Submission document for

Global District Energy Climate Awards 2011

District Cooling System at Marina Bay, Singapore

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INTRODUCTION

Located at the southern tip of Singapore, Marina Bay is a 360ha new business district which extends from Singapore's downtown area. A District Cooling System (the "System") has been successfully implemented. The System is investor-owned and operated as a public utility service under a regulatory framework.

Reliable utility grade chilled water supply at well regulated supply temperature and round-the-clock availability facilitates commercial activities and vibrancy of the new business district. The System demonstrates the sustainable benefits of district-scale chilled water production and distribution in lieu of building-scale facilities for energy and economic efficiencies in addition to a higher service level. An energy conversion ratio in the range of 5.0-5.5 kW_rh per kW_eh is achieved, substantially outperforming the average benchmark of 3.5 for building-scale facilities in Singapore. The reduction of equivalent CO_2 emissions is estimated to be 23,000 tonnes per annum at the current demand level.

In the mid 1990's, Urban Redevelopment Authority (URA), the Singapore town planning authority, conducted a feasibility study for the construction of common services tunnels in the new business district to house utilities lines. The study also identified district cooling as a new urban utility suitable for introduction at Marina Bay.

Singapore Power [1] and Dalkia [2] conducted feasibility studies and advocated the implementation of a district cooling system for the new business district. Their effort was rewarded with the concession of a pilot district cooling system. Singapore District Cooling (SDC) was incorporated as a joint-venture in 2000 to implement the pilot system.

The System came into commercial operation in May 2006 with one district cooling plant. In 2010, a second district cooling plant was completed together with the installation of a 5km network of pipes in the common service tunnels. The System currently has an installed capacity of $157MW_r$ out of $330MW_r$ planned for the two plants. It is serving $1,100,000m^2$ of commercial space. The ultimate potential of the System is $900MW_r$ serving 8 million sq m of commercial space.

The harmonious integration with inconspicuous presence of the plants in commercial developments is a distinctive feature of the System. The regulatory framework that fosters the successful implementation of the greenfield project is also the first of its kind in the district energy industry. It promotes economic efficiency of the System while balancing the interests of both the service users and system operator.

Singapore is a city-state lacking the endowments of natural energy resources. The focus on improving energy efficiency is a key strategy to reduce CO_2 emissions. The System, as a

[1] Singapore Power Group is a leading energy utility group with headquarters in Singapore. It owns and operates electricity and gas transmission and distribution businesses in Singapore and Australia.

[2] Dalkia is the district energy subsidiary of Veolia Environnement and Electricité de France – respectively world leaders in environmental services and in power generation.

macro-level initiative, has made a major impact in lifting the energy efficiency associated with air-conditioning at Marina Bay. This is an attribute of excellence for the distinctive business hub.

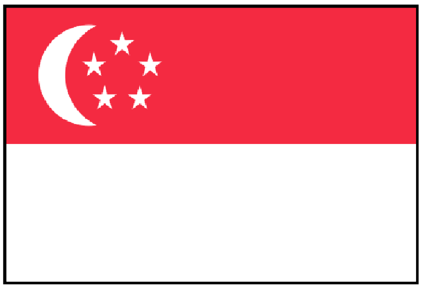
SDC is proud to present the System for consideration of the Global District Energy Climate Awards 2011 in the 'District Cooling' category.

PROJECT SUMMARY & LOGOS

Marina Bay is a new business district on reclaimed land at the southern tip of Singapore. District cooling was identified in the mid 1990's as an urban utility suitable for the new business district to serve an estimated cooling load of $900MW_r$ for $8,000,000m^2$ of the planned commercial floor space. An investor-owned district cooling system has been successfully implemented since May 2006. The system now comprises two plants with a combined installed capacity of $157MW_r$ out of $330MW_r$ planned. The two plants are harmoniously integrated as part of two large-scale commercial developments. They operate as an interconnected system with 5km of piping network installed in common services tunnels in the district.

The project demonstrates the sustainable benefits of district-scale chilled water production and distribution in lieu of building-scale facilities. Reliable utility grade chilled water supply at well regulated supply temperature facilitates commercial activities, reaping both economic and environmental benefits. The energy conversion ratio for chilled water production outperforms the building-scale facilities, resulting in substantial reduction of equivalent carbon emissions.

A unique regulatory framework encourages subscription to the new service to bring about economic benefits of large-scale operation while promoting efficiency and safeguarding users' interests.

Singapore + Marina Bay	Logos of SDC's shareholders[3]
 marina bay singapore	SINGAPORE POWER Dalkia Asia

[3] SDC , a joint-venture company without its own logo, may be represented by logos of its shareholders.

PROJECT DESCRIPTION

- **Service Area**

Figure 1. Marina Bay New Business District

Located at the southern tip of Singapore, Marina Bay is a 360ha new development area designed to seamlessly extend Singapore's downtown district (Figure 1).

The URA Master Plan envisaged 8,000,000m^2 in gross floor area for commercial development. The peak cooling load for the entire district was estimated at about 900MW_r which could be served by five district cooling plants. In order to optimise land use, the district cooling plants are to be co-located within selected large-scale developments.

At present, the District Cooling System serves an estimated 1,100,000m^2 of commercial development with an aggregate contract supply capacity of 110MW_r. Major premises served or soon to be connected include:

- One Raffles Quay, an office building complex with key financial institutions among its anchor tenants.
- Marina Bay Sands, a glamorous integrated resort complex comprising hotel, convention centre, shopping, casino, theatres and a museum.
- Marina Bay Financial Centre with a breathtaking blend of three office towers, two luxury residential towers and an underground retail mall.
- Asia Square, a mixed-use development comprising of premium grade office space, a five-star hotel and retail space.

Also connected to the System are Gardens by the Bay (with conservatories for cool climate plants) and Ocean Financial Centre (an office complex), which are two neighbouring premises outside the concession area.

• System Details

The District Cooling System now comprises two chilled water production plants which are interconnected by a piping network (Figure 2).

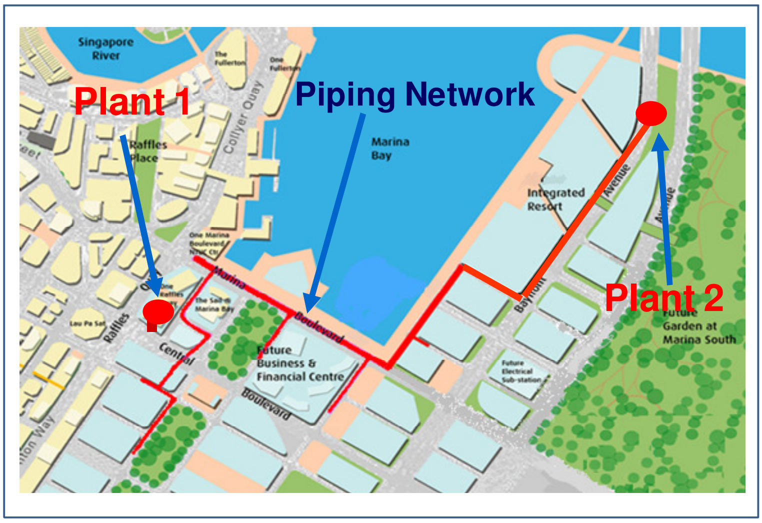


Figure 2. Overall View of the District Cooling System

<u>District Cooling Plant No. 1 (Plant1)</u>

Plant1 is located at One Raffles Quay, a premium office complex completed in 2006.

Plant1's machine room is located in Basement 2 of the complex. Cooling towers sit on the podium roof between two office towers (Figure 3). The key equipment is listed below.

Plant1 Planned Capacity	$157MW_r$
Plant1 Currently Installed Capacity	$97MW_r$

Key Equipment	Ultimate Quantity	Stage 1 – May 06	Stage 2 -Oct 09
$10MW_r$ Water Chiller	2	-	2
$7MW_r$ Water Chiller	2	2	-
$3MW_r$ Water Chiller	1	1	-
$10MW_r$ Brine Chiller	6	2	1
Ice Storage Subsystem - $10MW_r$ discharge capacity - $80MW_rh$ storage capacity	6	2	1
$5MW_r$ Cooling Towers	23	10	8
Total Capacity	$157MW_r$	$57MW_r$	$40MW_r$

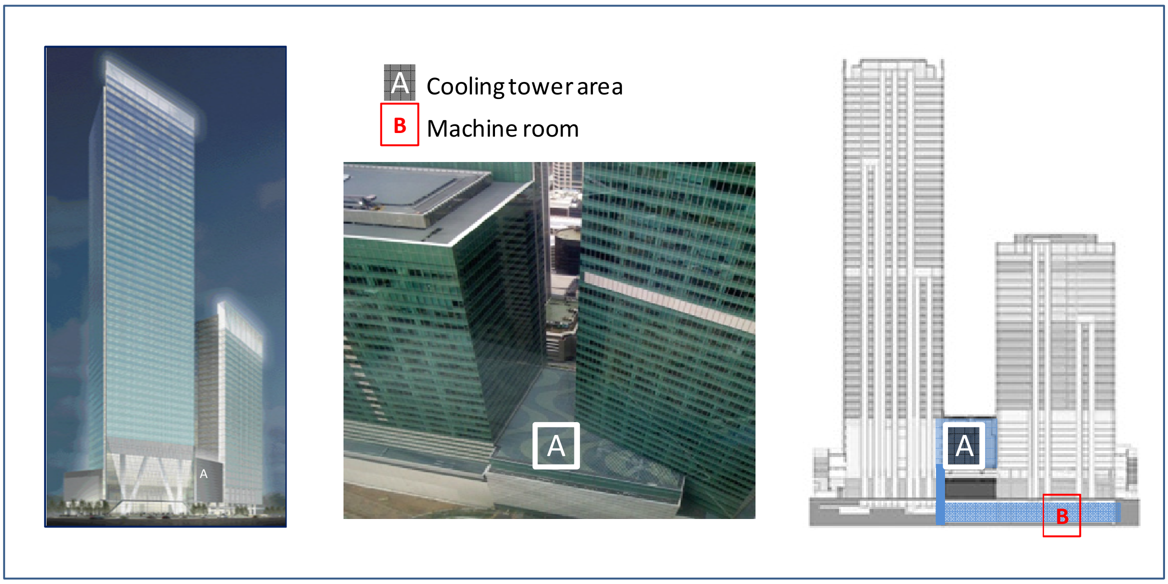


Figure 3 Plant1 in One Reffles Quay Development.

Figure 4. View of machinery in Plant1 : (Left) 10MW Brine Chiller. (Right) Distribution pumps

<u>District Cooling Plant No. 2 (Plant2)</u>

Plant2 is located under Bayfront Avenue which forms part of the land site for the new integrated resort developed by Marina Bay Sands. The machine room is at Basement 5 while cooling towers lie in a narrow strip of land between two major thoroughfares (Figures 5).

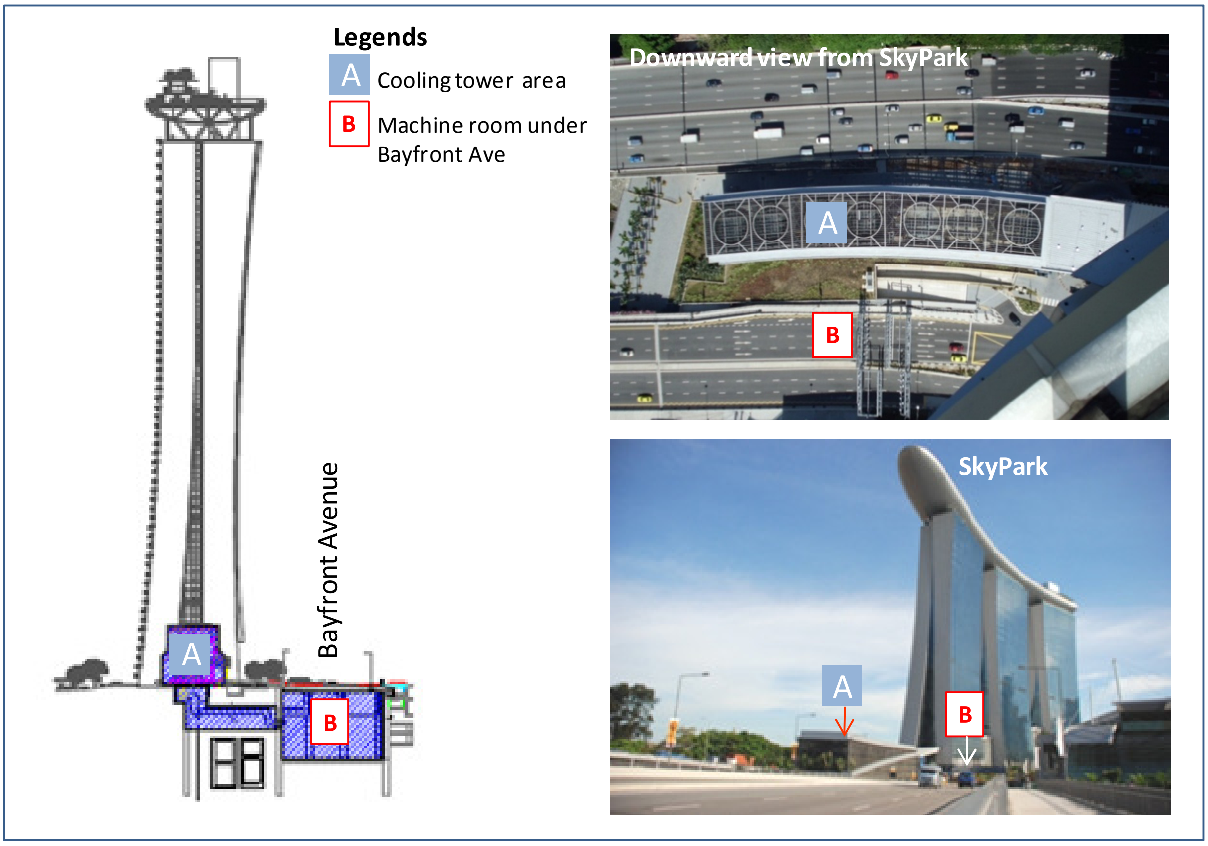


Figure 5 Plant2 in Marina Bay Sands

Plant2 has similar design concept and configuration as Plant1.

Plant2 Planned Capacity	$180MW_r$
Plant2 Currently Installed Capacity	$60MW_r$

Key Equipment	Ultimate Quantities	Stage 1 - Started Operation May 10
$10MW_r$ Chiller	6	6
$10MW_r$ Brine Chiller	6	-
Ice Storage Subsystem - $10MW_r$ discharge capacity - $80MW_r h$ storage capacity	6	-
$22MW_r$ Cooling Towers	7	4
Total Capacity	$180MW_r$	$60MW_r$

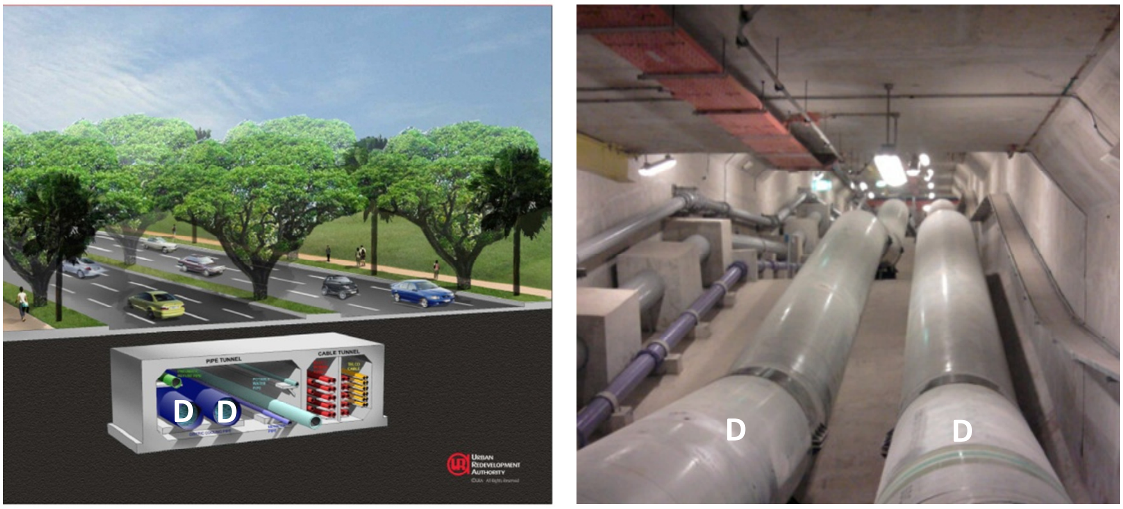
As a "green" initiative and also a business enhancement, hot water is generated using heat pumps with recovery of waste heat from the condensing water circuit of the chillers. The heat service is supplied to the hotel and eating establishments in the integrated resort. Four units of $900kW_r$ heat pumps are installed.

Figure 6. View of machinery in Plant2 : (Left) 10MW Water Chiller. (Right) 900kW Heat Pump

Chilled Water Piping Network and Control Network

Chilled water piping network is installed in the common services tunnels (CST) (Figure 7). The trunk section of network comprises pipes of 1.5m diameter. Buildings to be served are connected by branch pipes from the trunk network. These pipes are insulated with foamglass. Currently the network pipes total 5 km in length.

Fibre optic control cables are installed alongside the network pipes forming the communication network for supervisory control of the System.



D: District cooling pipes

Figure 7. Piping Network: (Left) Artist impression of the common services tunnel (CST) (Right) District cooling pipes in CST.

Customer Intake Stations

Chilled water is supplied to customers via heat exchangers which serve as a connection interface. Heat exchangers are housed in an Intake Station (or energy transfer station) located within the customer's development. The metering and control panels for the Intake Stations are linked to the System Control Centre located in Plant2 via the fibre optic communication network.

The Intake Station also accommodates the downstream pumps owned by the developer for the distribution of chilled water within the building.

Control Systems

Each of the district cooling plants has a dedicated Plant Control System for intra-plant control and monitoring functions. The metering and control panels at the Intake Stations are interconnected via the fibre optic communication network to form the Intake Station Network. A Supervisory Control and Data Acquisition (SCADA) system is installed to interface the Plant Control Systems and the Intake Station Network via gateways or connection servers. The SCADA system facilitates the coordinated control of chilled water production from each district cooling plant and its distribution to the Intake Stations. Figure 8 shows the System Control Centre at Plant2.

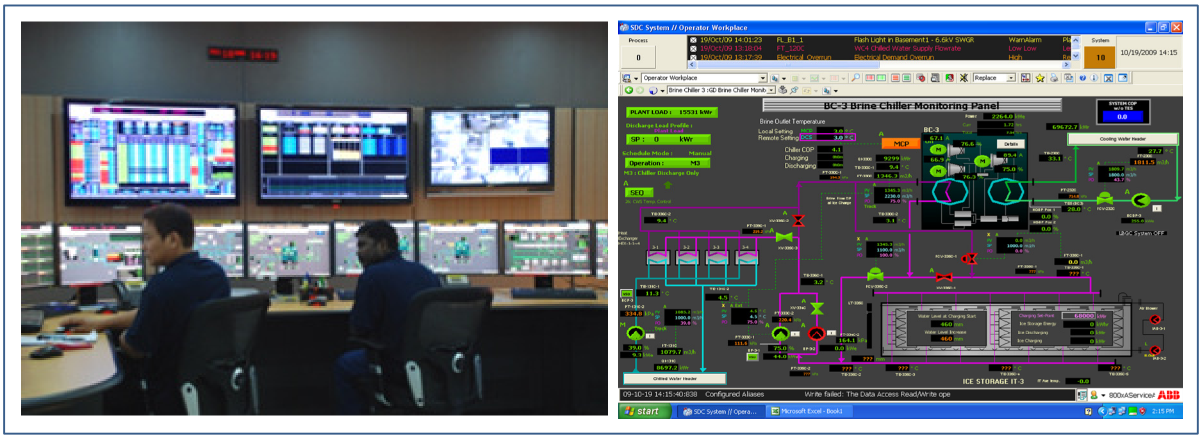


Figure 8. (Left) System Control Centre. (Right) A control display screen for Brine Chiller-Thermal Storage system

• Energy Efficiency & Reduction of CO2 Emissions

SDC's system COP (Coefficient of Performance) for direct chilled water production, measured by the overall energy conversion ratio, is in the range of 5.0-5.5 kW_rh/kW_eh. The chilled water header supply temperature is 4.5°C. It outperforms the commercial buildings' average COP benchmark[4] of 3.5 kW_rh/kW_eh at 6.7°C or higher.

SDC's ability to operate the District Cooling System at a higher energy efficiency level lies in its operation philosophy to fully exploit the two fundamental attributes of District Cooling System:

- Loading chillers at or close to their design capacity at their most energy efficient loading level and in the merit order of their efficiencies.
- Constant professional attention to operation and maintenance of the system.

The higher energy efficiency in chilled water production has led to an annual reduction in equivalent CO_2 emissions of about 23,000 tonnes at current demand level of 450GW_rh cooling per annum for the business district. The reduction is projected to reach 100,000 tonnes annually when the System is fully developed.

• Water Conservation

The average water usage index for typical building-scale chiller plants in Singapore is about 2.4m^3 per MW_rh cooling energy. Through a performance-based outsourcing contract for water treatment, SDC's system achieved 1.8m^3 per MW_rh for water usage. The estimated water saving is projected to be about 1.2 million m^3 annually for the ultimate system.

• Outstanding & Innovative Features

o ***Harmonious Integration of Plants within Commercial Developments***.
In land-scarce Singapore, the Authority decided that the district cooling plants shall be integrated within selected large developments in order to optimise the land use at the new business district. The uninitiated would not have noticed the presence of the two large industrial facilities locating within One Raffles Quay and Marina Bay Integrated Resort respectively (Figure 3 and Figure 5). The harmonious integration of the district cooling plants within commercial developments is a distinctive feature that differentiates the System from many other systems around the world. The inconspicuous presence of district cooling plants and the concurrent elimination of

[4] The presentation file, "Energy Efficiency Assistance Scheme" by National Environment Agency, for the APEC Workshop on Sustainable Energy Development in the Built Environment held in April 2009, contains Information on the efficiency of 33 air-conditioning plants in Singapore.

alternative in-building facilities (especially the cooling towers) in many other buildings contribute to urban design excellence of the new business hub.

- ***Efficiency-Promoting Regulatory Framework***[5]

The District Cooling Act is a unique piece of legislation that has facilitated the development of district cooling service as a public utility at Marina Bay. The subscription of the district cooling service is mandated for commercial developments in the new business district. The regulatory framework is administered by the Energy Market Authority of Singapore. The framework requires the new utility service to be priced at a level no higher than the equivalent costs of chilled water production by building-scale plants employing similar technology. Over time, the district cooling operator is allowed to earn a baseline return based on its invested assets. When the operator has recovered its start-up losses after achieving the critical mass of demand for efficient operation, any efficiency gain above the baseline return shall be shared equally between the operator and its customers. Customers are thus assured of long-term savings while the start-up demand risk associated with a green-field project is also mitigated. Due to the benefit sharing scheme inherent in the framework for efficiency improvement, the operator is incentivised to continually pursue economic and energy efficiencies without the need for intrusive regulatory oversight.

- ***Performance Based Supply Contract***

As a public utility service, the chilled water has its supply temperature well regulated at 6.0ºC±0.5ºC. The customer is required to adopt a "variable flow" scheme for its downstream reticulation so as to achieve at least 14°C in the return water. If the hourly average supply temperature exceeds 6.5ºC, SDC pays a rebate that is twice the equivalent hourly rate for Contract Capacity Charge. Similarly, if the monthly average return temperature falls below 14ºC, the customer pays a surcharge on the Usage Charge. The scheme provides a useful price signal to spur adequate maintenance by the building owners of their downstream facilities. Consequently, good "Delta-T" in the customer's air-conditioning installation also results in better demand-side energy efficiency.

- ***Coordinated Operation of Interconnected Plants***

The plant and network system design together with modern and sophisticated control systems, have facilitated optimal machine commitment and load despatch in the manner similar to the operation of a power system, to achieve highest energy efficiency and lowest production costs. SDC have achieved substantial energy efficiency improvement since the start of two-plant coordinated operation in August 2010.

[5] More details on the regulatory framework can be found at the website of the Energy Market Authority: *www.ema.gov.sg*

- ## Challenges and Solutions

  - ***Integration of Chiller Plants Within Developments***

Integrating a district cooling plant, an industrial facility, into a high-end commercial development presented complex engineering challenges. It was necessary to ensure that the primary objective of the commercial development was not compromised in hosting a large chiller plant. The building design process necessitated multiple iterations on the basis of functional requirements instead of prescriptive specifications. The collaborative effort of SDC and the design teams of the developments yielded the successful outcome.

The machine rooms for both plants are inconspicuously located in the lower basements of the respective developments. Instead of space-inefficient vehicle ramps, hoists and hatches are creatively deployed to solve transportation problems for the delivery of bulky, heavy machinery.

Active steps were taken to address the concerns expressed by the developers on possible adverse effects due to noise, vibration and plume from the cooling towers. These included:

– Extensive computer modelling of noise and air discharge (Figure 9).
– The use of ultra low noise fans (Figure 10).
– Incorporation of plume abatement feature, the first of its kind in Singapore, in the design of the cooling towers (Figure 10).

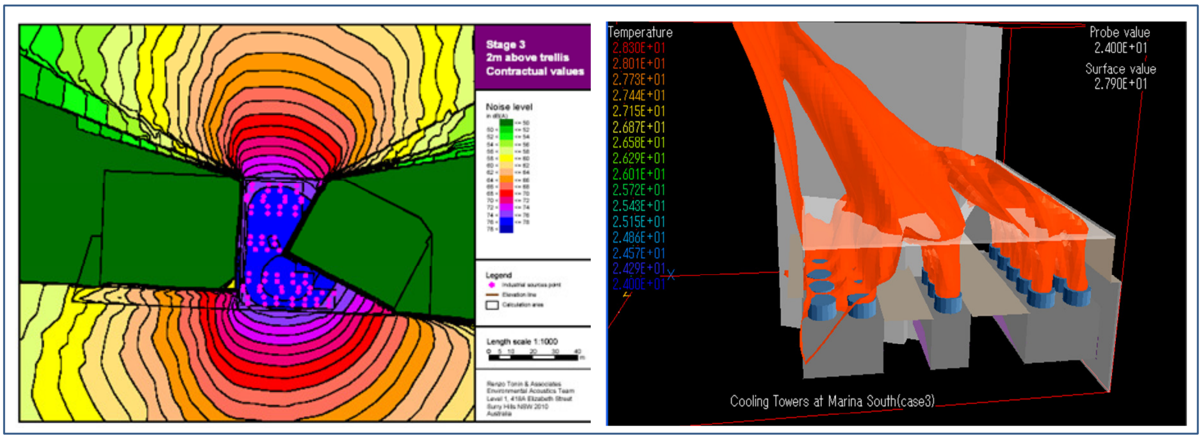


Figure 9. Computer modelling: (Left) Noise Study. (Right) Air discharge simulation

Figure 10. Special provisions for cooling towers: (Left) Ultra-low noise fans. (Right) Plume abatement coils A

○ ***Start-up Demand Risk***

District cooling, as an infrastructure system and in the context of Singapore, derives its economic advantages primarily from its large-scale operation when compared to building-scale facilities. On the other hand, developments subscribing to district cooling service, as in the case of any other public utilities, have little flexibility to discontinue the subscription of the service. The concerns about the lack of control over the supply quality and pricing of the new utility service present major impediments for a greenfield district cooling system to attain the critical mass of demand if development owners have the option to continue building their own in-building plants. The authorities in Singapore accepted the submission for district cooling to be made a mandated utility service in order to mitigate the start-up commercial risks. Legislation was made to provide the regulatory framework to address concerns of both the utility operator and building owners.

Despite the legislation, the demand build-up was unexpectedly slow due to the property market downturn soon after the first plant commenced construction in 2002. The commercial viability of the system was severely threatened. SDC is fortunate to have established utilities operators as its shareholders to render unwavering support at the start-up phase of the pilot project. With the attainment of critical mass of demand with the passage of time, the project is now a commercial success.

○ ***Sustained Effort for Energy & Cost Efficiencies***

Under the regulatory framework, the district cooling tariff is required to be set lower than the benchmark economic costs of chilled water production in building-scale facilities. The costs of any inefficiency cannot be passed through to the service users. Vigilant attention is constantly required to control capital, operation and energy costs in order to stay commercially sustainable.

As an infrastructure system, the project is capital intensive. Careful staging of system capacity in phase with system demand growth is necessary to avert the heavy capital charges from eroding the benefit of better energy efficiency of centralised chilled water production. The system at Marina Bay is thus developed in stages.

Beyond the initial engineering design and choice of equipment, the attainment of high energy efficiency is the outcome of the following measures:

- Continuous efforts to review and refine the control schemes for various subsystems with increasing operational knowledge of the System.
- Daily operation reviews to ensure observance of standing operation instructions and to improve operational strategies as an ongoing effort.
- Initiatives taken to foster positive mindsets in plant operational personnel. (One example is holding competitions among the operation teams to recognise good operation results.)

The judicious deployment of thermal energy storage system enhances energy cost efficiency. Plant1 currently has 240MW_rh thermal storage in its ice-on-coil systems. Ice thermal storage systems have often been criticised as energy inefficient in terms of site energy (electrical inputs) for chilled water production. However, due to different time-of-day energy efficiency of the power system, their use does not actually result in more carbon emissions in terms of raw energy input to the power system. Instead, thermal storage systems provide an additional means to lower energy cost for chilled water production. Singapore has a real-time electricity market with electricity prices updated at every half hourly interval. With a thermal storage system, SDC has been able to take into account the real-time electricity price signals to optimise the mix of direct chilled water production and ice discharge to achieve a lower energy cost for chilled water production. SDC's avoidance or reduction of electricity usage during periods of peak demand and high real-time prices is also indirectly beneficial to the electricity system.

- **Project Funding**

The System was implemented on the basis of a commercial venture without public funding support. The initial 57MW_r Plant1 construction was funded wholly by shareholder equities. The subsequent Plant1 expansion, Plant2 construction and installation of the 5km network pipes were funded by bank loans secured through a project financing scheme from a leading bank in Singapore.

30 March 2011

The Distinguished Members of the Evaluation Panel,
Global District Energy Awards 2011
c/o Mr Jayen P. Veerapen
International Energy Agency
9, rue de la Fédération
75739 Paris Cedex 15
FRANCE

Dear Sirs,

SUBMISSION FOR GLOBAL DISTRICT ENERGY AWARDS 2011
-- DISTRICT COOLING SYSTEM AT MARINA BAY, SINGAPORE

We are proud to present our project 'District Cooling System in Marina Bay, Singapore' for consideration of the Global District Energy Climate Awards 2011 in the 'District Cooling' category.

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The harmonious integration with inconspicuous presence of the plants in commercial developments is a distinctive feature of the System. The regulatory framework that fosters the successful implementation of the green-field project is also the first of its kind

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We seek your support and consideration for the award. Thank you.

Yours truly,

Tey Peng Kee
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Enclosure: The submission document