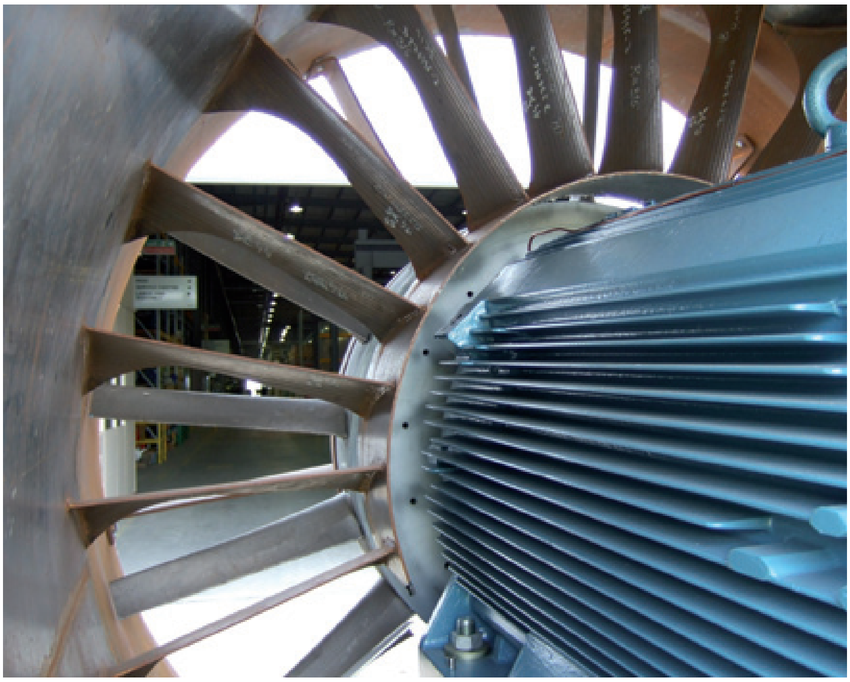
IS TUNNEL VENTILATION SUSTAINABLE?

Tunnel ventilation can consume substantial power, which can amount to several megawatts, as well as requiring expensive structural space and electrical facilities. Although sustainability is now recognised to be a key goal for infrastructure development, its application to tunnel ventilation is still in its infancy. This article by **Fathi Tarada**, secretary of the World Road Association *PIARC*, and MD of *Mosen* summarises some key lessons from the forthcoming *PIARC* report on sustainable road operations, and draws some examples from practice



***Above:* A large Flakt Woods axial fan during certification tests**

THERE IS increasing interest in the application of sustainability concepts to tunnel ventilation design, installation and operation. This is due to the need to reduce energy consumption as a means of minimising carbon footprint, the commercial imperative to reduce costs at all stages of the infrastructure life cycle, and the requirement to enhance equipment availability.

The World Road Association (PIARC) is about to publish a report on "Recommendations for Sustainable Road Tunnel Operation", which contains a survey of existing frameworks for sustainability, including various national regulations and guidelines. The report also includes chapters on identifying and reducing costs associated with tunnel civil works and equipment. This paper includes a summary of some aspects of the PIARC report in the areas pertinent to tunnel ventilation.

SUSTAINABILITY CONCEPTS

The Brundtland Report (1987) and the 1992 Rio Summit have set a general framework for the concept of sustainability. According to the Brundtland Report, sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The sustainable development concept is based on three main pillars:

- Social: meeting needs in terms of health, education, housing, employment, etc.;
- Economic: creating wealth and improving living standards;
- Environmental: preserving species, natural resources and energy resources.

The end-goal of a sustainable development approach is to find a balance between the three pillars and preserve this balance over the long term.

Contrary to certain common beliefs, the concept of sustainable development does not solely rest on the objective of preserving the environment. It also aims to meet social needs and economic requirements. It is thus generally represented by three pillars, which should roughly have the same weight (see Figure 1, page 42).

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Sustainable development represents a holistic approach of the whole life cycle of a project, and requires a balance to be struck between economic, social and environmental objectives. A sustainable design must recognise the integrated nature of human activities and must therefore include a commitment to coordinate planning and design amongst all relevant sectors, disciplines and groups.

IS TUNNEL VENTILATION REQUIRED?

The first issue to be addressed is whether tunnel ventilation is required at all. Short tunnels, defined by the EU Directive on Road Tunnel Safety [1] as being 500m or less in length, or tunnels less than 300m in length in accordance with NFPA 502 (road tunnels) and NFPA 130 (rail tunnels), do not generally require any tunnel ventilation. Ventilation for such short tunnels is provided by natural air movements and by the piston effect of moving traffic. In case of fire, natural buoyancy and wind effects can push smoke towards one portal, possibly leaving the other portal clear for tunnel users to evacuate from.

For longer tunnels that do require mechanical ventilation, a number of variables including the tunnel length, vertical gradient, traffic flow, vehicle mix and the number of lanes can significantly influence the required ventilation capacity during normal operations. Due to the piston effect, many road tunnels less than 3km in length do not require any mechanical ventilation to preserve in-tunnel air quality during normal operations - with the possible exception of rush-hour traffic. Such an approach has recently been used to significantly reduce the energy consumption within the Mersey Kingsway and Queensway Tunnels, for example. Reducing energy consumption is good for the environment in terms of reduced emissions; saving financial resources may mean that public funds can be released to other social ends.

For many tunnels today, the determining design criterion for mechanical ventilation is smoke control in case of fire, rather than maintaining adequate in-tunnel air quality. Tunnels can therefore be equipped with significant ventilation equipment "in reserve", which is not normally used to full capacity. The reason for the installation of such equipment is for life safety, as evidenced by compliance to codes or by means of a risk assessment. Nevertheless, certain methods are available of reducing the power consumption of such an 'over-sized' ventilation system during normal operations: for example by switching all available fans on at lower speeds, and by including "redundant" fans in the normal operating cycle.

EXTERNAL AIR QUALITY

Tunnels do not create any emissions – rather, they contain and redirect emissions to outlet portals and ventilation stacks. However, the discharge of vitiated air can impact on the health of residents living close to the exit portals. In order to mitigate this effect, polluted air can be extracted up through exhaust stacks and dispersed, achieving 'zero portal emissions' – but this comes at a very significant cost in terms of civil, mechanical/electrical equipment and ongoing power consumption.

The Australian experience is very pertinent in assessing the sustainability of zero portal emissions.

Commencing with the M5 East Tunnel in Sydney (which opened in 2001), a restriction was applied to protect residents living in the vicinity of the tunnel portals, by arranging the ventilation system to achieve zero portal emissions. This restriction was later retained for the Cross City Tunnel (2005) and Lane Cove tunnel (2007). Zero portal emissions have subsequently become the de-facto standard for road tunnels in Australia.

To achieve zero portal emissions, all of the tunnel air must be expelled from the ventilation stack, with air being drawn in from all portals. This requires pulling air against the piston effect of traffic at the exit portal. Such an effect can only be achieved by increasing the volumetric flow rate of the air discharging through the stack, and increasing the stack's cross-sectional area.

Table 1, opposite, provides a summary of the power consumption figures for four Australian tunnels. The M5 East ventilation system energy use is equivalent to that of nearly 7,400 households; it is open to question whether such a ventilation system can be considered sustainable from an environmental perspective.

Nevertheless, any sustainable ventilation system must win the confidence of the community in the management of air quality within tunnels, as well as preserving local ambient air quality. A number of trials involving switching off the portal extract systems for the CityLink and Lane Cove Tunnels overnight and during low traffic conditions have been undertaken, with little impact on the ambient air quality levels being reported [2].

TUNNEL LIFE CYCLE

The operation of a road tunnel is highly dependent on the design and construction phases, which preceded the commissioning of the work. More precisely, it is necessary to

*Below: **The Three Pillars of Sustainability***

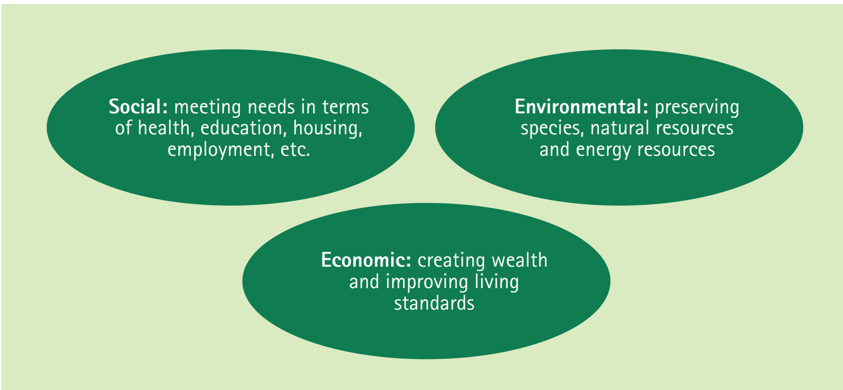

Table 1. Electricity Consumption for four Australian Tunnels				
Project phase	Electricity consumption (MWh/annum)	Total (two way) tunnel length (km)	Traffic (vehicles per day)	MWh/km per annum
Eastern Distributor Tunnel	4,400	3.2	110,000	1,375
Lane Cove Tunnel	15,400	7.2	70,000	2,139
CityLink Tunnel (Melbourne	21,500	5	100,000	4,300
M5 East Tunnel	54,000	8	100,000	6,750

Source: Author

take account of the effect of solutions opted for during a project's design phase on operating conditions. If the selected design solution is not ideal, it will be very difficult to improve the tunnel's sustainability throughout its life cycle.

PIARC has provided an estimate of the impact of the various phases of a tunnel project on operating costs. The data is presented in Table 2, and highlights the importance of good design to minimise operating costs.

The planning phase (study/design) is normally three to 10 years, the building/construction phase two to three years while the operation phase may be from five to 20 years for installations/equipment and 80 to 100 years for the tunnel structure. This does not account for possible refurbishment work undertaken on the tunnel.

Table 2. Impact of project phases on operating costs	
Project phase	Estimated impact
Design / study	60 – 80 per cent
Build / construction	10 – 30 per cent
Operate / tunnel lifespan	10 – 30 per cent

Source: Author

LOW-SPEED FANS

As an alternative to the installation of conventional axial fans in conjunction with attenuators to control noise levels, one option that may be considered is the installation of low-speed, large diameter fans.

Such fans typically run at speeds less than 200 rpm, and their impellers are produced from GRP material. The low-speed fans emit less noise than conventional axial fans, reducing or eliminating the need for attenuators and reducing the power consumption.

An overall saving in power consumption of 75 per cent may be possible with low-speed fans, compared to conventional axial fans.

However, these fans generate less static pressure than conventional axial fans. This makes the selection of the low-speed fans more difficult, since these fans are more susceptible to variations in pressure generated by traffic movement and wind effects.

Low-speed fans have been installed in a small number of tunnels, including the Spier Tunnel in Switzerland. However, the low-speed fans in the Spier Tunnel are almost never used, and thus there is almost no operational experience reported from them.

TECHNICAL INNOVATION

The forthcoming PIARC report outlines a number of technical innovations that can improve the sustainability of tunnels in general, and tunnel ventilation in particular. One of these innovations is the MoJet, which is a type of jet fan that features shaped nozzles.

The shaped nozzles reduce the Coanda effect, which is the tendency of the air steam produced by each jet fan to be drawn to nearby walls, leading to increased friction and significantly increasing the energy required to move the air.

This effect occurs because the jet flow close to the wall decelerates, creating a pressure difference across the jet that reinforces its attachment to the wall, even at high velocities. The reduction of the Coanda effect was confirmed by the use of 3D CFD calculations.

As an example project, an approximately 0.6km long dual tube road tunnel at a major international airport required significant refurbishment. The original specifications for the refurbishment called for 710 mm internal diameter conventional jet fans with two-pole motors. It was anticipated that this installation would be noisy, take up a lot of space, and possibly require increased safety precautions due to high jet velocities required for effective operation.

Four-pole motors were selected that run at half the speed of equivalent two-pole motors were selected for the design. The result was a 30 per cent reduction in power consumption and a 7dB reduction in sound pressure level in the tunnel, along with significantly reduced jet air velocity. In addition, the innovative jet fans could be installed much closer to tunnel walls and at reduced distances along the tunnel, reducing construction and cabling costs.

UNNECESSARY INSTALLATIONS

There is a significant amount of evidence that some aspects of tunnel ventilation installations are unnecessary, and hence do not represent sustainable infrastructure. A good example of this relates to tunnel air filtration systems.

For example, the filtration plant for NOx and particles within the Opera

The Byfjord Tunnel was recently refurbished with MoJet fans

tunnel in Oslo, Norway is no longer on operation due to its excessive energy consumption, large maintenance and operation costs and its low efficiency. The same decision has been also made for six other tunnels in Norway, which were equipped with more recent generation of filtration technology.

In the case of M30 tunnels in Madrid, the filtration system is automatically switched on when the corresponding exhaust fans are in operation. However, these operate very rarely due to a limited level of pollution, which is largely lower than the one expected during the design phase.

Air filtration is successfully used in a number of tunnels in Japan. For example, the air cleaning equipment has been installed and is still operational at the Chiyoda and Yamate tunnels in Tokyo, Japan.

FUTURE SUSTAINABILITY

A robust approach to achieving sustainability requires the simultaneous consideration of the social, economic and environmental impacts of any design and operation proposals throughout a tunnel's life cycle. Statutory requirements, technical guidelines and frameworks should all be considered in formulating holistic strategies for the design and operation of tunnels.

The application of such holistic considerations is very challenging, but progress can nevertheless be made through focusing on certain aspects of sustainability, such as reducing operating costs, eliminating unnecessary installations and ensuring social acceptability.

Tunnel ventilation provides a significant opportunity for sustainability improvements, particularly for long tunnels, which can absorb significant amounts of power.

Although the initial design of a tunnel has the greatest impact on a tunnel's subsequent sustainability, it is still possible to achieve significant improvements based on improved operations and through the subsequent installation of innovative technology

References

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[2] http://www.transurban.com/sr11/interactive/files/images/pages/page17.swf
[3] NSW Government's "Initial Report on Tunnel Air Quality", July 2014