FEATURE

ENERGY EFFICIENT HOMES

THE NORTH AMERICAN EXAMPLE

David Olivier

This article outlines North America's startling progress with energy-efficient housing over the last few years. It cannot give a complete picture, but covers some of the most interesting projects.

The key point to emerge from a 1985 fact-finding trip is that, over the last 2-3 years alone, North America has made more practical progress with efficiency and renewables than the UK has made in the last decade. The activity is highly dispersed among federal agencies, state, county and town governments, voluntary and private sector organisations. However, added up, it is starting to change the face of the North American energy system.

Even in temperate regions, authorities in North America ensure that new dwellings are fairly well-insulated and sealed, and have effective heating systems. Most new timber-frame houses have 200-250 mm mineral or cellulose fibre insulation in the roof (U-0.15 or 0.20 W/m^{2}K), 125-150 mm in the walls (U-0.3 or 0.35), double glazing with insulated and weatherstripped external doors. Masonry dwellings have comparable measures.

The wall of 40 × 90 mm (the so-called 2 × 4") wooden studs, with only 90 mm (3½") insulation, is vanishing from the scene. The single-glazed window has disappeared in the cooler climates; indeed, in the whole USA, including the sub-tropical southern half, triple glazing has 20% of the new window market and double has over 50%. In addition, a few million windows are of newer types, such as Heat Mirror, with an energy performance even superior to triple glazing.

New Superinsulated houses

In the cool and cold regions, probably 30,000 houses are the 'superinsulated' models pioneered in the 1970's. Combining heavy insulation, high-performance windows and — most important — airtight construction, usually with less than 0.1 ac/h air infiltration, they are reducing heating costs to trivial levels, even for large houses in harsh climates.

No exact definition has been settled on. However, common practice would be to insulate with 300-400 mm glass fibre (U-0.09-0.15) in fairly cold climates, with the same heating degree-hours as Scotland, and 200-300mm (U-0.12-0.2) in more moderate climates, resembling southern England's.

Several companies are building entirely 'superinsulated' houses. A firm in Toronto, Canada, routinely designs and builds houses with under 0.5 air changes/hour at 50 Pa pressure — equivalent to about 0.02 ac/h of air infiltration in winter. One in Gorham, Maine, USA, achieves 0.15 ac/h at 50 Pa on all its new construction as a matter of course. At least two other firms across North America achieve below 0.2 ac/h at 50 Pa, a level unmatched anywhere in the world, not even in Sweden (see *Energy in Buildings*, Mar-Apr '85). These buildings are 25-100 times more draughtproof than modern UK houses!

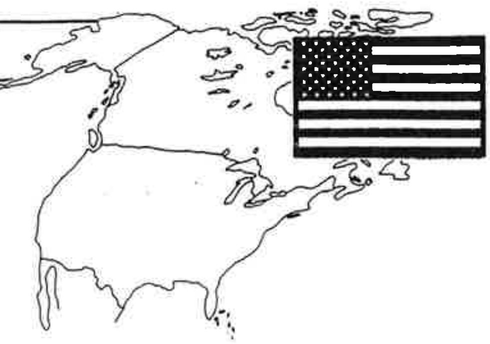
Mechanical ventilation and heat recovery is an integral part of such dwellings, to ensure good indoor air quality. In winter, windows are closed and the house is mechanically ventilated at usually 0.3-0.6 air changes/hour, depending on the number of occupants, living habbits, etc. So far, this is giving excellent air quality, probably better than in old houses which depended on random air leakage through accidental cracks and holes. In regions with cool summers, householders usually turn off the mechanical system in late spring, and open windows for summer ventilation.

Effective implementation of energy-efficient housing

Canada is steadily progressing with its R-2000 program, which will involve expenditure of about £30M between 1983 and 1990. Thousands of builders voluntarily improve the energy efficiency of their houses, close to superinsulated standards, and obtain the home-buyer's agreement to monitoring of its energy performance for the following two years. In exchange, the government pays for the time taken to educate workers in new procedures, prepare new construction drawings and carry out the extra publicity and marketing. For the first R-2000 home a firm builds, it receives about £3,000 towards these one-off costs. By 1990, government and industry expect that about 20% of new dwellings will be R-2000 homes, without the need for any legislation at all.

So far, 1,000 R-2000 homes have been pressure-tested. Preliminary results are that the houses average 0.8 ac/h at 50 Pa; i.e., 4 times better than the Swedish standard, 20 times better-sealed than British dwellings and 2 times better than the standard which the Canadian government set specifically for the R-2000 program. Their annual average space heat consumption, again preliminary, is 0.1-0.15 GJ/m^2, somewhat more in very cold climates and less in temperate ones.

Quite often, the main marketing points for superinsulated houses are not just their energy efficiency, and the reduced outgoings; i.e., energy plus mortgage costs, but their unique thermal comfort. Most occupiers state that, after experiencing draught-free, uniform warmth for the first time in their lives, they would not wish to live in a conventional, leaky house again.



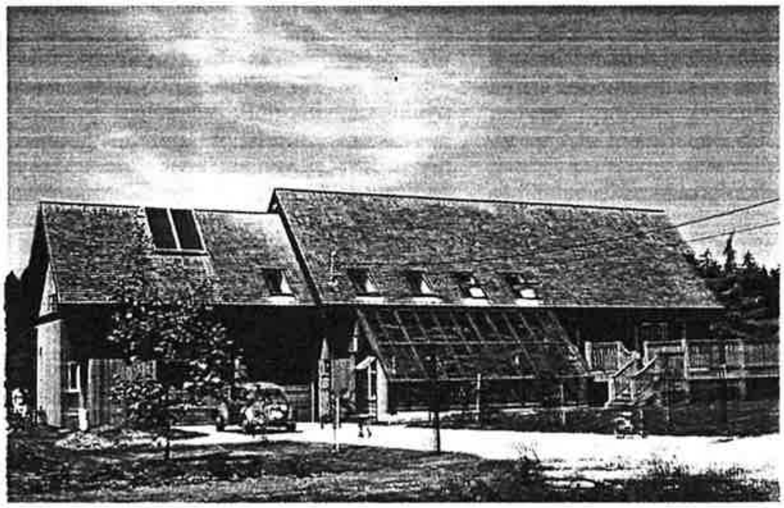
Projects — USA

Colorado

Near Aspen, the 400 m² headquarters of the Rocky Mountain Institute, founded by Amory and Hunter Lovins to research the sustainable use of resources, is a showcase for energy efficiency. Although custom design and unusual construction materials greatly raised costs, the energy-efficient design features only added £5,000. The energy bills of the house and office together are around £250/year, while a conventional local building of similar size and function, with propane space heating, would cost £4,000/year. Interesting devices include a compressed-air shower which uses 90% less hot water than usual, and fridges/freezers — now in pilot production in California — whose electricity usage is 95% less than the North American average.

The building shell is so well-insulated and tightly-sealed that, given high mass construction and a sunny climate, space heat consumption is zero and about 30% of the solar and internal heat gains over the winter are merely vented. A woodstove was fired-up during drying-out phase and while there were still 'holes' in the building. Now, it is more for ornament than for any practical purposes.

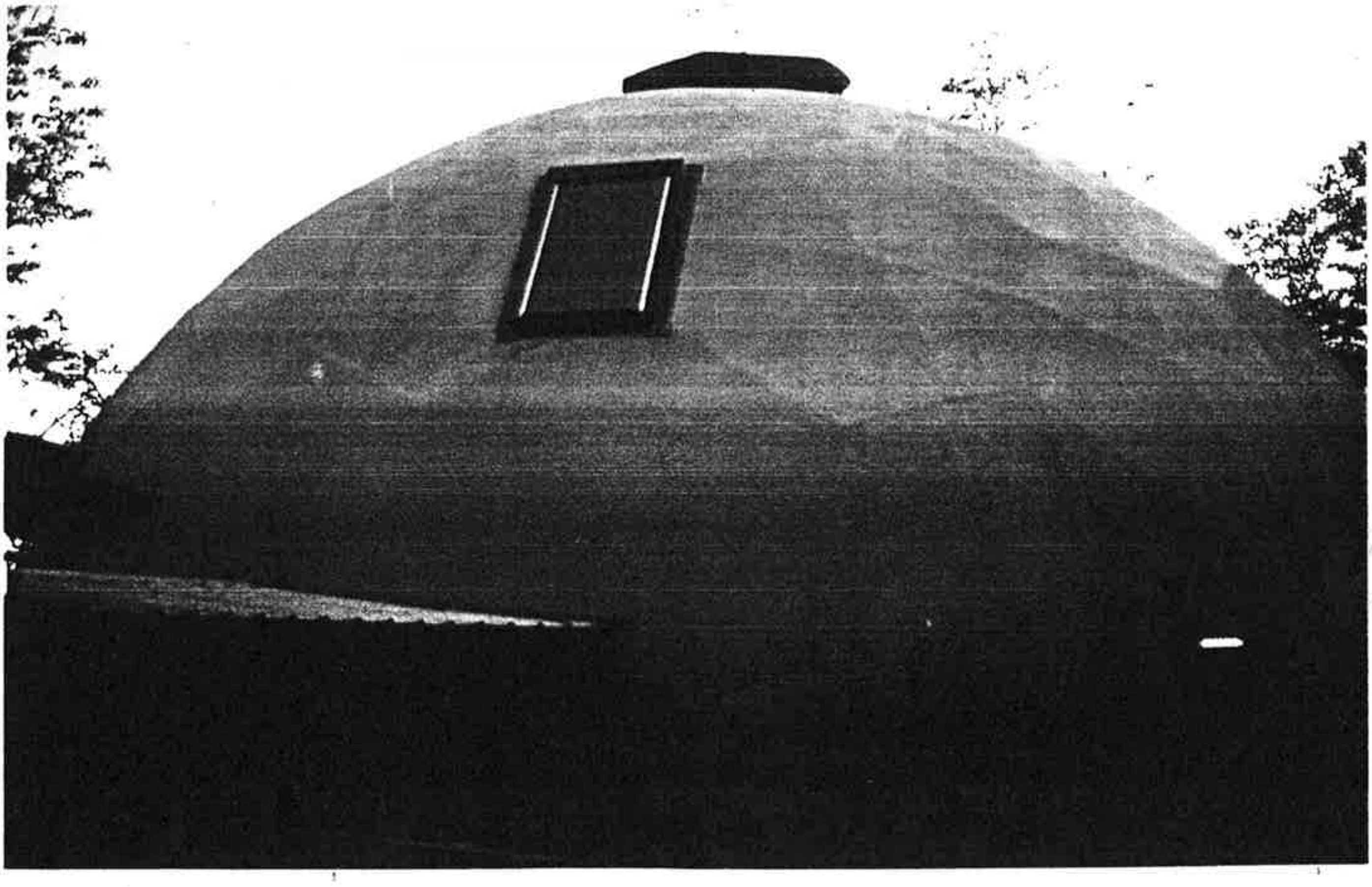
Walls are cavity masonry, with inner and outer leafs of 150 mm local stone. Cavities contain 100 mm slabs of foil-faced polyurethane foam, whose aged thermal conductivity is warranted at only 0.018 W/mK, and the overall wall construction is about U-0.16. Windows are argonfilled Heat Mirror; i.e., U-1.0 — even the greenhouse, which is not isolated thermally from the rest of the building. Since the structure stays within a few degrees of 21°C all winter, the greenhouse is suitable for germination of seedlings, and pawpaws and other exotica flourish.



Left: The Duncan House in Victoria, British Columbia which has an annual space heating bill of £10. Below: The Anderson House, near Northfield, Minnesota

Montana

Buffalo Homes, in Butte, constructs about 1 'ready-to-move' building/week, mostly detached bungalows and small



commercial buildings. The houses are guaranteed to have air leakage of under 1.0 ac/h at 50 Pa — in practice, they all have under 0.5 ac/h at 50 Pa. The electric space heating bill for a 150 m² house, at £9/GJ, is guaranteed to be below £70/year; ie., a heat consumption of under 8 GJ.

In fact, Buffalo used to guarantee heating bills of under £35/year, with no complaints, but customers did not believe it, so the limit was doubled. This is perhaps understandable; Butte has one of the coldest climates in the USA (coldest month average temp. -6°C, warmest month 19°C.)

Unexpectedly, these houses sell for virtually the same price as other prefabricated US houses — around £320/m² floor area, including all except land. The cost of extra energy efficiency improvements, above a 'building code' house, is £10/m² at most, insignificant in the context of total US house prices, which are on par with those of south-east England.

The houses all have U-0.10 roofs, U-0.13 external walls and polyurethane foam-insulated external doors. Windows are airtight even in a 80 km/h storm, and contain double glazing with one selective coating. Walls are double stud construction, with three successive layers of glass fibre; i.e., they have 90 mm between inner studs, 150 mm in the centre airspace and 90 mm between the outer studs, for a total of 330 mm. Ceilings usually have 400 mm cellulose fibre. All buildings have mechanical ventilation, usually with the Van Ee air-to-air heat exchanger, which is a common model in western North America.

Also in Butte is the federally-funded National Centre for Appropriate Technology. Its most impressive work has been as a resource centre for information on energy efficiency and renewables that the public find dificult to obtain through conventional channels. It provides a free nationwide, technical advisory service, funded by the US Department of Energy. Numerous publications cover everything from condensation problems in buildings, and how to provide combustion air to gas appliances in virtually airtight houses, to how to superinsulate your old house and reduce its heating bill by 80-95%. Montana has a large number of old, 19th century houses and flats with 330 mm solid brick walls — of the same type as the UK's 10M solid-walled dwellings — so the last subject is of considerable importance to the UK.

Studies by NCAT generally showed that the small, 'through-the-wall', air-to-air heat exchangers marketed since the late 1970's were not a good solution to the air quality problems experienced in tightly-built houses. The consensus is that central air-to-air heat exchangers and a full ductwork system to all rooms provide much more effective ventilation, although the Swedish system of exhaust ventilation and air-to-water heat pump, with air inlets in all rooms, is promising for moderate climates, especially regions with cheap hydro-electricity.

Oregon and Washington states

In the coastal north-west USA, despite a temperate, maritime climate, dramatic increases in insulation and airtightness levels are proving economic. Many authorities in Europe have doubted that heavy insulation and airtight construction is worthwhile in moderate climates. However, after government training and demonstration programs, most builders can construct a new house with U-0.15 or -0.20 walls, triple glazing, under 0.1 air changes/hr (ac/h) air infiltration, and mechanical ventilation, so cheaply that

the savings on heating costs easily compensate owners for the extra mortgage payments.

UK utilities still do not consider improved energy efficiency an alternative to investing in new energy supplies. In contrast, the north-west USA's legislation demands that public authorities invest in improved energy efficiency whenever it costs less than investing in new electricity supply. This region of 8 M people is gearing up to invest about £20 billion of public funds in energy conservation over the next 15 years.

Throughout the north-west USA, most town and city councils — which adopt and enforce their own building regulations — will make superinsulation part of the building code by 1989. Several have already adopted the model code recommended by the North-West Power Planning Council, the regional agency set up to manage the transition to the new era of energy efficiency. Those that lag behind will be surcharged on their wholesale supplies of electricity by the federally-owned Bonneville Power Administration.

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Projects — Canada

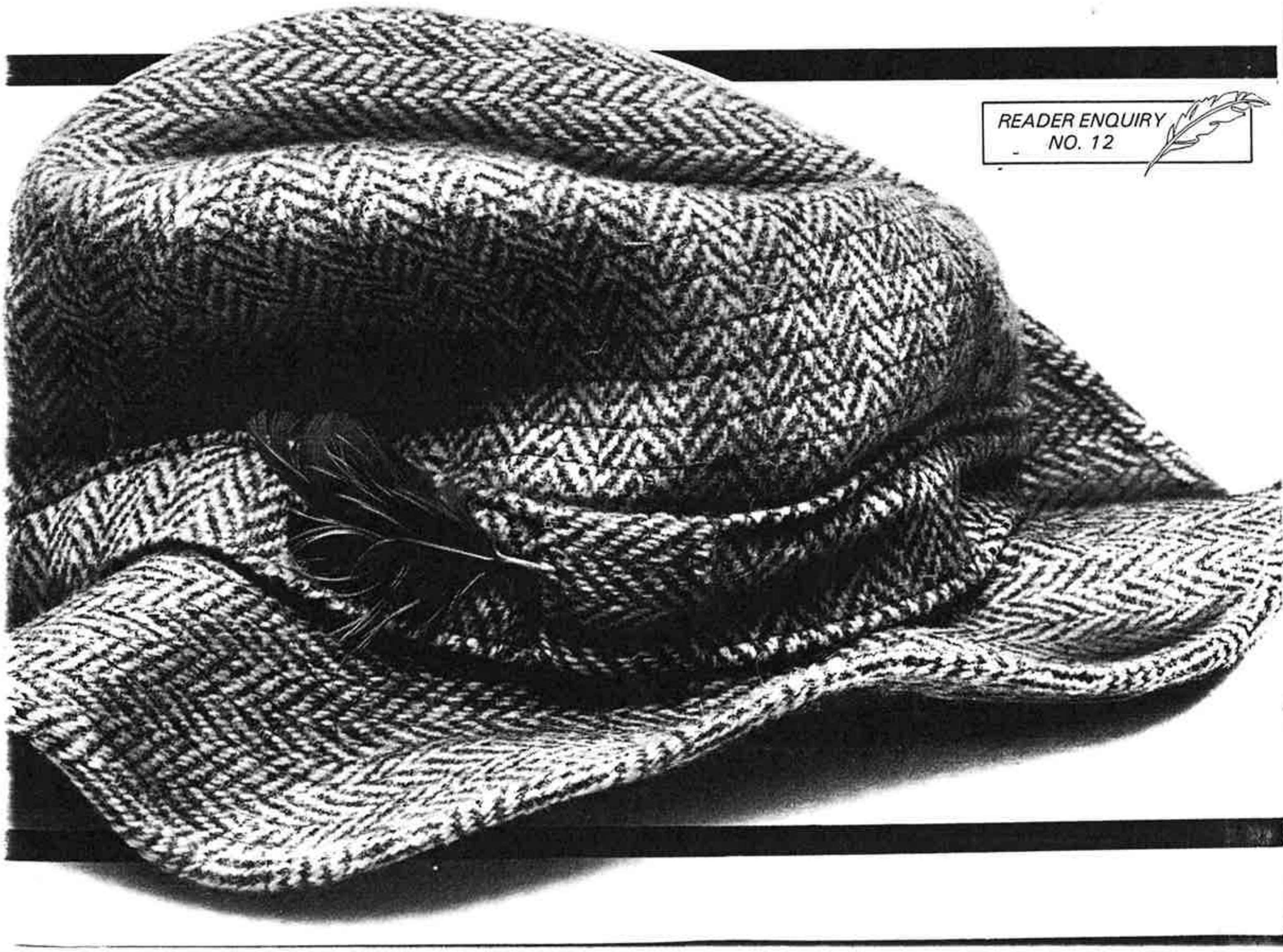
Toronto, Ontario

The firm of Allen-Drerup-White Ltd is building about 40 superinsulated dwellings/year, up from a negligible number 10 years ago, together with some public and commercial buildings. All their new dwellings have air leakage of under 0.5 ac/h at 50 Pa. To illustrate the general level of energy efficiency, one 3,000 m^2 bungalow and its basement are heated satisfactorily by a single wood-burning fireplace, with an outside air supply and other energy-efficient features.

ADW designed and built a super-insulated church near Ottawa. Though 700 m^2 in floor area and generally 6 m high; i.e., almost 4,000 m^3 of heated volume, it costs £250/year to heat electrically. It was even found to overheat slightly in the choir area during services, so the local ventilation rate was raised slightly. The entire building has triple glazed casement windows. The above-ground timber frame walls contain 140 mm glass fibre plus 50 mm of insulation between internal cross-hatching; i.e., a total of 190 mm, giving U-0.10. The sloping ceilings have 300 mm; i.e., U-0.14. The concrete basement walls have 100 mm extruded polystyrene on the outside, with a stucco finish above ground.

The showcase 400 m^2 Toller house in Ottawa, now four years old, performs as well as the day it was built, with a total gas bill for space/water heating, and cooking of about £100/year. Although energy consumption was not submetered, the space heat proportion is thought to be £0-10/year.

The Toronto house of Greg Allen, a partner in ADW, is an exemplary super-insulated retrofit. During major rehabilitation, an extra floor was added to an existing bungalow, creating a 150 m^2, two-storey house, plus the old unheated basement. The gas heating bill is now about £80/year whereas, if one had done the bare minimum to improve the energy efficiency of the existing structure, the bill would be at least £700/year. The following measures were important:



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(a) The old insulated timber-frame walls; with 90 mm glass fibre; i.e., U-0.5, were upgraded to about 300 mm; i.e., U-0.14. This was done by hanging 200 mm non-structural trusses on the outside of the old wall, after the roof was finished. A similar technique was used for the walls of the new building;
(b) The roof of the new building had 400 mm cellulose fibre; i.e., U-0.09,
(c) Most old windows were replaced by new, tight, triple glazed ones;
(d) The few windows in good condition were double glazed and weather-stripped;
(e) The walls were fitted with a continuous polythylene vapour barrier before adding the extra 200 mm of insulation externally.
(f) A mechanical ventilation system was installed, based on the Air Changer, a common air-to-air heat exchanger in eastern North-America.

Peak space heat demand is now about 3 kW at the design conditions of 20°C inside, −17°C outside. The energy efficiency improvements added £2,500-£3,000 to the cost of the rehabilitation; consequently, they are very profitable, even at present low Canadian gas prices.

British Colombia

British Columbia has numerous energy-efficient houses, mostly built since 1980. Essentially, as a starting point, architects took either the hundreds of thousands of passive solar houses, 'full of glass and mass', built in the USA since the 1970's, or the pioneering Saskatchewan conservation house — 'built light and tight', which was constructed in the Canadian prairies in 1977 and started the current trend towards 'superinsulation'. With varying success, they tried to redesign these houses in a manner appropriate to British Columbia's maritime, cloudy climate.

The houses based on the passive solar houses of sunnier climates contain considerable added thermal mass; e.g., internal concrete walls, plus large south windows. Often, a lean-to greenhouse produces surplus heat for storage in the mass of the building, or in an isolated rock-bed below the ground floor. However, in north America, such added mass adds considerably to the cost of small, domestic-size buildings.

The trend now is towards 'superinsulation'. A fine example is a house in Victoria, on Vancouver Island, which Mr Bob Duncan finished in June 1983. There is no added thermal mass beyond that present in the normal building materials. However, in its insulation and airtightness levels, the house is almost a direct copy of the thousands of superinsulated houses in the Canadian prairies. Experience suggests that what performs well, economically and technically, in the prairies' severe cold also works superbly in the milder, cloudy conditions of Victoria.

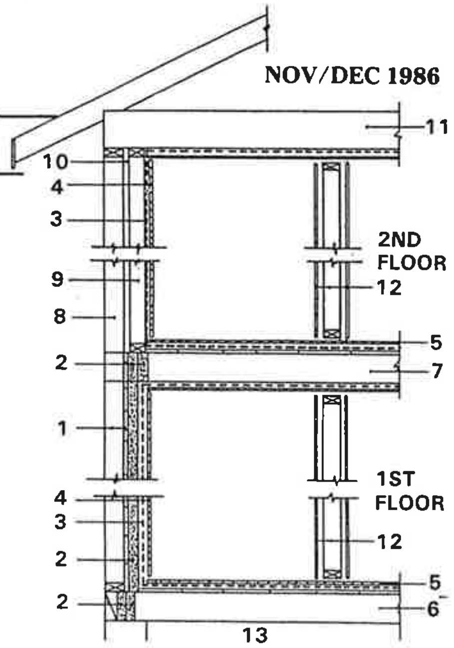
The house contains 320 m² of floor-space, plus a lean-to greenhouse on the south wall. The basement also has a separate, insulated 'cold room'. The house's external walls have 300 mm glass fibre; i.e., U-0.15, the roof has about 400 mm; i.e., U-0.11, and the crawl space, including its walls, has 250 mm; i.e., U-0.17. The windows are triple on the north, including some skylights, and double on the south side, with insulating shutters. The external doors are foam-filled steel; i.e., U-0.6. The entire house has a tightly-sealed, continuous polyethylene vb. The air infiltration rate with doors and windows shut is about 0.03 ac/h. A Van Ee air-to-air heat exchanger ventilates the entire house in winter at about 0.3 ac/h.

Bob Duncan did not install a space heating system, reasoning that little heat would be needed. In the first winter, a few incandescent lights were left on during extremely cold nights, which, for Victoria, means down to −8°C. In the second winter, 1984-85, the house was heated by a sub-metered electric radiator, and some space heating was required to maintain the normal 18-19°C thermostat setting for the whole house. Still, a £12/year electric heating bill for a 320 m² house; i.e., a heat consumption of 2 GJ, at £6/GJ, is a revelation.

The decision to superinsulate was taken late in the design process. Consequently, a conventional forced air space heating system was originally priced for the same house, but just meeting local building regulations. Quotations were in the range £3,000-£4,500. Even at £3,000, omitting the space heating system paid for the improved insulation, airtight construction and mechanical ventilation system. So, the house cost essentially the same as a standard British Columbia 'building code' house.

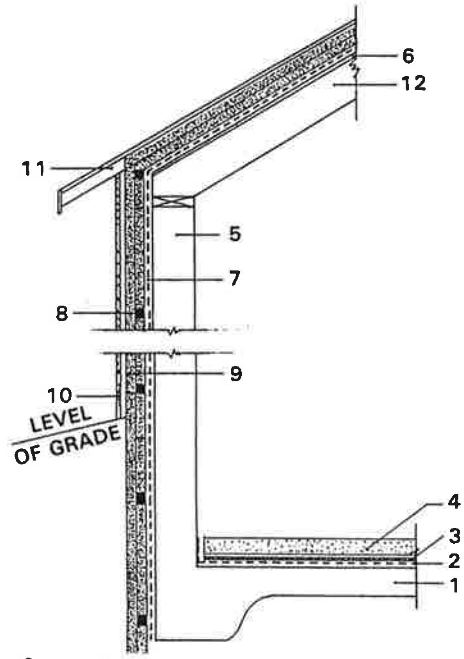
The house has an active solar hot water system. By significantly oversizing the collectors, relative to the standard 4-6 m², it gives a 95 per cent solar fraction in Victoria's rather cloudy climate. Normal short-term heat storage is used. This is one of the best-designed solar systems for temperate climates that the author has seen.

Since 1983, the builder of the Duncan house has found lots of follow-on business in constructing highly energy-efficient houses for other customers. It is deeply ironic that Vancouver Island, with a population of barely 500 000 has more superinsulated houses than the whole UK.



Superinsulated retrofit project in timber-framed house in Ithaca, New York State.

1. Existing wall cavity and planking filled with cellulose; 2. 2¼" Thermax insulation; 3. Air-vapour barrier; 4. 5/8" Drywall over air-vapour barrier; 5. 1/2" Plywood over air-vapour barrier; 6. 6" Fibreglass insulation; 7. 6" Cellulose insulation; 8. Existing framing; 9. New 2x4 exterior frame wall; 10. 9" Wall cavity filled with cellulose insulation; 11. 15" Cellulose insulation; 12. Interior partitions and drywall; 13. Unheated basement.



Superinsulated retrofit project in masonry house in Ithaca, New York State.

1. Existing concrete slab; 2. Air-vapour barrier; 3. 1/2" Thermax insulation; 4. New 4" slab; 5. Existing block wall; 6. Existing roof sheathing; 7. Air-vapour barrier; 8. Horizontal strapping 24" O.C; 9. 4" Thermax insulation. 10. Strapping, lathe and stucco; 11. 2"x3" rafters, sheathing and roofing; 12. 3½" fibreglass in rafters.

David Olivier is principal of Energy Advisory Associates, Milton Keynes, a consultancy specialising in efficient energy use and renewable energy systems.

This article is mainly based on a 1985 fact-finding trip to North-America. A detailed report, 'Energy efficiency and renewables: Recent north American experience,' is available from Energy Advisory Associates, 15B Bradwell Road, Bradville, Milton Keynes, Buckinghamshire, MK13 7AX, tel (0908) 314381. £45 each including UK postage. Prepaid orders only. An accompanying slide set is also available.