer also found the process beneficial but from a different perspective.

*"…the contractor getting a chance to see how frustrating the design process can be because of client input or the input of[others] into the design process….. for them to see how the whole process weaves and spirals around along the way to a completed article has been useful for them and has been interesting for me"*

*".....it's been wonderful going to meetings where there have been design-related decisions to be made, where the contractor has actually turned round and said "well shall we find out about that?", "shall we look into that?", which is exactly the opposite to what you'd normally expect.."*

For others the lack of confrontation was of considerable benefit and provided a much less stressful environment in which to work.

> *"The biggest benefit, in our experience, is the confrontational attitude with normal contractors disappears".*

> *"I just find it a less stressful and less confrontational way of working. I suppose my background has been in development ……. and I'm used to that kind of fairly confrontational way of working but that's not to say I like it or feel comfortable with it. If there are other ways in which you can do it and still recognise that partners in there have different objectives…….. and you can marry those together in a way, then it feels a much more positive way of working."*

Any fears that are sometimes raised about a loss of control over information was certainly not an issue in the project. The architect actually found it a much more satisfying one as he saw him self as an "information broker" as well as "information provider", a role that enhanced the learning experience.

> *"I much prefer the architect's role as a kind of central information-shuffler, information-broker, as well as an information-producer. I think it's a much more fruitful one, it's a much more satisfying one, and I've learned much, much more through the process than I would have done through a conventional project, which for me has been the big bonus."*

The impact of partnering on the transmission and sharing of knowledge was also remarked upon as being of benefit to the project.

> *"I think the beauty of listening to other people is we all have experience of how not to do things as well as how to do things. One thing that really comes out of this project is the spirit with which people are coming to the table, they are there to assist everyone, it's not only open financial book recording, but it's open book on knowledge. I think that's brilliant."*

At the time the interviews were carried out and the project frozen pending the outcome of land acquisition and a final decision on the scheme, the design work was substantially complete. It was generally acknowledged, however that in any construction project the production phase carries the largest potential for disruption, and breakdown in relationships and that only after the experience of construction and occupation would the team be able to assess the success or otherwise of the partnering approach. One team member stressed the importance of the relationships and culture that is developed as a way of combating any tendency for participants to "revert to type" when the "going gets tough".

> *"Yes the relationships that are forming are pivotal to the success of a construction project. They are deep, people can talk honestly to one another, openly. Most construction jobs come together at the 59th minute of the 11th hour on site and often there is no relationship between site manager, architect, even the contractor's team or the client's team. Those lack of relationships, I think, lead to conflict, lead to a lack of openness, lead to position taking. I think with this team already there is a degree of openness ……… that has come about, even through the adversity of the*

*scheme when we didn't know if it would start or not. I would be quite happy to be honest and open with any of them. I don't think I'd have to hide anything which I think is a process of forming that relationship………..*

*"When the going gets tough the people revert to type - for me that means the relationships aren't deep enough. As soon as problems arise people run for corners, contracts come out…….. Standard forms of contract lead to confrontation. You need an umbrella partnering champion on board for when things get fraught on site…"*

The impact of partnering on cost was also something that was impossible to determine. This is because of the particular circumstances of the project and the land acquisition delays as well as the novelty of the process for almost all of the participants. Team members responsible for assessing costs were happy to acknowledge that there were, in theory at least, cost advantages to the approach but that the costs associated with greater involvement in the design phase (particularly given the delays on this project) could negate any savings that would accrue later.

*"Generally, from a cost point of view, we would have a saving in terms of the estimating process. This is somewhat different now because what we would have saved……… was spent many times over because of the delays but I would say the principle, though is sound. By reducing the estimating time, we would reduce our costs and the overall effect of that is that the saving does eventually get passed onto the client."*

The question of cost and partnering cannot be considered in isolation from value and quality. The client was happy to acknowledge that higher costs were likely but that this may be justifiable in terms of the value obtained through higher quality.

*"I like partnering. I like the social aspect of it. It takes more time but on the other hand, in the end you get the result. Whether that's true or not I don't know because we haven't got there yet. We're not necessarily experienced on this job and only time can tell. By selecting the contractor on a basis other than cost you are not necessarily going to get the lowest costs …… and the theory is that you end up with the best product and that's still to be tested. I'm thinking of another job where we've been partnering but on a much smaller job, a conventional rehab in fact. The costs have been high and higher than they would have been if we'd gone out to competitive tender, yet the consensus is that we are getting a better job"*

The lack of a construction phase makes any conclusions about the quality of the scheme or the impact of partnering on quality impossible to determine. However the comments of team members on the thoroughness of the design discussions and the co-operative atmosphere suggest a high degree of confidence in the quality of the design decisions made.

## 7.5 Research team impact

In Chapter 6 we describe the participation of the research team in both design decisions and in training. The purpose of this section is to outline the view of that input from the perspective of other team members. Much of the material in Chapter 6 acknowledges the significant role played by the research team in providing specific information and general guidance on the critical design issues. In addition, however the interviews also indicated that the research team played an important role in maintaining the standard and in championing solutions that seemed to provide the best chance of achieving the required performance. The following extracts seek to give a flavour of the mood expressed by some members of the team:

> *"The other key decisions to do with detail design have been to do with the work which [the research team] have done on thermal bridging and what effect that has and how it becomes significant in well-insulated buildings and how we might address that, so that's been important".*

> *".... the warm roof/cold roof debate. I suppose the key point in that was carting [the client] down to see the [Holgate Park] self-build houses and for them to marvel at the roof space and decide that maybe yes it was worth spending the extra few hundred pounds on the extra habitable space of the sleeping shelf..... I think partly …… of [the research team] grinding [the rest of the team] down in terms of us going for a warm roof, and [the client] seeing how good a space up in the roof could be. We have shifted and the house types now have warm roof...."*

Again on the cost debate concerning the roof construction:

> *"…under a normal process, once the QS and the contractor had said 'it's going to cost too much', it would have been dropped, and that would have been the end of it, but because [the research team] hassled and hassled, and talked and talked, we ended up re-examining it and going back and saying, 'well the budgets have to go up anyway because of the time delay, I think they will have to go up a bit more and incorporate the warm roofs'.*

It is difficult, from within, to judge the extent to which the presence of a strong source of advice on alternative construction approaches was able to influence final design decisions in this case but, in the minds of some team members at least, the role played by the research team was an extremely influential one. As we have seen in the case of the wall design, once the thermal bridging problem had been articulated, the design revision (from a 189mm stud to and externally insulated 89mm stud) was a relatively low cost and obvious one. In the case of the roof design, however, cost arguments held sway until there was a re-evaluation of the value side of the equation (additional accommodation) coupled with a delay in the programme, both of which enabled the technical argument to prevail. Whatever the position in this particular case it is likely that if construction technology is to respond to the challenge of ever improving standards of thermal performance, the development of new technologies will be inevitable. The difficulties faced in this project to illustrate the issues that would have to be addressed in making the necessary transition.

# Chapter 8 Reflections on the design process

## 8.0 Introduction

Perhaps the single most important ingredient in the project was the considerable commitment shown by all members of the team, most of whom have incurred costs that may have to be written off if the acquisition delays result in the loss of the project. However that commitment required a clear focus and the team needed to feel its way to an acceptable solution as they sought to merge their existing understandings with the requirements of a new set of objectives and what, for many, was a new way of looking at the problem of designing and constructing houses. Chapters 5 and 6 chart, in some detail, the story of that journey. In this chapter we attempt to draw out some of the wider implications and to anticipate the general issues that would have to be faced as the industry is forced to confront the problems of responding to ever tighter regulation designed to address the imperatives of climate change.

## 8.1 The role of the prototype standard

As with current regulations, the standard provided a very clear focus for the design work and was used on numerous occasions as a way of assessing solutions and ideas. In this sense, the prototype operated as a quasi regulation and was accepted as such by the team. It was noted in Chapter 6 that not all members of the team thought that the standard was easy to achieve and expressed doubts about whether it could be done in a "normal" housing scheme given the current industry norms and solutions. However such reservations did not diminish their efforts. To some extent this could be attributed to the nature of the team approach and the sense of confidence expressed by other members but perhaps the most significant factor was the client's desire to achieve the standard and their confidence in the team to deliver. In the absence of enforceable regulation, the client had set up a contractual (or through partnering a quasi-contractual) obligation that drove the design. This may be unusual when dealing with matters relating to building regulation but is familiar territory when addressing questions of accommodation, quality of finish, colour and servicing requirements. In effect, the client brief had substituted the prototype standard for the existing regulations and the team accepted the challenge as with any other scheme.[5] As one of the contractor team members pointed out:

> *"As constructors, we are given a design to build and we go along and do it. That's our involvement in a typical job. So we would rarely have any great concerns… we just do as we are told."*

The influence of the client as a key determinant of what is achieved was recognised by a number of team members. An influence that can have a very positive impact on energy performance:

[5] Of course, compliance with the then current regulations (ADL95) remained the prime legal requirement.

*"I thought the client was a key factor: you don't normally get clients who want to do this kind of thing. [They] could have quite easily knocked up some brick block houses for £30,000 each and saved a few grand but they are the driving force behind the scheme, the key influence in doing this."*

Or can work in a more negative way;

*"All the schemes I've been involved with have tried to push them [clients] further than building regulations standard, although as often as not ,because of the priorities the [clients] had, that ended up getting kicked out along the way."*

Thus the client, having decided to use the prototype standard as a cornerstone of the brief, set up an effective regulation that everyone accepted and attempted to work to. A similar situation can be observed in the design phase of the Brookside farm project.[6]

As indicated in Chapters 6 and 7, the research team played a significant role in providing support for both the standard itself and the project team. At one level they acted as the guardian of the performance standard and were able to provide a constant reminder of the level of performance required, reflecting the role played by the existence of a formal regulation and enforcement mechanism. On another level, the team facilitated training in the key principles of energy efficient design and provided a technical support service for design development and the analysis of construction details.

## 8.2 The design solution and technological development

The design that emerged was a mixture of modified conventional construction for the walls and floors and a more adventurous roof construction. The roof design process demonstrated the difficulties of making the transition from traditional well-understood solutions to more novel approaches. In the initial design phase the I-beam solution was rejected almost immediately on grounds of cost and, possibly, unfamiliarity. The focus of attention was on making the trussed rafter solution work, a process that promised to produce some complex details as attempts were made to resolve the problems of airtightness, structural thermal bridging and housing the ventilation equipment. The technical simplicity and potential superiority of the I-beam solution was widely acknowledged but was not enough to overcome the cost arguments. As indicated above, achieving change required a strong alliance of different needs coupled with a delay in the programme and cost reductions elsewhere. The wall construction is a similar case in that the external insulation layer compromises, to some extent, the client's desire to minimise the environmental impact of the materials used. The obvious solution, using I-beam walls with cellulose fibre was, however, rejected on cost grounds and a compromise was found based on the modification of a traditional construction form.

[6] The sister project to the St. Nicholas Court project – PII reference CI 39/3/663 Lowe and Bell (2001).

The story of the wall and roof design throws into sharp relief many of the strategic issues faced as the industry grapples with the need for higher and higher energy and environmental performance standards. As standards rise, the ability of the industry's stock of familiar solutions to deliver the required performance is progressively reduced. Eventually the industry is likely to reach a point where a major shift is required in design and construction thinking. Perhaps the masonry construction lobby's assertion that to go beyond the 2002 regulations would require a "step change" in construction techniques is not entirely without foundation[7]. However, rather than resist change, the industry is under increasing pressure to embrace it and a considerable amount of work is required to develop and refine a new range of solutions.

There are parallels here with Kuhn's notion of a paradigm shift in the development of science (Kuhn 1962)[8]. In broad terms Kuhn presents a picture of scientific development that exhibits a series of step changes involving the rejection of an established order or existing set of shared understandings (a paradigm) and the adoption of a new one. During the currency of a particular paradigm it is constantly reinforced within the scientific community through text books, scientific training and other apparatus of the scientific establishment. It also sets the research agenda in that the paradigm both defines the problems to be solved and provides the framework in which experiments are designed and data collected. Kuhn referred to such activity as "normal science" which continues as long as the paradigm is able to solve the problems it sets itself. However, at some point, along comes an individual or group who realise that there are anomalies that cannot be resolved within current theories and/or that even the definition of the problems being worked on are no longer relevant or do not address some "real" problem. The emergence of the idea that the old paradigm cannot resolve the difficulties created by anomaly leads to crisis within the relevant scientific community. There then follows a period of change in which the defenders of the old paradigm redouble their attempts to resolve anomalies, with an increasing tendency to failure. Incremental modifications are made to the theories supported by the old paradigm in an attempt to force a fit that becomes less and less convincing. Meanwhile a new paradigm gains ground and eventually replaces the old one because it shows more promise and appears to provide a more appropriate set of solutions, understandings and techniques. Following such a shift in paradigm normal science resumes but in a world different from before.

We believe that the notion of paradigm and paradigm shift provides some insights that are relevant to the development of an appropriate response to the needs of low-carbon

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[7] This assertion was made quite strongly during the 2002 regulations review and was intended primarily as an argument against radical regulatory change. It is ironic however that the experience of the St. Nicholas Court project (timber frame) and the Brookside Farm project (masonry) would suggest that to push standards beyond the 2008 prototype (e.g., an average envelope U value of say 0.1 $W/m^2K$) may well require a much more fundamental rethink of timber frame construction than of masonry.

[8] We are aware that we tread a difficult path (particularly in a report of this nature) in seeking to draw parallels between Kuhn's work in the philosophy of science and the development of construction technology. Indeed, having noted the tendency for his work to be applied in other fields, Kuhn sounded a note of caution in a postscript to his second edition; "I see what they mean and would not like to discourage their attempts to extend the position, but their reaction has nevertheless puzzled me." ; pointing out that " Though scientific development may resemble that in other fields more closely than has often been supposed, it is also strikingly different."

construction technology. The design team on the St. Nicholas Court project were faced with a situation, which at first sight appeared to be little more than an extension of existing standards and norms. As such the problems were considered to be solvable by the application of familiar construction solutions. Hence the proposed use of 189mm stud walls (just make existing construction thicker) and the trussed rafter roof. However, on closer inspection it became clear that the standard represented a significant shift in the nature of the problem. For example, the 189mm stud wall did not address the problem of thermal bridging and was wasteful of timber, the trussed-rafter cold roof made it difficult to achieve the insulation and airtightness requirements as well making inefficient use of timber and space. The team were being asked to operate in a modified world, one that required both a different perception of what determined good performance (a one-dimensional U value was no longer an acceptable measure of thermal performance) and a rethinking of well-worn solutions. In short, they were operating in a different paradigm, a paradigm in which thermal bridging was highly significant, airtightness a serious issue (more than a set of tips about draught-proofing), well controlled ventilation crucial and the heating system less dominant in ensuring thermal comfort.

To some extent the design solution adopted was a transitional one, set between the relatively undemanding thermal performance requirements of the late 1970s, 1980s and 1990s (which presented few challenges to traditional construction technology) and the much more demanding trajectory set by an effective response to climate change imperatives. The solutions and the design debates that surrounded their choice tended to display a tension between the conventional solutions that were well known and understood but increasingly difficult to apply[9] and the more novel. In the case of the wall design a compromise was possible and a hybrid solution emerged very quickly although, from an environmental point of view, it was sub-optimal. In the case of the roof, a similar compromise was not so easy to achieve as the progressive modification of the trussed rafter became more and more complex and the more novel technology was eventually chosen. One wonders what might have happened if the wall decision had not been finalised so early and the I-beam solution adopted for the roof before the wall construction decision had been made thus precipitating a fundamental rethink of the whole structural solution. Decisions about the heating system also took on a transitory tone as the team hedged its bets about the need for radiators in bedrooms by providing extension stubs to facilitate their installation (if needed) at a later date.

Before leaving this section it is perhaps worth reflecting on the long term development of the technological response to the need for improved energy and environmental performance. In doing this, there is one more aspect of Kuhn's thesis that has relevance for the development of low carbon construction technology: the resumption of "normal science". The purpose of a resumption of normal science is the explanation and development of understanding about the world as seen through eyes directed by the new paradigm. The acceptance of a new paradigm often requires an act of faith, since when first conceived it may not be any better at predicting or explaining natural phenomena than the one it replaces. However, acceptance lies in

[9] In retrospect it is hard to see how, in the context of a sustainable housing scheme, a timber frame solution that was over-designed structurally by a factor of 2 (189 deep studs), used at least twice as much material than necessary and required very high grade timber from outside the UK could have been contemplated.

the promise it holds for greater understanding: understanding which is provided later by normal science as it fills in the detail and solves many of the new problems raised. As with science, so with technology: the acceptance of a new paradigm (in our case low carbon construction) requires a lot of effort at all levels as the new detail is worked out. This is the job of "normal technology".

Working out the detail will involve the development of the supply chain for new hardware, such as I-beam roof and wall construction, leading to an improved product and lower costs[10]. Normal technology will also involve the development of the skills and understandings that enable the effective design, construction and maintenance of whole buildings capable of delivering the required performance. In the UK at least, this process has only just begun. Our experience on the St Nicholas Court project reveals a constant tension between familiar, low cost, solutions that were becoming difficult to apply with confidence and novel solutions that carried greater promise but higher costs.

The standard adopted in this field-trial stretches current technological solutions close to breaking point but, perhaps, not beyond[11]. However, further developments are likely to increase the pressure for new technological developments. To drive U-values and air infiltration levels below the prototype standard would require the widespread adoption of triple glazing, more attention to thermal bridging and air sealing and would have a marked influence on the design of space and water heating systems. As space heating demand is reduced, the possibility of integrated heat recovery ventilation systems becomes more feasible and cost-effective. Similarly, as water heating becomes dominant (see Chapter 3), further reductions in $CO_2$ emissions will require greater attention to such technologies as active solar and heat-pumps. The job of normal technology in a new, low carbon, construction paradigm is to make it possible for designers and constructors to have ready access to such hardware and the systems that support their use, maintenance and replacement. In short, it should be possible for an integrated solar and heat-pump device to be installed, used and maintained with the same ease as is the case with a gas boiler in current heating systems.

What the above discussion amounts to is a realisation that the industry is approaching a critical point in its response to climate change and that it is time for it to retool.[12] A

[10] In principle there is no reason why an I-beam roof should cost more than a trussed rafter roof. There is less material, material from lower grade (cheaper) timber can be used and the manufacturing process is no more complex than in the trussed rafter case. The current difference lies, of course, in production volumes and the relative maturity of the supply chains. As we noted in Chapter 5, there are signs that the cost of I-beam technology is coming down and many roof forms may be approaching parity with trussed rafter construction.

[11] This is a difficult question to resolve at this stage. The roof debate hinged on argument and counter-argument related to the expected performance of the different systems and the ease or certainty of achievement. It would be possible to envisage a trussed rafter roof that achieved the thermal and airtightness requirements and provided an insulated space for the MVHR equipment (see Figure 6.3, Chapter 6) but whether this could be achieved in practice as easily as in an I-beam roof remains an open question. Even if the scheme were built, evidence could not be provided without a controlled experiment in which both constructions were used and ease of application and final performance measured, not an easy research task to accomplish.

[12] The retooling metaphor was used by Kuhn in referring to the problems faced by science as it grapples with the process of change. ***"****As in manufacture so in science – retooling is an extravagance to*

retooling that will require change to both technical solutions and the skills needed to develop and apply them. Although it must be acknowledged that retooling is an expensive business, the costs involved are transitional and represent an investment in improved future benefits. In the context of this discussion, investment in retooling would reduce the long term costs of climate change, avoid potential security of supply problems and at a more commercial level, enable the UK construction industry to catch up and compete with North America and Scandinavia in a growing market for low carbon expertise and technology. In any event, a continuation of the regulatory trajectory established by the 2002 and 2008 standards will render the expense of retooling unavoidable. The most important strategic questions for normal technology, post paradigm shift, are about how to manage the retooling process. Government and the industry at large need to address these questions sooner rather than later.

## 8.3 Retooling the knowledge base

As discussed above, the job of normal technology, once the imperatives of low carbon construction are accepted, does not extend to technological hardware alone. It must also revise the knowledge base. At a general level the text books will have to be rewritten or at least up-dated and specific training will be required to support design, construction and maintenance of a low carbon built environment. This is a much larger question than can be dealt with in a report of this nature. However the experience on this project provides some insights into the nature of such a task.

In Chapter 6 we describe the explicit training activity that took place within the project team. This was enhanced up by the involvement of the research team and by the environment in which the design was developed. Useful though the formal training was, much of the learning that took place was, principally, a function of the project environment (aided by the partnering approach) and the discussion of emerging design solutions. This involved not only input from the research team and outside experts on low energy design but also the knowledge of others from within the project team. The interplay between the requirements of the energy standard and the other requirements of the scheme (accommodation, layout, buildability and the like) was important in ensuring that the principles of low energy housing design were thoroughly absorbed and integrated with existing understanding. For, as any educator knows, context and the application of knowledge is crucial to the learning experience. In this project the existence of the prototype standard and the desire of the team to embrace it provided the initial impetus and, as indicated in Chapter 7 (section 7.4), drove much of the knowledge development in the early phase.

Having caught the team's attention and provided a clear context for learning, the standard acted as a springboard for what followed. Key principles were absorbed very quickly and applied in design. In many cases it was a matter of tapping into existing knowledge, pointing out its significance and how it can be applied within the project. For example, thermal bridging and airtightness were understood as concepts but their significance and prevalence in existing practice were not appreciated. And since normal practice takes little notice of these issues, the team's stock of solutions was

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*be reserved for the occasion that demands it. The significance of crises is the indication they provide that an occasion for retooling has arrived" (Kuhn 1962 p. 76).*

very small or non existent. Clear illustrations of significance were enough to convince team members that these aspects were to be taken seriously and incorporated into all aspects of design decision making. As indicated in some of the quotations used in Chapter 7, one team member found this an eye opening experience:

> *"One particularly outstanding piece of knowledge was how leaky buildings are. I thought that air-tightness day was a revelation………I've become so aware of cold bridging. I was impressed by the degree to which it has been addressed on this scheme - the amount of thermal bridges that I wasn't aware of!"*

From this base the team were able to develop solutions reasonable easily even though, in the case of the roof design, this required considerable discussion on costs and the provision of additional space.

Retooling the knowledge base in support of successive improvements to building regulations will require not only the formal programmes of industry workshops and training seminars but also support for the informal transfer of knowledge such as that experienced in this project. Since the research team played a full part in the design process, their tacit understanding and knowledge of the issues and possible solutions was integrated with the expertise of other members of the team. The opportunities this provided for a two way transfer of knowledge were considerable. Many of the team members interviewed indicated that they had learned a great deal from participation in the design meetings and workshops and valued the range of views expressed on all aspects of detailed design. This deeper learning would be hard to replicate in traditional training programmes and is much more likely to be developed through informal osmotic processes as the industry gains in experience. It is suggested that a strong case could be made for developing as much of this experience as possible, prior to regulatory change, possibly through a more extensive programme of pilot projects. In this, the building control community has an important part to play. As guardians of the standard in force at a particular time they are in a pivotal position since they provide feedback to designers and constructors on the performance of schemes submitted for approval. They are also in a good position to provide informal advice prior to submission and often have to explain the regulations and the rational behind them. Our discussion with building control officers (Chapter 9) would suggest that, in the past, they have often felt under-prepared for regulatory change and that, like the rest of the industry, the change can take a considerable amount of time to absorb. It is our contention that a strong programme of pilot projects involving the building control community could help to disseminate not only the particulars of an impending change but also set the scene for the next. If done within the context of a clear strategic programme this would enable the industry to retool while keeping the costs of retooling to a minimum.

# Chapter 9  Building control issues

## 9.0  Introduction

The aim of the Building Control Exercise was to monitor and evaluate the impact, response and concerns of the Building Control (BC) team to their application of EPS08 – the proposed Environmental Performance Standard for 2008, written by the research team at LMU (Lowe & Bell, 1998a) on the St Nicholas Court project. The initial intention was to follow the progress of the BC team through their training, the submission stage and, later, the site checking stage. Unfortunately, this latter stage was never realised in this research project but building control officers (BCOs) were able to comment on likely implications of EPS08 on site checking.

Early meetings (spring 2000) were held with LMU, the architect, YHA and York Building Control to establish a framework for implementing EPS08. Concerns that an additional submission be made under the then current (1995) regulations were unfounded as it was shown that EPS08 subsumed the demands of the earlier standard in every respect.

Once the design of the dwellings was progressing well, meetings were held with LMU, the senior BCO and the BCO who would be checking the submission. These meetings introduced the EPS08 and tried to establish the method of checking the application. The EPS08 and accompanying documentation were given to York Building Control so they could become familiar with the standard before the checking process began. This documentation is included as appendices to this report and includes:

1) EPS08

2) Thermal bridging catalogue (Appendix 9). This contains additional thermal performance data for junction details that were designed by the architect for the houses to be built at St Nicholas Court. The data was calculated using Therm 2.1, a thermal modelling software package.

3) SAP worksheet (Appendix 2). The sheet was based upon version 9.60 with additional input boxes provided for inputting thermal bridging data. Formulae in the sheet incorporated this data in to the fabric heat loss coefficient.

At a later meeting, LMU explained in detail what the standard was hoping to achieve Unfortunately, the timing of the St Nicholas Court application coincided with the 2001 revision of the actual regulations. This meant that BC had an additional workload, as it was necessary to become familiar with two new standards and to not confuse the two.

It was acknowledged that the learning process of a real revision of ADL would be different in that a general awareness of the impacts of the changes would affect discussion throughout the industry. Knowledge and discussion of the new ADL would come from many sources including builders' merchants, RIBA, product manufacturers, architects, and the press, as well as from Government-run training seminars. However, one BCO later remarked that this preparation for EPS08 was as good as it could be given the circumstances.

The submission was processed in the spring of 2002 and in the following summer, a Focus Group was held with representatives from LMU, the architect and Building Control. The purpose of the session was to review the experience of BC dealing with the application and the experience of the architect who made the submission using EPS08.

The discussion topics covered two main areas, design verification issues and process/management issues, although, inevitably, some discussions did overlap.

**Discussion topics - design verification issues:**

1. Insulation verification
   U values
   Incorporation of psi values
   Integration of the various methods (elemental, target, carbon rating)
   Levels of aggregation

2. Airtightness and ventilation implications
   Verification of airtightness standard
   Implications for ventilation and internal air quality (parts F and J)

3. Heating systems (space and DHW)
   Verification of compliance

4. Other
   Overheating

**Discussion topics – process / management issues:**

5. Tools (checking, design)

6. Specialist input

7. Training requirements

8. Presentation of design data

9. Resource implications

10. Site tests and inspections

## 9.1 Findings from Focus Group, held 9th October 2002

One of the first questions asked was about the clarity of EPS08. How easy was it to follow? How difficult were the concepts to understand? BC thought that it took a while to become familiar with, it being new to them. The layout of EPS08 was different to the Part L and yet easier:

> *"The latest revisions to Part L are two huge unwieldy documents. EPS08 seems a lot simpler and easier to use – I don't know if you intend adding more tables and so on but it was relatively straightforward."*

The principle was easy to work with although BC felt, as they went through the document, that they were increasingly asked to become more and more of a specialist (in environmental and energy performance). One BCO thought that the specialisms might be too much for some individual BCOs to work with. Part P (electrical) consultation was mentioned as an example of how it appears that there is now more and more of a need for a specialist in that area. This now applies to services and for part L. It was felt that someone is needed to do this kind of work who knows what he or she is doing and does it on a regular basis.

Estimates were made of 50% of BC time is spent dealing with part L. When asked how learning EPS08 compared with getting to grips with ADL 2001, one BCO said:

> *"The ADL2001 has caused a wide debate, not just among ourselves, a wide range of views on interpretation – it's a bit vague. Different authorities and people could interpret it differently. EPS08 would be no more difficult conceptually and, with specialists available, it would be easier to take on board. The new Part L (2001) is an accumulation of changes which affects workload."*

A useful analogy that the SBCO used was that of a General Practitioner (GP):

> *"The role of a Building Control Officer is likened to that of a GP - they have a good all round knowledge of a number of different fields, but if they require information on a specialist matter, then they consult and refer it to an expert in that field."*

A current example cited was structural calculations. Simple structures are not a problem to BC but with complicated structures, a consultant engineer is used because they are the ones who know what they are doing.

A problem that arises with any amendment to building regulation is when a builder wants to change something on site and asks BC if it will be OK to do so. Often, the BCO involved may prefer to go back to the office and consult with colleagues and the literature before giving a decision. When BCOs are very conversant with the standard (in other words, the standard has had time to become well established) decisions can be made on site with confidence. One small alteration to a specific part can have a knock-on effect to other areas and, ultimately, there can be a large effect that had not been previously considered. Builders can sometimes make a change without notification (like installing a boiler with a different efficiency as a cost-saving measure) but without realising it is a problem as far as the standard is concerned. Something like this may only be discovered after the house has been built.

## 9.2 Software tools

BC thought that standardised software should be made available to cope with the additional energy requirements. The tools that LMU provided (SAP sheet, thermal bridging calculator, catalogue of thermal bridges) were said to be fine and should be developed into an expert system and that the one same program should be used by everyone all over the country. It was mentioned that there are, at the moment, a whole host of software companies with products on the market to do various SAP and energy calculations and other variants. They have been known to give different results, sometimes a small difference, but it doesn't inspire confidence in the product or the user. From past experience, BC know that some designers use those specific pieces of software which will give them favourable or higher ratings. Not being experts at computer programming, BC was unable to comment on why or how this was able to happen.

The architect found the Excel SAP sheet easy to work with. The sheet had been typed in by hand reading from a printed document (SAP 1995). Although the submission happened over a year previously, the architect admitted he was still uncertain about what a 'carbon coefficient' actually was, but said it was straightforward to put numbers in the spreadsheet and get some kind of figures out the other end. Whether that was a good thing, automatically calculating coefficients without understanding how, the architect was unsure. He suggested that we should know more about what goes on in the workings of the sheet.

BC used the elemental approach to check for compliance although the architect had done the SAP sheet, which included the carbon index. They were not used to seeing SAPs greater than 100! The insulation levels were easy to discern and far exceeded the requirements of ADL 2001. Instinctively, BC look at elemental levels first and see how they stack up and then look further. It is usually the most practical route and one that leads to practical answers for designers on what needs to be done to meet the standard. BC find that, by far, the greatest percentage (99% was quoted) of builders and designers go down the elemental approach. If a very unusual building is designed, other routes of compliance are used but that is rare. In these cases, the target U value approach tends to be used as a last resort: many designers are not used to using it and are not confident using it. From their time point-of-view, they prefer to improve elements individually so they meet the elemental rather than do a lot of calculations to try to trade off items.

One point raised was that a great number of current designers are known to remember, and are partial to, the 1976 regulations, which were very prescriptive. Some builders have even stated that they prefer to be told what to do to meet the standard. The SBCO thought that modern designers often are unaware of the thermal implications of their designs until it is pointed out to them and. He added,

> *"The majority of designers are more comfortable designing than calculating."*

The architect, in this case, seemed to do most of his work around the SAP sheet. Like other architects, he finds the target U value method more complex and tends to avoid it. In fact, the architect considers the target U value method more complicated than the SAP sheet. He saw the SAP as a checking system:

*"The elemental U values and other items are automatically checked as you work through the SAP sheet."*

The additional thermal bridging section was useful as it alerted him to examine those aspects of the building, which may pose a problem – junctions where additional heat losses occur. So the spreadsheet provided a logical tool for checking before the architect submitted it to BC.

The SBCO thought that the actual revision should include a spreadsheet on a disc that is included with the approved document. Everyone working to that document would use the same software. He thought that a more uniform approach would make everyone more comfortable, both the designer and BC. BC was looking for ways to make the process easier. With structures, for example, the structural consultant tells BC which 'code' they are using to check the calculations so that BC are able to follow and check using the same code.

This comparison with structural consultants was thought to be useful as a system where specialist input is already in place. It happens rarely in domestic construction. Smaller schemes were thought to be no problem but when a design occurs in a grey area between the two, there is a need for a specialist check. Often, though, builders on small schemes do not employ a specialist consultant on cost grounds and asks BC to check the submission. One consequence of this has been that BC becomes an 'unpaid consultant'.

*"The larger the scheme, the more people there are checking the checkers, certainly from a structural point of view. In a situation where there is a complex design, it has been designed by an engineer, checked by his senior and, as, part of quality control, maybe checked by a third party before it even gets to BC. So larger schemes are usually no problem due to this audit trail."*

BC thought that this situation of being an unpaid consultant could easily develop with the increasing importance of thermal issues: applications may come in expecting BC to advise on thermal issues.

The SAP sheet could be viewed as a 'checklist' and used in the design stage but at the moment, SAP has to be filled in but only prior to completion. Most BCOs seem to fill in the SAP sheet on behalf of those submitting because builders may not have software or necessary information. If the building regulation document came with SAP software attached (and operating instructions) that would overcome that problem. The SBCO added that any procedure like this would be consistent and easier to discuss over the telephone in order to come up with solutions for builders. BC liked the pop-up help (that LMU included with their SAP sheet and thermal bridging calculator) which gave dedicated assistance at the point of data entry. Many other automated features could be included to provide reminders and to detect anomalous data entries.

The SBCO liked the Excel spreadsheet approach used by LMU because it gave transparency to the calculations:

*"To know what goes on in the background [of a software calculation] is equally important to the BCO as the front end. Putting numbers in boxes in other 'glossy' front-end software such as MVM, NHER, etc is easy enough but if the number is wrong the software doesn't tell you why."*

This reasoning is further strengthened by the fact that BCOs are hoping to move over to internet-based submissions in the near future.

## 9.3 Thermal bridging

Generally, the change in U value calculation to include thermal bridging heat losses is unlikely to be of major concern. The main concern will be the reduction of U value and the need for extra thickness of insulation.

BC is used to looking up the tables in the ADL for insulation thicknesses and using manufacturers' data. It was thought that thermal bridging information might be more difficult to find although manufacturers may provide guidance as part of their literature. It was noted that manufacturers have to be trusted with the information they provide. A web site of one insulation manufacturer was known to provide outdated and inaccurate data.

Thermal bridging was thought to be a case where overlap occurred between the performance of different building elements and so, simple tables were therefore inapplicable. This blurs the distinction between the construction and the overall design of the dwelling because bridging cannot be separated out easily. The architect thought that, unlike nominal one-dimensional U values which can be calculated easily, the values of the thermal bridging coefficients are taken from a catalogue and used as they are. This means that thermal bridging coefficients can be treated like any other number but where they come from is vague.

The Wärmebrücken-Atlas (Hauser & Stiegel, 1992), which is used in Germany to supply thermal bridging coefficients for construction junctions, was discussed. The SBCO wondered if such a comprehensive atlas could be included as an appendix to the SAP for those who wish to delve deeper into the mechanisms behind bridging. He thought that interpolation between values using a graphical method could be subjective.

It was thought that the majority of the industry (75% of whom are builders and tradesmen on site) are not interested in how the calculations are arrived at, they just want to know what to build, e.g., 'how thick is the insulation'.

## 9.4 Plausibility

Would BC be tempted to accept the word of an architect who submitted a SAP sheet that appeared to be plausible and they knew the architect to be knowledgeable in thermal performance matters?

*"A 'comfort zone' exists with certain architects we have dealt with before but we do accept many applications from other areas and the number of designers to whom this could apply is small."*

It was admitted that such an architect could make a mistake, which could go unspotted, but generally, that architect would be more likely to get it right than somebody else would.

Higher workloads for BCOs were felt to increase the likelihood of something being overlooked. This may not be as disastrous with thermal calculations as it could be with, say, structural calculations. However, it was noted that airtightness test failures, especially in large non-domestic buildings, could be very costly to remediate.

*"It is unrealistic to expect that each building is actually built exactly to the drawings that were submitted".*

It seems that BC do the best job possible with the resources available within the constraints that they face. Constraints could be client-led or designer-led as they wish to amend the details and require a response from BC.

When asked which tools BC would use to check U values and thermal bridging, the reply was that all tools would be used until they became familiar with the process and what is involved. As an example, it is instinctively known that a certain joist would be correct in a certain floor structure because of past experience but initially, and with any new revision of regulation, that knowledge has to be learnt. BC needs to know where to find further information to work out problems. The same is envisaged for thermal details, a learning period will occur before confidence is had in the calculation of thermal details.

The same would apply to quantitative information. At the moment, most people could estimate whether a particular thickness of wall insulation would allow that wall to meet an elemental standard but a period of experience with linear thermal bridging coefficients, for example, would be needed to allow a similar familiarisation to occur.

One avenue that was not possible to examine as part of this project was that of providing prescriptive details. However, Robust Details is some way towards a kind of prescription. One BCO felt that most builders do not really want to know how to calculate thermal performance for each of their construction details, they merely desire details that will work and will get them the approval:

*"The majority of builders and designers are not looking for the reasons why they have to do thermal performance calculation using behind the calculations, they only want the answers."*

The architect agreed that being asked to provide designs for a building could mean a complicated set of details that have to be shown to work. Sometimes it is easier to opt for details that are known to work rather than design new ones.

It was thought possible that a prescriptive house-type could be designed (for example, a builder may his design 'A-type') and after it had been shown to perform acceptably it could be used anywhere. Individually designed buildings were thought to pose more of an issue for the appropriateness of Robust Detailing. The architect could foresee occasions where a mixture of robust details (although each satisfactory on its own) could be used in an individually designed dwelling and not achieve overall satisfactory performance.

Is it a BC function or role to make sure the details are constructed correctly? BC thought not, since the timing of site visits meant that details quickly become covered up as construction progresses. Certain important items, such as trench inspections before footings, are routinely checked before pouring concrete. One BCO added that since BC do make a number of site visits and would comment on any bad details that were found, it was in the builder's interest to make sure all details were correctly constructed. This semi-random checking acts like a deterrent.

The SBCO said that the branding and marketing of new thermal regulations should be very high profile and in-the-face of the public and the builders. The legal implications of non-compliance also need to be spelt out. If site staff are made aware of the legal implications they are more likely to get the details right. A recent case was cited where a client sued a contractor for not providing the building to the specified standard (the contract stipulated an airtight building but a pressurisation test proved it to be very leaky).

One BCO commented on the demise of the trades foremen were the norm a decade or so ago. Now, most sites have managers who deal mainly with paperwork and a setting out engineer. A time was recalled where foremen joiners, foremen bricklayers and so on, provided a job to a certain standard. The contractor provided that element of 'quality control' but this function is not present any more. This could be why the finished building which can only be described as adequate is as much as can be hoped for.

> *"Any building which is better than adequate is a bonus".*

An example was given where a BC visited a site where internal linings were being replaced on a new portal framed building and it was discovered, while the BCO was there, that there was no insulation at all behind the linings. Here was a case where the subcontractor signed the job off as done in the office without the work actually being checked.

## 9.5 Airtightness testing

The SBCO and other BCOs attended a pressurisation test earlier in the year. He thought that the industry should be made aware of how various products, materials and techniques affect airtightness. This way, the industry can become prepared in advance for the next major revision of building regulations. One example was electrical sockets:

> *"I witnessed a pressurisation test and the areas I anticipated would be leaky were not at all – leaks were happening at unexpected places. Smoke tests showed air rushing through electrical sockets and it was very dramatic."*

He added that the implications of failed pressurisation tests should be made clear well in advance of new regulations which stipulate mandatory testing for air leakage and thought that practical demonstrations (like the one performed by LMU) would be an excellent way to demonstrate this.

The problem of inter-relationship between Robust Details was discussed. One BCO asked if the building would necessarily be airtight when using properly constructed Robust Details. The architect made the point that copying details (from such as Robust Details) without understanding how they work could have a negative effect. BC agreed and added that reliance on robust details could lead to a blasé attitude to construction which could lead to airtightness test failures, not because the details are not right but because not enough attention is given to the construction of those details on site. There was a feeling that, although the Robust Details were fine in themselves when constructed properly, a lot of care has to be given from the very start of construction, not just an add-on at the end.

BC saw the pressurisation test as a good way to check workmanship and the current drains test was mentioned as an existing, similar and accepted routine. With a drain test failure, the onus is on the contractor to locate and then dig up faulty pipe runs and replace them. Every drain is tested. One consequence of BC being present at each drain test is that contractors try and make sure the drain runs are correctly installed. The idea of post-construction testing was thought to be desirable especially if the alternative was for BC to be more involved in the design stage and additional site checks.

> *"Pressurisation testing is a practical way to see what was specified is there and is working and it also stops the contractor thinking he can take short cuts. It suddenly makes them think harder about those construction details. Also it is a way of testing airtightness at one go without having to make many checks at every construction detail."*

The SBCO thought that eventually it would be reasonable to pressure test every property (not just 10%) since, by comparison, every drain is tested at the moment. The expected or proposed high thermal standards in or around 2008 were thought to be quite exacting and it was not worth running the risk of not testing for airtightness.

One BCO had seen an infra red cameras in operation but they were considered to be prohibitively expensive for BC use.

The question of making changes to properties after handover was raised. For example, what would be the effect of installing a patio door on the airtightness of the house? The team thought that whole-house mechanical ventilation systems could mean additional problems for design and construction of house extensions. One possible avenue might be to look at fuel bill reporting whereby home-owners fuel statements could be checked in order to identify homes which appear to no longer perform as originally designed. This does raise many practical legal issues as to which part of the building is causing poor performance and ultimately who could be to blame.

BC could not envisage taking on the task of pressure testing, rather, independent accredited testers should be used. It was argued that the cost of pressure testing might cause outcry from builders but compared to the overall cost of a dwelling, the test might only account for a fraction of one per cent. Self-certification along the lines of electrical testing might be considered. Although the introduction of pressure testing could be seen as a contractor cost, once the system of pressure testing was established throughout the industry, it seemed natural to suppose that the client would actually pay for the test in the form of a slightly higher house price. It would become part of the contract sum, maybe under sundries in contract work.

One BCO thought that builders will staff sites differently after 2008 with the re-emergence of the clerk of works role due to the increased supervision and checking necessary to comply with airtightness targets.

BC thought that pressure testing all houses was reasonable rather than, say, just 10%. Test costs per house will drop due to economies of scale. SBCO envisaged a test certificate making up part of the seller's packs that house buyers receive. The implications on detailed design were thought to be the development or evolution of new solutions to controlling air leakage and so future designs would be slightly different to those used now.

The feeling of being part of a team could be more important for airtight construction because maintaining the airtight barrier is a cross-trade operation with everyone needing to understand how the building operates as a whole in terms of leakiness.

> *"I remember when I served my apprenticeship, there was more awareness of other trades and how your role fitted in with everyone else."*

Again, it was stressed that the clerk of works role is crucial in re-establishing the links between the trades. One recent trend that may assist this is that more tradesmen are now 'on the books' of building firms rather than self-employed and this factor could lead to more care being taken on site. One BCO has noticed such improvements in firms who employ tradesmen directly. More pride in the job should take the place of an approach to working simply based on cost.

## 9.6 Ventilation

With ventilation requirements, BC took the view that the ventilation manufacturer was the 'expert' and reliance was placed on their drawings and layouts for the scheme. They briefly checked that each area appeared to be properly ventilated. The only concern was on how ventilation systems controlled emissions from combustion appliances, especially airtight houses. It was felt that the design of the appliances themselves would have to change to make them more suitable for airtight homes.

BC agreed that there is a strong link between parts L, F and J and that it would be easier and very useful to see how each part affects each other in an integrated document. It was felt that coal-effect appliances appear to be popular with homebuyers but that the market could adjust to supplying balanced room-sealed appliances although this seemed a bit draconian to enforce this at the moment. It might be possible to drive the development of room-sealed appliances this way but open fireplaces would be more difficult.

One problem identified was that a house could be built and sold without a fireplace and the client could then alter his house and build one in. One BCO thought that it would be reasonable to allow open flues appliances provided that energy efficiency measures elsewhere were improved, such as more wall insulation, higher efficiency boiler, etc. It was noted, however, that, with airtight houses, a danger exists that unwanted flue gases (from open flues appliances) could be drawn into the room if, say, an extract fan was operated in another part of the dwelling.

With a general move towards more continually operating mechanical ventilation systems, BC envisage more reliance on manufacturers' literature in order to check energy performance, as is the case currently with non-domestic buildings. Also with continuous mechanical ventilation, BC foresaw areas that need further research such as acoustic and fire dampers on ducts, sprinkler systems, etc.

Bacteria growth inside ducting and ventilation equipment was discussed. At the moment there is very little long term data available in the UK but smooth ductwork, cleanability, ease of filter replacement and keeping the cooker hood separate from the main ventilation system were thought to be ways to minimise or eliminate these problems. BC identified this as an area where more research is needed.

## 9.7 Heating

Design criteria include boiler efficiencies as stated by the manufacturer. Site checking by BC could include confirmation that TRVs have been fitted, pipe runs are insulated and that the specified boiler has been fitted but it is not possible for BC to do all these checks. After commissioning, BC have no way to check that the system actually performs as designed, all they receive is a self-certification from the installer which states that the system has been commissioned. An area where the team felt that BC could not (and should not) have jurisdiction is in how the user operates the controls.

For carbon intensity of space and water heating, BC anticipated that manufacturer's data would be used. It was hoped that a move towards simple, standard ratings would appear before 2008. The possible rating of heating equipment into A B C D categories (not unlike white goods are now) for carbon intensity seemed sensible to BC. This takes into account the carbon burden of the fuel type and efficiency of the equipment. It was hoped, at the time of writing EPS08, that the industry would be addressing this by developing systems with lower carbon intensities but his does not appear to have taken place so far. One way round this would be to make the inclusion of an efficient gas fire boiler a pre-requisite for using the elemental or target methods and if the carbon intensity could not be met, trade offs would be possible but only in the carbon index method. BC thought that this could be workable provided it was kept as simple as possible. The architect suggested that might only happen if the regulations were based around the carbon index. The potential offered by heat pump technology is, as yet, largely unexplored in the UK and it is hoped that by 2008 more work will have been done in this area.

## 9.8 Staffing resources

It was felt that extra staff would be needed to cope with the additional workload that EPS08 would generate. The SBCO could envisage another member of staff to augment his current team of six staff. The 'specialisms' mentioned earlier could either be borne by the new member (who would then become the 'energy specialist') or the additional work could be divided equally among the team. The point was made that each revision of the regulations requires additional work for BC. BC are quite comfortable with the prospect of an enhanced workload at the next major revision (2008 or thereabouts) but stress that extra staff will be needed.

The SBCO thought that a specialist services expert would be necessary at the next major revision and would continue to be an increasingly useful addition to the BC team as thermal performance standards are enhanced in ensuing years. He was unsure whether college training could give this specialist knowledge to all BCOs or, indeed, whether it was sensible to expect each BCO to deal with applications at such a level of detail. Additionally, even if each BCO could incorporate specialist duties into the normal workload there would be a time constraint involved. The possibility of using outside agencies as specialists was also mooted. Self-certification was another method discussed. Certificates could be included at the time of submission. Not everything could be self-certificated, however.

## 9.9 Windows

This particular BC deals with a very wide range of house designs - urban rural and historic - and therefore a wide range of windows. BC thought that the simple whole window U value would be most widely used and designers might resort to DWER if they wanted a particular design to meet the requirements. It was pointed out that in SAP, DWER actually simplifies the existing system by treating all windows with the same solar gain.

> *"The U value is the favourite at the moment, unless there was a need to use a rating system."*

> *"The majority of builders and designers either don't want to use carbon index or do not have a clue about it."*

## 9.10 Realism and validity of the 'building control exercise'

BC thought that the 'building control research exercise' was realistic although admitted that this particular architect (being very knowledgeable about environmental and energy issues) made the submission very easy to follow. The information was all included and BC did not have to 'chase' additional information. The biggest challenge was thought to be actually on site, checking construction. The architect made the point, however, that the contractor has already contributed a great deal of design input concerning buildability due to the open way the contract was partnered. He added that the contractor has to make sure airtightness is achieved because remedial work could eat into his profits. BC are now looking forward to the construction stage and are interested to see how practical the details will be to construct. The validity of the 'exercise' could be further strengthened by allowing another architect (unfamiliar with the proposed standard) to make a submission using EPS08 and by analysing the problems that ensued.

BC were asked what additional information, in hindsight, they would have liked to perform the 'exercise', the answer was "very little". One grey area is knowing how much design advice to give to designers:

> *"It can be a thin line between throwing non-compliant designs back at architects and providing design advice. On one hand it is desirable for designers to get to understand new any regulations on their own and on the other hand, we do feel we like to provide an element of 'customer care' especially as building control is essentially under competition from NHBC and others."*

It was acknowledged that initially there would have to be an amount of education given and that knowledge could then be passed on in the industry.

If EPS08 had been used for real, BC would have been able to thrash out issues amongst the whole team (7 staff). Brainstorming and playing 'devil's advocate' could have dealt with grey areas. With this 'exercise' only two BCOs were actively involved in learning and enforcing EPS08. Other BCOs in the office were aware of EPS08 but not in detail.

### 9.11 Education and training

Government training for BC was discussed. Recent seminars were found to have delivered useful information although presentation could be improved. Designers and builders need to know about new regulations as much as BC and might benefit from seminars tailored to their needs. Hypertext CD-ROMs were considered to be a useful medium for transferring information as well as a printed counterpart.

The SBCO compared the additional workload created by the 2001 revision with that anticipated around 2008 (assuming it does, in fact, resemble EPS08). The workload could be similar if more preparation was done in advance. He suggested working with the new standard at least six months prior to it coming into force. A whole range of seminars and workshops need to reach a large proportion of the industry. At the moment, many builders and BCOs are so busy they have little time to spend on training and often send one member of staff on a course so they can pass on information to colleagues. Trade press can be a source of information but it has to be remembered that they are trying to sell a product as well.

This particular BC office has delivered free seminars in the past aimed at the specific needs of builders and designers and were very well received. The familiarity of BCOs with all aspects of the industry makes them able to target individual training needs. In recent years their seminars have become less frequent due to pressures of work. One BCO thought that BC could play an important part in the training process leading up to the next major revision, provided more staff were allocated. Any trainers need to understand the regulations fully and not just learn them 'parrot fashion'.

It was thought that the present revision (2001) will take up to 18 months before the industry is familiar with it. Some builders rewrite their standard specification within 6 months but others take much longer. It was suggested that the next major revision be given a 'fanfare' to make everyone aware that there will be changes. The team thought that any new standard has to have respect otherwise it may be difficult to impose on the industry. It was felt more important to help and to guide people through the learning process rather than drag them 'kicking and screaming'.

As part of the consultation process, BC thought that a year-long dry run (similar to this kind of research exercise) would be necessary, the difference being that the dry run would be for real. Comments on consultation documents would be much more informed if such a dry run took place. This would allow useful comments on grey areas. Items could be identified which are not working from a position of real knowledge. Also, when the regulations actually came into being, BC would be in a position to act immediately with having to go through a learning process.

It was felt that it is the role of the whole industry e.g., builders merchants in providing information.

One problem identified was that of some builders requiring a very quick turnaround between submission and acceptance. Periods of one week have not been uncommon. Some builders start work before all the drawings are checked. If areas of non-compliance are found after construction, BC has to prioritise resources on that site at the expense of others. The ideal situation would be where a knowledgeable builder/designer submits an application that complies first time.

### 9.12 Overall perception of EPS08

In summary, the SBCO thought that the proposed 2008 standard would be a large step for the industry if it were to come into force immediately but provided sufficient preparation was made (education, training, etc), although still a radical step, it would not be unobtainable. Against this background of increasing complexity of construction methods BC see a trend of more unskilled operatives on site. Training for semi-skilled and skilled trades is lower than it ever has been:

> *"The demise of apprentice training has lowered the accountability that was once there, hence the need for greater training."*

The SBCO suggested, rather than making one big major revision in 2008, why not change some parts of the regulation maybe two years before (2006). In two years time the industry should be comfortable with ADL2001, the materials and principles. The leap from there to 2008, although still a large step, would be far easier to make.

> *"To summarise, to enable the proposed standards two things must happen, EITHER:*
>
> *1) Staff are trained to use the new standards and software - this has resource implications with regard to staff numbers, as additional staff may have to be*

*employed to allow for the additional workload. It should be noted that unlike a lot of the changes to the building regulations, this is a fundamental change in working practice (if done properly) not just a cosmetic or "number" change. OR:*

*2) Local Authorities may have to employ "experts" on a consultancy basis.*

*Both options may well have an effect on the fees Local Authority's charge for building regulation applications as additional resources (funding) will have to be allocated to pay for such consultation. To enable the proposals to work effectively, it must be recognised at the highest levels that there are resource implications. Failure to gain this recognition, and action to follow it through, will result in poorly and ineffectively applied standards."*

### 9.13 Conclusions and recommendations from the Building Control Exercise

<u>EPS08 document</u>

- Brevity was helpful.
- U values well understood.
- Concepts and broad understanding OK but the way it works in practice may need some specialist input.

<u>Software</u>

- Need for computer software to manage heat loss calculations
- The SAP tool (carbon index) was easy to use and provides a 'checklist' and a logical approach to setting out the design.
- The SAP sheet be included with the ADL on CD-ROM.
- Need for standardisation of software so that the same software is used by everyone.
- Problems of compatibility – some existing packages give slightly different results.

<u>Thermal bridging</u>

- Generally, the change in U value calculation to include thermal bridging heat losses is unlikely to be of major concern. The main concern will be the reduction of U value and the need for extra thickness of insulation.
- The majority of the industry is not interested in how thermal bridging calculations are made, they only want to know what to build.

Plausibility

- EPS08 was thought to be plausible but an increased workload would mean some checks could get overlooked unless addition staffing resources were made available.
- New revisions to the regulations should be branded and marketed in a very high profile way to gain the respect of everyone in the construction industry.

BC role

- The BC is often used as an unpaid specialist consultant.
- BC is not a quality control officer.

Airtightness

- Air pressure test every property.
- Pressure testing a good way to check workmanship.
- Everyone to be made aware of the legal implication of pressure test failures.
- Cost of testing will ultimately be borne by house buyer.
- Copy of air pressurisation test certificate to be included as part of sellers pack to home buyer.
- A reintroduction of the clerk-of-works role would help ensure airtightness is achieved.
- Feedback from testing is an important element in the training of the industry.

Ventilation

- BC is concerned about the relationship of heat producing appliances and airtight construction and therefore more research needed.
- More research also needed on acoustics and fire dampers.
- A greater need to rely on the ventilation specialist for the scheme.

Integration of parts L, F and J

- Useful to see parts L, F and J as an integrated document.
- Possible link to part B (fire stopping).

Heating

- Possibility of a move to A, B, C, D carbon intensity ratings for heating equipment.

- More development needed in low carbon heating equipment and heat pump technology.

Staffing resources

- An increase in BC staff would be needed (suggest 1 in 6) to deal with the energy performance requirements.

- Specialist services experts needed to augment BC teams.

- Need for more clerks of works on sites.

Windows

- Very few people in the industry are familiar with energy rated windows. More could be done to bring attention to DWER.

Education and training

- There is a need for training well in advance – this often does not happen.

- It is anticipated that it could take 18 months or more for changes to settle down.

- BC to work with the 2008 revision of the standard 6 –12 months in advance.

- BC is ideally placed to organise and deliver training seminars for the industry, but this will depend on additional resources being made available.

Selling the standard

- BCOs are advocates for the standard.

- It is important to develop respect for the standard and the need for change.

- Need for informed consultations backed up by forms of training and trials.

- A ‘dry run’ should be part of the consultation process leading up to the next major revision in order to feed comments into the consultation process.

- Any changes to new thermal regulations should be brought to the attention of everyone in the building industry, designers, builders, operatives and building control and also to the house-buying public. Legal implications of non-compliance should be made clear.

# Chapter 10 Reflections on methodology

## 10.0 Introduction

The purpose of this chapter is to present a brief reflection on the implications of the adoption of the action approach for this project. The adoption of this approach has raised a series of theoretical and practical issues. These include questions of:

- the validity of our results
- the role of the research team
- their generalisability and replication potential
- ethics

## 10.1 Validity of results

The question of how one ensures the validity of results of an action research approach has been debated repeatedly over the last 50 years. Seen from the standpoint of more conventional approaches, problems with action research arise from:

- the absence of classical experimental design in action research projects
- the blurring of the boundary between the researcher and the 'object' or 'objects' of research
- the possibility of collusion between (or indeed, of delusion among) the partners in an action research project.

Conventional research implicitly takes place in a stationary universe. Experiments are repeatable. Systems are simple, interactions deterministic, consciousness is either an unwanted intrusion, the effects of which must be minimised by experimental design, or simply irrelevant. The standard form of empirical investigation of such systems is the controlled experiment or field trial, ideally conducted blind or double blind where there is a risk that attitudes to the intervention may affect the measured outcome.

Action research on the other hand, sets out to stimulate and facilitate change, by harnessing the combined capabilities and intellects of a team of colleagues to an agreed task, and through the process, to begin to explore and understand the dynamics of change itself. It catalyses rather than avoids non-stationarity.

In this model of research, the concept of control is not central. Certain aspects of the original St Nicholas Court project – associated with construction of the dwellings and their performance under occupation - would have been susceptible to controlled experiment. Indeed limited experimentation was planned, though the enforced truncation of the project has ultimately prevented us from pursuing this course. But the conceptual and developmental aspects of the Project do not come into this category. The most fundamental reason for this is the impossibility of attempting to use the participatory approach with a control group. The qualitative results from the design phase of the St Nicholas Court project emerged from a series of group processes. These processes, in which the research team participated fully, would have been impossible to initiate in the absence of the central technical task imposed ultimately by York Housing Association – the design and construction of affordable, sustainable housing. The necessary qualitative difference between a hypothetical control group and the actual St Nicholas Court team – the experimental group – would be so fundamental as to render any comparisons meaningless. The resulting impossibility of running action research field trials with large numbers of matched design and construction teams renders the conventional approach to establishing the validity of results by statistical techniques, inappropriate.

Similarly, the concept of a blind or double blind trial of the impacts of an enhanced performance standard on professionals involved in its design and construction is untenable from the outset – it is impossible to ask a group of colleagues to implement a new dwelling performance standard without their knowing that this is what they are doing and without oneself knowing that this is what one is requesting of them.

In the absence of the conventional concepts of blinding, objectivity, statistical significance and control, how does one attempt to ensure validity of action research results? What does "valid" mean in this context?

There are a variety of ways of looking at this problem. The most defensive is to argue that results of action research are context-bound, with the implication that they are not generalisable. The first assertion, though not the second, is made by Levin and Greenwood (2001).

We take the view that this is too limiting. As noted in Chapter 2, Dewey's notion of 'warranted assertion' appears to a powerful argument supporting claims for the validity of action research results (Dewey 1938). Essentially, it rests on the proposition that to test ideas in real-world situations is to subject them to the most severe challenge possible. As Levin and Greenwood (2001) put it:

> *"Action research is not only scientific, but it insists on much stronger criteria and processes for creating new knowledge. Not only must theories pass the acid test of being negotiated by the involved parties, but the knowledge must also pass the acid test of creating workable solutions to real-life problems."*

But it is important to realise that Dewey's challenge applies to all members of an action research partnership. Our co-researchers placed their professional reputations and livelihoods on the line in agreeing to collaborate with us, and we placed our academic reputations in their hands when we agreed to work with them.

Specific questions on validity were received from DETR during the negotiation of the PIP. These were phrased in terms of how we proposed to avoid possible "Hawthorn effects." Though the phrasing of the question suggests that its originator may have been unaware of the extensive discussion around the concept of validity in the action research community, the core of the question was important.

It was originally proposed to address the possibility of bias during focus group interviews by using external focus group facilitators. In the end, this proposal was found to be impractical because of the requirement for the focus group facilitator to possess a good understanding of the subject matter under discussion. Our considered view is that our partners were sufficiently robust and professional in their approach not to have been unduly swayed by the views of the research team. Our partners knew their businesses and were direct in telling us when our contributions to discussions were technically or financially infeasible.

Had the St Nicholas Court project proceeded to construction, validity may have been compromised in other ways. These include the possibility that the Contractor will make extraordinary resources available to the project (e.g. by putting together a hand-picked team), the possibility that some or all of those involved will come to identify with the enhanced standards to the point where they are unable to offer objective views on them, and the possibility that judgements (perhaps particularly of site crews and dwelling occupants) will be affected by the very act of observation.

We proposed to adopt a number of strategies to prevent and/or detect such effects. These included asking the contractor not to hand pick management or construction teams. We also proposed to request information (anonymously where possible) on qualifications and roles of all personnel involved in the project. Comparison of this data with suitable baseline data, together with interview data from all members of the design team, would have allowed the research team to detect obvious departures from industry norms.

The collection of substantial amounts of quantitative data, both on process (costs, materials, time sheets) and on outcome (air tightness, energy use, quality of indoor environment), would have provided some check on the validity of interview data. For example, claims from site management that airtightness had been easy to achieve would have been suspect if unusually large amounts of time had been spent on this aspect of the dwellings, or if the dwellings had failed to meet airtightness standards, or if contrary statements were to be made by the workforce, the architect, or by our partners in Building Control.

### 10.2 The role of the research team

Many of the concerns raised during the negotiation of the PIP can be condensed down to the proposition that the results of the project were pre-determined from the outset. To say that the goal of action research and the task of the action researcher is to achieve change is not to say that the process of change is pre-determined or deterministic. A successful action research project is founded on a partnership of equals. One of the keys to this success is that everyone's pre-conceptions, including the action researcher's, be offered up for scrutiny.

However, this is not to say that the action researcher has no pre-conceptions about the likely path of the project – and here we would draw the reader's attention back to the key role played the energy and ventilation performance standard in providing focus and a performance benchmark throughout the project. Indeed, depending on the nature of the research project, it might well be irresponsible and unethical for the researcher to embark on a project without:

- strong grounds for believing that change is desirable
- a reasonably clear idea of the direction and nature of desirable change
- some understanding of the mechanisms by which change in any particular setting or field might be achieved.

The tensions within the role of the action researcher have been explored by a number of authors, including Chiu (2000). Our view is that both these tensions, and a keen awareness of them, are essential to any successful action research project.

It may at this stage be appropriate to address the question of the background of the research team itself. While one might well expect that action researchers possess a background in social science, it is clear that a conventionally trained social scientist would be unlikely to possess the understanding of the architectural and engineering context within which this particular project was embedded and against which it would ultimately be judged. Once again we find it useful to refer to Levin and Greenwood (2001):

> *"Generally speaking, most significant problems have messy boundaries and require the mobilisation of a broad and eclectic array of forms of expertise, none of which is predictable in advance. The conventional academic answer is to simplify the problem until the departmental expertise seems sufficient to manage it, which, of course, makes the knowledge offered at the end of the process utterly useless."*

Interestingly, Levin and Greenwood acknowledge that the social sciences are much more badly affected than the physical sciences by the excesses that they describe. As an aside, their next few paragraphs make sobering reading for a research team with a background in energy policy, building physics, housing management and construction management who had the temerity to embark on what we sometimes refer to as technological anthropology:

> *"Prestigious departments of social sciences and the humanities are proudly and aggressively boundary conscious. Anthropologists greet sociologists doing ethnography as invaders. Humanists studying race and ethnicity are told that they are social scientists manqué. Social workers who claim to be doing 'research' are ridiculed by their 'betters' in the core social science disciplines."*

We, however, make no apologies. We consider our investigation to have been necessary, and we can see no other way in which it could have been done.

### 10.3 Replication potential

Aside from the epistemological question raised above, replicability of the results of the St Nicholas Court project are constrained by the fact that it deals with only a single constructional solution to meeting a possible future energy performance standard. We consider this to be less of a constraint than may appear at first sight. At a fundamental level, high energy and environmental performance demands an airtight, highly insulated construction, free from thermal bridges, with appropriate and efficient ventilation and heating systems. In terms of the ways in which design and construction teams come to terms with these fundamental demands, many of the lessons from the York Project will be transferable to other forms of construction. Most UK domestic construction is any case composite (timber-framed with concrete ground floors and masonry cladding, or load-bearing masonry with timber intermediate floors and roof structures). A number of the specific results of this Project will therefore be transferable to other forms of construction. Finally, One of the most positive developments of the last year has been the decision of DTI to fund a second field trial, the Brookside Farm Project, which will extend the evaluation of EPS08 to load-bearing masonry housing in the context of a development of approximately 700 dwellings on a National Trust site on the Dunham Massey estate in Cheshire.

## 10.4 Did the Project conform to accepted models of PAR?

There were problems of inexperience, but also of resourcing, both within the research team and for partners. A fully participative approach places a considerable load on all parties in terms of reflection and negotiation of meanings. What ideally should be a process characterised by repeated iteration, in practice defaults to a rather small number of interactions. The research team itself arguably did not plan sufficiently carefully for the job of keeping documentary track of interactions with and between partners.

Additional problems were imposed on partners in the St Nicholas Court Project by the long delay in construction. At the simplest level, this led to a situation where everyone involved in the project moved onto other work. At best this made it hard for people to remember what had happened, what had been agreed and when. At worst, it meant that people moved onto new employment and retained only tenuous contact with the project.

## 10.5 Concluding remarks

Validity is ultimately a matter for the judgement of the partners and replicability and generalisability for the reader. We have told a story that we and our partners feel represents the process that we went through, and justifies the judgements that we made. We have attempted to provide sufficient evidence of the process to enable others to follow it, to question it, to see parallels with their own situations and, we hope, ultimately to share in the conclusions that we ourselves reached.

Action research is not a replacement for the more conventional approaches of science, but an approach that enables science to interact with the real world to promote change.

# Chapter 11 Conclusions and recommendations

## 11.0 Introduction

The aims of the St Nicholas Court Project were:

> "…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 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 $CO_2$ 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."
>
> Project Implementation Plan

The purpose of this chapter is to review the results of this work and to present overall conclusions of the project.

## 11.1 Impacts on performance

**11.1.1** The primary impact of EPS08 is to reduce expected energy use and $CO_2$ emissions for space heating from new dwellings. Based on a standard $80m^2$ semi-detached house, the predicted reduction is of the order of 45% compared with ADL02 and around 70% compared with ADL95. Overall reductions in carbon emissions for space and water heating and ventilation amount to just over 30% against ADL02 and just over 50% against ADL95. The carbon index for the standard dwelling rises from 7.36 to 8.85.

**11.1.2** There are reasons for believing this picture is conservative. The most important of these is that ADL02 is, in our view, likely to lead to a wider range of performance than EPS08. This, in turn, is likely to mean that mean performance of dwellings built to ADL02 will be significantly higher than the figures presented in Chapters 3 and 4. Absence of statistically reliable data on the impacts of ADL02 on energy use and other parameters unfortunately makes it difficult to be certain on this point.

**11.1.3** 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 (Chesshire 2001). EPS08 reduces gas consumption by approximately 33% compared with ADL02 and by approximately 54% compared with ADL95.

**11.1.4** 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, water heating may exceed space heating by a factor of 5 or more.

**11.1.5** Related to the declining importance of space heating is 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 January[13]. 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 poverty[14]. Minimum temperatures in compact dwelling types can be as much as four degrees higher still.

**11.1.6** One further result of the reduction in the demand for space heating was that the design team and the client felt able to agree to a reduction in the number of radiators in dwellings with heat recovery ventilation (MVHR).

## 11.2 Cost effectiveness

**11.2.1** The overall picture of impacts of EPS08 on costs is complex and indeed was the final aspect of the project to be fully understood. Our current estimate of the overall cost of moving from ADL02 to the EPS08 standard is between £961 and £1900, with a financial payback time in the region of 19-39 years. This is relatively long compared for example with rates of return expected in manufacturing industry, but straddles the payback time - 25 to 30 years - expected in the social housing sector itself.

**11.2.2** The above represents a micro-economic picture of cost effectiveness, which in particular, excludes shadow costs of carbon emissions. We estimate the residual cost of avoided carbon emissions for the range of designs examined in the St Nicholas

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

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

Court Project, to be between zero and £102/te (carbon). On these estimates, and except at the lower end of the range of costs, EPS08 is not a "no-regrets" carbon abatement package. The range of costs nevertheless compares favourably with the range of carbon prices suggested by Clarkson & Deyes (2002). Clarkson's and Deyes' proposals amount to a median levelised cost of around £90/tonne with a lower limit at half, and an upper limit at twice the median.

**11.2.3** The internal rate of return for the step from ADL02 to EPS08, including the shadow price of carbon, is between 2.9 and 6.0%. This can be compared with the 3% test discount rate proposed in the recent Treasury Green Book. The tentative conclusion from all of this is that EPS08 is likely to be cost effective against current median estimates of the shadow cost of carbon emissions.

A number of clear conclusions relating to uncertainties in cost have also emerged:

- **11.2.4** Costs are *design* rather than *standard* dependent - put another way, EPS08 is not so challenging that the costs associated with it became a dominant feature of the predicted overall cost of St Nicholas Court development.

- **11.2.5** In all cases where work on costs beyond what would be normal practice for a small housing scheme was undertaken, cost estimates have fallen – the harder we looked, the smaller they got (though it is yet to be formally documented, this effect appears even more clearly in the companion Brookside Farm Project).

- **11.2.6** Industry procedures for producing budget costs in the context of individual 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 site[15], 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, a partnership approach and significantly higher overall costs in the design-phase.

**11.2.7** 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 Project[16].

**11.2.8** 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 costs 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. Where costs are for non-standard specifications, costing becomes

[15] Our more experienced and care-worn readers may accuse us of unjustified optimism at this point.
[16] 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 (1998).

defensive to ensure that downside risks are low. The ability of such simplified cost models accurately to reflect marginal changes is low.

**11.2.9** The implication of all of the above is that predictions of costs of implementing improved performance standards nation-wide, in advance of such a change, are likely to be systematically over-estimated by conventional costing approaches. The St Nicholas Court Project has enabled us to observe shifts in cost estimates consistent with this picture. Our current view is that it is likely that costs associated with the EPS08 standard will continue to fall.

**11.2.10** It is necessary to utter a final word of caution on costs and cost effectiveness. This report does not cover the construction phase of the St Nicholas Court development, nor the performance of the dwellings in use. While we hope that projects currently in the pipeline will shed light on costs and performance, our conclusions must at this stage remain tentative.

## 11.3 Impacts on Construction technology

**11.3.1** 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 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. Our specific conclusions on technological impact are set out below:

<u>Wall and roof construction</u>
**11.3.2** 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. Its disadvantage is the need to use a more expensive and (some would argue) a less environmentally acceptable insulating material.

**11.3.3** Increasing the thickness of overcladding to 100 mm would enable this construction to deliver U values as low as 0.2 $W/m^2K$ – 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 and, as suggested in Chapter 5, that cost barriers are reducing. But in our view, the most significant potential change in timber frame construction would be a shift to pre-fabricated structural insulated panels.

**11.3.4** 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 debate on the technical and living space merits of cold versus warm roof construction and work on costs suggested that trussed rafter construction is likely to face considerable competition from I-beam structures.

Windows

**11.3.5** The target of a U value of 1.3 $W/m^2K$ 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, if the date of the next review of Part L were brought forward to 2005, it may in practice be unachievable by the majority of the UK window industry. The inclusion of the target in EPS08 has stimulated one European manufacturer to offer a revised specification that achieves it 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 windows[17]. 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.

**11.3.6** 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 are so reluctant to introduce it. Nevertheless, a number of warm edge spacers are now available which are a drop-in replacement 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.

**11.3.7** 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 argument) 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.

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[17] A brief web search reveals at least a dozen manufacturers of Passivhausfenster (superwindows with U values of 0.8 $W/m^2K$ or less) in Germany, Austria and Switzerland. Unlike windows of Scandinavian origin these are not currently marketed in the UK.

Airtightness
**11.3.8** Conclusions on the technological impact of the airtightness standard must remain tentative since dwellings were not constructed and airtightness details not developed fully. However, as reported in chapter 6 the issues had received considerable attention from which we are able to make a number of concluding observations.

- **11.3.9** 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.

- **11.3.10** 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.

- **11.3.11** 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 designed to simplify the problems. 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
**11.3.12** The levels of airtightness envisaged on this project (set, initially at 3m/h but later relaxed to 5m/h) would require a continuous whole house ventilation system. Mechanical systems were chosen for this project with half 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:

- **11.3.13** The exploration of the feasibility of integrating space heating with a heat recovery ventilation system concluded 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 reductions in heating and ventilation installation costs.

- **11.3.14** Desk studies undertaken in support of the design team do not support the contention that temperatures in highly insulated dwellings will be difficult to control due to interactions between the envelope and heating system. 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 information from occupants of energy efficient dwellings.

- **11.3.15** The St Nicholas Court design team accepted the EPS08 standard, in combination with MVHR, would enable radiators to be omitted in bedrooms and avoid the need for radiators 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).

## 11.4 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 conclusions in this area are as follows:

- **11.4.1** At 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.

- **11.4.2** 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.

- **11.4.3** 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.

- **11.4.4** Although the team grasped the requirements very quickly, their familiarity with and ability to use thermal bridging calculation techniques did not develop very strongly, 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.

- **11.4.5** 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.

## 11.5 Implications for training and professional development

**11.5.1** 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:

- **11.5.2** As one would expect, conventional seminars and workshops have an important part to play. 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 in these areas.

- **11.5.3** There was widespread recognition that the open workshop style adopted throughout the process and the participation of the research team resulted in extensive knowledge development. Working on a real project 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 be designed as part of a CPD programme during any regulatory transition period.

- **11.5.4** 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.

## 11.6 Methodological and research management conclusions

**11.6.1** For the reasons laid out in Chapters 2 and 10, the action research approach, in conjunction with partnering in the supply chain, appears to be an effective approach to the organisation and carrying out of projects aimed at evaluating the impacts of new performance requirements on the procurement process and exploring innovative approaches to construction

**11.6.2** he 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 problem 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. 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 industry[18].

[18] The companion Brookside Farm Project at 6-700 houses over 4 years, does appear to have crossed this threshold.

**11.6.3** **O**ne of the demands of projects such as this is for a wide range of skills within the core research team. The LMU team is fortunate in having undertaken a significant number of housing field trials over the last ten years. This project, with its participatory action research framework and partnering approach has been the most demanding. We are fortunate in being able to transfer much of our own learning directly to the companion Brookside Farm Project. We wish, nevertheless, to identify the importance of continuity of research teams in this area.

## 11.7 Directions for future work?

**11.7.1** The publication of the white paper *Our Energy Future* (DTI 2003) has prompted us to revise and expand this section of the report. We ask for the reader's indulgence if some of the proposals in this section appear to take us rather further from the direct lessons of the St Nicholas Court Project than is conventional for a research report. We feel, however, that the pivotal nature of the White Paper makes a more speculative and wide ranging discussion unavoidable.

**11.7.2** 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.

<u>Ventilation requirements and indoor air quality</u>
**11.7.3** The development of performance-based ventilation standards for dwellings is one of the most important tasks that remains to be undertaken in the UK. 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.

**11.7.4** 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.

**11.7.5** 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 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.

<u>Heating and ventilating systems</u>
**11.7.6** 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.

**11.7.7** Support systems for continuous ventilation technologies need to be developed and commercialised. Such support systems need to be integrated or combined with existing support systems, for example for maintenance of gas fired central heating systems, in order to provide support at marginal cost.

**11.7.8** By comparison with overseas standards, existing 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.

**11.7.9** 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 go[19]. 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) 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.

**11.7.10** 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 has probably been to act as a means of price support for manufacturers. 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. The logical next step for Part L – a level of performance predicated on the use of condensing boilers – is therefore likely to 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, is unhelpful in the long run.

**11.7.11** There is a strategic need to develop and commercialise non-gas sources of heat, including heat pumps and solar DHW, particularly in the context of all-electric houses. 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

[19] 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.

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.

**11.7.12** 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.

<u>Construction systems</u>

**11.7.13** 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 - we are where we are - but to argue that in certain areas, the state does have a role in picking and supporting winners.

**11.7.14** 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 however, also a need to support the development and adaptation of more conventional, near-term construction systems such as the overclad 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.

**11.7.15** Recent UK development of foundation systems for timber framed dwellings appears 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 formwork[20]. 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.

[20] This approach is exemplified by the "Houses Without Heating", designed by Hans Eek and built in Göteborg in southern Sweden (Eek 2001).

Windows and doors

**11.7.16** 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 use 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 rating[21] have a major part to play in this context. As we have indicated in Chapter 3, the integration of window energy rating into SAP is a relatively simple task. It is nevertheless important that it be done.

Monitoring and feedback

**11.7.17** 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* – 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 actual in-use performance, if it is to achieve the objectives of raising building performance and reducing environmental impact.

**11.7.18** 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.

**11.7.19** Measurements in both new and existing dwellings would include:

- temperatures (to determine the rate of approach to saturation and the temperature level at saturation in different house types and for different categories of occupant);
- annual gas and electricity use;
- appliance ownership and energy ratings;
- envelope and heating system characteristics (levels of insulation, window performance, boiler type and SEDBUK rating, and so on);
- patterns of occupancy and use.

**11.7.20** It would also be useful to measure dwelling heat loss by the co-heating method in small numbers of new and existing dwellings, again on a rolling basis.

[21] The BFRC scheme is the most comprehensive currently available in the UK.

**11.7.21** 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 Paper.

Beyond 2008

**11.7.22** The development and evaluation of EPS08 or similar standards is a short-term goal. That we have been able to move as quickly as we have towards this goal is due to 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 the last few pages. 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 Chapter 3 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.

# Appendix 1 Temperature droop in unheated upstairs rooms

**David Roberts** **15th December 1999**

With an ultra-insulated house it may be possible to omit the upstairs radiators and rely on heat gain from the rooms below to provide thermal comfort conditions. This aim of this paper was to estimate typical temperature levels in the upstairs rooms.

A simple calculation was initially made where the whole of the upstairs was warmed by heat through the first floor from below. Heat was lost from the upstairs through the roof structure and the walls. It was assumed that the room at the other side of the party wall was unheated. This simplification provided an approximate, if pessimistic indication of upper floor temperatures.

The simple model (Case 1) was then extended by adding extra detail:

**Case (2)**. The stairwell may increase the heat transfer to the upstairs. Wall surfaces in the stairwell (adjoining living room and kitchen) were then included to account for these extra areas of transfer. It was assumed that the under stair cupboard was filled with objects that acted as insulation.

**Case (3).** As bathroom walls are insulated for noise, it was assumed that this insulation would also resist heat flow. The area of the bathroom floor was taken out of the calculation of heat transfer from below. The area of bathroom walls and ceiling were similarly taken out of the calculation for heat loss from the bedrooms. **).** The effects of Cases 2 and 3 were combined and estimated bedroom temperatures are shown in Figure (1).

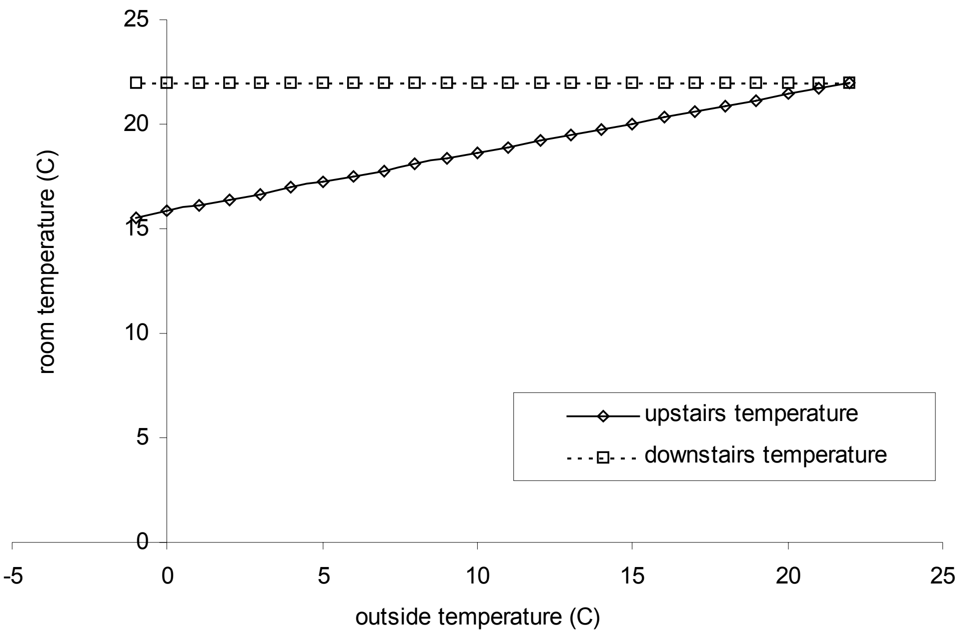



Figure (1). Temperature drop in unheated upstairs rooms.

**Case (4).** As the downstairs was thermostatically controlled, the temperatures remained constant at $22^0$C. When the outside temperature was $-1^0$C, the temperature in the unheated upstairs rooms dropped to $15.54^0$C. This is only slightly lower than the level of $18^0$C recommended by the CIBSE guide for bedroom temperatures. At ambient temperatures of $7^0$C and above, the CIBSE recommended bedroom temperature was provided. The bedroom temperature may actually be higher in practice as no allowance has been made for the intermittent opening of doors, which would allow warm air to circulate.

**Case (5).** The effects of a heat recovery system were included by considering extra heat losses to the upstairs rooms. Downstairs additions/losses were neglected, as the room thermostat would compensate. The effect of heat exchanger efficiency is shown in Figure (2). With a heat exchanger efficiency of 85%, bedroom temperatures of $15.23^0$C were predicted when outside ambient temperatures dropped to $-1^0$C.

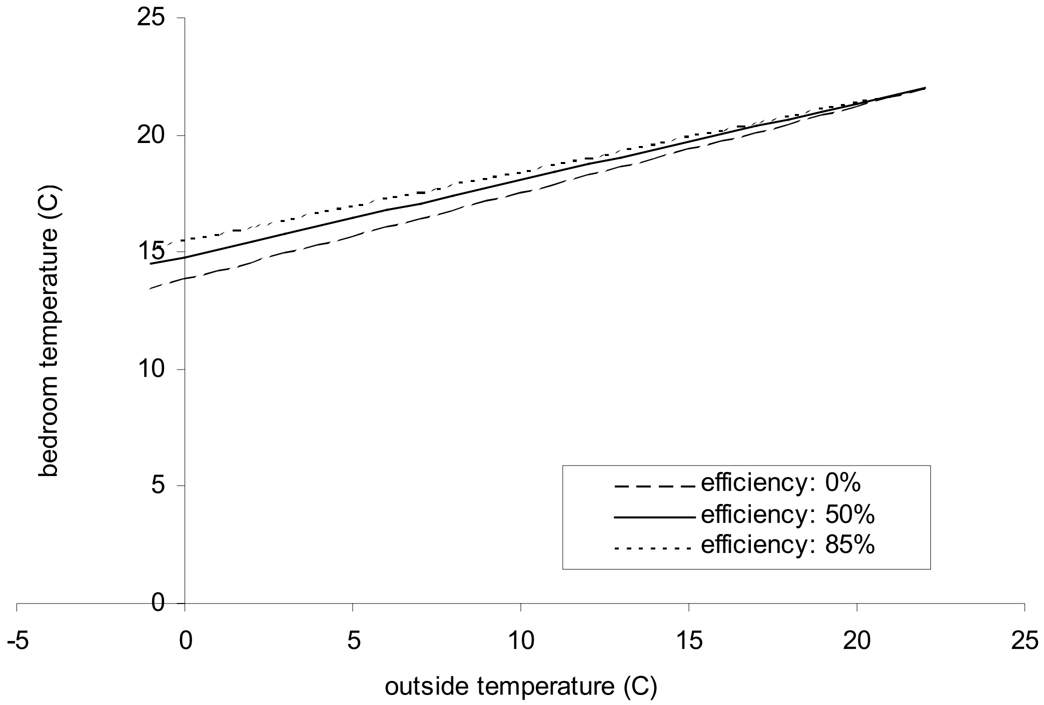



Figure (2). Sensitivity of bedroom temperature to heat exchanger efficiency.

**Case (6).** As Case (5) but with the addition of a small radiator at the top of the stairwell. This gave extra heat gain to the bedrooms through the stairwell walls. The stairwell was taken out of the upstairs heat loss calculations. Although there was less floor area for heat gain from below, there was less heat loss through the roof. Figure (3) shows the effect that adding a small radiator in the stairwell has on bedroom temperatures. When ambient temperatures were $-1^0$C, predicted bedroom temperatures were $17.82^0$C, assuming a heat exchanger efficiency of 85%. This represents a $2.5^0$C bedroom temperature increase when using a radiator in the stairwell.

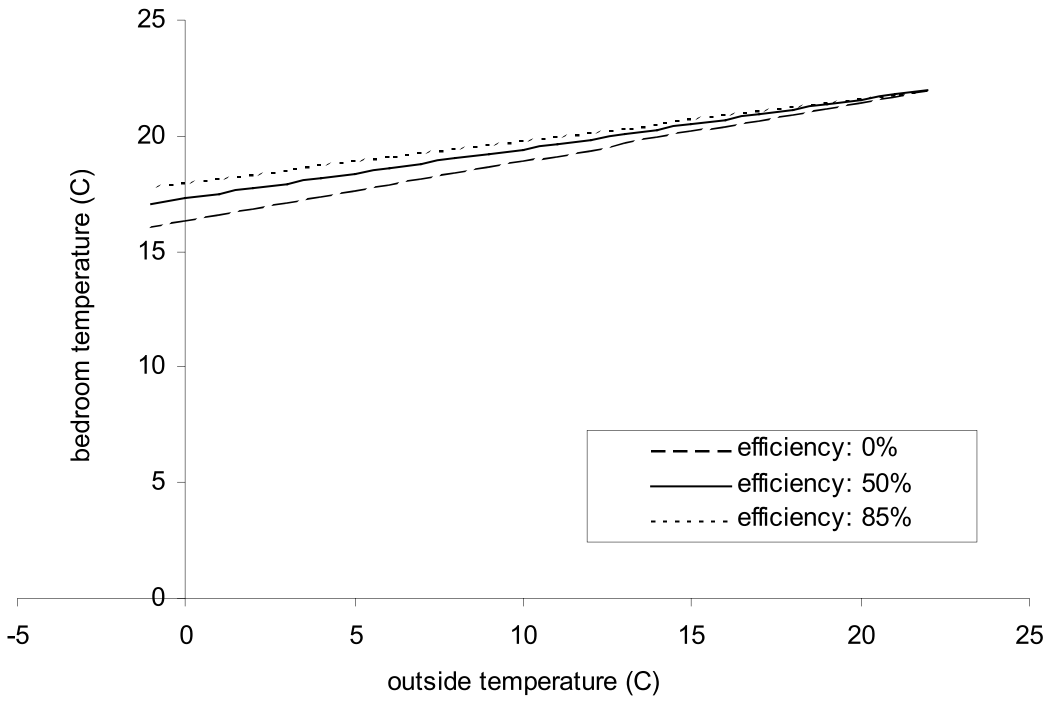



Figure (3). Effect of adding a small radiator in the stairwell.

**Previous work**

I understand from Bob Lowe that Chris and Martin were involved in a Baxi field trial at Watson House where they omitted upstairs radiators and yet achieved comfort conditions.

Figure (4) shows data, which was measured as part of the York Demonstration Project, that Bob and Malcolm worked on. Temperature trends were found that are very similar to the calculated values of St Nicholas Court in Figure (1). Insulation levels were lower than the proposed development, which suggests that temperatures would actually be warmer than predicted.

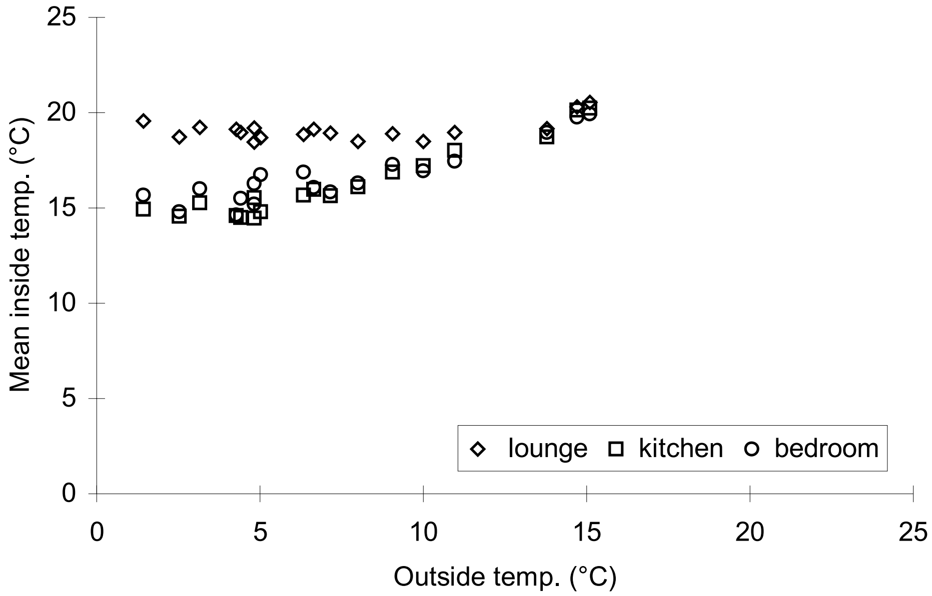



Figure (4). Measured temperatures from the York Demonstration Project 1999, CeBE report R3.

**Conclusion**

It may be feasible to omit radiators in the bedrooms at the St Nicholas Court development and still provide comfort conditions. The upstairs temperatures estimated in this paper are likely to be slightly higher in practice because no allowance has been made for:

- solar gain
- heat from people
- lighting
- heat gain from appliances
- warm air circulation through open doorways
- the insulating effects of a warm party wall.

# Appendix 2 Parametric Domestic Energy Model

The Parametric Domestic Energy Model was based on the SAP worksheet with an additional parametric input sheet as a front end, as shown below. The output stage (shown as yellow boxes) is on the same sheet.

| | | |
|---|---|---|
| GFA | 80 | gross floor area |
| occupants | 2.56 | |
| storeys | 1 | |
| terrace level | 1 | mid-terrac (0 for detached, 0.5 for semi-detached, 1 for mid terrace) |
| dwelling type | top | floor top, mid, or ground-floor flat, or house |
| storey height | 2.50 | m |
| plan aspect ratio | 1.4 | ratio of plan depth to width |
| width | 7.56 | m |
| depth | 10.58 | m |
| GR | 0.2 | glazing ratio |
| glazing asymmetr | 0.5 | proportion of glazing on main façade |
| orientation | 0 | of main façade with respect to due South (0, 45, 90, 135, 180 degrees |
| solar panel area | 2 | m2 |
| energy standard | 1995 | Part L 1995, Part L 2002, or '2008' |
| U value multiplier | 1 | for electrically heated houses - "1" gives same U values as gas heated |

**Summary of results:**

| | | |
|---|---|---|
| Target U value | 0.37 | (W/m2K) |
| Mean U value | 0.71 | (W/m2K) |
| Sigma UA heat loss | 77.3 | (W/K) |
| Additional thermal bri | 6.0 | (W/K) |
| Fabric heat loss | 83.3 | (W/K) |
| Space heating | 1.05 | (t/year) |
| Water heating | 1.08 | (t/year) |
| Other | 0.15 | (t/year) |
| Total CO2 | **2.282** | (t/year) |
| CARBON INDEX | **6.35** | |
| Total space & water h | 301.3 | (£) |
| SAP rating | 61 | |

| | | | | Nominal U values | | |
|---|---|---|---|---|---|---|
| | U W/m2K | A m2 | AU W/K | 2008 | 2002 | 1995 |
| roof | 0.25 | 80 | 20.0 | 0.16 | 0.16 | 0.25 |
| wall | 0.45 | 22 | 9.8 | 0.25 | 0.35 | 0.45 |
| ground floor | 0.45 | 0 | 0.0 | 0.22 | 0.25 | 0.45 |
| windows | 3.30 | 16 | 47.5 | 1.30 | 2.00 | 3.30 |
| roof windows | 0.00 | 0.00 | 0.0 | | | |
| doors | 0.00 | 0.00 | 0.0 | | | |
| additional bridging | | | 6.0 | 0.00 | 0.15 | 0.20 |
| Aexposed | | 117.8 | | | | |
| Atotal | | 250.7 | | | | |
| Cf | | | 83.3 W/K | | | |

| | | | |
|---|---|---|---|
| design ach | 0.5 | ac/h | |
| volume | 200 | m3 | |
| volume flow | 0.028 | m3/s | |
| ventilation type | mvhr | mev or mvhr | |
| leakage rate | 3.76 | ac/h at 50 Pa | |
| pressurisation test result | 3.00 | m/h at 50 Pa | |
| effective ventilation rate | 0.20 | ac/h | |
| Cv | 13.4 | W/K | |
| heating type | central | | (central, point) |
| primary fuel | electricity | | (gas, electric, oil) |
| secondary fuel | none | | (gas, electric, oil, none) |
| primary heat source | boiler | | (boiler, heat pump) |
| heating efficiency | 100 | % | |
| secondary space heating efficiency | 100 | % | Table 4a (defaults to heating efficiency if no secondary system used) |
| secondary water heating efficiency | 100 | % | (defaults to heating efficiency) |
| specific heat loss | 96.7 | W/K | |
| heat loss parameter | 1.21 | W/Km2 | |
| fabric heat load | 2082 | W | 26 W/m2 GFA - Cf **10 W/m2** GFA Passivhaus criterion |
| ventilation heat load | 334 | W | |
| design heat loss | 2416 | W | |
| design Tin | 20 | C | |
| design Tout | -5 | C | |
| supply air temperature lift | 60.0 | C | (needed to allow all space heating to be supplied through a mechanical ventilatior |

Figure 1: Sample page from the Parametric Domestic Energy Model.

Appendix 2

# Appendix 3 Comparison of $\Psi$ values calculated using Therm with values from the Wärmebrücken-Atlas

**David Roberts** **December 2000**

## Wall/ stud

A simple detail of a timber-framed wall with one stud was taken from the Wärmebrücken Atlas and modelled in Therm using the same thermal conductivities and boundary conditions. The linear thermal bridging coefficient or *($\Psi$)* psi value was found by subtracting the U factor of the wall with no stud (Figure 1) from the U factor of the wall with one stud (Figure 2).

U factor of wall with no stud = 0.2638 $W/m^2K$

U factor of wall with stud = 0.2866 $W/m^2K$

Therm calculated $\Psi$ = $0.2866 \times pw - 0.2638 \times pw = 0.0228$ W/mK

(where *pw* = projected width, which was 1.0 m in each case).

$\Psi$ given in the Wärmebrücken Atlas = 0.022 W/mK

## Conclusion

Therm predicted linear thermal bridging coefficients appear to be reasonably similar to those calculated in the Wärmebrücken Atlas for the wall / stud junction.

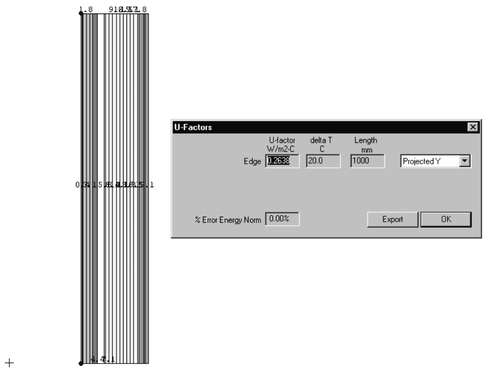



Figure (1): U factor of wall with no stud.

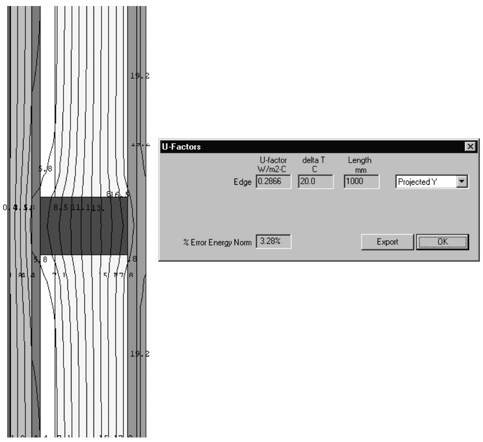



Figure (2): U factor of wall with one stud.

**Wall / wall junctions**

The linear thermal bridging coefficient ($\Psi$) for a wall/wall junction is given in the Wärmebrücken Atlas, page 62. This same detail was then modelled using Therm to enable a calculation to be made of the $\Psi$ value. The two values were then compared. The same boundary conditions and conductivities for the materials specified in the Atlas were used.

The U factor of the 'wall only' predicted by Therm = 0.2353 W/m$^2$K as shown in Figure (3).

The U factor of the wall junction was found by creating CEN internal and external boundary conditions along one wall only (the LHS wall), the other wall had adiabatic conditions. The U factor of the wall junction = 0.2985 W/m$^2$K as shown in Figure (4).

The linear thermal bridging coefficient *($\Psi$)* of the junction was found by subtracting the wall U factor from the junction U factor:

$$U_{junction} - U_{wall} = \Psi$$

$$\Psi_{LHS} = 0.2985 - 0.2353 = 0.0632 \text{ W/mK}$$

However, as the junction was not symmetrical, a further $\Psi$ value was obtained by reversing the adiabatic and CEN boundary conditions for the two walls: this time the LHS wall had adiabatic conditions and the RHS wall had CEN internal and external boundary conditions. The U factor of this junction was 0.3258 W/m$^2$K, as shown in Figure (5).

$$\Psi_{RHS} = 0.3258 - 0.2353 = 0.0905 \text{ W/mK}$$

A $\Psi$ value for the whole junction was found by averaging the LHS and RHS values:

$$\psi = \frac{(\psi_{LHS} + \psi_{RHS})}{2} \text{ W/mK}$$

$$\psi = \frac{(0.0632 + 0.0905)}{2} = 0.07685 \text{ W/mK}$$

**Conclusion**

This Therm predicted value compares favourably with that given in the Wärmebrücken Atlas of 0.07 W/mK.

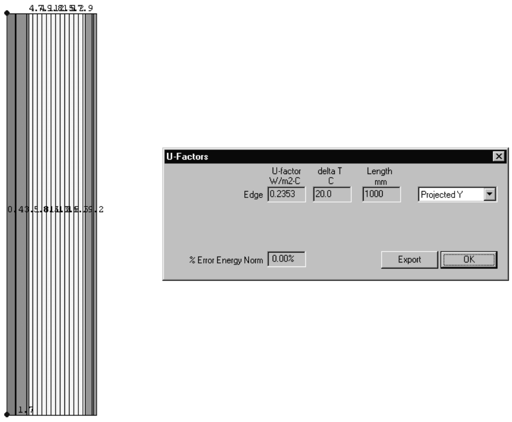



Figure (3): U factor of wall = 0.2353 W/m$^2$K

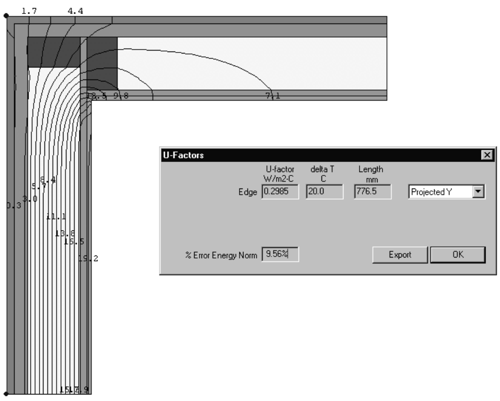



Figure (4): Isolines at junction using adiabatic conditions on the RHS wall. U factor of junction = 0.2985 W/m$^2$K

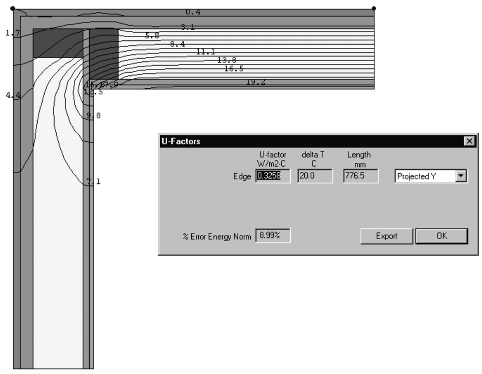



Figure (5): Isolines at junction using adiabatic conditions on the LHS wall. U factor of junction = 0.3258 W/m$^2$K.

# Appendix 4  Partners interview questionnaire

**Malcolm Bell, David Roberts, Robert Lowe** **18 October 2000**

**Introduction to be read to each interviewee:**

I'd like to read a short introduction to explain the format of the discussion and what I'm trying to achieve. After that I'd basically just like you to talk about your involvement in the St. Nick's project.

As you know the purpose of doing the St. Nick's scheme is to design and construct houses to a much higher energy and environmental standard than the existing building regulations. Malcolm, Bob and I want to see how this higher standard would work in practice. If we are to do this, it is important that we gather the views of everyone involved, from designers and constructors right through to the client and the end-users.

So, the purpose of this interview is to record the story of your involvement in the project so far. I am interested in your background, your interest in the project and your general views and opinions as well as the part you have played in the work to date. There are no right and wrong answers to any of these questions and there will be a range of different views and perspectives. I'm hoping to gather as clear a picture as possible of your opinions and views.

The interview will be tape-recorded but only to enable me to write a transcription of the discussion. No one else will hear the tape. I will send you a copy of the transcript, and if you feel that there is anything that I have misunderstood or misinterpreted, or that could be more clearly expressed, you are welcome to make amendments. When you are happy with the content I will keep the transcription and the tape in a secure and confidential file.

The material will be incorporated in a general way into the project outputs (report, CD ROM etc.) as part of the analysis and discussion. However short extracts from the transcript of this interview may be used for illustrative purposes and in such cases it will often be necessary to state the general role of the person giving the interview. Where this is necessary, titles such as architect, client, contractor, subcontractor and so on will be used. No proper names will be given.

I've divided the discussion into five areas:
1) your background
2) how you became involved
3) the process of design and development
4) the development of knowledge
5) the development of attitudes, interest and motivation

**(A) Background**

The first thing I would like to do is to get an idea of your background. We are conscious of the fact that the people and organisations involved in the project will come from a wide range of backgrounds and it is important for the research project that we get a good understanding of these.

1. Before we explore areas related directly to the project I would like you to provide a brief overview of your professional background. (a short CV if you like)

2. I would now like to turn to aspects of your background which relate specifically to the project and the energy and environmental issues it is attempting to address. Could you tell me about any experience you may have had of energy and/or environmental projects prior to the St. Nicks project.

Prompts/supplementary:

- Is this experience based on work inside your current organisation? - If not where from?

- Does any of the experience you describe come from personal experience outside your normal professional sphere of activity?

3. Knowledge about energy efficiency and environmental matters is likely to vary across the range of people and organisations involved in the project. Perhaps you would describe the extent of the energy and environmental knowledge you had before you became involved in the project?

Prompts:

- Can you provide any examples of …………

- How would you describe the depth of your knowledge of ………

4. What about the state of knowledge generally within the organisation for whom you work? How would you describe that?

Prompts:

- Can you provide any examples of …………

- How would you describe the depth of the knowledge of ………

5. Before you were introduced to the project, what did you think about the adequacy of the energy standard in the current building regulations?

Prompts

- Is this a personal view?

- How would you describe the predominant view or views with in your organisation?

**(B) Involvement in the project**

We've covered the first of the five areas of discussion. Now I would now like to move onto the second and explore some of the reasons why you were prepared to become involved in the project.

6. Could you outline why, in your view, your organisation was interested in being part of the project.

Prompts: [do not use any specific prompts] - are there any other reasons?

7. I am also interested in why, from a purely personal point of view, you were prepared to get involved in the project. Could you say something about this?

Prompts: [do not use any specific prompts] - are there any other reasons?

8. Did you or your organisation have any misgivings about becoming involved?

Prompts/supplementary -If Yes:

- What were they?
- Why were they of concern?

9. How would you describe your personal views, at the beginning of the project, as to its energy and environmental objectives?

Prompts:

- I am thinking of views about such things as: its necessity, how worthwhile you thought it was, or how realistic you thought it was.
- Are there any other points you would like to make on this?

10. To what extent, if at all, did your views match the predominant view or views within the organisation for whom you work?

Prompts:- Please elaborate

11. Do you have anything further to add about the background to your involvement?

**(C). The process: design, development and approach to procurement.**

What I would like to do now is move onto the third discussion area and explore the design and development process of the St Nicholas project and find out how the partners have interacted with each other. I would like to explore how each partner sees their own role and that of other partners. I would then like to explore the design and management processes.

12. Could you, first of all, describe what you see as your role in the project?

13. How does this role differ from that which you would normally take, in a more typical social housing project?

14. How does the role you describe relate to the roles of others?

Prompts:

- If it would help, you could, perhaps, draw a bubble diagram to explain.
- People not mentioned – prompt with "what about the role of {name} the {position} (e.g. Phil Bixby, the architect)"?

15. From the point at which you became part of the project could you outline what you have done? Please provide as near a chronological account as you can?

Prompts

- Identify the start of involvement and then keep asking – "What did you do next?"
- Reminders about stages may be required - such as design of concept, design of details, involvement in cost assessments etc.

I would now like to ask some questions concerning the design the scheme.

16. Bearing in mind the energy efficiency and environmental objectives of the scheme, I would be grateful if you would describe, from your point of view, what you see as the key design decisions that have been taken so far?

Prompts: Supplementary

- What has been the extent of your involvement in this decision.
- For each area mentioned – ask what do you think were the main factors in making the decision.
- In your judgement, how likely are any of these decisions to change?

17. Please would you outline those areas where design decisions are still to be taken?

Prompts:

- How involved do you expect to be in … {decision/aspect}
- What, do you think, will be the most important factors in reaching a decision on …… {particular aspect}
- Any other areas?

18. Please comment on how easy or difficult you think it will be to meet the energy standards set for the scheme?

Prompts: - Can you say more about the ease/difficulty of ……{aspect}

19. Do you have any other comments on the way in which the various aspects of design have been or are being addressed?

Prompt/supplementary: - Can you elaborate?

I would now like to explore your views about the overall management process for this scheme.

20. In what ways, if any, has the management of this project differed from other projects that you have been involved in?

Prompts: -if differences:

- Can you tell me more about……..{aspect}
- Are there any other differences?

If no differences:

- How surprised are you at the lack of difference?
- Why do you think there is no difference?

21. Based on your experience in this scheme and from the point of view of your organisation, I would like you to describe what you see as the benefits and/or disbenefits of the partnering approach. Lets start with the Benefits, if any.
What about the disbenefits?

Prompts – [Do not prompt this question]

22. Do you have any other general comments about the partnering process in this project?

Prompt: - Please elaborate.

**(D). Development of knowledge, skills and understanding**

For the fourth discussion area I would like to move away from the process itself and discuss the extent to which the team and its members acquire knowledge about various aspects relevant to the scheme. In the discussion of your background we covered the extent of the knowledge and experience you and your organisation had at the start of the project. I now want to explore your views on what has happened since then.

23. Would you say that your knowledge of the relevant issues has changed during the time you have been involved?

Prompts - If Yes:

- In what way? Can you elaborate?
- How did you learn (more) about *[particular aspect*]/ this?
- Can you give any specific instances or examples?
- Are there any other aspects?
- I would like us to focus mainly on specific things related to the project. [to be used if the answers get very general]

If No:

- Can you say why you think that?

24. Do you think that you have been able to contribute to the knowledge of the team?
Prompts - if Yes

- In what way? Can you elaborate?
- How did you get *[particular aspect*]/ this across?
- Can you give any specific instances?
- Who were the main recipients?
- Are there any other areas?
- I would like us to focus mainly on specific things related to the project. . [to be used if the answers get very general]

If No:

- Can you say why you think that?

25. Do you think, there are any areas where the team needs to learn more in order for the project is to be successful?

Prompts:

- Can you say more about the areas where more knowledge in required?
- What do you mean by *[particular aspect*]/ this?
- Can you give any specific examples?
- Who needs to acquire this knowledge?
- Are there any other areas?
- I would like us to focus mainly on specific things related to the project. [to be used if the answers get very general]

26. Do you have any other comments you would like to add about the questions of knowledge we have just been discussing?

**(E). Development of attitude, interest and motivation**

In this fifth and final section of the interview I would like us to focus on the general views you have about the project and its objectives as a whole. At the beginning of the interview we explored the views that you and your organisation held at the start of your involvement. I would now like to look at whether those views have changed.

27. Do you feel that any of your personal views about the energy and environmental objectives of the project have changed over the course of your involvement?

Prompt/supplementary: -if Yes:

- Can you say something about what has changed?
- How would you describe your current view?
- Is there anything else you would like to add about your current view?

28. Do you feel that the views within your organisation about the energy and environmental objectives of the project have changed over the course of your involvement?

Prompt: If Yes:

- Can you say something about what has changed?
- How would you describe the current views within your organisation?
- Is there anything else you would like to add?

29. During the course of the project, have your views about the adequacy of the current building regulations changed?

Prompt: - If Yes: - Please elaborate on how your views have changed

30. Are there any other areas in which your views or those of your organisation have changed during your involvement in the project?

Prompt: - If Yes:

- Please describe them and the extent of the changes.

31. Are there any other comments you would like to make regarding any part of this interview?

Prompt: - If Yes: - Please elaborate

Thank you for taking part in this interview.

# Appendix 5 Airtightness Afternoon, 20th June 2000

|Present:

Bob Lowe, LMU
Malcolm Bell, LMU
David Roberts, LMU
David Johnston, LMU
John Gilham, YHA
Jenny Brierley, YHA
Tony Ashton, YHA
Ron Bailey, YHA
Phil Bixby
Robin Dodyk, Oregon Timber
Chris Palmer, Baxi
Martin Searle, Baxi
Roger Stephen, BRE
Phil Hughes, Wates
Alan Smith, Harrison Smith (Batley) Ltd
John Funnel, York City Council Building Control
James Haigh, LEDA

Introduction

A demonstration of dwelling air-tightness testing was given by LMU to the partners of the St Nicholas Fields project followed by an air-tightness seminar at YHA offices. The pressure test was done using a Minneapolis blower door on a first-floor two bedroom flat owned by YHA in York. A smoke emitter was then used to demonstrate typical air leakage paths in dwellings. The seminar held immediately after the demonstration was led by Roger Stephen of the BRE and explored the issues raised in the demonstration including air-tight design, workmanship on-site, possible air-tightness failures and robust details.

Summary of response to evaluation sheets

An evaluation sheet was given at the end of the air-tightness seminar asking partners to rate how the demonstration and seminar influenced their views on air-tightness. Several partners made detailed comments.

1. 11 people responded to the evaluation sheets. Roger commented that the test and seminar may not have affected the way he thinks about air-tightness as "he has been in the business a long time".

2. Of the 11 respondents, only 2 had seen a pressure test before – Roger and Chris.

3. 7 people found the test 'very informative' and 3 found it 'fairly informative'. Only 1 expressed no opinion – Roger.

4. The test changed the way most people felt about air-tightness - 2 'significantly' so, 4 'quite' so and 3 'slightly' so. Robin responded 'hardly' changed and Roger expressed 'no change' in the way he felt.

5. Almost everyone (including Roger) felt that the discussion was useful. Only 1 person said 'not applicable' – Martin.

6. Most people said that they will change the way they work as a result of the seminar. 4 said 'definitely', 3 said 'yes' and 2 said 'maybe'. Phil Hughes said 'not yet' and Roger 'possibly not'.

7. Unlike the other questions, the 'areas which might change' question had multiple responses. 6 people voted for changes in design and 6 for checking of construction on site. 5 respondents might increase staff training while 2 said they might introduce elective pressure testing. 4 people would consider modular and factory-made components – Phil Hughes, James Haigh, John Funnel and Ron Bailey.

8. For the possibility of a CPD exercise on air-tightness - most strongly recommended it apart from 2 people who had no opinion and 1 who said no (Tony Ashton of the YHA).

9. other comments (eight partners made detailed comments):

Robin Dodyk:

I like the informal yet useful way the details and construction are being developed – everyone in the team seems to be heading for the same result – BUILDABILITY AND ENERGY SAVING!

John Funnel:

Application and viability of the systems must be an important point. Operatives on site must be able to apply the system easily and understand the reasons behind the methods. The application of the system must also take into account future alterations, extensions, etc. Can it be maintained?

James Haigh:

Please provide the results of the air-tightness test performed in the YHA property. I'll be performing a commercial air-tightness test next year (Theatre / Chapel – a BRE fan test). All welcome to attend – I'll provide details.

Phil Hughes:

St Nicks specific very good – we need legislation before wider adoption.

Alan Smith - Harrison Smith (Batley) Ltd:

Air-tightness = ventilation. [Concerned about the need for extra ventilation as air-tightness is increased, for occupants, combustion appliances and inside cavities containing gas pipes in case of leakage].

Chris Palmer:

More consideration of penetrations of air-tight membranes (especially telecom cabling). Site training is essential!

Martin Searle:

Very useful obtaining a greater appreciation of issues (sorry – opportunities).

Roger Stephen:

Interesting discussion that highlighted that designing for a high level of air-tightness is not as simple as it first seems. Having seen the general arrangement drawings of the proposed house I can see a few areas where the design makes achieving an air-tight barrier more challenging:

- the floor 'overhang' in the sun-space,
- using the plasterboard as the air tight layer (raised at the meeting as a bad idea because services will still penetrate the air-tight layer) better to keep the air-tight barrier outside the services void in the walls,
- some parts of the room-in-the-roof construction may lead to problems – especially the junction of the sloping roof with an intermediate floor?
- I am certain a great deal can be learned from the publication by the Canada Mortgage and Housing Corporation and the Canadian House-builders Association. I was pleased to see Bob Lowe had a copy of one of them at the meeting.

Evaluation sheet

A copy of the evaluation sheet is shown below. The numbers in the tick boxes are the numbers of responses to the questions.

1. Name:

2. Had you observed a pressure test before today? 2 yes / no 9

3. Did you find it:

| very informative | | | | uninformative |
|---|---|---|---|---|
| 7 | 3 | 1 | | |

4. Did it change the way you think about air-tightness:

| significantly | | slightly | | not at all |
|---|---|---|---|---|
| 2 | 4 | 3 | 1 | 1 |

5. Did you find the subsequent discussion:

| useful | | no opinion | | not useful |
|---|---|---|---|---|
| 9 | 1 | | | 1 n/a) |

6. Are you likely to change the way you work as a result?

| definitely | | maybe | | no |
|---|---|---|---|---|
| 4 | 3 | 2 | 2 | |

7. If so, can you identify which areas you might change?

| design | checking of construction on site | staff training | elective pressure testing | consider modular and factory-made components |
|---|---|---|---|---|
| 6 | 6 | 5 | 2 | 4 |

8. Would you recommend a similar workshop to colleagues/other members of your organisation, for example, as a CPD exercise?

| recommend | | | | no |
|---|---|---|---|---|
| 7 | 1 | 2 | | 1 |

9. Any other comments?

# Appendix 6 Innovations Brief.

## YORK HOUSING ASSOCIATION LTD.
## ST NICHOLAS' COURT, YORK.

This brief is designed to complement the Association's normal briefing documents by setting down the areas in which the St Nicholas' Court Scheme will contribute to innovation, not only in the Association's own objectives and methods, but also in the aspirations for the construction industry outlined in the Egan Report, "Rethinking Construction" and in the wider context of sustainable housing.

**OBJECTIVES.**

**1. Construction Industry Task Force.**

The Association's experience, like that of many clients of the house building industry, is that the end product could always be improved. The process of getting this imperfect end product is confrontational, time-consuming and frustrating. Our procurement objective must be to get a better product, quicker, cheaper and in co-operation, not conflict, with our partners in the process. On a sustainable housing scheme (see below) where it is vital to get the right materials from the right sources and to maintain standards of construction which will deliver a product meeting our sustainability objectives, a non-traditional method of procurement is the way forward. The Egan report points the way towards integrative processes of construction management such as partnering.

In terms of the CITF objectives, we aim to achieve significant improvements as compared with conventional schemes in some or all of the following areas:

Product development
Project implementation
Partnering the supply chain
Production of components

**YHA's objectives are as follows:**

**Product Development.**
To source and use products which conform to sustainability criteria and which will set standards for the building industry into the 21st century.

**Project Implementation.**
To reduce construction time as compared with a conventional scheme, to increase predictability of key construction events, and to achieve a scheme with zero defects.

**Partnering in the Supply Chain.**

To involve fully all partners from the earliest possible stage to achieve a

co-operative process which delivers desired outcomes to all parties.

**Production of Components.**
To encourage the use of standard components which are fully integrated into the overall design, thus reducing time-consuming redesign during the construction period, re-work, and waste.

**2. Sustainable Homes.**

York HA aims to provide housing at an affordable rent for people in housing need. Running costs should be as low as possible. Sustainable housing will allow the Association to provide prospective tenants with homes which minimise the use of non-renewable resources in construction (and ultimately demolition!) and during the lifetime of the property, in particular by reducing dramatically the energy requirements for heating and the need for high levels of water use. Cost savings in these areas are particularly important to tenants on low incomes/benefits. Attached at Annex 1 is a sheet which summarises the issues to be addressed and the targets which it is hoped to achieve. These will be refined as design work progresses, with anticipated improvements in some areas.

**METHOD**.

**1. Construction Industry Task Force.**

**Product Development.**

In order to achieve the objective of sourcing and using products which conform to sustainability criteria we will be "partnering the supply chain" (see below). Through early identification of suppliers of sustainable materials, and their involvement with the main contractor in the design process, we, will ensure that specification standards are adhered to and that the use of ecologically friendly materials is fully integrated into the construction process. The involvement of Leeds Metropolitan University Centre for the Built Environment, whose proposals for the 2005 revision of the Building Regulations Part L will provide performance targets for the scheme, will encourage development of methods and materials to meet future requirements affecting the entire house-building industry.

**Project Implementation.**

Integrated project process. To reduce construction time, increase predictability, and achieve zero defects, it is essential that the main contractor and suppliers are involved in the process much earlier than at present, integrating the design and construction programmes. A shorter contract time can be achieved because there is a longer lead-in time during which design of components, sub-components and systems can be integrated, suppliers can be geared up to a firm delivery date within the programme, and the benefits of predictability can help to ensure the minimisation of defects. Quality control on site can take a higher priority than crisis management.

**Partnering the Supply Chain.**

Partnering will be achieved by:

a) Identification of possible main contractors - those with a track record of innovative housing schemes and a positive response to the recommendations of the Egan Report. A number of large construction firms have already shown an interest in both these areas. It will be of advantage both to the Association and to the industry more generally to secure the involvement of one of the bigger players. Production of shortlist.

b) Investigation of shortlisted main contractors - financial and quality checks and references, in-depth discussion to determine commitment to the implementation of the Egan report recommendations and to sustainable housing. Production of tender list.

c) In parallel, sourcing of materials and identification of suppliers meeting the sustainability criteria.

d) Selection process.
(i) It may be that at this stage there is a very clear preference to proceed with a contractor whose commitment to all the principles and objectives of the scheme sets that firm in a different league from all others. We would then proceed on the basis of a negotiated tender, with careful reference to the Housing Corporation. If not we would proceed to:
(ii) Initial tendering process. Contractors to tender against an initial design and method proposal which would include a requirement to maintain original design team, work with nominated suppliers, and to follow site procedures in conformity with CITF recommendations. This would be a variation on a design and build tender though we note the Egan report's comment that a reduced demand for tendering leads to immediate savings (para.71).

e) Post-tender, the process of detail design remains within the control of the client and original design team, but now with the full participation in design team meetings of the lowest tenderer and the nominated suppliers. The culture of co-operation and team-working must replace the culture of confrontation and be directed to eliminating unnecessary costs, ensuring clear understanding of the objectives by all participants, and to delivering the desired outcomes. Sub-contractors must also be introduced at this stage. The post-tender, pre-start on site stage will be relatively longer than a conventional design and build scheme due to the greater time spent on pre-planning the site processes, but time on site will be less as re-work, design hold-ups and supply delays will have been eliminated.

f) Maintain principles on site. Substitute culture of co-operation and problem-solving for culture of blame and bodging.

| | |
|---|---|
| g) Take benefits: for YHA | fulfilled brief, high standard of construction, zero defects, low maintenance, low running costs |
| for Contractor | smoother process, less abortive time spent on tendering, more predictable, no defects problems |
| for Consultant | as contractor. |
| for Housing Corp. | increased predictability, less risk. |

**Production of Components.**

The partnering process will allow the design team to identify opportunities for standardisation of components and the avoidance of special manufacture.

**2. Sustainable Homes.**

a). Employ architect familiar with concept of sustainable housing, with experience of energy efficient construction, with research ability, and committed to co-operative methods of working.

b). Implement programme to thoroughly familiarise key YHA staff with sustainable housing work in this country and abroad, including access to literature, organisations promoting sustainable housing eg. "Homes 2000", "Sustainable Homes", and visits to sites.

c). Build links with other sustainable housing developers, research organisations etc.

d). Integrate scheme with other local initiatives eg. Local Agenda 21, energy efficiency schemes, draft Local Plan guidance.

e). Build design team committed to sustainability objectives, to include contractor and suppliers as well as consultants.

f). Incorporate "sustainable thinking" as widely as possible in process.

John Gilham. 11.1.99.

# Appendix 7 Minutes of the Design Review Meeting, 26 October 1999

**Robert Lowe** **26 October, 1999**

Present:
Phil Bixby (Constructive Individuals), Brian Stace (RWS Partnership), Phil Askin & Graham Cooper (Wates), Chris Palmer & Mike Connor (Baxi), Steve Irving (Oscar Faber), Robert Lowe & Malcolm Bell (LMU), David Olivier (Energy Advisory Associates on behalf of Design Advice Service).

Introduction
RL gave an introduction to the standards that would be required by the draft prototype Parts L, F and J of the Building Regulations (see attached)

DO gave an introduction to high-latitude practice in Canada and Sweden
Saskatechewan Conservation House, R2000, Advanced House
Mats Wolgast, SBN80, SBN89

PB reviewed design of St Nicholas as it now stands.

DO commented on difficulties posed by external toilet (heat loss, air sealing and additional heating). PB stated that this cannot be changed at this stage. [Is this an issue for regulations?]

Solar access
DO Solar access?

PB There is little shading – two storey factory building some distance to East, and willow wall of 3m height to South.

PB referred to Design Review Meeting

Roof design
DO Condensation on sun pipes? Warm roof with sun pipe or Velux minimises cold bridging.

CP warm roof is a must for MVHR

DO costs of warm roof lower in mass production – in SE UK, cost of 2½ storeys < cost of 2 storeys for the same gross floor area.

DO cold roof is cheaper if roof space not valued, but MVHR losses push for warm roof.

PB YHA likes idea of sleeping shelves in half storey having seen examples.

DO Roof: discrepancy in U values, U 0.15≡300 mm glass fibre ($\lambda \cong 0.035$)

PB Oregon comments on roof ... meeting in July or August, took on board this issue. Considering a number of options including stubbed fink truss. Oregon now looking at warm roof construction and economics. Also looking at I beams, Stressed Skin Panels and purlin constructions. PB still waiting for their considered view.

DO Arkansas truss. In principle uniform 300 mm is better than 300±100 – beware thinning at eaves. Warm roof also minimises $\Delta\lambda$ due to air movement through outer layers. Masonite beams expensive in UK because of little demand. But can use I studs at 1.2m instead of 0.6m centres. Also TJI [previously Trusjoist Macmillan] as alternative supplier (importing from US).

PB I beam roof makes sense if we move towards sleeping shelves.

MB use of centre section of roof as service void.

CP need to consider visual acceptability.

Summertime overheating

DO Overheating due to sun spaces. Trondheim overheating in February in lightweight timber frame. US also at 45°N in New Hampshire - 18-27°C daily range in February. not acceptable.

Glazing ratio (south) should be less than 8% - 12% to avoid overheating in timber framed dwellings.

PB Self build houses have similar arrangements. semi-isolated sunspace allows more control over living room temperature. [CP similar to my house.]

MB thermal mass in floor less important than shading.

PB Shading measures so far are:
pergola at first floor
extension of roof line to shade sun space.

Also option of clematis or Russian vine. [RL expressed doubts about controlling Russian vine]. Thermal mass in floor ≅1/4 mass in walls

DO Cheap options are:
16mm plasterboard;
putting plasterboard offcuts in wall cavities;
thin tiled floors on timber;
tiled walls in WC and kitchen.

SI BRE timber framed test homes overheat - check with Roger Steven.

<u>Window and doors</u>
DO Windows U 1.3 but need to account for DWER; BFRC.

PB Ecoplus U≅1.3.

DO more likely to be 1.6.

MB DWER - we will have a go.

DO maybe get best DWER with hard coat Ar/Kr in wood. Might get best value from overseas – Danish or Swedish windows and doors. But cost of Swedish windows in the UK is much greater than in Sweden due to premium market in UK.

PB/CP It might be better to use project to lever best practice into UK.

PB We have been looking at possible details for wall and windows.

DO Need for insulated doors

PB ecoplus door – claimed to give U≈1.3 $W/m^2K$

RL steel faced doors with U ≤ 1 $W/m^2K$, approximately £200 in Canada

<u>Wall design – cold bridging and air leakage</u>
DO probably need a vapour barrier in external walls

PB looking at junctions

PB Wall panels - 89x50 studs
+ 25 service void and 43 cellotex
+50 mm battens and timber

DO If you are aiming for a wall U value of 0.25 - this is tight.

PB looking at moving towards balloon frame and excluding structure from insulation layer at first floor.

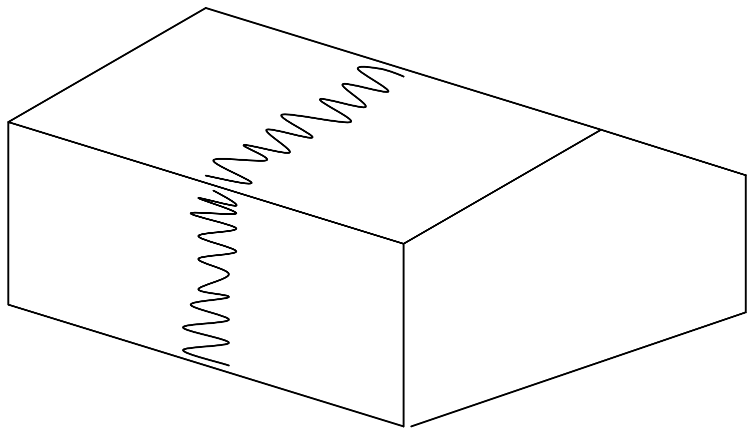
PB moving away from deep studs. Oregon looking at horizontal timber

DO Give Oregon a target of 17% through-timber to minimise cold bridging.

DO First floor always a source of leakage in platform frame. Intermediate air barrier in external wall. Tyvek external air barrier.

PB We are considering polythene skirt at first floor inside Cellotex

DO Party wall air leakage. Minimise leakage through party wall by air tight layer at junction between party wall and external envelope (see diagram). This is easier with warm roof. Insulation must be continuous across boundary.



PB current design for party wall uses plasterboard only as air barrier. Maybe need a separate vapour barrier.

RL could use same construction in party wall as in external walls. Still need to provide air barrier (see diagram) to prevent air movement through cavity in party wall.

DO Must carry out the **"pen-on-section"** test for airtightness and thermal bridging.

DO gave example of Harlow Park project. Timber framed houses with initial specification of 2 m/h @ 50Pa, but not achieved. Air leakage at lights fittings, doorbell etc. In other houses telephone wiring, TV socket, entry phone gave problems. All penetrations of air barrier must be designed.

PB We are already talking about entry points for future cabling.

DO Also need to consider impact of DIY on airtightness. Some countries (possibly Switzerland?) ban DIY.

PB The current design has a continuous polyethylene vapour barrier in walls and roof.

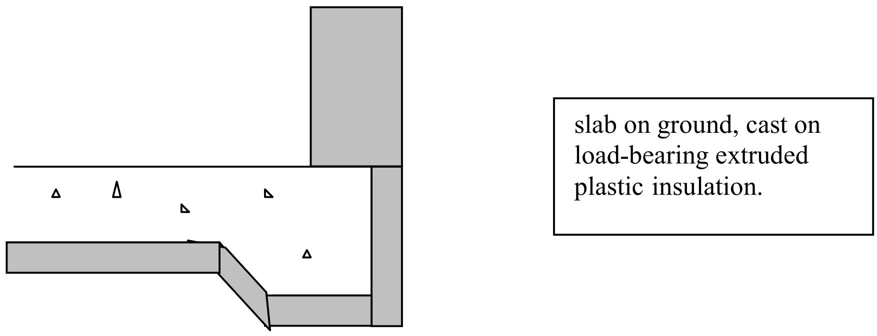
DO You still need to define responsibilities for air sealing.

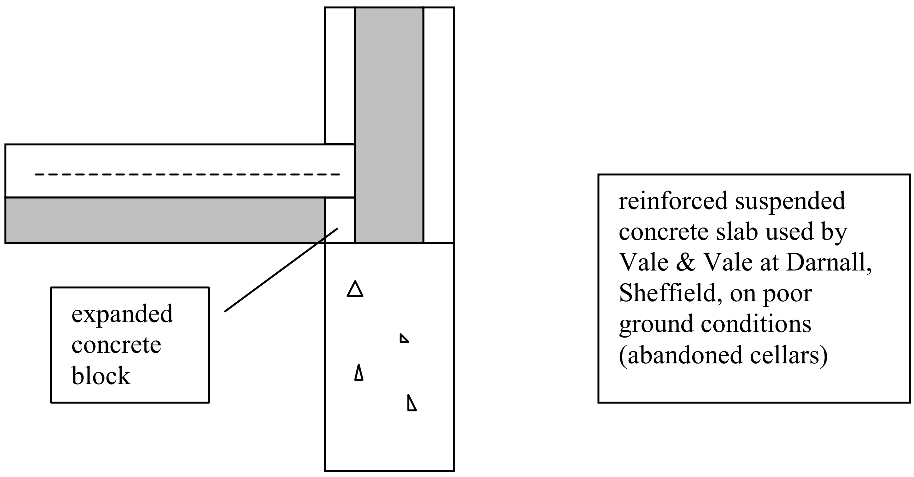
GC This will not be a problem. It will be in their job descriptions…

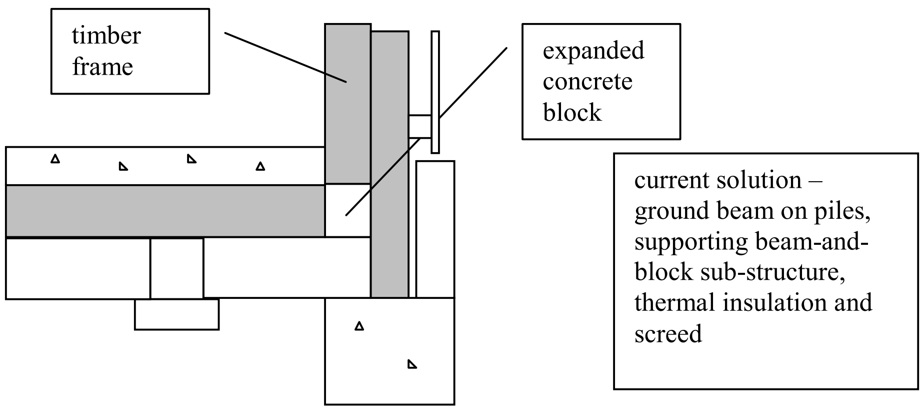
MB Service routing problem came up on Friday - reinforce.

Ground floor
PB We have adopted solid ground floor to get some thermal mass into the dwelling.

DO The project is currently Eganising by using piles, beams and blocks. But alternatives exist – raft and suspended reinforced slab. May use less material than piles, beams and blocks (see diagrams). Timber frame on concrete sub-structure leaks if not carefully detailed.




GC Raft foundation raises questions of on-site time and buildability – weather dependent.

Space heating
DO 2.9 kW for end-of-terrace realisable if target U values and airtightness are achieved.

CP We have been involved in many trials where we have not achieved comfort due to uncontrolled air leakage and inadequate insulation.

DO There is a widespread problem of air leakage being higher than expected.

CP But this is the first time we have had any confidence in leakage and U. We want to look at MVHR with $\eta$=0.9 and DC motors $\Rightarrow$ COP 7-10. I've yet to see extract only system which avoids need for upstairs heating.

DO Overseas practice is often extract-only and radiators.

CP In pure energy terms need $n_{50} \leq 1.5$ ac/h

SI Fans need to be quiet.

CP Yes, big fans, DC motors, high efficiency

CP We are now talking about condensing boilers with radiators. From our point of view, want to look at condensing and non-condensing technology. Is c $\approx$ 64kg/GJ realistic given industry pressures?

DO Yes. Might be appropriate to test extract-only and MVHR ventilation strategies.

MC  Baxi's condensing boiler is $\cong$ 10 kW minimum.

DO Effect of electricity use by boilers - fans, controls may make a difference of 10% in efficiency. COP - argument.

CP limited points of discharge and efficient boiler. We would like to see a non-condensing boiler option - trade off condensation vs. MVHR. Capital cost argument.

DO We must remember that we are aiming for a delivered energy target of 50-80 kWh/m$^2$/a not 30. Equivalent to the German **low energy house standard**, not to the **passive house standard**. Also equivalent to Lower Watts House and the Longwood House.

PB The client will allow different heating and ventilating strategies, provided they cannot be identified in advance as “best” and “worst”. We need to deliver heat other than by air.

RL A wet heating system would require $\cong$3m$^2$ radiators for the whole house (assuming 1 kW/m$^2$).

BG What will be the lifespan for fans etc.?

CP Ten years. But Baxi is exploring option of offering a lifecycle package.

GC Will you (Baxi) also give price for installation?

MC We will not fit taps, but we can do the rest of the installation. We are proposing to use indirect DHW. We need to define plant spaces.

PB Are you considering a combi boiler??

MC No, on grounds of cost, complexity, reliability, performance. How will project account for occupancy effects in measuring differences between energy use in 2 groups of houses with different systems?

PB We are aware of issues. We are planning "education", logbook, manual (1 sheet)

PB We need more information on how people use these homes - we do not have all the answers yet.

MB We will measure all of these factors during occupancy.

CP Information on mechanical design would be useful. Does David Olivier have any comment? We are planning on ventilation rates of 5 l/s × no of occupants => 20 l/s overall. RL and CP to explore.

DO It would be very interesting to explore options of:
condensing boiler and extract-only ventilation, versus
MVHR and non-condensing boiler.

<u>Lighting & appliances</u>
SI Current review of Building Regulations is considering requiring dedicated CFL fittings. Also considering efficiency of external lighting.

PB We are looking carefully at external lighting.

DO CFL external lamps with continuous use, use more energy than tungsten on PIR.

PB Looking at external lighting quality.

DO Solar powered external lights.

SI Proposed regulations for 2000 will concentrate on fixed external lighting.

RL Main saving of photovoltaic-powered external lighting is on costs of external wiring, rather than energy costs.

BG But must be vandal-proof.

DO Cooking and appliances?

PB There is a scheme for supplying high efficiency appliances [unclear who is responsible for this – RL].

DO maybe just do one house with high efficiency appliances.

DO Clothes drying - can be built into house

PB YHA insist on a sheila [ceiling mounted drying rack, in kitchen or bathroom].

DO An alternative is an airing cupboard with connected to a ventilation extract point and with a door grill.

[SI left the meeting at this point]

Water efficiency
DO Water efficiency - taps, low flow shower, water efficient wc's. Will these houses be water metered?

PB Need to check costs to tenant of a metered tariff.

DO/RL Current Water Byelaws outlaw the most effective low water consumption wc's (valve flush). Affects products such as the Ifö. But these Byelaws are being amended to bring the UK into line with rest of Europe, probably by next year. One housing association has installed valve flush wc's in 200 houses and challenged the local water authority to take them to court.

Other energy and sustainability issues
PB We are intending to use timber from UK sources. Minimises transport energy use.

PA The proposed move to 89 mm studs makes UK timber possible.

DO Not all timber is sustainable. Eg. avoid use of Western Red Cedar.

DO Use of PVC? PB will eliminate if possible.

PB Intending to specify recycled roof slates.

DO How is lifecycle costing and computation of embodied energy use being implemented?

BS We will do LCC on the back of our cost model.

RL Information on implementation of LCC at www.greenbuilding.ca. Also see Anink, Boonstra & Mak.

MB Comparison of LCC of the proposed 2005 regulations vs. the 1995 regulations would be very interesting.

DO LCC comparison should be worked out at 2 TDR's – suggest 6% and 2%.

RL We will look at engineering vs. catalogue-based estimates for costs of innovative products and technologies.

PB Remaining areas: roof
ventilation
DWER
Solar shading
Foundations

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# Trial of dwelling energy performance standards for 2005…

aims:

- develop prototype Part L standard
- explore impact on all members of design and construction team through real-life project
- measure extent to which energy and environmental goals are attained **on completion** and **in occupation**

# Structure of proposed ADL…

offer two compliance routes

- elemental
- carbon rating

average U value route as minor variant of elemental route…

# Elemental Method

## Standard performance targets for dwellings

The requirement will be met if the performance targets in Table 1 are met. If you do not satisfy **each and all** of these requirements, you may not use the **Elemental Method**, and you will have to use the **Energy Rating Method** instead.

| Table 1a **Standard U values for dwellings** | |
|---|---|
| exposed walls | 0.25 |
| roofs | 0.15 |
| floors | 0.2 |
| windows, glazed outer doors & rooflights | 1.3 |
| opaque outer doors & hatches | 0.6 |

| Table 1b **Standard air leakage and heating system performance targets for dwellings** | |
|---|---|
| air leakage rate (m/hr at 50 Pa) | 3 |
| carbon intensity of heating (kg/GJ) | 64 (≈54/0.85) |

carbon intensity $\equiv$ performance
of useful heat of gas fired
condensing boiler

$$c_{useful} = c_{delivered}/\eta$$

heating system
thermal
efficiency

carbon intensity
of delivered energy

**concept can be expanded to include auxiliary electricity consumption of boilers etc…**

ventilation

continuous mechanical extract

MVHR

retain option for manufacturers to demonstrate that other solutions achieve equivalent perfomance…

elemental U values should include all thermal bridges

studs, wall ties
geometrical bridges at junctions between elements

effects of localised thermal bridges to be calculated using EN 6946

effects of heat loss at junctions to be calculated by rule of thumb, or by 2-D thermal simulation (THERM or equivalent)

# Part J – Heat Producing Appliances

- CO poisoning results in 30-50 deaths per year from open-flued appliances

- an unknown but potentially large number of people suffer from ill-health

- open flued appliances are significantly less efficient than balanced flue appliances

**presumption against open-flued appliances…**

# Appendix 8 Are space heating control problems likely to be more severe in highly insulated dwellings with over-sized boilers?

**Robert Lowe** **9 December, 1999**

Outline of the problem

The smallest condensing boiler that is currently available has an output rating of around 10 kW. Dwellings built to current Building Regulations have a design heat load of around 4 kW. It is possible that dwellings built to building regulations in force in 2005 will have a heat load that is only half as large. It has been suggested that, in the absence of smaller boilers, there would be tendency for internal temperatures in dwellings to become less stable as insulation levels rise.

This question has arisen in the context of the St Nicholas Court project, where it is proposed to install condensing boilers with a rating of 10 kW in low thermal capacity dwellings with a peak space heat demand of around 3 kW. The question is a complex one, and a complete answer has not yet been derived. But it is possible to address parts of the problem by a combination of analytical and simple numerical tools.

Heating system response

The purpose of a heating system is to maintain the internal temperature of a dwelling at some chosen set-point. Most heating systems make use of two-state (on-off) thermostats. If the heat stored in the heating system at the moment when the thermostat stops calling for heat is too great, or if the thermostat responds more slowly than the heating system and dwelling, then the dwelling will overheat toward the end of every room thermostat cycle. This problem might be particularly noticeable at the beginning and end of the heating season, when the rating of the boiler will exceed the heat load of the dwelling by many times.

The heat stored in the heating system is given by the following equation:

$$Q_{system} = c_{system} \cdot (T_{system} - T_{room}) \quad \text{(J)}$$

where:

$c_{system}$ is the heat capacity of the heating system (J/K)
$T_{system}$ is the instantaneous temperature of the heating system (°C)
$T_{room}$ is the room temperature (°C)

The heat capacity of the heating system depends on the water and metal content of the boiler, pipework and radiators. Examination of a domestic central heating system with a 10 kW condensing boiler, and pressed steel radiators with an output capacity of 2 kW, suggests that the contributions to heat capacity are as shown in Figure 1.

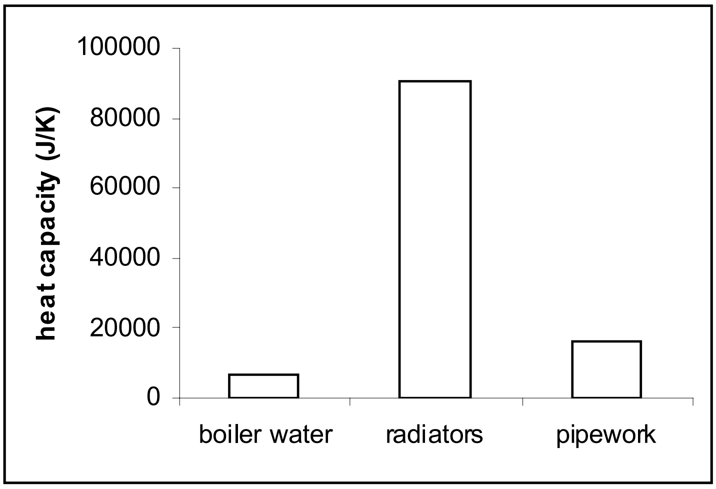


Figure 1. Contributions to the heat capacity of a domestic central heating system

This figure shows that the radiators contribute nearly 80% of the thermal mass of such a system. In a system with a larger area of radiators, the proportion would be even higher.

The next few paragraphs will explore the problem of heating system dynamics by comparing the behaviour of two heating systems. Both are driven by a 10 kW boiler. In the first system, this boiler is connected to a radiator system with a rating of 4 kW. This system represents a high level of mis-match, but one that is likely to occur in dwellings constructed to current building regulations. In the second, the boiler is connected to a radiator system with a rating of 2 kW. This system represents a level of mis-match that may occur in dwellings constructed to building regulations that may be in force in 2005. The key parameters of the two systems are summarised in Table 1.

| | boiler rating (W) | radiator rating (W/K) | system heat capacity (kJ/K) |
|---|---|---|---|
| 4 kW | 10000 | 73 | 220 |
| 2 kW | 10000 | 36 | 130 |

Table 1. Key physical characteristics of 2 and 4 kW heating systems

The figure below shows the initial response of two heating systems described above, in conditions under which boiler firing is limited by the boiler thermostat, and in which the water flow rate is high enough to prevent tripping of the boiler thermostat until the return water temperature begins to rise.

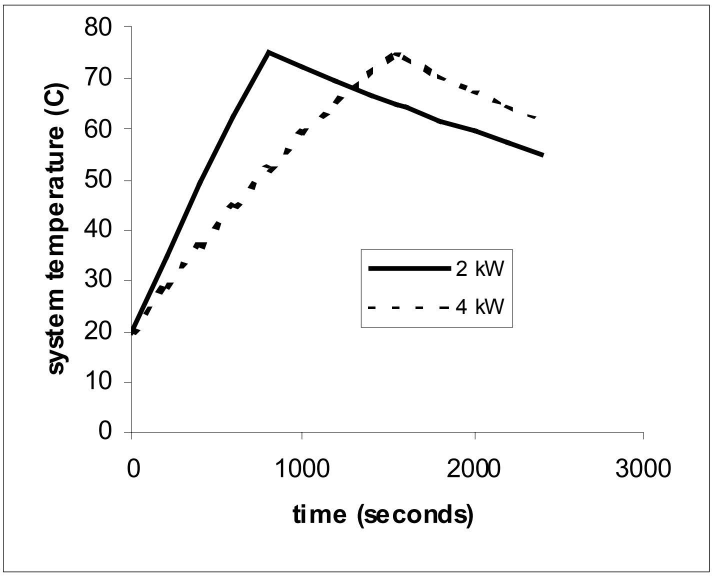


Figure 2. Initial response of a wet central heating system with a 10 kW boiler connected to 2 and 4 kW of radiators.

For systems in which boilers are oversized with respect to radiators, the initial temperature rise is effectively linear. The rate of temperature rise following a call for heat from the room thermostat is determined by the ratio of the boiler output to the system heat capacity, most of which is determined by the area of radiators connected to the system. Thus, the more oversized the boiler is with respect to the radiators, the quicker the system heats up.

Once the system temperature has reached the boiler thermostat set-point, heat input to the heating system stops. The system then cools, approximately exponentially, at a rate determined by the ratio of radiator area to system heat capacity. Since system heat capacity is itself largely determined by radiator area, the cooling time constant is almost independent of radiator area.

The behaviour of the internal temperature of a dwelling connected to one or other of the heating systems will be determined to a first approximation by the cumulative heat output of the heating system. The cumulative heat output of the two heating systems is shown in Figure 3 below.

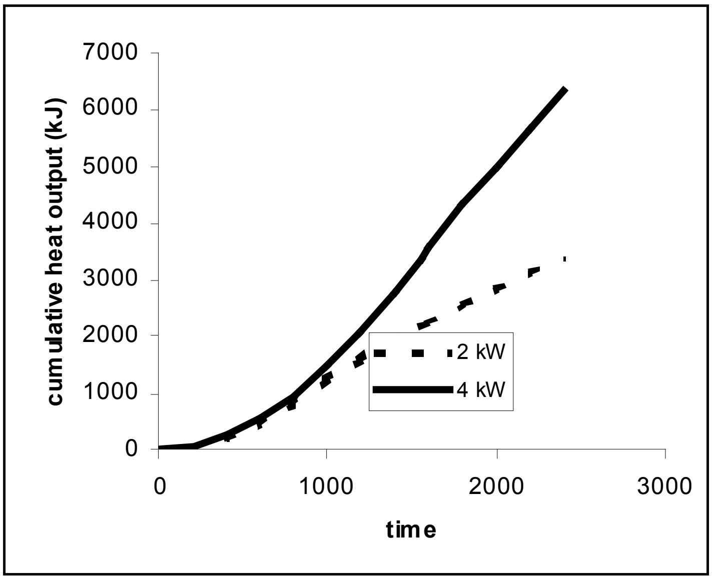


Figure 3. Cumulative heat output of heating systems with a 10 kW boiler connected to 2 and 4 kW of radiators.

This figure shows that until the boiler thermostat trips, the cumulative heat outputs of the two heating systems are similar. Until this point is reached, cumulative heat output is almost independent of the area of radiators connected to the heating system. A system with more radiators is more massive and so heats up more slowly. But lower temperatures are offset by larger area of radiator. In the longer run, the heat outputs of the two heating systems diverge. Long run cumulative heat output, for a system whose output is not limited by a room thermostat, is simply proportional to radiator area.

Dwelling response

As noted above, thermal instability is likely to be most pronounced at times of low heat load – at the beginning and end of the heating season. The worst case is likely to occur where the inside-outside temperature difference is close to zero. Under such conditions, it is only necessary to consider the dynamic response of the building to the heating system. Whether the heat output patterns shown in Figure 3 suggest that a dwelling with a 2 kW design heat load will be less thermally stable than an otherwise identical one with a 4 kW heat load, depends on the short run response of the dwelling in each case.

The initial response of a dwelling to heat input consists of a rise in internal air and surface temperatures, and the propagation of a temperature wave into the fabric of the dwelling. With some simplifying assumptions, the equation that governs the propagation of this wave is:

$$\lambda \frac{d^2T}{dx^2} = -c\frac{dT}{dt}$$

where:

$T(x,t)$ is the temperature a distance x into the fabric of the dwelling at a time t
$\lambda$ is the thermal conductivity of the fabric
c is the volumetric heat capacity of the fabric of the dwelling

If temperature is assumed to vary sinusoidally with time, this equation can be solved. The solution is:

$$T = T_o \exp i(\varpi t - x/L) \,.\, \exp(x/L)$$

This describes a wave travelling into the fabric of the building, but with an amplitude that decays exponentially in a distance equal to the reduced wavelength L.

$$L = \sqrt{(2\lambda/\omega c)}$$

This reduced wavelength is itself a function of the frequency of the wave. The expression for L can be rewritten in terms of the period P of the wave.

$$L = \sqrt{(\lambda P/\pi c)}$$

This length represents, crudely and approximately, the distance into a surface that a wave will propagate in a time P. This distance is graphed for plasterboard in Figure 4.

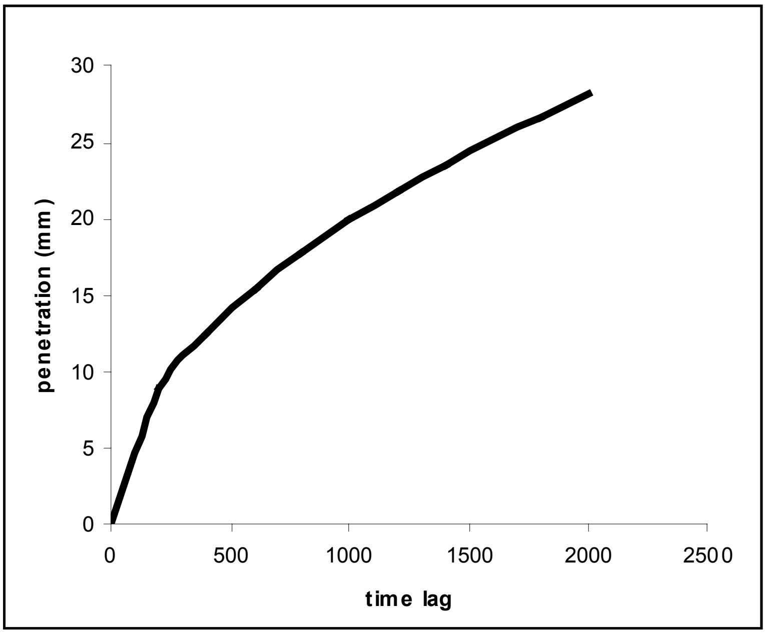


Figure 4. Penetration of thermal wave into plasterboard.

This analysis suggests following a call for heat from a room thermostat, the heat output from a heating system penetrates roughly 2 cm into the fabric of the building. This is deep enough to include the whole of the plasterboard thickness in a timber framed dwelling. Further analysis shows that flow of heat through the thermal insulation in a timber framed dwelling proceeds at much the same speed. In other words, over a period in which dynamic problems might occur, the dynamic thermal response of dwellings with 80 mm or more of thermal insulation will be independent of the precise thickness of thermal insulation.

It is possible to calculate an upper bound to the rise in internal temperature in such buildings following a call for heat from a room thermostat. This temperature rise is given by:

$$\Delta T = Q_{system}/c_{house}$$

where $c_{house}$ is the internal heat capacity of the dwelling. This consists of plasterboard on external and internal walls, plasterboard to ceilings, the surface of the first floor (approximately 2 cm of timber) and the first 2 cm or so of the ground floor slab. This heat capacity is independent of the level of thermal insulation of the dwelling. A crude calculation suggests the following contributions for a 90 $m^2$ dwellings:

| internal heat capacity of dwelling | A (m2) | heat capacity (MJ/K) |
|---|---|---|
| external walls | 135 | 1.6 |
| partitions | 210 | 2.5 |
| ceilings | 90 | 1.1 |
| first floor | 45 | 0.6 |
| ground floor | 45 | 1.1 |
| **total** | **525** | **6.9** |

Table 2. Contributions to the internal heat capacity of a 90 $m^2$ timber framed dwelling.

Table 3 shows the rise in internal temperature following a call for heat from the room thermostat for the two cases presented in Table 1.

| | boiler rating (W) | radiator rating (W/K) | transient temperature rise (K) |
|---|---|---|---|
| 4 kW | 10000 | 73 | 1.7 |
| 2 kW | 10000 | 36 | 1.0 |

Table 3. Pessimistic estimate of temperature rise in 90 $m^2$ timber framed dwelling following a call for heat from a room thermostat.

Conclusions

The results presented above show that, if anything, temperatures will be more stable rather than less in a very well insulated dwelling with an appropriately sized heat distribution system. The main reasons for this are:

- the heat capacity of a typical wet central heating system is determined mainly by the mass and hence the area of radiators;
- therefore the heat stored in the heating system that is available to drive a temperature overshoot falls as the insulation level increases, and the heating system shrinks;
- the transient thermal wave resulting from a call for heat from a room thermostat takes many hours to pass through the external envelope of the dwelling;
- the short term transient response to such a thermal wave is therefore dominated by the internal thermal mass of the dwelling;
- this internal thermal mass is independent of the level of thermal insulation in the envelope – for timber framed dwellings, it consists mainly of the layer of plasterboard on the surfaces of external walls, partitions and ceilings.

# Appendix 9 Thermal bridging heat loss calculator

**David Roberts** **November 2000**

This 'thermal bridging heat loss calculator' was written in Microsoft Excel and consists of several work sheets:

1) instructions
2) window and door dimensions
3) building dimensions
4) thermal bridge catalogue
5) U-value list
6) calculation page.

Data are entered for building dimensions, thermal bridging coefficients and U values at the appropriate entry points. A final worksheet shows the calculated heat loss through both fabric and thermal bridging. These worksheets are shown below:

**Instructions on how to use the 'Fabric and thermal bridging heat-loss calculator'**

written by David Roberts, November 2000

This Excel workbook can be used to calculate dwelling fabric heat loss and additional losses attributable to thermal bridging effects.

**In addition to this workbook you will also need:**
a) a set of fully dimensioned construction drawings for each house type
b) a thermal bridge catalogue
c) a list of U values
(However, for the purposes of the St Nicholas Fields project, the thermal bridge catalogue and list of U values are included here, for convenience.

As well as this introductory explanation worksheet, this Excel workbook contains several other worksheets:
*2) window and door dimensions; 3) building dimensions; 4) thermal bridge catalogue; 5) U value list; 6) calculation page.*

**Procedure:**

| | |
|---|---|
| Worksheet no 2: | Enter window and door dimensions using information from the drawings. |
| Worksheet no 3: | Enter building dimensions using information from the drawings. |
| Worksheet no 4: | Select the appropriate thermal bridging coefficient from the catalogue and enter this value in the calculation page (worksheet 6) against the appropriate construction detail. (This may seem laborious to transfer data from one sheet to another, but future thermal bridging catalogues are likely to be available in printed format). |
| Worksheet no 5: | Look up the U value for each building element and enter it in the calculation page (worksheet 6). |
| Worksheet no 6: | This is the worksheet where thermal bridging coefficients and U values are entered. For the purposes of the St Nicholas Fields project, these are listed in worksheets 4 and 5 respectively. The total fabric and thermal bridging heat loss for the dwelling will be calculated automatically. |

Figure 1: Instructions.

### Window and door dimensions

**Instructions:** Enter the height and width (in millimetres) of each window and door in the greyed boxes.
Areas and perimeters are calculated automatically.

| | Location | width (mm) | height (mm) | area (m2) | head length (m) | cill length (m) | jamb height x2 (m) | SUB TOTALS |
|---|---|---|---|---|---|---|---|---|
| **wall glazing:** | living | 1150 | 1050 | 1.208 | 1.150 | 1.150 | 2.100 | **total wall glazing area** |
| | kitchen | 1150 | 950 | 1.093 | 1.150 | 1.150 | 1.900 | **4.31** m^2 |
| | bed 3 | 1150 | 800 | 0.920 | 1.150 | 1.150 | 1.600 | |
| | bed 1 | 1150 | 950 | 1.093 | 1.150 | 1.150 | 1.900 | **total roof glazing area** |
| | …other location… | | | 0.000 | 0.000 | 0.000 | 0.000 | **3.04** m^2 |
| **roof glazing:** | bathroom | 800 | 950 | 0.760 | 0.800 | 0.800 | 1.900 | **total sunspace glazing area** |
| | roof room | 800 | 950 | 0.760 | 0.800 | 0.800 | 1.900 | **10.61** m^2 |
| | bed 2 a | 800 | 950 | 0.760 | 0.800 | 0.800 | 1.900 | |
| | bed 2 b | 800 | 950 | 0.760 | 0.800 | 0.800 | 1.900 | **total door area** |
| | …other location… | | | 0.000 | 0.000 | 0.000 | 0.000 | **4.00** m^2 |
| **Sunspace glazing:** | sunspace wall, front | 1975 | 2200 | 4.345 | 1.975 | 1.975 | 4.400 | **total head length** |
| | sunspace wall, side | 1050 | 2200 | 2.310 | 1.050 | 1.050 | 4.400 | **14.80** m^2 |
| | sunspace roof | 1975 | 2000 | 3.950 | 1.975 | 1.975 | 4.000 | |
| | …other location… | | | 0.000 | 0.000 | 0.000 | 0.000 | **total cill length** |
| | | | | | | | | **12.80** m^2 |
| **Doors:** | door, front | 1000 | 2000 | 2.000 | 1.000 | | 4.000 | **total jamb length** |
| | door, back | 1000 | 2000 | 2.000 | 1.000 | | 4.000 | **35.90** m^2 |
| | …other location… | | | 0.000 | 0.000 | | 0.000 | |

Figure 2: Window and door dimensions.

### Building dimensions

**Instructions:** Enter the relevant dimension for each construction element in the greyed boxes.
Some elements may require length, perimeter or area.

| building element | length (m) | Area (m^2) | notes: |
|---|---|---|---|
| **floors** | | | |
| area of ground floor | | 58 | |
| perimeter of ground floor | 26.4 | | |
| perimeter of first floor | 28.8 | | |
| **walls** | | | |
| area of external walls | | 114.4 | Ignore window and door openings as these areas will be subtracted automatically. |
| length of external wall - external wall junctio | 10 | | Measure the total length of the external corners of the building from floor to roof. |
| **roof** | | | |
| total area of roof | | 76.2 | Use actual area not plan area. Ignore windows as these will be subtracted automatically. |
| total length of gable wall roof junction | 11.9 | | |
| total length of eaves | 12.8 | | |
| External wall - party wall junction | 9.2 | | Measure the total ground to roof heights of external wall - party wall junctions. |
| Party wall - roof junction | 11.9 | | |
| ridge length | 5.4 | | |

Figure 3: Building dimensions.

## Thermal bridge catalogue, November 2000

**Instructions:**
For each construction detail, read off the corresponding thermal bridging coefficient and enter this value in the calculation page (worksheet no 6)

| Construction detail | Linear thermal bridging coefficient (w/mK) |
|---|---|
| External wall - external wall junction | 0.2443 |
| External wall - first floor joist junction | 0.0108 |
| External wall - ground floor junction | 0.1234 |
| Window cill reveal | 0.1473 |
| Window / door jamb reveal | 0.1374 |
| Window / door head reveal | 0.1622 |
| external wall / roof junction at gables | 0.1537 |
| external wall / party wall junction | 0.0614 |
| external wall roof junction at eaves | 0.0400 |
| roof junction at ridge | 0.0220 |

**Notes:**
The following coefficients refer only to construction details supplied by Phil Bixby for the St Nicholas Fields Housing project
U-factors for each detail were calculated by Therm modelling software for 'total length', 'projected X' and 'projected Y'.
The linear thermal bridging coefficients (for projected Y) are high-lighted in grey in column B and were calculated from:
[ U2d - U1d ] x (the length of the wall in metres). where: U2d = the U-factor of the detail (W/m2K) and: U1d = the U-factor of the wall

Figure 4: Thermal bridge catalogue.

## U values list

**Instructions:** This worksheet contains a list of U values for the St Nicholas Fields project.
Select the U value for each building element and enter this information in the calculation page (worksheet no 6).

| BUILDING ELEMENT | U-value (W/m2K) |
|---|---|
| Doors | 0.6 |
| Windows | 1.3 |
| Roof-lights | 1.3 |
| Ground floor | 0.25 |
| Walls (type 1) | 0.2013 |
| …other wall type… | |
| Roof (type 1) | 0.15 |
| …other roof type… | |
| …other… | |

Figure 5: U-value list.

## Calculation page

**Instructions:**
1) Enter the thermal bridging coefficient for each building element in the grey boxes.
2) Scroll down the sheet and enter the U value for each element in the blue boxes.
3) All other values are entered automatically
4) The total fabric and thermal bridging heat losses are shown in the pink boxes

| Construction detail | Linear thermal bridging coefficient (w/mK) | Individual thermal bridging heat losses (W/K) |
|---|---|---|
| External wall - external wall junction | 0.2443 | 2.443 |
| External wall - first floor joist junction | 0.0108 | 0.311 |
| External wall - ground floor junction | 0.1234 | 3.258 |
| Window cill reveal | 0.1473 | 1.885 |
| Window / door jamb reveal | 0.1374 | 4.933 |
| Window / door head reveal | 0.1622 | 2.401 |
| external wall / roof junction at gables | 0.1537 | 1.829 |
| external wall / party wall junction | 0.0614 | 0.565 |
| external wall roof junction at eaves | 0.0400 | 0.512 |
| roof junction at ridge | 0.0220 | 0.119 |

| TOTALS (W/K) | |
|---|---|
| Total thermal bridging heat loss | 18.26 |
| Total fabric heat loss | 59.59 |
| Total fabric and thermal bridging heat loss | 77.85 |

| Building element | U-value (W/m2K) | Individual fabric heat losses (W/K) |
|---|---|---|
| Doors | 0.6 | 2.400 |
| Windows | 1.3 | 5.606 |
| Roof-lights | 1.3 | 3.952 |
| Ground floor | 0.25 | 14.500 |
| Walls (type 1) | 0.2013 | 22.161 |
| …other wall type… | | |
| Roof (type 1) | 0.15 | 10.974 |
| …other roof type… | | |
| …other… | | 0 |

Figure 6: Calculation page.

(this page only contains the formulae for calculation and would not normally need to be seen)

| window area (m^2) | |
|---|---|
| total wall glazing area | 4.3 |
| total roof glazing area | 3.0 |
| total sunspace glazing area | 10.6 |
| total door area | 4 |
| total head length | 14.8 |
| total cill length | 12.8 |
| total jamb length | 35.9 |

| building dimensions | length (m) | Area (m^2) |
|---|---|---|
| area of ground floor | | 58 |
| perimeter of ground floor | 26.4 | |
| perimeter of first floor | 28.8 | |
| area of external walls | | 114.4 |
| length of external wall - e | 10 | |
| total area of roof | | 76.2 |
| total length of gable wall ı | 11.9 | |
| total length of eaves | 12.8 | |
| External wall - party wall j | 9.2 | |
| Party wall - roof junction | 11.9 | |
| ridge length | 5.4 | |
| wall area - window area | 110.1 | |
| roof area - window area | 73.2 | |

| thermal bridge catalogue | (w/mK) |
|---|---|
| External wall - external wal | 0.2443 |
| External wall - first floor joi | 0.0108 |
| External wall - ground floor | 0.1234 |
| Window cill reveal | 0.1473 |
| Window / door jamb reveal | 0.1374 |
| Window / door head reveal | 0.1622 |
| external wall / roof junction | 0.1537 |
| external wall / party wall jui | 0.0614 |
| external wall roof junction a | 0.04 |
| roof junction at ridge | 0.022 |

| U values | (W/m2K) |
|---|---|
| Doors | 0.6 |
| Windows | 1.3 |
| Roof-lights | 1.3 |
| Ground floor | 0.25 |
| Walls (type 1) | 0.2013 |
| …other wall type | 0 |
| Roof (type 1) | 0.15 |
| …other roof type | 0 |
| …other… | 0 |

Figure 7: Calculation section (not normally seen).

# Appendix 10  Original design drawings

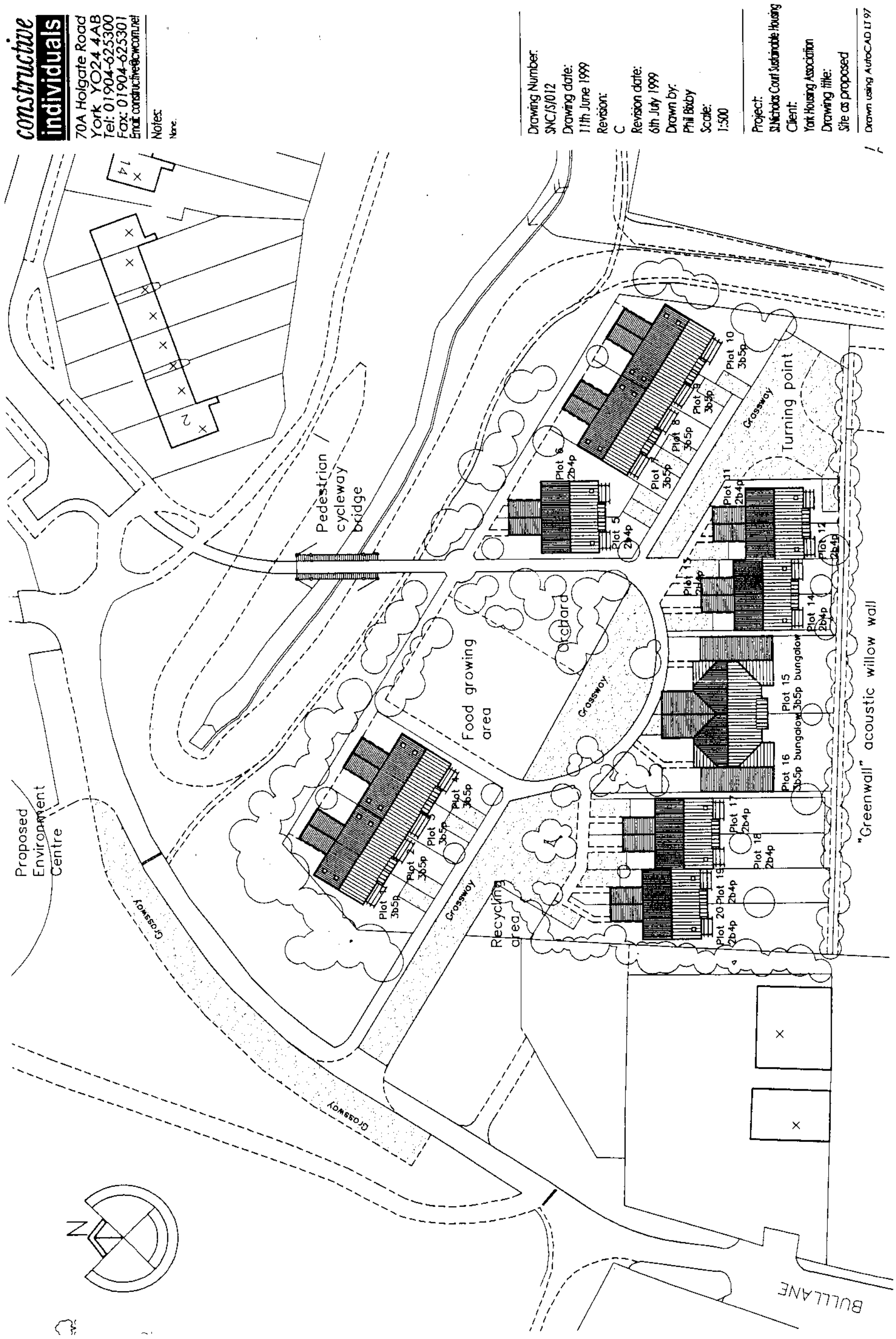


Figure 1: Original site plan.

Appendix 10

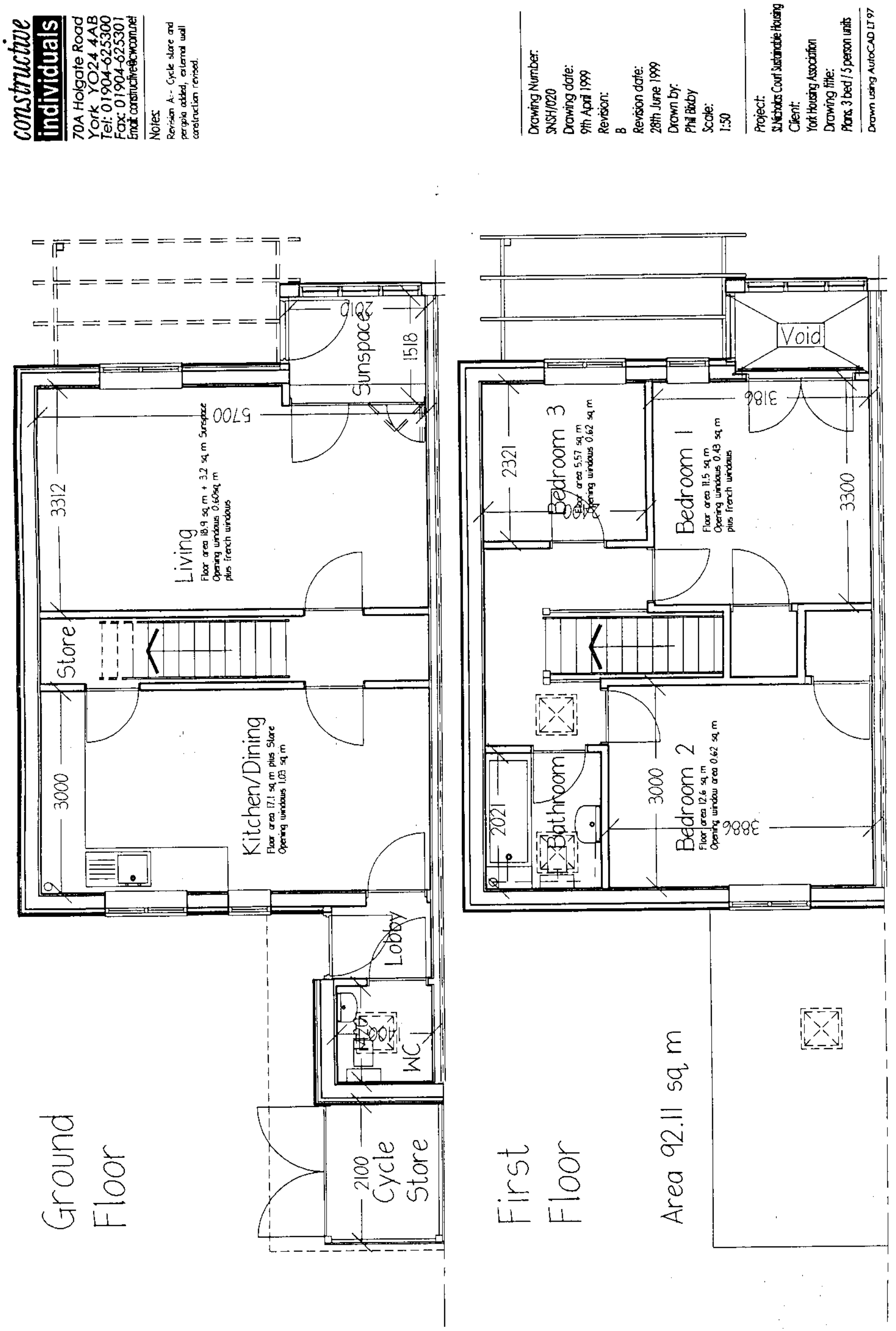


Figure 2: Original floor plan.

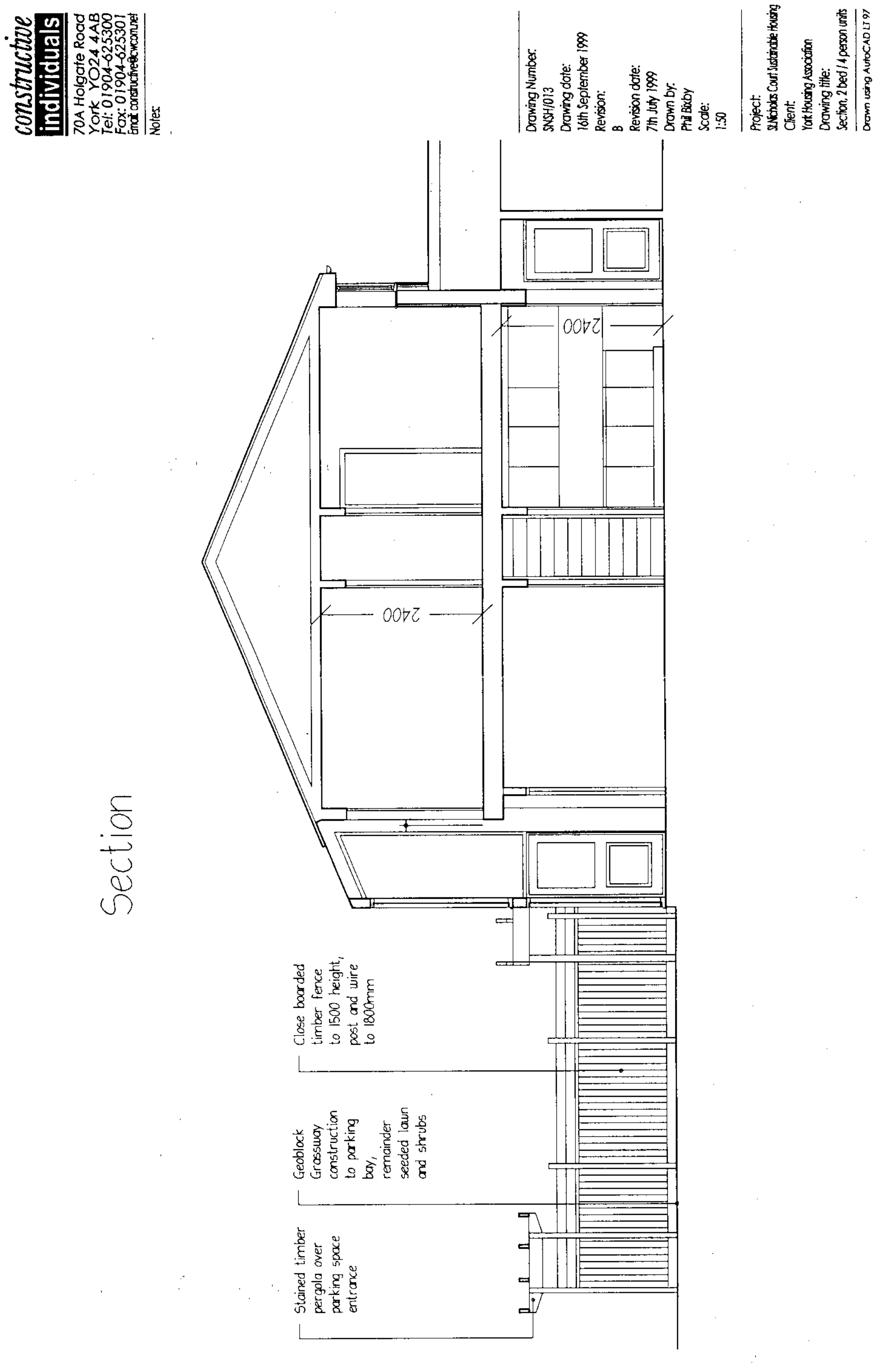


Figure 3: Original section.

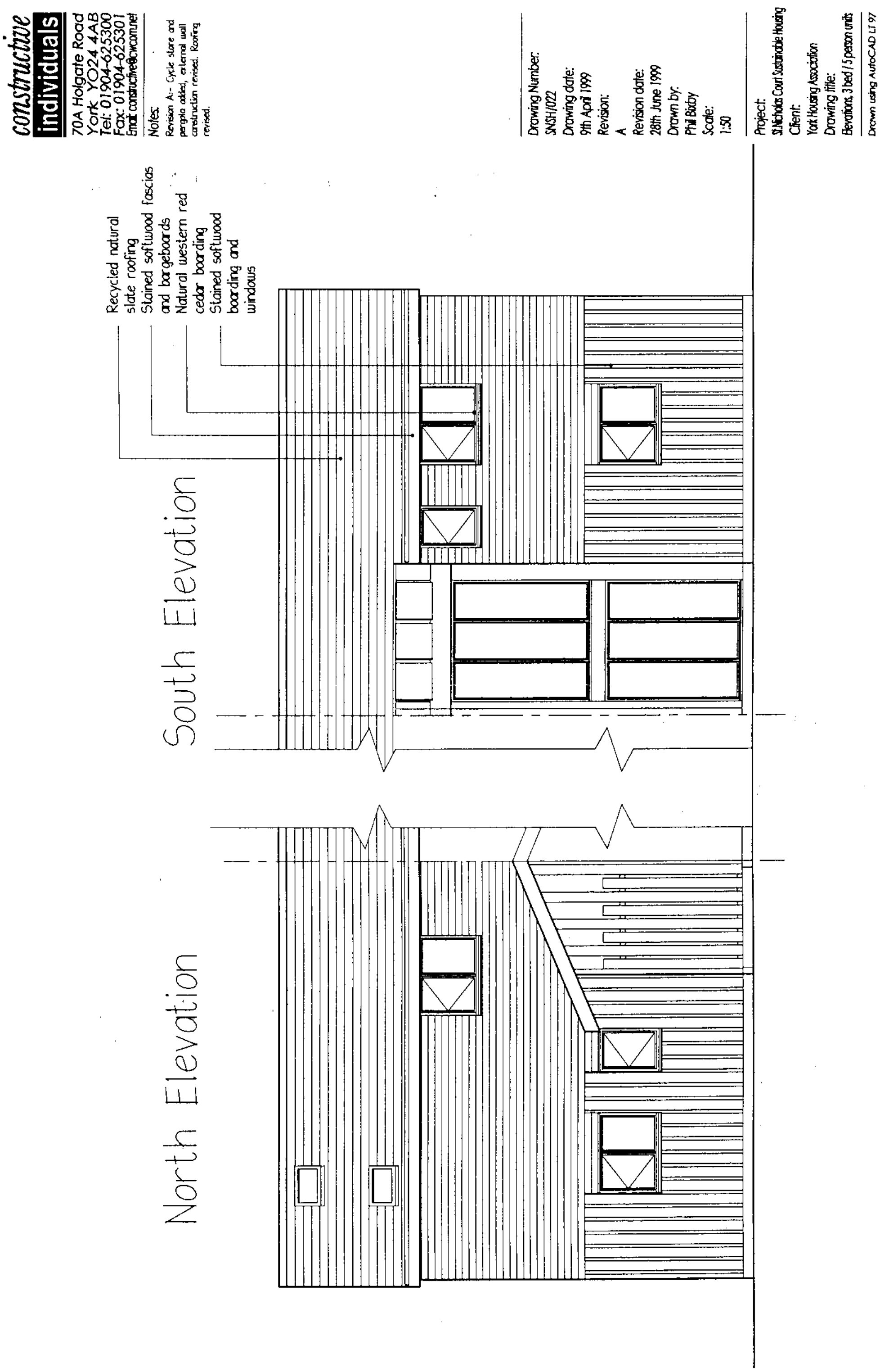


Figure 4: Original north and south elevations.

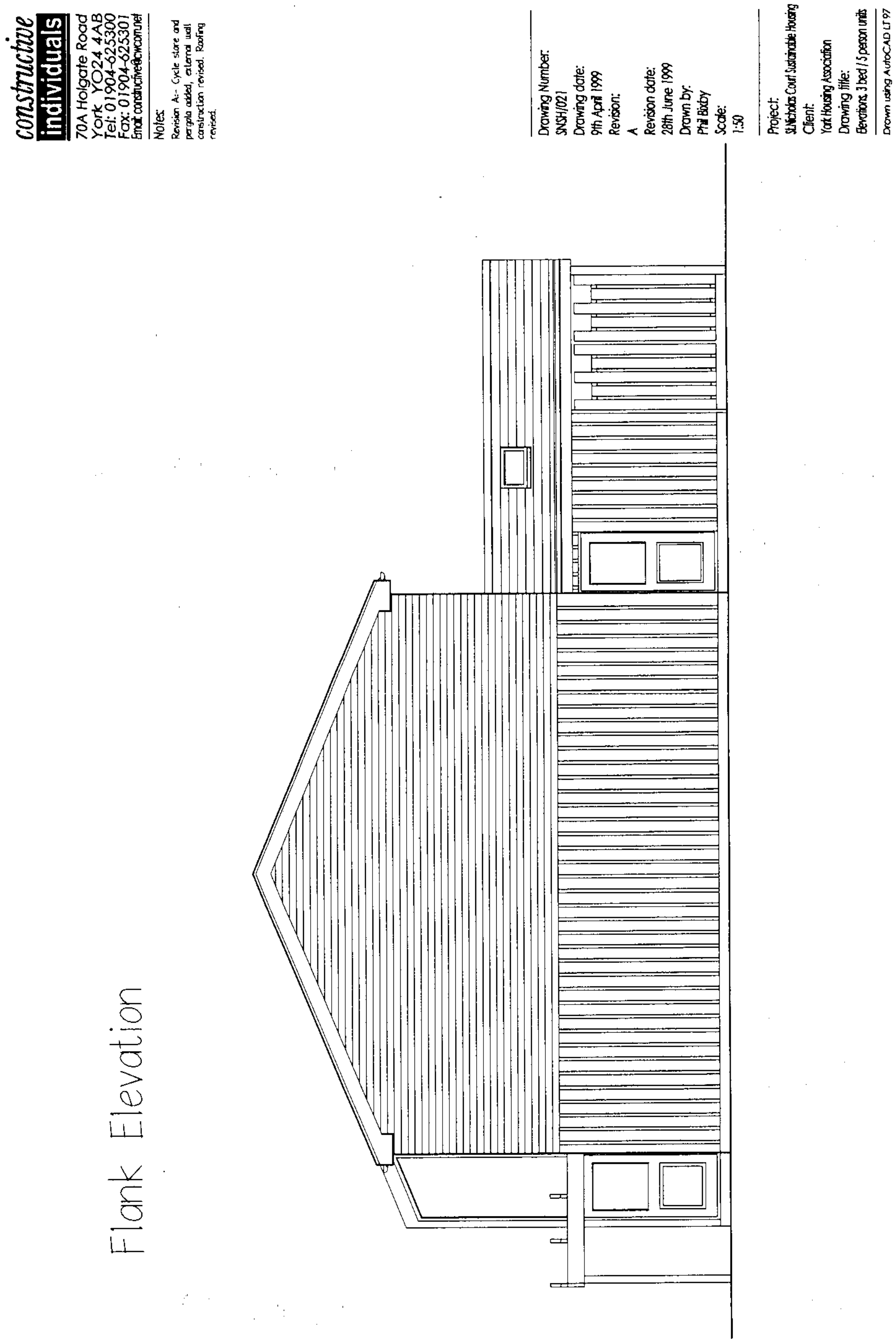


Figure 5: Original flank elevation.

# Appendix 11 Cultural dimensions to energy use

There follows a clip of a netmeeting conversation between Phil Bixby and his friend Pam who lives St. Louis, USA. Phil shared the conversation with the research team.

| | |
|---|---|
| Pam | Is there such a thing? I've heard of mud wrestling... |
| Phil | Probably, and if there is, it'll be in the US of A. |
| Pam | ...and jello wrestling... |
| Phil | Yerk. |
| Pam | ...land of opportunity... |
| Phil | Mm indeed. Got sent a link via the Greenbuilding mailing list to the current Doonesbury cartoon. |
| Pam | and.... |
| Phil | It's about the banning of washing lines in California - I'm kind of assuming it's true. |
| Pam | Washing lines? what are washing lines? |
| Phil | Drying clothes outdoors? |
| Pam | Clothes lines? |
| Phil | I'm worried now.. is it all of you??? |
| Pam | I haven't seen those in years anyway...maybe, down south more... |
| Phil | So how do you all dry clothes? |
| Pam | With a clothes dryer... |
| Phil | Hmmm. |
| Pam | ...hence the name.... |
| Phil | I was worried you may say that. Okay smartypants LOL! |
| Pam | How do you dry your clothes? |
| Phil | Erm... washing lines. |
| Pam | Hang them out for all the world to see? |
| Phil | Solar powered zero energy washing lines. We all do it, so no-one's too interested, not even in my undies. |
| Pam | Well I'd have to have about 100 yards of line... (editor's note - Pam has 6 kids). |
| Phil | True... you'd need a big yard |
| Pam | I would have to encircle my yard and the two next-door neighbors... |
| Phil | LOL but think of the privacy it would afford. |

Pam It's so much more private to walk into my utility room and throw the load into the dryer...

Phil Mmm okay.

Pam ...and whatever the hour of the night or day that I wish...and if it rains, I can still dry my clothes...really, I haven't seen a clothesline since I was probably about fifteen...

Phil It's fascinating how different our expectations are.

Pam ...in fact, at camp last year the kids were asked to bring a clothespin for something that they were going to be doing there....my boys had NO IDEA what a clothespin was.

Phil Wow... I emailed the line to the energy researchers who are working with us on the housing scheme. I got an email back saying "I guess this actually ISN'T a joke??"

Pam Not a joke at all...NO ONE in my neighborhood has a clothes line...

Phil As I say.. different expectations. Okay... something new learned today, I can relax now.

Pam I think it would be considered "sub-standard" and in bad taste any more...

Phil Uh-oh.

Pam ...but it does smell better...

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