

MEETING REPORT

COOLING THE TUBE

by Stuart Westgate and Mark Gilby

A report of the LURS meeting at All Souls Club House on 8 May 2007

The speakers began by introducing themselves. Stuart Westgate stated that, beginning his career as an electronics engineer, he spent six years in the London Underground (LU) Rolling Stock department, followed by six years with Alcatel designing signalling for the Jubilee Line Extension, and then via various project leadership roles, he became deputy programme director for this project.

Mark Gilbey began as a mechanical engineer specialising in tunnel ventilation, in which field he gained experience in both Hong Kong and New York transit systems, and was now Development Engineer Manager and technical specialist for this project.

Setting the scene, the speakers remarked that traditionally, the London Underground tunnels have been fairly warm and over time are getting gradually warmer. The temperature at platform level remains fairly stable whilst the street level air temperature may fluctuate, and this is due to reasons of geology. The clay surrounding the tunnels insulates and stores heat given off by passing trains during the day, and gradually releases that heat back into the tunnels at night. This will increasingly become problematic with the projected increase in service frequency to be brought about by the various PPP contracts and the increased equipment fitted to trains such as air conditioning. Increase in usage equates to increase in heat; moderately little heat is given off by passengers, lighting or other equipment compared to the heat given off by the trains. The proportions of heat given off by the trains' systems vary for each line; a study for one line indicated 38% generated by train braking, 16% through inefficiency in creating train movement ('drive losses'), and 22% from general mechanical inefficiency and air drag which would otherwise cause a moving train to eventually come to rest on a flat piece of rail. The bulk of this heat is going into the tunnels, very little is dissipated through ventilation. There will be a net increase in heat in the underground environment over time.

The next question is: as it is getting warmer down there, how warm should we let it get? Comfort and Safety are the two factors to consider here. Comfort is equated to heat strain and there are very few expressly stated rules for humans that can be applied to the tube train environment. The problem is complicated because heat strain can be affected by any number of factors such as relative humidity, air temperature, Carbon Dioxide, condensation, air movement, wind outside the tunnels. To calculate the maximum tolerable thermal environment it is necessary to use either a stress index or a strain index. A stress index relates the passenger response to temperature exposure over time. Tests would be required to develop such a stress index particular to a train environment. Heat strain calculations are the only practical way to measure this, and can be done using several different methods, the most effective of which, the speakers felt, was ISO7933, which calculates the core temperature of the blood inside one's body. If one's core temperature reaches 38 degrees or above, then comes the onset of syncope (fainting, nausea, sickness) and it is this that we want to avoid. However, heat strain indices developed for the industrial environment are not easily transferable to the railway; crush loading on a

train is a very different model. Using detailed models to represent the blood flow between the core muscle, fat and skin of the body, the speakers said that it was possible to develop a usable correction factor which applied to heat strain models would take into account crowding. One of the speakers explained the concept of radiant heat exchange – because the walls floor and furniture surfaces of a room are at a lower temperature than one's skin temperature, one can lose heat by radiance to all of these surfaces and thus feel cooler. But crowded and surrounded by other people, 'all my body can see is your body at the same temperature, so the ability to lose heat by radiance drops off dramatically'. The speakers said that by analysing different scenarios of crush loaded trains, train stalled in section, two trains in section, lack of tunnel ventilation and so forth, it was possible to get a good idea of what the maximum acceptable conditions could be.

But if we know the maximum, then what is the ideal comfort level? Scientists have long puzzled over what makes people comfortable. Sedentary position, stillness, little air movement. But tunnel environments are far from ideal – different layers of clothing, large differences in passenger volume, people entering and exiting; there is much scatter in the data concerning what makes people comfortable. The Cooling the Tube programme undertook to interview around 5,000 people around the network and correlated their views of what makes people comfortable, but even then this accounted for only 29.5% of the comfort variation. There was a lot that could not be physically modelled, but the audience was shown by way of a graph that by using the 'relative warmth index' (for example, a passenger running to the station is hot from hurry and baked by the sun, then comes into the shade of the station and ceases to hurry, then goes to the platform where the heat begins to rise again) it is possible to determine the ideal – this seems to be 24 to 26 degrees C on trains, 28 degrees on stations. The speakers stated there are many challenges to get to this figure; with the line upgrades 'we cannot wait until they are complete and then decide, we must be proactive'. Thus the programme has devised many simulations, building lots of different station models (slides of some were shown to the audience) to determine air flow, the effect of trains pushing air through stations and tunnels (the piston effect) and these are used to predict temperatures, velocities and conditions in the future. To solve these issues it is possible to use either known or future technologies. Innovation, the speakers said, is part of the Cooling the Tube programme, but railways traditionally like to choose the known, tried, tested and less risky options, the safer way to go.

Regardless of which technology is used, the goal is to implement industrial scale cooling on the underground. There are three levels at which this can be achieved. Ideally the amount of heat going into the system must be minimised (for example by optimising trains to use less energy). Where the level is already at the minimum, the next best step is to maximise the flow of air through the system by ventilation, relying on the piston effect and configuring vent shafts to encourage air flow in a more beneficial direction. The least desirable level is through mechanical systems of air cooling, air conditioning and high volume forced ventilation systems.

Optimising train energy usage can be applied across the London Underground network by adjusting the timetable to give less frequency, more gaps between trains, more coasting. Newer trains can utilise more efficient use of energy. Older trains might be provided with openings for more ventilation. Cooling pipes might be inserted into tunnels. On stations chiller units can force cool air through the stations.

In all of this there is a clear relation between the greater the energy used and the more cooling needed.

The speakers having outlined the calculations and conclusions they had arrived at then went on to detail the ways in which they are tackling the increased heat on the tube.

The first level they are tackling is working with the Infracos and suppliers (such as EDF energy) to help them develop optimised systems to increase the efficiency of the railway and to encourage them to give more thought to energy efficiency, such as briefer acceleration and more coasting by trains, thereby creating less heat.

The next level is the practical level, the 'application of innovation' as one of the speakers put it. The various schemes being developed by the Tunnel Cooling programme were then detailed to the audience.

Victoria Station: use of naturally occurring seepage water from rainfall and the river Tyburn which runs beneath the station, to provide air cooling to the middle lower concourse on the station, encouraging heat exchange with the water by use of fans in the air cooling units, the heat thus being extracted via the sump area. The beneficial cooling effect from the existing discharge of water gave a temperature cooling of 2 degrees during the trial. This scheme may be extended via the station upgrade with fans above each platform 'chucking out serious quantities of cooling' and pushing cool air round the system by the movement of trains.

Attention has been given to rehabilitating the 126 ventilation fans on the network, some of which had ceased to work through reliability issues, noise complaints from neighbours and sometimes merely from people not being aware of the importance of switching them on. Some 92 are available for service, 'making a major beneficial effect on the way we extract air from the system'. Slides were shown of a new fan fitted in an old vent shaft at Liverpool Street. Also, using ideas gleaned from practices used on the Paris Métro, fans may be used to over-cool tunnel walls during winter and carry some of that cooling through to the summer months.

A new cooling system has been installed in Oxford Circus Station Ticket Hall using chillers to bring comfort and air cooling to people passing through the ticket hall.

Mention was made of an innovative scheme to use the under platform voids on station platforms to extract air at track level from the under train equipment when berthed, before the heat has a chance to leak into and warm the passenger environment. Slides of such a void were shown.

One of the speakers stated that ventilation is always the preferred option and has smoke management advantages too, but when it is not possible to ventilate it may be necessary to mechanically cool.

Borehole Cooling: North of London are the Chiltern Hills, and south of London are the North Downs, both are exposed rocky outcrops. Under the centre of London is a layer or strata of chalk. Over a geological timescale the rain falling on these rocky outcrops has collected beneath London in what is essentially an aquifer, a highly fissured and fairly wet chalk layer containing water which is quite cool at around 13 degrees C all year round and has been there for thousands of years. The speakers detailed their plans to drill down into the chalk aquifer, extract the water, pass it through cooling units and re-inject it. In order to prevent the aquifer becoming warm when the water is re-injected, advantage will be taken of the natural flow gradient in the aquifer, but to do this the extraction and re-injection boreholes must be

separated by at least a few hundred metres. This is a relatively new concept, being used by the Royal Festival Hall, and the audience were shown slides of how it is proposed to trial this scheme at Stockwell station. The transmissibility of the aquifer to the London clay layer above is low, the clay being 'aquitar' in nature. The water stays where it is. The boreholes need to be around 200m apart and about 100m deep. Use will then be made of cable tunnels, the deep level World War Two shelter, and the under platform voids, to transfer the water through pipe work from the extraction bore hole, through the cooling and air handling units on the station (disguised as station over-bridges above the platforms) and back to the re-injection borehole. Water can be extracted at 25 litres per second, but as the chalk layer is quite fissured, if the flow of water is not so good, a mild acidification process may be used to improve the flow. If this trial goes ahead and is successful, this solution could be viable at up to twenty stations on the network.

The idea of evaporative cooling is being investigated (if you stand next to a fountain you will notice the air is cooler round the fountain. As the moisture droplets evaporate they take energy from the air in order to do so, thus cooling the air and making it slightly more humid). LU tunnels are usually warm and dry so evaporative cooling could be provided in three different ways, by either a rigid media system, (water cascading through a sponge medium picks up humidity but reduces in temperature), or by spraying water into the tunnels or into the adits. A full scale trial of this technology is planned but it is not suitable for everywhere on the network since it would create a huge humidity problem rather than a huge temperature problem. But at some locations it would work.

Rolling stock air conditioning: Sub-surface trains are getting air conditioning, but air conditioned trains are net rejecters of heat causing a net increase in tunnel temperature. But not all trains are continuously in tunnel at all times, so LUL are investigating a thermal storage system using a phase change medium (probably ice). It is planned to trial having a condenser and evaporator unit under probably the trailer car of a Piccadilly Line train, circulating water through the phase change medium when the train is outside, building ice, then a little bit of residual cooling would go to a cooling coil then back to the condenser and evaporator unit. When the train is outside, it could be building ice, in the open section where heat rejection is not a problem, then when in tunnel section turn off the evaporator and condenser unit, then circulate the water round the phase change medium to melt the ice and cool the carriage via the closed water circuit. This system is to be trialled on the Piccadilly Line stock, and whereas it might work on certain lines such as the Jubilee and Central which have open section at both ends, it would not work on the Bakerloo and Northern which are effectively tunnel at one end. It is still in the concept design stage but could work.

Then the speakers invited questions from the audience. A number of questions were forthcoming including:

Q: During train braking there is a big loss of energy, is there any thought given to regenerative braking?

A: *Yes, there are plans for a full scale trial of an inverter substation, to increase receptivity to regenerative braking. Also the programme is promoting the investment in fitting 'low loss' and 'ultra low loss' conductor rails. But a problem with regenerative braking is that there is an upper limit to the voltage accepted on the traction power network after which there is again energy loss through blended braking and use of the rheostatic brake once the maximum level of voltage*

acceptance has been reached. 'If we can increase the receptivity of the system by lowering the transmission losses we will'. Also, traction packages will be re-assessed, with the subsurface lines already having 750v and serious consideration being given to 750v on the Piccadilly Line. The idea of large on-train storage capacitors has been looked at and Network Rail are trialling this at present, but the idea has large scale safety risks and there are issues of limited storage space under trains to consider.

Q: How do we equate the use of more energy efficient solutions with service enhancements?

A: We are interested in quicker acceleration (using power over a shorter period) and more coasting at the latter end of a journey between two stations. Although coasting is a low energy solution, its penalty is time. Coasting uses natural losses in the system, the 'Davis Equation' losses and air drag to slow the train down, but the time lost there can be recouped by optimising the acceleration at the beginning of the trip.

Q: Why not use the large scale fans, such as on the Jubilee Line, to blow at full power during engineering hours to cool the tunnels down at night, not creating discomfort for the passengers? And does the fact that there are larger diameter tunnels on the JLE and Victoria line prove a help or hindrance to the piston effect in air circulation?

A: No, we can only do it on lines which have these fans, which is only the Jubilee Line extension. We can only run these noisy fans at half speed at night because of resident complaints if they were run at full speed. Also there is no space to install noise attenuation in the vent shafts without demolishing them and starting again. But we will try running them at full speed during the day when we can get away with it. Larger diameter tunnels are more of a hindrance but not much of one. But subtle differences such as decreasing the headway between trains as a result of service enhancement does lead to a drop off in the piston effect. Likewise, the design of the tunnel can be important as well, since cast iron segment tunnels hinder air circulation whereas the smooth walls of concrete tunnels help it.

Q. There have been trials on painting train carriage roofs white to cause a reduction in interior temperature. Are there any plans to introduce painted roofs or tinted windows on trains to help cool the tube?

A: We haven't ruled out or closed our minds to this, but our prime concern is where the principal sources of heat exist such as from traction motors. Once the big problems have been addressed, then the little ones can be scrutinised. This summer we are investigating whether putting parasols in the depots to cover the trains laying over outside on sunny days is viable. Perhaps this may be another way of decreasing the heat inside trains. One of the main challenges of this project is that there are not many disciplines it does not touch, so we have to prioritise things. Painted roofs have not escaped our attention but we have other things to target first before moving there.

After the conclusion of the questions, the audience expressed their thanks in the usual manner.

Donald McGarr