Institution: London South Bank University

Unit of Assessment: General Engineering

Title of case study: An innovative approach to cooling underground railways through the application of sustainable ground source geothermal engineering.

1. Summary of the impact (indicative maximum 100 words)

This case study demonstrates how research into ground source geothermal cooling has benefited a public service organisation (London Underground Ltd (LUL)), an international engineering consultancy (Parsons Brinckerhoff (PB)) and the safety and comfort of staff and users of the London Underground.

Impact includes:

- Implementation of the cooling method at Green Park and Oxford Circus stations in 2012;
- Inclusion of the cooling approach within LUL's £500m Victoria line upgrade (2013);
- Additional revenues of £500k (PB) and new contract research for LSBU (£500k);
- A new commercial capability in design and analysis of ground water cooling (PB);
- Creation of a specialised professional level post (PB);
- A 2012 Rail Business Award for environmental innovation (LUL);
- International adoption and significant interest in the cooling method.

2. Underpinning research (indicative maximum 500 words)

The impact described in this case study is underpinned by research carried out over the period from 1999 to the present day by Dr John Missenden (senior lecturer, LSBU, retired 2010) and Dr Graeme Maidment (senior lecturer, LSBU). The research was supported by contracts from London Underground Ltd (LUL, 2002-8; £202k), Parsons Brinckerhoff (PB, 2007-8; £72k) and grants from The Carbon Trust (2005-7; £71k), a Knowledge Transfer Partnership project (KTP001678; 2006-9; £375k) and an EPSRC DTA studentship.

The research explored the concept of using low carbon ground source geothermal cooling to assist in reducing the increasing temperature of the underground passenger environment [1]. It involved: (i) a review of measured and reported thermal conditions on the Underground compared with thermal comfort metrics used by ergonomists [2] (ii) development of complex simulation models for heat inputs supported by detailed thermodynamic steady-state and quasi steady-state mathematical models for wall heat transfer [3, 4]. These permitted additional thermal analysis to take place; calculations and simulation studies to be performed; and cooling technology options to be evaluated [5].

This preliminary research led onto a detailed investigation of the geothermal cooling potential of the aquifer under London (with LUL and PB) and to a number of innovative cooling techniques being assessed. The research included the development of novel cooling delivery methods [6].

On the strength of the research findings, the LSBU researchers and PB collaborated on research to evaluate candidate cooling models. This was financed through a £375k Knowledge Transfer Partnership (KTP), co-funded by PB and the Technology Strategy Board which ran from 2006-9.

A key outcome from the KTP was the design and development of a pilot ground source cooling system which was installed at Victoria station in August 2007 [5]. The pilot scheme was conducted by LSBU in conjunction with LUL. It confirmed the promise of the initial research and demonstrated significant local reductions in platform temperature i.e. 3°C, improving thermal comfort, using a viable, low carbon, environmentally sound and cost effective technology. The technology was demonstrated to be three times more energy efficient than a traditional air cooled chiller system [6].

The pilot scheme affirmed that: 1) the seepage water cooling system was a sound concept; 2) the

cooling efficacy was comparable to traditional approaches for station thermal control; 3) the system was more sustainable using less energy than traditional approaches; 4) the air-water heat exchanger installed at the platform was highly susceptible to fouling through dust; 5) that the dust problem could be ameliorated through making the air paths larger.

The research also demonstrated that: 1) there is a complex interaction between aquifer, near surface watercourses (Tyburn and Fleet rivers) and the underground railway tunnels; 2) a strong relationship exists between the need for water to be removed from the underground continuously to prevent flooding and the cooling needs at Victoria; 3) water temperatures between 12 and 17°C are appropriate for providing effective cooling.

This research has implications for the cooling of all underground transport systems where seepage water and the companion technology of groundwater cooling from an aquifer are available.

3. References to the research (indicative maximum of six references)

[1] Maidment G.G., Missenden J.F., Evaluation of an underground railway carriage operating with a sustainable groundwater cooling system, International Journal of Refrigeration, 25 (2002) 569–574. Doi: 10.1016/S0140-7007(01)00055-X

[2] Ampofo F, Maidment G.G., Missenden J.F., Underground Railway Environment in the UK, Part 1: Review of thermal comfort, Applied Thermal Engineering, 24 (2004) 611-631. Doi: 10.1016/j.applthermaleng.2003.10.017

[3] Ampofo F, Maidment G.G., Missenden J.F., Underground Railway Environment in the UK Part 2: Investigation of heat load, Applied Thermal Engineering, 24 (2004) 633-645. Doi: 10.1016/j.applthermaleng.2003.10.018

[4] Thompson J.A., Maidment G.G., Missenden J.F., Modelling low-energy cooling strategies for underground railways, Applied Energy, 83 (2006) 1152–1162

[5] Ampofo F, Maidment G.G., Missenden J.F., Underground Railway Environment in the UK Part 3: Methods of delivering cooling, Applied Thermal Engineering, 24 (2004) 647-659. Doi: 10.1016/j.applthermaleng.2003.10.019

[6] Ampofo F., Maidment G.G., Missenden J.F., Application of groundwater cooling scheme for London Underground network, 2011, International Journal of Refrigeration, 34 (2011) 2042-2049. Doi: 10.1016/j.ijrefrig.2011.05.016

4. Details of the impact (indicative maximum 750 words)

The underpinning research summarised in this case study has delivered benefits directly to a public service provider, London Underground Ltd (LUL) and a leading international engineering consultancy, Parsons Brinckerhoff (PB). It has also provided professional technical guidance to building services engineers and influenced the use or consideration of ground source geothermal cooling in other underground railways and networks worldwide.

Using LSBU research findings together with data emanating from the KTP programme, LUL and its client engineer PB invested significant resources and expertise in assessing groundwater movement across the London basin to identify potential locations for the implementation of the technology (2008–2009). The successful Victoria pilot provided LUL with reassurance and confidence that the technology was viable. As a result, LUL has incorporated the cooling concept into its £500m plans for the Victoria line upgrade [1]. The Victoria pilot also enabled a number of additional lessons to be learnt by LUL, including an understanding of the energy usage involved, the optimal system design configuration and the most appropriate maintenance regime for this cooling technology. These lessons have been carried forward by LUL and its engineering contractors into the final designs for future station cooling schemes [1]. LSBU research in collaboration with PB also indicated a potential benefit for the waste thermal energy to provide useful heating output for local infrastructure. This offers further carbon savings such that a typical LUL mechanical ventilation shaft could be used to produce heat energy for local buildings at half the carbon cost of a condensing gas boiler and with one sixth of the system energy requirements. LUL are currently investigating the commercial prospects of this associated benefit [1].

LUL are basing most of their current station cooling installations on cooling concepts proposed by the LSBU research. In 2012, LUL installed such a scheme at Green Park station. This scheme has been recognised for its environmental impact, winning an Environmental Innovation award sponsored by Eurotunnel at the 2012 Rail Business Awards [2], giving exposure and recognition to LUL and its partners. The judge's comments included: *"A clear need at a customer level requiring an innovative solution – clear objective, nicely explained trial and correction process of arriving at final workable design, with an excellent implementation process and an outcome delivering real benefits - a real marvel".* Aspects of the technology implemented and developed at the Victoria and Green Park schemes have also been adopted by LUL at the Oxford Circus installation which was completed in 2012 [1].

The schemes at Green Park and Oxford Circus reduce the carbon footprint relative to other more traditional cooling schemes, providing a more comfortable, lower cost and more efficient travelling experience for those using Green Park (34m passenger entries and exits per annum) and Oxford Circus (81m)) as well as to LUL station staff. [3]

As a result of the successful KTP collaboration with LSBU and work with LUL, PB have created a new professional level post and successfully integrated their traditional tunnel ventilation capability with these new sustainable cooling technologies. To date this has generated over £500k of additional revenue for PB. The ability to successfully design and analyse groundwater cooling schemes for underground railway tunnels is now a marketable skill [4].

The strong relationship established between PB and LSBU continues to bring mutual benefits. For example, (i) PB are being consulted by other metros around the world with similar temperature issues to London [4]; (ii) LUL has commissioned further contract research with LSBU (2009-2013; £500k) to investigate novel cooling processes within underground systems; (iii) LSBU have been approached by Crossrail to study groundwater cooling systems for, and their potential benefit to, the Crossrail programme; (iv) the LSBU research was recognised by the Institute of Refrigeration in 2008, winning the Ted Perry award for sustainable cooling of underground railways through enhancement of the heat sink effect [5]; (v) a number of joint conference papers by LUL, PB and LSBU have been produced since 2009, including at the CIBSE Technical symposium in 2011 [6,7, 8].

Two important industry-leading Technical Memoranda have also been generated directly as a consequence of the LSBU research on ground source cooling [9, 10]. Specifically, the CIBSE Technical Memorandum on Ground Water Cooling systems directly refers to the collaboration between LSBU, LUL and PB, and refers to the Victoria trial.

The LUL groundwater cooling system has generated considerable interest worldwide. The Naples Metro have applied the method [11] and a number of other underground operators are actively contemplating its use. For example, the Metropolitan Transport Authority is evaluating its use to cool the New York Metro [12], as are metros in Vienna, Glasgow, Beijing and Ontario.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[1] Contact: - Programme Delivery Manager, Power, Communications & Cooling, Capital Programmes Directorate, London Underground Ltd.

[2] http://www.railbusinessawards.com/uploads/files/Winner/Rail%20Business%20Awards%202012%20winners.pdf

[3] http://en.wikipedia.org/wiki/List_of_the_busiest_London_Underground_stations

[4] Contact: Senior Engineer and Professional Associate, Parsons Brinckerhoff.

[5] http://www.ior.org.uk/14EXPOQNAJ

[6] Thompson J.A., Gilbey M.J. and Maidment G.G., Control of train air conditioning in the stalled train event, Proceedings of the 13th International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels, New Brunswick, 2009.

[7] Gilbey M.J., Duffy S. and Thompson J.A., The potential for heat recovery from London Underground stations and tunnels, CIBSE Technical symposium, De Montfort University,

2011.
[8] Thompson J.A., Missenden J.F. Gilbey M.J. and Maidment G.G., Response of wall heat transfer to steady and transient flows along a cylindrical cavity, Proceedings of the 13th International Symposium on Aerodynamics and Ventilation of Vehicle Tunnels, New Brunswick 2009.
[9] Groundwater Cooling Systems TM45 – CIBSE Technical Memorandum, 2009. ISBN: 928-1-903287-89-7
[10] Ground Source Heat Pumps TM51 – CIBSE Technical Memorandum, 2013. ISBN: 978-1-906846-32-9
[11] http://www.maxfordham.com/projects/stazione-av-napoli-afragola
[12] http://scienceline.org/2010/02/what-would-you-do-with-eight-million-gallons-of-water-every-day/