EXPERTISE

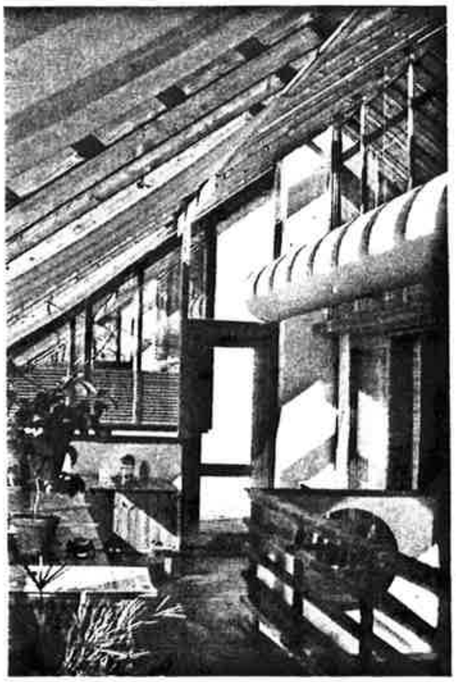
Towards the Zero-Energy House

David Olivier

FOR DECADES, the Scandinavians have insisted that new buildings have effective insulation and heating systems. Swedish and Norwegian houses built *in the 1920's* were recently found to have as much insulation as new UK dwellings of the 1980's; they were also built with double windows, and are as draughtproof as new UK buildings.

Buildings on the other side of the North Sea, then, have been insulated and weatherstripped for a long time. However, things have changed dramatically since the 1973 'oil crisis'. Under current regulations, timber-frame walls in Scandinavia are usually insulated with 150-250mm mineral fibre. In Denmark, the standard cavity masonry wall has 150mm mineral fibre; 'energy-efficient' buildings have 200-300mm. Elsewhere, masonry walls are usually built of lightweight concrete/foamed plastic sandwich elements, with 100mm polyurethane foam or 200mm expanded polystyrene. Typical new detached houses in Sweden, with a floor area of 140m^2, now use less energy for space heating than water heating, despite a climate as cold as the Shetland Islands and average indoor temperatures of over 20°C.

With Sweden in the lead, the Scandinavian trend is towards superbly-insulated, almost airtight buildings which, over the cold part of the year, use some form of forced ventilation to maintain high indoor air quality. More stringent minimum energy efficiency standards are now under discussion for new single-family houses in Southern Sweden and will probably be made part of the building code during 1985. Multi-family dwellings will probably continue to require greater airtightness, and dwellings in northern Sweden to require higher insulation levels.



Above: **Inside one of the Heimdal energy efficient houses. The air duct removes heat for short-term storage.** *Below:* **The Royal Garden Hotel, Trondheim employs a series of atria between residential blocks.**

The northern UK is actually as cold as southern Scandinavia – see later – and overall conditions in the UK are not very different. Recent innovations from Scandinavia could be equally appropriate to this country. Since the Swedish Council for Building Research alone now spends about £15m per year on energy-related work, this article cannot be comprehensive, but it gives an indication of these countries' enormous contribution to the subject.

Energy-in-buildings projects

Sweden's proposed 1985 building code is the most energy-efficient in the world. Naively, the casual reader might expect this to be the end of the matter. However, the Swedes are apparently not stopping there. With the help of the Council for Building Research, Rockwool built two detached 109m^2 bungalows in Skovde, near Gothenburg, in 1982. One meets the planned 1985 building code, with 400/240/200mm mineral wool in the roof/walls/floor (U-values 0.10/0.17/0.20 W/m^{2}K). The better of the two, which is unusually well-insulated even for Sweden, has 600/400/400mm mineral wool in the ceiling/walls/floor (U-values 0.08/0.12/0.11). The houses are otherwise identical; they are built from the now common mineral wool-filled box beams instead of normal timber; have electric heat pump/resistance warm air heating; coupled 2/1/1 quadruple glazing with white venetian blinds between the two outermost panes, one air-change per hour at 50 Pa, and balanced mechanical ventilation with heat recovery.

With a peak heat demand of about 2.5kW at –20°C outside, 20°C inside, the experimental house is said by its occupants to give exceptional comfort, owing to the warm walls, absence of cold air infiltration, negligible stratification and freedom from cold window surfaces or downdraughts. The National Testing Institute is monitoring both houses to determine the value of the extra insulation in terms of reduced energy costs; early results are promising.

Such innovation is not confined to single-family dwellings. In Stockholm (59°N), the city council and the Swedish Council for Building Research have sponsored several large building companies to design and construct five energy-efficient blocks of flats. These will vary widely in design. One block will consist of heavily-insulated and

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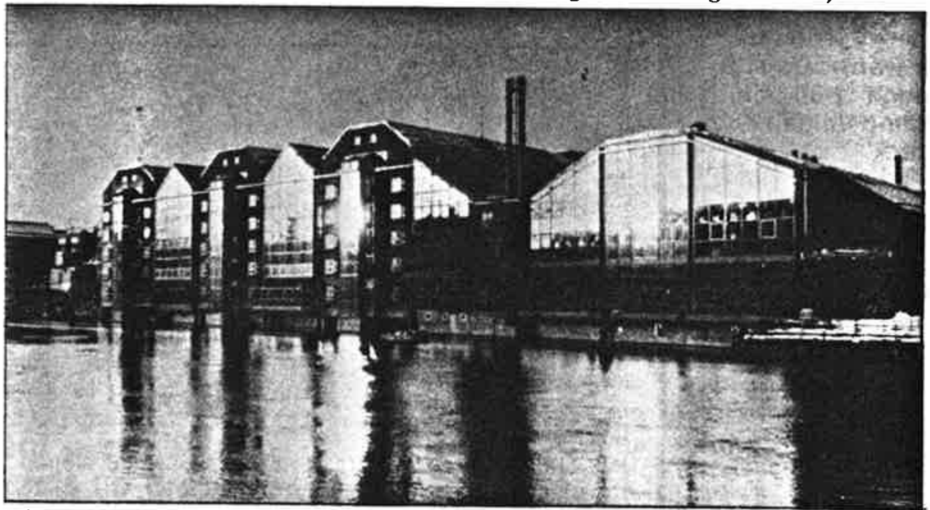
well-sealed dwellings. Another group of flats will have glazed courtyards and heating systems which are integrated with neighbouring office cooling systems. However, all schemes are expected to require less than 0.3 GJ/m^2 of purchased energy annually. In some cases, this will be as low as 0.18 GJ/m^2 ie, only 15GJ for a 80m^2 flat.

Norway's chief energy-efficient housing demonstration project is a group of 14 two-storey detached houses, each about 120m^2, in Heimdal, near Trondheim (63°N). They have a mixture of timber-frame and masonry construction, varying insulation levels, etc. Three houses have attached sunspaces on the south side, together with short-term heat stores. One timber-frame house compares to other countries leading 'superinsulated' designs, with 400mm of mineral fibre in the roof, 300 mm in the walls, 200 mm in the floor, argon-filled triple glazing with two selective coatings (U-0.8) and balanced mechanical ventilation with heat recovery.

The houses all have air change rates of below 1.5 ac/h at 50 Pa, the average being about 0.9, which is 4-5 times better than the building code requires. Actual infiltration rates, for the houses that have had tracer gas tests, are in the range 0.01-0.09 ac/h in winter weather. A number of the dwellings, both the heavily-insulated ones and those with sunspaces, are using only about 20 GJ of purchased energy annually for space and water heating. However, while high insulation and air-tightness standards seem to pay for themselves, it is proving difficult to finance sunspaces in Norway unless credit is allowed for their value as pleasant living spaces for much of the year. On the Heimdal houses, for instance, they are usable from March to November.

Masonry dwellings make up 10-20% of the new housing market in Sweden/Norway/Finland, and more in Denmark. They are usually more airtight than timber frame – ironically, in view of the performance of UK dwellings, which are largely masonry! In all-masonry construction, even though a separate polyethylene vapour barrier is not normally used, total air leakage is often low enough to satisfy the 1 ac/h at 50 Pa test, without any additional effort. Most of the air leakage occurs around doors/opening windows, and between window/door frames and wall.

Among the Scandinavian countries, Denmark has done most to develop details for superinsulated masonry buildings. Following the six Hjortakaer energy conservation houses of 1978, workers from the Thermal Insulation Laboratory, Technical University of Denmark, are planning a further demonstration dwelling to incorporate some of the most successful individual construction methods and energy-saving features. Walls will probably be a hybrid design, load-bearing dense concrete as the inner leaf and wooden cladding externally, with 300mm mineral fibre. Also, a more airtight sealing method will be used between window and door frames and walls. Although the three original masonry houses were all quite well-sealed; ie, under 0.08 ac/h in winter weather, most air leakage still occurred around windows and doors.



The Royal Garden Hotel, Trondheim. The atria are heated year-round, though the building remains fairly energy-efficient.

Problems and their solutions

With almost a tripling of insulation and airtightness levels since the mid-1970's, more than any other Scandinavian country, Sweden has not been free of problems. Yet they seem almost minor, viewed against the UK's stock of cold, draughty, energy-dependent buildings. Fortunately, other countries can take heed of the lessons which Sweden learned the hard way, so that the difficulties in, say, the UK could be even less.

Sweden has a number of condensation and mould growth problems in 1970's single-family houses, built with slab-on-ground foundations and before the key importance of forced ventilation was recognised. In houses which had air infiltration rates of below 0.1 ac/h and no other provision for fresh air, serious internal condensation was almost inevitable, especially where the damp-proof course was slightly imperfect, allowing water to evaporate into the living space. The Swedish building regulation that mechanical ventilation systems must be sized for a 0.5 ac/h fresh air input was introduced to avoid such pitfalls in the future, as background infiltration rates drop still further.

However, at some stage, the figure will probably be differentiated further, according to dwelling type. A study at Chalmers University of Technology, Gothenburg, found that a mechanical fresh air input of 0.2-0.3 ac/h was enough for good air quality in new, airtight timber-frame houses, conditional on the mechanical ventilation system being well-designed and adjusted. Only in dwellings with radon problems, which in Sweden means older houses with basements in uranium-rich soil regions, or properties built of certain lightweight concretes, would 0.5 ac/h or more normally be necessary.

Another problem has been condensation in roofspaces, although seemingly not on the UK scale. Sweden also reacted to the risk in a radically different way from this country. Workers at the Royal Institute of Technology, Stockholm, and elsewhere found that ventilating outside the insulation did not seem reliably to prevent condensation but that, if the key component – the vapour barrier – was built airtight, ventilation was unnecessary in this kind of construction. After a series of major investigations, non-ventilated tiled roofs are approved for new construction. This is particularly convenient for upstairs sloping ceilings, where a special airspace need no longer be provided between the insulation and roof coverings. In six such dwellings monitored in different parts of Sweden, the roof timbers seem to settle down near 15% water by weight, which is quite satisfactory.

Mechanical ventilation

Most specialists in Sweden believe that the problems with the better insulation and airtightness levels have basically been solved, and that the only difficult issue remaining is ventilation.

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Although virtually 100% of new Swedish buildings now have mechanical ventilation for use during the colder part of the year, there are two main opposing systems available – balanced ventilation, with supply and exhaust ducts; and exhaust ventilation, with exhaust ductwork and air inlets below windows or at another convenient place in every room. The energy consumption of balanced ventilation can be reduced; eg, by using an air-to-air heat exchanger to transfer heat from the stale exhaust air to preheat incoming cold fresh air. That of exhaust ventilation can also be reduced; eg, by using a heat pump to recover heat from the warm outgoing air for water or space heating.

Exhaust ventilation is obviously lower in capital cost. Also, in houses which are only moderately airtight by Scandinavian standards; say, 0.15 ac/h air infiltration at typical temperatures and wind speeds, exhaust ventilation gives more stable air flows within the dwelling, owing to the constant negative pressurisation. If the dwelling has electric space heating, exhaust ventilation plus heat pump may then use little, if any, more energy than balanced ventilation and air-to-air heat exchanger. In electricity-rich Sweden, exhaust ventilation seems to be gaining ground.

Balanced mechanical ventilation and air-to-air heat exchangers, although giving better comfort than exhaust ventilation, and allowing a smaller space heating system to be installed, really need more airtight buildings; say, 0.05 ac/h, to work at their best. The National Swedish Institute for Building Research has been monitoring 200 dwellings with different mechanical ventilation systems, in various parts of Sweden. Several of the balanced systems gave problems due to inaccessible controls, poor installation and balancing of air flows, and low heat exchanger efficiencies. Exhaust ventilation gave rise to complaints about draughts, although experts believe that just redesigning air inlets would prevent these.

To sum up, balanced ventilation systems with heat recovery have not yet fulfilled their energy-saving potential on a wide scale. Even the Swedes believe that they still need continuing worker education, more efficient and carefully-designed hardware, and far more careful installation and adjustment.

Divergent heating systems

In Sweden, exhaust ventilation seems to be gaining ground, in conjunction with direct electric resistance heating. This last heating system is only permitted in exceptionally well-insulated, airtight buildings – similar specifications to the planned 1985 building code. In neighbouring Norway, with vast hydro reserves, direct electric resistance heating has long been dominant, although only the larger buildings usually have mechanical ventilation to all rooms. In detached houses, exhaust fans in kitchen and bathroom, with natural ventilation elsewhere, are still the norm.

By contrast, in neighbouring Finland, where relative energy prices are more like the UK's, there has been a strong move in recent years away from traditional radiator systems towards integrated warm air space heating systems and mechanical ventilation with air-to-air heat exchangers. The energy source for warm air systems would be oil or, increasingly, district heat (DH) from combined heat and power (CHP) stations.

Denmark, with a greater percentage of DH than anywhere else in the western world, is still profitably extending it to what, in other countries, are the 'impossible' areas; eg, dispersed suburbs,

Location	Annual heating degree-hours (Kh to 21°C)	Annual average temperature (°C)	Design temperature (°C, 50 h/y basis)
Sweden:			
Malmo (56°N)	115,000	8	-13
Denmark:			
Copenhagen (56°N)	115,000	8	-12
Norway:			
Bergen (60°N)	120,000	7	-11
Stavanger (58°N)	115,000	8	-10
Scotland:			
Lerwick (60°N)	120,000	7	-8
Aberdeen (57°N)	115,000	8	-8
Eskdalemuir (55°N)	125,000	7	-10
England:			
Newcastle-upon on-Tyne (55°N)	110,000	9	-7

Table 1: Design temperatures for the UK and Scandinavia

villages near to district-heated towns/cities, and superinsulated houses using 20-25 GJ/year of space plus water heat. Even the natural gas coming ashore from Denmark's North Sea fields may be used increasingly in CHP stations, in preference to the less energy-efficient option of piping it to individual boilers in buildings.

There is a move throughout Scandinavia towards using much lower temperatures in central heating systems, well below the conventional figures of 70-80°C. To maximise long-term flexibility, Sweden insists that all new dwellings with the standard heat-saving measures have a low-temperature water or air-borne heating system, which can readily be changed from one primary energy source to another. Direct electric resistance heating is not flexible in this way, and is not permitted in such buildings.

It is now normal in Sweden to size radiators for water temperatures of only 55°C supply, 35°C return on the coldest winter day, when the outside temperature is around -15°C outside in the south of the country and -30°C in the north. Denmark and Finland have largely followed suit. A typical radiator heating system would now work at peak temperatures of just 60°C/40°C. Naturally, warm air or floor heating would use even lower temperatures.

Costs and benefits

As in North America, it is being shown that, with careful design, superinsulated houses can be built at little more cost than traditional houses. For example, virtually all new Swedish single-family houses meet the airtightness standard of 3 ac/h or less at 50 Pa. To reduce this to 1 ac/h at 50 Pa, as the new building regulations may require, seems to cost as much as £400 in a typical 1½-storey, 160m² timber-frame house, making ad-hoc changes to past building designs. However, by redesigning thoroughly to make a continuous, sealed vapour barrier easier to attain on the building site, the extra cost drops to nearer £150. Also, the capital cost of the space heating system falls slightly. At the southern end of Sweden, in a climate as cold as Newcastle-on-Tyne or Edinburgh – 10% colder than the UK average – the measure then saves heat for £3-4/GJ, so that it is quite cost-effective at present energy prices.

As a second example, it may cost £250 in the same house to increase the wall and roof insulation by 50 mm mineral fibre, using conventional framing techniques. Using the so-called light building components; eg. timber/hardboard beams filled with hard rock wool, the same improvement may only cost £150. To go from about 200 to 250 mm mineral wool in the walls and from 250 to 300 mm in the roof, the cost of heat saved is about £2/GJ in southern Sweden, so that such changes are very profitable at present energy prices. When 200mm or more insulation is needed in a timber-framed building, the light building components almost always provide the cheapest solution.

Overall, most experts in Sweden agree that the current building standards were introduced with remarkably few problems. Costs for better insulation and airtightness have consistently been less than the construction industry predicted in the mid-1970's, when it was alleged that the proposed doubling of insulation levels and halving of air leakage rates would raise building costs too much. In fact, all the changes seem to have been extremely profitable, and a few prefabricated housing companies now claim to be mass-producing super-insulated houses – with 200-300mm mineral fibre, triple windows with one selective coating and 0.4-0.6 ac/h at 50 Pa – for the same cost in real terms as relatively 'leaky' houses a decade ago.

Even though the energy efficiency improvements now being used, or considered, in Sweden, are cost-effective to the nation, they may still have payback times of 8-10 years or more if considered from the private viewpoint. However, financing them in new homes is simple, because virtually all consumers buy their house or flat with the aid of a state housing loan anyway. In practice, this works like an index-linked mortgage, with first year repayments of under 5% of the sum borrowed. To householders, the minor increase in mortgage repayments is outweighed, from the first day, by the saving on heating bills – a saving which will continue, year, after year, far into the future.

Lessons for the UK

A common perception is that the UK has mild, gentle winters, whereas Scandinavia is a land of deep snowdrifts and bitter cold, making its experience irrelevant. This is quite misleading. The northern UK has similar average temperatures to southern Scandinavia, and the design temperatures are not very different, as *Table 1* indicates.

Relative humidities in these parts of Scandinavia are also similar to the UK, so that the condensation risks and potential moisture problems with various building practices are really little more or less in; say, Edinburgh than in Malmo.

Such figures suggest that, if the Danish or Swedish climates justify exceptional efforts to keep out the cold, then so does the Scottish climate. There is a powerful case for new buildings in the northern UK adopting the Scandinavian insulation and airtightness standards, together with forced ventilation to provide fresh air during the colder part of the year. Even in the southern UK, field trials would be worthwhile. If we make this effort, we have much to learn from recent research and development work in Scandinavia.

David Olivier is an independent energy consultant specialising in efficient energy use and renewable energy systems. This article is based substantially on a study trip to Scandinavia made in spring 1984. Copies of the main report on that trip, and colour slides on most of the topics covered, are available from the author.

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