IET Railway TPN – Cooling the Tube

Sharon Duffy
Head of Station Systems Engineering
BEng CEng FCIBSE MIET
8th June 2017
Cooling the Tube Presentation

- Background
- Cooling the Tube Objective
- Challenges
- Cooling analysis
- Existing cooling solutions
- New solutions & technologies
- The Future - Waste Heat Utilisation
- Key Successes to date
Background
Bakerloo line publicity 1906

SHOPPING AND THEATRES
Comfortably, Quickly, Cheaply, by the

BAKERLOO TUBE.

Stations:

BAKER STREET.
Change for Metropolitan and Great Central Railways.
Covered Way Connection.

REGENTS PARK.
(Park Crescent Gardens)

OXFORD CIRCUS.
Change for Central London Railway, Covered Way Connection.

PICCADILLY CIRCUS.
(Top of Haymarket)

TRAFFALGAR SQUARE.
Near Charing Cross Station (S. E. & C. R.)

EMBANKMENT.
Change for District Railway (Charing Cross)
Covered Way Connection.

WATERLOO.
Change for L. & S. W. and Waterloo and City Railways.
Covered Way Connection.

KENNINGTON ROAD.
Change for South London Tramways.
(Three minutes by Tram from City and South London Railway).

Elephant & Castle Station . .
... will be opened shortly.

Fare 2d. Trains every few minutes. Fare 2d.
Average time between Stations 13 Minutes.


The Coolest Place in Hot Weather.

Maximum Temperature 85°F.
The heating effect

LU tunnels built in London clay were approx. temperature 14°C.

Year on year of running electric trains has heated the clay and caused temperatures to rise.

Running more trains will result in even more heat.
Typical values for Internal and external temperatures

Northern line data: Chalk Farm to Hampstead
Heat Sources

Energy Sources:
- Braking energy (50%)
- Aerodynamic drag and other frictional losses (21%)
- Motor and drive losses (15%)
- Train auxiliary energy (6%)
- Electrical system losses (6%)
- Passengers (2%)

Energy Sinks:
- Heat transfer into tunnel walls (79%)
- Train piston effect (11%)
- Mechanical ventilation (10%)
- Passengers (2%)
Increase in heat input

Network Heat Input (main interconnected tube tunnel network)

Absolute heat input

Millions

Year

kW/yr

JL

Victoria

Jubilee (orig)

Piccadilly

Bakerloo

Central

Northern (Hampstead & Highgate)

Northern (CSLR)
Heat Reduction

- Regenerated energy (avoided heating) (32%)
- Aerodynamic drag and other frictional losses (21%)
- Dissipated energy (18%)
- Motor and drive losses (15%)
- Electrical system losses (6%)
- Train auxiliary energy (6%)
- Passengers (2%)
- Total braking kinetic energy (50%)
Cooling the Tube Objective

Our challenge is to keep customers cool enough to protect their wellbeing.

Our plan is to tackle temperatures through innovation and excellence.
Challenges
Increased passenger journeys

![Graph showing increased passenger journeys over time. The y-axis represents passenger journeys in millions (m), ranging from 0 to 1200. The x-axis represents years from 1860 to 2010. The data shows a significant increase in passenger journeys from 1860 onwards, with a notable rise in the early 20th century and a dramatic increase in the late 20th and early 21st centuries.](Image)
Demand for the Tube

KEY - Operation Modes
Blue is London Underground
Orange is London Rail
Challenges of Cooling the Network

- Working with existing historical assets – the older deep tube lines are significantly under ventilated.
- Difficult and expensive to add more ventilation or install equipment within the network.
- Subsurface environment requiring high levels of maintenance for any air handling equipment.
Cooling Analysis
Cooling the tube relationships

- Cooling Requirements
- Train Operations
- Trains and Train Systems

Dependent relationships:
- Cooling Requirements to Train Operations
- Cooling Requirements to Trains and Train Systems
- Train Operations to Trains and Train Systems
Heat factors

- Line upgrades = more trains & more passengers
- Increasing passenger demand, up 7% per year
- London is a ‘heat island’ compared to other areas in the UK (due to the density of infrastructure and population)
- Climate change – this only plays a small part
Modelling of future conditions

Network Model

Station Geometry

Temperature and Airflows
Existing Cooling Solutions
Cooling solutions delivered

Completed to date:

• Air conditioned rolling stock – S-Stock fleet
• Groundwater cooling
• Fans installations
• Fan and mid-tunnel ventilation upgrades
• Chilled water system
• Borehole cooling system
• Supply MTVSs complete with cooling coils
Air conditioned S-Stock trains
Ground water cooling - Victoria

Award winning trial complete (started 2006)

Cool water sourced from an underground water supply (station sump)
Small Station Fans installation

- Fans are interim measure that deliver instant cooling effect (local convective cooling only)

- Large fans located at 9 stations in 2007

- 94% of customers thought fans were “good” or “very good”

- Installed large fans at over 30 stations in Summer 2008

- Ceiling mounted Impulse fans are also being trialled
Ticket Hall comfort cooling

• Mechanical chillers utilise vapour compression refrigeration systems to chill circulating water

• Chiller installed in Oxford Circus and Euston ticket hall providing cooling to the public.

• New comfort cooling system installed at Seven Sisters
Mid-tunnel ventilation
Mid-tunnel ventilation

- Mid-tunnel ventilation shafts are located all over London

- Upgrading their air handling capacity will enhance ‘cooling’ on the network.
Tunnel Ventilation Fans
Attenuation equipment
Tunnel Ventilation Systems upgrade

- Upgraded 14 No. Victoria Line mid tunnel ventilation (MTV) shafts.
- New fan installed at Liverpool Street to extract warm air
- Reinstated 40 out of service fans along the network
- Improved ventilation to Holland Park Station
Platform air handling unit
Chilled water system
Borehole cooling system

- Abstraction Borehole
- River Terrace Gravel
- Clay
- Chalk
- Water Filtration Unit
- Submerged Pump
- Air Handling Unit
  - Complete with a cooling coil
  - Cooling coil is similar to a radiator but providing cooling instead of heating
- Cool Water from the Aquifer below London
- Warmed Water returned to Aquifer at a distance from abstraction points

(Underground logo)
Case Study - Green Park Borehole Cooling

- Green Park station platform temperatures maintained at pre-upgrade conditions during warm weather, following the Victoria Line and Piccadilly Line upgrades.

- Victoria Line platforms cooling load - 400kW.

- Piccadilly Line platforms cooling load - 400kW.

- Borehole water cooling system - 800kW of total cooling capacity.
Modelling shows that borehole abstraction temperature is predicted to increase by a manageable 2°C over 60 years.

An alternative mitigation is to find a third party heat user.
Primary Borehole Water Distribution Circuit

Environment Agency license permits LU to abstract water from and reinject water back into the deep level chalk aquifer in Green Park.

There are five boreholes, two abstraction and three reinjection.

Water is pumped up to surface level and circulated, from the boreholes to the station plant room, via distribution pipe work buried in trenches in the park.

The aquifer is a source of potable water, therefore the system has been designed not to have any adverse environmental impact.
300mm diameter holes drilled to a depth of 50m – 60m into the upper chalk.

Steel borehole casings are installed from the surface level to 6m into the chalk.

Boreholes were acidized to open up fissures in the chalk and cleaned, then the borehole hydraulic performance was tested.

All boreholes have a water temperature, conductivity and level sensors.
Secondary Station Cooling Water Circuit

Closed loop pressurised distribution system complete with platform air handling units.

Secondary pumps distribute the cooling water from the station plant room to the Victoria and Piccadilly Line platforms.

The cooling water flow temperature is 15°C off the heat exchanger.

The cooling water return temperature is 23°C from the platforms.

The platform air handling units deliver 100kW of cooling each, with two units on all of the Victoria and Piccadilly Line platforms.
Delivery and installation of PAHU’s
Two new MTVSs complete with cooling coils have been commissioned to serve St Pauls station and Forest Road MTVS.
Forest Road – chilled supply ventilation
New Solutions & Technologies
Trials and research

- In Train Hybrid Cooling
- Regenerative Braking & Train Optimisation
- Under Platform Exhaust Systems
- Evaporative Cooling
- Air Handling Unit – design development
- Trigeneration
Air conditioning

London’s deep lines do not have enough air passages to the surface to let the warm air escape.

Sub-surface lines

Deep level lines
In train hybrid cooling

- Ice built whilst outside
- Unit located under carriage floor
- Heat rejected whilst outside
- Ice melted and cooling delivered whilst in tunnel
- Ice Reservoir
  - Condenser
  - Refrigeration Unit
Regenerative braking

Regen braking increases the amount of energy trains can convert back into electricity during braking to be used to power other trains.

Up 25% of the kinetic energy is NOT converted into braking heat.
Under platform exhaust

Removes heat from the track area within stations while trains are waiting at the platform.
Cooling Panel

Patent pending
Trigeneration Feasibility Study

Image courtesy of Arcadis
Waste Heat Utilisation
Tunnel Heat Energy Recovery

Opportunity to utilise waste heat generated by the railway by extracting it via absorber pipes embedded in the segmental lined tunnels.

Low-grade heat can be run through a heat pump to provide energy-efficient hot water or space heating to commercial/residential users near stations.

Potential revenue stream of energy supply, and savings on the operational cost of running fans for cooling.

Image courtesy of Zublin and Crossrail
City Road Ventilation Shaft - Waste Heat Recovery

The new LUL fan will move 70m³ of air a second.

Islington's heat exchanger coil will absorb heat from the air passing through.

Islington's combined Heat and Power Plant (CHP) will produce heat and electricity.
Key Successes to date
Delivered Cooling Works

- Evaluating waste heat utilisation opportunities across the network
- Trigeneration Feasibility
- Oxford Circus chilled water system
- Green Park borehole cooling system
- St Pauls and Forest Road supply MTVSs complete with cooling coils
- Upgraded 14 No. Victoria Line MTVSs
- Restored 50 ventilation fans – doubling capacity of the fan network
- Restored 10 No. long term out of service fans
- Further designs in development for 5 No. long term out of service fans
- Ground water cooling trial at Victoria
- Deployment of portable summer fans at many locations
The last 11 years....

<table>
<thead>
<tr>
<th>Line</th>
<th>Fan</th>
<th>Fan &amp; Coil</th>
<th>PAHU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jubilee</td>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Victoria</td>
<td>13</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Northern</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Piccadilly</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Central</td>
<td>5</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Bakerloo</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>26 Sites</td>
<td>2 Sites</td>
<td>2 Sites</td>
</tr>
</tbody>
</table>

8th June 2017
Projected - the next 20 years...

Oxford Circus – chilled supply ventilation system
Bond Street - chilled supply ventilation system
Renewals to existing tunnel ventilation systems
Deep Tube Upgrade Programme – associated cooling and draught relief enabling works
Station Capacity Upgrades – opportunity hybrid waste heat utilisation and cooling schemes
Trigeneration opportunities
Thank you

For more information email:

sharonduffy@tfl.gov.uk