



Smart green underground metro station in Singapore

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ABSTRACT

A metro system is normally designed for an operation life of 100 years or above. Thus, a smart, energy-efficient metro system should be designed to cater for potential changes in passenger flow and passenger comfort needs. In Singapore, the Land Transport Authority (LTA) has put much effort in driving the use of innovative systems and the latest technologies to achieve smart green underground metro stations. This paper provides a brief introduction on the Building and Construction Authority Green Mark Rating and the various energy-saving initiatives that have been implemented recently in Singapore metro stations. More studies and exploration of green design engineering solutions, such as the use of fuel cells to replace the uninterrupted power supplies (UPSs) etc. will be carried out as part of the LTA's continuous efforts to improve the energy efficiency of its metro station.

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Introduction

Singapore, being a resource-scarce country, is committed to environmental sustainability and the efficient use of resources. As the metro system is one of the most energy-efficient means of transporting large numbers of people, Singapore has embarked on a rapid expansion of its metro network and much effort has been made to ensure that the stations themselves are both smart and green. This paper introduces the energy-saving schemes that have been developed for the underground metro stations in Singapore.

In Singapore, the air-conditioning and mechanical ventilation (ACMV) systems constitute the major portion of the energy consumption of the metro stations, using about 55%, while lighting consumes around 15% to 20%. Studies have been carried out and several features have been implemented to reduce the energy consumption and improve the energy efficiency of these systems.

Many technical measures have been engineered to attain more efficient ACMV systems, including maintaining different indoor temperatures for different public areas in the underground stations, increasing the temperature of the chilled water to achieve a better chiller efficiency, adopting CO₂ sensors to modulate the fresh air requirements for public areas, interlocking the mechanical ventilation systems of staff toilets with occupancy sensors, and using variable speed drive (VSD) to modulate chilled water pumps and cooling tower fans, among others. To further increase the efficiency of the chilled water plant, the chilled water can be supplied to nearby commercial areas that are developed

together with the station to benefit from the increased efficiency of larger chillers. In fact, this kind of sharing scheme can also reduce the overall space required for chiller and cooling tower plants. As a result, the optimum use of valuable space – which is especially important in land-scarce locations such as Singapore – is achieved.

It is not always true that mechanical ventilation systems are more energy efficient than air-conditioning systems. This paper demonstrates that the energy use of air-conditioning systems in some of the plant rooms in an underground station can be less than that of mechanical ventilation systems.

The use of light emitting diode (LED) lighting for the whole station, meanwhile, can cut down the lighting energy use by about half. Also, different types of LED fittings can create a more interesting environment for the passengers. In addition to saving energy, this paper presents green design features for Singapore metro stations, including the use of NEWater (treated recycled water from utility) for cooling tower make-up water, condensate recovery from the air handling units (AHUs) to the cooling tower, the use of skylights in underground stations, the use of green roofs for station entrances, and so on.

Green mark rating

In Singapore, the Building and Construction Authority (BCA) launched the Green Mark Scheme in January 2005 as an initiative to drive Singapore's construction industry towards creating more environmentally-friendly buildings. It is intended to

promote sustainability in the built environment and raise environmental awareness among developers, designers and builders during the conceptualisation and design phases of projects, as well as during construction. Apart from having a positive effect on corporate image, the benefits of the BCA’s Green Mark Scheme include [1]:

- The facilitation of a reduction in energy, water and material resource usage;
- A reduction in the potential environmental impact;
- An improvement of the indoor environmental quality for better health and well-being; and
- The provision of clearer direction for continual improvement.

The Green Mark Scheme for the Rail Transit System (RTS) framework was drawn up as a holistic approach to ensure that the design of the RTS takes into account the environmental and sustainability considerations. The framework covers various aspects of an RTS and is supported by three green strategies [2] (Figure 1):

- The effective use of energy;
- Environmental protection and sustainable development; and
- Water conservation.

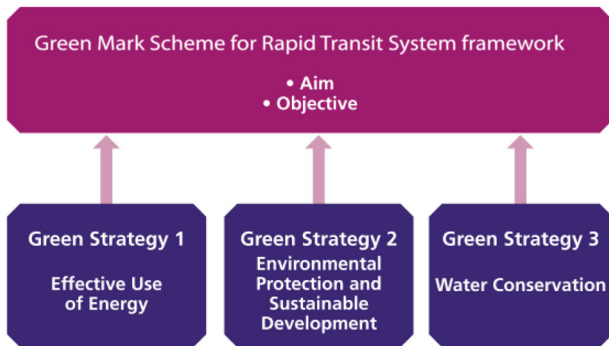


Figure 1. Green Mark Scheme for the RTS framework [2].

There is a scoring system for different criteria defined per strategy, with four Green Mark Scheme levels:

- Green Mark Certified;
- Green Mark Gold;
- Green Mark Gold^{PLUS}; and
- Green Mark Platinum.

New stations with air-conditioning space of more than 5000 m² are targeted to achieve the highest rating, Green Mark Platinum, which will result in an energy saving of at least 30% through the green design features mainly planned in the early design stage.

Energy usage in the metro system

In an enclosed air-conditioned metro system, energy will be used for the following systems [3]:

- ACMV systems or environmental control systems (ECSs);
- Lighting systems;
- Lift and escalator systems;
- Trackway ventilation systems;
- Tunnel ventilation systems;
- Railway systems (e.g. signalling, communication, etc.); and
- Other systems (fire services systems, plumbing and drainage systems, etc.).

Figure 2 shows the annual energy consumption in an enclosed air-conditioning system with the following characteristics:

- Underground station with platform screen doors (PSDs);
- Indoor design temperature (platform, concourse) of 25°C; and
- Platform length of ~ 200 m.

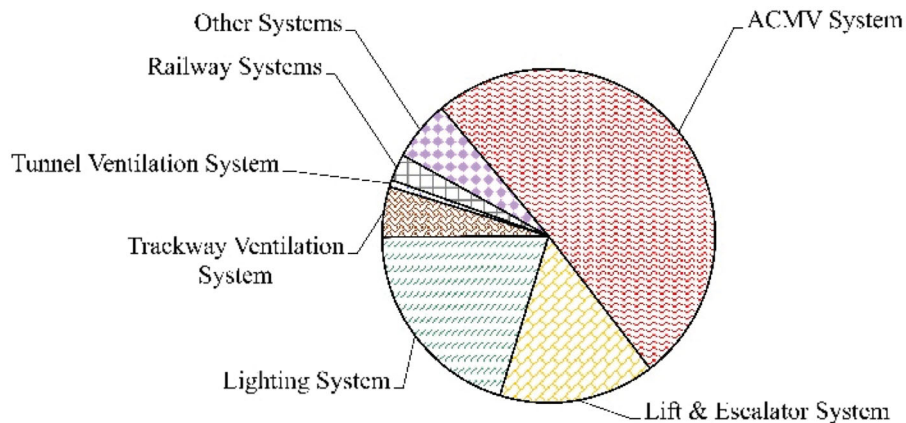


Figure 2. Annual energy usage of an underground station [3].

ACMV systems

As Singapore is a hot and humid place, air conditioning is provided for underground stations so that passengers can enjoy a comfortable environment during their journey. The design of the station's ACMV systems has to meet Singapore's Standard SS530 "Code of Practice for Energy Efficiency Standard for Building Services and Equipment"[4] and SS553 "Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings" [5]. In the paper "Energy Efficiency in Singapore's Rapid Transit System", various energy-saving methods were introduced, which included the use of PSDs, CO₂ sensors (saving 0.36% of a typical station's power consumption), VSDs for chilled water pumps and cooling towers (resulting in a reduction of up to 0.4% of the station's power consumption), and temperature sensors in some mechanically-ventilated plant rooms [2]. In addition to the above, the following concepts have been used in recent metro projects in Singapore.

Design criteria for public areas

In Singapore, the summer evening peak hour outdoor design condition is 32°C. The design criteria for underground concourses and platforms is 25°C. There may be long subways connecting the station concourse to remote entrances, so in order to save energy, the subway is designed to maintain a temperature of 27°C. This arrangement provides a transition from outdoors to trains [6] and not only saves energy, but also achieves the objective of providing an improved thermal environment as passengers move from the subway's entrance to the main concourse and platform.

Chillers

In order to attain improved energy saving and a better environment, state-of-the-art high-efficiency magnetic chillers are used in Singapore. As the chillers operate under the part-load condition for most of the time, units which operate at a high efficiency under this condition are selected. In addition, as a magnetic chiller operates with less vibration and a lower noise level, it provides a better acoustic environment than conventional chillers.

To further improve the efficiency of the chilled water system, the chilled water supply temperature is increased from 6.7°C to 8.5°C. By increasing the chilled water supply temperature, the chiller temperature lift becomes smaller, which improves the chiller efficiency. For a typical metro station, the chiller efficiency can be improved by between 0.04 kW/RT and 0.10 kW/RT if the chilled water supply temperature is increased from 6.7°C to 8.5°C. However, with the increase in the chilled water supply temperature, the size of the AHU

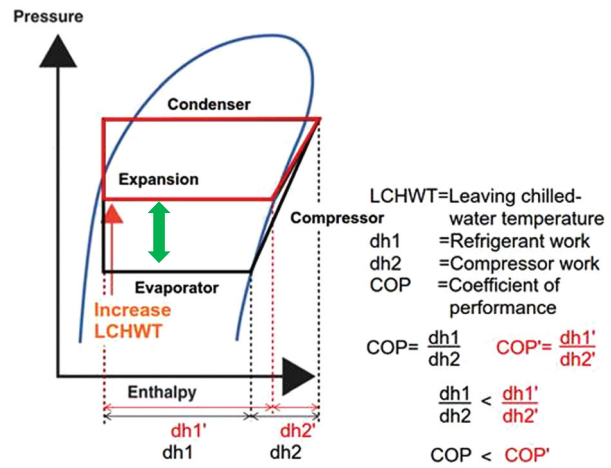


Figure 3. Vapour compression refrigerant cycle with the increased chilled water temperature.

or fan coil unit (FCU) has to be increased in order to achieve the heat exchange requirements at the cooling coil (Figure 3).

Another strategy adopted in Singapore to improve the efficiency of the chilled water system is to increase the temperature difference between the chilled water supply temperature and the chilled water return temperature from 6.0°C to 6.5°C. By increasing the temperature difference, the water flow rate is reduced, which leads to savings in energy consumption of chilled water pumps.

Cooling towers

In the efforts to seek further energy savings for the station's chilled water system, ongoing studies are being conducted on reducing the condensing water temperature, which will reduce the temperature lift and potentially improve the chiller efficiency (Figure 4).

For a typical screw chiller, the chiller part-load power consumption drops when entering condensing

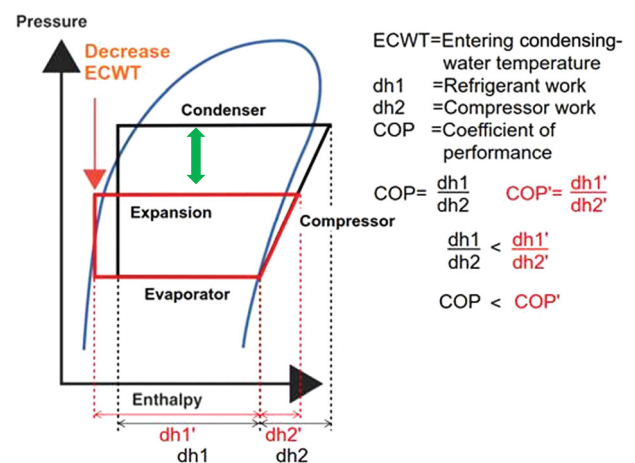


Figure 4. Vapour compression refrigerant cycle with the reduced condensing water temperature.

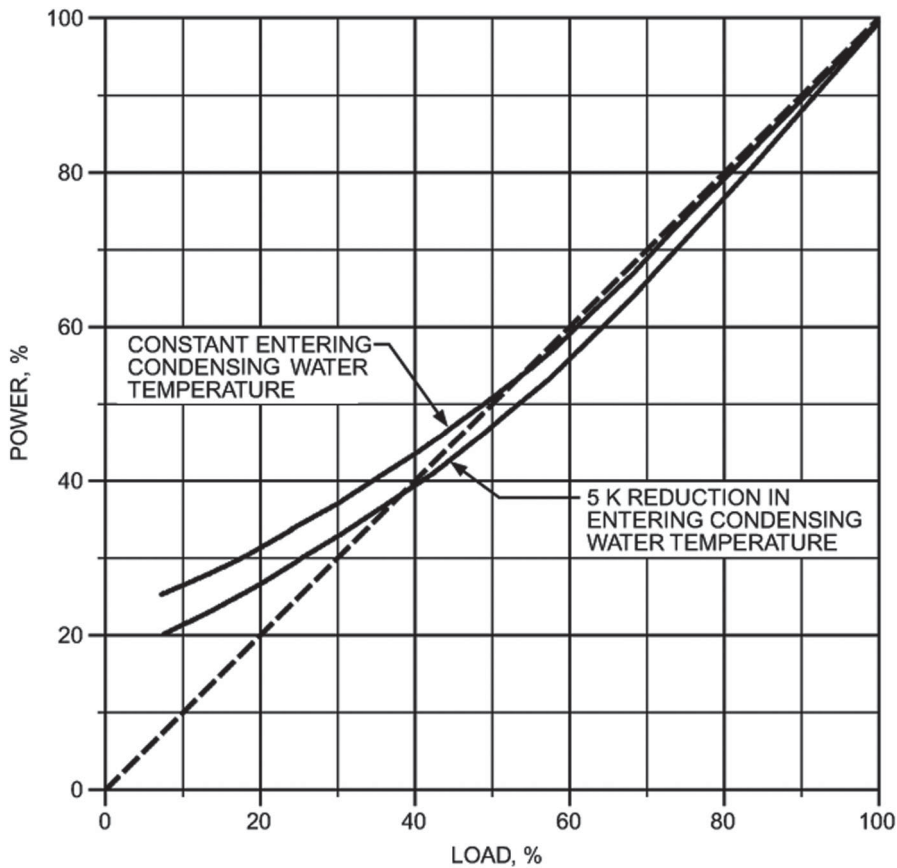


Figure 5. Typical screw compressor chiller operating with part-load power consumption.

water temperature reduces. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) figures (Figure 5) [7] show a 4% chiller power saving at 50% part load when the entering condensing water temperature is lowered by 5 K. However, an increase in the power consumption of the cooling towers is required in order to achieve the reduction in the condensing water temperature. Thus, the combined energy consumption of the chiller and cooling tower shall be analysed in order to optimise the chilled water plant efficiency.

Centralised chilled water plant

Using a centralised chilled water plant in a single location to serve several stations instead of providing a chilled water plant in each station can potentially achieve an overall saving in the initial cost, as well as the operating and maintenance costs. The use of larger centralised chillers also leverages on the better efficiency offered by chillers of larger capacity. For stations with limited footprints, this eliminates the need for using a chiller plant and a cooling tower space,

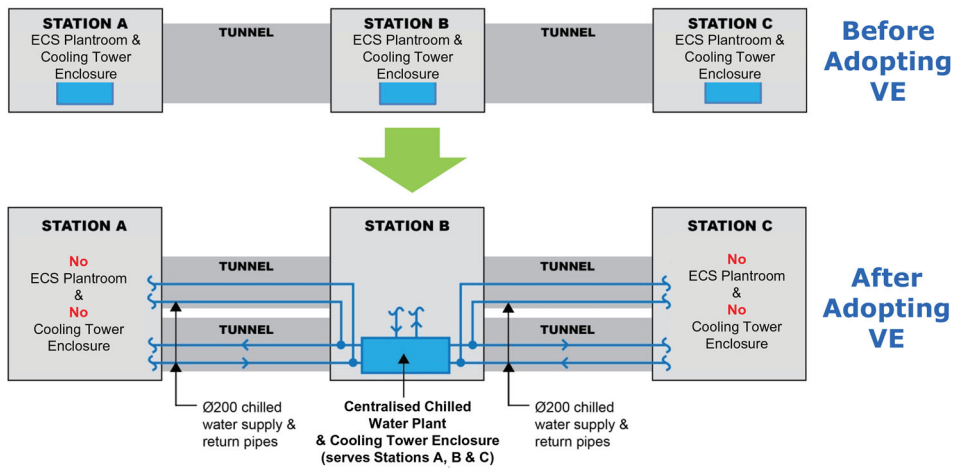


Figure 6. Sample of centralised chiller plant concept (for three stations).

thereby improving the ambience of the underground station and the station entrance. However, this scheme must be implemented in the early design stages of the project, as it is difficult to introduce it once the land take has been carried out for each station. Due to the temperature difference between the tunnel environment and the chilled water supply and return pipe, it is necessary for the chilled water pipe to be adequately insulated. Thus, spatial requirements for the insulated chilled water pipe need to be allowed for in the tunnel. In Singapore, the centralised chilled water plant scheme shown in Figure 6 was implemented in an existing line extension which is currently under design. The centralised chilled water plant was also implemented in a new line that is under design to serve both the station and the commercial area near the station. As a result, both the station operator and the owner of the commercial area reap the benefits of a reduction in energy costs and the optimisation of land use.

Use of an air-conditioning system instead of a mechanical ventilation system

All electrical plant rooms in the existing underground metro stations are ventilated by mechanical ventilation systems comprising fans and ductwork. Besides requiring a substantial amount of energy to move air along an extensive network of ducts and ventilation shafts leading to and from the underground electrical plant rooms, the existing design results in service congestion, resulting in the need for large ventilation shafts and hence more land take.

For a new line under design, the LTA went against conventional wisdom by providing air conditioning in lieu of mechanical ventilation to the underground electrical plant rooms. This idea takes advantage of a better

chiller efficiency due to the technology advancement and leverages on the chilled water plants which are already provided to air-condition the station's public areas.

Using air conditioning in the electrical plant rooms has multiple benefits. Firstly, it improves energy efficiency as a bigger chilled water plant yields a better performance, translating to an annual saving on operating costs. Secondly, the size of the aboveground ventilation shaft can be reduced by 50% due to the reduced requirements for mechanical ventilation, resulting in a lower civil construction cost, a reduced construction period, an optimised station at-grade structure footprint and a reduction of land take. Thirdly, large fans and ventilation ductwork for the electrical plant rooms are eliminated, which reduces the installation costs and also alleviates the service congestion, allowing more space for maintenance and access. Lastly, the reliability of the power supply equipment can be further enhanced, as the air-conditioning system provides a cleaner and cooler environment in which to operate the electrical equipment.

Station's lighting system

The design of the station's lighting has to meet Singapore Standard SS530 [4]. In the paper "Energy Efficiency in Singapore's Rapid Transit System", it was mentioned that in the development of the lighting concept within a station, the importance of functional lighting generally takes precedence over other aesthetic requirements [2]. Also, various energy-saving methods were introduced, which included the use of T5 fluorescent technology or fast emerging LED lighting sources, the utilisation of natural lighting at station entrances, and different lighting control levels [2].

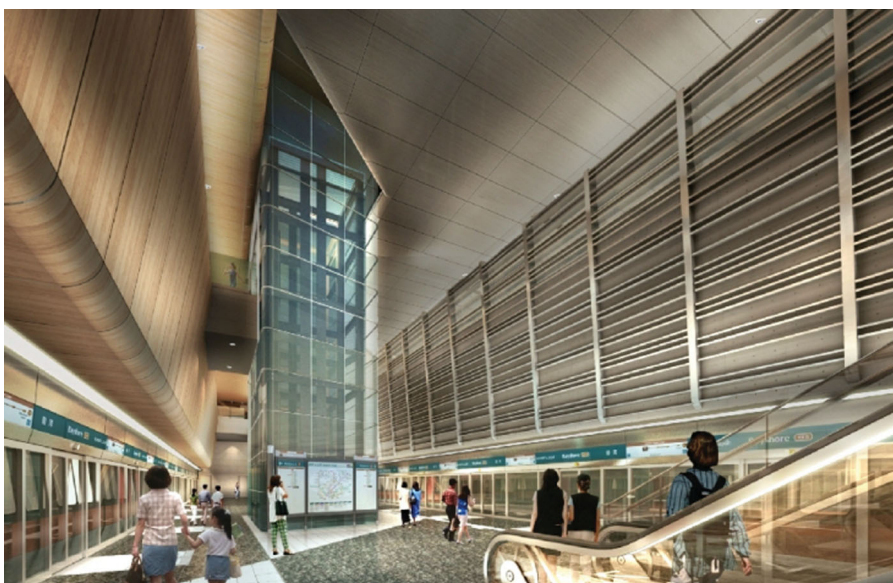


Figure 7. Sample of a full LED underground station.

LED lighting sources

With the recent improvements in LED technology, the upcoming metro projects will fully implement the use of LED lighting throughout the stations and tunnels. This can significantly reduce the energy cost of the lighting system. In addition, the lighting concept for the whole station will be different from the traditional station. LED lighting gives more flexibility for the lighting consultant to develop a new lighting concept so as to provide a better travel experience for the passengers. For example, LED lighting can be integrated into the escalator to avoid having light fittings mounted above it, which means that there will not be any lights to be maintained above the escalators, something that will be well appreciated by the maintenance staff (Figure 7).

Use of skylights

In Singapore, the possibility of utilising natural lighting is often explored in order to reduce the energy consumption of lighting systems. In general, natural lighting is used for station entrances – and for some underground stations, skylights will also be provided for concourse areas (and platform areas, if possible) (Figure 8). The natural lighting from skylights can easily result in an indoor illumination level of 1000 lux, while the required illumination level in a typical mass rapid transit (MRT) station is 200 lux. With the use of photo sensors in combination with a suitable lighting circuit design and a sophisticated control and monitoring system, appropriate levels of lighting in different areas of the station can be automatically controlled, thus reducing lighting energy consumption.

As well as the improvement in energy efficiency, the use of skylights also brings in sunlight, which will enhance the travelling experience of the passengers. In order to avoid increasing the station's cooling load,

indirect sunlight is preferred. Engineers and architects have to work together to come up with a cost-effective solution in order to incorporate this element of the lighting system.

Other considerations

Use of NEWater

NEWater, a pillar of Singapore's water sustainability strategy, is high-grade reclaimed water. Produced from treated used water that is further purified using advanced membrane technologies and ultraviolet disinfection, it is ultra-clean and safe to drink [8].

In the metro system, the water for the cooling tower is supplied by NEWater; where NEWater is not yet available within the station vicinity, the provision for future connection to a NEWater source will be reserved. NEWater is also used for irrigating the green roofs provided in most of the newly-built metro stations, which supports Singapore's push for water conservation.

Condensate recovery

To reduce water consumption, condensate from the air conditioning system for the station's public areas will be collected and used for cooling tower make-up water. A small condensate recovery tank is provided in the AHU rooms to collect condensate water from the AHUs that serve the station's public areas, where the main latent load comes from. Duty and standby condensate transfer pumps will operate in order to pump the condensate water to the cooling tower water basin when the condensate recovery tank is full. Condensate recovery is not feasible for plant rooms and office areas within the metro stations where there is limited latent load. In general, 7.5 m³ to 16.0 m³ condensate water can be collected each day for a typical four-car train station,



Figure 8. Sample of an underground station with skylights.

resulting in a saving of 10% to 18% for the cooling tower make-up water.

Green walls, green roofs and solar panels

Singapore is widely known as a “garden city”. The use of green walls and green roofs can not only reduce the heat transfer from the outdoors to the station and the area below the linkway, but can also provide a green environment for passengers and nearby residents. It is noted that the selection of light is important for the plants and the lighting consultant will coordinate with the green wall designer to ensure that the correct lighting requirements are specified and fulfilled. With the continual advancement in solar panel technology resulting in lower cost and better efficiency for solar panels, their installation into metro systems will become more attractive in the future. Solar panels have been adopted in railway depots by utilising their big roof areas; however, in underground metro stations, solar panels are still not cost effective because of the limited roof space. The entrance roof structures of the new stations have been designed as green roofs, an arrangement which allows for the future replacement of the green roof with solar panels when the technology advances and the cost of solar panels goes down enough to make the scheme cost effective for stations; for this future purpose, the roof structure has been designed to be strong enough to support solar panel installation.

Use of fuel cells

Fuel cells offer the ability to convert chemical energy directly into electrical energy with a very low environmental impact. A fuel cell is an electrochemical device used to create electricity through a reaction between fuel (such as hydrogen) and an oxidant (such as oxygen) in the presence of an electrolyte. In addition to producing electricity, the reaction generates by-products, which typically are only water and heat. Therefore, using fuel cells is an environmentally-friendly way to produce electricity.

Fuel-cell technology shows great promise and is already used in various systems globally, including in telecommunication data centres and vehicles. The use of a fuel-cell system to replace the batteries in an underground station has been considered. In order to enable the use of a fuel-cell system, the following challenges need to be overcome:

- An increase in fuel-cell efficiency that significantly reduces the heat removal requirements;
- Better storage methods for hydrogen gas;
- A lower initial cost, as well as reduced operating and maintenance costs so that the technology is commercially attractive; and

- Approval from the local fire services department on the use of such technology in an underground area.

Conclusion

Achieving a smart green underground metro station requires the cooperation of multiple disciplines (e.g. architects, mechanical and electrical engineers, civil engineers, lighting specialists, rolling stock engineers, traction power engineers, etc.). In Singapore, the LTA works with a design team and a construction team to continuously explore innovative ideas and new technologies that might be used to improve the energy efficiency, productivity and safety of metro stations. The implementation of the various initiatives mentioned in this paper has resulted in a better environment and travel experience for passengers, as well as adding value to the surrounding area and helping create a sustainable environment for the future.

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