4TH GENERATION DISTRICT ENERGY

THE BACK BONE OF LIVEABLE AND RESILIENT CAMPUSES AND CITIES

Anders Dyrelund, Senior Market Manager, Ramboll Energy
PRESENTATION AND BACKGROUND

- Ramboll
  - Independent Multidisciplinary Consulting Eng. Comp. Owned by the Ramboll Foundation
  - 13,000 Employees 300 offices in 30 countries, mainly Northern Europe
  - World leading within several energy services
- Anders Dyrelund
  - Civ.Eng. in buildings, Graduate diploma in Economics
  - 1975-81 Ramboll (BHR)
  - 1981-86 Danish Energy Authority
  - 1986- Ramboll
  - 1980 The First Heat Plan in Denmark for Aarhus, PM
  - 1981- Copenhagen Regional DH, task manager/consultant
  - 1990- Consultancy services to more than 20 countries
CHARACTERISTIC OF THE 4TH GENERATION ENERGY SYSTEM

- The 4 energy carriers are fully integrated with conversion technologies
- The HVAC systems in buildings are integrated with the district heating and cooling infrastructure
- Larger energy storages
- Low-temperature heating and high-temperature for cooling in buildings
- Integrate low quality and fluctuating low-carbon energy production
- More efficient conversion technologies for heating and cooling with CHP and heat pumps
THE SMART ENERGY SYSTEM
INTERCONNECTING THE 4 ENERGY CARRIERS

• International power grid
  • Hydro power, but limited storage capacity

• International gas grid for natural gas (and biogas)
  • Large storages, CHP, industry

• City district heating grids
  • Storage for CHP, electric boilers, heat pumps and RES

• City district cooling grids
  • Storage for and optimal cooling in symbiosis with heat

• Buildings - end-users the basis for 4th GDH
  • Optimized building envelope
  • **Low temperature heating**
  • **High temperature cooling**
  • Adjust consumption to dynamic prices
OUR VISION IS TO CREATE LIVEABLE CITIES
SMART SOLUTIONS FOR THE CITIZENS
THE COPENHAGEN DISTRICT HEATING NETWORK

Heat supply areas:
- CTR + HOFOR
- VEKS
- Vestforbænding
- Other

- Waste-to-energy plant
- CHP station
- Peak load plant
- Transmission pipeline

10 km
DEVELOPMENT OF DH&C PIPE CONSTRUCTIONS IN BRIEF IN 5 DECADES

• 1970 Concrete ducts, expensive, long life-time, but some failures, first preinsulated pipes in Løgstør, but poor quality

• 1980 Danish standard for DH pipes in the ground, Better quality of preinsulated pipes of various principles and competition

• 1990 Preinsulated pipes of good quality almost 100% market share, bonded system, welded mufffs, no expansion joints, surveillance system

• 2000 Curved pipes, twin pipes <DN200, no-dig methods etc.

• 2010 Preinsuated pipes all over the world for DH&C

• Two options for DC systems in competition:
  • Preinsulated pipes: DH technology, no oxygen, Copenhagen DK
  • PE-pipes: Water supply technology, Frederiksberg DK
STANDARDS FOR DH PIPE SYSTEMS AND PIPES
FREEDOM TO GOOD DESIGN LOWER COSTS

• Standards for use of preinsulated pipes
• Standards for the preinsulated pipes
• Safety regulations and classification, e.g. pressure and temperature
• Standards for specific components, boilers etc.
• Environmental requirements

• Guidelines for infrastructure in the ground in roads – “the guest principle”
• Way of right, same importance as roads for public use
• Declaration in land-owners register
TYPICAL DESIGN PARAMETERS

• Pressure level: 6, 10, 16 or 25 bar max. pressure
• Maximal temperature: $< 85 \, ^\circ\text{C}, < 95 \, ^\circ\text{C}, < 110 \, ^\circ\text{C}$ or $< 160 \, ^\circ\text{C}$
• Normal off peak operation temperature: 65 °C
• Return temp.: as low as possible: $< 40 \, ^\circ\text{C}, < 50 \, ^\circ\text{C}$
• Hydraulic design: Optimize based on life-cycle cost, use available pressure, but max 3,5 m/s, typical 10 mm/m for new networks, as much as possible in old networks
• Bonded without expansion joints for temp. $< 110 \, ^\circ\text{C}$
• Twin pipes $< \text{DN200}$ if regular flat trench
• Long trench, “gas pipe” technology
DISTRICT HEATING TRANSMISSION AND DISTRIBUTION SYSTEMS – ECONOMY OF SCALE

- Interconnect
- New waste CHP
- New gas CCGT CHP
- Heat accumulators
- DH&C stations

- Economy of scale
  - Larger heat market
  - Larger dimension
  - Lower unit costs and
  - Lower unit heat loss

<table>
<thead>
<tr>
<th>DN (mm)</th>
<th>Flow (m/s)</th>
<th>Capacity (MW)</th>
<th>Price pr km trench (Euro/km)</th>
<th>Price pr. km pr. capacity (Euro/km/MW)</th>
<th>Price pr. km pr. annual sale (Euro/km/MWh/a)</th>
<th>Heat loss pr. km (%)</th>
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<tbody>
<tr>
<td>100</td>
<td>1,0</td>
<td>2</td>
<td>0,6</td>
<td>265.775</td>
<td>66</td>
<td>2,96%</td>
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<tr>
<td>200</td>
<td>1,5</td>
<td>13</td>
<td>1,0</td>
<td>75.726</td>
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<td>300</td>
<td>2,0</td>
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<td>43.488</td>
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<td>400</td>
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<td>2,1</td>
<td>30.197</td>
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<td>500</td>
<td>2,6</td>
<td>125</td>
<td>2,7</td>
<td>21.622</td>
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<tr>
<td>600</td>
<td>2,9</td>
<td>203</td>
<td>3,3</td>
<td>16.110</td>
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<tr>
<td>700</td>
<td>3,2</td>
<td>301</td>
<td>3,7</td>
<td>12.222</td>
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<td>800</td>
<td>3,5</td>
<td>431</td>
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<td>9.632</td>
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<td>900</td>
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<td>551</td>
<td>4,8</td>
<td>8.711</td>
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<tr>
<td>1000</td>
<td>3,5</td>
<td>681</td>
<td>5,4</td>
<td>7.949</td>
<td>2</td>
<td>0,05%</td>
</tr>
</tbody>
</table>

Preinsulated pipes
Supply temperature: 120 °C
Return temperature: 60 °C
Pressure loss: 10 mm/m
Max load hours: 4,000 hours

A case based on Danish data
- 300 MW heat capacity 10 km from city
- Annual heat transmission 1,200 GWh/a
- 10 km DN700: 37 mio. Euro
- Annual heat loss 2%
- Pressure loss 2 x 10 Bar
- Transmission cost: 2,5 Euro/MWh
PRESSURE SECTIONING AND SHUNTS
AN ALTERNATIVE TO HEAT EXCHANGERS

• Remove heat exchangers from transmission to distribution
• No heat exchangers from distribution to building system
• Only heat exchanger og tank for hot tap water preparation
• Pressure and temperature control + reduction
• Transient analysis to design pressure vessels to secure against water hammering
• Leak detection valves to close in case of leaking water

Fjernvarme Fyn Denmark:
• 70,000 consumers
• **No heat exchangers**
• High and low pressure
• Two large pressure vessels
THERMAL ENERGY STORAGES
ADVANCED HIGH TEMPERATURE HEAT STORAGE TANKS PRESSURIZED AND PRESSURE SECTIONED

• Temperature **above 100 °C** can be necessary due to consumer needs (poor heating installations),

• But - the larger temperature - the larger investment.

• Pressure sectioning can be necessary due to the pressure level in the DH grid and due to necessary pressure variations at the location

• Pressure sectioning increase costs, but is cheaper and more efficient than a heat exchanger connection

• Avedøre CHP plant, Copenhagen
  
  • 2 x 24,000 m³
  
  • Maximal temp **120 °C** actual temp. 105/50
  
  • Pressure diff: 10 Bar

  • Storage capacity 2,400 MWh, e.g. 300 MW in 8 hours
THE SIMPLE HEAT STORAGE TANKS PRESSURELESS AND DIRECT CONNECTION

- All CHP plants have heat storage tanks in Denmark
- Optimize operation of the CHP plant > 8 max load hours
- Can integrate surplus heat from waste, solar, wind etc.
- Optimize the operation of the DH system
- Maintain the pressure
- Provide peak capacity the coldest day
- Fjernvarme Fyn at Fynsværket power plant, Odense
  - 75,000 m³
  - Direct connection
  - Maximum temp 95°C. 90/40
  - Storage capacity, 3,6 GWh, e.g. 300 MW in 12 hours
HEAT STORAGE PITS
PRESSURELESS AND SECTIONED BY HEAT EXCHANGER

• Heat storage pit, an innovative combination of:
  • Landfills for establishing liners to a water proof pit
  • Heat storage tank for diffusers
  • Off shore technology for diffusers and pipes
  • A floating cover (newly developed)
• Impossible to avoid oxygen in the water, therefore sectioned by heat exchanger
• Maximal temp $85 \, ^\circ C$ up to $90 \, ^\circ C$
• Storing weekly or monthly fluctuations
• The driver for this development in Denmark has been to increase share of solar heat up to 60%
HEAT STORAGE PITS
PRESSURE-LESS AND SECTIONED BY HEAT EXCHANGER

• Test plants with subsidy
  • 10,000 m³ Test plant in 2010 in Marstal
  • 70,000 m³ Full-scale test plant 2012 in Marstal
  • 62,000 m³ Full-scale test plant 2014 in Dronninglund

• Commercially, without subsidy, new floating cover
  • 125,000 m³ Gram district heating 2015
  • 200,000 m³ in Vojens district heating 2015
  • 70,000 m³ in Toftlund district heating 2017
  • 150,000 m³ in Løgumkloster district heating 2017/18

Several more in the pipeline, may be 100 in 2025
CHILLED WATER STORAGES, REDUCING THE DAILY COOLING PEAKS

- Steel tank, district heating technology, Halmstad
- Concrete chamber, water supply technology, e.g. under new road in Carlsberg city
- Cold water storage, heat storage pit technology
- Ground source cooling (ATES)
ECONOMY OF SCALE FOR HOT WATER STORAGES
EUR/MWH HEAT STORAGE CAPACITY

- One family house, 0.16 m³ 300,000
- Large building, 4 m³ 40,000
- DH tank, 160° C 7,000
- DH tank, < 95° C 4,000
- Storage pit, 150,000 m³ 800
- Pit alone, 100,000-200,000 m³ 500
- Marginal extension of the pit 200

- Sources: Henrik Lund and Ramboll
**ECONOMY OF SCALE**

Investment costs storage tanks (TTES) and storage pits (PTES) incl. design, construction and materials.

- **TTES Storage, design 95 °C, not recommended >2000 MWh**
- **TTES Storage, two storage tanks, design 115 °C**
- **TTES Storage, one storage, design 170 °C, not recommended >350 MWh**
- **TTES Storage, 6 storage tanks, design 170 °C, not recommended > 2.100 MWh**
- **PTES Storage, design 90 °C**

A capacity of 2,000 MWh corresponds approximately to a volume of 43,000 m³ at a temperature difference of 40 °C.
GRAM CONSUMER OWNED DISTRICT HEATING
A MIX OF TECHNOLOGIES FOR INTEGRATION OF RES

• Heat production 30 GWh
• 120,000 m³ heat storage pit
• 44,000 m² solar panels (61%)
• A 10 MW electric boiler (15%)
• A 900 kW heat pump (8%)
• Industrial surplus heat (8%) and
• A 5 MWe/6 MWth CHP gas engine (8%)
• Gas boilers for spare capacity (0%)
SYSTEM RESPONSE ON FLUCTUATING ELECTRICITY PRICES
A COST EFFECTIVE “VIRTUAL” ELECTRICITY STORAGE
COMBINED HEATING AND COOLING WITH HEAT PUMPS
THE SECRETS OF DISTRICT COOLING
THE SECRET OF DC A KEY TO SCREENING THE DC POTENTIAL

- Save investment, which can justify the network
  - Simultaneity factor and flexibility of capacity
  - Storage levels daily fluctuation and reduce peak
  - Economy of scale for chillers and heat pumps
- Optimize electricity consumption with storage
- Heat pump has 3 modes of operation:
  - Cogeneration of heat and cold COP=5-7
  - Produce heat / waste the cooling, COP= 3-4
  - Produce cooling / waste the heat, COP= 7-8
- Better use of ground source cooling, ATES
- Høje Taastrup district heating, Copenhagen
PRINCIPLE OF GROUND SOURCE COOLING (ATES)

Summer

Cooling

20° C

4-10° C

Hot

Cold

Groundwater

Winter

Elec. Heat

20° C

4-10° C

Hot

Cold
ON NOISY CHILLERS ON THE ROOF TOOP
COMBINED HEAT AND POWER, CHP
CHP, FYNSVÆRKET DK
EXTRACTION PLANT – SIMPLE DIAGRAM

Simple power plant sketch

RAMBØLL

4TH GENERATION DISTRICT ENERGY 06-12-2017
CHP EXTRACTION PLANT – MIX OF HEAT AND POWER FYNSVÆRKET DK

Operation diagram for CHP extraction turbine,

\( 1/Z = \text{Cv in MWh lost electricity per MWh heat extracted from the turbine} \)

- Pressure less line
- Back pressure, normal
- Maximal load
- Maximal load HP bypass
- Back pressure HP bypass
- Minimal load
- Condensation line
- 2. pressure less line
- Actual operation point

Heat Production in MW hot water

Electricity Production in MW
CHP POTENTIAL FOR NEW POWER GENERATION COMPARED TO NEW POWER ONLY PLANT

- Assuming that **a good 300 MW CCGT condensing plant** is the baseline (on the margin), corresponding to the new CHP plants

- Calculation of the fuel consumption for production of heat by various sources with the same fuel (small but never zero)

<table>
<thead>
<tr>
<th>Cases</th>
<th>Reference plants</th>
<th>Today</th>
<th>DK today</th>
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</thead>
<tbody>
<tr>
<td>Poor Reference power condensing plant gas fuelled CCGT on the margin</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Heat only boiler</td>
<td>Heat only</td>
<td>160</td>
<td>120</td>
</tr>
<tr>
<td>300MW CCGT</td>
<td>300MW CCGT</td>
<td>160</td>
<td>120</td>
</tr>
<tr>
<td>300MW CCGT</td>
<td>300MW CCGT</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>300MW CCGT</td>
<td>60MW CCGT</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>300MW CCGT</td>
<td>300MW CCGT</td>
<td>90</td>
<td>91%</td>
</tr>
<tr>
<td>Maximal temperature, °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat efficiency Backpressure</td>
<td>90%</td>
<td>40%</td>
<td>52%</td>
</tr>
<tr>
<td>Power efficiency Backpressure</td>
<td>90%</td>
<td>35%</td>
<td>38%</td>
</tr>
<tr>
<td>Total efficiency of plant, LHV</td>
<td>90%</td>
<td>75%</td>
<td>90%</td>
</tr>
<tr>
<td>Power to heat ratio</td>
<td>90%</td>
<td>0,88</td>
<td>0,73</td>
</tr>
<tr>
<td>Power efficiency of Ref plant, LHV</td>
<td>90%</td>
<td>0,60</td>
<td>0,98</td>
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<tr>
<td>Estimated marginal loss from central plant</td>
<td>90%</td>
<td>0,60</td>
<td>1,28</td>
</tr>
<tr>
<td>Ref power eff. local grid</td>
<td>90%</td>
<td>0,60</td>
<td>1,46</td>
</tr>
<tr>
<td>Extraction Z-factor or COP</td>
<td>90%</td>
<td>0,60</td>
<td>1,46</td>
</tr>
<tr>
<td>Extraction of heat MWh fuel/MWh heat</td>
<td>0%</td>
<td>0,60</td>
<td>1,46</td>
</tr>
<tr>
<td>Heat producer MWh fuel/MWh heat</td>
<td>0%</td>
<td>0,60</td>
<td>1,46</td>
</tr>
<tr>
<td>Heat loss in district heating grid</td>
<td>0%</td>
<td>0,60</td>
<td>1,46</td>
</tr>
<tr>
<td>Heat supply MWh fuel/MWh heat</td>
<td>0%</td>
<td>0,60</td>
<td>1,46</td>
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<tr>
<td>Savings compared to a boiler</td>
<td>-65%</td>
<td>15%</td>
<td>42%</td>
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<tr>
<td>EE directive, total saving of heat and power: good CHP &gt; 10%</td>
<td>5%</td>
<td>19%</td>
<td>22%</td>
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</tbody>
</table>
GAS FUELLED CC CHP, ABSORPTION HEAT PUMP AND LARGE-SCALE SOLAR HEATING IN SILKEBORG

- Gas fuelled CC plant 106 MW elec./120 MW heat
- Total efficiency of the plant 102%
- Heat storage tanks 4 x 16,000 m³ = 64,000 m³
- Large-scale solar heating 156,000 m²
- Absorption heat pumps 25 MW cooling
- Heat production solar 70 GWh
- Heat pump from solar 10 GWh
- Heat production CHP (market) 210 GWh
- Heat pump condensation 30 GWh
- Heat production boilers 80 GWh
WASTE INCINERATION AND BIOGAS
ARC COPENHILL – NO WASTE TO BE DUMPED AT LANDFILLS
ENERGY PRODUCTION - FLEXIBILITY - AND LIVEABILITY

Credit: BIG
FROM SLUDGE AND WET WASTE TO BIOGAS
FROM LOW COST ELECTRICITY TO H2 TO NATURAL GAS

• Biofoss, Lynetten, Copenhagen
  • Sludge to biogas
  • Biogas to city-gas for cooking and process energy
  • Sludge incineration to district heating
• Biofoss, Avedøre Holme, Copenhagen
  • Sludge to biogas
  • Biogas to natural gas and CO2
  • Sludge incineration to district heating
  • Power to H2 (test)
  • H2 and CO2 to natural gas (test)

• Nymindøgab MOD DK
  • Wet waste to biogas to CHP to heat and power
LARGE-SCALE SOLAR WATER HEATING
LARGE-SCALE SOLAR HEATING DEVELOPED IN 10 YEARS IN DK

- Marstal DH, 18,000 m² with subsidy
- Danish manufacturer ArconSunmark
- Status 2017, installed without subsidy
  - 100 plants in DK
  - Total panel area 1,100,000 m² in DK
  - +10,000 m² in Norway
  - +39,000 m² in Chile
  - +xx m² in USA
  - 155,000 m² in Silkeborg, so far the largest
- Heat Plan Denmark in 2035
  - 8 mio.m² estimated in DK
COST OF LARGE SCALE SOLAR FACTOR 3 FROM HOT TO MILD CLIMATE

<table>
<thead>
<tr>
<th>Temperatures in panels</th>
<th>Low DH temperature</th>
<th>High DH temperature</th>
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<tbody>
<tr>
<td></td>
<td>Mild</td>
<td>Warm</td>
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<tr>
<td>Climate zone</td>
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<tr>
<td>Annual solar radiation</td>
<td>kWh/m² panel</td>
<td>1.150</td>
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<td>Average outdoor temperature</td>
<td>°C</td>
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<tr>
<td>Supply temperature</td>
<td>°C</td>
<td>60</td>
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<tr>
<td>Return temperature</td>
<td>°C</td>
<td>40</td>
</tr>
<tr>
<td>Expected production</td>
<td>kWh/m² panel</td>
<td>550</td>
</tr>
<tr>
<td>Investment in plant 10.000 m²</td>
<td>€/m² panel</td>
<td>200</td>
</tr>
<tr>
<td>Annual O&amp;M cost 10.000 m²</td>
<td>€/m² panel</td>
<td>2</td>
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<tr>
<td>Investment in plant 10.000 m²</td>
<td>€/MWh/a</td>
<td>364</td>
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<td>Capital costs, 30 year 3%</td>
<td>€/MWh</td>
<td>19</td>
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<tr>
<td>Annual operation costs</td>
<td>€/MWh</td>
<td>4</td>
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<tr>
<td>Average production cost</td>
<td>€/MWh</td>
<td>22</td>
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## Economy of Scale for Solar Heating

### Factor 3-6 from Field to Building Roof-Top

### Table: Economy of Scale for Solar Heating, Warm Climate Zone, Low DH Temperature

<table>
<thead>
<tr>
<th>Typical Heat Consumer</th>
<th>Building, Roof Top</th>
<th>District Heating, Field</th>
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</thead>
<tbody>
<tr>
<td>Size of Consumer</td>
<td>Small</td>
<td>Medium</td>
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<tr>
<td>Solar panel area</td>
<td>m²</td>
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<tr>
<td>Small</td>
<td>5</td>
<td>200</td>
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<tr>
<td>Medium</td>
<td>750</td>
<td>800</td>
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<tr>
<td>Large</td>
<td>2,000</td>
<td></td>
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<tr>
<td>Expected production</td>
<td>kWh/m² panel</td>
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</tr>
<tr>
<td>Small</td>
<td>1,000</td>
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<td>Medium</td>
<td>1,333</td>
<td>563</td>
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<tr>
<td>Large</td>
<td>2,000</td>
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<tr>
<td>Total annual investment</td>
<td>€/m² panel</td>
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<tr>
<td>Small</td>
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<td>7</td>
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<tr>
<td>Medium</td>
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<tr>
<td>Annual O&amp;M cost</td>
<td>€/m² panel</td>
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<tr>
<td>Small</td>
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<tr>
<td>Medium</td>
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<tr>
<td>Investment in plant</td>
<td>€/MWh/a</td>
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<td>Capital costs, 30 year 3%</td>
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<td>Small</td>
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<td>Large</td>
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<td>Annual operation costs</td>
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<td>Medium</td>
<td></td>
<td></td>
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<tr>
<td>Large</td>
<td></td>
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</tr>
</tbody>
</table>

### Notes:
- Typical heat consumer: Small, Medium, Large
- Solar panel area: m²
- Expected production: kWh/m² panel
- Total annual investment: €/m² panel
- Annual O&M cost: €/m² panel
- Investment in plant: €/MWh/a
- Capital costs, 30 year 3%: €/MWh
- Average production cost: €/MWh

*Source: Ramboll*
THANK YOU FOR YOUR ATTENTION QUESTIONS & ANSWERS

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