Cost analysis for Cold District Heating versus Low Temperature District Heating

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SMART ENERGY SYSTEMS AND 4TH GENERATION
DISTRICT HEATING

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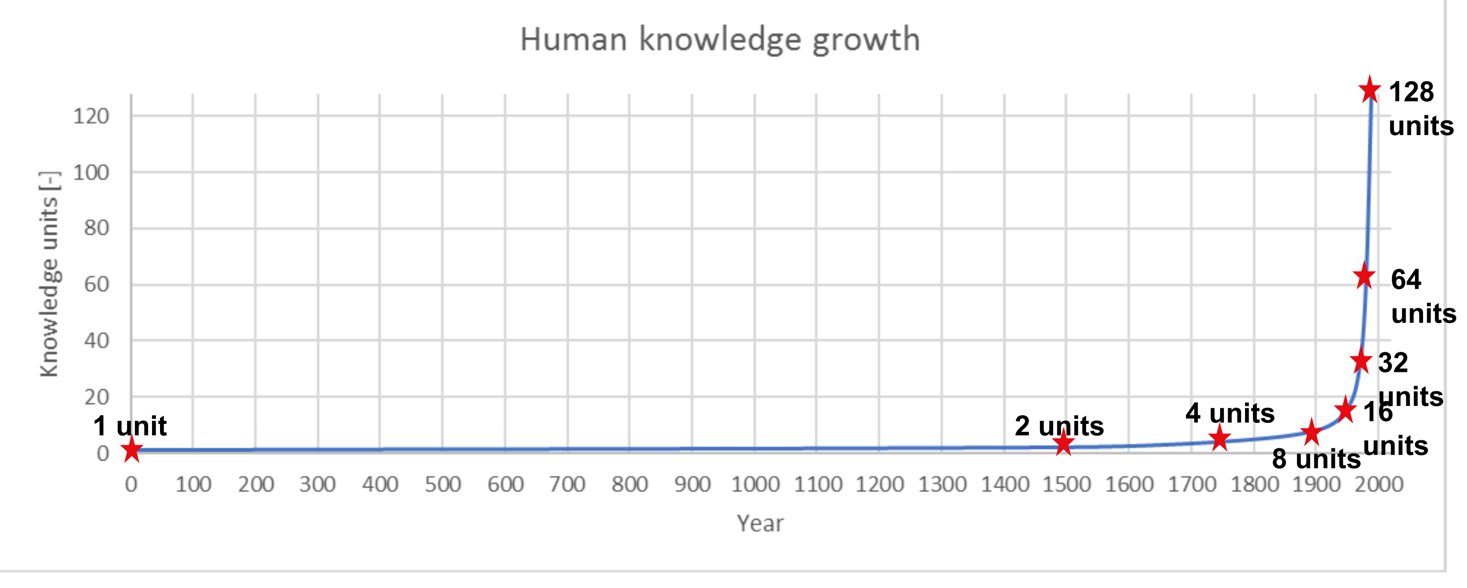
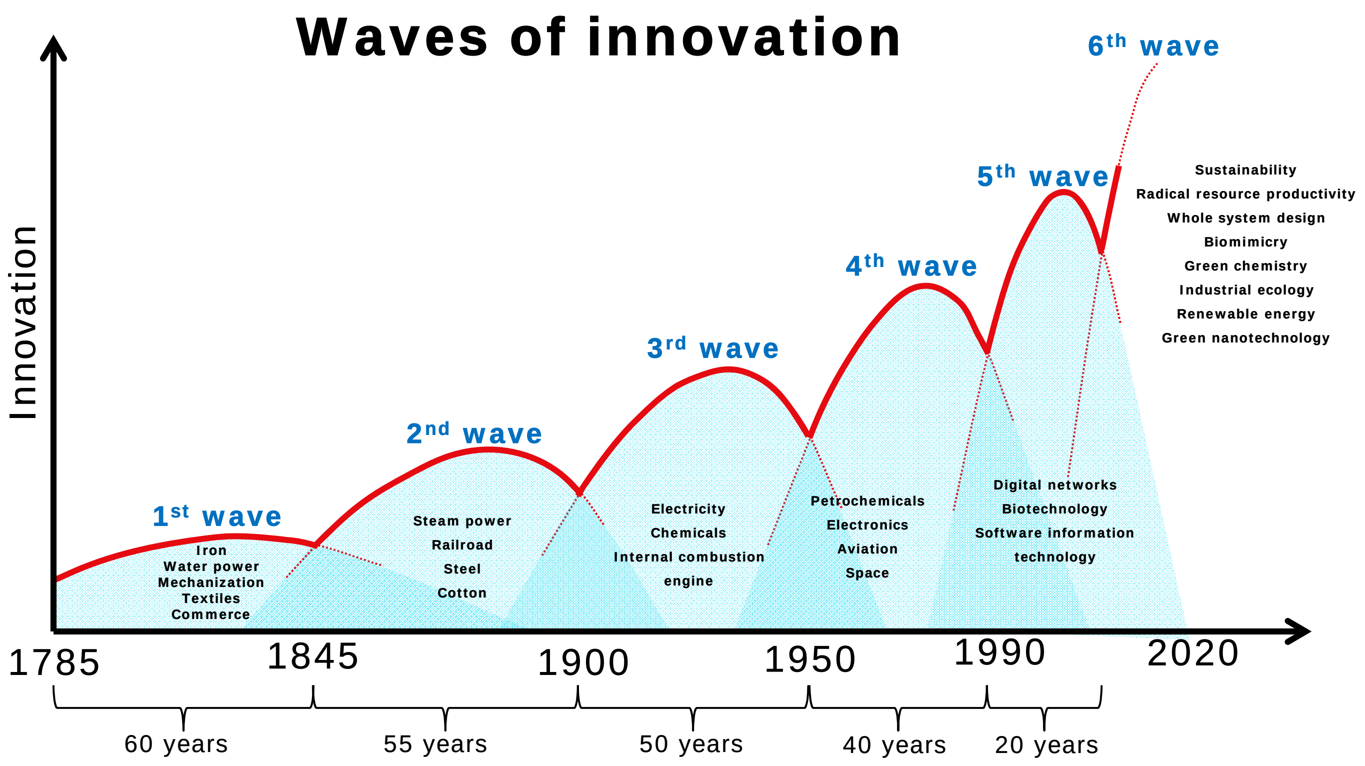
The knowledge doubling curve
- The American futurist Richard Buckminster Fuller

- In 1982 the American futurist Richard Buckminster Fuller estimated the time it has taken to double the human knowledge in the past
  - Fuller estimated that it took 1500 years to double the human knowledge of the base year zero!
  - From year 0 to year 1988 it is estimated the knowledge has 128 folded!
  - IBM estimates that today the human knowledge doubles every 13 months!
    - In the near future it could be every 12 hours…



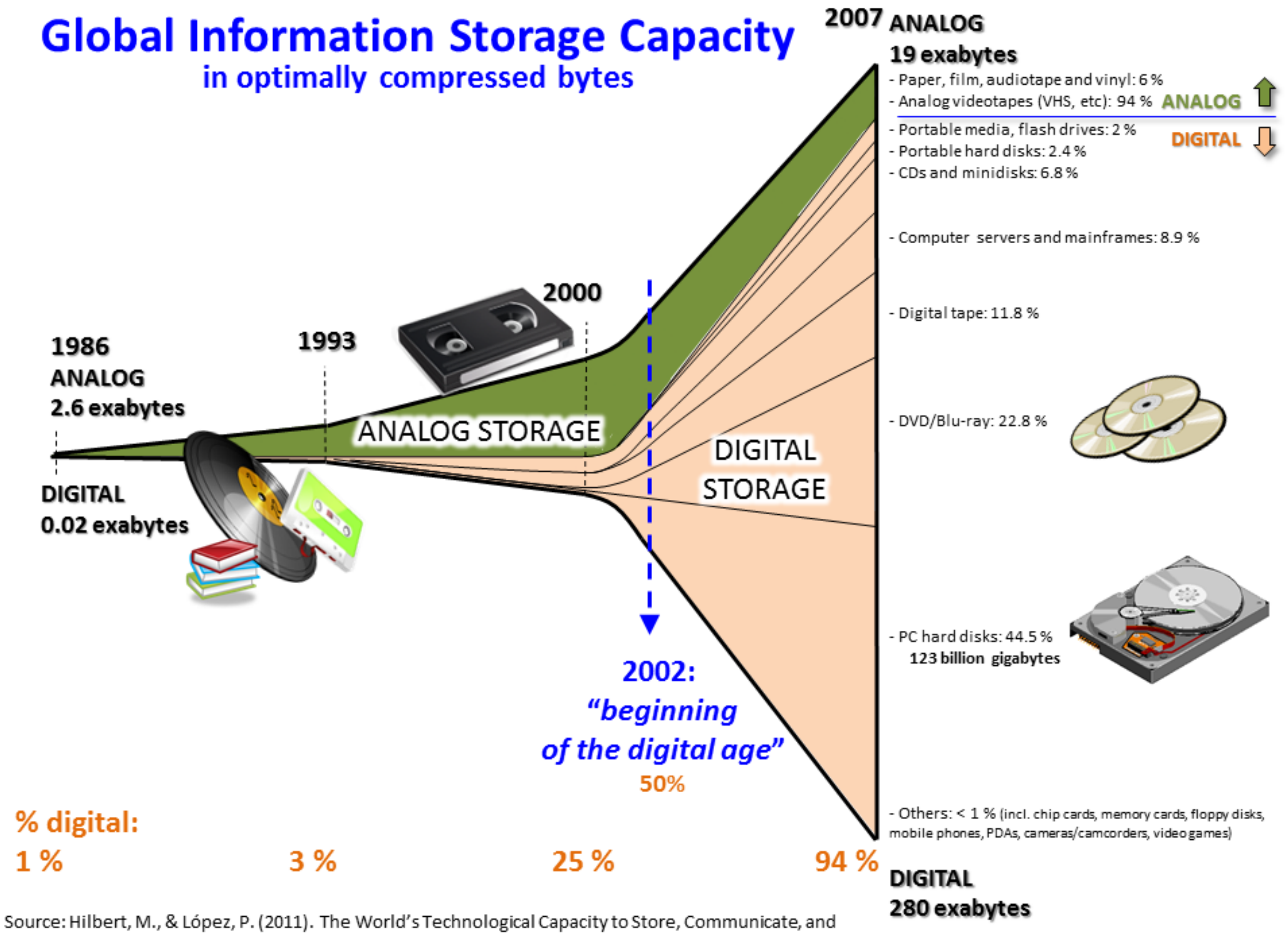
Waves of innovation

- When looking back in time it seems that innovations comes in waves with increasing frequency
  - The world is speeding forward and we in the DH industry should work hard to develop and position our technologies in respect to future innovations



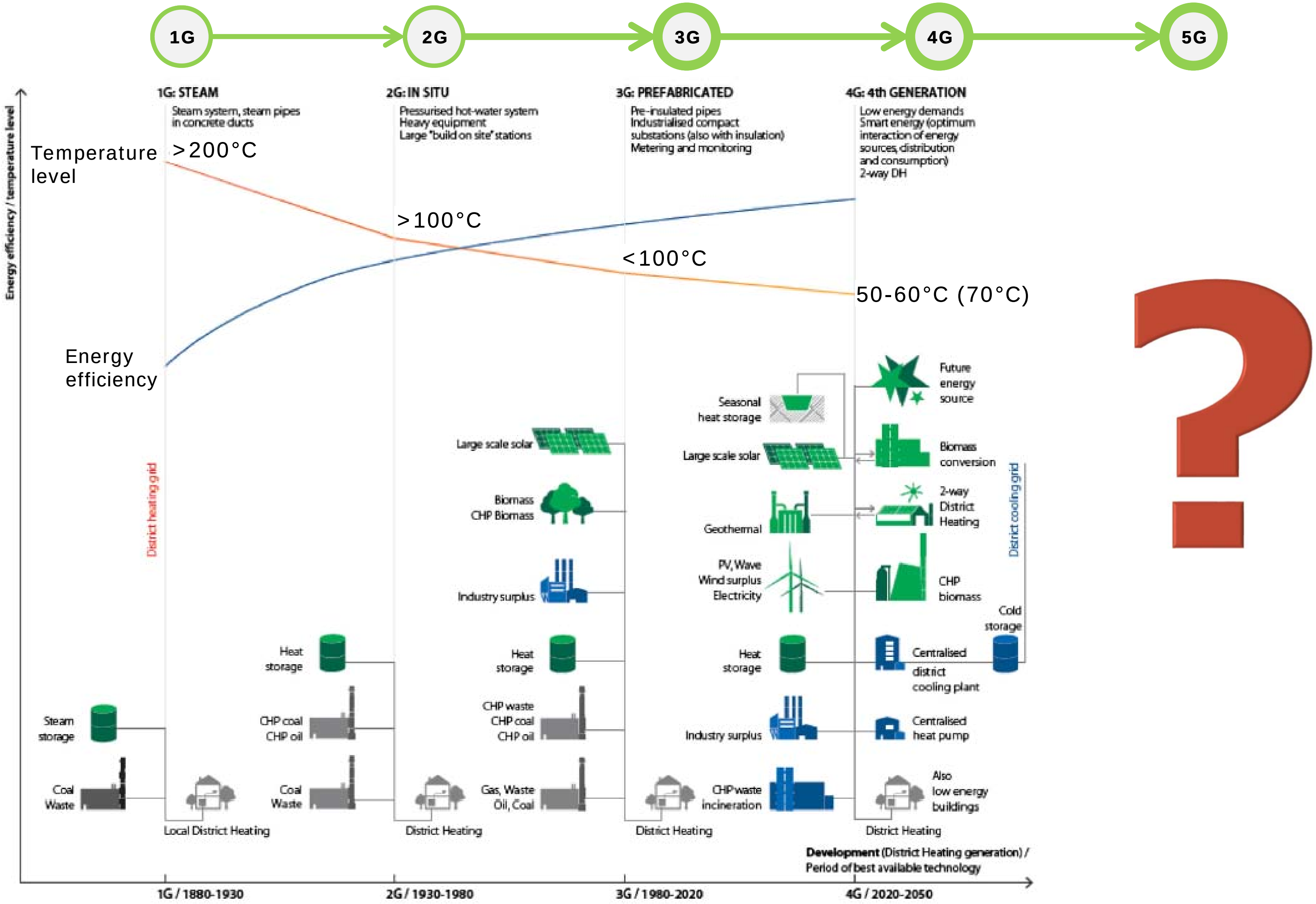
Source: The natural Edge Project 2004

The age of data has arrived..

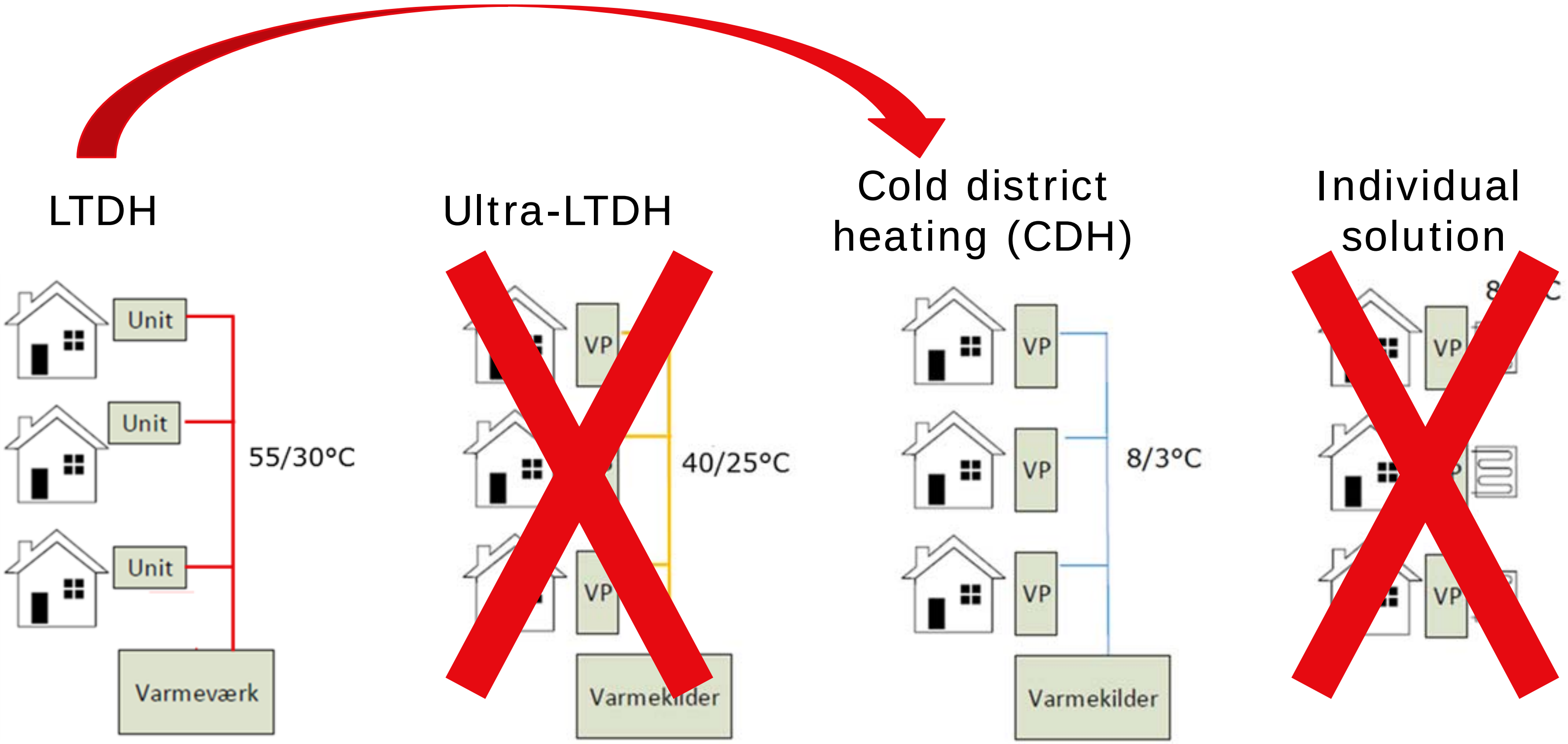


Source: Hilbert, M., & López, P. (2011). The World's Technological Capacity to Store, Communicate, and Compute Information. *Science*, 332(6025), 60 –65. http://www.martinhilbert.net/WorldInfoCapacity.html

District heating generations
- Mega trends



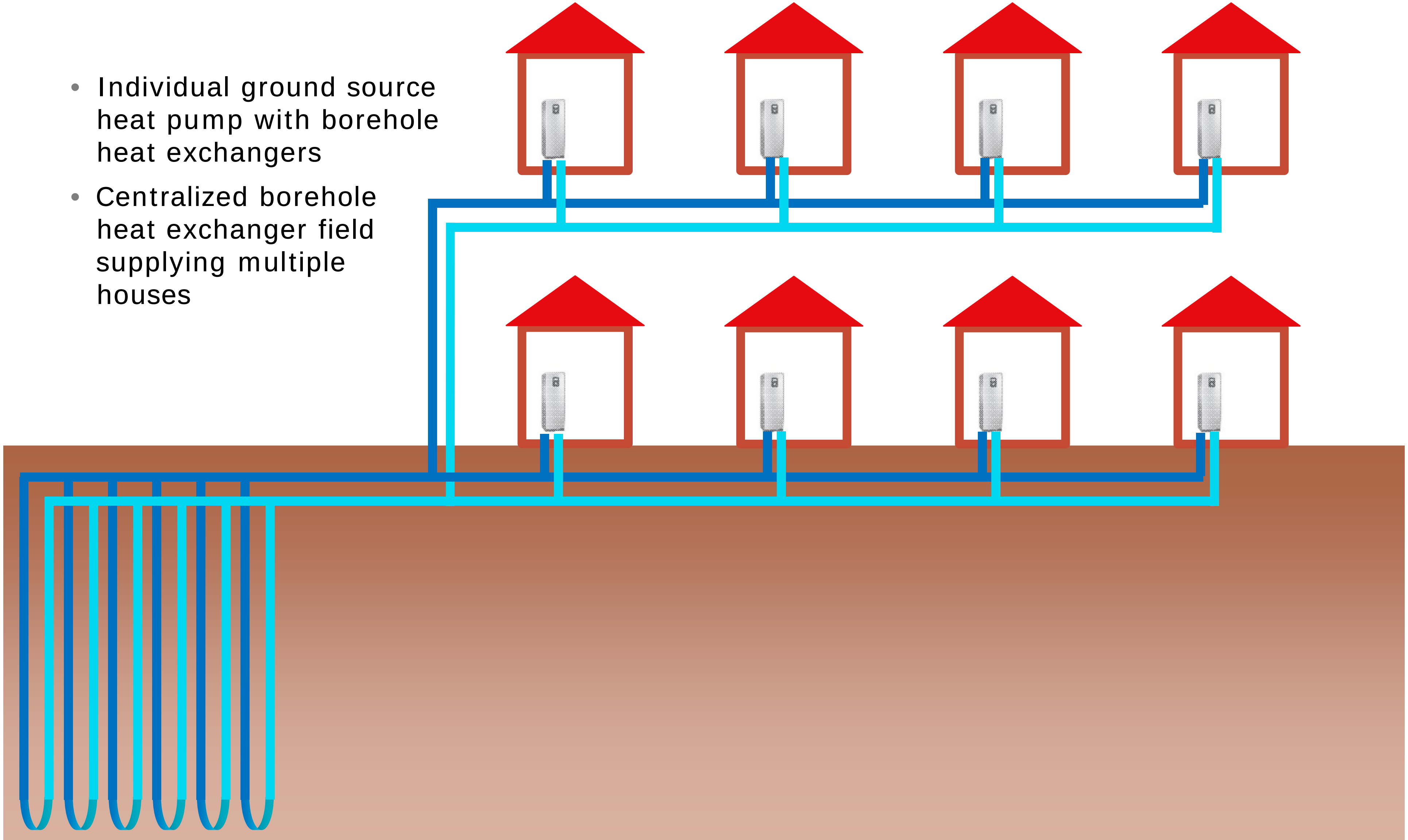
What could be next steps with reducing the temperature levels?



- **Basic requirement:**
  - The systems are supplying heat for both space heating and DHW purposes

Cold District Heating

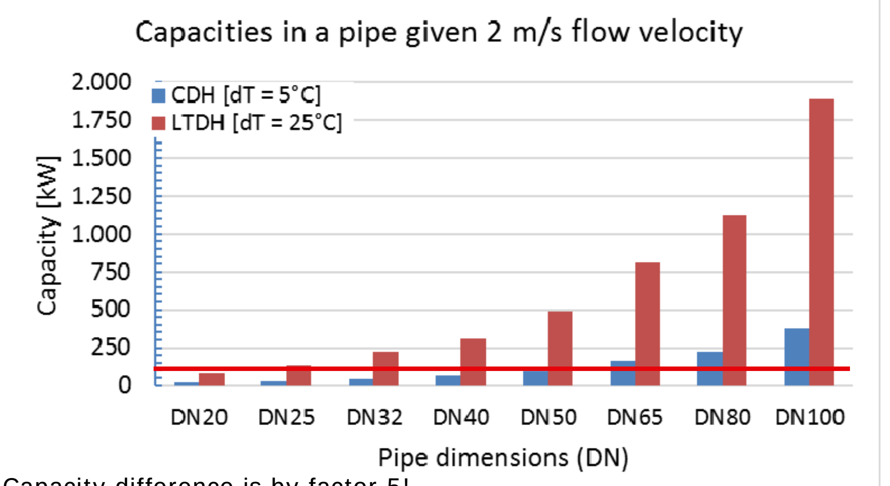
- Individual ground source heat pump with borehole heat exchangers
- Centralized borehole heat exchanger field supplying multiple houses



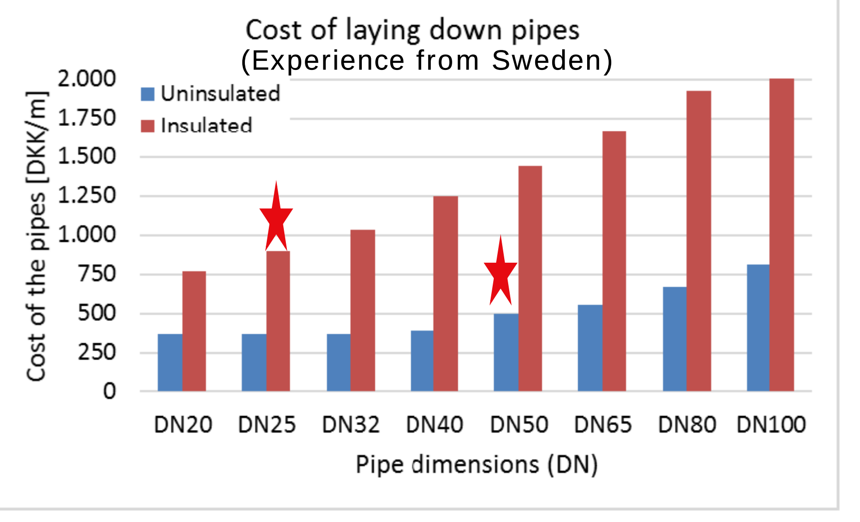
What are the main differences going from LTDH to CDH?

- Limited cooling of the supply
  - Results in large pipes and large flow rate

- No need for insulation on the pipes
  - Cheaper pipes



Capacity difference is by factor 5!



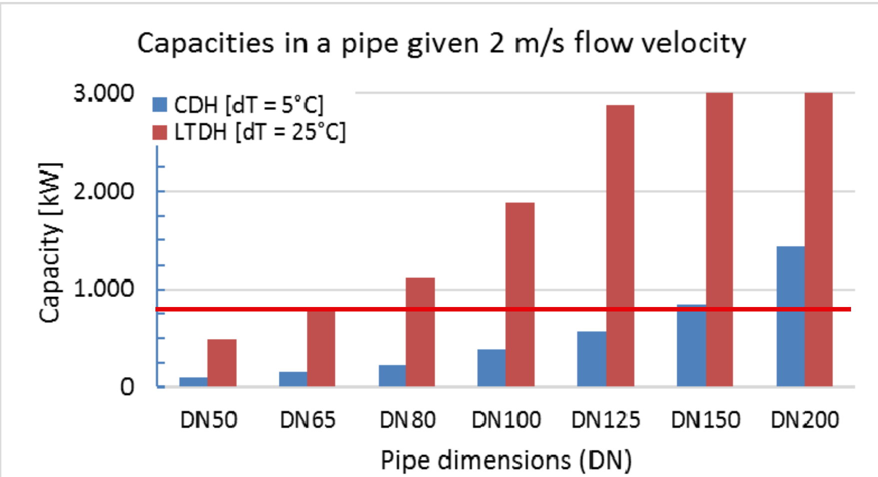
Pipe size to deliver 100 kW
LTDH ➔ DN25
CDH ➔ DN50

Cost of pipes to deliver 100 kW
LTDH ➔ DN25 ➔ 770 DKK
CDH ➔ DN50 ➔ 500 DKK
} CDH ~35% cheaper

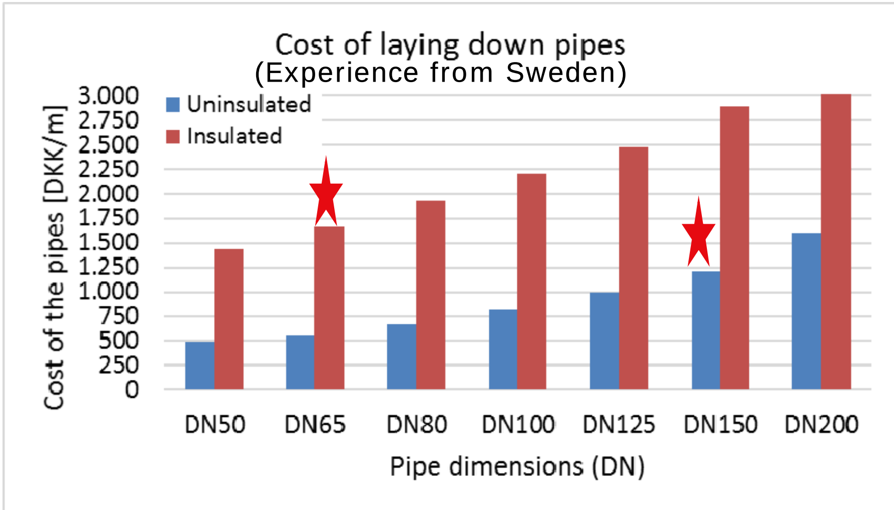
What are the main differences going from LTDH to CDH?

- Limited cooling of the supply
  - Results in large pipes and large flow rate

- No need for insulation on the pipes
  - Cheaper pipes



Capacity difference is by factor 5!



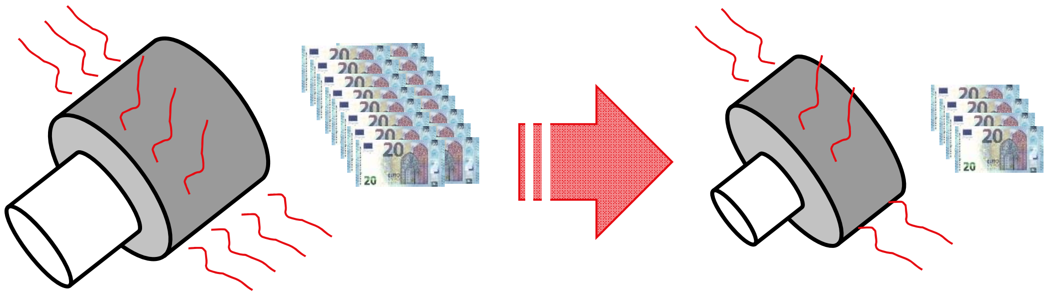
Pipe size to deliver 750 kW
LTDH ➔ DN65
CDH ➔ DN150

Cost of pipes to deliver 100 kW
LTDH ➔ DN65 ➔ 1.650 DKK
CDH ➔ DN150 ➔ 1.200 DKK
} CDH ~27% cheaper

Pipe network design

- The design of the distribution network is dependent on the operating cost and the operating limits of the equipment

- The main operating costs are:
  - Distribution heat loss



  - Pumping cost

Importance?	
LTDH	**CDH**
√	X
√	√

Heat demand of buildings in the study

- Low energy buildings are the future.
  But perhaps not low heating demand..

- **The idea was to go with the current DK building standard but take into account people behavior**

Table 1
Primary energy factors and energy frames for residential building in Denmark in accordance with BR08 and BR10.

Energy frame calculation [kWh/(m^2.a)]		Prim. energy factors	
		DH	Electricity
BR08			
Class BR08	70 + 2200/A[b]		
Low-energy class 1	35 + 1100/A	1	2.5
Low-energy class 2	50 + 1600/A		
BR10			
Class BR10	52.5 + 1650/A	1	2.5
Class 2015	30 + 1000/A	0.8	2.5/2.2[a]
Class 2020	20	0.6	1.8

[a] The value will be based on share of renewable sources, not decided yet.
[b] Gross heated area [m^2].

- Buildings fulfilling: Building Class 2015
  - Single family house: 6,25 MWh/year (159 m2)
  - Row house apartment: 4,3 MWh/year (110 m2)
  - Apartment building: 3,85 MWh/year (95 m2)
    - Likely this is too low estimation of heat demand..

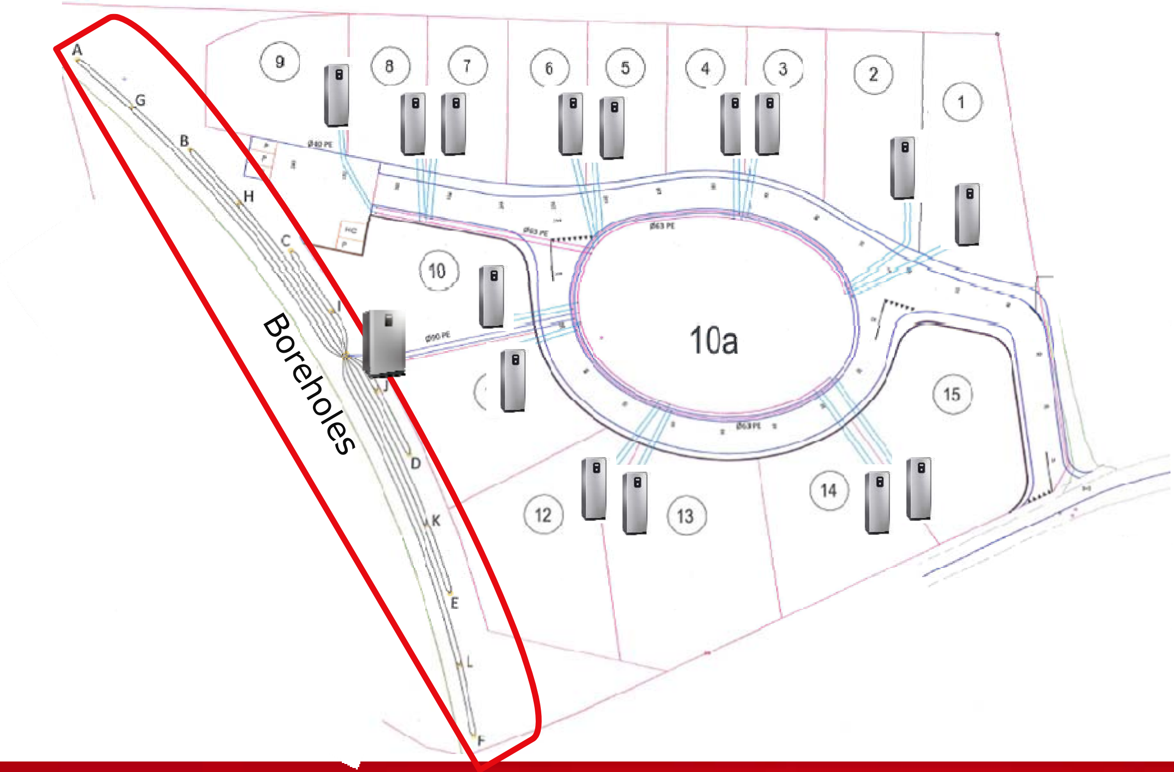
- **According to studies performed at DTU a more realistic demand could be:**
  - **Single family house: 10 MWh/year (159 m2)**
  - **Row house apartment: 7,5 MWh/year (110 m2)**
  - **Apartment building: 6,9 MWh/year (95 m2)**

Case 1

– Small network with 15 consumers

- **Basic idea:** Avoid individual boreholes and do a collective borehole field to supply decentralized heat pumps
  - **Reasoning:** Fewer boreholes = less cost
  - **Economic comparison:** Centralized heat pump vs. decentralized heat pumps

LTDH CDH



Case 1

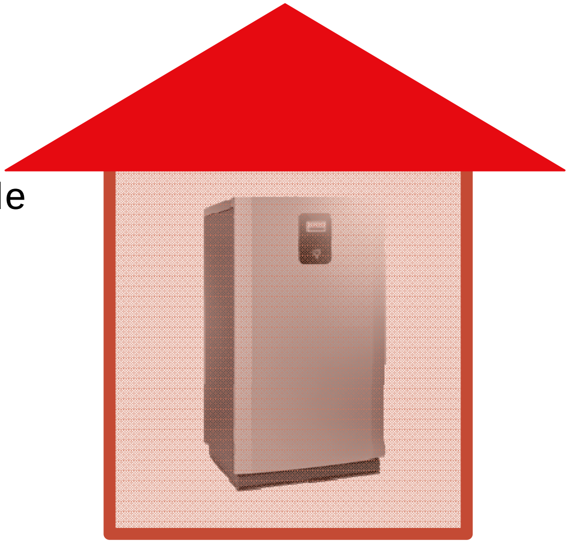
– Small network with 15 end consumers

- Basic results are following:

Network type	Cost of distribution [DKK]	Cost of consumer installation [DKK]	Cost of centralized heat pump [DKK]	Annualized cost of investment [DKK/y]	Maintenance and operation [DKK/y]	Cost of heat boosting [DKK/y]	Cost of heat loss [DKK/y]	TCO system [DKK/y]
CDH	427.000	1.035.000	0	108.000	25.000	48.700	0	181.700
LTDH	498.000	300.000	223.500	71.000	19.000	46.300	10.000	146.300
Difference CDH-LTDH				37.000	6.000	2.400	-10.000	35.400

Average TCO/year/house
- CDH ~12.100 DKK
- LTDH ~9.800 DKK

- Could LTDH be justified in this case?
  - Not necessarily..
  - Because:
    - Cost of the central HP does not include the housing cost



Assumptions:
Pipe network:
- Experience from Sweden
- CDH assuming prices from cold water distribution

House units
- Decentralized heat pump: 69.000 DKK → COP of 4.0
- Multi-apartment heat pump: 223.500 DKK → COP of 4.2
- DH substation: 20.000 DKK
- Multi-apartment substation: 94.000 DKK

Central unit
- Heat pump → COP of 4.2

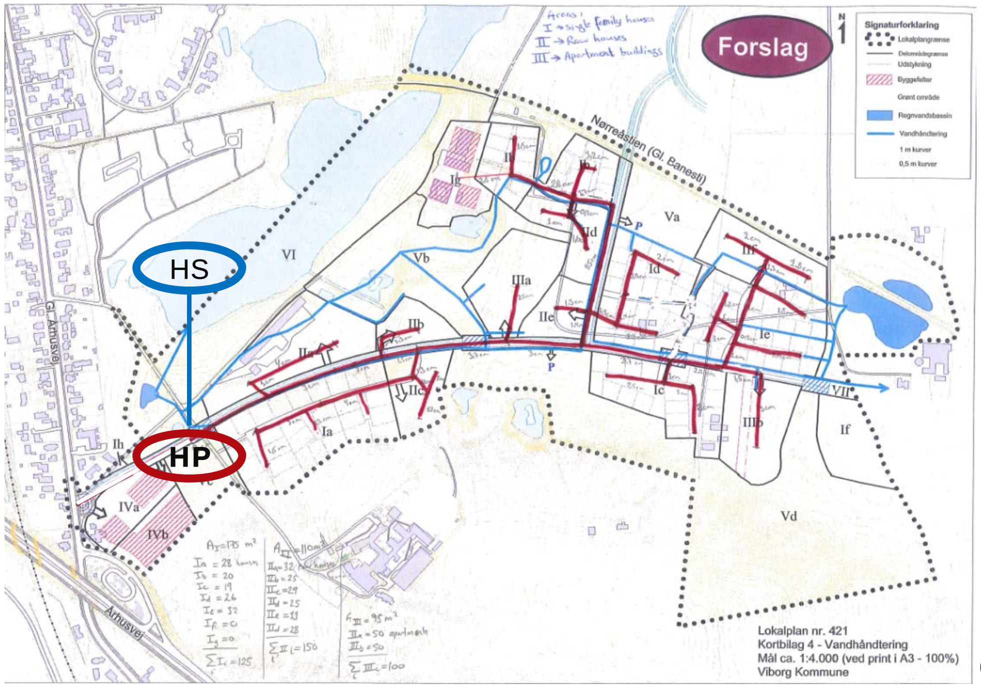
Other
- Electricity cost is the same for both cases
- Applied interest rate is 5%

Case 2

- Medium sized distribution network with 383 end consumers

- Are the results from **case 1** scalable?
- **Benefits towards CDH:** Larger the system the more heat loss, could that work in favor of DH?
- **Benefits towards LTDH:** The larger the system becomes the more money is available to invest in the centralized solution

- **System simplification:**
  To avoid multiple borehole fields it is assumed that there is a nearby lake that can be used as a heat source



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Case 2

- Medium sized distribution network with 383 end consumers

- Basic results are following:

Network type	Cost of distribution [DKK]	Cost of consumer installation [DKK]	Cost of centralized heat pump [DKK]	Annualized cost of investment [DKK/y]	Maintenance and operation [DKK/y]	Cost of heat boosting [DKK/y]	Cost of heat loss [DKK/y]	TCO system [DKK/y]
CDH	5.728.000	20.419.000	0	1.956.000	508.000	988.000	0	3.452.000
LTDH	8.095.000	6.036.000	6.258.000	1.419.000	451.000	940.000	213.000	3.023.000
Difference CDH-LTDH				537.000	57.000	48.000	-213.000	429.000

Included

- LTDH is favorable!

Average TCO/year/house
- CDH ~9.000 DKK
- LTDH ~7.900 DKK

Assumptions:
Pipe network:
- Experience from Sweden
- CDH assuming prices from cold water distribution

House units
- Decentralized heat pump: 69.000 DKK → COP of 4.0
- Multi-apartment heat pump: 223.500 DKK → COP of 4.2
- DH substation: 20.000 DKK
- Multi-apartment substation: 94.000 DKK

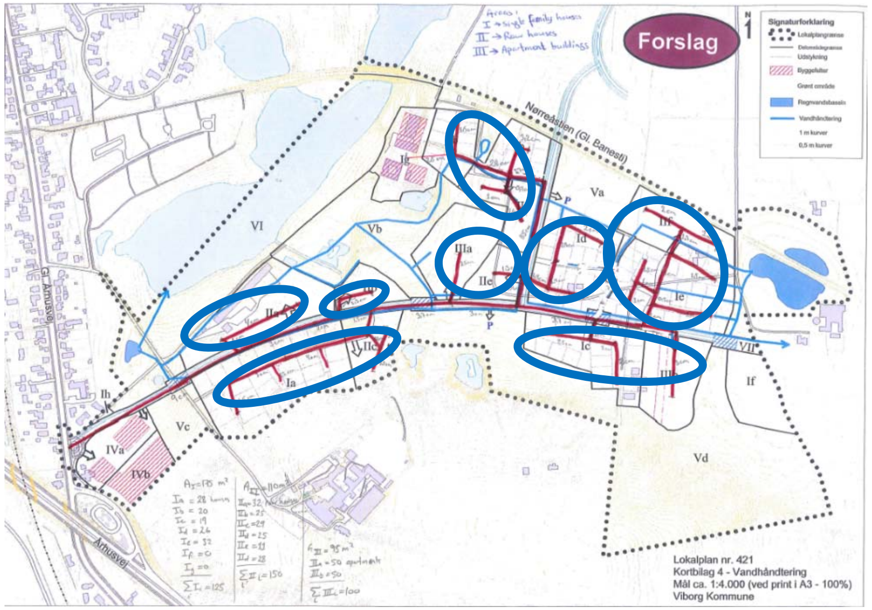
Central unit
- Heat pump → COP of 3.5

Other
- Electricity cost is the same for both cases
- Applied interest rate is 5%

Case 3

- What if there is no lake?

- Now we would compare multiple small CDH systems with one large LTDH



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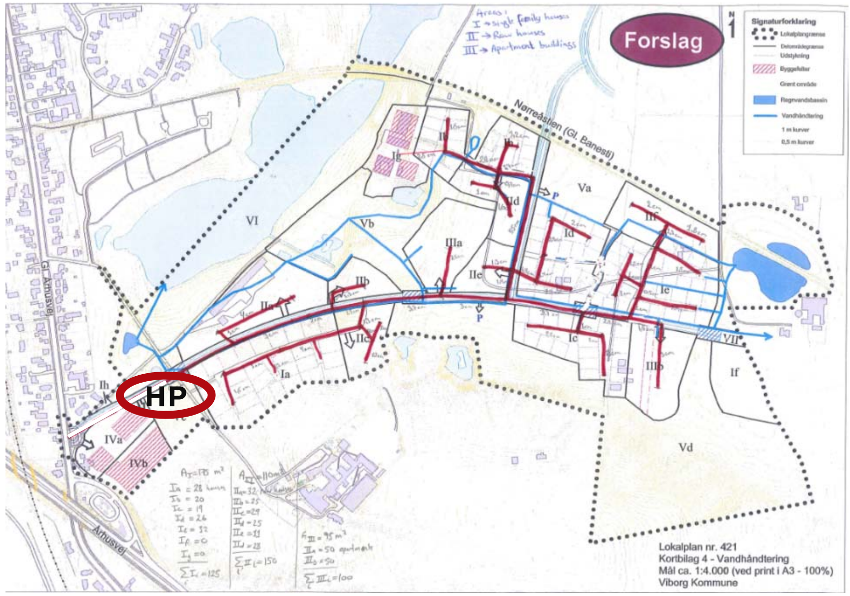


- In this case the comparison will be between case 1 and case 2 supplied with air source heat pump

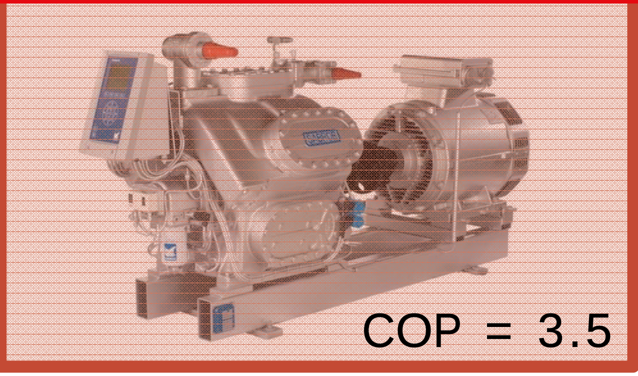
Comparison of TCO between CDH and LTDH with A2W heat pump

- Basic results are following:

Network type	Cost of distribution [DKK]	Cost of consumer installation [DKK]	Cost of centralized heat pump [DKK]	Annualized cost of investment [DKK/y]	Maintenance and operation [DKK/y]	Cost of heat boosting [DKK/y]	Cost of heat loss [DKK/y]	TCO system [DKK/y]
LTDH	8.095.000	6.036.000	6.258.000	1.419.000	451.000	1.129.000	256.000	3.255.000
				Case 3 – A2W LTDH		TCO/house		8.500
				Case 1 – CDH		TCO/house		12.000

Included

- LTDH is still favorable!
  - Note: The cost of drilling the geothermal wells for CDH are excluded!



Average TCO/year/house
- CDH ~12.000 DKK
- LTDH ~8.500 DKK

Assumptions:
Pipe network:
- Experience from Sweden
- CDH assuming prices from cold water distribution

House units
- Decentralized heat pump: 69.000 DKK → COP of 4.0
- Multi-apartment heat pump: 223.500 DKK → COP of 4.2
- DH substation: 20.000 DKK
- Multi-apartment substation: 94.000 DKK

Central unit
- Heat pump → COP of 4.2

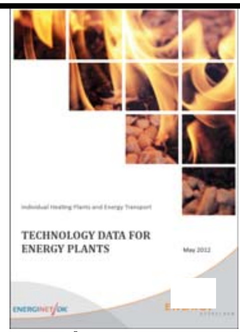
Other
- Electricity cost is the same for both cases
- Applied interest rate is 5%

What could influence the results?

- Heat sources
  1. Currently there is a wide price range for both small and large heat pumps
  2. A major benefit of district heating is the option to use the cheapest available heat

- COP of the heat pumps
  - For single family heat pumps a COP of 4,0 was used
  - For the larger W2W heat pumps COP of 4,2 was used
  - For the larger A2W heat pumps COP of 3,5 was used

- Source of the electricity
  - Being a large consumer gives some possibilities to receive cheaper electricity



Annual average:

3,3 for FH, 3 for radiators

4,3

3,7

Cost of electricity for industry
- Info from the "Drejebog til store varmepumpeprojekter i fjernvarmesystemet"

- The cost of electricity to an industry identity, such as DH utility, varies:
  - How the consumer is connected to the grid
  - Location (which electricity company is the supplier)

Elomkostning	Sats [kr./kWh]
Elpris (gennemsnit af fastpriskurs 2015-2019 DK2 (øst) inkl. handelsomkostninger)	0,280
Net- og systemtarif (2014)	0,069
Distributionstarif (B-lav, varierer i 2014 fra 0,048-0,231)	0,133
Elafgift (2014)	0,412
PSO-tarif (3. kvartal 2014)	0,230
I alt	**1,124**

Which Voltage:

Kunde	Distributionstarif [kr./MWh]	Aftagepunkt
C	287	0,4 kV-nettet
B-lav	131	På 0,4 kV siden af 10/0,4 kV transformerstation
B-høj	109	10 kV-nettet
A-lav	41	På 10 kV siden af en hovedstation
A-høj	38	50/30 kV-nettet
A-0	1	132 kV-nettet

Heat pumps in district heating

Afgift [kr./MWh]	2014	2015 (LOV nr. 1174, 2014)
Alm. elafgift	833	878
Refusion ved anvendelse til fjernvarme	-421	-498
Netto elafgift for fjernvarmeproducenter	412	380

Whom is the electricity provider?

Distributionstarif [kr./MWh]	B-lav	B-høj	A-høj
Højeste	231	150	86
Laveste	48	58	30
Uvægtet gennemsnit	133	106	50

- Bottom line is that it matters whom is buying the electricity!
  - In this analysis it was although considered that the same electricity price would be used in both individual heat pumps and centralized heat pumps

Conclusions

- The main obstacle for CDH is the high cost of decentralized heat pumps

- Given the assumptions, the benefits of CDH over LTDH are not obvious.
  - Even in case of air source heat pumps the CDH is not an economically feasible solution

- **Advantages of LTDH over CDH**
  - If alternative heat sources become available it would be simpler and more cost efficient to add them to the LTDH than the CDH system
  - LTDH will be simpler to operate due to more centralized location of equipment
  - If the DHU can get cheaper electricity prices it will significantly favor the LTDH
  - In a large system a centralized thermal storage would allow to optimize the operation in case of:
    - Fluctuating electricity prices from renewables
    - Peak load smoothing

- **Advantages of CDH over LTDH**
  - With the low supply temperatures it would be possible to provide cooling during the summer period

Thank you for your attention

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Data sources

- Main data sources are coming from:
- **Estimation of cost of laying down the distribution network:**
  - Nordenswan, T. (2007). *Kulvertkostnadskatalog.* Stockholm: Svensk Fjarrrvarme.
    - The costs were adapted to inflation between 2007 and 2016 (12%)
  - Cost of uninsulated PE/PEX pipes and installation in case of CDH is coming from the Vandprishåndbogen
- **Centralized heat pump data**
  - Cost of heat pumps with various capacities
    - Danish Energy Agency. (2016). *Technology Data for Energy Plants - Updated chapters, August 2016.*
    - Christian Boissavy. (2015). *Cost and Return on Investment for Geothermal Heat Pump Systems in France.* Link to report
- **Decentralized equipment**
  - DH substation:
    - Danfoss A/S
    - Danish Energy Agency. (2016). *Individual Heating Plants and Energy Transport. Technology data for heating plants.* Danish Energy Agency.
  - Heat pump cost and efficiency data
    - Cost of decentral heat pump is acquired from Søren Andersen from Skjold-Andersen.
    - Danish Energy Agency. (2016). *Technology Data for Individual Heating Plants and Energy Transport - Updated chapters, August 2016*

Electricity prices

- Residential electricity price in DK is: 1.79 DKK/kWh (excluding VAT)
  - Electricity for space heating with a heat pump is subsidized: 1.15 DKK/kWh (ex. VAT)

- Depending on at what stage in the power distribution system the electricity is taken the industry can avoid certain taxes and transportation fees.
  - In case the DH company can access the power grid at high voltages it will make a significant benefit towards the centralized solution
  - See next slide on possible variations of electricity price for large consumers and DHU

- Data from the European commission on electricity prices by countries shows that the electricity prices vary between household and industry
  - This needs to be considered when comparing the systems outside DK

	Electricity prices						Gas prices					
	Households (¹)			Industry (²)			Households (³)			Industry (⁴)		
	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
EU-28	0.202	0.206	0.211	0.118	0.120	0.119	0.071	0.072	0.071	0.040	0.037	0.034
Euro area (⁵)	0.215	0.218	0.221	0.126	0.129	0.125	0.079	0.079	0.076	0.041	0.038	0.035
Belgium	0.222	0.204	0.235	0.110	0.109	0.108	0.067	0.065	0.062	0.034	0.029	0.029
Bulgaria	0.088	0.090	0.096	0.073	0.076	0.078	0.052	0.048	0.039	0.035	0.034	0.027
Czech Republic	0.149	0.127	0.129	0.099	0.082	0.078	0.058	0.056	0.058	0.033	0.030	0.029
Denmark	0.294	0.304	0.304	0.100	0.097	0.091	0.098	0.088	0.076	0.044	0.037	0.034
Germany	0.292	0.297	0.295	0.144	0.152	0.149	0.069	0.068	0.068	0.048	0.040	0.038
Estonia	0.137	0.133	0.129	0.097	0.093	0.096	0.048	0.049	0.038	0.035	0.037	0.027
Ireland	0.241	0.254	0.245	0.137	0.136	0.136	0.072	0.075	0.072	0.047	0.042	0.037
Greece	0.170	0.179	0.177	0.124	0.130	0.115	0.089	0.080	0.075	0.051	0.047	0.036
Spain	0.227	0.237	0.237	0.120	0.117	0.113	0.089	0.096	0.093	0.038	0.037	0.032
France	0.160	0.162	0.168	0.086	0.093	0.095	0.073	0.076	0.073	0.039	0.038	0.037
Croatia	0.135	0.132	0.131	0.094	0.092	0.093	0.047	0.048	0.046	0.043	0.040	0.035
Italy	0.232	0.234	0.243	0.172	0.174	0.160	0.095	0.095	0.091	0.038	0.035	0.032
Cyprus	0.248	0.236	0.184	0.201	0.190	0.141	–	–	–	–	–	–
Latvia	0.136	0.130	0.165	0.115	0.118	0.118	0.050	0.049	0.049	0.037	0.036	0.029