UNDERGROUND SOLUTION

The National Maritime Museum has a hidden exhibit that is providing an innovative source of low carbon energy. **Andy Pearson** investigates

Captain Cook's journals; the log-book of Robert Maynard, the man who killed the pirate Blackbeard; and the grave marker of Bounty mutineer John Adams – these are just some of the unique artefacts housed in the National Maritime Museum in Greenwich, London. Now, with the opening of the Sammy Ofer wing, the museum has one more piece of history to add to the list. The wing is home to the UK's first major aquifer thermal energy storage (ATES) system.

The big difference between the ATES system and the museum's other unrivalled exhibits, however, is that the ATES is not on public display. Far from it: it uses a heat pump and the ground water deep below the museum as a giant thermal store to deliver a low carbon heating and cooling solution to the new wing, which makes it particularly suited to this historic location.

The ground beneath the new wing of the National Maritime Museum acts as a giant thermal store to provide heating and cooling for the building

The National Maritime Museum is part of the Maritime Greenwich World Heritage Site, which includes the Royal Observatory, Greenwich Park and Sir Christopher Wren-designed Royal Naval College. The new, £35m Sammy Ofer Wing has been designed to connect the National Maritime Museum's 1876, Grade I-listed South-West Wing to Greenwich Park to create a new main entrance from the park as well as provide additional exhibition spaces, a café and a restaurant.

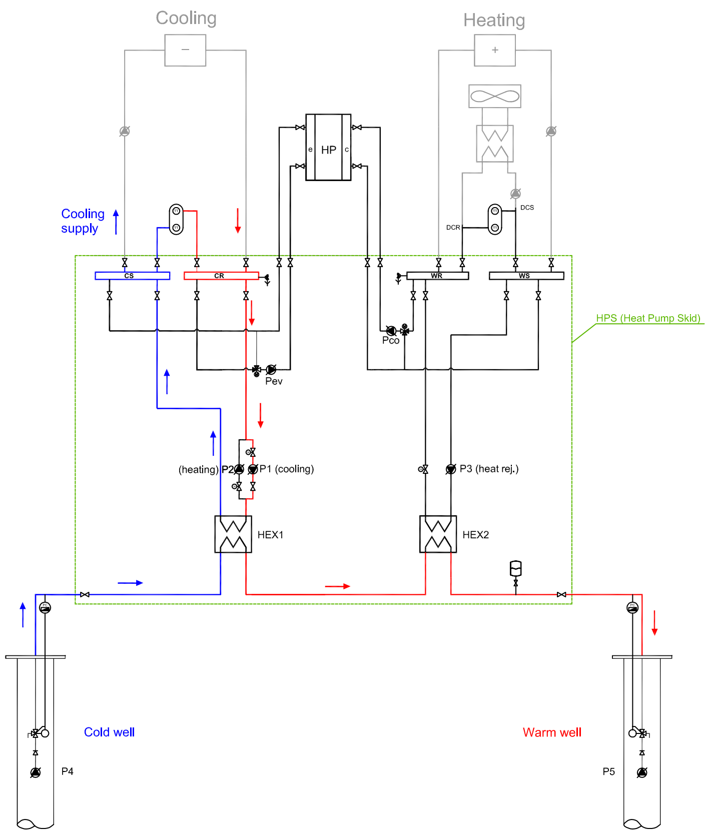
Architect CF Moller's design for this historically sensitive site placed the bulk of the 55m-long, 35m-wide and 10m-deep wing below ground. 'It was one of the most difficult and challenging sites conceivable,' says Julian Weyer, a partner at the practice.

The advantage of the architect's subterranean solution is that it helps stabilise heating and cooling loads. However, for the scheme's building services engineers, Mott MacDonald Fulcrum, the disadvantage of this concealed solution is that the building's roof is visible from both the Royal Observatory and much of Greenwich Park and, as a result, it had to be kept clear of plant.

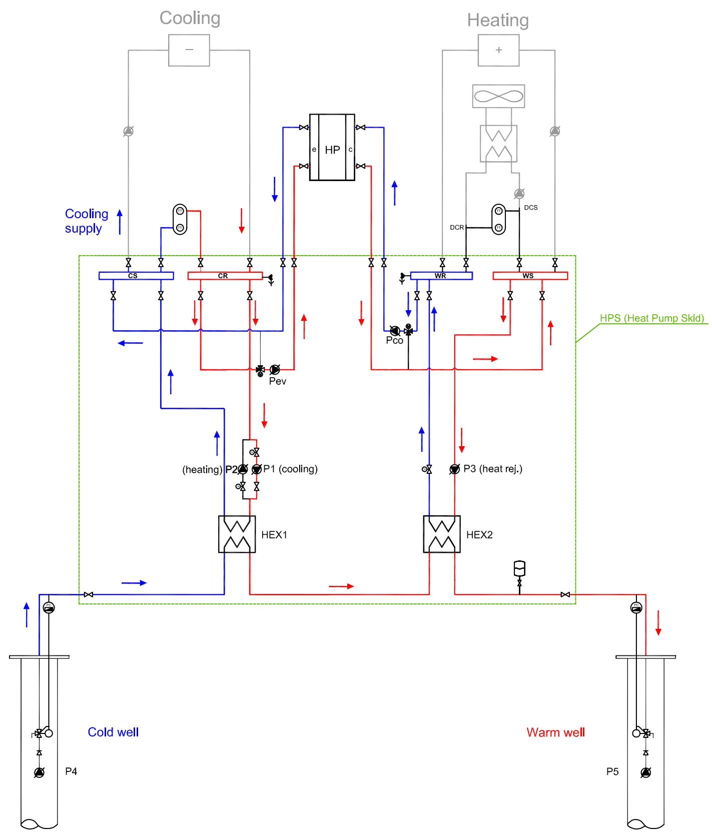
The need to keep heating and cooling equipment away from the roof was one reason the engineers were keen to adopt

Morley von Sternberg

ATES system in direct cooling mode – directly from the cold well with no heat pump



Cooling mode, with heat pump



HP: Heat Pump
HEX: Heat Exchanger
DCS: Dry-Cooler Supply
DCR: Dry-Cooler Return
CS: Cold Supply
CR: Cold Return
WS: Warm Supply
WR: Warm Return

> The reversible energy store drives up the coefficient of performance of the heat pump because it helps drive up the temperature difference between the heat pump's on- and off-temperatures

an ATES solution. 'Because heat rejection in an ATES system is into the aquifer, the scheme does not need rooftop refrigeration machines,' says Richard Shennan, a director at Mott MacDonald Fulcrum. He says the system's other big advantage is that it has low running costs, which is important for the museum.

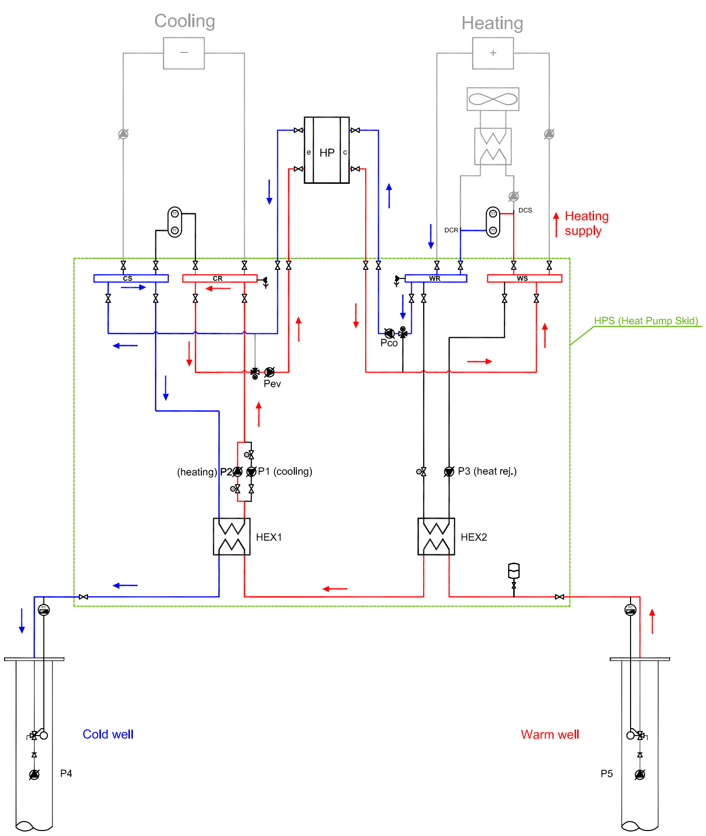
ATES systems are common in the Netherlands, but before it could be used in London the engineers had to ensure ground conditions were suitable. Greenwich is situated in the London basin. Before construction could commence, the engineers had to establish conditions in the chalk aquifer, buried over 60m below the surface beneath layers of gravel, impermeable clay and thin layers of sedimentary deposits. Rainwater water enters the aquifer mainly from the Chiltern Hills to the north and the Downs to the south, before making its way slowly towards the axis of the syncline and eventually to the coast following the hydraulic gradient.

The speed at which water moves through the aquifer and the rate at which water could be extracted were key factors in determining whether the ATES system would be suitable for the new wing. If the ground water moves too fast it will carry away the heating or cooling energy stored underground before it can be utilised. 'You have to test to confirm the system's feasibility because of variations in the chalk,' explains Shennan.

A trial borehole was drilled outside of the wing's eastern boundary to establish the amount of water that could be extracted from the aquifer. 'In London's chalk aquifer, we say that 40 cubic metres per hour is a good flow rate to achieve, per well, if you have a sustainable drawdown associated with that rate,' says Nicholas Boid, a director of IFTech, the AETS system suppliers.

The borehole was tested at flow rates of up to 50 cu m/hr. At this rate the water level in the borehole dropped from its rest level of 12.5 metres below ground level to 17.5m below ground level, a drawdown of 5m. 'This was a very positive performance,' Boid says. According to him, 'a drawdown

Heating mode, with heat pump



of 10m to 15m is probably the limit but this depends greatly on the depth and construction of the borehole and also the rest water level'.

To provide heating and cooling to the museum's new wing, two 350mm diameter, 80m deep boreholes are needed. After the scheme's feasibility had been established, a second borehole was drilled 70m away from the first, just outside at the western boundary of the new wing. A smaller-diameter borehole, not part of the ATES system, was also drilled into the aquifer to serve the wing with water for flushing toilets. From readings and measurements taken from all three boreholes, the groundwater flow direction and velocity were established and fed into the computational thermal model of the system. The aquifer is at a standing temperature of around 12C.

The aquifer surrounding the main eastern borehole is used to store heat energy, while the aquifer surrounding the western borehole stores cooling energy. Each borehole contains a submersible pump to supply ground water to a heat pump situated in the basement of the new wing.

In summer, when cooling is needed, ground water is pumped from the cool borehole at a rate of up to 46 cu m/hr. Depending on the cooling demand, the ground water is either used to cool the building directly or it is passed through the heat pump, to lower its temperature further, before being used to cool the building.

The system will operate in direct mode at the beginning of the cooling season, when the cold well temperature is at its lowest (having been charged over winter). In this mode, system efficiencies are very high because there is no electrical demand from the heat pump's compressor. However, if the cooling demand is too high the heat pump will kick in, to bring the chilled water temperature down to the required level (see diagrams).

Once it has left the heat pump, the warmed water is returned to the ground at 20C through the warm borehole, charging the aquifer with heat ready for winter.

In winter the ground water flow is reversed so that warmed ground water passes through the heat pump. Once its heat has been extracted, the cooled ground water is returned to the aquifer at approximately 8C, via the cold borehole, where it is used to recharge the ground ready for summer.

The control logic is very simple. The system includes a 350kW output heat pump, twin heat exchangers and two 1,000-litre buffer tanks, one for the heating circuit and one for cooling. 'The demand is led by the two buffer vessels,' explains Boid. If the building is asking for heat, it will get it from the warm vessel at 45 C, while cooling will be from the cold vessel at 6C.

Factfile Principles of aquifer thermal energy storage (ATES)

During the warm season, water from the cold store at around 7C to10C is passed through a heat exchanger, providing direct cooling water to the building. The heat pump is available automatically as support in periods of peak demand.

The store circuit water will pick up energy from the building and thus be raised in temperature to around 18C to 20C (or higher for fresh air load).

This water, the temperature of which is higher than the natural groundwater temperature, will be run to an underground 'warm energy' store.

The heat stored in the warm energy store is used for heating during the winter. Water from the store at around 20C is passed through a heat exchanger and connected into a heat pump, which in turn provides water at around 40C to 50C for use in building heating.

While the groundwater passes through the heat pump it cools to around 7C. The cooled water is run to the underground 'cold energy' store.

The cold stored in the 'cold energy' store is used for cooling, completing the annual cycle.

Any excess heat or cold in the system over a year is balanced using an external heat exchanger.

Source: Iftech (www.iftech.co.uk)

Top: Plant room showing the prefabricated, skid-mounted unit containing the plate heat exchangers and control valves
Bottom: Ground-level chamber for one of the boreholes

> The approach has been to design and build the energy centres in a modular format to enable plant to be added in the future

'What happens in our system to enable those buffers to maintain temperature is a controls strategy set up to deliver hot and cold to the buffers in the best way,' he says. 'This means signals to and from the building are minimal'.

The ATES system provides all of the 278kW heating and 330kW cooling loads for the new wing. 'There is a slight imbalance in terms of annual energy with a higher annual cooling demand,' says Boid. This could have resulted in excess heat being stored in the ground. 'To overcome this possibility there is a circuit that can reject heat from the ATES system to the HWS cylinder,' he explains. Making use of the ground to store heating and cooling energy helps to drive up the system's operational efficiencies. 'The reversible energy store drives up the coefficient of performance of the heat pump because it helps drive up the temperature difference between the heat pump's on- and off-temperatures,' explains Shennan.

Further efficiencies were obtained by designing the heating system to run at lower flow and return temperatures of 45C to 35C, and the chilled water circuits run at a higher flow and return temperatures of 6C to 12C.

The majority of spaces in the new building are mechanically ventilated, so deeper heating and cooling coils have been used in the building's air handling units to compensate for the reduced flow and return temperatures.

Shennan expects other schemes to utilise ATES technology in the future. 'The system is at the smaller end of where the technology works,' says Shennan. He is currently working on a study for a giant 20 MW scheme for South Kensington in London, which includes all the area's museums, the Royal Festival Hall and Imperial College. The system is not confined to the London basin. 'The system could also be suitable for Birmingham, which sits on a sandstone aquifer,' he says.

The National Maritime Museum's system will have to run for a year before the aquifer can achieve its full energy storage capacity. If all goes to plan, it is predicted the ATES will reduce the new wing's Co2 emissions by 21% below 2006 Part L of the Building Regulations. In terms of lifespan for the system, Shennan says it is difficult to be precise.

'There are very few schemes to compare this with,' he says. However, he adds, the boreholes 'should have a life of a minimum of 30 years but probably longer because the system is reversible, so it self-purges every year'. Which means the public will be able to enjoy Captain Cook's journals in low-carbon comfort for the foreseeable future. **CJ**