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Pooled resource

Ground-coupled ventilation has gone a step further in Australia. Roderic Bunn examines a Melbourne school where supply air will be drawn through water-filled foundations, quadrupling the passive cooling capacity

Australia is a continent of extremes. In summer, temperatures can soar into the mid-forties celsius, but even for a coastal city like Melbourne, hail and snow in winter is not unknown.

These characteristics don't make life easy for designers trying passive solar design. Full air-conditioning is the norm and given that electricity in Australia is 95 percent generated by dirty brown coal, low carbon design is rather a challenge.

In the Broadmeadows district of Melbourne, a new primary school is under construction that takes ground-coupled ventilation to a new level. A gaggle of school buildings that make up the Meadows Primary School are being constructed over foundation beams created by sealed water tanks. Ventilation pipes traverse the water tanks, carrying supply air drawn from outside.

Supply air will be induced through the pipework, into the occupied space via displacement grilles, and out of the building by wind-assisted thermo-siphoning. Even at 40°C external ambient, the cooling effect of the tanks is predicted to reduce incoming supply air to 15°C - the average annual temperature of the clay substrate.

So how is it being done? More importantly, will it work?

Project background

Meadows Primary School is part of a major Australian schools rebuilding programme, the AUS $16 bn Building Education Revolution (BER). The BER is similar to the UK's Building Schools for the Future initiative (see box).

The State of Victoria is investing AUS $1.9 bn into the Victorian Schools Plan, a programme that will take approximately four years to complete. As usual with schools, money is tight, on-site premises management expertise is often lacking, and physical resources are precious - especially water.

The Meadows Primary School comprises a number of single-storey timber-framed buildings of 3477 m² (gross floor area) housing classrooms,

EDUCATING AUSTRALIA

The Building Education Revolution (BER) is a national AUS $16.2 bn (£8 bn) programme designed to deliver 24 000 new libraries, halls, classrooms and science and language laboratories in Australia's 9500 schools. The investment is regarded as recession-busting construction work, an element of the AUS $42 bn economic stimulus package introduced by the Labour Government of Kevin Rudd.

There is widespread criticism of the BER in the national press, including claims of inflexibility, inflated prices and site management fees by contractors of between 12.5 and 16.5 per cent. Many of the complaints have originated in New South Wales (the State for Sydney) where the state government set up a team of auditors to keep track of projects.

Above: The school's plan is formed by combining modules whose cross-sectional shape induces airflow. The long walls of the gymnasium will be formed by a dual skin of translucent corrugated fibreglass sheet. This aims to give even natural lighting during the day and allow heat harvesting or rejection by flap controls.

adminstration offices, staff areas, a kitchen and a large sports hall. Construction is due to be complete by November 2010.

The basic layout involves seven buildings constructed on 17 m² modules arranged around a central courtyard. The project's sustainability credentials include timber-framing, high levels of fabric insulation and various forms of active on-site energy generation, such as a 6200 kWh per annum wind turbine and 15 900 kWh per annum from photovoltaics.

All this is overshadowed by the school's most innovative engineering: the integrated structural water storage and ventilation system. This involves the concrete raft foundations sitting on water filled trenches in which are run the school's air supply ducts.

Each trench is around 1 m deep. In total the tanks are storing around 600 000 litres of water. The tanks are filled with load-bearing, clip-together void formers made from recycled plastics. These can carry 11 tonne/m² which enables the structural loads to be shared between the tanks (and the soil inbetween) rather than through more substantial concrete footings.

It is estimated by the architects that the load bearing tanks saved over 300 m³ of concrete in comparison to a more conventional approach. Although some concrete piles have been sunk to take some of the main room loads, only four internal columns per classroom module are required.

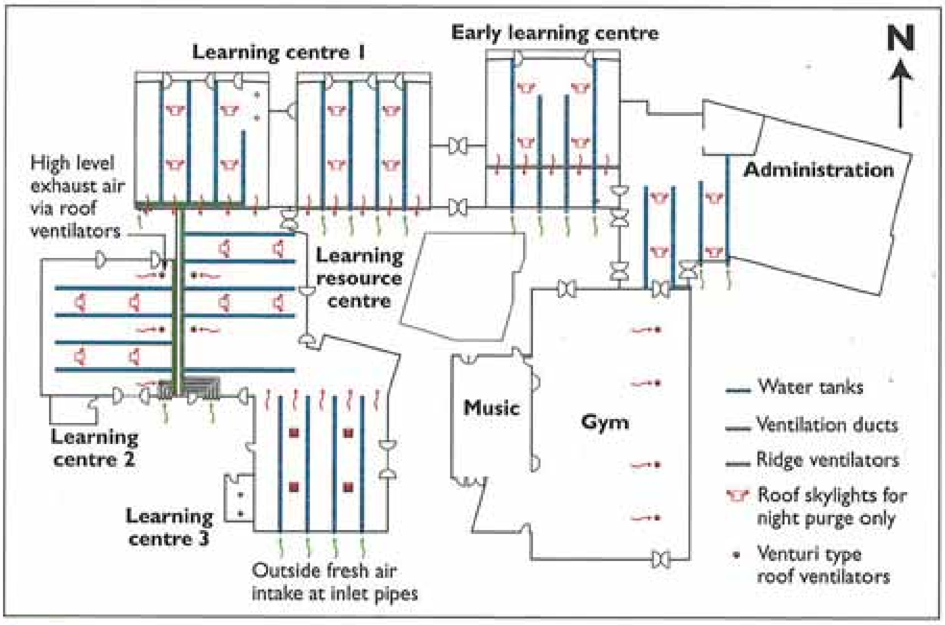
Each tank contains a single 300 mm diameter plastic air duct that enters from a header at one end of the tank. The duct runs down the centre of each trench, with load-bearing crates stacked either side, then loops back on itself. Holes cut in the top of the duct allow spigots to be heat welded in place.

The spigots penetrate above the slab to serve as air supply points. The tanks themselves are encapsulated by plastic liner, heat-welded and pressure tested to ensure water tightness. Ventilation air is drawn through tubes in the underfloor tanks to be discharged through channel recesses in the floors.

The air is tempered by the water tanks to provide cooling in summer and to raise the temperature of external air in winter. The logic behind the water-based ground-coupled ventilation is based on ground temperature, at 2 m depth, holding at a near constant 15°C all year round.

"The thermal capacity of water is over twice that of clay soil and three times that of concrete," said project architect Neville Cowland of Now Architecture. "That's where we started. 1000 litres per 10 m² will give us enough heat exchange to provide supply air at 15°C in summer."

The water storage is claimed to provide a four-fold increase in heat



Above: The plan form of Meadows Primary School showing the arrangement of water tanks beneath the structural concrete slabs, the four structural columns per 17 m² building module (shown in the learning centre to the south), and the rooflights in the other modules. Note that in Australia the sun shines on the north elevation.

INTEGRATED STRUCTURAL WATER STORAGE

Step 1: Dig a trench. Line it with a liner commonly used in Australia to create underground water tanks. The former school on the site used diesel generators, and construction work was delayed while the site was excavated by 2 m to remove contaminated soil.

Step 2: Clip together the load-bearing plastics crates (recycled car bumpers) which are said to be 98 per cent void. Install the ductwork, locating and supporting them in frames.

Step 3: Cut holes for supply spigots. **Inset:** The spigots themselves are heat-welded onto collars and sealed into position. Pressure test the ductwork to ensure integrity before filling the water tanks.

Step 4: Wrap up the tanks and seal them once the ductwork sections have been pressure tested. Top-hat sections seal the spigots above and below the water line to the tank liner. These have yet to be welded to the liner over the ventilation spigots, which can just be seen straining against the now-sealed water tanks. **Inset:** Architect Neville Cowland checks the the seal of the top-hat sections with the contractor.

transfer capacity compared with dry ground.

The physics of all this was checked out by running various water tank and duct configurations through computational fluid dynamics (CFD) modelling. The Flovent software tool helped the designers to determine laminar flows and air volumes and to optimise the balance between duct size and length.

"Poor ventilation in schools is a major problem in Australia," said Judith North of Now Architecture. "The major objective here was to get air moving through the school without energy penalty."

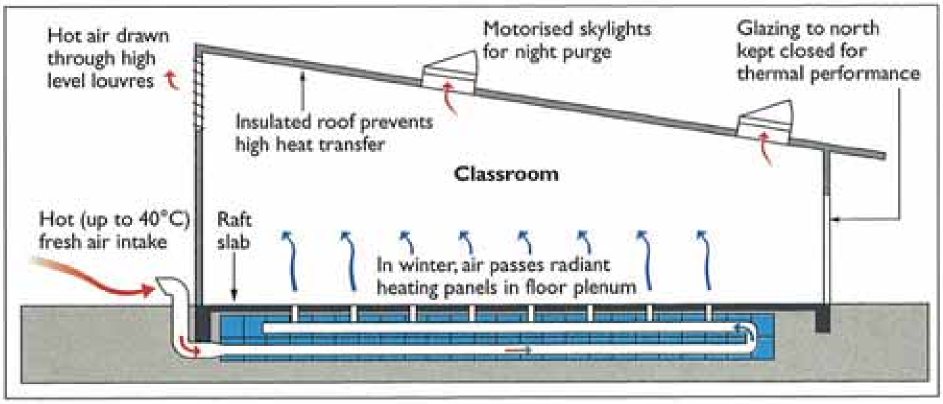
Outlets of 150 mm diameter will therefore discharge tempered air to the occupied spaces by the displacement principal, each outlet serving around 12 m^2 of floor area. Air supply will vary as ambient external temperature increases, air movement induced and modulated by varying the opening of louvre windows and skylights at high level.

Taking 35°C as an example external ambient summer condition, the modelling confirmed that the ventilation system could deliver approximately 30 litres/s of tempered air from each outlet to approximately at close to 15°C.

In heating seasons, the supply air will be heated by a conventional hydronic system serving finned tube radiators located in ventilation channel recesses run in the floor. This is regarded as the most effective and efficient method of heating: retaining, as it does, the heat at low level without loss to ventilation systems.

The heating will be zoned by using separate small on-demand gas hot water units to supply heat to the school modules, with emitter capacity between

Right: Cross-section of a typical classroom module and water tank, showing the operating condition for the summer months. The air intakes will be from large funnels feeding into a slightly enlarged (375 mm) pipe. Fabric airtightness will be crucial for ensuring that the supply air traverses the air ducts rather than short-circuits through intentional and unintended gaps in the facade.



8-10 W/m² depending on design load. Each zone will be controlled by individual thermostats and timers.

The school's environmental systems were run through Australia's environmental rating tool, Greenstar, the Australian equivalent of BREEAM and LEED. Meinhardt (Vic) Pty Ltd undertook the energy modelling and estimated the energy consumption as per the *Greenstar Education Energy Calculator Guide.*

The assessment awarded the school a score of 14 stars out of a possible 20. Total greenhouse gas emissions (at the time of design) were estimated at 17·6 $kgCO_2/m^2$ per annum. Compared to Australian norms, this equates to a saving of 149 347 $kgCO_2$ per annum between the proposed building and the prevailing Greenstar benchmark, which is a percentage reduction of 71·5 per cent.

For the record, the carbon dioxide conversion factors currently applicable in Australia are 0·45 for natural gas, 0·50 for oil, 0·8 for black coal, and 1·2 for brown coal. Australia's electricity is 95 per cent coal-fired.

System assessment

So will it work? The key variables are more likely to be behavioural rather than technical, but it's worth looking at the technical variables first.

At first glance the system seems counter-intuitive. How can a passive cooling system work in a region with such extreme climate? Melbourne has winter temperatures below 8°C in the day and summer daytime temperatures up to 44°C and little in the way of wind. Will there be enough thermal bouyancy for hot air to be drawn down into tanks as enthusiastically as the thermal model would suggest? Will the stack effect be strong enough to drive a thermosyphon?

Lots of questions that will only be answered in operation, but the designers have run the simulations and seem satisfied that the tanks will do their job. Of course, it largely depends on the assumptions and boundary conditions dialed into the CFD model.

The water tanks are justified on the calculation that their thermal capacity will be over twice that of clay soil and over three times that of concrete.

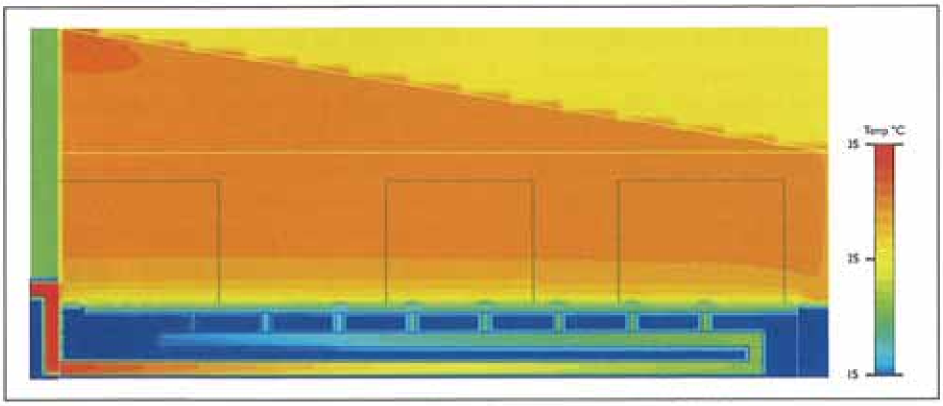
"Water speeds up the [thermal transfer] process enormously," said Neville Cowland. "That's the beauty of water: the water keeps flowing so the energy transfer happens 24 h/day and we keep transferring heat back into the ground."

One of the major differences between ground-coupled ducts run adjacent to a property and a thermolabyrinth as part of a building's foundations is that the latter tends to heat up over time and requires periodic purging. Could the same effect occur here?

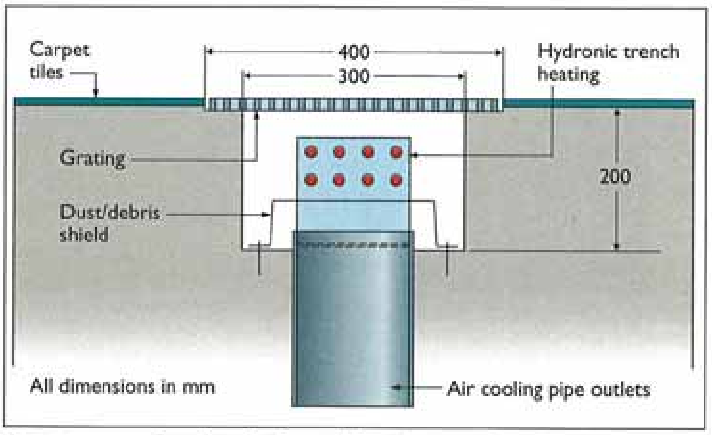
"The ground will heat up," says Cowland "but have a big surface area, and we understand that with 1000 litres per 10 m² we effectively have an infinite source of heat." The water in the tanks will also form part of the water recycling system for toilets and irrigation. Combined inlet filter and outlet pump pits connect to the tanks.

The next issue is simply one of buildability and robustness of components that, once buried under a concrete slab, will be inaccessible. Failure of the tanks from punctures to the liner, or leakage into the air ducts through joints, will be difficult if not impossible to fix.

Fortunately, Australian builders are well-versed in constructing underground water storage tanks as it rains little and infrequently. The materials and form of construction applied at Meadows Primary School is therefore typical fare for most builders, and robust products exist to do it.

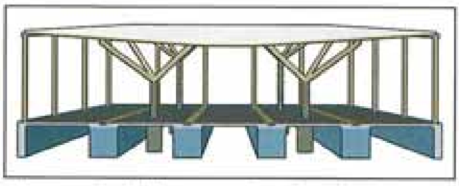


Above: The Flovent computational fluid dynamics package was used to test various permutations of water tank and pipework. Early studies involved a higher number of smaller air ducts in each duct, but these were dropped - for heat transfer efficiency and pressure drop reasons - in favour of a single, looped, 300 mm air duct. Interestingly, the CFD presumes a steady transfer of thermal energy from laminar flow rather than greater heat transfer where air changes direction, as tends to be the case for Termodeck and conventional earth tubes.



Above: A cross-section through the trench heating system, based on four groups of twinned copper pipes run in ventilation channel recesses.

Above: Most of the ventilation ducts will be connected to large inlet funnels, but one classroom requires a ventilation plenum, seen here under construction.



Above: A simplified cross-section through a classroom module showing the four internal columns sitting on piles between the tanks. The tanks shown are an early iteration, but the principle is close to the as-built version.

FACTS AND FIGURES

Meadows Primary School, Broad Meadows, Melbourne, Australia

Energy and carbon dioxide

Design greenhouse gas emissions
- 59 544 $kgCO_2$ per annum
- 17·6 $kgCO_2/m^2$ per annum

Renewable contribution (estimated)
- Photovoltaics: 15 900 kWh per annum
- Wind turbine: 6200 kWh per annum

Cost

The architect claims that the integrated structural water storage and ventilation system system added very little to the building cost.

A large part of budget for tanks would have been required for a conventional footing system. The heating and ventilation system will cost far less than an air-conditioning system. An additional two per cent expenditure has been provided for renewable energy generation and data logging equipment.

The construction budget has been set at AUS \$7.57 million (AUS \$2200 per m²) including services, siteworks and fixtures.

The clay ground conditions are stable enough for there to be little risk of the tanks puncturing over time. The liners used for the tanks are said to be guaranteed for over 20 years, even when exposed to the deleterious effects of sunlight. By being buried underground, the liners should, the designers believe, be good for 50 years.

So what about the sealing of the ductwork components. These are variously glued, seam welded and pressure tested to ensure they are watertight before the tanks are filled.

Fabric airtightness could be a significant variable in ensuring that the supply air does not short circuit the water tanks. A high standard of construction will be vital for the incoming air to obediently follow the coloured arrows on the cross-sectional drawings and to behave exactly as predicted by the CFD analysis.

Early UK experience with passive cooling systems, such as the combination of chilled beams and displacement ventilation in the early 1990s, revealed the importance of good fabric airtightness and continuous insulation. Without wishing to cast aspersions on Australian build quality, the construction industry down under is at least 10 years behind the UK's experience with airtightness.

Maintenance considerations aside, Australia's building codes do not yet cover fabric airtightness, a serious omission for a country beginning to embrace passive solar design as a way out of its carbon dioxide crisis. and it would be best if the construction industry didn't learn the hard way. To take a simple example, the author noticed that external swing doors are rarely fitted with draught seals.

"Airtightness is not so much of an issue here," admitted Now Architecure Judith North, "but these buildings will be pretty airtight. We've specified all window installations with foam seals. On other areas blankets will be stuffed in the gaps and covered by aerofoil [insulation] to get a high level of sealing."

This leaves the issue of how the building will be operated by its occupants. Being a school there will always be a tendency for doors to be wedged open. This might be convenient, but it will cause incoming air to short-circuit the water tanks, breaking the thermosyphon on which the school's ventilation system depends.

With the cooling systems invisible to the naked eye, the school's occupants won't necessarily realise the negative effect of leaving doors and windows open. Once the air flow through the tanks is compromised, people may tend to open doors more in a misguided attempt to alleviate a rise in thermal discomfort.

Education of the school's occupants and continuous awareness of how to operate the school's integrated water-based thermal storage systems will therefore be vital in maintaining comfort conditions over the long term. *Delta T* intends to return to this project after occupation to report on the school's performance in use.

Roderic Bunn is a principal consultant at BSRIA, specialising in building performance analysis.