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Report prepared by:
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1. PREFACE

This report has been elaborated in the RESCUE (Renewable Smart Cooling in Urban Europe) project. This IEE (Intelligent Energy Europe) co-funded project is scheduled from June 2012 to November 2014.

The sole responsibility for the content of this report lies with the authors. It does not necessarily reflect the opinion of the European Community. The European Commission is not responsible for any use that may be made of the information contained therein.

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If you would like to know more about RESCUE project please visit our website www.rescue-project.eu.

2. PROJECT DESCRIPTION

Cooling energy demand within Europe, especially in urban regions, is rising significantly, mainly caused by building design, internal heat loads, heat island effects, and comfort reasons. If served conventionally using small scale and distributed electric driven compressor chillers this would result in a significant rise in primary energy consumption, greenhouse gas emissions and peak electricity demand.

The RESCUE project focuses on the key challenges for further development and implementation of District Cooling (DC) using low and zero carbon emitting sources, thereby enabling local communities to reap the environmental and economic benefits of this mature technology. Although DC allows the application of high efficient industrial chillers or absorption chillers driven by waste heat it is estimated that DC market share today is about
1-2% in the service sector (which is about 3 TWh) but less than 1% of the total present existing European cooling market including residential. The main steps to extend the use of smart, energy efficient and renewable DC Systems are:

1. Dissemination of essential background information.
2. Decision making based on (pre-) feasibility studies exploring cooling options.
3. Implementation, monitoring and optimization.

The RESCUE project focuses on steps 1 and 2 within the project duration addressing main actors and target groups, i.e. Local Authorities (LA), utility companies, building owners, and the financing sector. The main objectives of the project are therefore:

- Promote DC as a high potential, sustainable energy solution.
- Increase familiarity and reliability of information available to decision makers and LA about the DC business.
- Improve networking activities and experience exchange.

A key action of the project is to provide a number of target cities with a decision-making support package assisting LA to account for DC in their planning policies and to guide them when looking for cooling options fitting best to their Sustainable Energy Action Plan (SEAP). Key outputs and main deliverables of the project, available to the public, are:

- An impact calculator which shows the key figures in comparison between Central and Distributed solutions.
- A set of guidelines and handbooks related to the DC business and the decision making process.
- Reports describing the cooling energy market, the energy performance evaluation as well as DC best practice and show cases.

The RESCUE project consists of seven Work Packages (WP), whereas WPs 1, 6 and 7 are dedicated for project management and communication, WP2 is dedicated to conducting a market survey for cooling in Europe and to establish how DC can contribute to the 20-20-20 targets. WP3 is to showcase examples of DC systems in Europe in order to demonstrate their performance and to provide details on the use of renewable energy sources (RES), improvements in energy efficiency and CO2-savings. Within WP4 a “Decision Making Support Package” is developed, applied and enhanced to guide and assist LA in their decision processes regarding cooling issues in local energy concepts. The purpose of WP 5 is to provide practical information related to start-up of DC systems and the DC business in general.
<table>
<thead>
<tr>
<th>WP1 Management</th>
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<tr>
<td>WP2 EU cooling market</td>
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<tr>
<td>WP3 District Cooling Show cases</td>
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<tr>
<td>WP4 Decision making tool</td>
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<td>WP5 Guideline – How to do It</td>
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<tr>
<td>WP6 Communication</td>
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<tr>
<td>WP7 EACI Dissemination</td>
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### 3. Definitions and Abbreviations

<table>
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<tr>
<th>Abbreviation</th>
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</thead>
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<tr>
<td>a</td>
<td>Annum (year)</td>
</tr>
<tr>
<td>ABS</td>
<td>Absorption (chiller)</td>
</tr>
<tr>
<td>CAPEX</td>
<td>Capital Expenses</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined Heat &amp; Power</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>COP</td>
<td>Coefficient Of Performance</td>
</tr>
<tr>
<td>DC</td>
<td>District Cooling</td>
</tr>
<tr>
<td>DE</td>
<td>District Energy</td>
</tr>
<tr>
<td>DH</td>
<td>District Heating</td>
</tr>
<tr>
<td>DHC</td>
<td>District Heating &amp; Cooling</td>
</tr>
<tr>
<td>EER</td>
<td>Energy Efficiency Ratio</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>HFC</td>
<td>HydroFluoroCarbon</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Operation and maintenance</td>
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<tr>
<td>OPEX</td>
<td>Operating Expenses</td>
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<tr>
<td>PE</td>
<td>Primary Energy</td>
</tr>
<tr>
<td>PEF</td>
<td>Primary Energy Factor</td>
</tr>
<tr>
<td>Rescue</td>
<td>REnewable Smart Cooling for Urban Europe</td>
</tr>
<tr>
<td>SSEER</td>
<td>System Seasonal Energy Efficiency Ratio</td>
</tr>
</tbody>
</table>
4. SUMMARY

This report discusses the complexity of calculating the different cost items and the factors influencing them for both the customers’ alternative and for District Cooling (DC).

MARKET PRICE

DC is a product which today is aimed mainly at the service sector. The price for DC is in most cases based on a market pricing. The market price for a product is what the product is sold at in the market, based on supply and demand. Basically it is equal to what the customer is prepared to pay for the product plus the potential added value to the customer’s business.

INDIVIDUAL BUILDING COOLING SOLUTION

The costs for the customer’s individual building cooling solution depend on many factors and it is not possible to easily define the costs with key figures per kW or MWh. Each customer is unique as well as national and regional differences so the cost for each customer is also unique. The price for cooling must be calculated individually for each customer’s specific needs and conditions.

The price range between different countries and different users of cooling is substantial depending on local differences. For example, a new 500 kW customer installation can differ between 45 and 140 EUR/MWh with a EU27 average at 81 EUR/MWh. A new investment installation cost a bit higher approximately 60-180 EUR/MWh (average 110 EUR/MWh), but the range is large. The energy cost is proportional to the energy demand but the capital cost in EUR/MWh depends very much on the energy demand.

DISTRICT COOLING

The varying conditions define the costs for the investment in DC and operating the system. For favourable conditions the DC system will consist of a mix of available production possibilities, natural cooling, electrical chillers or absorption chillers. It is therefore not very useful to describe the cost structure of a specific technology.

Each production plant will be unique in design based on the local conditions and the investments will vary significantly. The cost for DC also shows a large variation, due to local conditions.

The total costs for an assumed a DC market of 60 MW and 72 GWh can, depending on local condition, vary between 30 and 150 €/MWh with an EU27 average of 67 EUR/MWh.

PROFITABILITY AND RISK

It is important to evaluate the complete project, high production costs or expensive distribution might be compensated by a high market price.

A 60 MW DC project based on the costs in the report for the customers alternative as the market price and the cost for DC showed an IRR of 12 % and a NPV of 20 MEUR.
There are though risks that must be handled in order to secure the profitability. The organisation is usually the main risk in a DC project. An organisation with skilled and experienced personnel with enough resources and a well-developed risk management process supported by specialists are the keys to success.

5. DISTRICT COOLING AND THE CUSTOMER’S ALTERNATIVE COST

This report will describe DC from an economic perspective “What is District Cooling allowed to cost” and to evaluate the alternatives to DC.

5.1 MARKET PRICE

The market price for a product is what the product is sold at in the market, based on supply and demand and thus equal to what the customer is prepared to pay. The market price for a new and similar product on the market will be limited if there are less expensive alternatives to the product on the market that is able to satisfy the customer’s demand.

DC is a fairly new product on most markets in Europe and competes with available cooling technologies on the market. These available technologies are normally installed individually in each building to provide the cooling demand of a specific building (see section 0). The market price for DC is therefore equal to the cost for these available technologies.

\[
\text{Market price for district cooling} = \frac{\text{Customers local alternative cost} + \text{Added value}}{}
\]

The cost for the customer’s local alternative must be defined in order to determine what DC is allowed to cost to be competitive on the market.

There are several different alternatives for the customer to satisfy his cooling demand but there are two dominating technical solutions that will be described in chapter 0.

DC requires some form of large scale centralised cooling production and a distribution grid to reach the customers. DC is therefore associated with relatively high investment costs for the production and distribution which leads to high capital expenses (CAPEX) which must be compensated with lower operating costs. Different production technologies can be used to optimise the operating expenses (OPEX) with a centralised plant. The distribution grid constitutes approximately 50% of the total investments and DC will therefore only be economically viable in areas where the cooling demand density is high. Outside this area DC will be more expensive than the customers’ alternative. The cost for DC will be described in chapter 0.

There are additional values normally not considered by the property owner when evaluating the DC price.

- Reduced risk
- Increased availability.
• Increased price stability since electricity price normally influence the DC price less.
• Property owner can focus on core business
• Freed surfaces can be used for other purposes.

Another important benefit is that the price components (access fee, fixed fee, capacity fee and energy fee) can be negotiated and adjusted to the customers need. This depends on the DC provider’s price policy and setup. With an individual building installed chiller the investment is fixed and energy price is proportional to electricity price.

6. INDIVIDUAL BUILDING INSTALLED COOLING SOLUTIONS

6.1 TYPE OF CHILLERS

There are multiple potential cooling solutions for a real estate. Various geothermal solutions, which use natural cold from the ground or water, are very dependent of the local geographical situation of the real estate and are therefore only feasible for a very limited amount of scenarios. Being dependent on the local geographic situation also carries an investment risk; namely how well suited the ground is for drilling.

The more common alternatives to DC are instead electrical driven chillers. A chiller is more common than a geothermal solution and it is thereby easier to estimate its cost structure. In general it is also 20% cheaper than a heat pump. The chiller system can be constructed in various configurations; however this report will focus solely on the two most general configurations, namely water-cooled and air-cooled compressor chiller solutions.

There are other types of individual building installed chiller solution as absorption chillers and direct water cooled chillers (from a natural water source) but these are very rare (only a few per cent of all installations) since they require special local conditions to be economic viable and is therefore not evaluated.

6.1.1 WATER-COOLLED CHILLER

The water cooled chiller solution consists of two main parts; a chiller (Figure 1) and a cooler, see Figure 2.

Heat from the indoor air is transferred via a coil to the closed loop secondary system water. The secondary system water transports the heat to the chiller where the water is cooled and is then returned to the coil again.

The main components of a chiller are the evaporator, the electrically driven compressor and the condenser. Heat is transferred from the secondary water system water via the refrigerant with the help of the electrical driven compressor to the condenser where the heat is transferred to the coolant. The coolant is then pumped to the cooler where a new heat transfer takes place with the outdoor air. The most common solution is a dry cooler which requires less operation and maintenance (O&M) experience. Cooling towers are used when there is limited space or performance is important. The disadvantage is water consumption and higher O&M costs.
In some rare cases the building is situated close to open water and the chiller can then be cooled directly towards the water.

Figure 1. Water-cooled chillers

Figure 2. Dry cooler and cooling tower

As Figure 3 shows, the cooler is placed outdoors, often on top of the roof, with the purpose to transfer the heat out of the property, whilst the chiller often is located in the basement of the building. The cooler can be either a dry cooling type or evaporative.

This setup places the compressor and other sensitive machinery in a temperature- and moist neutral climate which enhances its lifespan compared to similar, outdoor based solutions. A water-cooled chiller solution can therefore expect a lifespan of 15 to 20 years depending on its quality.
6.1.2 AIR-COOLED CHILLER

In an air cooled chiller (Figure 4) the refrigerant is condensed directly in the air cooler towards the surrounding air. The functionalities of the chiller and cooler are placed in the same unit. This type of chiller is also called a “Roof top” unit.

Figure 4: Air-cooled chiller

Figure 5 reveals two major distinctions for how an air cooled system is constructed compared with a water cooled system. First of all, instead of having a chiller in the basement and a cooler placed on the roof, this setup only uses a chiller unit. Installations for pipes and valves for the refrigerant side are thereby redundant. These factors cut the investments costs. However, placing the chiller outdoors will expose vulnerable equipment for more unbeneificial climate such as rain, wind, dust and temperature variations. Due to this, the air-cooled chiller has a lower expected lifespan than water-cooled solutions. An air-cooled chiller solution can expect a lifespan of 7 – 15 years depending on its quality and 10 years is typically used as an average.
Water cooled chiller with the air-coolers on the roof has an expected lifespan of 10 – 20 years depending on its quality and 15 years is typically used as an average.

Figure 5: Example of the schematic of an air-cooled chiller installation.

6.2 INVESTMENTS

The chiller itself constitutes only 25-35 % of the total individual building chiller cost. The investments required for a complete installation of an individual building cooling system in a building includes:

- Chiller units
- Coolers
- Piping and valves etc. on chilled water and cooling water side
- Pumps and motors
- Power connection to electricity grid
- Electrical installations
- Automation and control
- Demolition and dismantling
- Building works (roof reinforcements, foundations, holes etc.)
- Space
- Engineering and design
- Project management
The investment does not include cost for the secondary system that distributes the cooling in the building because this report compares the customer’s alternative cooling cost compared with DC. The secondary system is assumed to be the same for both alternatives.

There are many factors that influence the level of the investments above such as:

- Capacity of the cooling demand
- New building, old building
- New- or reinvestment
- Ambient air conditions
- Available installation space
- Location of equipment, distances
- Secondary system design
- Adaptation costs
- Local laws (as for instance regarding refrigerants)
- Power supply conditions
- Local cost level
- Other special conditions

All these conditions are unique for each customer and the cost for each installation is therefore also unique.

The investment level of a typical installation in a country with average electricity and labour cost levels for the two individual building chiller solutions treated in this report (water cooled and air cooled), with a capacity of 300 kW is shown in Table 1.

The air cooled chiller cost is about the same as for a water cooled chiller and cooler. The air-cooled solution investments considering pipes and valves will be cheaper. We can also identify cost reductions in pumps + electrical instalments and overall design and engineering costs for the air-cooled solution. In total, an air-cooled chiller can expect 10 to 15 % lower new investment costs and 8 to 12 % lower reinvestment costs in comparison with the water-cooled solution.

Smaller plants are more expensive per kW and larger are usually cheaper.
<table>
<thead>
<tr>
<th>Cost [kEUR]</th>
<th>New investment</th>
<th>Reinvestment</th>
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<tbody>
<tr>
<td>Water cooled</td>
<td>200 – 230</td>
<td>130 – 160</td>
</tr>
<tr>
<td>Air cooled</td>
<td>180 – 210</td>
<td>120 – 150</td>
</tr>
</tbody>
</table>

Table 1: Investment costs for a 300 kW chiller

The costs in the table above are based on experience from executed projects. These costs should be viewed only as an average of the EU-27 countries and it is expected that local specific cost variations will diverge from this average. The spread upwards can be significantly higher than indicated in the table above if all conditions are the worst scenario.

Since free trade exists within the EU borders, it can be expected that most capital cost will stay relatively stable across the countries. There are however exceptions due to national subventions, inflation rate and additional taxes. For this reason a 20% deviation compared with the EU-27 average can be expected.

Special local laws may require special technical solutions that will drive the investment higher. An example of that is a ban on hydrofluorocarbon (HFC) refrigerants. Tax for refrigerants is planned in some countries which will have an impact on the overall investment.

Labour costs, on the contrary, have high deviations between the countries. Table 2 shows how much the employer, at an average, pays for labour per hour in each country. These number does not take into account what kind of profession it involves and might differ to some extent compared with the labour capital needed for installing a real estate’s cooling solution, but should still provide an estimate as to what diversions of labour cost can be expected when comparing different countries.
Table 2: Labour cost per hour in euros (Eurostat, 2013)

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
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<td>Germany</td>
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<td>Spain</td>
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</table>

6.3 OPERATING COSTS

6.3.1 ENERGY EFFICIENCY

The coefficient of performance (COP) for a chiller is normally rated at given conditions specified in a standard, for example ARI 550/590 from Air-Conditioning and Refrigeration Institute. The COP describes the performance of the chiller itself, not including auxiliary equipment.

In reality chillers never operate at those specific conditions and the chiller is only one of the parts in a cooling system. There is auxiliary equipment such as pumps required to operate the cooling system and these components have an electricity demand that will reduce the system performance.
When the chiller is running at a capacity between low and high, some supplying systems such as pumps and fans must be in operation. Often the supplying systems are designed for on and off mode. This leads to a situation where, for example, the circulation pump for the heating system will run at 100 % but the output from the chiller is below 100 %. The same situation also occurs for the fans in the cooling tower. The power economy for the chillers, running at low capacity, is also very poor. For multiple-cylinder compressors, a cylinder unloader which bypasses the compressor is less economic compared with speed modulation.

When accounting for all electricity demand of all equipment required for operating the cooling system during all load conditions during a whole year the energy efficiency ratio (EER) (sometimes also called SSEER, System Seasonal Energy Efficiency Ratio) is much lower.

A study carried out on refrigeration installations in France, Finland and Sweden shows that the nominal values of COP from manufacturers does not match with the real-life performances of the chiller systems (Ben Allel, Frohm, Merchat, Senejean, & Wirgentius, 1/2010). The chiller COP varied between 2,1 and 5,6 while the system EER varied between 0,7 and 2,8.

The chiller’s COP is not the same as the (SS)EER. Table 3 shows the difference between a nominal EER provided by a supplier and the practical efficiency which is corresponding more with the chiller’s real working conditions.

<table>
<thead>
<tr>
<th>Chiller system</th>
</tr>
</thead>
<tbody>
<tr>
<td>According to supplier (COP)</td>
</tr>
<tr>
<td>Real system (EER)</td>
</tr>
</tbody>
</table>

*Table 3: Energy efficiency (EER) for individual building chiller solutions*

The property owners usually do not measure the electricity consumption of the cooling system at all and in some rare cases the compressor electricity demand is measured but very rarely the auxiliary equipment as pumps etc. The electricity demand for the cooling system disappears in the total electricity demand of the whole building. The property owner therefore rarely knows high the actual cooling operational cost is.

*Natural cooling*

Natural cooling is an option for the individual building cooling alternative to increase energy efficiency but it is not very common. In the Nordic countries it is more common than in the southern part of Europe due to the colder climate. The cooling demand for an individual cooling solution, during winter when natural cooling is available, is very low and therefore the potential cost saving is very limited. Only customers with a high base load demand would benefit from chillers with free cooling mode.

6.3.2 ELECTRICITY COSTS

Figure 6 shows the industrial prices for electricity in EU member states. The figures presented cover average prices and include basic prices, transmission and distribution charges, meter rental, and other services. Taxes are excluded and variations in taxes between different countries are big, from zero to 94 €/MWh in Denmark.
The EU-27 average cost for electricity is 112 €/MWh. The cost does however vary significantly between countries. As an example, in 2011 the electricity was 40% cheaper in Bulgaria and 88% more expensive in Cyprus compared with the EU-27 average.

Table 4 shows how European prices for electricity have fluctuated between 2007 and 2011. The EU-27 average per year increase is 1.7% but variations are noticeable. Latvia, for example, has experienced an average increase of 5.2% whereas the Netherlands at an average have decreased their electrical cost by 0.4% per year.
<table>
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<th>2008s2</th>
<th>2009s1</th>
<th>2009s2</th>
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<td>0.716</td>
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<td>0.098</td>
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<td>0.116</td>
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</tr>
<tr>
<td>ES</td>
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<td>0.096</td>
<td>0.107</td>
<td>0.115</td>
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<td>0.085</td>
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<tr>
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<tr>
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<td>0.110</td>
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</tr>
<tr>
<td>FI</td>
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<td>IE</td>
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<td>0.063</td>
<td>0.064</td>
<td>0.070</td>
<td>0.078</td>
<td>5.2%</td>
</tr>
</tbody>
</table>

Table 4: Electricity prices for industrial consumers, average increase / year (Eurostat, 2013)

6.3.3 OPERATION AND MAINTENANCE (O&M)

Property owners almost always underestimate their costs for maintenance. They know very well the costs for their service contracts but forget to consider unforeseen costs and own time.

The lifetime of the equipment is limited and re-investments are required within typically 7 to 15 years. Unforeseen costs for refrigerant gas leakage or compressor break downs must be considered. These costs are normally forgotten in the analysis.

The costs for operation are very difficult to determine. Often the operation is carried out by the property’s caretaker, who has a lot of other duties to undertake and the cost for operation disappears. In some cases the O&M is outsourced to an external contractor, which makes it easier to determine the maintenance costs.

Following key figures have been constructed based on benchmarking results from different projects:

- Fixed O&M costs - 4% per year of the initial investment
  - Fixed costs for Operation consist of identified and scheduled manning, either by one’s own or external resources.
Fixed costs for Maintenance consist of preventive maintenance and fixed contract of service, leak detection, performance rating, emergency service etc.

Fixed costs for production consist of distribution fee, capacity fee and other fixed fees that do not stop even if you stop your chillers.

- **Variable cost - 2 € per MWh produced cooling energy**
  
  - Variable costs for Operation consist of non-scheduled manning such as extra work in connection with breakdowns, reconstruction of installations and other non-scheduled works.
  
  - Variable costs for Maintenance consist of corrective maintenance and spare parts, consumable supplies, overtime work, etc.

**6.4 INDIVIDUAL BUILDING INSTALLED CHILLER COST EVALUATION**

The parameter that influences the operating cost the most is the energy demand. The energy demand can vary significantly from customer to customer depending on the activity in the building. There are pure comfort customers in the northern part of Europe with around 400 equivalent full load hours up to shopping centres and hospitals with a high base load in the southern part of Europe which can have equivalent full load hours around 4000 h. Server centres are almost pure base load customers and close to 8760 h.

Equivalent full load hours = Energy demand in MWh/year / Installed capacity in MW

The extreme customer with the highest cost for cooling per MWh would most likely be a new investment for a small comfort customer in Denmark where the electricity price is high and HFC refrigerants are banned. The other extreme would be a re-investment for a server centre in a country with a low electricity price.

A typical office building in central Europe is used as a demonstration of how cost for cooling can vary. A typical value of the equivalent full load hours in central Europe is around 1200 h/year.

The evaluation is based on a weighted average electricity price for an EU-27, 112 EUR/MWh. The evaluation also includes the European extremes, which includes the cheapest and highest national costs for the chiller’s investment, O&M and electricity costs.

Utilisation time 1200 h/year

Electricity cost  112 €/MWh

Depreciation time (= average technical lifetime) 15 years

WACC (Weighted Average Cost of Capital) 7 %

The evaluation will consider the total cost per MWh cooling demand for a capacity interval between 100 to 3000kW with all other variables locked. Following four scenarios will be investigated:
• Water-cooled compressor chiller, new investment
• Water-cooled compressor chiller, re-investment
• Air-cooled compressor chiller, new investment
• Air-cooled compressor chiller, re-investment

6.4.1 NEW INVESTMENT

A customer that has to do a new investment must invest in a complete cooling system including all interconnecting piping pumps, electrical connections etc. which are not required for a customer that only makes a reinvestment.

The CAPEX for a new investment is for EU-27 average 45 to 55 % of the total cost.

Figure 7 shows the average price for customer’s individual building cooling solution when considering a water-cooled system for a new building.

The price for a 300 kW system is in the range of 70 to 200 €/MWh depending on country specific variations. When considering the size, the variation is even larger.

![Total cost, Water-cooled, New investment](image)

*Figure 7: Cost per MWh for a new investment of a water-cooled solution.*

The air-cooled chiller (Figure 8) is marginally more expensive than its water-cooled counterpart; the total investments are lower but a lower expected depreciation time and EER leads to higher costs over time. The cost for a 300 kW system varies from 80 to 220 € /MWh.
The cost for a new investment can be expected to be up to 40% cheaper and 70% more expensive than the average cost depending on country specific variations for both solutions.

6.4.2 RE-INVESTMENT

Figure 9 covers the water-cooled solution based on a customer who already has a chiller system installed in the real estate but needs to make a reinvestment. Capital costs for equipment such as chillers and coolers will stay close to the same as for the new investment case. Electrical installations and piping do not require any reinvestments, which leads to lower total investments. The cooling cost for a 300 kW system varies from 50 to 160 €/MWh depending on country specific variations. The size dependency is shown in the graph below.

The CAPEX for a re-investment is for EU-27 average 35 to 45 % of the total cost.

Figure 8: Cost per MWh for a new investment of an air-cooled solution.

Figure 9: Cost per MWh for a re-investment of a water-cooled solution.
Figure 10 shows the air-cooled solution in need of a re-investment. The price varies from 63 to 117 € /MWh, depending on the size of the system. The price can be expected to up to 45% cheaper or 60% more expensive depending country specific variations.

6.4.3 ENERGY DEMAND VARIATION

The costs in the graphs above are calculated for an average office building with an equivalent full load time of 1200 h/year. If the customer’s energy demand is lower, the capital costs will be divided on fewer MWh and the costs will therefore be higher. A base load customer will have lower costs and a comfort customer higher cost. In the graph below (Figure 11) the equivalent full load hours are varied and all other parameters kept constant.

There is a large variation in cooling costs for the customer’s individual building cooling installation when combining all factors influencing the investment and O&M costs.
6.5 SUMMARY OF INDIVIDUAL BUILDING COOLING SOLUTION

The costs for the customer’s individual building cooling solution for cooling depend on many factors and it is not possible to define a key figure per kW or MWh in a simple calculation. Each customer is unique and the costs for that customer are also unique.

The CAPEX is for EU-27 average between 35 and 55 % of the total cooling costs. While the electricity price influence the OPEX the most.

The customers cost for cooling depends on many parameters and must be calculated individually for each customer’s specific needs and conditions.

7. DISTRICT COOLING

The general idea of DC is to replace individual building cooling production units with a centralised solution. Individual building cooling solutions are in general small, ineffective and have a higher energy demand. DC utilise local resources to enhance the efficiency. Centralising the production enables potential scale effect benefits. Individual building cooling solutions are geographically limited to the area surrounding the real estate. DC can instead be located to areas where the production would be most advantageous, i.e. close to water sources with cold water from which it would be possible to use cheap and environmental friendly cooling. Figure 13 shows a concept of how cold water is produced and distributed to customers in a DC system.
A DC system is usually divided into

- Cooling production plant
- Distribution network
- Energy transfer station

### 7.1 COOLING PLANT

When considering DC it is important to consider the most beneficial design of the production line and how to supply the produced cold water to customers in the distribution network. This section briefly describes the three most commonly used techniques and the DC distribution system.

DC usually makes use of either natural cooling from local water supplies such as the ocean and lakes, conversional waste heat, high-efficiency chillers or a combination of the technologies. A cooling plant’s system architecture is based on available energy sources, economic and environmental variables. This makes each cooling plant configuration unique; every city or urban area has its own specific conditions.

#### 7.1.1 NATURAL COOLING

Natural cooling is about making use of locally available natural sources of cold energy and thereby avoid the expense of unnecessary energy usage. Natural cooling therefore, when available, offers a very simple, cost efficient and environmental friendly cooling solution. It is possible to use a wide range of cooling sources for natural cooling as long as their temperature is low enough. Using air as a natural cooling medium therefore limits the usability to northern latitudes where it is cold outdoors for the main part of the year. Water is a more stable medium; the bottom of many lakes is still cold during the midst of summer, in these cases it might be more of an economic restriction for installing pipelines that are deep enough.
The following list describes possible sources for natural cooling:

- Air
- Snow
- Ice
- Rivers
- Oceans
- Lakes
- Ground water

The amount of natural cooling that can be produced depends on the air or water temperature variation during the year and the DC forward and return temperatures. This variation must be considered when calculating the natural cooling potential.

*Figure 14: Water temperature variation and natural cooling possibilities. Ex. Shows a river in northern Europe with DC forward temp 6 °C.*

In order to produce all cooling energy with 100% natural cooling the water temperature must be at least 1 °C below the desired supply water temperature of the chilled water in the DC system. With 100% natural cooling it is possible to receive an EER in the range of 20 to 35. These conditions are extremely rare and natural cooling normally needs to be combined with chillers to control the temperature after the heat exchangers.
7.1.2 ELECTRICAL CHILLERS

Individual building cooling solutions are normally air cooled (see chapter 0) while chiller for DC plants are much larger and normally water cooled from natural sources.

Regular electrical driven compressor chillers reduce the load by reducing the pressure after the compressor with a sliding piston. Frequency controlled compressor chillers are technically identical to regular chillers with the exception that the load is controlled by reducing the pressure after the compressor by reducing compressor speed with a frequency controlled compressor motor.

A typical problem with regular chillers is that they reach their peak efficiency only on full load. On the other hand side, compressors driven with a variable-frequency drive increase their efficiency at part load at lower condensing temperatures. Using a combination of frequency driven and regular chillers, it is possible to construct a high-efficient production plant. Frequency controlled chillers can expect an EER of 5 to 14 depending on load and condensing temperature as seen in Figure 15.
A regular chiller in a building installation has a life expectancy between 7 to 20 years. The average life expectancy of a chiller installed in a DC plant under supervision of experienced O&M personnel is instead 25 to 30 years.

7.1.3 ABSORPTION CHILLERS

An absorption chiller has the same basic functions as a regular chiller, with the distinct differences that it is driven by heat instead of electricity and that it uses a saline solution as refrigerant, typically lithium bromide. The only electricity used for the chiller itself is for pumping the refrigerant and it is therefore possible to expect a total plant electrical EER of 15 to 25. The thermal heat EER is typically 0.7 to 0.74 for hot water around 90 °C.

A problem with absorption chillers is that they use heat as fuel, which has less energy quality than electricity; it takes more heat energy than electricity energy to produce one unit of cooling energy. Therefore heat as a fuel must be much cheaper than electricity in order to make the absorption technique profitable. A low heat price might be available if there is a district heating system where there is an over capacity of waste heat during summer periods. The production cost of district heating is more temperature dependent than electricity driven chillers. Heat during cold months is normally expensive. For this reason it is more beneficial to use absorption chillers during the year’s warmer months when the cooling demand is in fact at its highest and heat price is low (if there is a surplus of waste heat).

7.1.4 COMBINATION OF PRODUCTION TECHNOLOGIES

So far this chapter has involved three different technologies commonly used in DC systems. It is very uncommon that only one of the three is used. The main benefit with centralised large scale DC is the flexibility to design the production plant so that it is always
the most economic beneficial technique that is used for production. A typical setup would be to use natural cooling as long as its water source is cold enough, absorption chillers when the production cost of heat is low and electrical chillers for the remainder of the production.

Figure 16 describes an architectural design of a DC system. This example only shows one unit each of the techniques described. Most DC systems have a more advanced architectural design. As can be seen in Figure 16, the natural cooling water is not used only to cool the DC grid, but also has a function to cool the chillers in the cooling plant. In fact, even though the water supply might be too warm for natural cooling, it might still be possible to cool the direct cooling system’s excessive heat producing units throughout the year.

Figure 16: Principles of a District Cooling system architecture

Figure 17 shows an example of how the production might be distributed over the year. During the winter months it is possible to use natural cooling but during the spring and autumn it is swapped for electrical chillers and during summer absorption chillers are used. As can be seen, the electrical demand, compared with other solutions, is very low. A typical water cooled DC combination system is expected to have an EER of 8 to 30 on a monthly basis while the yearly average EER is between 10 and 15.
Figure 17: Distribution of production

7.2 DISTRIBUTION NETWORK

The distribution network is required to transfer the cold water from the centralised production plant to the customers. It consists of a back bone and the customer connections. There are many factors influencing the cost for a distribution network such as:

- Length of the network
- Type of area
  - inner city
  - suburban area
  - green area
  - development area
- Underground conditions
  - rocks (blasting required)
  - high ground water (sheet piling and pumping required)
  - other existing infrastructure (electrical cables, water, sewage, DH piping etc.)
- Ground surface material
• Local civil works cost level
• Local monopolies
• Difficult passages (railways, highways, rivers etc.)
• Pipe material
• Procurement model
• Contractor model

A DC distribution system, in general, uses one of following pipe material:

• Carbon steel pipes with foam insulation
• Stainless steel pipes with foam insulation
• PEH pipes without insulation
• Coated steel pipes without insulation, gas pipes

Pre-insulated pipes as the EN253:2009 standard are the most common since they experience small temperature losses and often have a built in leak detection wires for the surveillance system. One problem with pre-insulated pipes is that they often experience damages if installed above ground. It is therefore often preferable to use PEH pipes without insulation for these occasions. PEH are also cheaper but suffer from temperature losses and the lack of leak detection wire. In some cases a combination is the most viable, insulated forward pipes and PHE for the return pipe, will reduce the cost without increasing the capacity loss in the forward pipe.

7.3 ENERGY TRANSFER STATION

The energy transfer station (ETS) is required to separate the DC distribution network from the building internal secondary system. The ETS consists mainly of a plate type heat exchanger with measuring and controlling equipment. The ETS is usually owned by the property owner since it is installed in the building. The ETS either sold or specified by the DC provider.

7.4 COST ASPECTS OF DISTRICT COOLING

7.4.1 PRODUCTION PLANT

As for the customers’ internal building cooling alternative there are many factors influencing the investment level of the production plant and the production cost. In addition to the customers’ alternative the optimal system design vary depending on the additional factors.

• Plant size, capacity
• System diversity factor (required cooling capacity divided with total market demand)
• DC temperatures
• Availability requirements
• Availability and quality of energy sources
  o Natural cooling sources (temperature, water quality, distance to source)
  o Waste heat for absorption (quantity, temperature, distance to source)
• Availability of space
• Ambient air conditions
• Local legislation (as for refrigerants)
• Complexity of permit processes
• Power supply conditions
• Local cost level
• Other special conditions

*Plant Investment*

The plant investment varies due to the parameters discussed above and with the local condition.

The DC production plant investment curves below are based on a diversity factor of 0.85 (actually installed capacity divided with total market demand) and presented per installed capacity in MW.

![Graph showing variation in district cooling production plant investment in €/kW.](image)

*Figure 18: Variation in district cooling production plant investment in €/kW.*
Cost evaluation parameters

Utilisation time 1200 h/year

Electricity cost 112 €/MWh

Diversity factor 0.85

Calculation period 25 years

WACC (Weighted Average Cost of Capital) 7 %

Each production plant will be unique in design based on the local conditions and the investments will vary significantly.

A DC production plant in Europe is typically a combination of electrical chillers and natural cooling heat exchangers. Sometimes it is also possible to utilise district heating based on waste heat for absorption chillers. The chillers are either cooled directly by a river/lake/sea or it can be cooled with cooling towers. The design and selection of equipment is a complex issue that aims to reducing the total present value of the cost for the project. It is not possible to calculate the investment and operating costs with simple key figures since the variations in conditions are large.

The operating costs (OPEX) depends on the system architecture and cost for electricity and heat. If cooling towers are used the cost for water and sewage is also an important parameter. The electrical EER variation is from around 7 up to 15 depending on how much natural cooling and waste heat is available for absorption cooling.

The O&M costs consist mainly of organisational cost for operating and maintenance personnel as well as maintenance contracts and materiel for preventive maintenance. The technical lifetime of a well-managed DC production plant is around 25 years.

To get an understanding of the variation in costs, a reference plant for a total customer demand of 60 MW and 72 GWh/a will be used as an example. This plant has natural cooling, electrical chillers and absorption chillers in the production mix. The cooling source is river water.

The variation in electricity price, local labour cost and local price levels creates a wide spread in the DC plant cost as seen in Figure 19 below.
Figure 19: Variation in district cooling plant cost for a 1200 h equivalent full load system as function of market demand and local cost variation (high, average and low cost).

When calculating the cost per MWh it is important to keep in mind that the total energy demand has a great impact on the DC cost, a lower demand results in a higher cost which is shown in Figure 20.

Figure 20: Variation in district cooling plant cost for different equivalent full load hours.
Figure 21 shows the full range of the variation when combining the local cost variation and energy demand in one graph.

![DC plant cost - Full range variation](image)

*Figure 21: Full range of the variation in district cooling plant cost for different equivalent full load hours and local conditions.*

### 7.4.2 DISTRIBUTION SYSTEM

As described in chapter 0 there are many parameters influencing the cost of the distribution grid.

Each distribution system is unique and must be calculated individually but based on executed projects some performance key factors can be used to see in what range the investment should be in order to be economic viable. When calculating key numbers per meter the length is expressed as pipe trench with a forward and return pipe.

**Pipeline density**

Pipeline density greater than the values below indicates that the cost for the distribution system should be within reasonable cost.

- > 4 MWh/m
- > 3 kW/m

A lower line density can be compensated with lower production cost

**Investment key figures**

- Average specific pipe cost: 150 – 250 EUR/kW
- 650 – 1'000 EUR/m

A higher cost per meter can be acceptable when the line density is high. A higher cost or lower line density can also be acceptable if it is motivated by a better location of the production plant providing a lower production cost.
The viability of a DC project does not depend only on the distribution system but also the CAPEX and OPEX of the production plant. The project must be evaluated as a whole.

The cost for distribution cannot easily be evaluated with key numbers. Variation between different projects is large and distribution cost must be calculated from case to case.

7.4.3 ENERGY TRANSFER STATION

An ETS is standardised product manufactured by several different suppliers all over Europe and the cost is therefore relatively stable and known for the prefabricated ETS.

<table>
<thead>
<tr>
<th>Size</th>
<th>kW</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>500</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-fabricated ETS</td>
<td>kEUR</td>
<td>31</td>
<td>38</td>
<td>45</td>
<td>54</td>
<td>71</td>
</tr>
<tr>
<td>Labour cost</td>
<td>kEUR</td>
<td>13</td>
<td>17</td>
<td>20</td>
<td>25</td>
<td>37</td>
</tr>
<tr>
<td>SUM</td>
<td>kEUR</td>
<td>44</td>
<td>55</td>
<td>65</td>
<td>79</td>
<td>108</td>
</tr>
<tr>
<td>Specific cost</td>
<td>EUR/kW</td>
<td>440</td>
<td>275</td>
<td>217</td>
<td>158</td>
<td>108</td>
</tr>
</tbody>
</table>

*Table 5. ETS costs.*

The ETS must be installed in the building and the installation cost depends mainly of the local labour cost.

7.4.4 PROJECT COSTS

Additional costs to be included in the calculation are

- Project development costs
- Sales costs
- Administrative costs

For an average EU27 project the following can be assumed.

The project development cost is to a large part fixed and some part depending on the size of the project.

Project development 6 – 20 EUR/MWh

Sales and administrative costs are in the range of 2 – 6 EUR/MWh

Smaller projects = higher cost

7.4.5 TOTAL DISTRICT COOLING COST

When summarising all the costs that constitute the total DC cost:
- Plant costs
- Distribution costs
- ETS costs
- Project development costs

The curves below are for a 1200 equivalent full load hours and a variation of costs between 30 and 150 EUR/MWh for a 60 MW market demand can be seen in Figure 22 below.

![DC total cost - 1200 h](image)

*Figure 22. Total DC cost for 1200 eq. full load hours.*

### 8. PROFITABILITY OF A DISTRICT COOLING SYSTEM

The profitability of a DC system must be calculated with a cash flow analysis since the income; investments and cost are subject to local conditions and a great variation in influencing parameters.

It is important to evaluate the complete project, high production costs or expensive distribution might be compensated by a high market price.

Each customer is unique and each production plant is subject to unique conditions. To evaluate DC projects, both the income side (customers' alternative cost) and the investment and operating cost should be evaluated on a fairly detailed level.

DC businesses are capital intensive and therefore also sensitive to unforeseen costs and incomes. Market knowledge and experience from DC is important. It is also important that the energy company provide the DC project with enough resources to manage both the market and sales as well as well as the planning, design and execution of the production plant and distribution grid.

The main parameters influencing the profitability of a DC project are:
• Organisational capacity, knowledge and experience in DC business development
• Cooling market price
• Customer connection rate
• Energy/capacity density of the DC grid
• Available energy sources
• Distribution conditions
• Electricity price

8.1 PROFITABILITY ANALYSIS OF A 60 MW MARKET

In this chapter a cash flow analysis will be made of a fictitious market based on the findings in this report.

8.1.1 CONDITIONS

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total market capacity demand</td>
<td>60 MW</td>
</tr>
<tr>
<td>Total market energy demand</td>
<td>72 GWh</td>
</tr>
<tr>
<td>Market price (water cooled, re-investment, avg. size 500 kW)</td>
<td>80 EUR/MWh</td>
</tr>
<tr>
<td>Market connection rate evenly over 3 years</td>
<td></td>
</tr>
<tr>
<td>Required plant capacity</td>
<td>51 MW</td>
</tr>
<tr>
<td>Plant investment</td>
<td>294 EUR/kW</td>
</tr>
<tr>
<td>Year 1</td>
<td>9'000 kEUR</td>
</tr>
<tr>
<td>Year 2</td>
<td>3'000 kEUR</td>
</tr>
<tr>
<td>Year 3</td>
<td>3'000 kEUR</td>
</tr>
<tr>
<td>Distribution grid</td>
<td>220 EUR/kW</td>
</tr>
<tr>
<td></td>
<td>13'200 EUR</td>
</tr>
<tr>
<td>ETS</td>
<td>80 EUR/kW</td>
</tr>
<tr>
<td></td>
<td>4'800 EUR</td>
</tr>
<tr>
<td>Operating costs</td>
<td>10 EUR/MWh</td>
</tr>
<tr>
<td>Project development costs and administration</td>
<td>10 EUR/MWh</td>
</tr>
<tr>
<td>WACC</td>
<td>7 %</td>
</tr>
<tr>
<td>Project calculation time</td>
<td>25 years</td>
</tr>
</tbody>
</table>
8.1.2 RESULTS

The fictitious project based on the customers’ alternative costs described in chapter 0 and the costs for DC described in chapter 0 results in a project that shows good profitability.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV</td>
<td>20’000 kEUR</td>
</tr>
<tr>
<td>IRR</td>
<td>12 %</td>
</tr>
<tr>
<td>Straight pay-back</td>
<td>10 years</td>
</tr>
</tbody>
</table>

There are risks that must be considered and the main risks in order of importance are:

1. Market risks i.e. lower market price and delayed connection of customers
2. Investment risks
3. Performance risks i.e. lower EER

The risks and sensitivity are visualised in Figure 23 and Figure 24.

These risks are almost always realised to some extent and typical projects ends up with an IRR of 9 – 12 % if managed well.

![Figure 23. Cash flow of a fictitious 60 MW DC project.](image-url)
9. **KEY SUCCESS FACTORS**

**ORGANISATION**

The organisation is the main risk in a project like this. An organisation with skilled and experienced personnel with enough resources and a well-developed risk management process are the keys to success. Common mistakes are:

- Too few resources
- Resources not dedicated to the project.
- Afraid to use external resources during build-up of project

**BUSINESS GOVERNANCE**

The governance should focus on profitability of the entire project.

- Loosing focus on profitability
- Sub optimisation under each main discipline below
- Forgets the difficulties with permits
MARKET

Market price is not too difficult to achieve with experienced sales personnel that know what the market price is and aim to maximise profitability. Mistakes in the sales process are:

- Market communication is poor
- Sales personnel are unsure of the market price and lower the price too much
- Wrong incitement for sales personnel

PRODUCTION PLANT

Production plant design and execution is not hi-tech but management of the whole phase is important. Common mistakes are:

- Focus on the technology before there is a market.
- Cannot analyse the optimum system design. Investments versus operating costs.
- Focus on investment level and not profitability

DISTRIBUTION

The distribution is no hi-tech either and the main risk lies under ground. Common mistakes are:

- Wrong cost estimation during feasibility studies and pre-design phase.
- Purchase “off-the shelf” and not negotiate larger distances to different contractors creating competition.

9.1 MAIN KEY FACTORS

- Focus on profitability of entire project at all times
- Enough dedicated resources
- Use external experience for shorter periods and where experience is lacking.
10. BIBLIOGRAPHY

