



## FINAL FEASIBILITY REPORT

Male' and Hulhumale'

District Cooling Feasibility Study

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# 1 Executive Summary

Maldives is implementing its HCFC Phase-out Management Plan (HPMP) with funding from the Multilateral Fund for implementation of the Montreal Protocol. The plan targets complete elimination of HCFC use by 2020. HCFCs are widely used as refrigerants in Maldives in servicing of various refrigeration and air conditioning equipment, with significant majority use in air conditioners.

The overall objective with this feasibility study was originally to develop and evaluate options for a district cooling approach that would obviate the use of HCFC/HFC on the island of Male'. As a result of inception consultations with participation by the Maldivian Government the geographic focus has been altered to include i) the Hulhumale' developments and ii) the most feasible clusters of existing buildings in Male'.

The planned developments in Hulhumale' will generate a very large demand for cooling. Based on i.a. master plan data the potential demand has been calculated to 300 MW cooling capacity and 1.8 million MWh of cooling energy annually. The assessed clusters in Male' only have a small fraction of that demand.

Several production technologies have been considered and it has been found that a Sea Water Air Conditioning system with a minimum of installed chiller capacity can provide feasible and competitive district cooling in Hulhumale'. For the clusters in Male' it has not been possible to find feasible alternatives.

Since the Hulhumale' developments will be populated over several years a development of District Cooling in three phases of 100 MW cooling each has been recommended. Capital expenditure for each phase has been calculated to USD 108 million resulting in an IRR of 12.5%.

With fully implemented district cooling in Hulhumale' carbon dioxide savings of 426,000 tons annually can be achieved. Minor savings could be achieved also in the Male' clusters were they potentially realized.

The main recommendations going forward are as follows:

- Continue the stakeholder analysis with emphasis on appointing a Governmental or other body that can act as the primary stakeholder for the continued DC development.
- Prioritize a pilot DC system in Hulhumale' to demonstrate the technology. The large advantage for Hulhumale' is that building systems there can be adapted to receive the DC service from start without the substantial costs tied to retrofitting of existing buildings. If built in Hulhumale', installations for the pilot system can potentially be integrated in a commercial system later on.
- Assess the possibilities to obtain international development funding and/or green funding along with relevant competence and resources for continued DC development including a pilot DC system.
- It is also recommended that the Government of Maldives initiate a process to define building standards for new developments in order to promote ducted central air conditioning systems. Such standards will facilitate the introduction of DC.
- Assess the possibilities to co-ordinate all relevant previous and current sea water cooling plans in order to reduce cost and improve likelihood of success.

## **2 Introduction**

### **2.1 Background**

Maldives is implementing its HCFC Phase-out Management Plan (HPMP) with funding from the Multilateral Fund for implementation of the Montreal Protocol. The plan targets complete elimination of HCFC use by 2020. HCFCs are widely used as refrigerants in Maldives in servicing of various refrigeration and air conditioning equipment, with significant majority use in air conditioners.

CCO Holding AB with its office in Stockholm, Sweden is pleased have been appointed by the United Nations Development Programme (“UNDP”) in Maldives to perform this feasibility study as a result of responding to the Request for Proposal “Develop a Consultancy for conducting feasibility study of district cooling in Male’ for replacement of HFC and HCFC based air-conditioners with alternatives”.

Devcco is the operating brand of CCO Holding AB and herein after “Devcco” refers both to the company, brand and team of CCO Holding AB.

### **2.2 Basic project information**

Name of Work Assignment: Conducting feasibility study of district cooling in Male’ for replacement of HFC and HCFC based air-conditioners with alternatives.

Project reference: PS/2015/04

### **2.3 Objective**

The overall objective with this feasibility study was originally to develop and evaluate options for a district cooling approach that would obviate the use of HCFC/HFC on the island of Male’. As a result of inception consultations with participation by the Maldivian Government the geographic focus has been altered as follows. Development phases 1 and 2 of Hulhumale’ will be included in the study while the geographical scope on Male’ will be reduced to include only the most feasible “pockets” or clusters of existing buildings that could potentially be connected to district cooling. Identification of such pockets is part of the feasibility study.

### **2.4 Scope**

The scope of the feasibility study is to develop a set of minimum commercial and technical requirements for district cooling to:

- Drive efficiency upwards and optimize long-term costs
- Rely on best industrial practice and design standards
- Review and access the market expected cooling demand
- Identify the optimal district cooling system concept
- Describe the optimal technical concept
- Estimate OPEX and CAPEX
- Identify key success factors and risks
- Estimate main environmental impacts such as water savings, carbon footprint and ozone depletion potential

## 3 Market demand

### 3.1 Altered market and demand estimations

The overall objective of the feasibility study was originally to develop options for a District Cooling (DC) approach that would obviate the use of refrigerants HCFC and HFC on the island of Male'. As a result of inspection consultations in December 2015, in January 2016 and in April 2016, the geographical focus has been altered as agreed by the project steering committee including the Government of Maldives.

- Development phase 1 and 2 of Hulhumale' will be included in the study and is further described in chapter 3.2.
- The geographical scope on Male' will be reduced to only the most feasible "pockets" or zones of existing commercial and governmental buildings that would potentially be connected to district cooling. Identification of such pockets are further described in chapter 3.3.

Establishing a relevant market potential is critical in performing a reliable district cooling feasibility study. Assessing the market potential and trends includes combining and cross referencing data from several sources such as building and real estate registers, air-condition supply side information, refrigerant registers, electricity demand profiles and climate data bases to the extent available. For this project we have also undertaken limited focus group discussions. Readiness to change to a district cooling system service will largely depend on the existing type of air conditioning system installed by the potential clients, sometimes in combination with the remaining technical life of such installed systems. For a small number of key clients in Male', such information along with other building specifics have been collected through on-site surveys. Devcco has conducted a large number of such surveys and thereby has an established methodology including check-lists in place. The Ministry of Environment and Energy and its staff members have been very helpful assisting with surveys and gathering of information. Benchmark analysis of the collected data has been performed with the Devcco benchmark database. Cooling demand analysis has been performed for; constructed area, type and final use of buildings, current type of cooling systems, development schedule and conversion of existing building system to district cooling supply.

### 3.2 Hulhumale'

#### 3.2.1 Development phases 1 and 2

Phase 1 of Hulhumale' is partly developed while phase 2 has only recently been created and is yet to be developed. In particular, the undeveloped parts on Hulhumale' appear to have significant potential for developing a district cooling system.

Regarding data collection, the Housing Development Corporation (HDC) has provided a comprehensive on-site presentation of the developments including information regarding primarily building areas and building use for the different parts in terms of master plan spreadsheets for phase 1 and 2. The master plan spreadsheets have been integrated into the "Devcco Masterplan Cooling Demand Calculation Model". The model consists of:

- Master plan input
- Cooling load assumption input
- Load profiles input
- Cooling load estimate output
- Load profile output

- Cooling load district wise output
- Cooling load profile diagram output

The methodology for estimating the cooling demand has been based on the gross floor areas for the various building segments as described in the master plan spreadsheets. Specific cooling capacity demand based on Devcco's experience and data base in combination with findings from on-site surveys of existing building installations in the Maldives have then been applied on the various building segments. Segments such as buildings for religious and sports purposes have not been assigned any cooling demand.

The current assumption is that the yet undeveloped part of the phase 1 area and the whole area of phase 2 will be connected to the District Cooling System and divided into a number of sectors with a mixture of residential, hotel, institutional and commercial buildings. Detailed market assumptions and descriptions are further described in appendix 1.

The resulting preliminary cooling capacity demands in the different phases of the not yet developed areas can be summarized as follows:

- For phase 1 the cooling capacity demand is 100 MW
- For phase 2 the cooling capacity demand is 200 MW

### **3.3 Male'**

#### **3.3.1 Relevant market areas**

In connection with inception consultations and site visits one conclusion was that in terms of general feasibility only certain areas in Male', with only existing buildings, would be relevant for further assessment while new developments on Hulhumale' appear to have significant potential for developing a district cooling system.

The most relevant areas in Male' are:

- The northern sea front area here defined as Zone 1
- The I.G.M.H and the Dhiraagu Head Office in the south-west here defined as Zone 2. The I.G.M.H. is so far the only identified building in Male' that is equipped with a centralized air-conditioning system.

The specific blocks and buildings in each of the areas are listed in zone 1 and 2 and are highlighted in the map in Appendix 1.

The Ministry of Environment and Energy has suggested also the following specific buildings in Male' to be included in the study, here defined as Zone 3.

Zone 3 is also highlighted in the map in Appendix 1.

The resulting preliminary cooling capacity demands in the different zones can be summarized as follows:

- Zone 1: 9 MW cooling capacity
- Zone 2: 2 MW cooling capacity
- Zone 3: 2-3 MW cooling capacity



## 4 Marketing and Pricing structures

### 4.1 Market approach and general benefits

District cooling is often marketed as a competitive and sustainable service providing for long term price stability and simplicity to customers. The simplicity is due to the fact that customers won't need to care about investments/re-investments operation and maintenance of chillers, cooling towers or other complex installations on their own premises. With district cooling customers simply receive a reliable supply of chilled water ready to use in the buildings air conditioning systems.

Other benefits to customers are:

- Less valuable building space required for technical installations
- Architectural freedom since roof tops will not need to house cooling towers etc.
- No handling, refilling and reporting of refrigerants
- No noise or vibrations from fans and compressors
- Reduced power supply capacity

### 4.2 Pricing structures

In order to work out a competitive fee structure (not only based on financial performance of the district cooling system solely) the local market alternative to district cooling and local district cooling tariffs need to be compared. This section describes the general mechanism of the fee structure.

Most of the local /international private/public utility companies utilize a district cooling business model based on long term payback, relatively high debt ratio and cash flow to cover debt by maturity. Contracts vary from 10-25 years in term. The return on business is in line with other infrastructure projects i.e. IRR targets of 10-12% and return on equity IRReq 20-25%.

The utility provider business models are based on concession agreements and/or other long term agreement with main developer/city. The concessionaire (utility provider) signs dedicated agreements with each the sub developer/building owner etc. to provide chilled water from central plants thru a distribution network. The agreement with sub developers'/end users is commonly referred to as CSA (Cooling Supply agreement). A typical CSA covers the following items.

**Contracted Capacity:**

The contracted capacity is the required chilled water capacity that can be transferred to the end user premises in the distribution network. The developer dictates the required capacity and the utility provider makes such capacity available through the central plant and the dedicated network to the premises.

**Customer Connection:**

The utility provider prescribes the technical requirements to install an Energy Transfer Station (ETS), where the chilled water is supplied from the central plant (primary side) to the building owner (secondary side) via heat exchangers (ETS). The capacity that can be transferred is equal to the contracted capacity. Different ownership structures are used for the ETS (sub developer or utility provider).

The most common fee structure for district cooling utility services is divided in one-time payments and recurring payments.

One-time payments such as:

**Connection fee:** a fixed amount in USD per MW. This fee covers a limited part of the cost for the infrastructure. This is a one-time payment from the building owner/developer to the utility provider.

**Access Fee:** a fixed amount in USD per MW during a limited time (1-10 years). This fee can be an alternative to connection fee and covers a limited part of the infrastructure costs. The fee is paid from the building owner/developer to the utility provider and can be re-negotiated after the first terms expires.

**Activation Fee:** a one-time activation fee paid from the sub developer to the utility provider to activate the district cooling connection.

**Deposits:** utility providers sometimes ask for a refundable deposit for the annual capacity and consumption fees. This will be refunded at the end of the term in case of no default in payment. The deposit is paid by the sub developer to the utility provider.

Recurring payments such as:

**Annual/Monthly Capacity Fee:** This is an on-going fee under the duration of contract, charged in USD/MW,year, of the contract payable once per year /or month and covers the operation, maintenance, upgrades, capital investment, insurance, and other administrative costs required for operating the District Cooling plant, ETS and network. This fee is varied according to price index, and is payable by the sub developer or transferred to the unit owners by the sub developer.

**Consumption Fee:** This fee is based on the actual usage of the chilled water and is billed monthly based on the meter reading. This fee covers the cost of the power, water, and water treatment. The fee is linked to price index. The fee is payable by the sub developer or transferred to the unit owners by the sub developer.

**Other fees:** additional fees may be added from the utility providers. Fees such as administrative fees, metering fees and prioritized ETS fees.

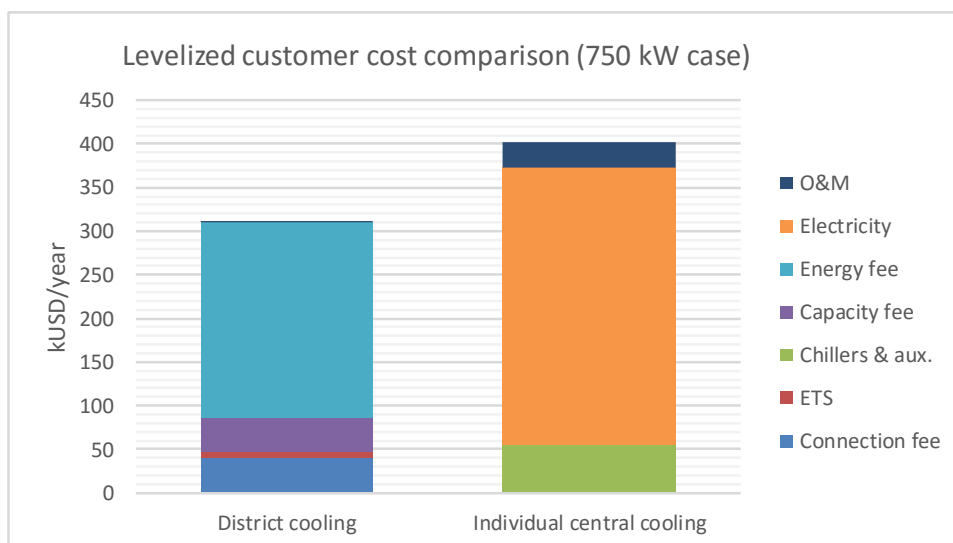
For the profitability calculation a model price structure that makes DC competitive compared to conventional building individual central air conditioning systems has been developed. This model price structure includes a connection fee of USD 500 per kW, a capacity fee of USD 50 per kW and year and finally a consumption fee of USD 50 per MWh.

The above fees are not directly based on the cost to build and operate the district cooling system, but rather an average rate level applying to the model building for which the below comparison is made.

In order to determine the competitiveness of district cooling with the above price structure a comparison with building individual central cooling production has been made. The comparison has been made for an average model building in Hulhumale' with a capacity demand of 750 kW of cooling. The graphs below illustrate the competitiveness of DC expressed as annual costs. Initial capital expenditures have been levelized over 15 years in order to be able to compare all relevant costs.

In the district cooling alternative the customer would pay the above mentioned fees to the DC supplier and would also install the required Energy Transfer Station (ETS) at own cost.

In the alternative with individual central cooling the customer would invest in chillers and other cooling production installation at a specific cost of USD 500 per kW cooling capacity. Electricity costs are based on average coefficient of performance (COP) of 4 and on 6,000 equivalent full load hours. O&M costs are based on bench-mark data.



*Cost comparison of District Cooling and the alternative with individual central cooling.*

## 5 Sourcing

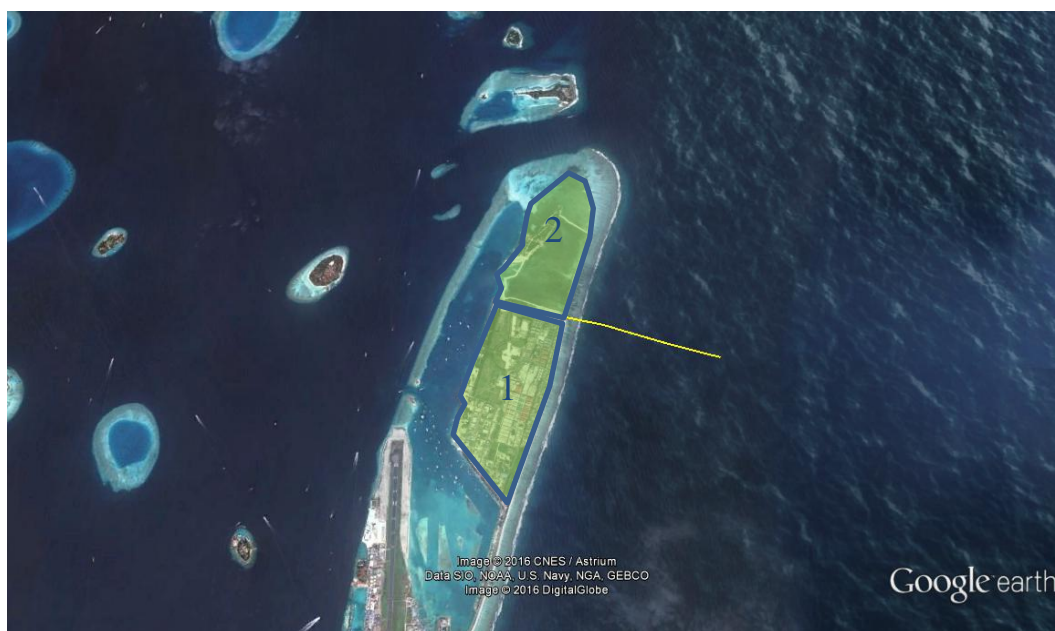
### 5.1 Sea water

When sourcing sea water for cooling purposes of course the available water temperature is of key interest. Typically, the water gets colder at greater depths and hence at greater distance from the shoreline. The water temperature drops quickly from the surface down to a depth of approximately 200 m. At greater depths the decline in temperature is much slower.

At the eastern side of Hulhumale' the seabed has a relatively steep slope and at a distance of less than 2.5 km from the shoreline the depth is more than 1,000 m, where the water temperature is approximately 6-7°C. Water of such temperature would be sufficient for a very efficient SWAC system.

Closer to shore, approximately 0.6 km from the shoreline, the depth is in the magnitude of 200 m where the water temperature is 14-15°C. Sourcing water from this depth would be sufficient for a hybrid system where sea water is used in combination with chillers to provide the desired temperature and capacity for the district cooling system.

Surface water available for shallow sea water hybrids at Male' has a temperature of approximately 28°C



*Hulhumale' phases 1 and 2. The yellow line is indicating a potential sea water pipe direction and length of 2 km for reference.*

## 5.2 Electricity

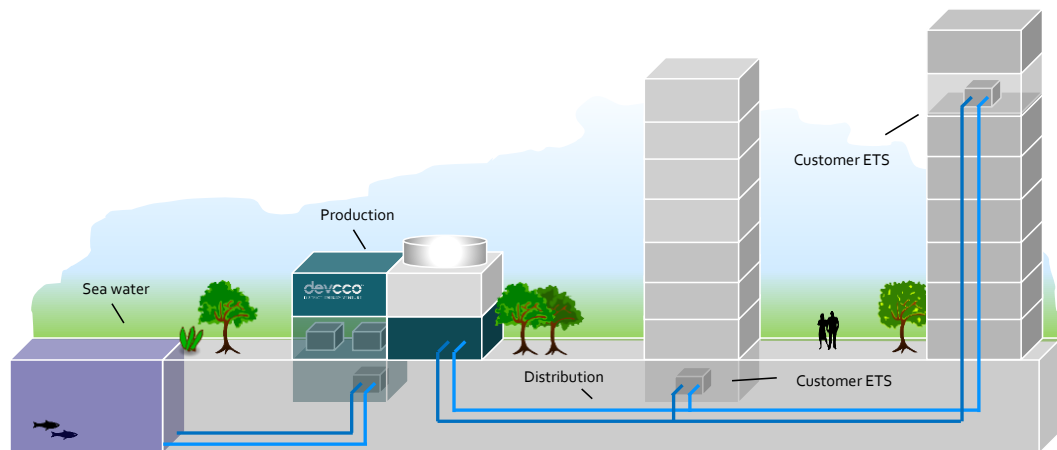
Sourcing of electricity for district cooling is vital in terms of acquiring sufficient capacity for the production and pumping locations but from a system wide perspective it is actually a question of avoidance of required power production capacity. The basics of the matter is that by introducing energy efficient district cooling, as compared to building individual cooling production, less electricity is required for cooling and air conditioning purposes. The magnitude of the avoidance in Hulhumale' is in the order of 25-40 MW installed power production capacity per phase. In addition to that, there are also substantial potential savings due to avoided power distribution requirements.

## 6 Technology Options

The technology options for a district cooling system are several. In this section we have divided the district cooling system into three different parts that each provide their own options:

- Production,
- Distribution,
- Energy Transfer Stations.

From a system architecture point of view, the different production options are most central and will define much of the operational and environmental aspects of the system.



*General illustration of district cooling system.*

## 6.1 Production

In this section the most relevant options for Male' and Hulhumale' will be described. For Hulhumale' they are:

- Conventional DC system,
- Sea Water Air Conditioning system,
- Hybrid system.
- Customer alternative/individual cooling

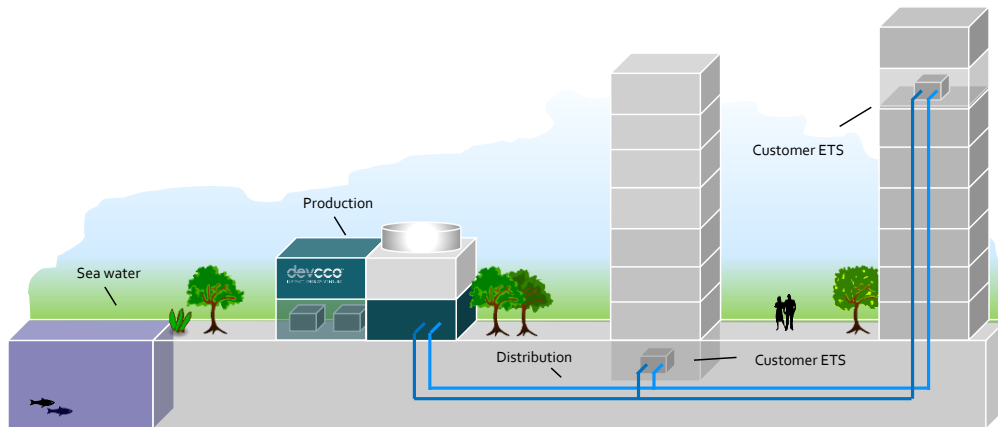
Currently there is no available source of waste heat why absorption cooling systems have been excluded. However, with the large electricity demand created by the Hulhumale' developments, future power plants may be able to produce significant amounts of waste heat that could be utilized in such absorption cooling systems

### 6.1.1 Conventional DC system

Conventional production is defined as production by electrically powered chillers cooled by open cooling towers. Such conventional systems provide cooling at a higher rate of energy efficiency than building individual systems and risks in engineering, construction and operation are very limited.

Main components:

- Building
- Chillers
- Cooling towers



*Illustration of conventional DC production system with chillers & cooling towers.*

### 6.1.2 Pros and cons with conventional DC system

Pros: Standard equipment

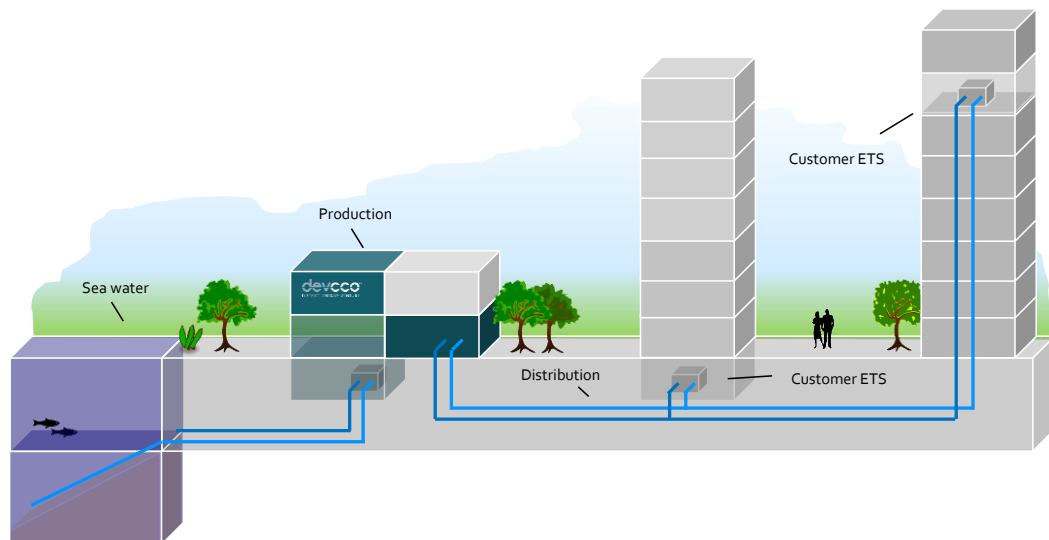
Cons: High capital expenditures (capex), high operational and maintenance, large amount of conventional refrigerants

### 6.1.3 SWAC (Seawater Air Conditioning)

The principle idea of SWAC or Seawater Air Conditioning is to utilize deep cold sea water that is cold enough to supply district cooling without the use of chillers or a minimum number of chillers. The main benefit of SWAC is the very high energy efficiency that can be obtained due to the utilization of natural cooling from the sea. Electricity will still be required mainly for pumping water through pipelines and heat exchangers. Compared to conventional systems the engineering and construction costs of SWAC systems are relatively high. SWAC systems are site specific by nature why risks in engineering, construction and operation are also higher than for conventional systems.

Main components:

- Building
- Seawater system with intake structure, intake and return pipes, outfall structure
- Sea water pumps
- Heat exchangers



*Illustration of SWAC system with deep seawater intake & no or minimum amount of chillers.*

#### 6.1.4 Pros and cons with SWAC

Pros: Low operational cost, no or low amount of refrigerants such as not-in-kind alternatives

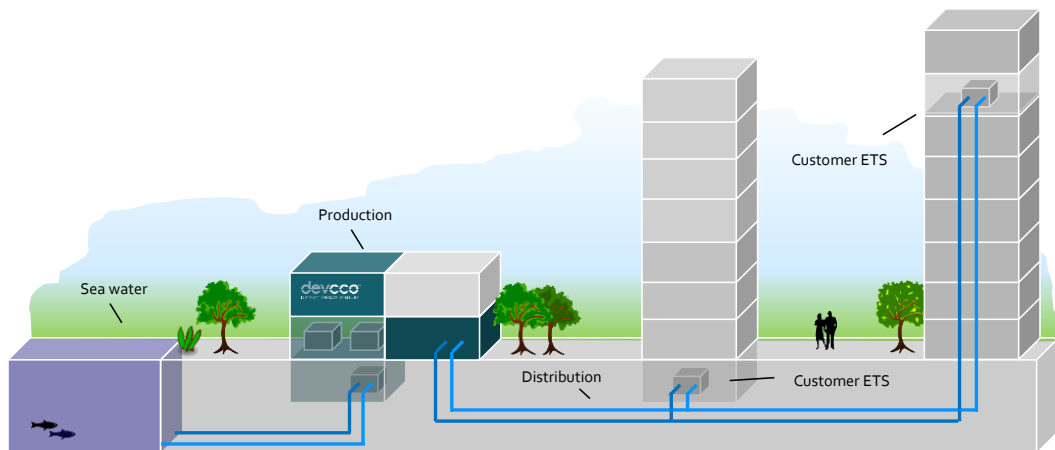
Cons: High capex, High initial capex (due to off shore piping)

#### 6.1.5 Hybrid systems

Hybrid systems are in this context defined as a version of SWAC systems where water is sourced from a lesser depth and with a higher temperature than is the case in traditional SWAC systems. In order to provide the required district cooling temperature and capacity, chillers are installed and integrated with the sea water system. The degree to which chillers are included is typically a tradeoff between total system construction cost and total system efficiency. A major benefit with a hybrid system is that chillers makes it possible to secure the district cooling supply temperature and capacity despite natural fluctuations in sea water temperature.

Main components:

- Building
- Seawater system with intake structure, intake and return pipes, outfall structure
- Sea water pumps
- Heat exchangers
- Chillers



*Illustration of hybrid system with shallow seawater intake & chillers.*

### 6.1.6 Pros and cons with hybrid systems

Pros: Medium operational cost, medium amount of refrigerants such as not-in-kind alternatives

Cons: High capex



*60 MW Hybrid production under construction in Amsterdam, the Netherlands.*

### 6.1.7 Small scale systems for Male'

Small scale systems to provide the Male' cooling areas (market pockets) could be of conventional type or of hybrid type using shallow sea water as a natural source. In the case of shallow hybrid systems, the main components would be the following:

- Building
- (Shallow) seawater system with intake structure, intake and return pipes, outfall structure
- Sea water pumps
- Heat exchangers



- Chillers

### 6.1.8 Customer alternative/Individual cooling

A major barrier for introducing district cooling and also a major barrier for phasing out HFC and HCFC is the wide use of “split systems” or VRV/VRF (“multi split” systems) for major buildings in Male’ and possibly also in the Hulhumale’ new developments.

Conventional individual building systems transfer heat from the space to the refrigerant by circulating air in ducted systems or water via pipes throughout the building. Split systems, or ductless products, are fundamentally different from ducted systems in that heat is transferred to or from the space directly by circulating refrigerant, often HCFC and HFC, to evaporators located near or within the conditioned space.

VRV/VRF systems are large and complex versions of ductless multi split systems, with the additional capability of connecting ducted fan coils units. VRV/VRF systems are more sophisticated than split systems with multiple compressors and many evaporators that are mainly roof top placed on Male’. Complex oil and refrigerant management and control systems are needed. Another disadvantage is the large amount of refrigerant being circulated to the conditioned spaces.

The vast majority of split system and multi split systems in the Maldives is a barrier for District Cooling due to extensive building modification required to convert to ducted centralized cooling and air conditioning systems. Thus leading to high costs. Conversion to ducted systems could potentially take place in a phased manner, but considering the costs such conversion would likely have to take place as part of major renovations of existing buildings or as existing buildings are replaced by new buildings. Thus, it would probably take several decades before such phased conversion would be complete.

As there to our understanding are no building guidelines in place to prevent such installations in new developments this could potentially become a barrier also in Hulhumale’. In order to prevent this from happening our recommendation is to implement building guidelines requiring ducted centralized cooling and air conditioning systems for new developments as soon possible.

Such guidelines would to our understanding also help achieve the goals of the Maldives phase-out management plan (HPMP) since a further use of VRV/VRF systems would result in increased use of refrigerants and thereby increased risks for leakage.

## 6.2 Distribution

District cooling is distributed to consumers by an under-ground closed loop pipe systems consisting of supply and return pipes running in parallel. The most common technology for distribution systems is to use pre-insulated steel pipes, but also other alternatives such as poly ethylene pipes are in use.

For the continued work with this feasibility study, the system design will be based on EN253 pre-insulated pipes with insulation standard series 1. Temperature level forward/return is expected to 6/16°C i.e.  $\Delta T = 10^\circ\text{C}$ .

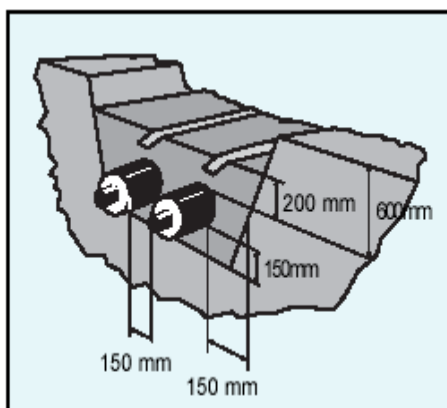
Pressure is maximum 16 bar which is standard in EN253 design.

Maximum pressure loss on pipe is 50 Pa/m.

The insulation of the district cooling pipes makes it possible to include the wires for a leakage-surveillance system, which is essential for the future safe operations.

Energy losses from district cooling pipe system are rather low due to similar ground temperatures.

Below a typical trench section of a double pipe distribution system is illustrated.



*Cross section for a pair of DN 150 distribution pipes (sufficient for approximately 2 MW cooling).*

Construction cost is to a large extent dependent on labor cost and to a lesser extent depending on cost for pipe material. Therefore large savings can be achieved by coordinating the construction with other utilities.



*Construction of pre-insulated distribution pipes.*

## 6.3 ETS (Energy Transfer Station)

In the ETS cooling energy from the Distribution network are transferred to the buildings internal system.

In general, there are two main alternative principles for ETS:

- Heat exchanger (HEX) connected ETS
- Directly connected ETS

In the heat exchanger connected ETS heat exchangers are installed in order to physically separate the distribution grid from the buildings internal system. Cooling / heating energy from the primary side is transferred to the secondary side through the heat exchanger. Capacity control is carried out by increasing/decreasing flow on the primary side.

Advantages:

- Different pressure levels on primary and secondary side independent from each other. No extra and complicated controls are needed.
- High safety – maintenance and repairs in one side does not influence the other side.
- A very clear and distinct separation between primary and secondary side.
- Separate water in the DC system and the buildings heating/cooling systems.
- Reducing risk of sludge and corrosion from the buildings systems operations.
- In case there is a leakage in the buildings heating/cooling system, the DH/DC water is still intact. No affected to other buildings connected to the DC system.

Disadvantages:

- A small temperature loss occurs in the heat exchanger; the primary side temperature then must be compensated in order to supply the requested temperature on the secondary side.
- Fouling of the heat exchanger may lead to losses in capacity.
- Extra investment costs for heat exchangers.

Directly connected ETS: In directly connected ETS are not the primary and secondary sides physically separated; the same water is circulated through the distribution grid and the buildings internal system. Pressure reducing valves in the ETS maintain the two different pressure levels on primary side versus secondary side. Capacity control is carried out by mixing supply and return water on the secondary side into actual set-point temperature.

Advantages:

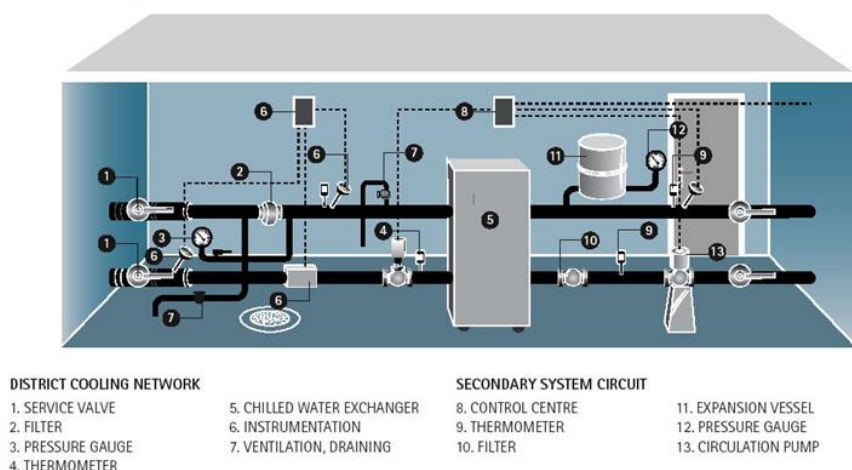
- No thermal losses, the same temperature as in the primary side can be distributed in the secondary side.
- No risk of fouling in heat exchangers.

Disadvantages:

- Complicated to maintain the different pressure levels.
- Systems with connection of high and low buildings will lead to un-necessary high pressure levels in the low buildings systems.
- Sensitive system; leaks and losses of water will be difficult to detect.
- Control of the water quality in the system cannot be guaranteed.
- No clear separation between primary and secondary side.

A technical description of a Heat exchanger (HEX) connected ETS is presented below:

## TECHNICAL DESCRIPTION OF A SUBSTATION



## 7 System architecture & Energy balances

In a previous stage in this feasibility study a rough order magnitude (ROM) life cycle cost comparison was made between conventional DC production, SWAC with the purpose to focus on the most feasible alternatives in the continued feasibility assessment. The result of that comparison of production alternatives was to continue to focus on both SWAC and Hybrid alternatives having the least life cycle costs. The conventional DC system with only chillers fell short mainly due to high operating costs compared to the other alternatives.

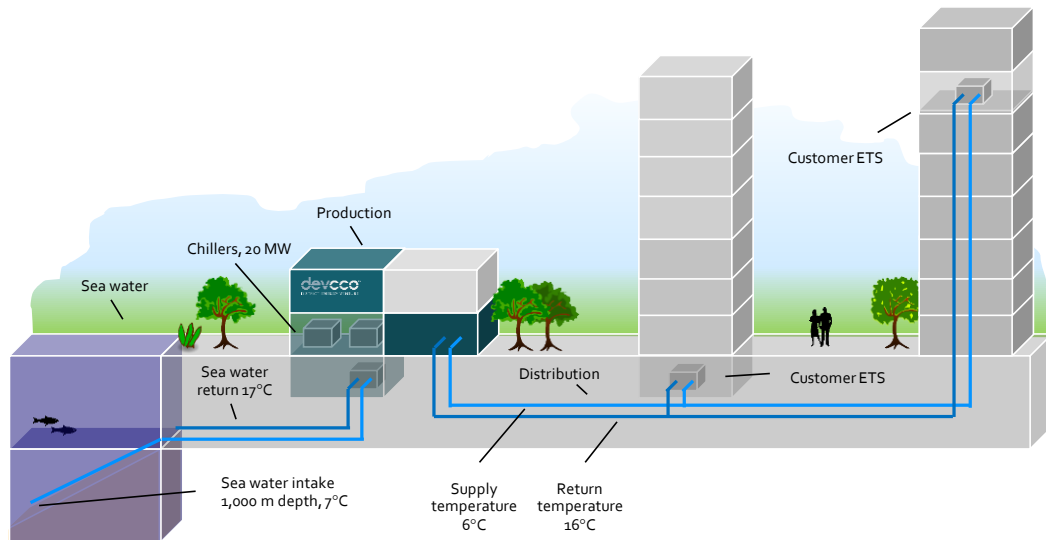
### 7.1 System architecture

Fundamental in the system architecture are the temperatures at which the cooling is supplied to, and returned from, the customers. These temperatures have large impact on e.g. the amount of natural cooling that can be utilized and on the dimensions of the distribution network. Typical temperatures in district cooling, also adopted in this assessment, are a supply temperature of 6°C and a return temperature of 16°C.

Border of delivery for the district cooling service is just inside the customer building wall before the energy transfer station that is normally the property of the customer.

The distribution system for a 100 MW phase is based on 134 average customers/plots with a demand of 750 kW cooling each.

In systems like the one planned for Hulhumale' with a large number of individual customers, not all of them will require their peak capacity at the same time. Therefore, a simultaneity factor needs to be introduced in order not to over dimension the distribution and production facilities. For the 100 MW phases a simultaneity factor of 0.8, which is typical for large systems such as those in Stockholm and Paris, has been adopted. Simultaneity is mainly a function of amount and diversity of connected buildings and apply to any climate conditions.



*Illustration of proposed SWAC system for a 100 MW Hulhumale' phase.*

## 7.2 Energy balances

An energy balance is the basis for calculating the energy efficiency of a district cooling system. The energy balance tells how the customer demand for cooling is met by different kinds of production, in this case chillers and natural cooling from sea water.

The ratio between cooling that can be provided by natural cooling from seawater and by chillers is largely determined by the available sea water temperature and by the district cooling system temperature.

The available sea water temperature depends on the depth at which sea water is extracted while the district cooling system temperature is a choice that is made based on customer requirements and preferences, distribution system design and costs and of course on available cooling sources.

A conventional district cooling supply temperature to customers is 6°C which is close to design temperatures for building internal central cooling systems. Such supply temperature makes conversion and adaption of buildings to be able to receive district cooling relatively easy.

The district cooling return temperature determines i.a. the dimensions on the DC distribution pipes and on the customer internal air conditioning system for a given capacity. A high return temperature creates a large difference to the forward temperature ("delta T") resulting in relatively small DC distribution pipes and relatively large e.g. ETS heat exchanger and air handling units in customer air conditioning systems. A high DC return temperature also allows for a relatively high ratio of natural cooling from sea water to be used.

As a base line for this study and for the potential DC systems in Male' and Hulhumale' we have chosen a DC supply temperature of 6°C and a DC return temperature of 16°C at the customer point of supply.

The energy demand for each phase in Hulhumale' and for each zone in Male' is the sum of all individual customer demands in each area. Total energy demands and production mixes are summarized in the table below.

ENERGY BALANCES		Hulhumale' 100 MW SWAC	Hulhumale' 100 MW Hybrid	Male' Zone 1 Shall. hybrid	Male' Zone 2 Shall. hybrid	Male' Zone 3 Shall. hybrid
DC demand	MWh	600,000	600,000	54,000	12,000	15,000
DC production	MWh	624,000	624,000	56,160	12,480	15,600
Sea water direct cooling	%	76%	9%	0%	0%	0%
Chiller	%	24%	91%	100%	100%	100%
Sea water	MWh	474,000	54,000	0	0	0
Chiller	MWh	150,000	570,000	56,160	12,480	15,600
SSEER*		10.3	5.1	3.7	3.7	3.7

\* SSEER = System Seasonal Energy Efficiency ratio and is a measure of how many parts of cooling that is produced by consumption of one part electricity.

In all cases sea water provides cooling to the chiller condensers, but only for the Hulhumale' cases where sea water is extracted from great depth does sea water also provide direct cooling to the return flow from the distribution loop prior to further temperature adjustment by the chillers.

In the 100 MW Hulhumale' phases the large number of buildings with diverse functions provide for peak demands being spread out in time and allowing for a simultaneity factor of 0.8. In the much smaller areas in Male' no simultaneity has been included in the calculations.

## 8 Business Development Schedule

The feasibility study is the first step in an array of activities leading to an implemented district cooling system and business, i.e. a new utility. These activities can be grouped together in a number of development phases in the overall development phase. Main subsequent phases in this process are:

- Business development phase
- Pre-construction phase
- Construction phase
- Operating phase



## 8.1 Business development

The business development phase includes activities such as:

- Structuring ownership and stakeholders
- Project Management
- Basic engineering
- Permitting
- Financing
- Developing customer concept and contracts
- Marketing and sales
- Risk management

For the Hulhumale' phases and for a project the size of Male' zone 1 it is estimated that the lead time for the business development phase is at least one year.

## 8.2 Pre-construction

The pre-construction phase generally includes activities aiming at securing contracts at all ends of the project including revenue stream (i.e. customer contracts), financing, operation and construction. Typical activities are:

- Project Management
- Basic engineering
- Procurement/contracting
- Permitting
- Securing land rights
- Financing
- Marketing and sales
- Risk management

For the Hulhumale' phases and for Male' zone 1 it is estimated that the lead time for the business pre-construction phase is approximately one year. For the much smaller areas zone 2 and 3 in Male' the business development phase and the pre-construction phase can probably be managed as one in approximately one year.

## 8.3 Construction

The construction phase includes several key activities apart from construction itself.

- Project Management
- Construction
- Construction management
- Acquisition of key administrative and operational staff
- Marketing and sales
- Technical support for customer installations

- Risk management

For the Hulhumale' phases the construction phase is expected to be 18-24 months. For the different zones in Male' one year for the construction phase is deemed to be sufficient.

## 8.4 Operation

The operational phase is not time limited like the previous phases and also less capital and labor intense. Focus is to maintain high reliability and quality of the DC service and to secure customer satisfaction and revenue stream. Continuous activities are:

- General business administration
- Technical operation and maintenance
- Marketing and sales
- Customer support
- Risk management

## 9 Permitting

For any large infrastructure a wide range of permits are typically required and district cooling is no exception. Specifically, when natural sources are utilized to produce energy efficient and sustainable cooling, environmental permits requiring environmental impact assessments (EIA) become central in the development and pre-engineering phases.

Assessments typically required when utilizing deep sea water for district cooling are:

- In situ flora and fauna inventory
- Desk top studies on water quality, other outfalls, occurrence of red listed species etc,
- Simulation of how return water is dispersed in the water body
- Social, recreational and cultural aspects
- Potential negative impacts

## 10 Capital Expenditures (CAPEX)

District Cooling is a capital intense business since large investments are required to achieve economy of scale advantages including the ability to utilize natural or other beneficial energy sources. The broad assumption in estimating capital expenditure in this feasibility study has been that the different parts of the DC system is contracted as EPC packages or similar where the contractor is responsible for both engineering and construction. The two major parts of the system are production and distribution, each of which can be broken down in to subsystems as required.

For the intents of this feasibility study CAPEX has been divided into the following four segments:

- Production System
- Distribution System
- Energy Transfer Stations (ETS)
- Project Development



## 10.1 Production System

The production systems intended for Hulhumale' and Male' can be divided into two main parts for purposes of comparison and eventually also for contracting. Those parts are district cooling plant ("DCP") and sea water system ("SWS"), which in turn consist of several main components and installations.

Main components of a DCP are building, chillers and pumps along with electrical and mechanical auxiliary installations. Main components of a SWS are sea water intake and outfall structure, shore crossing, pumps, heat exchangers and pumping pit. Capex breakdown have been worked out based on benchmark figures from similar projects.

Major design assumptions are that:

- Chillers are included to the extent required to cover the temperature gap between what can be achieved by direct sea water cooling and what is required to deliver DC of 6°C to customers. In case of the Hulhumale' SWAC alternative this means 20 MW chiller capacity and in the Hybrid case 75 MW.
- DCPs are located in close vicinity to the sea front.
- Shore crossing is achieved by means of micro tunneling and extends to a depth of approximately 10 m.
- Sea water intake is located at 1,000 m depth (7°C) with a required off shore pipe length of 2,500 m for the SWAC system and at 200 m depth (14°C) with a pipe length of 600 m for the Hybrid system in the case of potential Hulhumale' 100 MW phases.
- For the Male' systems, Capex is based on sea water intakes and outlets just outside the sea wall and at shallow depth (28°C).

Capex breakdown on main part for the different system alternatives are displayed in the table below. For breakdowns in further detail please see Appendix 2.

CAPEX		Hulhumale'	Hulhumale'	Male'	Male'	Male'
Production		100 MW	100 MW	Zone 1	Zone 2	Zone 3
		SWAC	Hybrid	Shall. hybrid	Shall. hybrid	Shall. hybrid
District Cooling Plant (DCP)	kUSD	34,410	41,987	5,426	1,206	1,507
Sea Water System (SWS)	kUSD	42,438	28,825	1,805	456	591
Total Production system	kUSD	76,848	70,812	7,230	1,662	2,098

## 10.2 Distribution System

At this feasibility stage the distribution CAPEX is based on the preliminary network length Bill Of Quantity (BOQ). Based on the preliminary network length and type the number and cost of fittings and valves has been estimated. The CAPEX is based on benchmark costs for mechanical works including installation and welding of pipes and fittings.

Major design assumptions are that:

- No synergies with construction of other underground infrastructure have been included.

- DC supply temperature of 6°C and return temperature of 16°C have been assumed.
- EN253 pre-insulated pipes with insulation standard series 1 with maximum pressure 16 bar.
- For distribution systems in Male' 50% higher specific costs than for Hulhumale' have been assumed due to the complicated construction environment and anticipated conflicts with existing infrastructure.

Capex for the different system alternatives are displayed in the table below. For breakdowns of costs please see Appendix 2.

CAPEX		Hulhumale'	Hulhumale'	Male'	Male'	Male'
Distribution		100 MW	100 MW	Zone 1	Zone 2	Zone 3
		SWAC	Hybrid	Shall. hybrid	Shall. hybrid	Shall. hybrid
<b>Total Distribution system</b>	kUSD	19,128	19,128	1,965	332	422

### 10.3 Energy Transfer Stations (ETS)

Prefabricated ETS installed is calculated at USD 65,000 per average building of 750 kW in Hulhumale' based on benchmark ETS figures from similar projects. The resulting total Capex per phase is 8.8 MUSD.

In the profitability calculations it has been assumed that the point of delivery for DC is upstream of the ETS, meaning that each customer own and finance their own ETS.

Capex for the different system alternatives are displayed in the table below.

CAPEX		Hulhumale'	Hulhumale'	Male'	Male'	Male'
ETS		100 MW	100 MW	Zone 1	Zone 2	Zone 3
		SWAC	Hybrid	Shall. hybrid	Shall. hybrid	Shall. hybrid
<b>Avg. building load</b>	kW	750	750	560	1,000	1,250
<b>Nmbr. of buildings</b>	Psc.	135	135	16	2	2
<b>Cost per ETS</b>	USD	65,000	65,000	55,000	85,000	100,000
<b>Total Energy Transfer Stations</b>	kUSD	8,775	8,775	880	170	200

### 10.4 Project Development

Project development costs include items such as project management and expenses, basic engineering, procurement, construction management, permitting, financing and business development. All tied to the initial stages of the project through the construction phase. Sometimes, but not always, such costs are considered capital expenditure.

Total project development costs for the different system alternatives are displayed in the table below.

PROJ. DEV.		Hulhumale'	Hulhumale'	Male'	Male'	Male'
		100 MW	100 MW	Zone 1	Zone 2	Zone 3
		SWAC	Hybrid	Shall. hybrid	Shall. hybrid	Shall. hybrid
Project Development	kUSD	12,480	12,480	1,002	264	264

## 10.5 Total CAPEX

Total capital expenditures for the different system alternatives are presented below.

CAPEX		Hulhumale'	Hulhumale'	Male'	Male'	Male'
TOTAL		100 MW	100 MW	Zone 1	Zone 2	Zone 3
		SWAC	Hybrid	Shall. hybrid	Shall. hybrid	Shall. hybrid
Production system	kUSD	76,848	70,812	7,230	1,662	2,098
Distribution system	kUSD	19,128	19,128	1,965	332	422
Sub total DC system	kUSD	95,976	89,940	9,195	1,994	2,520
Project Development	kUSD	12,480	12,480	1,002	264	264
Sub total DC system & development	kUSD	108,447	102,420	10,197	2,258	2,784
ETS	kUSD	8,775	8,775	880	170	200
Total DC related costs	kUSD	117,222	111,195	11,077	2,428	2,984

## 11 Operational Expenditures (OPEX)

Operational expenditures have been divided into the following main categories:

- Administrative costs including sales costs
- Electricity costs
- Operation and Maintenance ("O&M") costs

Administrative costs have estimated using benchmark numbers from projects similar to the Hulhumale' phases. For the Male' systems these numbers have been adjusted to reflect project size and complexity.

Electricity costs are based on the Stelco tariff rate for large non-domestic customers of 4.35 MVR/kWh which equals 0.283 USD/kWh (1 USD = 15.5 MVR).

Fixed annual O&M costs include organizational structure for operating and maintenance of the system including personnel for administrative/IT and support and are calculated as a function of CAPEX for the main system parts, i.e. 0.5% for sea water system, 2% for district cooling plant and 1% for distribution system. Flexible O&M costs include all related expenses in order to keep installations operational for the whole duration period such as: spare parts and renovation, planned and emergency service, consumption goods, i.e. as lubricants and refrigerants and are calculated in relation to produced cooling energy as 0.5 USD/MWh.

Annual opex for fully built out systems are presented in the table below.

OPEX		Hulhumale' 100 MW SWAC	Hulhumale' 100 MW Hybrid	Male' Zone 1 Shall. hybrid	Male' Zone 2 Shall. hybrid	Male' Zone 3 Shall. hybrid
<b>Administrative</b>	kUSD/year	1,750	1,750	175	60	60
<b>Electricity</b>	kUSD/year	16,408	33,388	4,110	913	1,142
<b>O&amp;M</b>	kUSD/year	1,392	1,475	164	36	45
<b>Total opex</b>	kUSD/year	19,549	36,613	4,449	1,009	1,246

## 12 Revenue

Revenues have been calculated based on the price model including a connection fee, a capacity fee and an energy fee for all customers. The fees are not directly based on the cost to build and operate the district cooling system, but rather set at a level providing for reasonable profitability in the district cooling business and at a level where district cooling is competitive in relation to building individual centralized air conditioning systems. The below rates are to be viewed as average rates and not as a blanket rate to apply for all customers. A central part in a development phase subsequent to this feasibility study will be to work out specific rates for different customer segments such as commercial, educational and residential.

The fees are as follows:

- connection fee of USD 500 per kW (as a one-time fee);
- capacity fee of USD 50 per kW and year;
- consumption fee of USD 50 per MWh.

For the Hulhumale' 100 MW phases it is assumed that 20 MW of customer capacity is connected annually over the first five years of operation. For the different zones in Male' it is assumed that all customers are connected at start of operation.

The table below includes total connection fees and annual amounts of capacity fees and energy fees for fully built out systems.

REVENUE		Hulhumale' 100 MW SWAC	Hulhumale' 100 MW Hybrid	Male' Zone 1 Shall. hybrid	Male' Zone 2 Shall. hybrid	Male' Zone 3 Shall. hybrid
<b>Connection fees (total)</b>	kUSD	50,000	50,000	4,500	1,000	1,250
<b>Capacity fees</b>	kUSD/year	5,000	5,000	450	100	125
<b>Energy fees</b>	kUSD/year	30,000	30,000	2,700	600	750

## 13 Financial feasibility

Financial feasibility has been calculated using the proprietary Devcco Profitability Model. This model can be further used for developing and analyzing procurement strategies and district cooling pricing models.

Profitability has been calculated based on the following key assumptions:

- Cash flows over 25 years, starting at commencement of the project development phase, are included in the calculation.
- A weighted average capital cost (“WACC”) of 7% has been used for baseline calculations.
- Calculation are based on prices and costs in real terms, i.e. fixed value of money.
- Revenues increase gradually as customers are assumed to be connected over a period of five years in the Hulhumale’ phases. For the Male’ zones it is assumed that all customers receive service at commencement of operations.
- No rest values or residual values are included

Basic output for the purpose of evaluating financial feasibility for the purpose of this study are the Net Present Value (“NPV”) of all included cash flows and the Internal Rate of Return (“IRR”) for each calculated system or phase.

It should be noted that avoided investments in power production and power distribution infrastructure are not integrated in the profitability calculations, even though they are a direct consequence of introduction district cooling. Based on avoidance of 25 MW power production capacity per 100 MW cooling phase and avoided specific investment of USD 1,200 per kW power production, the avoided capital expenditure in power production amounts to USD 30 million per phase or USD 90 million in a case where all three phases in Hulhumale’ are realized.

Results for baseline scenarios are presented in the following section.

### 13.1 Baseline scenarios

Baseline results for each calculated system or phase is presented in the table below.

PROFITABILITY		Hulhumale’ 100 MW SWAC	Hulhumale’ 100 MW Hybrid	Male’ Zone 1 Shall. hybrid	Male’ Zone 2 Shall. hybrid	Male’ Zone 3 Shall. hybrid
NPV	kUSD	45,870	-67,737	-16,741	-4,232	-5,102
IRR	%	12.5%	N/A	N/A	N/A	N/A

The results indicate that only the SWAC alternative for a 100 MW system in Hulhumale’ is financially feasible. An IRR of 12.5% and a NPV of MUSD 45,9 at this stage is deemed to be sufficient to make it interesting to various stakeholders.

The major reason for the poor outcome in the Hulhumale’ Hybrid case is low energy efficiency leading to high electricity costs compared to the SWAC alternative. For the Male’ systems the main reason is the small scale leading to high specific capex.

It should be noted that avoided costs for power generation and potential values generated from spin-offs made possible by the introduction of District Cooling have not been included in the profitability calculations.

For more detail please see Appendix 3.

General and project specific sensitivity analyses are provided in the following section.

## 13.2 Sensitivity analysis

In this segment basic scenarios will be briefly described and compared to the baseline case described above.

- CAPEX +10%: Deviations in CAPEX could be the result e.g. of design changes, state of construction and/or equipment markets and changed quality requirements.
- Electricity +10%: Change in electricity cost can be a result either in a lower system efficiency than anticipated or a result of increased electricity tariffs. On long term, increased electricity prices will result in a possibility to increase also district cooling fees thereby compensating for the cost increase.
- DC price -10 %: Even though the price to customers as calculated is competitive, the actual price is set in the local market and it is a key driver of profitability. Hence a scenario where the average district cooling price level is 10% lower than calculated in the base case.
- WACC 6%: the weighted average cost of capital is 7% in the base case but the actual level will depend on how the project can be financed. A WACC of 6% would also be a realistic scenario.

Results of sensitivities are presented below for all alternatives.

SENSITIVITY		Hulhumale' 100 MW SWAC	Hulhumale' 100 MW Hybrid	Male' Zone 1 Shall. hybrid	Male' Zone 2 Shall. hybrid	Male' Zone 3 Shall. hybrid
<b>Baseline</b>						
NPV	kUSD	45,870	-67,737	-16,741	-4,232	-5,102
IRR	%	12.5%	N/A	N/A	N/A	N/A
<b>CAPEX +10%</b>						
NPV	kUSD	38,308	-74,822	-17,491	-4,407	-5,323
IRR	%	11.3%	N/A	N/A	N/A	N/A
<b>Electricity +10%</b>						
NPV	kUSD	34,498	-90,877	-20,451	-5,132	-6,226
IRR	%	11.3%	N/A	N/A	N/A	N/A
<b>DC price to customer -10%</b>						
NPV	kUSD	18,484	-95,122	-19,928	-5,003	-6,066
IRR	%	9.4	N/A	N/A	N/A	N/A
<b>WACC 6%</b>						
NPV	kUSD	59,938	-70,158	-18,246	-5,353	-5,528
IRR	%	12.5%	N/A	N/A	N/A	N/A

Increasing the system temperatures to 7°C/17°C would result in a NPV of MUSD 62.7 and IRR of 14.1% In the Hulhumale' SWAC case.

For Zone 1 in Male' to return a zero NPV, DC prices to customers need to be increased by 53%. The corresponding increases for Zone 2 and 3 would be 55% and 53% respectively.

## 14 Environmental results

The major environmental benefits with district cooling are the high energy efficiency and the reduced use of refrigerants. In addition to those, there are several other environmental benefits such as significantly reduced noise and heat exhausts in the urban area close to homes and work places, improved building esthetics and reduced or eliminated risk of the legionnaires' disease by avoidance of building individual cooling towers.

High energy efficiency will result in reduced consumption of electricity and thereby in avoided emissions of carbon dioxide from power generation.

Reduced use of refrigerants will result in less leakage of very strong greenhouse gases and in the case of HCFC:s also in less leakage of ozone depleting gases to the atmosphere.

Electricity production in the Maldives is based on diesel generators which is the baseline for calculation of carbon dioxide savings in this study. For the calculations a specific carbon dioxide emission factor of 1,000 kg CO<sub>2</sub>/MWh generated electricity has been used.

Avoided electricity production and avoided carbon dioxide emissions are presented in the table below.

ENVIRONMENT		Hulhumale' 100 MW SWAC	Hulhumale' 100 MW Hybrid	Male' Zone 1 Shall. hybrid	Male' Zone 2 Shall. hybrid	Male' Zone 3 Shall. hybrid
Avoided electricity production	MWh/year	142,000	82,000	3,500	800	1,000
Avoided carbon dioxide emissions	Tons/year	142,000	82,000	3,500	800	1,000

In addition to the carbon dioxide savings due to reduced demand for electricity as described above, emissions of greenhouse gases will be reduced also as a result of avoided use of refrigerants. It has been estimated that 96 tons of installed HFC can be avoided when split/multi split systems are replaced by 100 MW SWAC as in a phase in Hulhumale'. Further, assuming annual leakage of 3% results in avoided leakage of 4,100 tons CO<sub>2</sub> equivalents of HFC per year (GWP 1,430 for R134a) for such 100 MW phase.

## 15 Business Plans

A successful business plan for district cooling in Hulhumale' will have to be closely linked to the development plans for the island. At this stage in this district cooling feasibility study we'll have so settle with a rough business plan built on the basic information at hand. The fundamental information shaping the business plan is:

- The island development will take place over many years,
- The cooling demand of the developments will be very large.

The major consequence of the above fundamentals is that the district cooling system will have to be developed in phases in order to limit up from capital expenditure and to create a dynamic system with high reliability and with moderate distribution pipe dimensions.

For Male' individual systems will have to provide district cooling to the separate zones since the distances between them are too long for the zones to be viably interconnected.

## 15.1 Hulhumale' Phases

For Hulhumale' development of a district cooling system in three phases with an approximate capacity of 100 MW cooling capacity each is deemed to provide for manageable up front capital expenditure and distribution pipe dimensions, and also to allow for a highly flexible and reliable supply.

Reasons for a phased system development and business plan are as described above that the system is expected to grow over a long time and that the cooling demand, as well as the development areas, are very large.

District cooling is a technology that is generally very flexible and that allows many alternatives for sourcing and production, but there are also some limitations. One of them is the cooling capacity that can be distributed through a pair of pipes from a single feeding point. Typically, 100 MW cooling capacity would require pipe dimension in the range of 1,000 – 1,200 mm, above which constructability and underground space alongside other infrastructure becomes a real issue. For this, and other, reasons systems of equivalent sizes normally are divided into separate interconnected phases with their own cooling production stations.

Such phased approach also provides for a desired reliability since, with several feed in points to the distribution system, the pipe dimensions are not only more manageable, but there will also be opportunities to undertake planned and unplanned maintenance with uninterrupted service to customers.

Production redundancy is one of the keys to an efficient and reliable district cooling system. With a phased approach and with separate production stations fed with electricity from separate transformer stations and by separate sea water pipes an adequate level of redundancy will be secured.

Major uncertainties in real estate developments are the speed at which the development takes place but also the size and nature of the buildings actually being developed. In order to manage these uncertainties and to allow for as much flexibility as possible, district energy systems are often developed in a phased approach. Besides the previously mentioned advantages, such approach also minimizes the initial capital expenditures and makes it possible for the district cooling investor(s) to generate positive cash flow that can be utilized in subsequent phases.

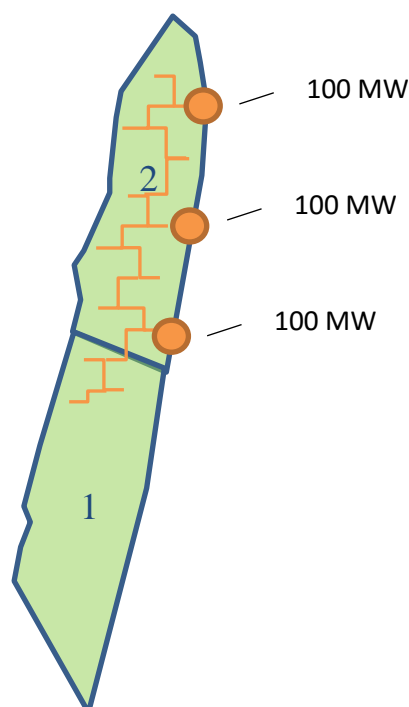
Each phase of 100 MW can also to some extent be developed gradually which is desirable since all customers are not likely to be connected at once. One of the possibilities to gradually expand the production capacity is to start service by installing and production district cooling with chillers only. This way, in the case with a SWAC system, up to 20 MW of DC can be produced by the chillers prior to installing the sea water piping and pumping system with the advantage that major capital expenditures can be postponed while the first customers still can receive district cooling.

## 15.2 Location of phases

Since the best sea water source is off the eastern coast of Hulhumale', the locations for the three cooling production stations would ideally be evenly distributed along that coast line, starting close to the border between phases 1 and 2 and then north ward along the phase 2 development.

For hydraulic pumping reasons it is preferred to locate the cooling production stations as close to the shoreline as possible.





*Indicative locations for the three phases with their separate production stations and interconnected distribution grids.*

### 15.3 Male' Production Locations

Potential locations for production facilities for zone 1 on the north shore would be adjacent to the MWSC pumping station west of the airport ferry jetty or at the fish market pier at the westernmost end of the zone.

For zone 2 which has a very limited demand the production facilities would have to be located very close to the IGMH and Dhiraagu buildings and the shore line in order to minimize construction costs.

Likewise, for zone 3 the production location would need to be at, or very close to, the university and the water front.

For zone 3 the sea water intake and outlet would be located just outside the outer sea wall.

## 16 Business models

There are several dimensions or approaches to developing a business model for large scale district cooling. Major questions to address are who is the present and future owner of the district cooling system and business, what financing is available, what contracting alternatives are available and what kind of resources and skills are required for the different alternatives?

In this section we will briefly address mainly the aspects of ownership and financing structures that could be adopted mainly for the Hulhumale' developments, but to some extent they apply to the smaller potential systems in Male' as well.

## 16.1 Ownership

The business model for a district energy system is very project-specific. It needs to ensure that all of the stakeholders involved – including investors, developers, owners, operators, utilities/suppliers, end-consumers and municipalities – can achieve financial returns, in addition to any other benefits that they seek.

The majority of business models for district energy involve the public sector to some degree, whether as a local policymaker, planner, regulator or consumer, or more directly through partial or full ownership of projects. Public sector involvement can be critical in coordinating multiple, diverse projects around a broader citywide vision. Even projects with a high degree of private sector control are often still facilitated or supported in some way by the public sector.

Local markets offer various options and models for the structuring of a district cooling project but generally the business models can be divided into two main groups:

- Non-concession structures
- Concession structures.

Both models have their pros and cons and the choice of model is often linked to main stakeholders' financial, technical and operational abilities.

### 16.1.1 Non-concession structures

These models are based on a structure where the project owner/main project developer maintains the ownership and title to the district cooling project through all its development and operation phases. Design and construction of the system is typically contracted out under an EPC contract while the operation of the system is undertaken by a district cooling provider/operator.

The structure is simple to execute and has relatively short lead times. Non-concession arrangements are common e.g. in Canada and in the UK.

### 16.1.2 Concession structures

Concession structures refer to structures where the project owner/main project developer issues a right towards a third party to supply district cooling to buildings within a development area on certain conditions. This agreement is normally referred to as concession agreement and in such cases the concession taker owns the district cooling system.

Benefits are that concession models bring considerable risk protection; cash savings and avoidance of liabilities to the project owner/main project developer. Critical to the business model are the conditions regarding off-take guarantee and consequential pricing. It also allows the utility business (i.e. district cooling business) to be separated from the real estate development. In some cases, concession structures are used to acquire sufficient financial, technical and operational capabilities from external parties.

Concession models are common e.g. in the GCC region.

## 16.2 Financing options

Financing options will have to be further assessed in the continued feasibility study as the total financing requirements and the intents of all stakeholders become clearer. In this section basic options are described separately for the debt and equity sides.

### 16.2.1 Debt financing structures

The typical debt financing structures for district cooling are basically:

- Corporate based structures
- Project finance based structures.

Corporate based structures are common in mature markets that are not necessarily market driven i.e. large government owned utility companies in Europe. A debt facility arranged with a syndicate/club of local banks. Alternatively, a bilateral facility may be entered into. To support the credit profile, a guarantee provided by the corporate owner and security over the assets to the lenders might be required. If it is also chosen to create a wholly-owned SPV to hold the assets, then the shares in the SPV will need to be pledged to the lenders.

Due to the size of the potential Hulhumale' district cooling project it is very likely it can qualify to be funded by way of a project finance ("PF") facility. Such structure is based on a project asset entity "SPV" with a shareholding from e.g. the main developer, either as a fully owned entity or with any rate of external shareholding. Vital to project financing is that a solid long term revenue stream to the project is secured up front.

## 16.2.2 Equity financing structures

How the equity side of the financing is organized to a large extent becomes a consequence of the overall business model that is chosen along with the debt arranging facility. In general, the equity structure follows with the debt structures and can be summarized into three main categories.

- Full developer ownership
- Joint Venture
- External ownership

Possible combinations of ownership and financing options will be assessed in the next steps of the feasibility study assignment.

## 17 Potential side businesses

By making deep sea water available in an on-shore facility there are several opportunities to use the water for other purposes than cooling. Such uses have proven to be very successful providing economic return and local job opportunities in Hawaii, where deep sea water is used for a variety of purposes. A general list of potential uses below:

- Desalination to provide drinking water
- Production of bottled mineral drinking water
- Aquafarming including shellfish and edible sea vegetables, making use of the high content of nutrients etc.
- Production of microalgae for nutritional and cosmeceutical purposes
- Agriculture by use of cold sea water making it possible to grow crops that would normally only grow in more temperate and/or humid climates.
- Research and development in different fields

## **18 Risk assessment**

Risk assessment is a central part of a successful district cooling development process, and will need to be continued through all development phases. The risks listed below are considered top rank risks to be considered in any continued risk management process.

### **18.1 Technology implementation & customer confidence**

District Cooling in particular and also SWAC are proven and reliable technologies providing several benefits to customers and others, but since the technologies are new on this scale in the Maldives, proving the function and reliability locally is likely key to achieving a high level of customer confidence in the service, thereby facilitating customer contracting which is essential to make a project bankable. The risk of lacking confidence in the product/service can partly be mitigated by designing the system for conventional DC temperatures and also by demonstrating the technology by implementation of a smaller scale pilot project.

### **18.2 Stakeholder structuring and development financing**

Development of district cooling on large scale require committed first tier stakeholders with an ability to finance, or to attract financing for, the development and pre-construction phases and also to structure the development in a way that attracts capable parties for owning, developing and operating the DC business and system. Lack of such financing and structure pose a potential risk in any large scale DC development.

### **18.3 Access to land**

Access to sites for production facilities and underground space for distribution pipes is essential in developing a successful district cooling project. In the case of Hulhumale' there are no specific sites or space reserved for district cooling at this point, but some areas will likely become available as a result of avoided power production capacity. In Male' available land is obviously scarce and here it will likely be critical to find opportunities to co-locate with other utilities.

### **18.4 Electricity supply**

The district cooling production facilities will require significant power supply which will have an impact on both existing and planned power distribution systems. However, this requirement is more of an opportunity than a barrier since the introduction of district cooling will result in very large reductions in electricity demand over all. This is due to the higher energy efficiency of district cooling as compared to individual cooling and air conditioning systems.

### **18.5 Existing air conditioning systems and standards**

A major barrier for phasing out HFC and HCFC and also a major barrier for introducing District Cooling is the wide use of "split systems" or VRV/VRF ("multi split" systems) for major buildings in Male' and possibly also in Hulhumale'. This barrier could be overcome by introducing building codes or similar stipulating centralized and ducted cooling systems for new developments.

### **18.6 Planning and coordination**

Planning and co-ordination with other planned infrastructure development in Hulhumale' is essential (roads, water pipes, sewage pipes, electrical cables etc.). The opportunity to include

district cooling pipes together with other planned infrastructure leads to synergies and cost reduction possibilities.

## **18.7 Geo-technical conditions**

Geo-technical conditions can have major impacts on construction costs when it comes to especially ground water table for construction of the distribution system, conditions for trenchless construction of shore crossing for sea water pipes. Risk assessment typically start with conducting a geo-technical survey as a basis for engineering and construction of the distribution system.

## **18.8 Sea floor and sea water conditions**

Sea water currents, temperatures and nutrient levels will have an impact on both construction and operating costs why further assessment will be required. Sea bed conditions will impact location and cost of the off shore portion of the sea water system. Risk assessment typically start with a seabed survey and monitoring of sea water conditions at the intended locations as a basis for engineering and construction of the sea water system.

## **18.9 Environmental impacts**

The potential environmental risks using deep sea water for cooling are typically related to the release of nutrient rich and warmed up sea water closer to the surface. The potential negative impacts of such release would be algae bloom due to the high nutrient levels and disturbing temperature sensitive sea life close to the outlet point. Such negative impacts can be avoided by designing the outlet either with a diffuser or in a location where sea current and surrounding temperature minimize thermal impacts, and in a location deep enough to avoid photosynthesis and growth of algae.

## **18.10 Operational risks**

Even though district cooling systems have proven to be very reliable, the risk of interrupted cooling supply should be prioritized in the design and operation of the system. For each phase redundancy can be achieved in the production facility by having back-up for the critical equipment such as sea water pumps, distribution pumps, heat exchangers and chillers. With additional phases and production facilities in place not only production redundancy but also the ability to create redundant distribution routes will increase. Customers with exceptional reliability requirements, e.g. hospitals and data centers will typically install district cooling as their primary system with a local system as back up.

# **19 Conclusions**

Very substantial reductions of emitted greenhouse gases can be achieved by introducing district cooling in the development areas of Hulhumale'. Avoided emissions of carbon dioxide alone amount to up to 142,000 tons per year. By avoidance of large numbers of building individual air conditioning systems leakage of refrigerants being powerful greenhouse gases will also be diminished.

Due to the warm climate and steady demand for cooling throughout the year, high system energy efficiency becomes a key driver of profitability. With relatively comparable investment costs the more efficient SWAC system turns out as financially feasible, while the less efficient

Hybrid system returns a substantial negative net present value for in the case of DC in Hulhumale’.

The significantly smaller systems considered for limited areas in Male’ deliver reductions in emitted carbon dioxide but they are far from being profitable.

The dominating current ductless air conditioning technology for large buildings in the Maldives is a threat to introduction of district cooling since, once installed, retrofitting to district cooling is very costly.

Introduction of district cooling in Hulhumale’ would bring several benefits in addition to avoided emissions of greenhouse gases, including reduced investment needs in power production and distribution, architectural freedom for new developments, less noise where people live and work, and not least reduced import of fuel for power generation.

Maldivian stakeholders that could participate in a potential development of district cooling include the Housing Development Corporation Ltd. (“HDC”), the Male’ Water and Sewerage Company (“MWSC”) and the State Electric Company (“STELCO”). To our understanding the HDC has a key position in the development of Hulhumale’ and would be a central stakeholder in structuring a district cooling business there. The MWSC or STELCO could, based on their expertise in operating existing utilities, play a role primarily in the technical operation of a district cooling system.

Due to the size and complexity of the potential Hulhumale’ DC phases some kind of concession model in order to attract the necessary funding and competence in district cooling appear to be the first hand option.

Since DC is new to the Maldives a pilot facility would help to demonstrate function and technical feasibility to potential stakeholders and users in advance of introducing DC in a large commercial scale.

## 20 Recommendations

The main recommendations going forward are as follows:

- Continue the stakeholder analysis with emphasis on appointing a Governmental or other body that can act as the primary stakeholder for the continued DC development.
- Prioritize a pilot DC system in Hulhumale’ to demonstrate the technology. The large advantage for Hulhumale’ is that building systems there can be adapted to receive the DC service from start without the substantial costs tied to retrofitting of existing buildings. If built in Hulhumale’, installations for the pilot system can potentially be integrated in a commercial system later on.
- Assess the possibilities to obtain international development funding and/or green funding along with relevant competence and resources for continued DC development including a pilot DC system.
- It is also recommended that the Government of Maldives initiate a process to define building standards for new developments in order to promote ducted central air conditioning systems. Such standards will facilitate the introduction of DC.
- Assess the possibilities to co-ordinate all relevant previous and current sea water cooling plans in order to reduce cost and improve likelihood of success.