

Chilled water store in Heathrow Airport



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In late 2001 the British Government announced its decision to approve the building of a new terminal (T5) at London Heathrow Airport. The building of T5 is of great importance to the UK and for the owner BAA plc it will be the largest construction project ever undertaken.

BAA plc is committed to design and build T5 in accordance with the principle of sustainable development. Environmental management is a priority for BAA and BAA is committed to minimise the impact of a growing business. This means that priority areas of performance include energy efficiency.

Focussing on analysis of flow pattern and heat capacity, using the computer Computational Fluid Dynamics (CFD), this article describes the design of a chilled wa-

Construction in progress at T5 - September 2003.



ter store, which is the first part of the T5 Energy Centre to be constructed.

The energy supply of heating and cooling to Terminal 5 at Heathrow Airport incorporates a chilled water store consisting of a 3,400 m³ concrete tank constructed below ground. The store was included in the T5 Energy Centre to achieve three advantages:

- To assist in meeting the demand during peak cooling periods so that the installed capacity of the chillers can be reduced; the output of the store after fully charging is approximately 4.4 W for 6 hours
- To enable the chillers to be operated at night taking advantage of reduced electricity prices and lower condenser water temperatures (which will result in higher efficiency)
- To maximise the use of the free cooling system as outdoor temperatures are generally lower at night

The idea to include a chilled water store came up at a time when a number of parameters for the detailed design were still not available. Space restrictions and the need to fit the construction of the store into a tight time schedule required some early decisions on the dimensions and the layout of the store, which could not be changed at a later stage. In consequence the design team had to comply with a number of fixed parameters during the store design phase and following analysis.

Chilled water store

The internal physical size of the chilled water store used in the study was: length

30m, width 15m and height 7.565m (water level).

The basic operating conditions considered for the storage tank are that during night-time (when electricity prices for running the chillers are lower than day rate), the tank is charged with 5.5 °C cold water through an inlet diffuser. Once the storage tank is fully charged, the cold water is stored until around midday (when electricity prices are high) when the system is discharged. During the discharge, 14 °C return water is fed back into the tank whilst cold water is extracted for cooling.

Based on the size and usage of buildings to be connected to the cooling system a yearly load data profile has been supplied. The data indicated an initial total estimated cooling requirement of around 55,700 MWh_{th} per annum with a peak estimated to be around 26 MW_{th}.

The profile indicates that the load in general is low from around midnight to 5 a.m. This period has therefore been chosen for charging the chilled water store as it also coincides with lower electricity tariff.

The operation strategy chosen to model the store has been to assume that the maximum discharge occurs at peak load. The discharge rate during the hours before and after the peak is then calculated in proportion to the load of the hour in relation to the peak.

The load data and the daily profiles around the period where the absolute peak occurs indicates that the chilled water store needs to be charged with 9MW for just over four hours to fully charge the store. The discharging rate is envisaged to be 4.4MW.

The discharge rate of 4.4 MW has been chosen as a compromise between a high discharge rate and a low storage flow velocity in order not to disturb the thermal layers in the chilled water store. Based on future operational experiences the discharge rate could be subject to changes.

Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) is an advanced computer program used for calculation of fluid and airflows. CFD can, for instance, be used for calculation of the distribution of air, temperature and particle concentration in ventilated rooms, spreading of pollution in the sea or, as here, analysis of the flow pattern and heat capacity of a chilled water store.

A CFD program can provide numerical solutions of the governing Navier-Stokes

equations for fluid flows and for heat transfer. The advantage of a CFD program is that it is possible to get very detailed information about the fluid motion and the thermal conditions during different operating conditions. The applied CFD programs are CFX 5.5 (CFX International, Harwell, 2001) and Star-CD v. 3.15A (Computational Dynamics, London, 2003).

In the CFD simulation the model of the chilled water store is divided into a computational mesh composed of small cells. The program calculates temperatures and flows for each cell. This means that the dissolution of the calculations is large and it is thereby possible to obtain knowledge of the physical conditions surrounding the flow pattern in the store.

The simulations have taken anything from a day to a week to perform but the number of mesh points and time increments can be varied to introduce simplifications. This is often used in the introductory phase when an indication of the usability is required.

The number of mesh points used for the different simulations ranged from 230,000 to 610,000 cells. During the control simulations 930,000 cells were used.

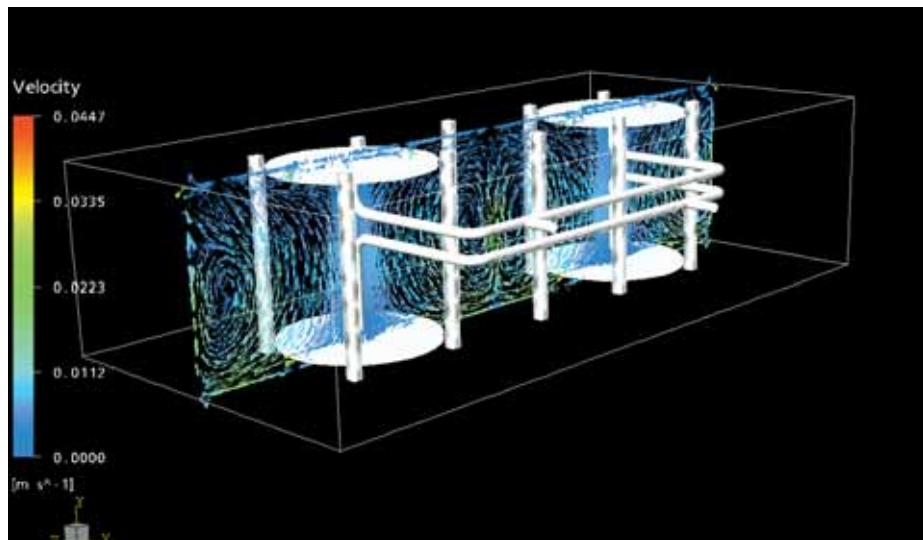
It is the intention that the large tank and the temperature difference of the fluid will cause the water inside the tank to be stratified horizontally. The idea is that the thermal stratification of the water will ensure that the mixing of the thermal water layer is limited.

As the chilled water store is underground, the heat transfer through the external walls should not influence the overall performance of the store. The design of the tank together with the size of the charge and discharge diffusers should be such that the internal heat flux between the low and high temperature water layers is limited to maximise the capacity of the store. The flow pattern must remain laminar to enhance thermal stratification of the fluid and thereby minimize the mixing between the thermal water layers, due to turbulence.

By using the CFD simulation, it has been possible to assess the storage capacity for different geometrical designs of the chilled water store and for different operating conditions predicting the operation of the store before it is built.

CFD models & findings

The first CFD model of the chilled water store modelled the tank as one large volume. The tank was equipped with four diffusers, two for charging the tank and two for discharging the tank. As part of the structural design the tank has ten internal columns, which are included in the model.



Picture from the CFD model showing the tank with its diffusers and construction pillars and the water flow inside the tank.

During the initial CFD simulation, the model included the whole tank and the piping within the tank. Analysing the flow pattern in this model revealed a possibility for introducing a number of simplifications, so that the model of the chilled water store was simplified compared to the real tank. This made the simulations more practical to perform.

The full simulation of both charge and discharge of the tank revealed that a chilled water store in its form as one large tank would not be able to produce the desired cooling load at an acceptable temperature. Due to the heat flux through the water in one large tank, the 14 °C water rapidly mixed with the 5.5 °C once the discharge began. This is predominantly a thermal problem and it is not considered that alterations to the diffuser design would have been able to improve on this.

However, to evaluate the affect of the diffuser on the flow pattern, different diffuser designs were evaluated and it was confirmed that the diffuser design does not have a significant affect on the thermal mixing.

The tank design was then modified so that in the middle of the tank, two walls were created to form a weir, thus partitioning the tank into two sections. It was anticipated that this addition would significantly limit the heat flux from the top warm layers to the cold layers at the bottom, due to a narrower temperature difference in each section.

In the model, the thickness of the baffle walls was set to 0.3 m and the walls were treated as an adiabatic. Therefore no heat transfer can occur over the vertical baffles. The opening distance from the top of the lower wall to the ceiling was 0.5 meter. The opening distance from the higher wall to the floor was also 0.5 meter. The dis-

tance between the two sectioning baffle walls was 0.6 meter.

Six pressure relief holes, each with a diameter of 100 mm, were placed in the lower wall. The holes ensured that the static water pressure during the initial filling and later emptying of the tank was released.

By partitioning the tank, only two diffusers are required, one for charging into one section of the tank and one for discharging from the other section of the tank. The diffuser design was optimised by placing the diffusers 0.15 m from the floor and ceiling, thereby limiting the possibility of dragging sediments situated on the floor of the tank into the piping system. The dimension of the diffuser is set to a height of 0.25 meter and a diameter of 6.4.

The introduction of baffle walls not only increased the useful storage capacity, but also resulted in the temperature at the outlet diffuser not starting to increase until after 5 hours and at a rate much slower compared to the tank without partitioning, see figure 1.

The pressure relief holes in the baffle wall do, however, have a small effect on the flow pattern and thermal stratification within the tank.

During discharge when using the revised design with pressure relief holes, heat transfer occurs across the baffle walls, and with an initial temperature of 5.5°C, the useful storage capacity is slightly reduced compared to a design with baffle walls without pressure relief holes.

During charging the pressure relief holes have a positive effect on the charge rate since cold water flows through the holes into the second section of the tank, thereby decreasing the temperature.

Water level and pressures

A large part of the chilled water store study evolved around the control strategies to be applied, and the effect of changes in water level and expansion of the water within the system were also assessed.

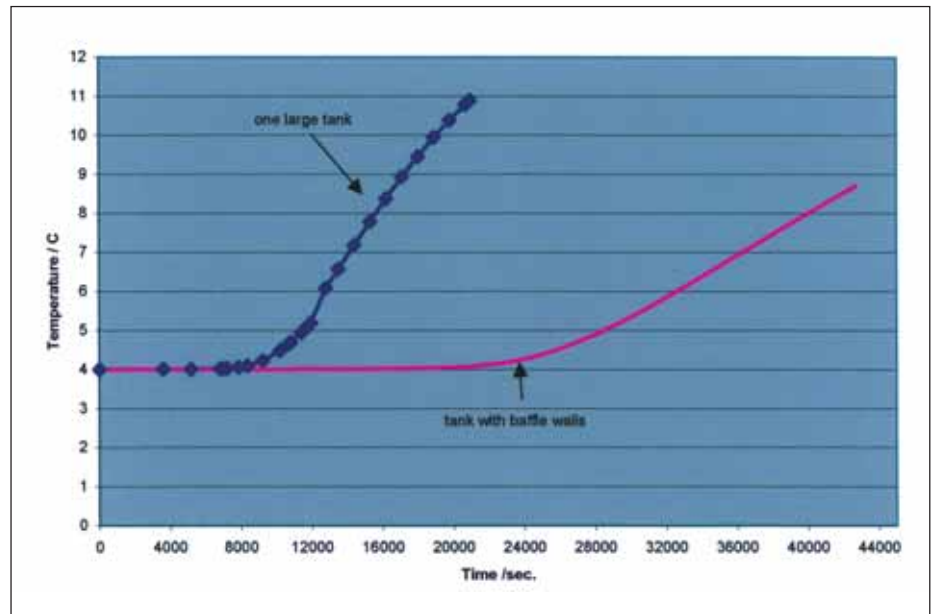
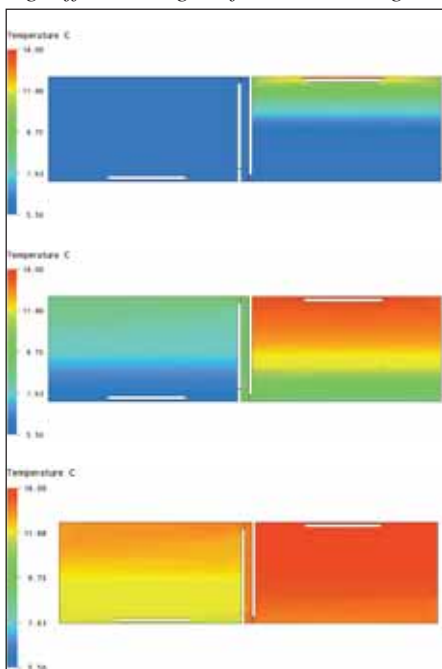
As a change to the preliminary design the chilled water store was constructed with four access shafts, two in each section of the tank. The shafts have two different sets of dimensions and one of each type was constructed in each section. The total volume of free space of the four shafts is 10.5 m³. It is the intention that the water level should rise 200mm into the shafts; leaving the free height in each shaft to be 1 m. This reduces the surface area of storage water in contact with air; thus the amount of oxygen absorbed into the water and potential corrosion issues. The "buffer zone" created by the shafts can accept 8.72 m³ of water.

A change in water level within the chilled water store is affected by two measures. One is the dynamic pressure - the pressure that causes the water to actually move through the store - which can create a difference in the water level between the two sections. Another is the difference in water temperature between a charged store and a discharged store, which will cause the water to expand or contract, i.e. the water level in the tank will increase or decrease.

Using the CFD, simulation provided information about the dynamic pressure inside the chilled water store.

The dynamic pressure difference is approximately 3.80 Pa during charge and 0.47 Pa during discharge. This is equivalent to a difference in water level between the two

Pictures from the CFD simulation showing different stages of 1 hrs discharge.



Average temperatures at the bottom of the tank with and without baffle wall partitioning.

sections of approx. 0.4 mm during charge and 0.05 mm during discharge.

The water in the tank can vary between the maximum and minimum flow and return temperatures, i.e. 5.5 °C and 14 °C. Considering the specific gravity for water at these temperatures means that the volume of water can expand by approximately 0.07 %. Hence the water volume can expand by approx. 2.64 m³, and with a total area of the four shafts of 8.72 m² the water level will be able to vary by around 0.30 m. If at certain times the variation in water temperature is between e.g. 0°C and 20°C, the water in the cooling system will expand by 6.0 m³ - i.e. the water level would be varying by around 0.67 m in the shafts.

It is the variation in temperature that will cause significant changes in the water level within the chilled water store; the contribution relating to the dynamic pressure is insignificant in this relation.

The operation of the chilled water store is intended as a non-pressurised system, and in the access shafts "buffer zone" there will be atmospheric pressure, i.e. 0 bar pressure gauge. As the water expands and pushes water up into the shafts, vents will relieve the air pressure.

The changes in water level, due to the dynamic pressure and thermal expansions, can be maintained in the store without any measures of regulation as long as the mass flow of water into the store is exactly the same as the mass flow out of the store.

The concept for controlling mass flow, and therefore water level in the chilled water store, is based on maintaining a fixed level in an expansion vessel connected to the district cooling network.

This means that the expansion in the district cooling network, due to changes in temperature is not absorbed by the expansion vessel connected to the district cooling system but is absorbed by the chilled water store instead. Hence, the water level in the store will vary between the outer limits

Conclusions

The use of CFD modelling in the design of the chilled water store has made it possible to increase the capacity of the store. The restrictions given in terms of dimensions that cannot be changed and a tight time schedule for the construction have been decisive for the design, but the CFD analysis has led to an increase in the capacity of the store by the introduction of baffle walls. This relatively simple partitioning of the store into two sections has led to a capacity, which is three times higher than the capacity obtained in the one-section store.

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