AIR LEAKAGE STANDARDS

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1st. DRAFT 2/8/99

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SUMMARY

This report discusses how air leakage standards may be introduced into the UK Building Regulations. The current problem is outlined, including the very large contrast in air leakage between new UK buildings and those overseas. New UK housing is still as pervious to air as Swedish or Canadian housing built between the two World Wars, and leakier than the existing Swiss housing stock. Modern >tight= UK non-domestic buildings only seem to match >normal= Canadian and Norwegian buildings constructed in the mid 1970s.

The view is that a mandatory standard should be introduced and should be phrased as a maximum leakage per unit of thermal envelope area. The proposed level of the standard is:

1. BR-2001, #10 m^3/m^2hr @ 50 Pa;
2. BR-2005, currently termed *Good Practice*, #5 m^3/m^2hr @ 50 Pa;
3. BR-2010, currently termed *Very Good Practice*, #3 m^3/m^2hr @ 50 Pa.

The standard would apply to virtually all new buildings. In the housing sector, the current mean for new dwellings is around 9 m^3/m^2hr @ 50 Pa. On the available evidence, such a standard could affect at least 35-45% of new construction. A similar proportion of non-domestic buildings would need to be improved.

The timescale of introducing a standard is discussed. It should not be introduced until late 2001 because of the current lack of understanding within the industry and the limited testing facilities. It would come in as soon as logistical factors permit.

The main impact of BR-2001 would be to require a minority of very leaky buildings to be greatly improved, and to make air leakage an issue for the first time in the UK. Until testing is carried out, most parties believe that current practice is totally satisfactory.

A program to test a large sample of new construction in all regions should begin as soon as possible. The period after testing and before a legal standard would be used to show the industry that many practices now are unsatisfactory, but that with reasonable design and workmanship, it is possible to pass a modest standard from late 2001 onwards.

Some construction systems are intrinsically relatively tight; others are not but can be improved by better design and workmanship; other methods may have difficulty in meeting a demanding requirement. The report discusses what guidance should be issued to the industry to meet the requirements in BR-2001 and indicates which systems could be readily improved to meet BR-2005 and BR-2010. The proposals for BR-2005 and -2010 would set more demanding standards and start to move new UK construction into the same air leakage range as other cool and cold countries. Recommendations for further work are made at the end of the report on *Standard Details*.

The current guidance in *AD-L* is discussed. It is felt that the list of measures given there is too limited. Suggested text to replace it would cover thermal envelopes as one issue and is provided as a section of the report on *Standard Details*.

The implications of an air leakage standard extend beyond Part L into other parts of the Regulations; e.g., J. The different sections must be harmonised. The necessary ventilation guidance and requirements would not be significantly altered by the proposed air leakage limit in BR-2001 but further ventilation measures would be needed in BR-2005 and beyond.

INTRODUCTION

Uncontrolled air leakage through building envelopes is a topical problem in the UK, but awareness of the problem goes back a long time. Tests in the USA in the 1920s showed the measured rate of air leakage under pressure through many types of plastered clay brick wall and several rendered and timber-clad timber-frame walls. Those authors cited still earlier work in Germany on masonry walls. Some research also took place in Canada in the early 20th. century.

After the 1973 oil crisis, further research in North America, Scandinavia and later, mainland Europe showed that the air leakage of buildings could be decreased almost to zero. These reductions in leakage required major improvements in detailing and workmanship throughout the polyethylene air-vapour barrier in dry construction; e.g., timber- and steel-framed buildings.

Ironically, the starting point was that these systems were intrinsically quite prone to leaks, but lightweight framed building construction was given so much attention and testing abroad that the best examples became extremely tight. A 1981 development of timber houses in Canada still holds the world record for low air leakage.

The improvement required significant changes to detailing in heavyweight load-bearing buildings. Overall, the extra demands placed on workmanship and inspection were less onerous than with lightweight construction. The end result was that from 1980, the 'best practice= air leakage standards in some countries were < 0.15 m^3/h per m^2 of envelope area at a 50 Pa pressure difference (m^3/m^2hr @ 50 Pa) for finished timber and concrete buildings and < 0.2 m^3/m^2hr @ 50 Pa for masonry.

To put matters into context, this standard is 60-70 times more demanding than any requirement which is likely to be considered in the UK in the near term for application to new buildings. It is 15-20 times tighter than the 1978 Swedish requirement.

Construction methods appear to fall into three classes:

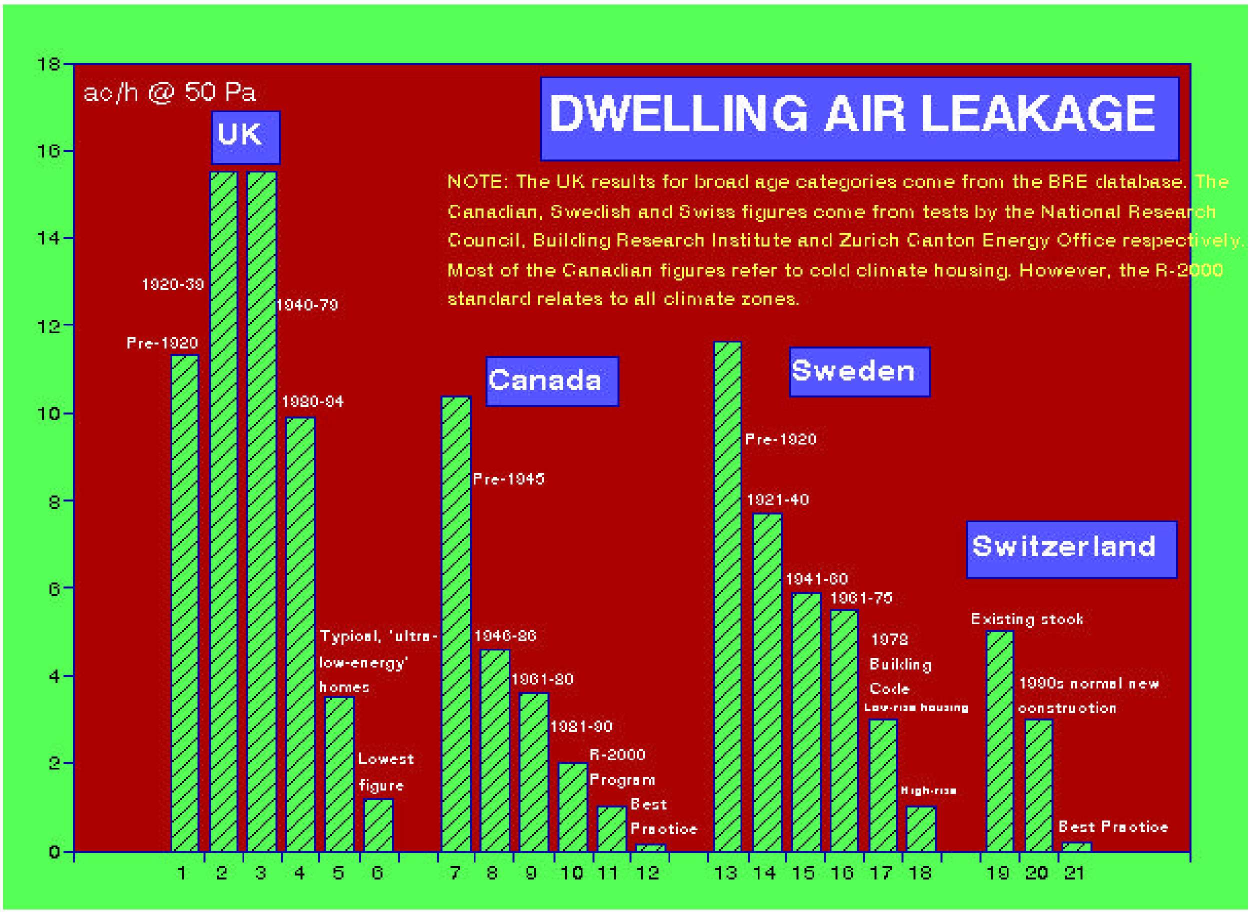
1. Intrinsically leaky even if they are constructed with good to excellent workmanship.
2. Usually leaky if built without care, but capable of being re-designed and made to meet a very good standard, which usually depends on training and workmanship;
3. Intrinsically tight, although often capable of further improvement.

Methods 1 may have difficulty in meeting a mandatory leakage requirement and could have to be modified considerably. This happened in Sweden and Norway between about 1975 and 1981. There was no requirement to use any particular technique; the industry was driven by the emerging performance requirement. Enough field testing was done *before introducing the standard* to show that some building methods were not easily well-sealed, and they were mostly phased out. The methods retained fell into categories 2 and 3 above as they are all made very tight if required:

1. *In situ* and precast concrete or large calcium silicate elements;
2. Solid and cavity masonry with concrete intermediate floors - in those countries, all in situ concrete or precast concrete planks;
3. Timber- and steel-frame with *continuous and reasonably well-sealed* air or air-vapour barriers. A range of techniques and materials have been developed.

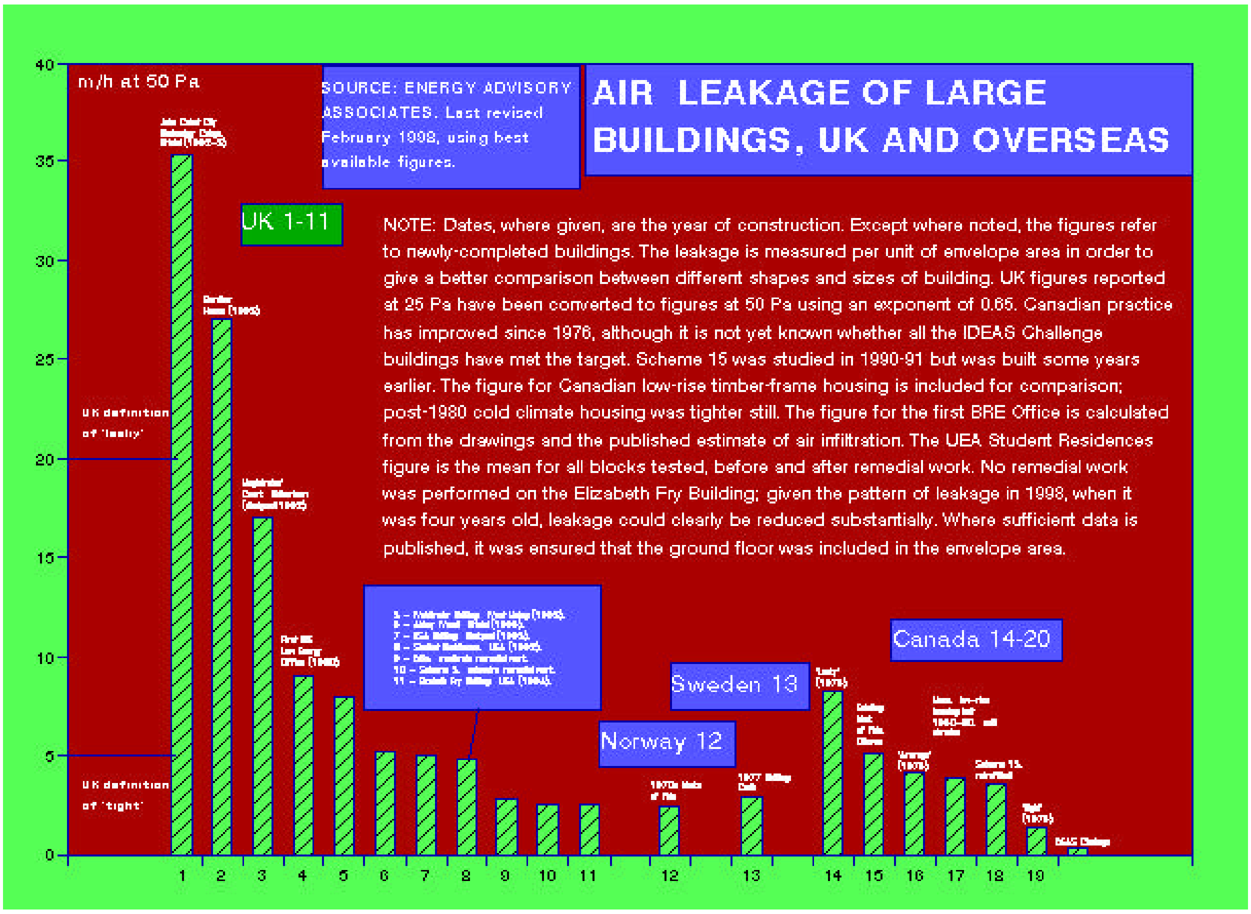
THE UK SITUATION

There are widespread misconceptions that new UK buildings are built to a high standard of airtightness. The attached graphs should bring this into perspective. Figure 1 shows housing air leakage by age of construction in the UK, Sweden, Switzerland and Canada.



NOTE: The UK results for broad age categories come from the BRE database. The Canadian, Swedish and Swiss figures come from tests by the National Research Council, Building Research Institute and Zurich Canton Energy Office respectively. Most of the Canadian figures refer to cold climate housing. However, the R-2000 standard relates to all climate zones.

Figure 2 shows some envelope leakage figures for larger buildings.



AIR LEAKAGE OF LARGE BUILDINGS, UK AND OVERSEAS

SOURCE: ENERGY ADVISORY ASSOCIATES. Last revised February 1998, using best available figures.

NOTE: Dates, where given, are the year of construction. Except where noted, the figures refer to newly-completed buildings. The leakage is measured per unit of envelope area in order to give a better comparison between different shapes and sizes of building. UK figures reported at 25 Pa have been converted to figures at 50 Pa using an exponent of 0.65. Canadian practice has improved since 1976, although it is not yet known whether all the IDEAS Challenge buildings have met the target. Scheme 15 was studied in 1990-91 but was built some years earlier. The figure for Canadian low-rise timber-frame housing is included for comparison; post-1980 cold climate housing was tighter still. The figure for the first BRE Office is calculated from the drawings and the published estimate of air infiltration. The UEA Student Residences figure is the mean for all blocks tested, before and after remedial work. No remedial work was performed on the Elizabeth Fry Building; given the pattern of leakage in 1998, when it was four years old, leakage could clearly be reduced substantially. Where sufficient data is published, it was ensured that the ground floor was included in the envelope area.

The housing figures are available in units of air changes per hour at 50 pascals (ac/h @ 50 Pa), but not in m^3/m^2 hr @ 50 Pa. The UK figures extend up to 1994; there is some limited evidence to indicate that the situation has improved slightly since then. The non-domestic figures were prepared before the extra information emerged which is published in the *Draft CIBSE Technical Memorandum* TM23:1999.

Figures 1 and 2 convey the impression that what is >tight= in the UK is >normal= in those three countries - that ***new UK housing is as pervious to air as Swedish or Canadian housing built between the two World Wars***. The new UK dwellings appear to be leakier than the existing Swiss housing stock built before 1990. The modern >tight= UK non-domestic buildings only seem to match >normal= cold-climate buildings constructed in the 1970s.

Despite the recent discussion of air leakage, new buildings constructed without a compliance target continue to under-perform. A good case of the gap between expectation and reality is some recent 100% timber-frame attached houses in northern England. An initial test showed 9.5 ac/h @ 50 Pa. The originally specified leakage was #2 ac/h @ 50 Pa, so they missed the target by a factor of five. They finally reached 5-6 ac/h @ 50 Pa with some difficulty.

Three small countries, Norway, Sweden and Finland, set limits to air leakage in new buildings. A few jurisdictions in the northern USA; i.e., individual counties or cities, set legal limits. Parts of Switzerland plan legislation, but new Swiss houses and other buildings are so well-sealed that this requirement could lag current practice. This is common with Building Codes abroad.

Canada set very high standards in 1980 and is exploring even higher ones, but only as part of voluntary programs including R-2000, IDEAS Challenge and others. These programs have set the world=s tightest leakage limits ever aimed for. IDEAS Challenge set a target envelope air leakage of 0.15 m^3/m^2hr @ 50 Pa after NRC=s research showed that leakier buildings were at risk of premature structural deterioration. However, there is no legal limit on leakage in ordinary new Canadian buildings.

In cold climates, however, such as Finland or central Canada, leaky buildings are almost unknown because they cause extreme user discomfort. From the observed practice in different parts of Canada, whose climate varies from mild to severe, the evidence is that while the buildings in the cold climates are subject to 50% more total degree-days than the buildings in the temperate climates, until the problem was drawn to the industry=s attention the cold climate buildings were typically built with *a third* the air leakage of those in the temperate zone.

In purely energy cost terms, the cold climate builders appear to have overcompensated. One might argue that we need more pressurisation testing in temperate climates. This is *precisely because* it is one of the few effective tools which such regions have to limit the number of construction defects.

It would be unnecessary to test buildings if designers and builders understood which measures were effective and which were not, and then applied this knowledge. This situation largely applies in Sweden and Norway and in parts of Canada and the USA and, with different construction techniques, in Switzerland, but the strategic knowledge is almost absent from UK site practice and from design offices. The access to such information, and the need to implement it, would enable the UK to move forward much more rapidly.

UNDERSTANDING AND AWARENESS

There are many reasons why UK air leakage figures are still so high. One clearly is that most designers and builders still believe that their current practices are wholly satisfactory, and are genuinely surprised when field tests show otherwise. Typically, there is a lack of sound design details, reasonable to rather poor site workmanship and total ignorance of the principles of airtightness on the part of site management, so supervision is sketchy or ineffective.

Misconceptions also abound in the design community. For instance, it is widely believed that materials such as mineral and cellulose fibre alone can block the air leakage. It was pointed out by scientists in Canada many years ago that these materials are used as air filters in mechanical ventilation systems. They are largely ineffective in blocking the air movement although they may slow and filter the air! Dark stains in the existing insulation, representing accumulated dust, are indeed used in Canada in retrofit work to trace the main leakage paths followed by the air as it enters the attic.

Most people believe that lower air leakage in masonry buildings must rely primarily either on better workmanship, like fully filling the perpends, or on greater attention to detail on site. It still seems almost unknown, despite papers in the English language being published in the USA in the 1920s, and an extension of this work in the UK in the 1990s, that plaster on masonry walls makes them airtight to a high standard but that plasterboard linings on the same walls have much less benefit.

We can take it that few in the UK construction industry have witnessed a pressurisation test. To see air disappearing into invisible gaps between two elements in the building, where the design did not specify a seal and therefore where the workforce did not install one, has a salutory effect on design teams as well as on tradespeople.

The misunderstanding and/or complacency is accentuated by the UK=s moderate winter temperatures, at least in southern England - see appendix. There is a clear parallel with other mild winter climates such as the north-west USA, where the air leakage of timber-frame houses was high until recently, sloppy practices were tolerated and occasional figures >20 ac/h @ 50 Pa still occur.

In the phase-in to a mandatory air leakage standard, increased field testing, witnessed by all parties, is the key requirement. This will vividly highlight the gross deficiencies seen now and thus catalyse improvements in design standards, construction practices and the ways in which suppliers incorporate their packages into the overall building envelope.

STANDARD OR APPROVED DETAILS?

Several experts were asked whether approved or recommended construction details could be used in some sort of guide, with the specific aim being to improve airtightness. They all agreed that people need guidance on what details to avoid, what is relevant, what problems to anticipate, etc. One UK expert who tests many buildings expressed concern that good practice guidance in the past has been misread as a comprehensive instruction manual. For instance, the building of some airtight details can usually only be shown on paper in two dimensions, whereas it has to be considered and built in three dimensions, especially in complex-shaped buildings.

Two experts said that one problem is the position of trade bodies who have a commercial interest in one particular product or system, and may publish details. They may know that there will be grave problems in achieving low as-built air leakage but, understandably, they still promote it.

The author feels that the existing Canadian, Swedish and US publications answer the objection that authoritative guidance may be mistaken for a detailed instruction manual. They draw the three-dimensional details of air sealing very clearly. In the author=s view, such publications are of use to large design firms and the larger builders but more comprehensive instruction can only come from hands-on builder or designer training. Small builders or some design firms do not necessarily read reference manuals; they may only be reached by site visits or seminars attended by their peers.

Given the extremely low air leakage of certain construction systems, we should be able to reduce the frequency of testing buildings whose details have been tested and certified as being tight despite the vagaries of site conditions. These are mainly forms of all-wet construction with plastered masonry or concrete walls and concrete roofs.

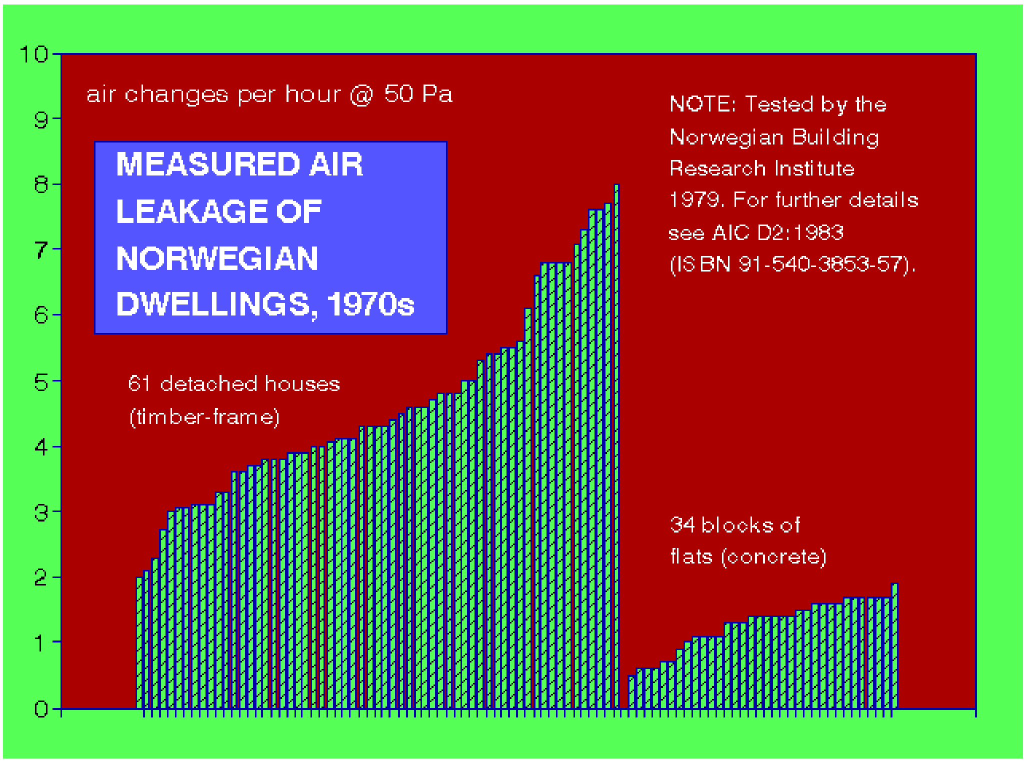
IMPACT OF CONSTRUCTION SYSTEMS

Other things being equal, we must stress that masonry and concrete buildings overseas are usually tighter than timber-frame and steel-frame ones. Many countries consider it historical fact that >wet= techniques, with concrete upper floors, have *fewer* leaks than timber-framed buildings and other >dry= construction. In situ concrete buildings can even >default= to fairly airtight by UK standards, with envelope air leakage in the range 3-5 m^3/m^2hr @ 50 Pa.

For large samples, it is probably best to look to other countries. To show the apparent influence of wet vs. dry construction, Figure 3 shows the air leakage of a reasonably large sample of timber-frame houses and concrete flats built in Norway in the period 1974-78. They were all measured in 1979. One presumes that on a large sample, the average standard of workmanship on the houses was not dissimilar to the flats.

A limitation is that Figure 3 for houses and apartment buildings shows leakage per unit volume, not per unit of envelope area. The flats would have perhaps half as much envelope area per unit volume. Nevertheless, even if the figures were converted to leakage per unit envelope area basis, one can expect that the >wet construction= flats would still have substantially less leakage than the >dry 5. construction= timber homes.

Swedish tests showed the same relationship. The large-element concrete housing was slightly tighter than the dwellings of plastered brick masonry, which in turn were tighter than the timber-frame.


MEASURED AIR LEAKAGE OF NORWEGIAN DWELLINGS, 1970s

NOTE: Tested by the Norwegian Building Research Institute 1979. For further details see AIC D2:1983 (ISBN 91-540-3853-57).

The contrary view seems to prevail widely in the UK - namely, that masonry construction is inherently leaky and that reduced leakage needs development of new details. This seems to reflect two special factors which are peculiar to the UK. Government and industry would have to give these careful consideration if air leakage becomes a regulatory issue.

The first factor is the high air leakage of UK masonry houses in which the industry has attempted to replace wet plaster by plasterboard and solid partitions by lightweight ones, and thereby achieve its ideal of >dry= construction. A trend from >wet= to >dry= has also occurred in non-domestic construction, seemingly because the design team saw that a time saving would result from dry construction but were unaware of the adverse air leakage implications.

The rest of Europe still uses plaster as an internal finish to all masonry walls. North America uses a separate membrane as the air barrier in tall masonry construction. This means that satisfactory results can be obtained and that the internal >drywall= finish no longer plays much of a role in achieving airtightness.

The second special factor is the continuing prevalence of timber upper floors - a dry form of construction - in UK low-rise masonry buildings. Most of the rest of Europe adopted *in situ* concrete intermediate floors in masonry buildings - even in 1.5- and two-storey houses - many decades ago. In the UK, concrete intermediate floors are quite >normal= between separate flats and in offices, but they are considered >non-traditional= in low-rise housing.

The BRE domestic air leakage database was not constructed for the purposes of this work and therefore does not permit us to separate out samples which are identical but for having three different wall finishes - plastered masonry; masonry lined with plasterboard; and timber-frame, usually with a polyethylene air-vapour barrier behind the plasterboard. However, almost all the modern masonry houses in the BRE database are dry-lined and the complete absence of an effective air barrier may explain their very high leakage compared to other categories.

A key point here, which such databases emphasise, is that the UK timber-frame industry is keenly aware that low air leakage is important and achievable. By contrast, the UK trade bodies concerned with masonry seem to be poorly aware of either point and labour under the misconception that masonry buildings are *intrinsically* less energy-efficient and leakier than timber-framed. This may lead to a position that proposals to improve *all* construction should be resisted and that any market which does develop for energy-efficient construction should be left to timber-frame.

PHRASING OF THE STANDARD

It is recommended that the UK standard is phrased in terms of allowable maximum leakage per unit of thermal envelope area. The building thermal envelope is the logical area over which to normalise air leakage measurements. Its usual definition is the combined area of all the elements which separate a conditioned space from an unconditioned space.

It is generally agreed that the envelope area of buildings should include obviously permeable elements, such as suspended timber ground floors above crawlspaces. However, a complete lack of consensus has emerged over whether envelope areas should include ground or basement concrete floors, or basement walls.

The current UK definition of non-residential building envelope area excludes concrete ground floors. The tests on UK dwellings and overseas tests on all building types include the ground floor area in the thermal envelope irrespective of whether it is very tight and built of *in situ* concrete or leaky and built of timber. The arguments on both sides can be summarised as follows.

The proponents of excluding the ground floor and sometimes the basement walls feel that we should only include ground floors when they are suspended and when they are obviously permeable. They believe that the other disadvantage of including the floor would be that we cannot use the existing non-domestic database - hitherto, all the UK measurements excluded ground-bearing slabs from envelope area. If the convention is changed, we would need to quote both figures for a limited time, with and without the ground floor, to permit comparison of test results on new buildings with the rest of the non-domestic database.

The proponents of including the ground floor feel that it is far from obvious to the uninitiated, including building control officials, whether floors are permeable or not. Canadian experts share this opinion and are adamant that they regularly see measurable air leakage even through concrete basement slabs, at service entries and other points which the UK has hitherto ignored.

To exclude such floors could give designers a perverse incentive to use suspended floors. This is because the resulting buildings could then have *lower area-normalised leakage*. Yet their total air leakage could be *raised*. A policy merely to eliminate elements from the envelope area because they are fairly tight could also be applied to concrete walls, plastered walls and concrete roofs; it seems a recipe for anomalies and for arbitrary misinterpretations of the rules. Nor do such figures allow like-for-like international comparisons, which can show how well we are doing.

The air leakage standards proposed here - £10, 5 and 3 in units of m^3/m^2hr *@ 50 Pa - assume that we include the ground floor*. If we exclude it, higher area-normalised leakage rates would be permitted because the envelope area is reduced. If the issue is to be resolved now; there is a small majority that we should always include the ground floor. If we want a consensus, further discussion is needed between different UK experts who are active in this field and obviously see test evidence from completely different buildings.

The procedure should be to carry out all tests at 50 Pa. There is merit in the rule that the UK should always follow the practice of countries earlier to a field, unless the proposed UK method offers such major advantages that the other countries are likely to see reason to change. This also reduces the impact of wind- and stack-induced pressure differences during the test. Some UK buildings are so leaky that a moderate-sized fan allows them to be (de-)pressurised to 25 Pa but not 50 Pa.

Tighter buildings, with a maximum envelope leakage of 10 m^3/m^2hr @ 50 Pa rather than the 30-35 maximum we see now, greatly reduce this problem.. If there are still some very large buildings which cannot be tested with the largest fans in the country, they can be tested at 25 Pa in sufficiently calm weather. The flow would then have to be extrapolated to 50 Pa, using an agreed power law, and the leakage at 50 Pa published.

On small buildings, it is conceptually simpler to set a maximum leakage per unit volume; i.e., a number of air changes per hour at 50 Pa. This is often quoted for housing. Two experts favour continuing with this. However, this would permit large buildings, which are often taller, to be built with leakier envelope areas. This is because large buildings have less surface area per unit volume.

As Table 1 below shows, regulating on a volumetric rather than envelope area basis would be difficult and would require more improvement from current practice in small one- or two-storey houses than in high-rise flats or offices. Yet tall structures are usually exposed to much greater wind and stack effects than low-rise ones. The stack effect alone at UK design temperature may give rise to a pressure differential of 50 Pa between bottom and top of tall buildings, although flats with *in situ* concrete intermediate floors, which are almost airtight, would tend to behave as a set of single-storey enclosures rather than as a single high enclosure.

Another possibility is to phrase the maximum in units of ac/h @ 50 Pa but set successively lower maxima on medium-rise and tall buildings to compensate for the reduced envelope area per dwelling and the increased stack and wind effects. Norway still uses this approach. However, it tends to introduce anomalies.

Sweden did the same as Norway for a time, with three different figures for low, medium and tall buildings - 1, 2 & 3 ac/h @ 50 Pa - but it later changed to a maximum permitted envelope air leakage. This is 0.8 and 1.6 l./s.m^2., equivalent to 2.88 and 5.76 m^3/m^{2}hr. @ 50 Pa, for residential and non-residential buildings respectively.

Single-storey industrial buildings are leakier than other typical non-domestic buildings. A laxer standard would be reasonable where these premises are clearly to be heated to lower temperatures or where they have a permanent heat surplus from processes, but there is no reason to have laxer standards on industrial offices. These offices tend to have outside walls and are normally heated as well as any other office.

There is no ideal, but regulating on an area-normalised basis, m^3/m^{2}hr @ 50 Pa, at least requires all envelopes of heated buildings to be tightened equally. The tightness achieved on low-rise housing can then readily be compared to flats and offices. It was a valuable lesson in some countries to be readily able to compare the two and to see that low-rise timber-frame houses had apparently become tighter than large buildings.

Building Type	**Floor Area**	**Dimensions**			**Volume**	**Envelope Area**	**Air Leakage** @ 50 Pa		
	m^2	m (width x length x height)			m^3	m^2	Definition	ac/h	m/h
Detached bungalow	90	7.5	12	2.5	225	277.5	Leaky	16.0	13.0
							Average	9.0	7.3
							Tight	5.0	4.1
Semi-detached house	100	6.25	8	5	250	242.5	Leaky	13.5	13.9
							Average	9.3	9.6
							Tight	4.0	4.1
Small four-storey block of flats	1200	30	10	12	3600	1560	Leaky	8.0	18.5
							Average	4.8	11.1
							Tight	1.6	3.7
Eight-storey office block	5000	50	12.5	30	18750	5000	Leaky	7.0	26.3
							Average	3.5	13.1
							Tight	1.2	4.5

Table 1. Relationship between Alternative Units for Regulating Air Leakage

NOTE: Typical leaky, average or tight by current UK standards.

A final possibility is to set a limit of ≤10 m^3/m^{2}hr or 10 ac/h in 2001, whichever is the lower. As Table 1 indicates, the rule would largely affect small detached bungalows with an extremely high surface area to volume ratio. These single-storey buildings are probably the least influenced by buoyancy and wind effects, and their expected air infiltration over a season is lower than two-storey houses for a given leakage in ac/h @ 50 Pa. It seems a needless complication.

When attached buildings are tested, either the adjacent building(s) should be pressurised or a correction should be made for this effect. Otherwise there is a risk that buildings which should actually pass will fail because of air leakage through the separating wall. However, such air leakage is highly undesirable in any case - it compromises acoustic and fire performance and leads to leakage of cooking smells and cigarette smoke between dwellings - and should be minimised. Several separating wall constructions currently shown in Part E appear to be in need of urgent improvement if the objective is minimal air movement between attached buildings.

At present, we see air leakage UK tests on small buildings being carried out to CGSB 149-GP-10, SS 021551, the BRE Recommended Procedure and others. We see envelope areas of dwellings being defined to include the party wall or just the actual heat loss area and we see envelopes of large non-domestic buildings being quoted to exclude the ground floor, but small ones include it.

Some large buildings in the early 1990s are known to have been tested with the concrete ground floor included in the envelope areas. We do not know where the boundary is drawn between small and large buildings. We see de-pressurisation tests only, and we also see the average quoted of pressurisation and depressurisation. In some tests the extract fans are sealed up and in others the fans= dampers are relied upon - not always successfully.

One tester expressed dissent at the ISO suggestion that a tracer gas test be carried out to validate the result of the pressurisation test. He considered that the UK document which is issued to govern test methods must include guidance on dealing with wind and stack effects and must state how to conduct tests under varying restrictions; e.g., local microclimates make fan testing difficult even when the weather forecast states suitable conditions. Areas of dark paving and dark roof create local thermals which generate small but significant wind effects around buildings

These different assumptions and procedures have already crept into UK testing and mean that many UK test results are not in fact capable of like-for-like comparison. This must be settled immediately if UK air leakage testing is to become routine.

Another matter is whether the envelope area is defined as extending to the internal faces of the external walls, roofs, etc, the mid-points or the external surfaces. The external surfaces of buildings are used for heat loss calculations on the continent. In current tests, it is not uncommon merely to ask a design team member for the envelope area and receive a figure which is produced from a cursory inspection of the drawings. It can be wrong either way by 10-25%.

The envelope area in future will become potentially a critical, pass-or-fail matter. Precisely-agreed procedures must be issued and the envelope area must either be independently-calculated by every tester or subject to random checking. Again, there is an overwhelming case for the UK setting down a list of procedures which reflect the existing consensus in the countries which came first to the field - Canada, USA, Sweden, Norway, Finland and Switzerland - and *not* inventing its own.

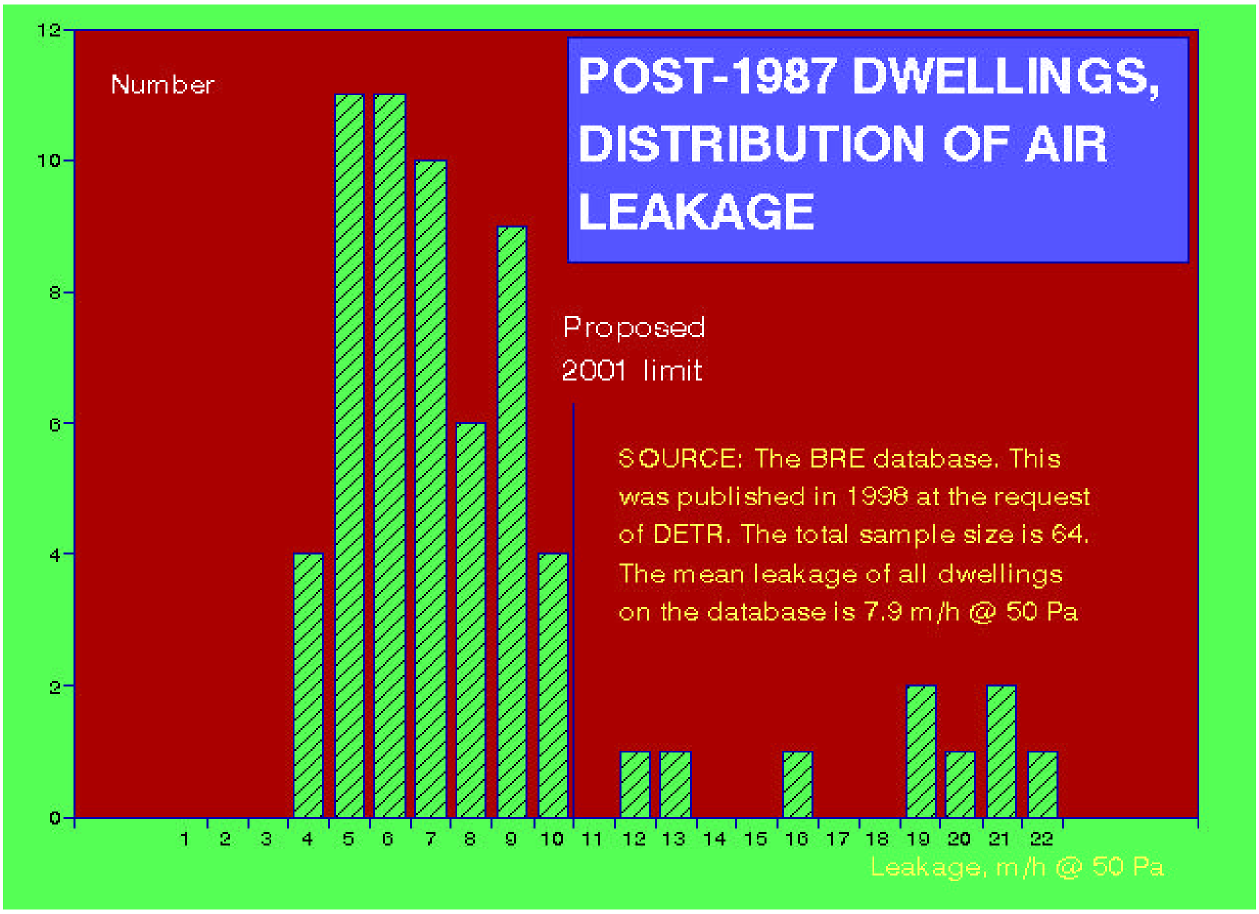
LEVEL OF THE STANDARD

The proposals for years 2001, 2005 and 2010 are given earlier in the section on proven and effective construction details, with suggestions of envelope leakage standards to be adopted as:

1. BR-2001, #10 m^3/m^2hr @ 50 Pa;
2. BR-2005, currently termed *Good Practice*, #5 m^3/m^2hr @ 50 Pa;
3. BR-2010, currently termed *Very Good Practice*, #3 m^3/m^2hr @ 50 Pa.

These would result in the UK having to meet almost the Swedish/Norwegian 1978/1981 air leakage standards by the year 2010. These standards must be introduced in stages, with a clear timetable laid down for what the industry needs to achieve.

Figure 4 shows the published 1998 BRE database of post-1987 housing and the proposed limit which would be introduced in BR-2001. On the BRE database, mean envelope air leakage for post-1987 housing is 7.8 m^3/m^2h @ 50 Pa, but the definition of envelope area includes separating walls. Making assumptions about a representative dwelling in the sample, BRE experts and the author agree that mean envelope leakage would be nearer to 9 m^3/m^2h @ 50 Pa. The sample size is small. BRE's recent evidence suggests that the situation now is not materially better or worse; i.e., improvements since Part L of 1995 have probably been small or minimal.


POST-1987 DWELLINGS, DISTRIBUTION OF AIR LEAKAGE

SOURCE: The BRE database. This was published in 1998 at the request of DETR. The total sample size is 64. The mean leakage of all dwellings on the database is 7.9 m/h @ 50 Pa

On this evidence, a limit of #10 m^3/m^2hr @ 50 Pa in 2001, which is slightly above the current mean, would probably rule out 35-45% of current housing practice. If Figure 4 is to be published, which would be useful, BRE needs to be commissioned to normalise these figures to *thermal envelope area* and to add the unpublished results for random samples of post-1995 housing.

A limit of #10 m^3/m^2hr @ 50 Pa might rule out a higher proportion of new non-residential construction but there appears to be stronger support for immediate improvements in that sector. *TM23:1999* recommends a limit of #5 m^3/m^2hr @ 50 Pa, which is lower than the Swedish limit.

The graph in *TM23:1999* quotes a current mean of 11 m^3/m^2hr for public and commercial buildings. If the envelope includes the ground floor, this is probably around 9 m^3/m^2hr. If so, testing would have a similar impact to housing and 35-45% might need to be improved upon to pass, but results vary from class to another.

TM23:1999 gives mean industrial building envelope leakage as 17 m^3/m^2hr @ 50 Pa; unsealed loading doors in industrial premises can be a significant source of envelope leakage. If the envelope includes the ground floor, the figure is more likely to be 11 m^3/m^2h @ 50 Pa, suggesting that on a typical statistical distribution, just under 50% would need to be improved. By contrast, experts who test new shopping centres feel that virtually all current construction would pass.

Overall, a uniform dwelling and non-domestic standard is preferred except for industrial premises which can show that they will be less well-heated, or will have sustained high heat gains from processes, for the life of the building. If this reasoning is accepted, domestic and most non-domestic would have to meet #10 m^3/m^2hr @ 50 Pa from late 2001.

A limit of #5 m^3/m^2hr in BR-2005 is proposed as a reasonable balance between current industry abilities and the industry=s proven ability in Scandinavia, North America and central Europe to achieve buildings which are more draught-free than this. This should, however, be finalised in 2004. Part of the decision-making then would be based on the findings after four years of experience in setting this as a *Good Practice* standard.

Most UK experts who were consulted thought that these standards were achievable and reasonable. One who sees mostly non-domestic buildings thought that they were too onerous. One who sees mainly housing and other residential buildings; e.g., student hostels, thought that they were far too lax and that we should tighten new buildings to the Swedish, Canadian, Norwegian, Finnish and Swiss levels by 2005.

All the UK pressure is to make *non-domestic* buildings better-sealed, but separate requirements for domestic and non-domestic buildings are a rather artificial distinction. Offices tend to have more >free= internal heat gains, and these actually *reduce* the justification for air sealing relative to dwellings - an argument apparently accepted in Sweden. Also, it is hard to justify placing buildings such as student residences, hostels, residential nursing homes, hotel bedrooms, hospital wards and prisons in two different categories.

IMPACT OF THE STANDARD

On the BRE database, the comparison between Victorian and Edwardian solid-walled housing, which is about as tight as post-1980 housing, provides fairly convincing evidence of the lack of progress. This is felt to provide reasonable justification to introducing an upper limit to air leakage even in the domestic sector.

The overriding concern is to make progress yet not move too quickly for the industry to assimilate the changes. It helps, therefore, to know what proportion of the industry=s output might have to be improved in order to meet a standard. We have earlier precedents in two countries for improvements which ruled out 60% of current practice in some sectors. *The new maximum in these sectors was 40% lower than the mean which the industry was achieving.*

Sweden=s and Norway=s improvements in the late 1970s slightly affected heavyweight construction - 70% of it complied - but over 60% of previous timber-frame building construction would have failed the new requirements. The *mean* air leakage of Norwegian timber-frame housing in the 1970s tested by the Building Research Institute was 5 ac/h @ 50 Pa - see Figure 3 - but the new legal *maxima* in Norway and Sweden for timber buildings were set from 2 to 4 ac/h @ 50 Pa, depending on building height. The maxima for medium- and high-rise buildings, normally in concrete, were 1 or 1.5 ac/h @ 50 Pa.

Their improvement to timber-frame - so far as one can judge, equivalent to a 50% reduction in mean air leakage, from 5 to 2.5 ac/h @ 50 Pa - was successfully taken up by the industry on the basis that government gave notice and provided support and guidance. In particular, it helped with training programs in the transition period.

The intent to regulate was announced several years before the improvement became law. The actual transition from leaky to tighter buildings mostly took place over the period 1975-78 in Sweden and 1978-81 in Norway.

In the UK, on current knowledge, we would be asking the domestic sector and the public and commercial sectors to improve from a current mean of approximately 9 to 7.5 m^3/m^2hr @ 50 Pa by 2001, 3.8 m^3/m^2hr @ 50 Pa by 2005 and to 2.2 m^3/m^2hr @ 50 Pa by 2010. This assumes that the scatter in practice in the industry=s abilities - the sum of design standards, construction skill, training and quality control - leads to the mean figure achieved, in practice, being approximately 25% below the legal limit. The timescale is thus broadly similar, or slightly more generous, to the timescale on which Sweden and Norway improved their new timber-frame construction from 5 m^3/m^2hr in 1975 or 1978 to 2.5 m^3/m^2hr @ 50 Pa by 1978 and 1981 respectively.

There are, of course, differences between us and them.. On UK climate, readers are referred to the appendix to the report on standard details. On this basis, it is at least arguable that the case for regulating air leakage in the northern UK is the same as in Norway. Another difference is that new concrete and masonry buildings in Norway and Sweden were less affected; most of them were tighter than timber. However, taking account of this the legislation still appears to have affected around 55% of new dwellings in Norway and 45% in Sweden - a greater proportion than it would affect in the UK.

TIMESCALE/PREPARATION FOR A STANDARD

Nearly everyone felt that 2000 is too soon for a legal limit because the construction industry, as a whole, does not understand the principles of tighter building envelopes. It would not be welcome if non-performing systems continue in use after tighter air leakage standards are mandatory, and fail badly. The spectacle of contractors being required to take apart elements which have failed and re-build them - then, often justifiably, attributing responsibility for the failure to the design team - could discredit the initiative.

The need for performance improvements should be impressed upon the industry. The contrast between UK practice and overseas practice, between the UK norm and good practice, and the failure of UK housing to become less leaky since the 19th century, may need to be made. This provides clear evidence of the problem and the scope for improvements.

For at least a year, starting as soon as possible, a statistically significant sample of new construction in all regions should be tested. The length of this period needs to provide a sufficient opportunity for all actors to see what passes or fails, but without the target being enforced by law.

This would demonstrate to the industry that many practices are unsatisfactory but that it is possible to pass the proposed standard, which is not particularly onerous relative to current practice.

Essentially, the period would be used to provide field support to builders and others. In late 2000, about a year from now, DETR would publish detailed guidance to satisfy the standard proposed for BR-2001. There is still another year of testing and in late 2001 a requirement would become law.

BR-2001 aims to outlaw the most unacceptable combinations of construction methods, workmanship and supervision levels and remove them from the market. It does not aim to mandate good practice but it would aim to make leakage an issue on every building site and in every architect=s office.

Having made improvements on this schedule, the industry would appreciate better the possibilities for improvements. A consensus should be possible that BR-2005 and -2010 should set more demanding standards and bodily move new UK construction into the same air leakage range as other cool and cold countries. Such standards are considered to need more substantial improvements to design and workmanship, especially BR-2010, but ten years should be ample if we prepare now.

It is possible that proposals at these levels may be accepted in one sector, notably large non-domestic buildings, where they are backed by CIBSE, but not in the domestic sector or other small buildings. If so, a fallback strategy would be to begin a voluntary UK program and inform the construction industry that legislation will be introduced in 2005 unless testing of the industry=s output - recommended anyway from 2000 onwards - indicates steadily falling rates of air leakage, with a mean of say 4 m^3/m^2hr by late 2004.

If a voluntary program was adequately-resourced, it would capture some of the benefits that would accrue from mandatory standards, and could help to defuse opposition to legislation. Such a process could and should be integrated into a training program for industry. The objective would still be to build a robust database that would enable changes in airtightness in all classes of building construction and type to be tracked and diagnosed. It would still require an absolute minimum of 1,000 tests on new dwellings per year.

There are two disadvantages in following this course. First, it would not stop the occasional construction of extremely leaky small buildings, which seem to be endemic in temperate climates. Second, nor would it be easy or even possible to provide correct guidance on recommended and effective ways to ventilate new buildings.

This could perpetuate for some time the current rather unsatisfactory situation, one in which new UK buildings appear to span the leakage range from 3 to 30 m^3/m^2hr @ 50 Pa. At the lower end of the range, the current consensus would be to recommend provision of mechanical exhaust-only ventilation to the whole building. Yet this advice is inappropriate at the upper end because it supplements an already high level of background air infiltration.

GUIDANCE TO MEET THE STANDARDS

General

The short section in *AD-L*, p. 20, shows improvements to windows, loft hatches, plasterboard-on-dabs and soil vent pipes. It advises that air leakage can be reduced by sealing more carefully the vapour barrier in timber-frame and similar systems, and sealing hatches and vertical service ducts in all buildings.

However, this page is imprecisely worded and is insufficient to remove the gross defects which are now seen throughout the industry. Very different interpretations of section 2.24 could be made; e.g., by a careful custom builder vs. a contractor who builds to the lowest standards permitted.

New guidance issued in *AD-L* should tackle the main different construction systems, which are all briefly discussed below, and list the gross deficiencies which now occur. Construction drawings should be shown in *Approved Construction Details* which correct these deficiencies.

Thus, four full-page cross-sectional drawings through buildings might be shown for low-rise masonry and timber-frame housing, concrete-floored masonry, concrete-frame and steel-frame, with all the characteristic leakage points described below listed on the drawing and subsequent pages showing sealing details. If construction is to incorporate an air barrier which continues substantially over the building envelope, removing the current deficiencies appears to require several measures to be clarified immediately, for instance in low-rise masonry-walled timber-roofed buildings:

1. That services risers, soil vent pipes and similar should be sealed to the roof as the current *AD-L* states - the *Approved Construction Details* can make the detail clearer;
2. That windows, doors and rooflights should be sealed to the wall or roof. Drawings can be made clearer than the current *AD-L*. Loft hatches should be sealed - the current *AD-L* drawing is clear. However, these items are a small proportion of total leakage, except in intrinsically tight buildings;
3. That timber intermediate floors in cavity-walled buildings should utilise joist hangers;
4. That external walls should be plastered, and that the plaster should continue past hollow partition walls. Other large potential gaps above substantial suspended ceilings, behind baths, behind an entire services riser, etc, should be plastered, especially in systems prone to leaks elsewhere - for instance with timber, not concrete intermediate floors;
5. That the ceiling plasterboard, or a polyethylene air-vapour barrier, should continue over the top of hollow partition walls or another form of tight seal should be provided; etc.

This implies that numerous gaps in the air barrier would still be tolerated. For instance, there would not be a continuous air barrier through the first floors or behind skirtings. Some leakage would occur around small points such as ceiling light fittings and through small gaps in the plaster, which would implicitly be allowed to continue.

We cannot issue quantitative guidance because the UK has not yet collected or collated enough data for this purpose. However, qualitative guidance is possible which indicates the priorities with all the main different construction systems.

There is strong evidence that if we do further work and tests, we shall soon be able to issue more precise guidance. The north-west USA felt confident enough with timber-frame after pilot projects in the 1980s to say in the Code that it is deemed to satisfy a figure of 7 ac/h @ 50 Pa if a long list of points are sealed. The current understanding of what is needed is summarised below.

Differences

In the light of overseas experience, it is not only a matter of issuing guidance to the industry on the required levels of workmanship and the appropriate supervision and inspection regime. It is also a matter of informing the design community that different construction systems vary in their intrinsic tightness, and that the necessary level of supervision and inspection may differ for equal levels of air leakage in the finished building.

With continental European-type masonry construction, or with *in situ* concrete, we actually need to inform designers that if the obvious openings are sealed, and normal construction practice is followed, the resulting buildings may be rather tight *without* a conscious plan to achieve low leakage. They are quite likely to justify mechanical ventilation now rather than 2005. Precast concrete has similarities to *in situ* except that the joints must be sealed, as in Sweden, where this material is common.

Because of gaps and breaks in the air barrier, caused by design features or construction errors, the results on >dry construction= buildings which are assembled on site seem to be far more sensitive to vagaries of workmanship than forms of wet construction in which either the structure itself is the air barrier; e.g., concrete or large calcium silicate elements or in which an obvious layer of material - the finish plaster - is specified to continue all over the building envelope and can easily be inspected for continuity.

All the lightweight buildings to date which have been very tight by UK standards, with volumetric leakage of 1-1.5 ac/h @ 50 Pa, have benefited from a combination of good design, careful workmanship, tight supervision and sometimes external scientific support. Some of the UK’s wet construction buildings have been equally tight and only had the usual architect’s visits and a little expert advice. They might have been tighter with more external support or outside inspections.

Concrete and Masonry

‘Continental European-type’

The following leakage sites were reported in a recent test of some cavity-walled, concrete-floored and -roofed flats in London. The >tower block= cited was built decades before the UK had any concern for airtightness, but it was built using the materials and procedures which are standard elsewhere in Europe on new masonry buildings, and in this case it had been retrofitted with tight replacement PVC windows:

1. Minor to major leakage around the windows where mastic sealing is incomplete, often at the ends and edges of window sills;
2. Leakage through the service void behind WCs;
3. Ditto behind the bath(s);
4. Around doorbell wiring and a few other cables;
5. Leakage through poor draughtproofing, on a door of the same age as the flat.

These flats and others have 4-7 m^3/m^2hr @ 50 Pa and are nearly as tight as Swedish dwellings of the same age. Clearly, this arose as a coincidence from the selection of construction system, not from any design effort or special workmanship. In the leakier existing buildings of this type, windows and doors often contribute >50% of total leakage and merely fitting tighter ones reduces infiltration dramatically. After the windows are replaced, the fortuitous ventilation provided by virtue of construction defects - the holes and gaps in the fabric - is lower than the area prescribed in the subsequent revisions to Part J of the Building Regulations.

It seems significant that the construction system normally favoured for flats - masonry with solid upper floors - is intrinsically more easily draughtproofed than the construction systems normally used on detached houses. The government=s policy of developing more new homes on brownfield sites might therefore yield energy benefits in the form of a reduced use of fuel for heating, as well as environmental ones, in the form of reduced need for development on greenfield sites and possibly a reduced use of cars.

The following leakage sites were reported in a test of a recent concrete-walled, timber-roofed bungalow in the south-east of England. It received the normal architect's visits plus a short visit from an energy expert when the roof was being built:

1. Some leakage around three windows which had not been sealed to the wall;
2. Leakage around the main service entry in the concrete basement wall;
3. Small leakage through one opening Swedish window;
4. Some leakage through the roof via remaining gaps between the joists and the in situ polyurethane foam which provides the combined roof insulation/air barrier.

Total leakage is 1.2 m^3/m^2hr @ 50 Pa.

The following leakage sites were reported in a test of a recent cavity-walled, concrete-floored and timber-/steel-roofed college building in the west of England. It had an air leakage clause in the specification but as it was the first block out of a total of five, the builder lacked prior experience and it was built on a design-and-build basis, a contract type which is not always known for the best results:

1. Large leakage via a poorly-sealed duct which houses drainage and water services and enters the roof void;
2. Fairly large leakage via all >closed= trickle vents;
3. Significant backdrafting via some 'dampered' extract fans;
4. Some leakage around the edge of and through window frames;
5. A little leakage above skirting trunking in rooms where the walls are not fully plastered below this level.

Despite large leaks via routes 1 and 2, if the ground floor is included in the surface area the total envelope leakage is below the Swedish limit of 2.88 m^3/m^2hr @ 50 Pa. The ventilation to the blocks only conforms to current Building Regulations, but in view of the result they might benefit from continuous winter exhaust ventilation.

A series of buildings by an entirely different design team and builders, but in similar construction, plus a concrete roof, were built in east Anglia in 1993. They had envelope air leakage 2.5-5 m^3/m^2hr @ 50 Pa. The vast majority of the leakage in the higher cases is via the vertical services ducts which contain plumbing, wiring and drainage. A little occurred around and through the windows. A nearby concrete-frame building, built in 1995, has leakage of 2.5 m^3/m^2hr @ 50 Pa. Most leakage is around rooflights and windows. If more resources were allocated to design or inspection, it would have been possibly 0.75-1.0 m^3/m^2hr @ 50 Pa.

There is reason to believe that with straightforward guidance, and allocation of more resources to correct detailing and inspection, these forms of construction would easily meet not only BR-2001 and BR-2005, but BR-2010. It is also clear that the main ways to improve these buildings probably have more to do with design, specification and supervision - better trickle vents or dampers, improved windows and re-designed services ducts - as with out-of-the-ordinary workmanship.

‘UK-type’

This refers to construction with masonry external walls but with suspended timber upper floors and timber roofs and, often, timber partitions. The following list of leaks is not atypical of recent tests on the poorer cavity-walled low-rise buildings, albeit still with plastered walls:

1. Fairly minor leakage at the edge of concrete ground floors between the edge of the slab and the bottom of the inner leaf; even through the vertical slab of expanded polystyrene which one is advised to place there;
2. Leakage around the skirtings, on all floors;
3. Leakage adjacent to the stairs;
4. Leakage behind the bath;
5. Occasional leakage above suspended ceilings;

with leaks 2-5 arising because the plaster layer is normally discontinuous here;

6. Leakage around all windows unless they have been sealed to the masonry;
7. Often leakage around the base of the doors;
8. Sometimes huge leakage through timber intermediate floors, especially if joists are built into cavity walls - even joist hangers and better sealing seem less than 100% effective;
9. Around services where they enter the ground floor;
10. Around the weatherstrips in the poorer quality windows;
11. Major leakage through gaps between rooflights and timber roof structures;
12. Other leakage through the roof itself if it does not have a continuous air-vapour barrier;
13. Through overhangs where the continuity of the airtight layer is lacking,

with leak 13 being especially severe where timber floors are involved, but sometimes concrete floors also.

Guidance on how to redesign masonry to meet future envelope leakage standards depends strongly on how the intermediate floors, roofs and partitions are built. At the two extremes of construction type, we have conclusive evidence that structures of >100% wet= construction can be made extremely tight except at openings and that >100% dry= structures, in which the industry has replaced plaster by plasterboard, are prone to be extremely leaky.

In masonry walls with plasterboard-on-dabs, acceptable results appear to be totally dependent upon a combination of good design, workmanship and supervision. Such walls would have difficulty in meeting the air leakage standard planned in BR-2001. Their current form also fails to provide an air barrier of reasonable continuity and they contain a ventilated airspace between the air barrier and the insulation layer, so would have to be modified anyway.

If the industry does not wish to rely on wet plaster, which is the established and proven approach in the rest of Europe, and still widely used in the UK, it might wish to explore the North American practice of dry-lined masonry walls, used as infill to steel and concrete frames, which utilise a discrete air barrier membrane attached to the outside of the inner leaf. This is a perfectly valid approach, as is the use of some types of plastic foam insulation, sealed at joints, as the air barrier.

It is difficult for us to offer the industry exact pass-or-fail guidance without assembling and examining all UK tests to date of air leakage of cavity-walled houses, with varying details, but we know qualitatively where they leak. There is strong suspicion that projects without gross deficiencies in the continuity of the plaster air barrier, and with some sealing of service entries, give good enough results to pass BR-2001 and BR-2005. All the signs are that the following features simply lead to progressively improved results:

1. Plastered walls over the vast majority of the area;
2. Timber first floors on joist hangers, with some attempts at sealing the >joist space for the best results;
3. Seals around the soil vent pipe(s) etc;
4. Fairly tight windows and doors;
5. Seals around the windows;
6. Solid, plastered masonry partitions on the first floor, or an air barrier over the top of hollow stud partitions, etc.

Thus the 1981 test reports on the Great Linford houses, Milton Keynes showed volumetric leakage of 6.4-8.2 ac/h @ 50 Pa, in a state with the main doors and windows weatherstripped. This corresponds to envelope air leakage of 6-8 m^3/m^2hr @ 50 Pa, which is low for UK speculative housing and comes within the proposed leakage limit of BR-2000.

Being part of a government-funded research project, the test was fairly sophisticated and included pressurisation of individual rooms to quantify room-by-room air leakage. It was seen during this exercise that 65% of total air leakage area was in the top half of the house and 50% was from the bathroom. Measures to reduce upward air movement from the bathroom into the roof, with a seal around the soil vent pipe specified at design stage, could have reduced leakage by a further large margin. Evidently masonry buildings with timber roofs still suffer major air leakage through the roof and need the same basic measures here as a timber-frame building.

The researchers who observed the Linford construction process felt that the level of workmanship on the estate was broadly typical of mass housing. The workforce were considered to have no real knowledge or understanding of airtightness. The project also predated the availability on UK sites of expanding foam, which makes remedial work on filling gaps and defects less skilled.

The 1993 Longwood House, west Yorkshire had an envelope leakage of 3 m^3/m^2hr @ 50 Pa and had leakage at only six of the 13 points listed earlier. Construction of all the individual elements was similar to Linford. The reduction partly reflects good workmanship - Longwood was constructed by a small speculative builder who wanted to build an energy-efficient house - but more importantly, he took advice from an academic building scientist who had seen overseas construction practice and had made laboratory tests of air leakage in masonry construction, and it was known by 1993 that air leakage was an issue. Several other projects in GIR 38-39 of this construction achieved envelope air leakage of 5-8 m^3/m^2hr @ 50 Pa.

Lightweight Construction

These techniques need a longer list of items to be checked. The details vary from one building shape to another, but the following lists some of the many leakage points seen on recent small timber-frame and steel-frame buildings, which were designed with some thought to better insulation levels but clearly without any understanding of air leakage:

Ground floor:

1. Unsealed boiler flue;
2. A hole beside the door where an entryphone is apparently to be fitted.
3. Gaps around window frames, particularly at high level above the living room windows;
4. Cable hole through the ceiling in the hall where a smoke detector is to be fitted;
5. Gap around cable to boiler;
6. Holes through the base of the cantilevered window to the living room;
7. Leakage behind the electrical distribution board beside the front door;
8. Leakage around and through electrical sockets and switches;
9. Around the edge of the ground floor, along the top and side of the skirting boards to all walls;
10. Substantial hole behind the fusebox where electrical cables run into service void in wall;
11. Numerous gaps to the underside of the stairs connecting to openings in the first floor;
12. Large gap around water supply pipe where it passes through the ground floor;
13. Leakage around services to the downstairs WC;
14. Hole at side of kitchen passive vent stack;
15. Leakage through framing of built-in cupboards;
16. Leakage at the edge of the plasterboard ceiling lining the base of the first floor.
17. Leakage around water pipes which run into the first floor void;

First floor:

18. Leakage around pipes to radiators that connect to the intermediate floor;
19. Large gaps around the internal cover strip to the rooflight reveals;
20. Leaks along either side of the wooden ridge beam - only buildings with rooms in roof;
21. Beside the light fittings next to the ridge beam - ditto;
22. Gaps at the head of the stairs;
23. Leakage around ceiling light fittings;
24. Leakage around TV aerial cables;
25. Leakage beside the bathroom passive ventilation duct where it is not flush to the ceiling;
26. Gaps around unsealed water pipes in the bathroom;
27. Leakage around the soil vent pipe in the bathroom.;
28. Behind pipes at the head of the bath emanating from the first floor;
29. In attached houses - along the top of the insulation slab in the first floor adjacent to the party wall;
30. Leaks around pipes in storage cupboards - gaps between pipe and plasterboard
31. Leaky loft hatches.

The mean for post-1980 timber-frame housing in the BRE database is under 7 m^3/m^2hr @ 50 Pa. This would meet BR-2001 by a significant margin. However, figures over 20 m^3/m^2hr @ 50 Pa are occasionally recorded in domestic timber- and steel-frame. Where the construction is documented, these high results seem to reflect complete lack of any air barrier and the absence of any requirement in the design for sealing at service penetrations or around windows. In non-domestic steel-frame buildings, experts consulted estimate that most figures they see are between 10 and 30 m^3/m^2hr @ 50 Pa, unless air leakage is an issue at the design stage and on site.

Improvement of lightweight construction to *reliably* meet BR-2001, -2005 and BR-2010 inevitably seems to be dependent on detailing and construction quality. The result of combining poor designs with the least good workmanship would be totally unacceptable.

The most proven approach in timber- and steel-frame is a polyethylene air-vapour barrier. Scandinavian and Canadian practice since 1975 has largely resolved the details of how to extend it over the entire thermal envelope and make buildings extremely tight, including difficult junctions where the air-vapour barrier is interrupted by structural timber members; e.g., in 1.5-storey houses. Other approaches are however workable and have been used, particularly in non-domestic steel-frame buildings.

In current practice in the UK and other mild climates, like the north-west USA, the polyethylene is discontinuous at many points in timber-frame buildings; e.g., there is no air barrier in the plane of the timber first floor and it is usually absent from the ceiling too. Moderately low air leakage is still achieved; e.g., pressurisation tests on some recent timber-frame flats in Leeds showed 8.5 m^3/m^2hr @ 50 Pa, a volumetric leakage of 4.5 ac/h @ 50 Pa. The builder=s skill was considered average and there was no attempt at a roof air-vapour barrier.

BRE staff have *retrofitted* timber-frame buildings to volumetric leakage figures of 4-5 ac/h @ 50 Pa. There is no reason why the proposed air leakage limit in BR-2001 or -2005 would need design or construction work to meet the requirements of the Swedish or Norwegian Codes, let alone the R-2000 Program, but the knowledge is there as and when we wish to apply it.

Other approaches to timber- and steel-frame should also be recognised as valid; e.g., the use of the plasterboard as the air barrier, with gasketed joints. There is less field experience of these buildings in the UK - their earliest use was in Canada/USA in 1980 - but the project by BRE and Orkney Housing Association in 1994 provides an example of construction which passes by a large margin the proposed air leakage limit of BR-2010, thanks to good design, field support to the builder and good, careful construction.

Other examples of low leakage in steel-frame include the Weidmuller Building, Kent and new supermarkets for four major UK companies. The former achieved <2 m^3/m^2hr @ 50 Pa after remedial work; fortunately the design was amenable to this and the leaks were accessible. The latter now regularly achieve 3 m^3/m^2hr @ 50 Pa, a figure which partly reflects experience and serial construction, with one contractor repeating a single design.

All Construction

The following are clearly widespread problems in all buildings:

1. Leakage through the frame and the opening lights of poor-quality windows and doors;
2. Substantial leakage around open fireplaces with openable glass doors and woodstoves, including many described by the producer as >airtight=.
3. Substantial leakage through ‘dampered’ ventilation fans;
4. Substantial leakage through ‘closed’ trickle vents;
5. Substantial leakage up ‘closed’ passive ventilation stacks.

Some of these sources of potential leakage are part of the ventilation system, examples being 4 and 5, but they are not fully under the designer>s control. He/she may place good faith in the manufacturers=s claims, but the tests on a finished building may show different results. This is an area which needs tightening-up of national standards and legislation of a different kind; see the list of initiatives later.

If a recommendation of this report is followed, that the Building Regulations require an air barrier of an approved material over the thermal envelope of new buildings, with no airspace between it and the insulation layer, then we could issue guidance with each edition of Part L which permits limited breaks in the continuity of this layer. These would become less with time as we aim for the low levels of leakage which are seen abroad.

For instance, Canadian practice on timber-frame buildings, required by *Code*, takes the airtight layer through the intermediate timber floors, using a wide range of design details, and across the roof. Continental European masonry buildings and the taller UK masonry buildings use concrete intermediate floors instead of timber, again giving potentially complete continuity of the air barrier.

VENTILATION

The wider implications of an air leakage standard extend throughout Parts F and J of the Building Regulations. Different ventilation systems are appropriate at different levels of air leakage. The guidance and requirements in Part L need to be harmonised with these other sections.

The leakage levels in BR-2010 presume that we follow the route ‘build tight, ventilate right’. The standard would introduce a need for effective whole-dwelling ventilation for use in winter, when doors and windows are closed. This is the trend pioneered in Sweden, Norway, Finland and Canada and being followed in moderate climates in the USA and now in Switzerland. It is ‘good practice’ in Germany and Denmark, but it does not apply to all of Europe.

The proposed air leakage standard in BR-2005 is on a par with older Swiss, Swedish or Canadian housing. These rarely have much deliberate ventilation except bathroom exhaust fans or passive stacks. A prudent proposal for BR-2005 would be to recommend the same minimum as BR-2010 - whole-house ventilation systems which are *quiet enough* to be operated continuously if needed.

In the north-west USA, whole-house exhaust ventilation with time-clocks - an intermediate step forward from bathroom and kitchen extract fans and trickle vents - is a commonly-approved system, with no heat recovery. Their new housing stock has the same air leakage levels which the UK is approaching.

Best practice on continuous exhaust-only ventilation for moderately airtight buildings may well be seen in Sweden, with the north-west USA also having used these systems for some time. Best practice on balanced supply and exhaust heat recovery ventilation in very airtight buildings is probably to be found in Canada. Again we should simply adopt procedures and standards for design and construction of ventilation in the tighter buildings from these countries. There is no point in our re-inventing them.

The 1998 UK consultation process suggested a public association between ‘airtight’ buildings and suffocation. Even the uncontrolled air infiltration of the world’s tightest buildings - some houses in central Canada are two orders of magnitude tighter than new UK construction - provides more than enough air if the ventilation system stopped working in winter.

With normal site practice, it has so far proved impossible to reach this standard in the UK. Even a three-fold reduction from the UK norm of around 9 m^3/m^{2}hr @ 50 Pa has generally only occurred when the designer or builder ‘knows what he/she is doing’ with the building envelope. On these rare occasions, he/she has therefore ensured that mechanical ventilation is provided to most rooms in the building.

The most serious consequences of inadequate ventilation are not lack of oxygen but indifferent air quality and, in badly-insulated buildings, condensation. The UK’s most severe condensation problems occurred in 30 year old dwellings which had air leakage in the range 3-5 m^3/m^{2}hr @ 50 Pa and lacked *heating or insulation*. In new UK buildings, given the relative U-values, the first signs of internal condensation would normally be confined to the windows. The existing statutory requirement for fans/trickle vents is mostly there to provide an assurance of satisfactory internal conditions even if the rest of the building is rather tight.

Public consultation documents should use terms such as 'air sealing', 'air leakage control', 'draught-free' or ‘reduced air infiltration’, not ‘airtight’. It may then be possible to have a rational debate on the merits of ‘build tight, ventilate right’, versus a policy of ventilation by adventitious defects and deliberate openings in the walls or window frames.

There are three problems in relying on leaky buildings for ventilation. If they are not over-ventilated in cold, windy weather, they are usually underventilated in mild weather. Research shows that some rooms usually have too much air, because the leakage area is concentrated there, and other rooms have too little. The effectiveness of a given amount of background infiltration in removing pollutants may also be lower than when the same volume of air is delivered by mechanical ventilation - piston flow is more effective than mixing flow.

The emergence of the new ASHRAE residential ventilation standard 62.2 P suggests some consensus on appropriate means to ventilate dwellings, and the extent to which they can safely rely upon uncontrolled air infiltration. The conditions which prevail in the UK heating season overlap those found in parts of the USA and Canada, so 62.2 P should provide a good foundation for UK work between now and publishing proposals for BR-2005 in late 2000.

OTHER WORK NEEDED

Typical air leakage figures on new buildings in other regions are better than the UK, but their experts see setting a stringent air leakage limit as more a sequel to efforts to educate and train the industry in the basic principles of good air barrier design than a prelude to it. Several practitioners abroad said that, in their experience, air sealing improvements beyond the figure envisaged for BR-2001 can only occur as the end result of the following process:

- Set reasonably ambitious targets on demonstration projects, with enough outside resources to ensure that they all meet or exceed the target, whether this be ≤5, #3 or #1 m^3/m^{2}hr @ 50 Pa;
- Provide education and training for architects, engineers and building companies to show why improvements are needed and how to meet them;
- Then set a maximum limit.

With the exception of intrinsically tight construction systems, mandatory air leakage standards as proposed for BR-2010 are unlikely to be achievable until/unless they are demonstrated in larger numbers beforehand. The numbers in existence are limited and they tend to be seen as exceptions, or as outside the industry's capability, rather than a standard which might eventually become normal practice. A separate section of this work discusses further initiatives which are considered to be outside the terms of the Regulations but are all designed to improve the long-term energy performance of the UK building stock.

CONCLUSIONS AND RECOMMENDATIONS

The UK air leakage standard should be phrased in terms of m^3/m^2hr @ 50 Pa. The entire thermal envelope separating the conditioned space from the outside air, the ground or unconditioned spaces needs to be included in the standard.

We should not introduce a legal limit to air leakage of new buildings until at least late 2001. This is because of the current widespread lack of understanding within the industry and the limited testing capability. The logistics of even this timetable are being checked by others.

We should, however, start testing random samples of new buildings as soon as possible in 2000 to educate and inform more in the industry. This is to give them reasonable notice of the coming change and to establish a statistically robust baseline. We need to show that the situation with some is not good but that many common techniques can be made to pass a modest air leakage requirement from late 2001.

If for any reason, legislation on some building types is delayed, air leakage data should still be collected from a sample of new buildings as soon as possible. Assumed that requests to test are granted, this work could begin before any legislation. This would produce a statistically valid time series, which is an invaluable policy tool.

Further work on the recommendations/requirements for ventilation in moderately tight dwellings is needed between now and late 2000, when BR-2005 would be published.

A Code requirement in Canada, parts of the northern USA, an implicit requirement in Denmark, Sweden and Norway, and the key to reaching more extensive air sealing standards, is that buildings should have a continuous air barrier which is in close contact with the thermal insulation layer, never separated by a ventilated airspace. This is a *sina qua non* of good thermal envelope design.

We should produce a specification clause which requires such an air barrier which extends over a *substantial* part of the thermal envelope. L*imited* exceptions to the requirement for continuity of this layer; i.e., defining what we mean in law by the word *substantial*, could be made at various stages in the evolution of Part L - 2000, 2001, 2005 and 2010.

A number of design deficiencies lead to new buildings suffering uncontrolled air movement which carries away heat from the interior, even though an air leakage standard would not control it. These could be dealt with by the same specification clause. It would need to make clear that the air barrier must extend across separating walls and/or separating floors and to show examples of acceptable constructions.

We need to monitor the situation carefully and do more random testing. However, there is clear reason to believe that all masonry and timber-frame houses without gross deficiencies in design or workmanship are capable of passing the BR-2001 and the BR-2005 standard. Most masonry-walled, concrete-floored flats or offices as built now seem readily capable of passing the BR-2010 standard. The principles in other large public, commercial or industrial buildings are exactly the same.

The specific air sealing points which appear in the Building Codes of the north-west USA are an excellent idea and a detailed UK list should be required in BR-2005, when we are aiming for similar leakage. Inspectors could then have a full list of points to check to determine whether the construction meets accepted standards or not.