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Application of groundwater cooling scheme for London Underground network

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ABSTRACT

The demand for acceptable thermal comfort conditions within the London Underground network has grown over the years. The operation of the network generates a large heat load, with high temperatures recorded in summer in train and on platforms. Different cooling methods and new sources of cooling have been proposed for cooling the network. Of the new sources of cooling proposed, groundwater cooling is the first to be tried. London Underground Limited unique characteristics of being close to the aquifer of the central London basin, rivers and also because they pump over 30 million litres of water from the network every day make it an ideal site for this technology. This paper investigates thermal issues within London Underground network and presents an overview of groundwater cooling schemes for the network.

Application d'un système de refroidissement faisant appel à l'eau souterraine au métro de Londres

Mots clés : Eau souterraine ; Faible consommation d'énergie ; Système de refroidissement ; Métro de Londres

1. Introduction

The demand for acceptable thermal comfort conditions within the London Underground network has grown over the years. The operation of the network generates a large heat load, with platform areas and train carriages temperatures of more than 31 °C and 34 °C, respectively, have been recorded on the Victoria Line in summer 2005. Different cooling methods and new sources of cooling have been proposed for the network. The authors proposed the application of groundwater as a new source of cooling for the London Underground network. London Underground Limited unique characteristics of being close to the aquifer of the central London basin, rivers and also because they pump over 30 million litres of water per day from the tube network make it an ideal site for this sustainable technology. Fig. 1 shows how close the current groundwater level at Trafalgar Square is from ground level. In Fig. 1, AOD stands for Above Ordnance Datum. As Fig. 2 (Environment Agency) shows, similar levels are found at different sites under the London Underground network. This paper investigates thermal issues

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Nomenclature

a	radius of hollow concrete cylinder enclosing the tunnel, m
b	far field radius, m
C_p	specific heat of water, kJ(kg^{-1}.K^{-1})
COSP	coefficient of system performance
$\dot{m}$	mass flow rate, kg s^{-1}
R	radius of tunnel, m
Q_{brake}	braking heat load, W
Q_{cond}	heat conducted into the tunnel through its walls and surrounding earth, W
Q_{fan}	train carriage ventilation fan heat load, W
Q_{floor}	conduction gain through floor of the train carriage, W
Q_{win}	conduction gain through window of the train carriage, W
Q_{pass}	passenger heat load, W
Q_{roof}	conduction gain through roof of the train carriage, W
Q_{train}	train carriage heat load in the tunnel, W
Q_{light}	train lighting heat load, W
$Q_{tulight}$	tunnel lighting heat load, W
Q_{tuvent}	tunnel shaft ventilation load W
Q_{vent}	train carriage vent load, W
Q_{wall}	conduction gain through wall of the train carriage, W
T_i	is the water inlet temperature, °C
T_o	is the water outlet temperature,°C

with London Underground network and presents an overview of groundwater cooling scheme for the network.

2. Thermal problems with London Underground network

The London Underground network was designed and constructed in the 19th and 20th centuries initially by the Victorians. The infrastructure was designed for a low train capacity, and the deep and small tunnels as shown in Fig. 3 make ventilating the underground environment difficult in comparison to modern networks. The authors have investigated the heat load in a generic underground railway network using a purposely developed mathematical model (Ampofo et al., 2004). A description of the heat loads in the tunnels and the trains are shown in Figs. 4 and 5 respectively. A theoretical analysis has shown that the major contributor of heat to the tunnel is from the braking mechanism and that from the train carriage is from the passengers. The heat generated by the train motors and electric lighting, together with body heat from passengers, is so great that it raises the underground temperature substantially. The problem is exacerbated by high ambient temperatures. In summer 2005, the authors measured air temperature, relative humidity, air velocity and surface temperature on the Victoria Line of the London Underground network in order to investigate the thermal comfort conditions within train carriages and platform areas. Some of the results are presented in Tables 1 and 2, and Fig. 6 shows the relationship between train carriage temperature and ambient temperature. It is possible to see from Fig. 6 that there is a relationship between ambient and train carriage temperatures. This is highlighted by the best-fit line that indicates a direct proportional positive relationship. A recent work (Gilbey and Thompson, 2009) on temperature control on the London Underground network confirms the authors' earlier work.

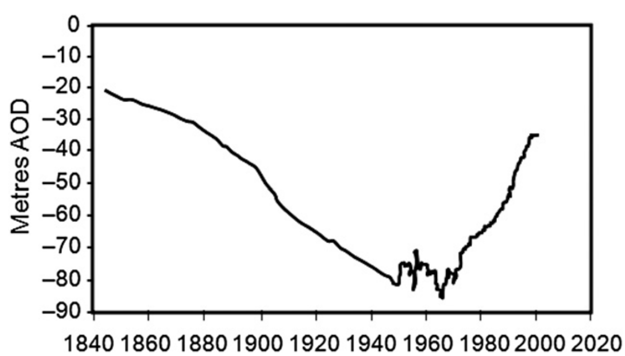

Fig. 1 – Groundwater levels at Trafalgar Square.

3. Concept of groundwater cooling

Cooling of the London Underground network may be achieved by using groundwater to directly cool the air within the tunnel. The principal aim of applying groundwater cooling to an underground railway system is to cool the tunnels. Applying conventional air conditioning as the only means of cooling the London Underground network is not straightforward because a conventional air conditioner is a heat pump and as such it will pump heat from trains into tunnels. Without better ventilation the tunnel temperatures will become excessive as shown in Fig. 7(a). However, as shown in Fig. 7(b), if the tunnels are cooled using the groundwater system the train temperatures will be lowered.

Fig. 8 shows a schematic diagram of groundwater cooling as would be applied to the London Underground network. The concept of groundwater cooling is as follows: groundwater is pumped through heat exchangers; hot air in the underground environment is cooled and then circulated by fans onto platforms; trains act as giant pistons which will circulate the air around the underground network; fans on top of trains suck in air to cool trains.

Groundwater can be drawn from nearby boreholes to cool the air. Groundwater is located at a level below London Underground network, which is in the London chalk aquifer at about 40 m below ground level, see Figs. 1 and 2. Groundwater in the chalk aquifer has a potential yield up to 30 l/s per borehole. With industry no longer drawing water from this lower aquifer, the hydrostatic level below central London has been rising at up to 2 m a year in places over the last 20 years. When coupled to the temperature needs of a ventilation system this cooling can be used without any mechanical refrigeration enhancement, thus providing a low energy sustainable solution. To make further use of this natural cooling resource after it is used for cooling, the groundwater may feed a greywater system serving toilet cisterns, to reduce the demand for refined mains water.