Taking The Heat Off Cooling:
A Greener Way to Cool

Studying the Impact of a Brownfield
Distributed District Cooling Network in Singapore

SPgroup Empowering the Future of Energy
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Taking The Heat Off Cooling: A Greener Way to Cool

This white paper was published by SP Group and Temasek.
A version of the report can be found at www.ecosperity.sg.

Forewords

Mr Masagos Zulkifli

Adviser to Tampines GROs,
Minister for Social and Family Development,
Second Minister for Health and
Minister-in-charge of Muslim Affairs

Tampines aspires to transform into an Eco Town by 2025, in support of the Singapore Green Plan 2030.

In recent years, our estate has been undergoing a green facelift to create a more sustainable living environment for residents.

For example, we have piloted Eco Boards at lift lobbies to help residents track how much electricity and water they use as a block. We also contributed to the national renewable energy drive through the installation of solar panels on our blocks and implemented programmes to recycle food waste. These were very well received by Tampines residents and encouraged a sustainability culture at the neighbourhood level.

Encouraged by these successes, we are now looking at how we can enable commercial buildings to adopt sustainable practices. Apart from being a residential estate, Tampines is also an active and mature business hub, home to an industrial park, several office complexes, and a cluster of shopping malls. There are many opportunities to do more in this area.

One challenge that we have observed confronting building owners is energy consumption. A large part of the energy consumed in commercial buildings goes to cooling.

Hence, we have offered Tampines Central as a testbed for an innovative cooling concept, known as the Distributed District Cooling (DDC) network. Conceived by SP Group, the network is a novel approach to district cooling in a brownfield development, allowing the building owners to use less energy for their cooling needs as a whole.

The results of the feasibility study look promising. There is a potential of 18 per cent fall in carbon emissions – equivalent to removing 2,250 cars from the roads annually – when the DDC network takes off. This is the first time in Singapore where existing buildings in a brownfield site pool together their resources to achieve substantial carbon footprint savings. Another first for Tampines!

I hope that the study will pave the way for such solutions to be explored in other townships and brownfield sites, contributing to our national sustainability efforts.

Ms Amy Hing

1 Deputy Secretary, Ministry of Sustainability and the Environment

Climate change poses an existential challenge for Singapore. Sea level rise threatens our island nation, while changes in the climate jeopardise our access to essential resources such as water and food, and have consequences for public health and diseases.

The Centre for Climate Research Singapore projected that by 2100, daily mean temperatures in Singapore could rise by up to 4.6 degrees Celsius. Days with peak temperatures hitting 40 degrees Celsius may appear as early as 2045. We are already experiencing such effects; four out of the last six years are amongst the top 10 warmest years recorded in Singapore.

We need a whole-of-nation effort to address climate change. The Singapore Green Plan 2030 is our roadmap towards sustainable development and to achieve our long-term net-zero emissions target as soon as viable. It involves everyone – from individuals and communities to businesses and the public sector.

A key pillar of the Green Plan is Energy Reset, which looks at how we can use cleaner energy and increase our energy efficiency. This is particularly relevant for our towns, which require energy for cooling needs. This study by Temasek and SP Group explores an innovative district cooling solution in a brownfield site that can potentially lower the carbon footprint while addressing the needs of residents and businesses in our tropical climate.

I hope that the data and insights gained from the feasibility study will encourage more ideas and collaboration on innovative district-level solutions, bringing us closer to our goals under the Green Plan.

Image: Artist's impression of Tampines Eco Town
Source: Tampines Town Council

Dr Steve Howard

Chief Sustainability Officer
Temasek International

The global community has moved from concern over climate change to recognising it as a climate emergency. As we see the consequences of climate change all around us, we know our window to act has been reduced. We must move with renewed urgency and greater ambition to decarbonise across sectors.

One key sector is the built environment, which contributes close to 40 per cent of global energy-related carbon emissions. A significant portion of this comes from the energy consumed by buildings, predominantly for heating or cooling. In tropical regions like Singapore where the weather is hot all year round, the demand for cooling will only increase and a more efficient way to cool buildings could significantly reduce their energy consumption and carbon emissions and reduce the burden on household budgets.

We need a tripartite effort from businesses, governments, and investors to rethink the way buildings and districts are designed, built, and operated. This has the potential to generate significant economic benefits, such as reduced lifecycle costs for buildings. Temasek's wide network of partners makes it possible to help bring together the different stakeholders necessary to address this challenge.

Temasek is delighted to partner with SP Group to study the feasibility of a novel distributed district cooling concept for brownfield developments, which could provide a proof-of-concept for developed cities worldwide.

Mr Stanley Huang

Group Chief Executive Officer
SP Group

Sustainable development underpins Singapore's long-term goal to build a resilient future. Enabling urban decarbonisation is pivotal to this vision.

In land-scarce Singapore, we must constantly innovate our built environment to optimise land and building resources as well as minimise our carbon footprint. In Singapore, with air-conditioning accounting for up to 50 per cent of the total energy consumed in a building, we need to redesign how interiors can be cooled in a sustainable and cost-effective manner.

Therein lies the solution of a district cooling network. Its benefits are fourfold: enhances energy savings, lowers cost of cooling, improves land use, and reduces carbon emissions. These are validated through SP Group's proven track record of 100 per cent reliability and up to 40 per cent improvement in energy efficiency in building and operating Singapore's first district cooling project at Marina Bay since 2006. We are also developing Singapore's first residential centralised cooling system for the Tengah precinct.

We are optimistic this feasibility study on a distributed district cooling network in Tampines will yield business and environmental benefits. This will pave the way for existing buildings and districts to go green and lay the cornerstone for future eco-districts.

Sustainability is central to our long-term strategy, and it requires the collective effort and collaborative partnership of building owners, government agencies, the community and solution providers such as SP Group. Together we can harness our combined strengths to enable widespread adoption of sustainable energy solutions in Singapore and build green energy ecosystems for commercial districts, residential towns, and campuses for a greener and better future.

Executive Summary

2011 to 2020 was the warmest decade on record. Earth's six warmest years have all occurred since 2015 – yet another sign of global warming's grip on the planet. Researchers around the globe have cautioned that this trend will not only continue, but also increase in extremity.

As temperatures climb, cities are desperate to stay cool. Unfortunately, the current simplest and most mainstream solution worsens the problem – air-conditioning. They are energy guzzlers, generate more waste heat than cooling, and contribute to climate change by emitting hydrofluorocarbons, chemicals that trap heat in the atmosphere at alarming rates.

There is a critical need to find a better way to cool down our living environment. One solution that has gained traction across the globe is district cooling – central cooling plants that supply chilled water to various buildings through an underground network of insulated pipes.

These plants consume less energy for the same amount of cooling, free up space, and reduce lifecycle costs as buildings do not need to invest in their own chillers. Such systems are already being used in Singapore, such as the Marina Bay district – cooling more than a dozen buildings in the area, including Marina Bay Sands, the Marina Bay Financial Centre, and One Raffles Quay.

There is, however, a limitation to the way district cooling systems are currently built. They are typically incorporated into the design of a new development, and hence are more suitable for greenfield sites.

For built-up or brownfield sites with buildings that already have their own chiller plant systems, it becomes much harder to introduce district cooling. Hence, a novel approach – a distributed district cooling (DDC) network – is being explored in Tampines Central, under the Tampines Eco Town initiative. It was conceptualised by SP Group, a leading energy utilities company.

In the DDC network, existing cooling systems of selected buildings will produce chilled water for their own cooling needs and that of other buildings within the district.

A preliminary feasibility study was conducted on this DDC network concept in Tampines Central, and the results were promising.

In one year, the DDC network could potentially achieve:

A 17% reduction in energy consumption – enough to power 1,665 three-room HDB households for a year

A 18% fall in carbon emissions from both energy savings and refrigerant reduction – equivalent to removing 2,250 cars from roads per year

S$4.3 million in annual economic value from energy, equipment replacement and maintenance cost savings, as well as potential earnings from leasing out freed-up chiller plant space

The findings show that the DDC network would be able to lower energy consumption and carbon footprint. It is a possible game changer that could green entire developments at one go – an attractive solution for brownfield sites such as industrial estates and existing townships.

With Singapore announcing the Singapore Green Plan 2030 to address climate change and promote sustainable living, district cooling networks could open the door to a cooler and cleaner future.

The Hot Issue of Keeping Cool

- As temperatures rise, so does the use of air-conditioners. There are over one billion air-conditioning units in the world right now – a number that is expected to increase to 4.5 billion units by 2050.
- These electrical appliances consume large amounts of energy to bring temperatures down. Cooling systems typically make up about 40 to 50 per cent of a building's total energy consumption.
- But beyond cooling you down, air-conditioners can also leak potent greenhouse gases that exacerbate climate change – leading to even higher temperatures. Air-conditioners commonly use hydrofluorocarbons (HFCs) as refrigerants, which are 116 to 12,400 times more efficient at trapping heat than carbon dioxide.
- The heat is on to find a more efficient way to cool.

The air-conditioner is hailed as one of the most important inventions in modern history, allowing people to control and cool the weather inside. But after removing the heat and humidity indoors, air-conditioners in fact lead to warmer temperatures outside, contributing to the Urban Heat Island (UHI)[1] effect.

Singapore has the highest per capita installed rate of air-conditioning among the Association of Southeast Asian Nations (ASEAN) countries, with about 80 per cent of households owning air-conditioners. While air-conditioners can provide thermal comfort, they consume a lot of energy to do so. Air-conditioning currently accounts for up to 24 per cent of the average household electricity bill in Singapore. For an entire commercial building, cooling systems typically make up 40 to 50 per cent of its total energy consumption.

Air-conditioners also often use hydrofluorocarbons (HFCs) that trap heat – making them potent greenhouse gases that contribute to climate change should they leak into the atmosphere. In fact, the concentration of HFCs in the atmosphere is growing at a faster rate than that of all other greenhouses gases, and studies have shown that their growth could cancel out the entire benefit of controlling carbon dioxide (CO_2) emissions.

On the whole, this means an enormous drain on power and a comparable jump in carbon emissions should electricity generation in Singapore continue to be dominated by fossil fuels – a future that Singapore is determined to avoid. The city-state aims to halve the amount of emissions it produces from its 2030 peak by 2050, eventually achieving net-zero emissions as soon as possible in the second half of the century.

[1] The Urban Heat Island (UHI) effect refers to a phenomenon where urban areas face higher temperatures than its surrounding rural areas. It is caused by the heat generated from human activities and trapped by urban surfaces such as buildings and roads.

DID YOU KNOW?

In Singapore, urban built-up areas can be up to 7°C warmer than areas that are more rural.

Recognising the need for more sustainable living, the Ministry of Sustainability and the Environment (MSE) set up a SG Eco Office in March 2020 to spearhead and coordinate sustainability projects across Singapore. Cooling is an important part of this work.

Building owners, developers, and regulators need to rethink their cooling systems. One town that is doing so is Tampines, which is transforming into an Eco Town where the spirit of sustainability is built into its infrastructure and instilled in its community. It has piloted dashboards at the lift lobbies of several residential blocks to help residents track electricity and water usage as a block, introduced programmes to recycle food waste, and potentially having the greatest impact – it is studying the possibility of implementing a novel distributed district cooling network.

This report takes a closer look at a preliminary feasibility study on a proposed cooling network that involved 14 commercial buildings in Tampines Central. The following sections will include details of the study's methodology, and the resulting energy savings and reduction in carbon emissions among the buildings.

District Cooling 101

- District cooling is a modern and efficient way to provide air-conditioning for a network of buildings, where chilled water is supplied from centralised cooling plants.
- The benefits of district cooling include enhanced energy savings, lowered lifecycle costs, and reduced carbon emissions.

A District Cooling System

Imagine a giant air-conditioner that can cool an entire district of buildings, rather than just individual buildings – but greener and more energy efficient. How does it work?

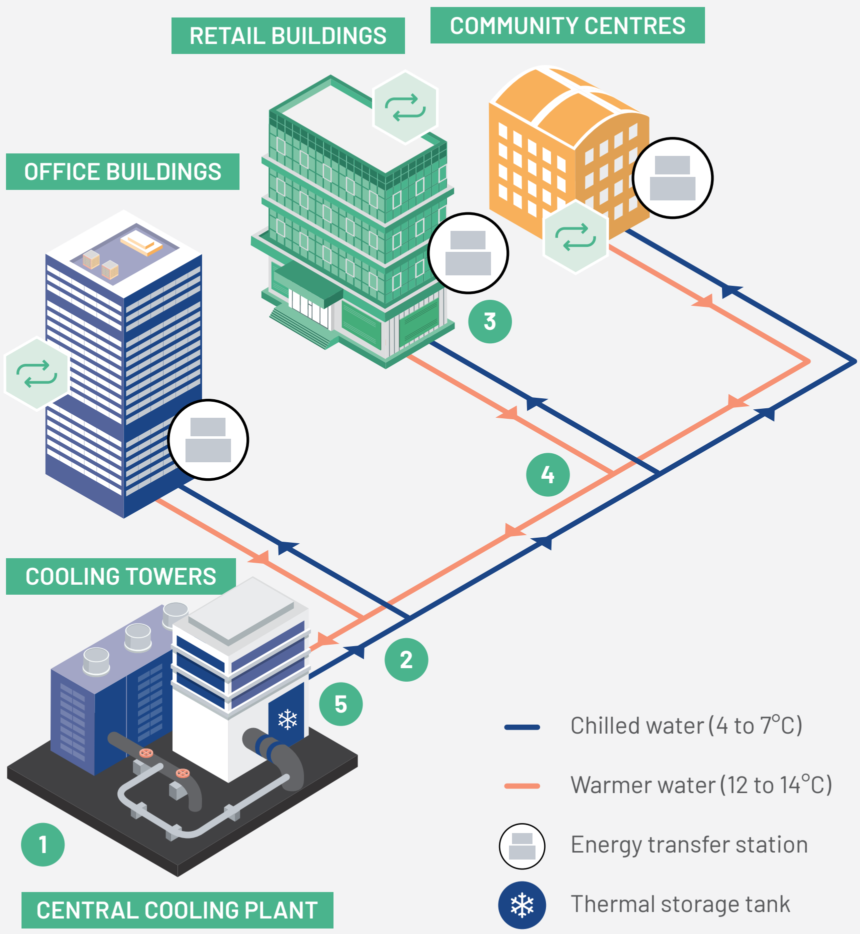
1 Chilled water is generated in a central cooling plant.

2 A closed loop network of underground insulated pipes distributes the chilled water to each customer's building.

3 When the chilled water reaches the customer's building, energy transfer stations within each building circulate the cold energy from the network into the building's air-conditioning system, which dehumidifies and cools the air.

4 The warmer water is then circulated to the cooling plant, via the return pipes, to be chilled again. The whole process repeats itself.

5 Thermal storage tanks (if used*), are designed to store cold energy, in the form of ice or chilled water. Thermal storage tanks help to regulate cooling demand and provide resilience.



*Not all district cooling system plants deploy thermal storage tanks.

Benefits of district cooling systems

Improves efficiency

A chiller plant system in one building is unlikely to be operating at its optimal efficiency at all times due to partial loading conditions. This is typical during actual operations, where the cooling demand of a building fluctuates. However, a district cooling system is expected to operate closer to its optimal efficiency level most of the time as it will accurately select the most suitable mix of chillers to meet the aggregated cooling demand.

Saves energy

Larger systems typically consume less electricity for the same amount of cooling due to economies of scale, which improves the energy efficiency of the system. When combined with thermal storage capabilities, the system can further reduce peak electricity demand for cooling by shifting chilled water production to periods where there is less demand on the electricity grid.

Frees up space

Each building no longer needs to house its own cooling equipment, which means that building owners are able to use the freed-up space for other purposes, or even lease them out.

Cuts costs

Building owners no longer need to buy their own chillers or incur operating and maintenance costs. The need to invest in additional chillers to buffer for potential increases in cooling needs and provide redundancy is also eliminated.

Reduces carbon footprint

With an overall reduction in refrigerants used, the amount of harmful HFCs emitted into the environment will be reduced as well. In addition, a reduction in overall energy consumption will in turn lower carbon emissions.

Provides the network effect

The initial cost of building the district cooling infrastructure may be high. However, once the infrastructure is laid, the cost of connecting an additional building will be significantly lower. Over time, the benefits that the system brings to customers would significantly outweigh the costs of connecting them to the network.

CASE STUDY

A cool secret beneath Marina Bay

Lying 25 metres beneath the ground in Singapore's Marina Bay district is the world's largest underground district cooling system. Designed, built, and operated by SP Group, the system produces up to 35,000 refrigeration tons (RT) of chilled water each hour, and serves 16 developments in the area, including Marina Bay Sands, the Marina Bay Financial Centre, and One Raffles Quay.

Water is chilled to 4.5 degrees Celsius at two cooling plants before being transported to the buildings through five kilometres of insulated underground network pipes. The chilled water is used to provide air-conditioning for the buildings by cooling the air circulating in the occupied spaces in each building before being pumped back to the plants to be chilled again. This cycle is then repeated. The heat extracted from the buildings is carried by the water back to the plants and released into the surrounding environment through large cooling towers above ground.

Building owners using the district cooling system have enjoyed significant energy savings and carbon emissions reduction. By centralising the production of chilled water and removing the need for buildings to have their own chiller plant, the district cooling system has also freed up some 25,000 square metres of prime land space for other uses, such as the Marina Bay Sands infinity pool, which is also the world's largest rooftop infinity pool.

Building owners using the system have enjoyed significant energy savings and carbon emissions reduction. The system has also freed up some 25,000 m^2 of prime land space for other uses.

Can district cooling be applied to existing developments?

Given the engineering complexity and the significant upfront infrastructure costs involved, a district cooling system is typically introduced in greenfield developments, where it is integrated into the design of the development – like the Marina Bay case study. But in a highly developed city like Singapore, where majority of land has been built up and individual building owners already equipped with their own chiller plants, how can the concept of district cooling still be applied?

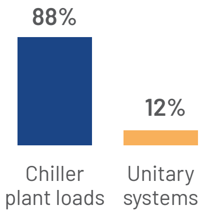
Tampines Eco Town: A Distributed District Cooling Network

The proposed Distributed District Cooling (DDC) network comprises 14 buildings interconnected via insulated network pipes. Instead of constructing a new centralised cooling plant, buildings in the DDC network with existing excess chiller capacity act as injection nodes, supplying chilled water to cool the rest of the buildings in the network.

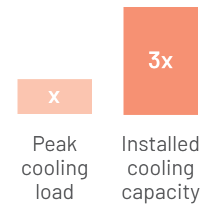
To find out if district cooling could be applied to existing developments or brownfield sites, a study was conducted at Tampines Central. It involved 14 buildings – a mix of retail and commercial premises, and data centres – each with its own chiller plant system.

An initial assessment made on the 14 buildings' existing cooling capacity yielded the following results:

A total annual cooling load of **42,897,215 RTh/year,** of which 88% belonged to chiller plant loads and 12% belonged to unitary systems



A current total installed cooling capacity of **25,836 RT,** which exceeds the hourly peak operating cooling load of 8,395 RT by three times



A unitary system refers to self-contained air-conditioning that provides cooling to a localised zone. The common examples are Multi-room split units, Variable Refrigerant Volume units, and Packaged units. Unitary systems are popular among users who require cooling for a specific area that the building might not have previously catered for (e.g. tenanted space and server rooms). Unitary systems are typically less efficient than chiller-based systems.

The results indicate that there were chillers operating at partial capacity and redundant chillers that were not in operation at all. This presented an opportunity to optimise the usage of the existing chiller plant systems to reduce the overall energy consumption and, ultimately, the greenhouse gas emissions of the buildings.

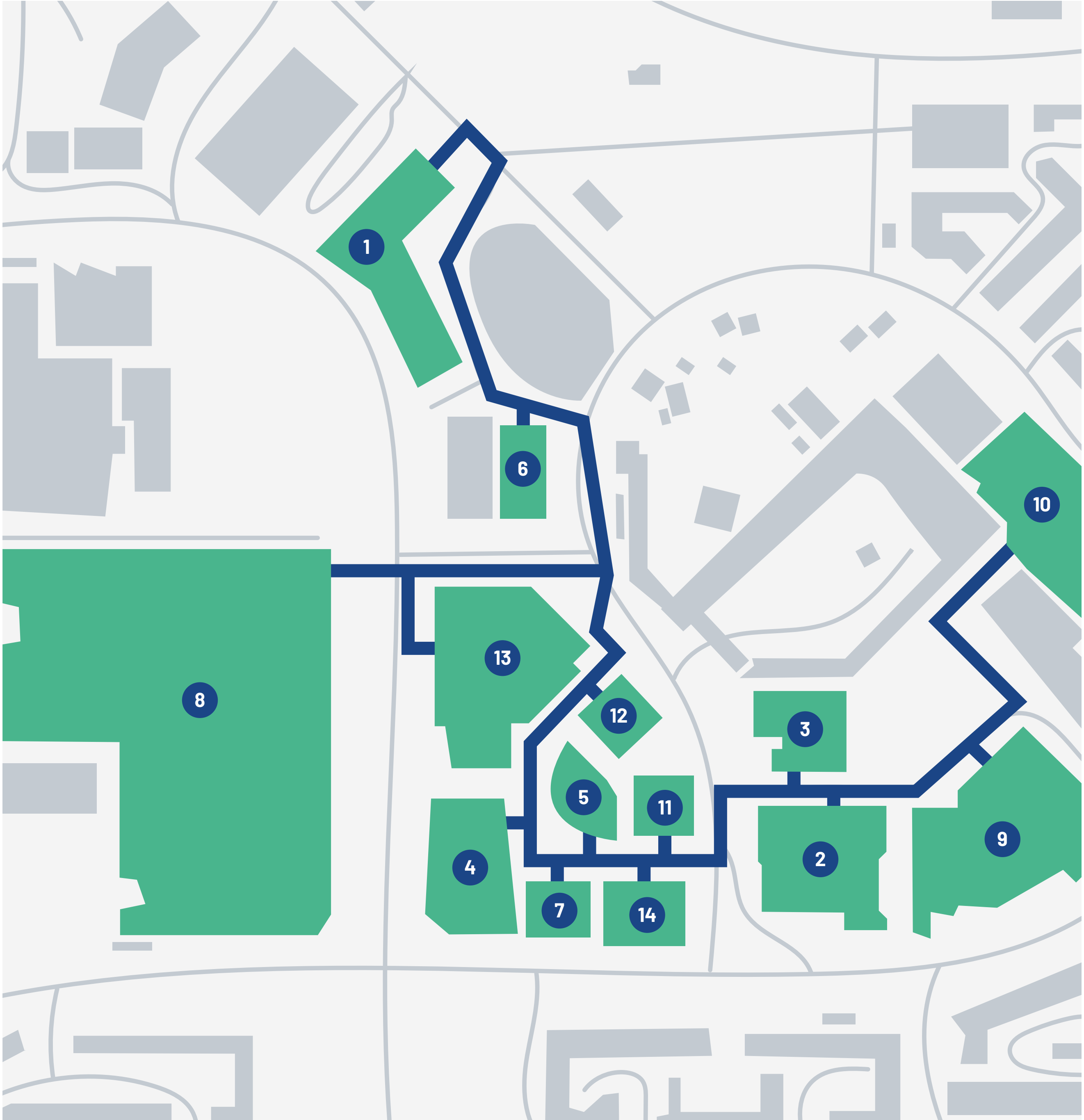
Applying the principles of district cooling, SP Group conceptualised a Distributed District Cooling (DDC) network, where 14 buildings would be interconnected via insulated pipes that distribute and circulate chilled water in a closed loop.

The key to the energy savings for the DDC network, compared to buildings operating their own chiller plants individually, lies in the concept of an integrated operation. Through the consolidation of individual buildings, the DDC network is able to choose the best combination of chillers amongst the different chiller plants to most efficiently meet the fluctuating cooling demands throughout day and night.

A few existing chiller plants are chosen to serve as "injection nodes" [2], producing and supplying chilled water to meet the cooling demands of all buildings within the network. This would allow the required installed cooling capacity to be streamlined to meet actual cooling demands, allowing the chiller systems to operate at optimum efficiency. The remaining excess capacities would subsequently be trimmed once these redundant chillers reach their end-of-life.

[2] The chiller plants that were selected to serve as injection nodes typically had excess capacities (≥1000 RT) and very good energy efficiencies (≤0.68 kW/RT).

The 14 Buildings Involved in the Feasibility Study of the DDC Network in Tampines Central



1 7 & 9 Tampines Grande
2 Century Square
3 CPF Tampines Building
4 Income At Tampines Junction
5 Income At Tampines Point
6 OCBC Tampines Centre One
7 OCBC Tampines Centre Two
8 Our Tampines Hub
9 Tampines Mall
10 Tampines One
11 Tampines Plaza 1
12 Tampines Plaza 2
13 Telepark
14 UOB Tampines Centre

DDC network pipes

Methodology

The energy savings and reduction in refrigerant that the DDC network could offer over the Business-as-Usual (BAU) scenario, over 30 years, were first calculated. 30 years is the typical tenure of a district cooling project. Thereafter, the total carbon emission reduction and long-term economic value were determined. More detailed information on the study's methodology can be found in the Annex.

STEP 1

What are the energy savings?

- Calculate the difference in the amount of energy consumed to cool the 14 buildings between the DDC network and the BAU scenario over 30 years.
- Calculate the resulting carbon emissions reduction from the energy savings (A), using the EMA Grid Emissions Factor.[3]

STEP 2

What is the reduction in refrigerant used?

- Calculate the difference in the type and amount of refrigerant used to cool the 14 buildings between the DDC network and the BAU scenario over 30 years.
- Calculate the resulting carbon emissions reduction from the reduction in refrigerant used (B).

STEP 3

What is the total reduction in carbon emissions?

- Total carbon emissions reduction from using the DDC system over 30 years = A + B.

STEP 4

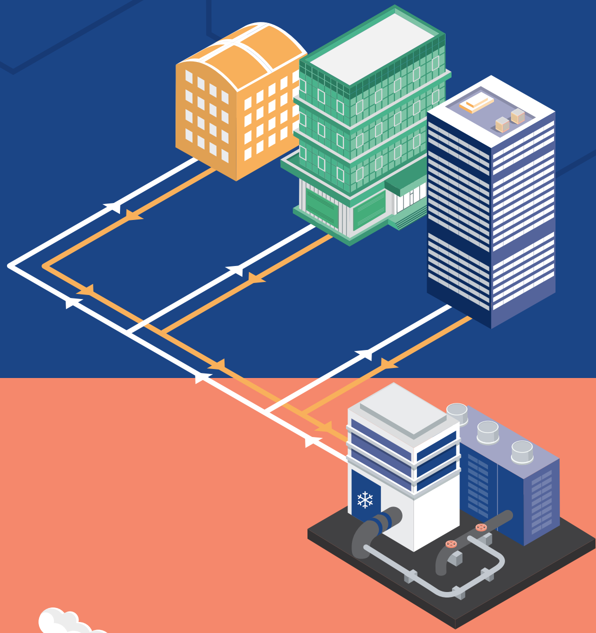
What is the long-term economic value?

- Calculate the economic value of the DDC network over 30 years from:
  - Electricity bill savings
  - Carbon tax savings
  - Equipment replacement cost savings
  - Operation and maintenance cost savings
  - Capacity charge savings
  - Potential rental earnings if the freed-up chiller plant space were to be leased out

[3] The Grid Emission Factor (GEF) measures the average CO_2 emissions emitted per MWh of electricity generated. For the study, the EMA GEF (2019) of 0.4085 $kgCO_2$/kWh was used.

Key Findings

Tampines Eco Town
Distributed District Cooling Network
Feasibility Study



ENERGY CONSUMPTION

17% reduction

An annual savings of **5,321,432 kWh**

Enough to power **1,665 3-room HDB households in a year**

CARBON EMISSIONS

18% reduction

An annual decrease of **2,475 tonnes of CO_2e**

Equivalent to taking **2,250 cars off the road per year**

ECONOMIC VALUE

$130 million over 30 years

Or **$4.3 million a year,** mainly from:

- Energy, maintenance, and equipment replacement cost savings
- Potential earnings from leasing out freed-up chiller plant space

Key Findings

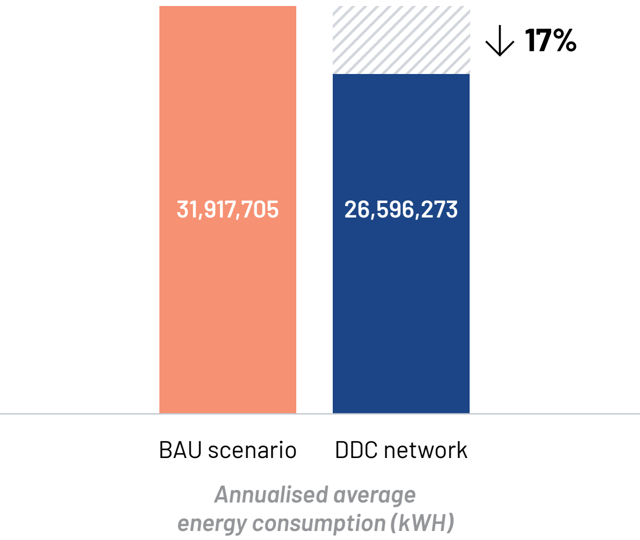
Energy Savings of 17%

In the BAU scenario, the efficiencies of the chiller plants ranged from 0.57 to 0.83 kW/RT, and the efficiency of the unitary systems was 1.57 kW/RT. This results in a weighted average system efficiency of 0.765 kW/RT from all the cooling systems across the 14 buildings. In comparison, the DDC network's efficiency is targeted to be maintained at 0.620 kW/RT or better across 30 years. In addition, the DDC network would be operated by a third-party professional service operator and comply with the National Environment Agency's (NEA) Minimum Energy Efficiency Standards (MEES) requirements by 2025/2029, which would help to ensure more consistent and efficient system performance over long periods.

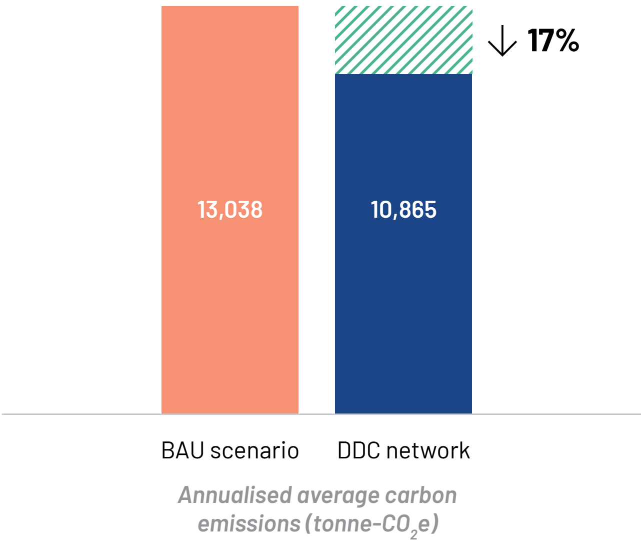
Therefore, moving to the DDC network would save the 14 buildings approximately 5,321,432 kWh of energy a year, or 17 per cent of the BAU energy consumption – enough to power 1,665 three-room HDB households.

With less energy expended, carbon emissions would also be reduced. The annual average carbon emissions reduction would be 2,174 tonnes of carbon dioxide equivalent (tCO_2e) – equivalent to taking 1,976 cars off the roads per year.

Potential energy savings from moving to the DDC network



Carbon emissions reduction from the potential energy savings from moving to the DDC network



Moving to the DDC network would save enough energy to power **1,665 3-room HDB households in a year.**

The annual average carbon emissions reduction is equivalent to taking **1,976 cars off the roads per year.**

Refrigerant Reduction of 76%

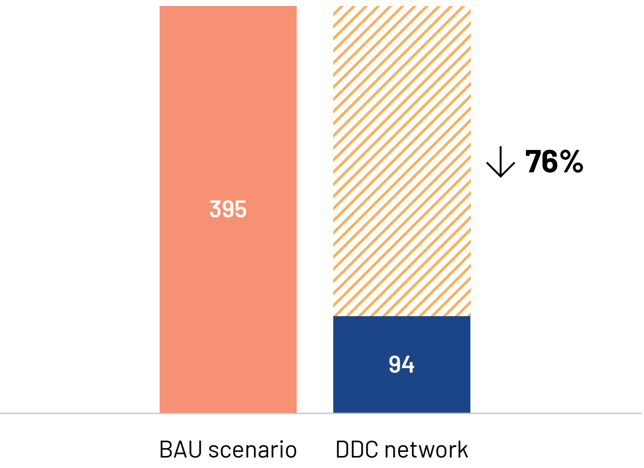
Hydrofluorocarbons (HFCs) are commonly used as refrigerants[4] in cooling systems and contribute more to global warming than CO_2. They are released into the environment mainly through cooling equipment leakages. A HFC leakage rate of two per cent a year was assumed for this study.

The combined hourly cooling load demand from both chiller plant and unitary systems of the 14 buildings peaks at around 8,395 RT. However, the current total installed capacity is about three times more at 25,836 RT (24,446 RT from chiller systems and 1,390 RT from unitary systems). In comparison, the DDC network is designed to have a total chiller capacity of 10,280 RT.

As the DDC network has a much smaller installed chiller capacity compared to the BAU scenario, significantly less amount of refrigerant will be used. In addition, the BAU unitary systems use the R-32 refrigerant, which has a higher global warming potential[5] compared to the refrigerant used by the chillers.

Once the buildings are interconnected in the DDC network, unitary systems will no longer be required as buildings would be able to enjoy the chilled water services at all times, removing the need for unitary systems to provide ad-hoc cooling. This would also lead to lower carbon emission numbers. The annual average carbon emissions reduction would be 301 tCO_2e – equivalent to taking 273 cars off the road per year.

Carbon emissions reduction from the potential reduction in refrigerant used in the DDC network



Annualised average carbon emissions from refrigerant use (tonne-CO_2e)

As the DDC network has a much smaller installed chiller capacity compared to the BAU scenario, significantly less amount of refrigerant will be used.

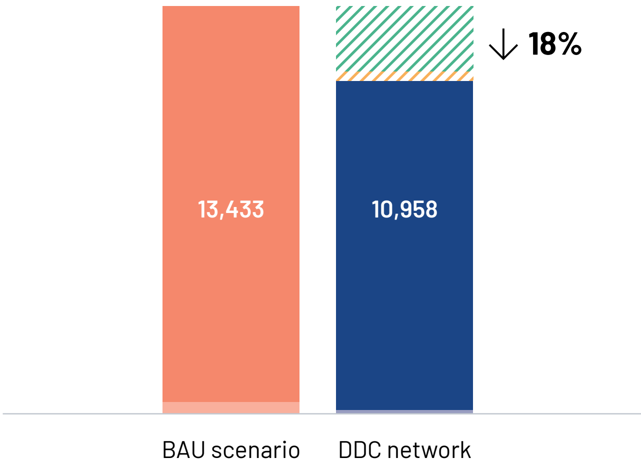
The annual average carbon emissions reduction is equivalent to taking **273 cars off the roads per year.**

[4] Refrigerant is a compound typically found in either a fluid or gaseous state. It readily absorbs heat from the environment and can provide refrigeration or air-conditioning when combined with other components such as compressors and evaporators.
[5] The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of CO_2. The larger the GWP, the more a given gas warms the Earth compared to CO_2 over that time period.

Carbon Emission Reduction of 18%

The total carbon emissions reduction is calculated by adding the carbon emissions reduction from the energy savings and reduction in refrigerant used. The annual average carbon emissions reduction would be 2,475 tCO_2e, or an 18 per cent reduction from the BAU scenario – equivalent to taking 2,250 cars off the roads per year.

Total carbon emission reduction from moving to the DDC network



Total carbon emissions from energy and refrigerant use (tonne-CO_2e)

Carbon emissions (tonne-CO_2e)

- **from BAU energy consumption:** 13,038
- **from BAU refrigerant use:** 395
- **from DDC network energy consumption:** 10,865
- **from DDC network refrigerant use:** 94

Carbon emissions reduction (tonne-CO_2e)

- **from energy savings:** 2,174
- **from reduction in refrigerant use:** 324

The annual average carbon emissions reduction is equivalent to taking **2,250 cars off the roads per year.**

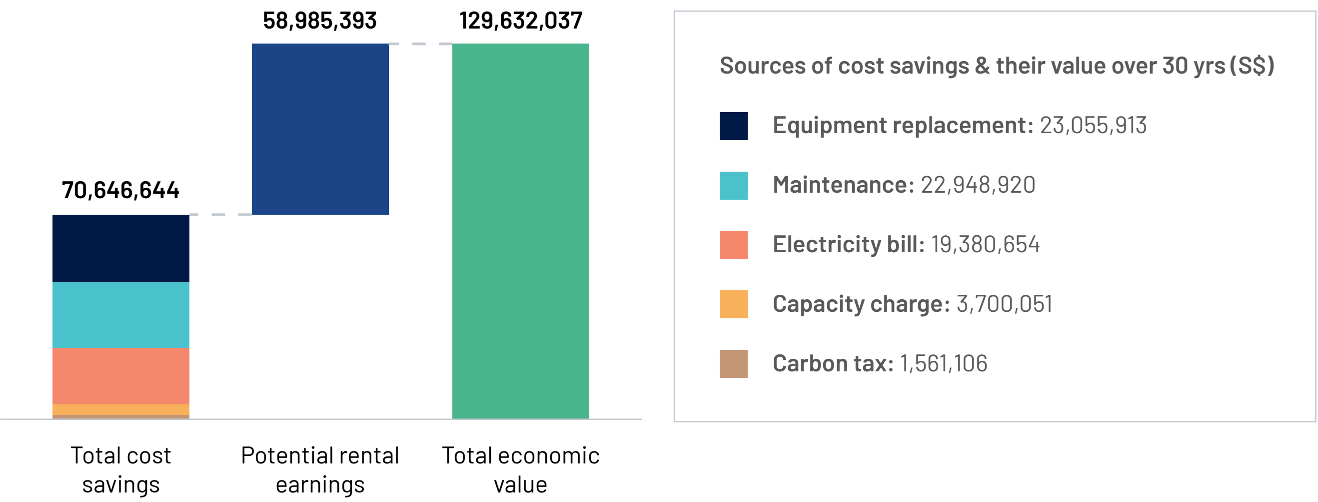
Long Term Economic Value of $130M

Besides clear environmental gains from the reduction in carbon emissions, building owners in the DDC network also stand to gain tangible monetary benefits. These include:

- **Electricity bill savings:** With less energy consumed, electricity bills will be reduced.
- **Carbon tax savings:** Singapore had implemented a carbon tax scheme on 1 January 2019 at a rate of S$5/t$CO_2$e, from 2019 to 2023.[6] With carbon emissions reduced through the DDC network, building owners will pay less carbon tax.
- **Equipment replacement cost savings:** In the BAU scenario, unitary systems have to be replaced every 10 years, while chiller plants have to be replaced every 15 years – capital costs that building owners will incur. With the DDC network, unitary systems are no longer required, and the installed capacity of the chiller plants will be significantly reduced from 25,836 RT to 10,280 RT to match the cooling needs of the district. As such, less capital expenditure will be incurred during a replacement cycle for the DDC network.
- **Maintenance cost savings:** With the installed chiller plant capacity significantly decreased, maintenance costs will be lower.
- **Capacity charge savings:** Connection to the DDC network will result in a diversified load with lower peak demand compared to the BAU scenario. This will translate to lower capacity charges (associated with peak demand) for the DDC network.
- **Potential rental earnings:** For buildings that are not injection nodes, their existing chiller plant room space could potentially be freed up and converted to a retail or office space. This could serve as an additional revenue stream in the form of rental income for building owners.

Using a DDC network over 30 years, approximately S$70,646,644 in lifecycle costs can be saved, and up to an additional S$58,985,393 in commercial value can be unlocked through the leasing of freed-up chiller plant space.

The potential economic value of the DDC network (S$)[7]



[6] Please refer to the Annex – Detailed Methodology for the full carbon tax scheme in Singapore.
[7] Please refer to the Annex – Detailed Methodology for the assumptions used in the calculation of each source of economic value.

Key Insights

- Planning for optionality is important when embarking on greenfield projects. It helps to accommodate future works, thereby becoming more cost-effective in the long run as there is less disruption to the surrounding infrastructure.
- Making the DDC network attractive to building owners is important as it encourages greater participation that contributes to the best district-level outcome.

1

In any brownfield development, a retrofit project can be complicated as there is often the need to navigate the existing built environment while ensuring minimal disruption to existing operations. This could also affect the economic viability of the project.

Therefore, **as today's greenfield development becomes tomorrow's brownfield development, it is important for developers and city planners to consider and build in optionality from the start when embarking on greenfield developments.** This would help in accommodating future works while avoiding the complex challenges of retrofitting projects.

A case in point would be the Marina Bay district, which was planned with optionality in mind. It has a common services tunnel that alleviates the need to dig up pavements or roads when additional underground pipes have to be installed to meet the needs of future developments.

While the short-term costs of building a common services tunnel are high, it becomes more cost-effective in the long run. This would allow district-level solutions such as a DDC network to be implemented in a brownfield site without incurring exorbitant costs and adversely affecting the current surroundings.

2

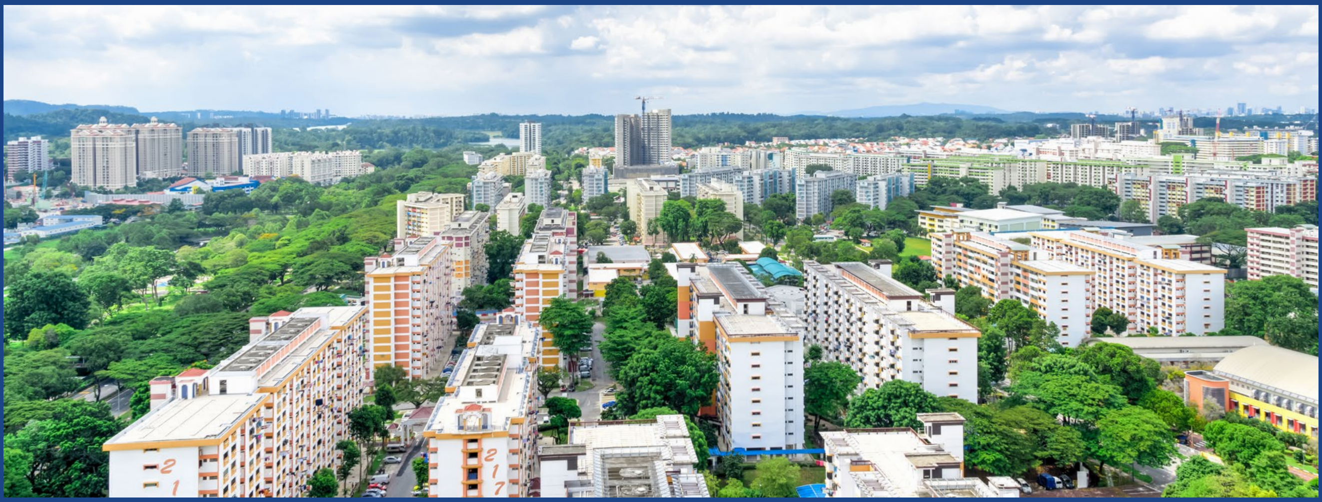
In a district-level system, greater participation paves the way for better outcomes due to economies of scale, and because certain critical roles may need to be fulfilled by specific stakeholders. **It is then useful to consider how incentives may be designed to ensure not only maximum participation, but also the participation of those critical to the success of the system.**

For instance, the proposed DDC network in Tampines Central comprises injection nodes and off-takers. Off-taker buildings will no longer have to house a chiller plant system, which frees up space for leasing to earn additional rental income. This makes it attractive for buildings to come on board as off-takers. On the other hand, while injection-node buildings will be compensated through lease and rental payments by the DDC network operator for housing chiller plants, the earnings may not compare to the more sizeable rental income that off-taker buildings could potentially enjoy.

As injection nodes play a critical role in the viability of the overall DDC network, it is important to consider how the role could be made more attractive to building owners. Some possibilities could include providing Gross Floor Area (GFA)[8] credits to injection node buildings or providing additional recognition through awards or certification programmes.

[8] All covered floor areas of a building, except otherwise exempted, and uncovered areas for commercial uses, are deemed the gross floor area of the building.

The Way Forward



Based on the key findings from the feasibility study, if a DDC network were to be implemented in Tampines Central, it would have the potential to reduce energy consumption and carbon emissions by 17 per cent and 18 per cent respectively, and provide economic value of some S$130 million over 30 years.

Electricity consumption in buildings and households contribute to approximately 20 per cent of Singapore's overall annual carbon emissions. A large portion of this is due to cooling, which consumes about 40 per cent of electricity in buildings and households. This means that cooling alone contributes roughly 8 per cent of our nation's annual carbon emissions. Should district cooling be scaled nationwide, Singapore is likely to see significant carbon emissions reduction and economic benefits.

If a DDC network were to be implemented in Tampines Central, it could provide economic value of some S$130 million over 30 years.

With the announcement of the Singapore Green Plan 2030 to address climate change and promote sustainable living, there is a strong impetus to explore the implementation of more district-level solutions, like the DDC network, to achieve a cleaner and greener future for all.

To scale such solutions in Singapore, it will be vital for all relevant stakeholders to come together to remove any regulatory impediments, build with the future in mind, and design incentives to encourage maximum participation of all.

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Participating Buildings and their Owners

CapitaLand

Tampines Mall

Telepark

Central Provident Fund Board

CPF Tampines Building

Frasers Property

Century Square

Tampines One

EVIA Real Estate and Metro Holdings

7 & 9 Tampines Grande

NTUC Income

Income At Tampines Point

Income At Tampines Junction

OCBC Bank

OCBC Tampines Centre One

OCBC Tampines Center Two

People's Association

Our Tampines Hub

UIC

Tampines Plaza 1

Tampines Plaza 2

UOB

UOB Tampines Centre

Useful Units of Measurements

Refrigerant Ton (RT)

A refrigerant ton refers to the rate of heat removal required to freeze a metric ton (1000kg) of water at 0 degree Celsius in 24 hours. It is a widely adopted unit of measurement for the cooling capacity of a refrigeration machine.

System Efficiency (kW/RT)

The system efficiency is computed based on the annual energy consumption (kWh) of the system over the annual cooling consumption in RTh. Therefore, the unit is in kW/RT.

Tonne of Carbon Dioxide Equivalent (Tonne-CO_2e or tCO_2e)

This is a standard measurement used to express the warming impact of other greenhouse gases in terms of the amount of CO_2 emissions that would create the same amount of warming.

Conversion Factors

As used in “Key Findings”

Item	Conversion	References
EMA grid emission factor (GEF) in 2019	1 kWh = 0.4085 kg-CO_2e	Information adapted from EMA Singapore Energy Statistics (SES) 2020 - T2.4 www.ema.gov.sg/singapore-energy-statistics/Ch08/index9
Annual energy consumption of a 3-room HDB flat	1 flat = 266.3 kWh/month x12 = 3,195.6kWh/year	2019 EMA Singapore Energy Statistics: www.ema.gov.sg/singapore-energy-statistics/Ch03/index3
Annual carbon emissions from 1 internal combustion engine (ICE) car	1 car = 1.1 tCO_2e/year	Information adapted from the LTA's Fuel Economy Calculator: vrl.lta.gov.sg/lta/vrl/action/pubfunc?ID=FuelCostCalculator **Assumptions:** • Average daily traveling distance: 9.5 km per trip reported by LTA • Assumed 750 trips per year (2 times per day)

As used in “Annex - Detailed Methodology”

Item	Conversion	References
Carbon emissions from R-134a refrigerant for a centrifugal chiller	1 RT = 1.8875 tCO_2e	Information adapted from the Leadership in Energy and Environmental Design (LEED)[9] guidelines and chiller specifications **Global warming potential (GWP):** • R-134a = 1300 • R-123 = 79 • R-1233zd(E) = 1 • R-410A = 1924 • R-32 = 677 **Maximum refrigerant charge:** • R-134a Centrifugal Chiller = 2.91 lb/tCO_2 • R-134a Screw Chiller = 2.87 lb/tCO_2 • R-123 Centrifugal Chiller = 2.00 lb/tCO_2 • R-123 Screw Chiller = 1.97 lb/tCO_2 • R-1233zd(E) Centrifugal Chiller = 2.00 lb/tCO_2 • R-410A Unitary System = 1.80 lb/tCO_2 • R-32 Unitary System = 1.80 lb/tCO_2 **Unit conversion:** 1 lb = 0.4536 kg
Carbon emissions from R-134a refrigerant for a screw chiller	1 RT = 1.8616 tCO_2e	
Carbon emissions from R-1233zd(E) refrigerant for a centrifugal chiller	1 RT = 0.0045 tCO_2e	
Carbon emissions from R-410A refrigerant	1 RT = 1.6982 tCO_2e	
Carbon emissions from R-32 refrigerant	1 RT = 0.5511 tCO_2e	

[9] LEED is an internationally recognised green building certification system developed by the non-profit organisation, the U.S. Green Building Council (USGBC). It includes a set of rating systems for the design, construction, operation, and maintenance of green buildings, homes, and neighbourhoods which aims to encourage building owners and operators to be more environmentally responsible and to use resources efficiently.

Annex: Detailed Methodology

STEP 1

Calculation of the energy savings and resulting carbon emission reduction

First, the cooling load profiles of the 14 buildings were generated using the information collected from the building owners via the following documents (in the order of most to least reliable):

1. **Operating System Efficiency (OSE) Report**
    - The cooling load profile was studied, typically from 9am to 6pm for commercial buildings and from 9am to 10pm for retail buildings.
    - Several buildings have night loads, but these were not reported, and hence assumptions were made:
        - The night load will be based on the last hour's load (if no building management system raw data is available) and the equipment run status;
        - The night time cooling system efficiency was estimated based on equipment specifications.
2. **Building Management System (BMS) Raw Data**
    - The raw data was scrutinised, and any anomalies or outliers were removed.
    - The 24-hour cooling load profile and cooling system efficiency were then calculated using the BMS raw data.
3. **Energy Audit Report**
    - The cooling load hourly profile was studied and the values estimated.
    - Several buildings have night loads, but these were not reported, and hence assumptions were made:
        - The night load will be based on the last hour's load (if no building management system raw data is available) and the equipment run status;
        - The night time cooling system efficiency was estimated based on equipment specifications.
        - The corresponding energy consumptions are calculated and verified with the energy end-use distribution.
4. **Electricity Bills**
    - Some buildings do not have any cooling system data to work with. To include these buildings in the study, assumptions were made based on other existing buildings' operation data. The assumptions can be seen in the table on page 28.

Assumptions used to determine cooling load of buildings with no cooling system data

Input Parameters	Space/Equipment	Reasonable Assumptions	Remarks
Operating Hours	Commercial	2,349 h/year	• Based on BCA GM NRB 2015 typical commercial hours of 9am to 6pm daily, 5 days per week
Cooling Load	Commercial	50 W/m^2 GFA	• BCA reported average commercial cooling demand of 72W/m^2 (For AC area) • Adjusted to 50 W/m^2, based on AC area: non-AC area of 70%:30%
Lighting Power Density (LPD)	Commercial	15 W/m^2	• Baseline LPD from GM V4.1: SS530-2006
	Data Centre (DC)	10 W/m^2 (With diversity of 20%)	• Baseline DC LPD from GM V4.1, 20% diversity mainly for maintenance, if not usually off
Equipment Power Density	Commercial	12 W/m^2	• Based on average office operation data collected for Green Mark Projects that have completed verification work
AC System Efficiency	Chiller plant	0.750 kW/RT	• Assumed average figure by SP Group and BSD
	Air Distribution Systems (Fan Coil Units, Air Handing Units and Precool Units)	0.470 kW/RT	• Derived from existing buildings' data
	Computer Room Air-Conditioning (CRAC)	0.327 kW/RT	• Derived from typical CRAC efficiency of 0.350 W/CHM and difference in temperature (dT) of 17 degrees Celsius
	Unitary System (Split Units, VRFs/VRVs)	0.930 kW/RT (for split-units) 0.808 kW/RT (for VRF/VRV)	• NEA Minimum Energy Performance Standards (MEPS) – As of June 2021

After the cooling loads were generated, the annual energy consumption from the chiller plant and unitary systems of the 14 buildings can be calculated for both the BAU scenario and DDC network using the following formula:

$$\text{Energy consumption}\left(\frac{kWh}{year}\right) = \text{Combined cooling load}\left(\frac{RTh}{year}\right) \times \text{System efficiencies}\left(\frac{kW}{RT}\right)$$

Over time, chiller plants and unitary systems will inevitably suffer from degradation. This degradation was factored in to provide a more accurate projection and accounts for an increase in the energy consumption of the buildings. The chillers in the DDC network and the chiller plants of buildings with Green Mark awards are assumed to not suffer from any degradation as the DDC network operator or building owner is required to maintain certain efficiency levels in order to comply with the respective building codes or Green Mark award. The methodology to determine the resultant energy savings and carbon emissions reduction in the long term (over 30 years) is as follows:

1. Incorporate chiller plant and unitary systems degradation factors to the BAU chiller plant and unitary system efficiency. The assumptions are as follows:
   a. Chiller plants degradation: 1% per year (for non-Green Mark buildings)
   b. Unitary systems degradation: 5% per year
   c. Proposed DDC baseline efficiency: 0.620 kW/RT
   d. For buildings that are Non-Green Mark Certified, we assume that their minimum efficiency upon retrofit is 0.750 kW/RT (to comply with latest BCA Existing Building Legislation)
   e. For buildings that are currently under BCA Green Mark Scheme, we assume that their minimum efficiency upon retrofit will maintain their respective Green Mark ratings
   f. For Unitary Systems, we assume their minimum efficiency to be of 0.776 kW/RT for split-units and equivalent 3-tick efficiencies for VRFs respectively (according to latest NEA's Minimum Energy Performance Standards)
2. Compute the BAU and DDC network energy consumption and resulting energy savings over a period of 30 years. The annualised average figures are obtained by dividing by 30.
3. Compute the carbon emissions reduction from energy savings over 30 years. The annualised average figures are obtained by dividing by 30.

   The carbon emissions reduction is calculated using the following formula:

$$\text{Carbon emissions reduction, 30 years}\ (\text{tonne-}CO_2e) = \text{Total energy savings}\ (kWh) \times \text{EMA Grid Emission Factor}\left(\frac{\text{tonne-}CO_2e}{kWh}\right)$$

STEP 2

Calculation of the reduction in refrigerant from stranded capacity & the resultant carbon emissions reduction

Documents provided by the building owners were used to identify the installed capacity and refrigerant types of the chillers and unitary systems of the 14 buildings. Most of the installed chillers and unitary systems run on hydrofluorocarbon (HFC) refrigerants which have relatively high global warming potential (GWP). At present, the installed water-cooled chillers are running on either the R-134a or R123 refrigerants and unitary systems are running on the R-410A refrigerant. To reduce greenhouse gas emissions, Singapore authorities have introduced measures such as banning equipment that use high GWP refrigerants and introducing climate-friendly alternatives such as hydrofluroolefin (HFO) refrigerants which are lower in GWP. Examples of HFOs are R-1233zd(E) for chillers and R32 for unitary systems.

The methodology to determine the reduction in refrigerant from stranded capacity and the resultant carbon emissions reduction is as follows:

1. Identify installed cooling capacity, replacement cycles, and refrigerant leakage rates of chillers and unitary systems, according to the LEED guidelines, in the BAU scenario and DDC network. The current installed capacities from all buildings amounts to 25,836 RT, where 24,446 RT is from chiller systems, and 1,390 RT is from unitary systems. The combined hourly cooling load demand from chiller plant and unitary systems is shown to peak at around 8,395 RT. In the proposed DDC network, the total utilised chiller capacity is 10,280 RT.
2. Identify the refrigerant type for the first and subsequent replacement cycles. The summary of installed cooling capacity, replacement cycle, refrigerant leakage rates, and refrigerant types for the BAU and DDC network scenarios are shown in the table below.

					Refrigerant Type	
Scenario	**System**	**Capacity**	**Assumed Leakage Rate**	**Replacement Cycle**	**1st cycle**	**2nd cycle onwards**
BAU	Unitary	1,390 RT	2.0% per year	10 years	R-410A	R-32
	Chillers	24,446 RT	2.0% per year	15 years	R-123, R-134a	R-1233zd(E)
DDC network	Chillers	10,280 RT	2.0% per year	15 years	R-123, R-134a	R-1233zd(E)

3 Calculate BAU and DDC network carbon equivalent emissions from refrigerant leakage and refrigerant impact over a period of 30 years. The annualised average figures are obtained by dividing by 30.

$$\text{Carbon emissions } (\text{tonne-}CO_2e) = \text{Combined cooling capacities } (RT) \times \text{Refrigerant charge} \left(\frac{lb}{RT}\right) \times \text{Mass conversion factor} \left(\frac{\text{tonne-}CO_2e}{lb}\right)$$

from LEED guidelines

4 Calculate the resultant carbon equivalent emissions reduction for 30 years. The annualised average figure is obtained by dividing by 30.

$$\text{Carbon emission reduction, 30 years } (\text{tonne-}CO_2e) = \text{BAU carbon emissions, 30 years } (\text{tonne-}CO_2e) - \text{DDC carbon emissions, 30 years } (\text{tonne-}CO_2e)$$

Certain key assumptions were made. Firstly, for the first replacement cycle, only carbon equivalent emissions due to refrigerant leakages were considered as there would not be any new installations. For subsequent replacement cycles, the impact on refrigerant changes due to the installation of new chillers and unitary systems were considered as well.

The chiller and unitary systems were also assumed to be replaced with that of a refrigerant that complies with the latest authority requirements. By 4th Quarter 2022, the National Environmental Agency (NEA) will ban the supply of water-cooled chillers using refrigerants with a GWP of more than 15 and household air-conditioners with GWP of more than 750. For the study, chillers previously using R-123 and R-134a refrigerants were assumed to be replaced with chillers using the R-1233zd(E) refrigerant (which has GWP of 1) after the first replacement cycle. Likewise, for unitary systems previously using the R-410A refrigerant, they would be assumed to use the R-32 refrigerant (which has GWP less than 750) after the first replacement cycle.

STEP 3 — Calculation of the total carbon emissions reduction from using the DDC network

Resultant carbon emission reduction ($tonne-CO_2e$) from using the DDC network over 30 years = *Carbon emission reduction from energy savings ($tonne-CO_2e$)* **STEP 1** + *Carbon emission reduction from reduction in refrigerant used ($tonne-CO_2e$)* **STEP 2**

The annualised average figure is then obtained by dividing by 30.

STEP 4 — Calculation of the long-term economic value from using the DDC network over 30 years

The economic value was calculated in terms of electricity bill savings, carbon tax savings, equipment replacement cost savings, maintenance cost savings, peak demand savings, and potential earnings if the chiller plant space were to be leased out over a period of 30 years. A summary of the calculation methodology and the assumptions made is shown in the table on page 33.

Calculation methodology and assumptions used to determine long-term economic value of the DDC network

Source of Economic Value	Calculation Methodology (30 Years Cumulative)	Assumptions
Electricity Bill Savings from Operational Energy Savings	**Energy Cost Saving over 30 Years (S$)** = [BAU Energy Consumption –DDC Network Energy Consumption] x Tariff Rate	**Tariff Rate:** S$0.1214/kWh
Carbon Tax Savings	**Carbon Tax Reduction over 30 Years (S$) =** [BAU Carbon Emissions –DDC Network Carbon Emissions] x Carbon Tax Rate at Respective Year	**Carbon Tax Rates (per tCO_2e):** Year 2021-2023: S$5 Year 2024-2029: S$10 Year 2030-2039: S$25 Year 2040-2055: S$50
Equipment Replacement Cost Savings from Reduction in Stranded Capacity	**Replacement Cost Savings, 30 years (S$) =** BAU Replacement Cost – DDC Network Replacement Cost Where, Replacement Cost = No. of Replacement Cycles in 30 Years x Replacement Cost per Cycle for Respective Chiller Plants or Unitary Systems = [30 Years / Replacement Cycle Years] x [Replacement Cost Rates x Installed Capacity]	**Replacement Cost Rates:** DDC Network and BAU Chillers: S$1,500/RT BAU Unitary Systems: $650/RT **Replacement Cycle Years:** DDC Network and BAU Chillers: 15 years BAU Unitary Systems: 10 years
Maintenance Cost Savings from Reduction in Stranded Capacity	**Maintenance Cost Savings, 30 years (S$) =** [BAU Chiller Plant Installed Capacity – DDC Network Installed Capacity] x Annual Maintenance Cost x 30 Years	**Annual Maintenance Cost:** S$54/RT
Peak Demand Savings from Operational Energy Savings	**Peak Demand Cost Savings, 30 Years (S$)** = BAU Peak Demand Cost – DDC Network Peak Demand Cost Where, BAU Peak Demand Cost (S$) = Sum of {[Annual Cooling Energy Consumption for Individual Buildings (kWh) / Annual Cooling Load for Individual (RTh)] x Individual Building Peak Cooling Demand (RT) Over 30 Years for All 14 Buildings} x Monthly Peak Demand Cost x 12 Months DDC Network Peak Demand Cost (S$) = Sum of {DDC Network Maximum Efficiency over 30 Years (kW/RT) x Annual Maximum Cooling Load of All 14 Buildings (RT) over 30 Years} x Monthly Peak Demand Cost x 12 Months	**Monthly Peak Demand Cost:** S$8.90/kW **DDC Plant Efficiency (kW/RT):** 0.62
Potential Earnings from Leasing Out Freed-up Chiller Plant Space	**Potential Earnings from Leasing Out Chiller Plant Room Space, 30 Years (S$) =** [BAU Chiller Plant Room Area that may be converted to retail space (m^2) x Annual Retail Leasing Rate per m^2] + [BAU Chiller Plant Room Space that may be converted to office space (m^2) x Annual Office Leasing Rate per m^2]	**Monthly Leasing Rates:** Retail: S$20 psf Office: S$6 psf

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