FEATURE

A section of the 1.4km thermal labyrinth that runs below Federation Square.

Underground movement

It is more than 10 years since Federation Square opened in Melbourne. Of the milions who have visited the square in that time, few would know that below their feet lays one of the world's best examples of decoupled thermal mass design: a thermal labyrinth. **Sean McGowan** reports.

Whether or not the architecture of Melbourne's Federation Square resonates with you, what continues to be evident 11 years on from its opening is that in this project, form and function have both been paid heed to.

The "function" credentials are evidenced by the inclusion of a 1.4km long thermal labyrinth located below the civic square in the middle of the 3.8 hectare site.

The labyrinth plays dual roles – that of a structural support to the public plaza above, as well as delivering energy-efficient cooling to the large atrium, and pre-chilled air to the refrigerated systems serving other buildings on the site.

"Unlike many ESD projects that go out of their way to paint wind turbines on the roof yellow – to call attention to their supposed ESD credentials – the systems at Federation Square are all about being integrated and embedded in the design and the architecture," says Donald Bates, chair of Architectural Design at the University of Melbourne, and a keynote speaker at AIRAH's coming The Future of HVAC conference.

With fellow architect Peter Davidson, Bates was one of the primary architects of Federation Square. The pair had formed LAB Architecture Studio in London in 1994, and three years later entered the international design two-stage competition for the project.

Short-listed for the first stage of the competition, they formed a jointventure agreement with long-established Melbourne architectural firm Bates Smart to undertake the second stage of the competition. In late July 1997, they were announced as the winner.

According to Bates, the idea to include a thermal labyrinth as part of the design came about in the very earliest days of their design work, when LAB collaborated with London-based environmental engineering firm, Atelier Ten.

Having previously worked together on other design competitions, and with their offices in close proximity to one another, it made sense that discussions about the project's engineering be included from the earliest stages. Here, indeed, was integrated design in practice.

Among a number of initiatives to come from this work was the thermal labyrinth.

"They had previously produced a scheme in the UK for the Earth Centre in Doncaster, and it included a small-scale labyrinth under the main slab of the building," recalls Bates of LAB.

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"The work undertaken during the competition design, as well as with other initiatives apart from the labyrinth, convinced us that this would be an important feature of the sustainable design of Federation Square."

It would prove to be an astute decision. Eleven years on, the thermal labyrinth is playing a major role in Federation Square becoming carbon neutral by the end of the year.

At the time, however, Bates says the potential of the labyrinth had to be justified on more than several occasions throughout the project's duration.

"Partially this was because in 1997–98, fuel costs in Australia were very low," he says. "The small price difference in favour of a traditional cooling solution versus the labyrinth was seen as a cost saving to a project that had significant funding pressures."

Time would show this to be a false economy, lending weight to Bates' assertion that making decisions only with regard to existing energy costs is both short-sighted and naïve.

The labyrinth's inclusion also forced a rethink in respect to the fee mechanism of the project for the services engineers, Atelier Ten.

"There was a slight 'discipline' barrier to the development of the labyrinth," says Bates. "Effectively, the development of the labyrinth was to use a structural element as an HVAC element. The concrete walls of the labyrinth hold up the public plaza above it. But these walls also operate as part of the cooling system.

A CAPITAL PROJECT

ACT's Gungahlin College, Library, Canberra Institute of Technology Learning Centre and Town Park project uses a thermal labyrinth.

The northernmost town centre of Canberra, Gungahlin is home to a recently completed development featuring a new senior secondary college and small tertiary facility associated with the Canberra Institute of Technology (CIT), integrated with a community library, performing arts theatre and gymnasium.

Naturally, each building features highly variable usage patterns, such that the Department of Education adopted the philosophy during design that the need for active air conditioning within the secondary school be negated.

Rather, it directed the design team to achieve acceptable comfort control through passive design approaches alone. Those facilities shared with the general public – such as the library, theatre and tertiary facility – were permitted active air conditioning.

According to Cundall principal Caimin McCabe, M.AIRAH, the variety of functional uses in play, and the facilities' different operating hours – as well as a strong passive design response being sought – led to the idea of a thermal labyrinth being implemented.

This was integrated into the structural solution below the paved courtyard between the library and CIT building and the main school building.

"The selected location offered the ability for the thermal labyrinth to serve the college during school hours and the library ... CIT or the theatre after hours, weekends and during school holiday periods," he says.

The labyrinth has been designed to achieve up to 9°C cooling of ambient air in summer and 7°C heating in winter.

It provides a shared resource to the different parts of the development, and offers a number of predicted benefits including:

- Passive comfort control within the learning hubs of the school during the summer without the need for active cooling and pre-heating in winter. It also provides 100 per cent outside air ventilation all year round, and enhances the effectiveness of the natural stack ventilation strategy adopted within the school.
- A 30 per cent reduction in CO_2 emissions associated with heating and cooling of outside air required for the library and CIT spaces during library operating hours.
- A 46 per cent reduction in CO_2 emissions associated with heating and cooling of outside air required for the theatre.

"The more the services engineers of Atelier Ten developed this design, the more they eliminated the traditional pieces of equipment that define the costs – and fees – of the services engineers. We had to find a different fee mechanism to allow them to develop the design."

INSIDE THE LABYRINTH

The basic design and operation of Federation Square's thermal labyrinth follows the rules of decoupled thermal mass.

The labyrinth's location – on top of the structural slab above railway lines, but below the sloping surface of the public plaza – is unorthodox, and its size is substantial. Yet the system works in much the same way as any other thermal labyrinth.

At night, fans draw the cool ambient air from outside through vents placed along the southern edge of the development, close to the Yarra's riverside. These fans move the air through the 1,600 sq m labyrinth, cooling – or charging – the zigzag of 3m high corrugated pre-cast concrete walls to the lowest night-time temperature.

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During the day, the warmer ambient air is then drawn through the labyrinth by the fans and is cooled as it comes into contact with the chilled (charged) walls. This air is then distributed into Federation Square's large atrium via a displacement system at floor level.

A glass-walled, high-volume structure approximately 18m high, the Atrium covers a floor area of approximately 2,040 sq m. The warmer air in this space is displaced and evacuated through vents in the ceiling.

Bates says the use of the labyrinth generally produces a 10–12°C temperature differential between the daytime external temperature and that of the internal Atrium temperature.

Additionally, there are many days throughout the year when the air from the labyrinth is not required in the open-ended Atrium. At these times the system is used to provide pre-cooled air for the refrigerated systems that service the offices and cinemas of the Alfred Deakin Building, housing SBS and the Australian Centre for the Moving Image (ACMI).

This significantly reduces the amount of energy required to cool these spaces.

"The labyrinth reduces the cooling loads on the Atrium, compared to a mechanically chilled, forced-air system, by more than 90 per cent," says Bates.

Compared to a mechanically chilled displacement air system, the reduction is said to still be more than 40 per cent.

DRAWING INSPIRATION

Speaking from his London office, where the original design and operational diagrams of the Federation Square labyrinth remain displayed on the wall, Atelier Ten principal Patrick Bellew says the firm's work with thermal labyrinths continues apace.

Along with the Earth Centre and Federation Square labyrinths, Atelier Ten also designed a similar system at Davis Alpine House at the Royal Botanic Gardens in Kew, London.

It has two thermal labyrinths under construction – one in Ankara, Turkey, beneath the headquarters of the Turkish Contractors Association, and a particularly large system beneath a building in Luxembourg, designed with Foster + Partners.

Despite many technological advances in the HVAC field in the years since Federation Square was completed, Bellew says little would change if the labyrinth was designed today.

> ‘The labyrinth recouped its slightly greater construction costs within six years, and has been delivering substantial savings to Federation Square ever since’

"We continue to look at systems that use many of the same ideas," he says.

Reflecting on his involvement on the Federation Square project, Bellew says that Melbourne's large diurnal temperature ranges were identified early on as being ideal for a thermal labyrinth system. Yet it took some for a labyrinth to be confirmed as part of the final design.

"There were some concerns that, for the labyrinth to be effective, it needed to be in contact with the ground – which was somewhat problematical in the context of the site where the superstructure is suspended above the railway tracks," he says.

"It was therefore mooted as an idea with the intention that the labyrinth would sit beneath the deck and between the railway tracks. It only really emerged into the design in its current form somewhat later in the design process when a large volume of unused space was identified beneath the public plaza."

In that sense, he says the design is somewhat opportunistic. However, once the opportunity had been identified and the technical benefits analysed, the architects fought passionately for its retention as a major environmental component of the scheme.

Both Bellew and Bates reveal that there was a real desire within both the design and client teams to minimise the use of air conditioning and mechanical refrigeration as much as possible.

With a design imperative that the large Atrium be open-ended and to face the public streets, the idea of introducing cooling was deemed illogical and expensive to operate. Searching for alternatives to offset heat gain in the Atrium without incurring substantial energy penalties, the labyrinth proved to be the answer.

"The labyrinth solution allowed us to eliminate any form of mechanical cooling from this area," Bellew says, "but still allowed us to guarantee the comfort for the occupants on warmer days."

Federation Square's Atrium building sits atop the thermal labyrinth cooling system.

MACRO V MICRO

According to Bellew, thermal labyrinths are particularly well suited to Melbourne because the night-time air is almost always cool, due largely to the effect of the Southern Ocean.

The Federation Square labyrinth has been reported to take advantage of the micro-climate created by the Yarra River at night. Bellew says, however, that the data sources drawn upon for analysis were not sufficiently refined as to provide this level of detail.

Rather, he says the design team was more focused on Melbourne's macro weather conditions. Any advantage the Yarra River provides is a bonus.

"Our analysis suggested that we could expect up to 15°C or even 20°C of potential cooling capacity on the hottest days of the year," says Bellew, who returned to the city last year for a commemorative lecture at the University of Melbourne's Faculty of Architecture, Building and Planning.

"The operation of the system has been tested through some record temperatures in the past few summers. And at a recent reunion, reports from the Federation Square management staff (FSM) were consistently positive – particularly as to the benefit felt in the hottest weather without any supplementary cooling."

> Like any heating, ventilation and air conditioning system, there are rules to the design of a thermal labyrinth

Bellew says thermal labyrinths are notoriously "tricky" to model.

From its continuing work in the field, Atelier Ten has evolved a method that combines dynamic simulation and some CFD modelling to make assessments.

"The design philosophy is quite straightforward at one level, but we use some unusual control arrangements to get the most out of the system – in particular the control of the labyrinth cells in a series arrangement during the day, switching to a parallel operation mode at night during the purge cycle," he says. "This adds to the complexity of the modelling."

The calculation of payback periods can also be complex.

"On Federation Square, we ran the energy model with conventional chillers and set-points as a reference case, and then ran the labyrinth, factoring in only the fan energy for the labyrinth," Bellew says. "This gave us a projected energy saving."

The design team then looked at the "add and omit" items on the capital cost, such as chillers, pipework and coils, and came to a net additional cost.

Only then were they able to do a life-cycle and payback analysis.

According to Bates, the labyrinth recouped its slightly greater construction costs within six years, and has been delivering substantial savings to Federation Square ever since.

Eleven years on, Bellew says more attention would now be paid to reducing the embodied carbon within labyrinth systems. Today, his firm works closely with structural engineers to design

DID YOU KNOW?

Although yet to be accurately modelled, Atelier Ten's Patrick Bellew says an area of exploration is the integration of phase change materials (PCMs) into the concrete mix to extend the capacity and range of performance of thermal labyrinths. Such a modification allows smaller footprints while achieving the same output.

"It may be a while before we have enough certainty on performance," Bellew says, "to get the full benefit of this idea."

concrete walls to use the minimum cement content consistent with their structural integrity.

This needs to be achieved while maintaining the two critical issues associated with the design and construction of labyrinth walls: surface area and air movement.

He says the spacing of the walls is also important – a function of the design velocity of the air through the chambers to ensure good heat transfer.

"If the air moves too fast, the convective heat transfer effect reduces and pressure drop – and therefore fan energy demand – is increased," Bellew says, adding that minimising fan energy use is important.

"The other important factor is that the heat transfer effectiveness increases when the air turns the corners of the labyrinth. We believe it is because of the change from laminar to turbulent flow, which increases the heat transfer."

Atelier Ten is using a concrete-filled profiled block at its project in Turkey to achieve a degree of roughness on the surface, and to reduce the amount of time that the air-flow next to the walls becomes laminar.

Other than these factors Bellew says the construction of labyrinths, while time – consuming, is relatively straightforward.

"The most difficult issue is sometimes the liability and warranty for the design, particularly when the project is using a 'design and build' form of contract," he says.

THE UNDERGROUND MOVEMENT

The number of thermal labyrinths in Australia is greater than you might realise. Perhaps, like Federation Square, they are the victim of remaining hidden below buildings – away from the public eye.

A little-known example is located below Victoria's Parliament House in Melbourne. Likely built during the first stage of construction in the 1850s, it runs beneath the building to an adjacent park and was rediscovered during investigations into a proposed restoration of the building in the late 1990s.

More recently, thermal labyrinths have been used as key ESD elements at a number of Victorian schools – among them the Suzanne Cory High School in Werribee and Hume Secondary College in Broadmeadows.

In the ACT, a large system serves the Gungahlin Senior Secondary College as well as adjacent community library, performing arts theatre and gymnasium (see sidebar).

Involved with these projects, and others both under construction and in design, is Caimin McCabe, M.AIRAH, principal with Cundall.

McCabe says there are a wide range of strategies being adopted around thermal labyrinths, both within Australia and around the world.

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These include rock-store labyrinths, earth (or Canadian) tubes, earth-mounted concrete culverts, zigzag labyrinths and channel labyrinths.

"Like any heating, ventilation and air conditioning system, there are rules to the design of a thermal labyrinth," McCabe says.

The rules to which McCabe refers cover air speed, turbulent airflow, length of run and the material used.

"Air speed should be low to encourage the air to flow over the thermal mass and not run down the centre of the thermal labyrinth without touching the sides," he says. "There is also a need for turbulent airflow to maximise connection of the air to the exposed thermal mass through ribbing of the boundary walls, rocks and fins in the airstream."

Additionally, ensuring sufficient length of run within a labyrinth is critical to getting the maximum cooling benefit out of the system. It is also important that a construction or bounding material with poor thermal performance is used to store and release energy.

"A further very important step is to ensure that the control logic of the ventilation fans drawing air through the labyrinth is correctly set up to facilitate a night-purge cycle to remove heat stored in thermal mass overnight to prime it to be able to provide beneficial passive cooling the following day," McCabe says.

According to McCabe, the benefits of thermal labyrinths can be further enhanced if the heat-purge cycle of the thermal mass is used as a means to provide a night purge, or a night ventilation strategy, to the building. This removes the heat stored within it, as well as reducing the need for cooling the following day.

"Importantly, a by-pass needs to be incorporated within the design so that the building is not overcooled overnight, requiring heating input the following morning, but allow the thermal mass to be further cooled," he says.

McCabe cites one example he is aware of where the comfort control strategy for a rock-store labyrinth system was incorrectly commissioned as a traditional air conditioning system. This resulted in a reversal of the design intentions.

In this instance, rather than running a purge cycle overnight to remove the heat stored in the labyrinth during the day, the heat was left in the rocks overnight.

"The implication and outcome of this is that the rocks progressively heated up further and further to the point that air passing through the rock store was progressively cooled less and less," he says.

"Ultimately, the rocks began to operate in reverse, adding heat to the air on milder days so that the air entering the labyrinth came out hotter than it went in, which created obvious comfort issues within the offices."

It is understood that once this error was identified, the controls were modified to reflect the need for a night purge, and the system has operated as intended since. ▮

A keynote of note

Donald Bates will be the keynote speaker on day two of AIRAH's The Future of HVAC conference.

For more info, go to www.airah.org.au/TheFutureofHVAC