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Solar District Heating Systems

UPV-EHU, Bilbao, 01-04 December 2020

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 768567

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1. Context

1.1 Heat Loads in Buildings

- Energy balance of a building (Space Heating)
- Heating/Cooling Degree Days
- Domestic Hot Water preparation
- Energy Supply to EU households
- Need for renewables

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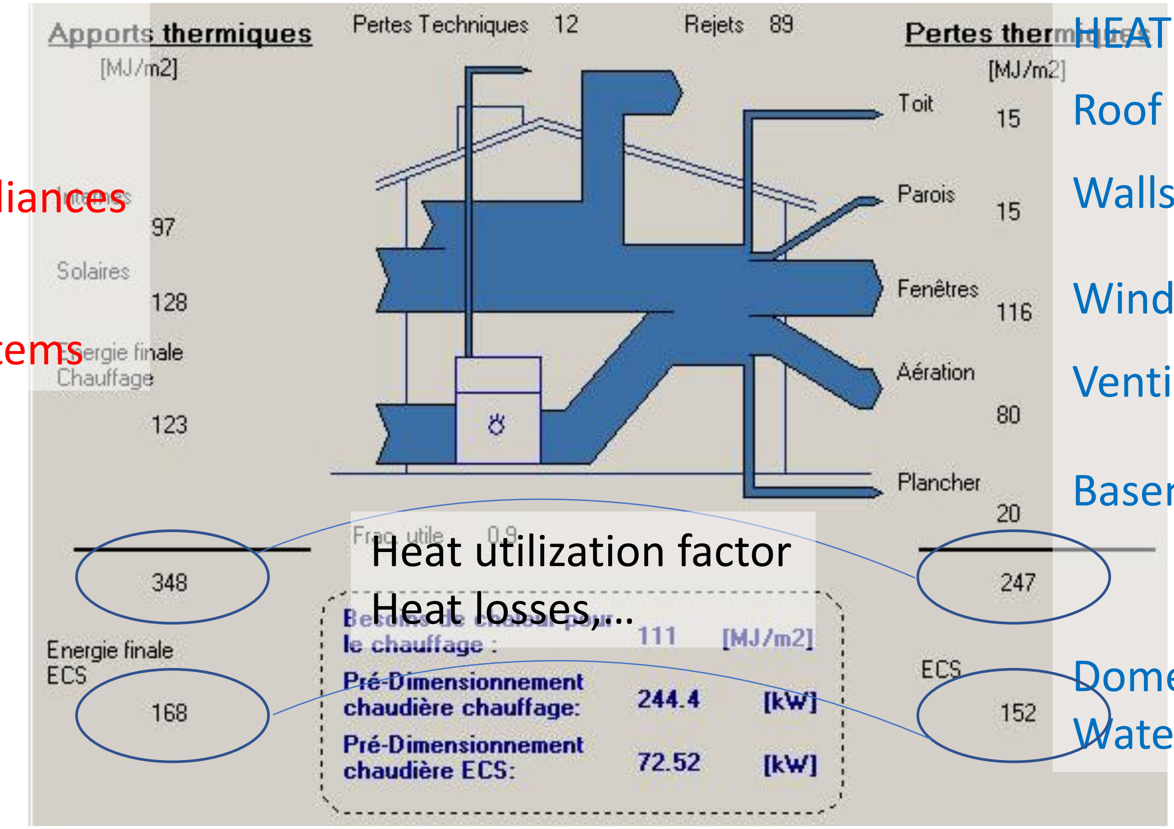
Energy balance of a building (Space Heating)

HEAT GAIN

People, appliances

Sun

Heating Systems



HEAT LOSS

Roof

Walls

Windows

Ventilation

Basement

Heat utilization factor

Heat losses,…

Domestic Hot Water

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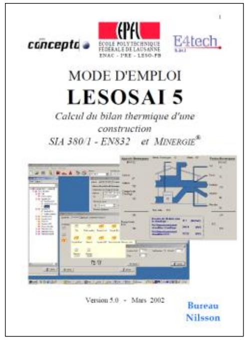

LESOSAI 5. Mode de Emploi. 2002.
https://docplayer.fr/57528916-Lesosai-5-calcul-du-bilan-thermique-d-une-construction-sia-380-1-en832-et-minergie.html

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Heating/Cooling Degree Days

- Heating & Cooling loads are correlated with outdoor temperaturas
- Degree-Day Methods compute negative/positive deviations of daily mean ambient temperatures vs a reference temperature
- Reference temperatures (typical)
  - Heating Degree Days: 15ºC
  - Cooling Degree Days: 23ºC
- Reference temperatures are building dependent
  - NZEB. HDD temp. ~10-12ºC
  - Glazed building. HDD temp. ~20ºC

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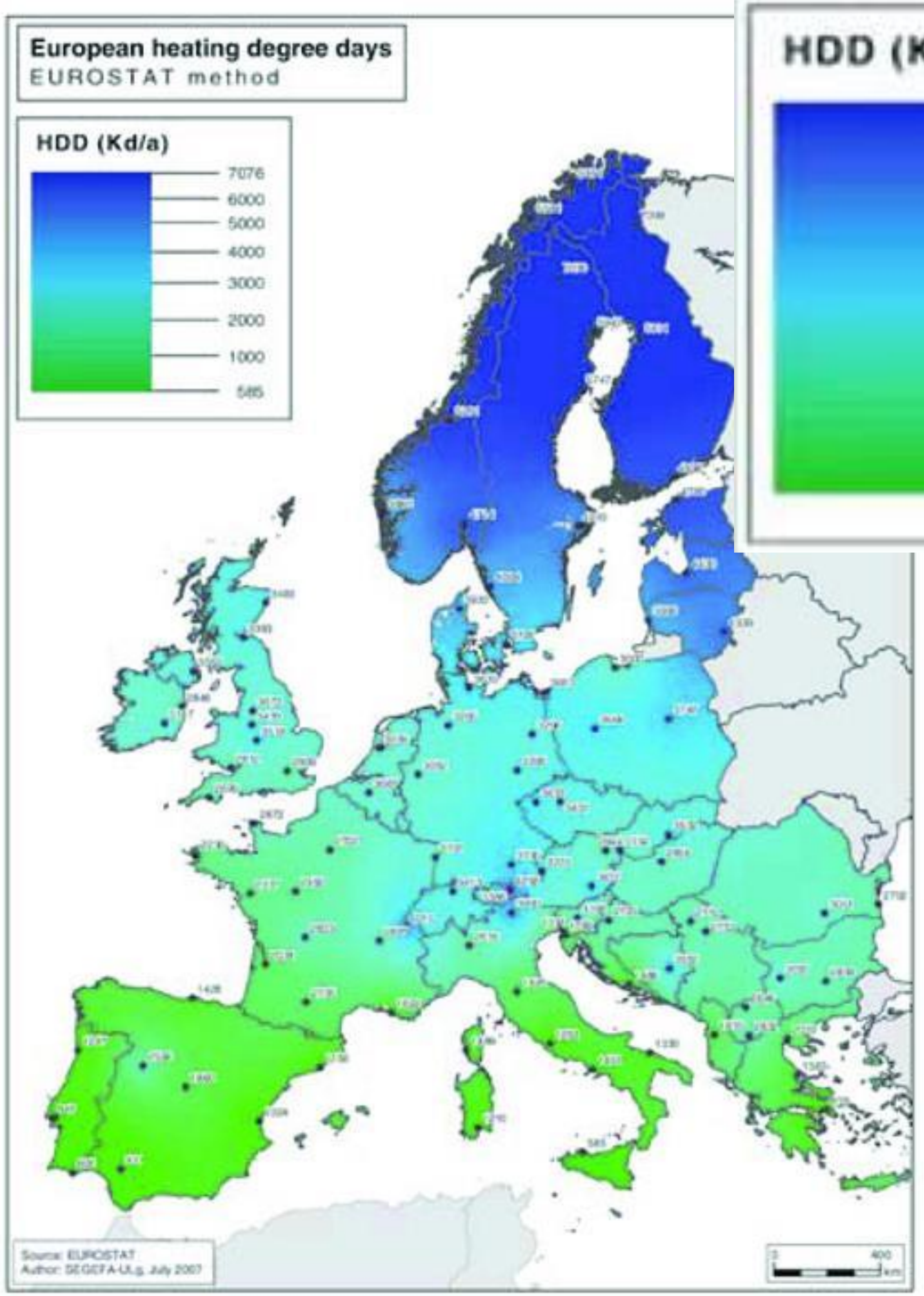
Figure 5: European heating degree days map (EUROSTAT method)



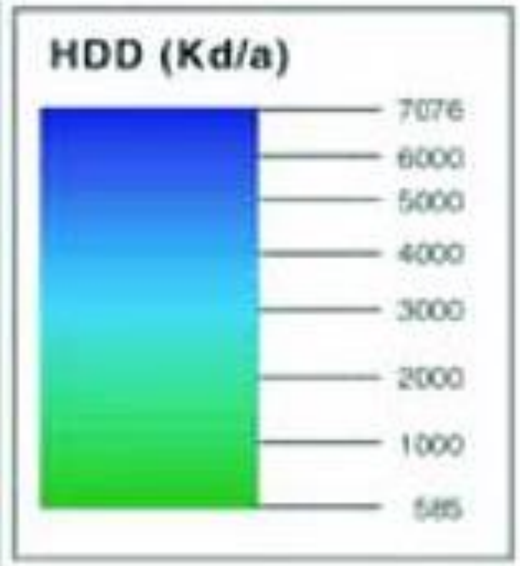
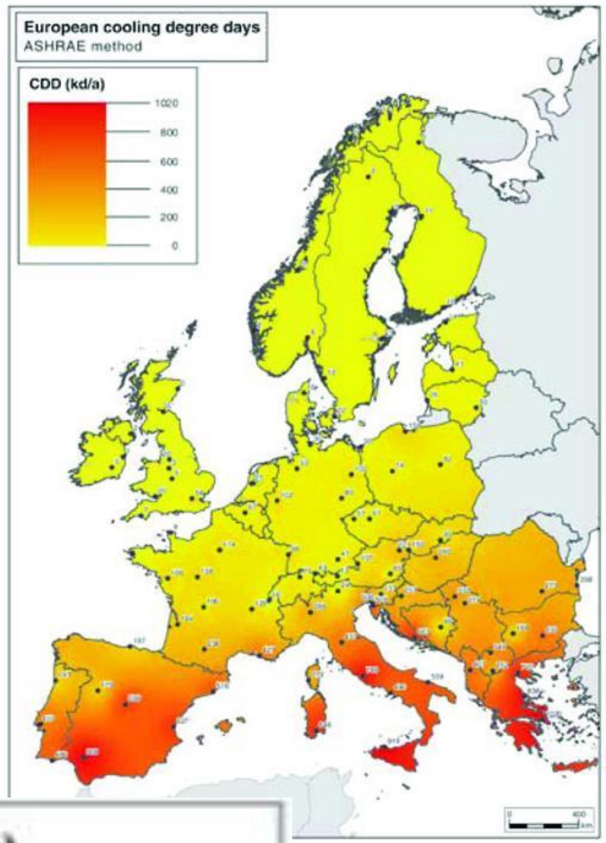
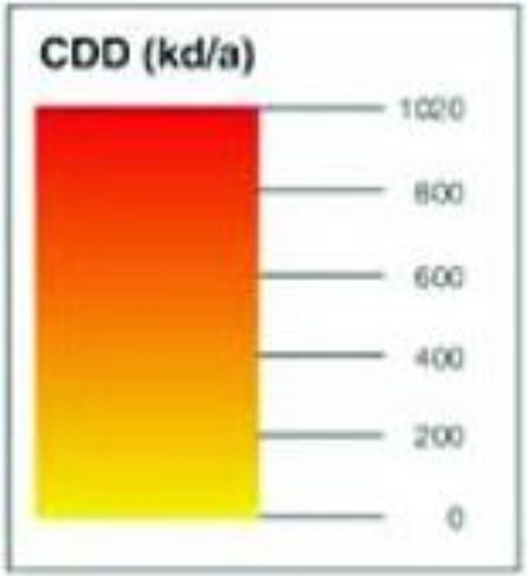


Figure 6: European cooling degree days map (ASHRAE method)





EURIMA, facts & figures https://www.eurima.org/resource-centre/facts-figures.html

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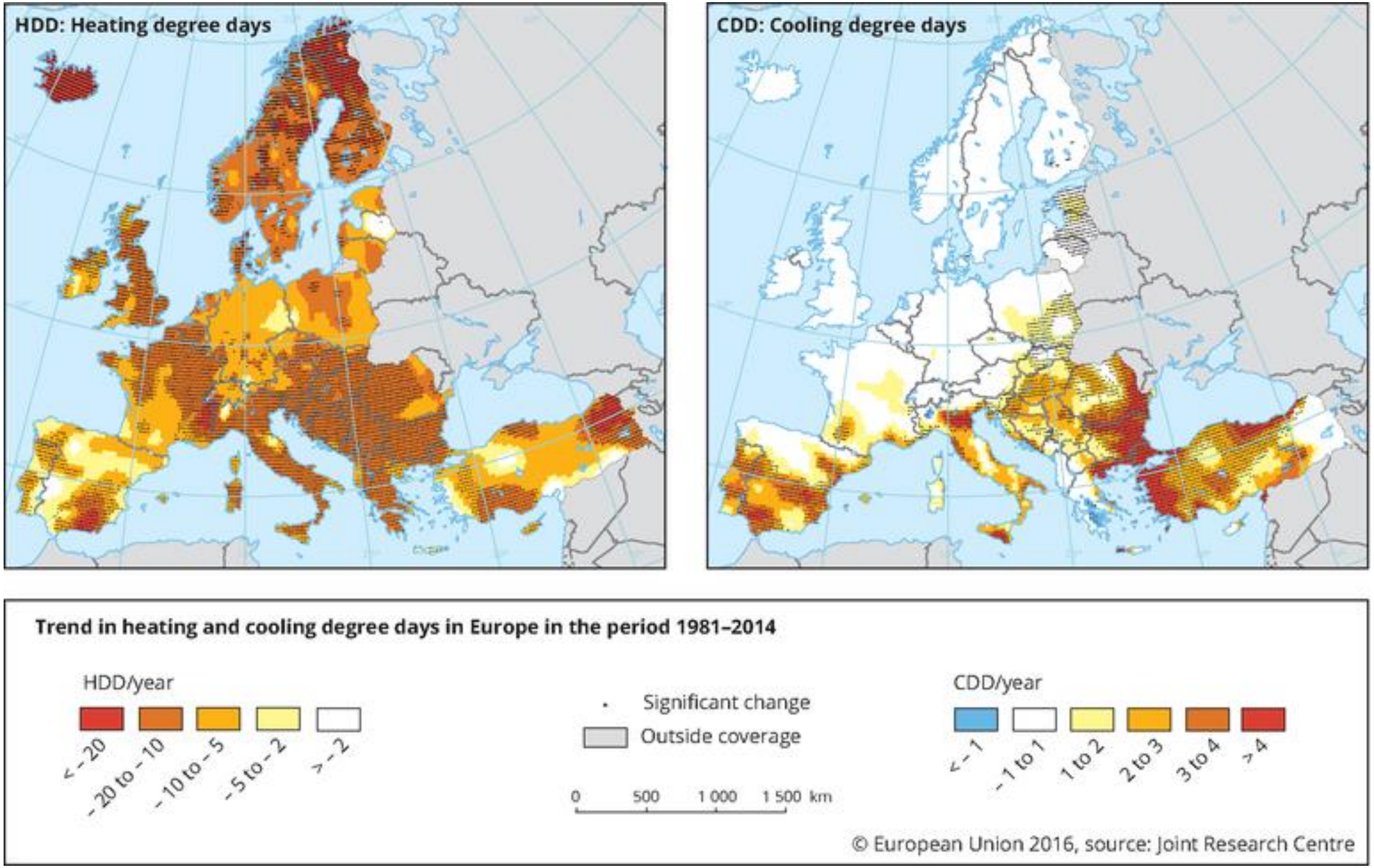

European Environmental Agency, Observed trends in heating & cooling degree days 1981-2017 https://www.eea.europa.eu/ds_resolveuid/f2a5588e42b543d4be499359c34ca617

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Provincia	Estación	Indicativo
Vizcaya	Bilbao (Aeropuerto Sondica)	1082

UBICACIÓN: ENTORNO CIUDAD

a.s.n.m. (m)	Lat.	Long.
39	43º17'53"	02º54'21" W

Nº DE OBSERVACIONES Y PERIODO

T seca	Hum. relativa	T terreno	Rad
87.600 (1998-2007)	(3) 29.200 (1998-2007)		58.400 (1998-2007)

CONDICIONES PROYECTO CALEFACCIÓN (TEMPERATURA SECA EXTERIOR MÍNIMA)

TSMIN (ºC)	TS_99,6 (ºC)	TS_99 (ºC)	OMDC (ºC)	HUMcoin (%)	OMA (ºC)
-6,0	-0,2	1,2	10,7	89	31,4

CONDICIONES PROYECTO REFRIGERACIÓN (TEMPERATURA SECA EXTERIOR MÁXIMA)

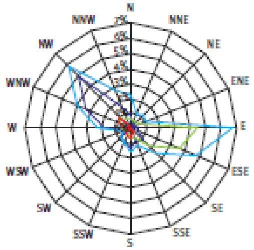
TSMAX (ºC)	TS_0,4 (ºC)	THC_0,4 (ºC)	TS_1 (ºC)	THC_1 (ºC)	TS_2 (ºC)	THC_2 (ºC)	OMDR (ºC)
41,9	31,2	21,9	28,8	21,3	26,8	20,6	16,3

CONDICIONES PROYECTO REFRIGERACIÓN (TEMPERATURA HÚMEDA EXTERIOR MÁXIMA)

TH_0,4 (ºC)	TSC_0,4 (ºC)	TH_1 (ºC)	TSC_1 (ºC)
22,8	30,6	21,8	29,5

VALORES MEDIOS MENSUALES

Rosa de los vientos: velocidad media 2,98 m/s



Calmas: 20%

HDD (15ºC)

HDD (20ºC)

CDD (20ºC)

Mes	TA (ºC)	TASOL (ºC)	GD_15 (ºC)	GD_20	GDR_20
Enero	9,3	10,9	183	332	0
Febrero	9,3	10,9	168	303	1
Marzo	11,8	13,7	126	258	4
Abril	12,8	14,5	94	221	5
Mayo	15,7	17,4	42	150	17
Junio	18,7	20,2	10	74	33
Julio	19,8	21,3	3	47	42
Agosto	20,7	22,4	2	36	58
Septiembre	18,9	21,1	11	69	37
Octubre	16,7	18,7	33	123	21
Noviembre	11,6	13,4	117	252	1
Diciembre	9,3	11,0	181	330	0

IDAE. Guía técnica Condiciones climáticas exteriores de proyecto. 2010
https://www.idae.es/uploads/documentos/documentos_12_Guia_tecnica_condiciones_climaticas_exteriores_de_proyecto_e4e5b769.pdf

B.1 Severidad climática de invierno

La severidad climática de invierno se obtiene mediante la siguiente expresión:

$$SCI = a \cdot GD + b \cdot \frac{n}{N} + c \cdot GD^2 + d \cdot \left(\frac{n}{N}\right)^2 + e \qquad (8)$$

donde:

GD es la suma de los grados-día de invierno en base 20 para los meses que van desde octubre a mayo.

n/N es el cociente entre número de horas de sol y el número de horas de sol máximas, sumadas cada una de ellas por separado para los meses que van desde octubre a mayo.

a, b, c, d, e son los coeficientes de regresión, cuyos valores se indican en la Tabla 1

Tabla 1: Coeficientes de regresión para la severidad climática de invierno (SCI)

a	b	c	d	e
3,546E-04	-4,043E-01	8,394E-08	-7,325E-02	-1,137E-01

Tabla 3: Intervalos para la zonificación de invierno

α	A	B	C	D	E
$SCI \leq 0$	$0 < SCI \leq 0,23$	$0,23 < SCI \leq 0,5$	$0,5 < SCI \leq 0,93$	$0,94 < SCI \leq 1,51$	$SCI > 1,51$

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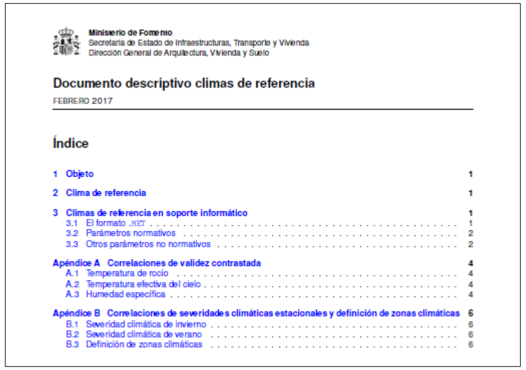
Ministerio de Fomento
Secretaría de Estado de Infraestructuras, Transporte y Vivienda
Dirección General de Arquitectura, Vivienda y Suelo

Documento descriptivo climas de referencia

FEBRERO 2017

Índice

CTE Documento de Apoyo. Documento descriptivo climas de referencia
https://www.codigotecnico.org/images/stories/pdf/ahorroEnergia/20170202-DOC-DB-HE-0-Climas%20de%20referencia.pdf

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Domestic Hot Water preparation

- ~ Stable heat load (+-20%)
- Calculations defined in building codes
  - Water Flow
  - Supply temperatura
- Source temperatura defined by climate. Stable ~8-18ºC

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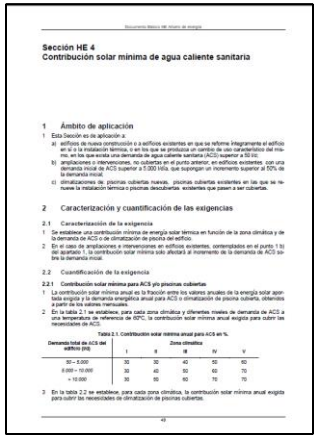
Tabla 4.1. Demanda de referencia a 60 °C[1]

Criterio de demanda	Litros/día·unidad	unidad
Vivienda	28	Por persona
Hospitales y clínicas	55	Por persona
Ambulatorio y centro de salud	41	Por persona
Hotel *****	69	Por persona
Hotel ****	55	Por persona
Hotel ***		
Hotel/hostal **		
Camping		
Hostal/pensión *		
Residencia		
Centro penitenciario		
Albergue		
Vestuarios/Duchas colec		
Escuela sin ducha		
Escuela con ducha		
Cuarteles		
Fábricas y talleres		
Oficinas		
Gimnasios		
Restaurantes	8	Por persona
Cafeterías	1	Por persona

	l/day-person
Dwellings	28
Hospital	55
Health centre	41
Hotel *****	69
Hotel ****	55
Hotel ***	41

Tabla 4.2. Minimum ocupancy in residential buildings for DHW calculation

Rooms	1	2	3	4	5	6	≥6
People	1,5	3	4	5	6	6	7



CTE Documento Básico HE 4. Contribución solar mínima de agua caliente sanitaria
https://www.codigotecnico.org/images/stories/pdf/ahorroEnergia/DBHE.pdf

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Domestic Hot Water preparation

Q = m * Cp * (T_sup – T_netw)

- m as defined in CTE HE4
- Cp = 4,18 kJ / (l*K)
- T_sup = 60 ºC
- T_source as per local climate

Tabla B.1 Temperatura diaria media mensual de agua fría (ºC)

Capital de provincia	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
A Coruña	10	10	11	12	13	14	16	16	15	14	12	11
Albacete	7	8	9	11	14	17	19	19	17	13	9	7
Alicante/Alacant	11	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13	12
Almería	12	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14	12
Ávila	6	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	6
Badajoz	9	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12	9
Barcelona	9	10	11	12	14	17	19	19	17	15	12	10
Bilbao/Bilbo	9	10	10	11	13	15	17	17	16	14	11	10
Burgos	5	6	7	9	11	13	16	16	14	11	7	6
Cáceres	9	10	11	12	14	18	21	20	19	15	11	9
Cádiz	12	12	13	14	16	18	19	20	19	17	14	12

Bilbao: 9-17ºC

- For educational purposes only
- Typical issues out of the scope of this exercises
  - Monthly variation
  - Variations in load profiles (e.g. vacations)
  - Complex behavior in buildings
  - Relationship with solar radiation
  - …

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EXERCISE 1

Heat Load for one building

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- Space Heating load of a building
  - Climate: 900 degree-days (~Bilbao)
  - Coupling Coefficient 200 W/K 4800 W.h/K.day 4.8 kW.h/K.day
  - Surface: 80 m2

  - Total load 4320 kWh/year
  - Specific load 54 kWh/m2.year

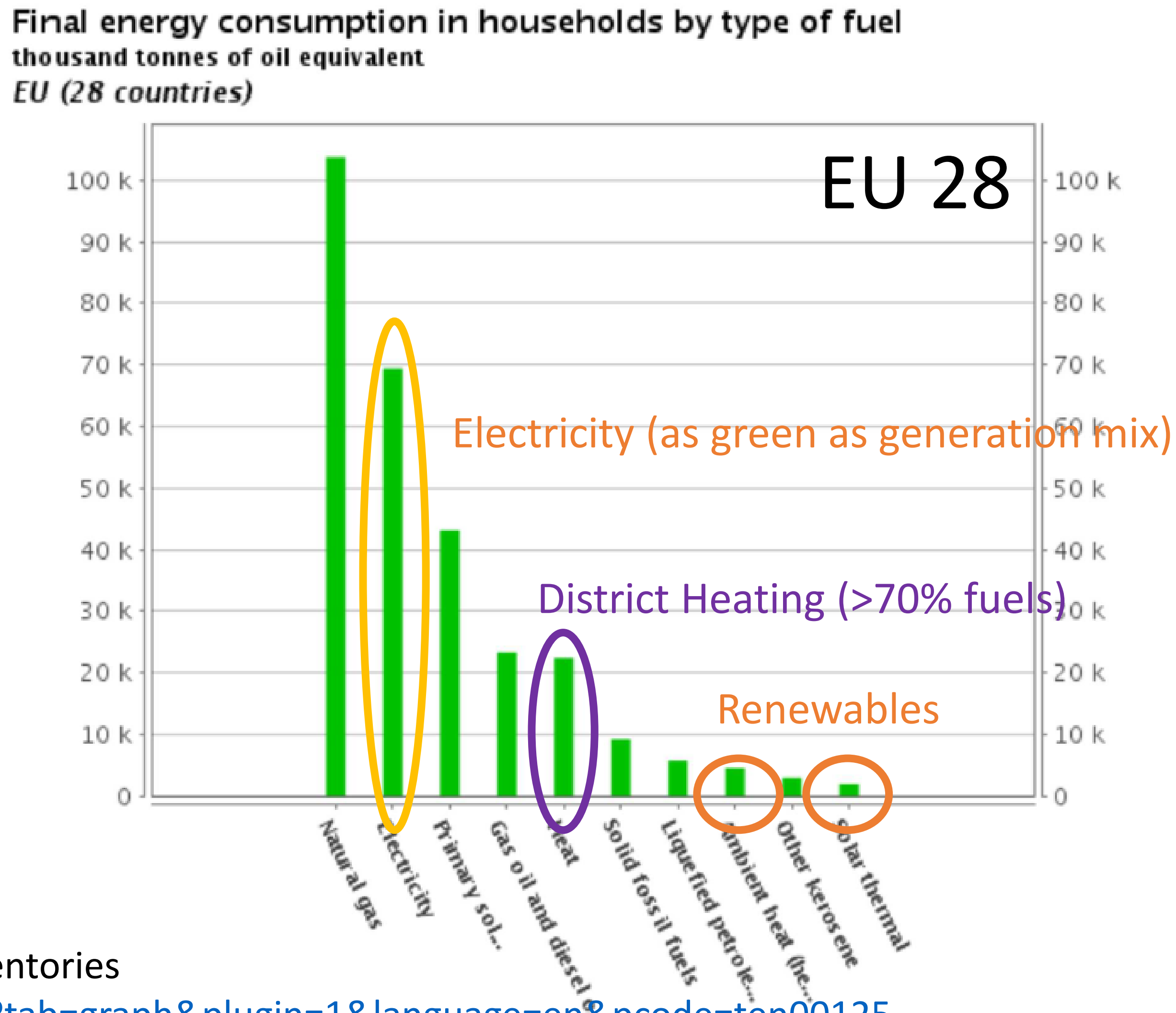
- Domestic Hot Water
  - Residential use 28 l/day.pers
  - 2 people, 300 days 16800 l/year 16.8 m3/year

  - T supply 55ºC
  - T source 14ºC
  - AT 41ºC

  - Cp 4,2kJ/kgK 1.16 kWh/m3K
  - Load 803.6 kWh/year
  - Specific load ~10 kWh/m2.year

- Total Load 64 kWh/m2.year

1.2 Energy Supply to EU households



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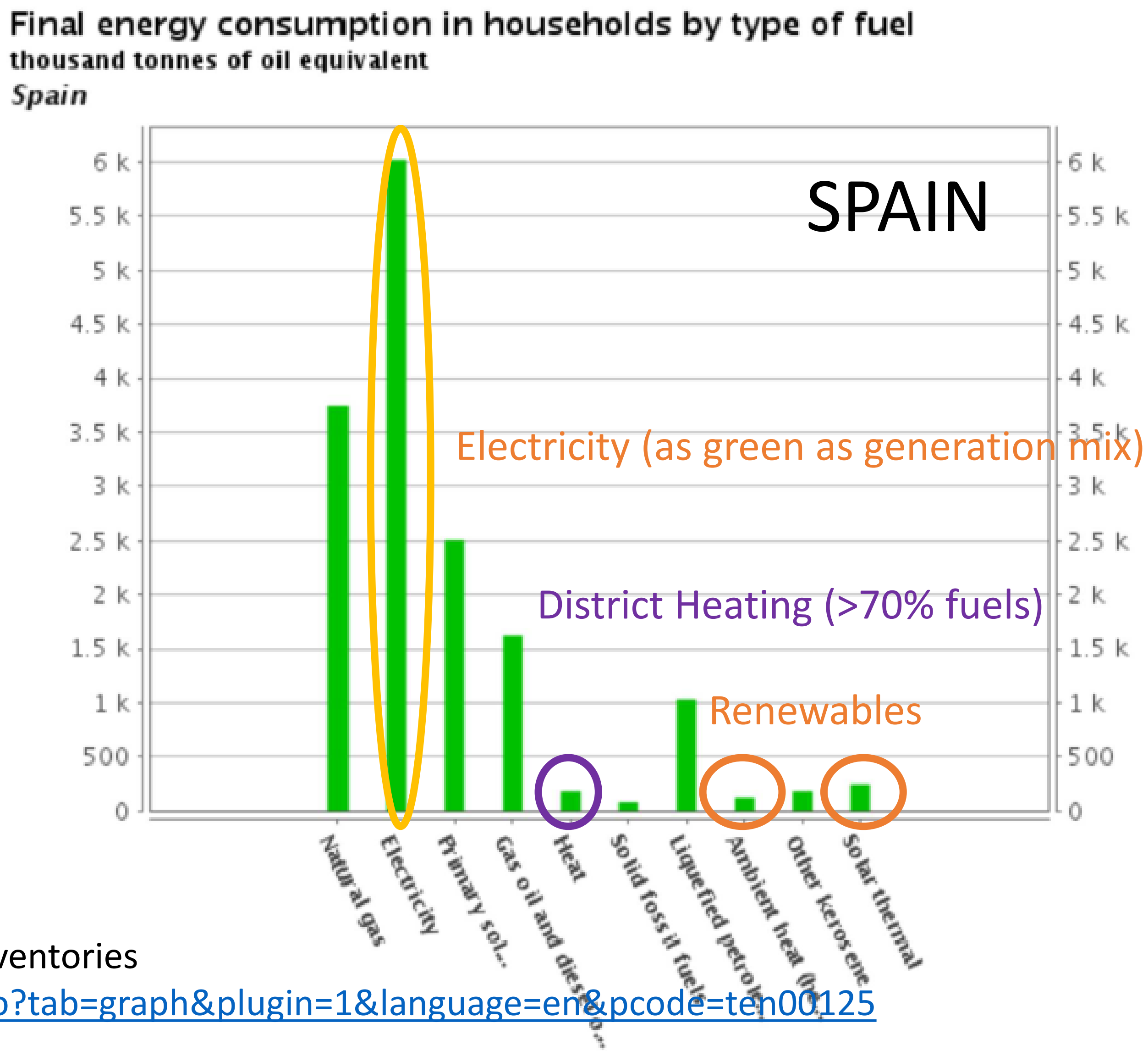
EUROSTAT. Custommized quary to energy inventories
https://ec.europa.eu/eurostat/tgm/graph.do?tab=graph&plugin=1&language=en&pcode=ten00125



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EUROSTAT. Custommized quary to energy inventories
https://ec.europa.eu/eurostat/tgm/graph.do?tab=graph&plugin=1&language=en&pcode=ten00125

Need for renewables

- Scarcity of fossil fuels
- Mitigation of climate change
- Security of supply
- Price stability
- Competitive industries/society in an energy intensive world

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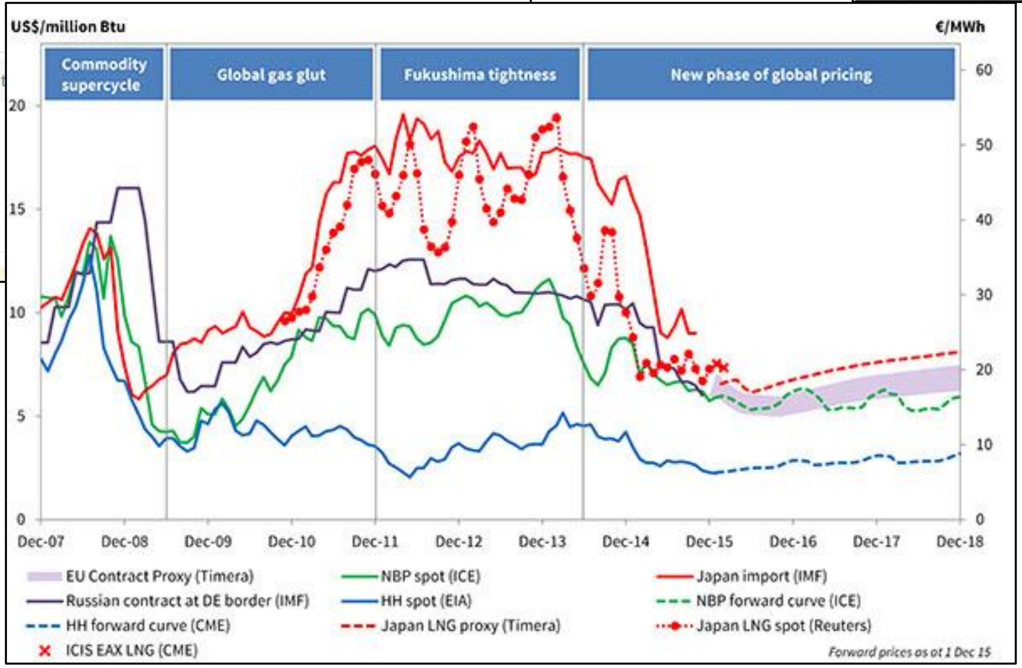
Setting the price

Published by Callum O'Reilly, Senior Editor
LNG Industry, Tuesday, 19 January 2016 15:45



1.3 Solar Thermal (ST) Systems

- Basic Configuration(s)
- Collector Technology
- Requirements in Building Codes

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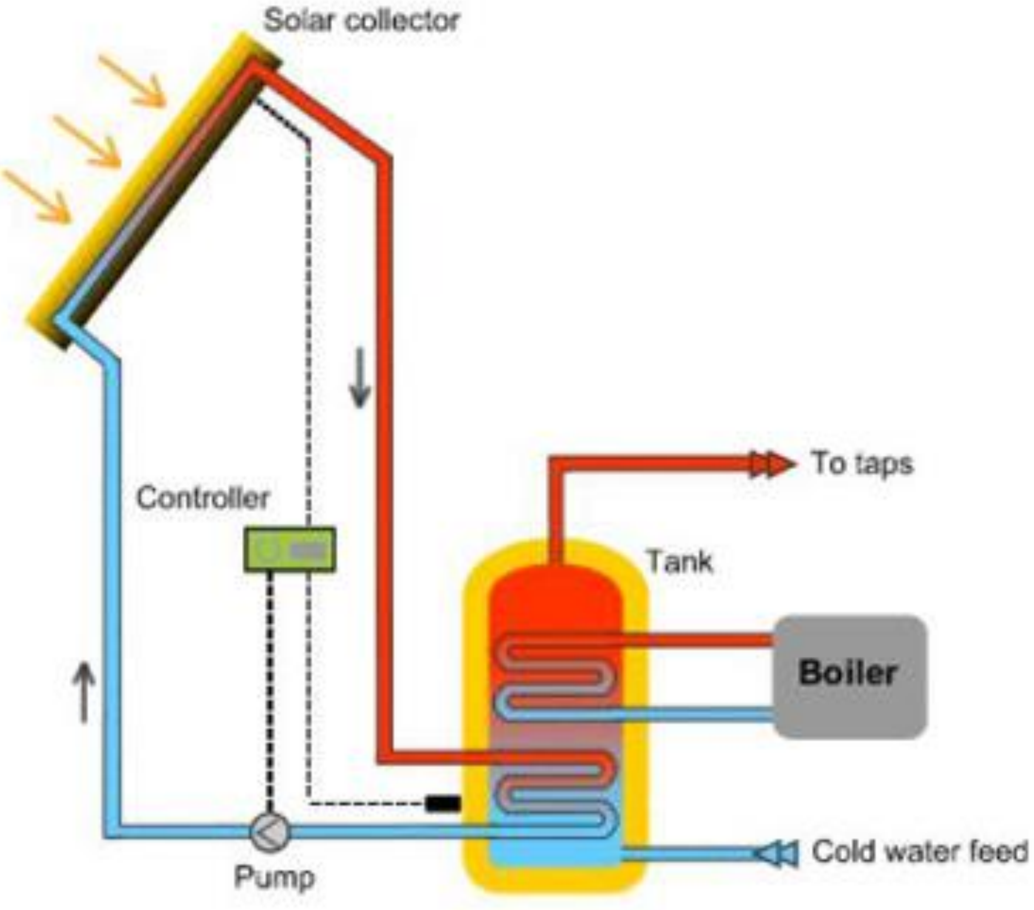
Basic Configuration(s)

- Collector field
- Thermal store
- Backup heat source
- Heat load



https://www.therenewableenergycentre.co.uk/solar-heating/

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Collector Technology

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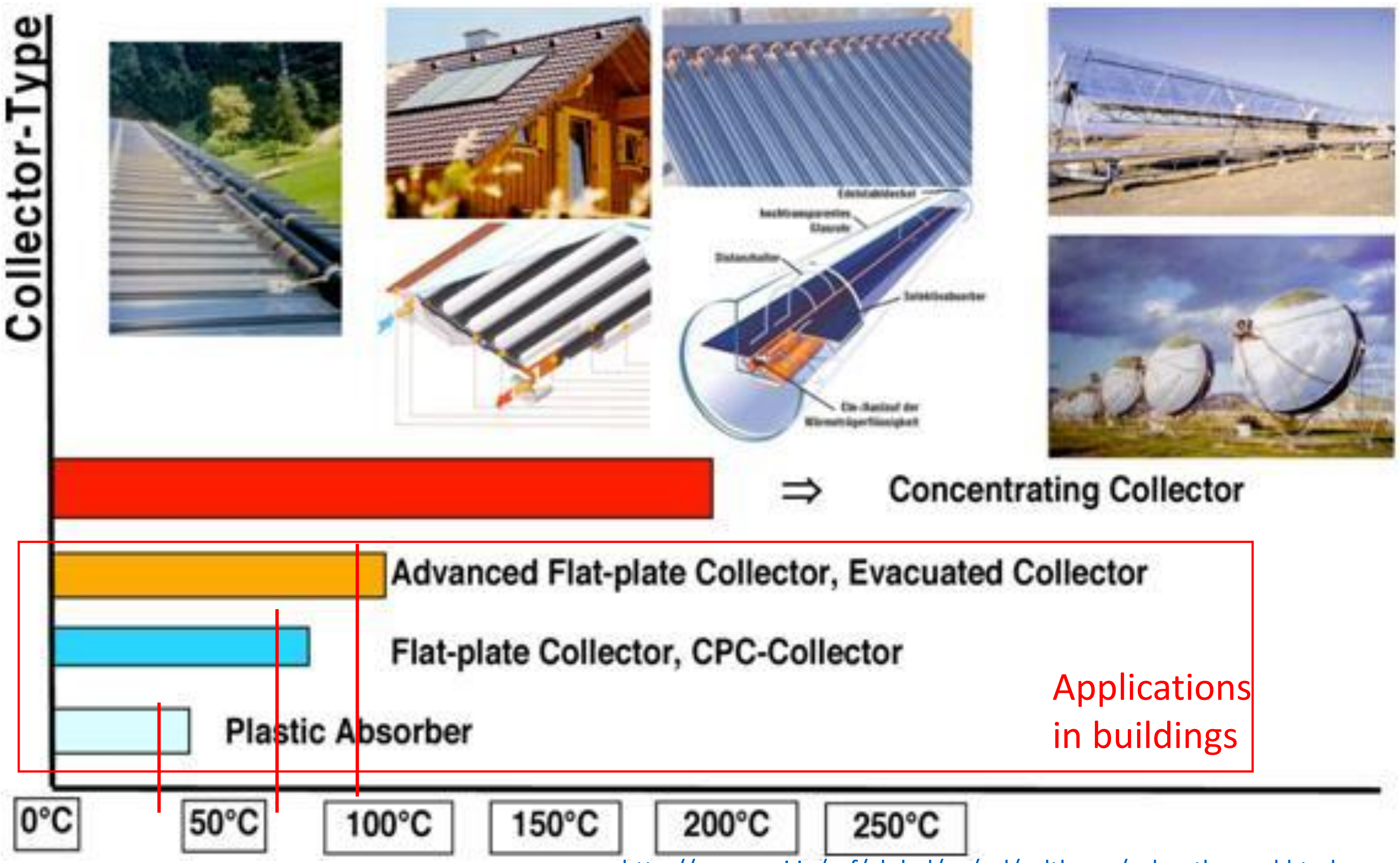
Space heating, 45-70 ºC
DHW pre-heating 20-45ºC
Swimming pool heating ~30ºC
Other low-grade app. ~20ºC



http://www.eai.in/ref/global/ae/sol/soltherm/solar_thermal.html

Requirements in Building Codes

- 30-70% of heat needs for DHW production and swimming pool heating (Spain)
- Thermal store: 50-180 l/m^2
- No requirement fo space heating

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1.4 District Heating (DH) Systems

- Basic Configuration
- Relevance in EU heat supply
- EU Strategy on Heating and Cooling

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Basic Configuration

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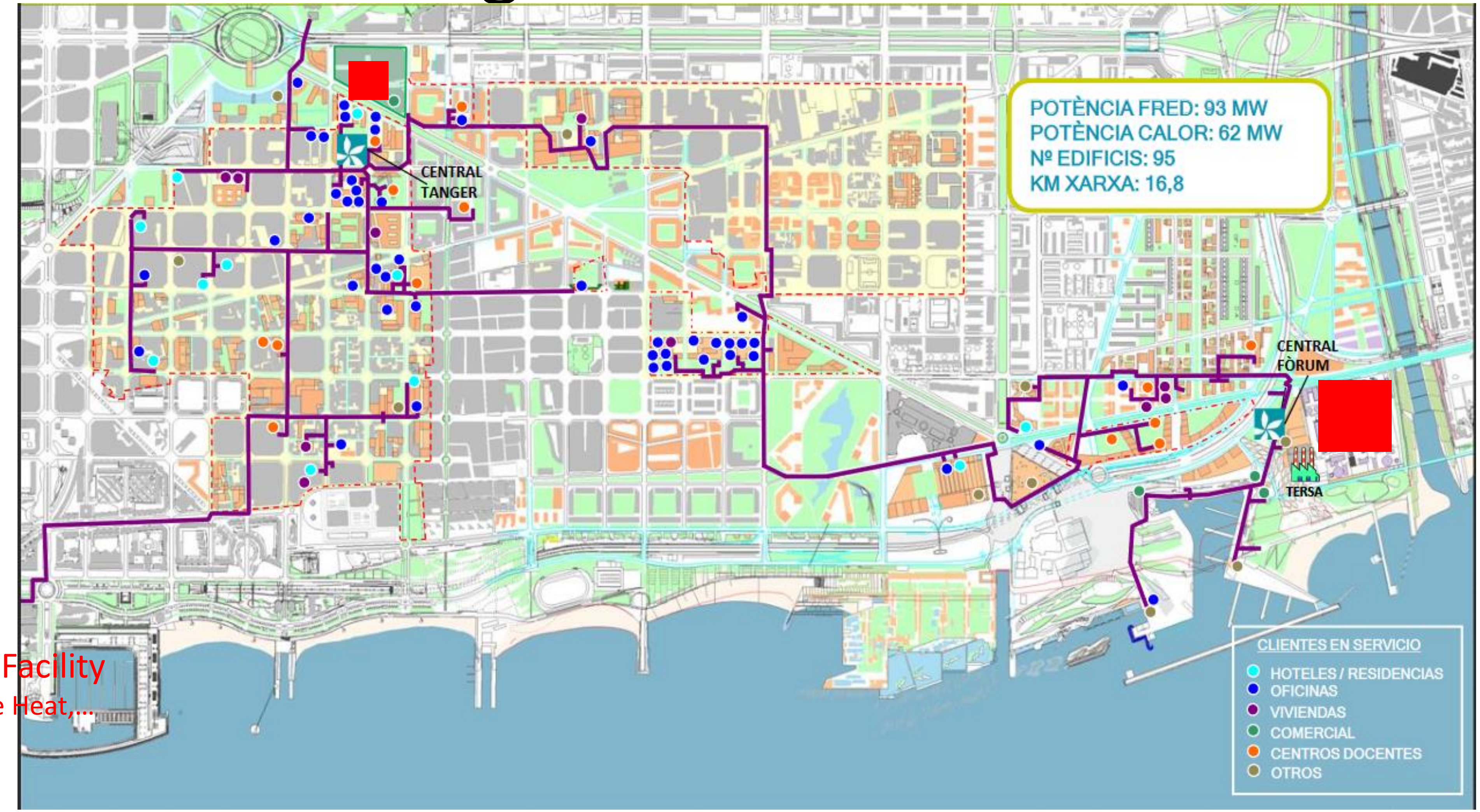

Main Heat Production Facility

Commonly CHP, 3G, Waste Heat,...

Peak Boilers

Commonly fossil fuels

http://www.districlima.com/districlima/uploads/descargas/presentaciones%20y%20otros%20documentos/2019_06%20Presentaci%C3%B3n%20est%C3%A1ndar%20Districlima%20(CAST).pdf

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Basic Configuration

https://passivehouseplus.ie/magazine/insight/district-heating-and-passive-house-are-they-compatible

http://www.districlima.com/districlima/uploads/descargas/presentaciones%20y%20otros%20documentos/2019_06%20Presentaci%C3%B3n%20est%C3%A1ndar%20Districlima%20(CAST).pdf

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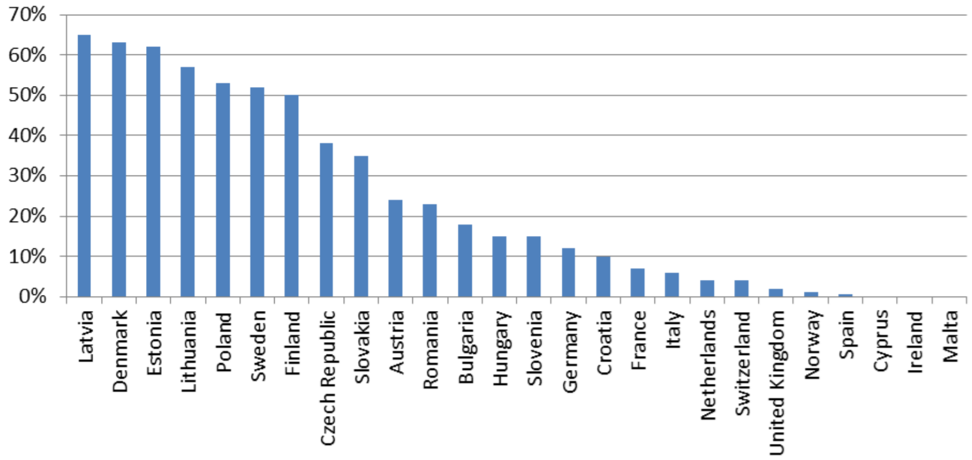
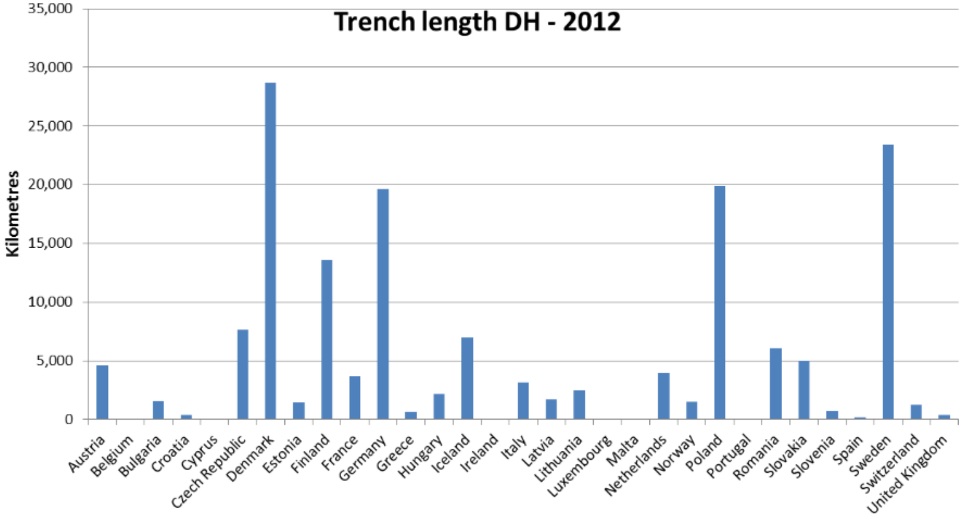
Relevance in EU heat supply





COMMISSION STAFF WORKING DOCUMENT Review of available information Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU Strategy for Heating and Cooling

SWD/2016/024 final

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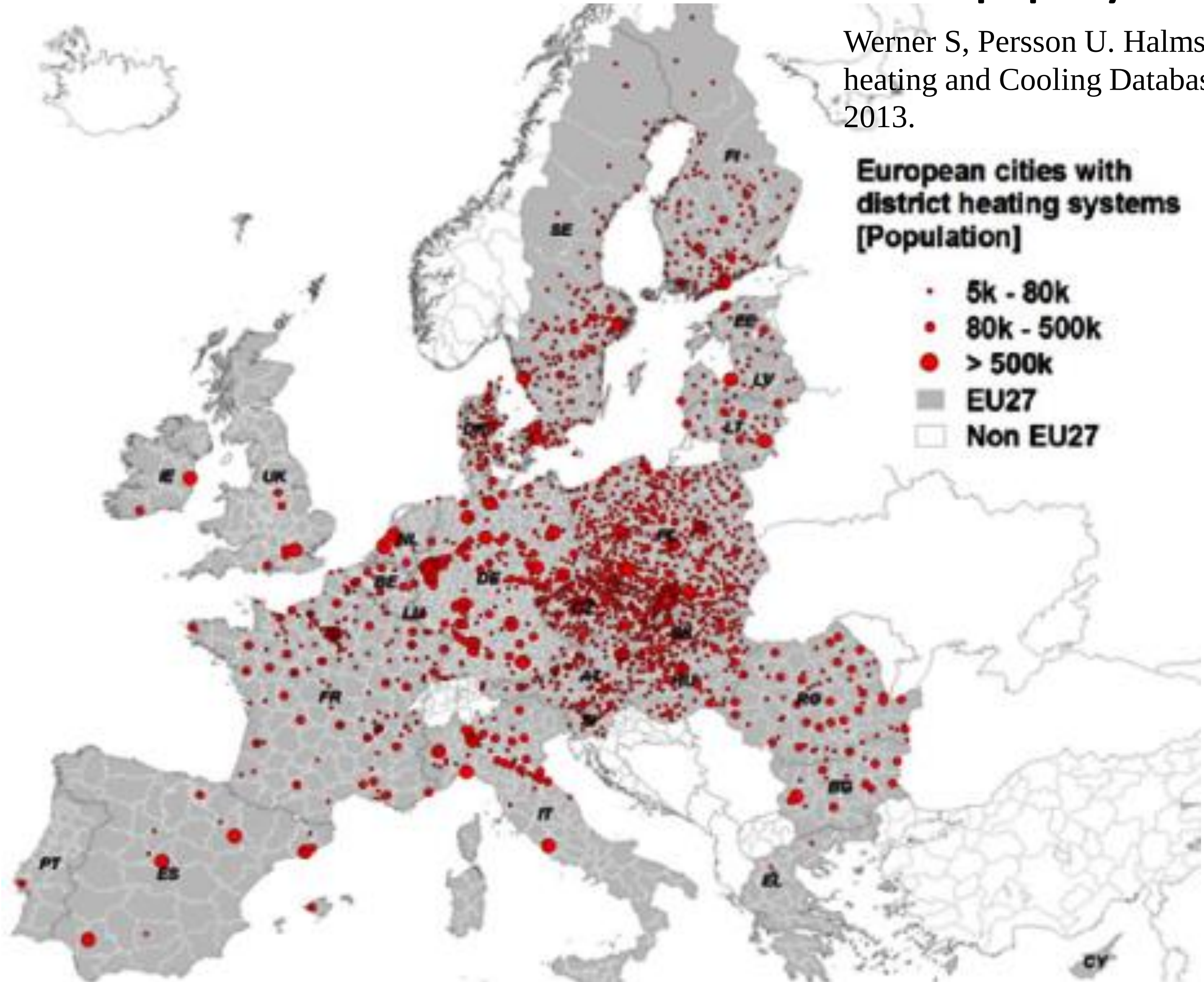
Relevance in EU heat supply

Werner S, Persson U. Halmstad University District heating and Cooling Database. Halmstad University, 2013.



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https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_ACT_part1_v14.pdf

EU Strategy on Heating and Cooling

- Heating and cooling consume half of the EU's energy and much of it is wasted.
- 75% of the fuel … comes from fossil fuels (~ half from gas)
- Renewable energy sources (RES) share of energy used in heating is highest in Baltic and Nordic Member States (ranging from 43% in Estonia to 67% in Sweden)
- Europeans spend 6% of their consumption expenditure on heating and cooling
- 11% cannot afford to keep their homes warm enough in winter

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https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_ACT_part1_v14.pdf

EU Strategy on Heating and Cooling

- Some industries generate heat as a by-product. … could be … sold to heat buildings nearby. … waste heat from power stations, the service sector and infrastructure such as metros
- The barriers … lack of heat networks; and lack of cooperation between industry and district heating companies.
- District heating can integrate renewable electricity (through heat pumps), geothermal and solar thermal energy, waste heat and municipal waste.
- It can offer flexibility to the energy system by cheaply storing thermal energy, for instance in hot water tanks or underground.

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- For educational purposes only
- Typical issues out of the scope of this exercises
  - Size of district (energy)
  - Size of district (distance) & geographic issues
  - Type of fuels
  - Need for redundancy
  - …

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EXERCISE 2

Monthly heat Load for one district. How to select plants

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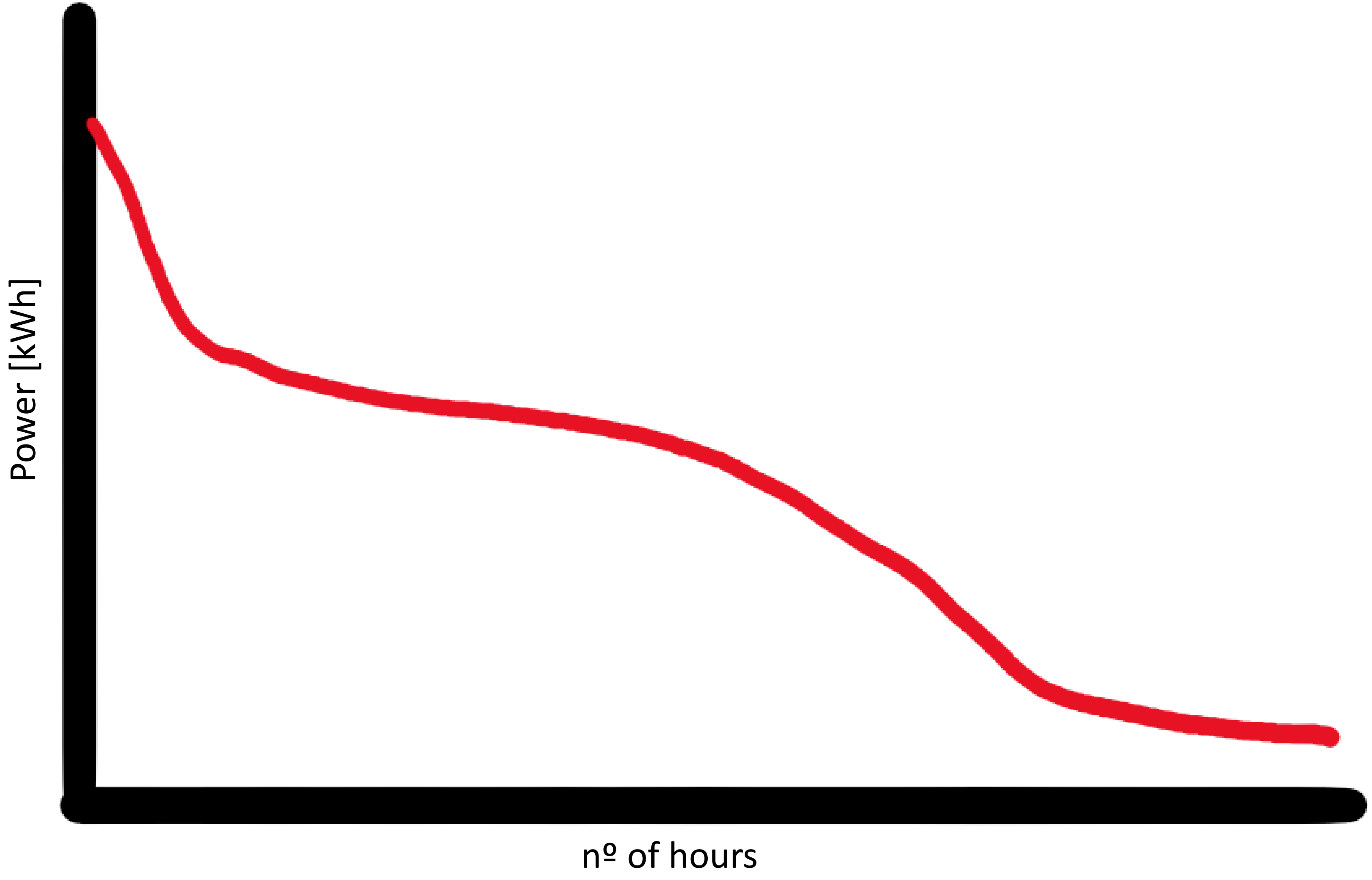

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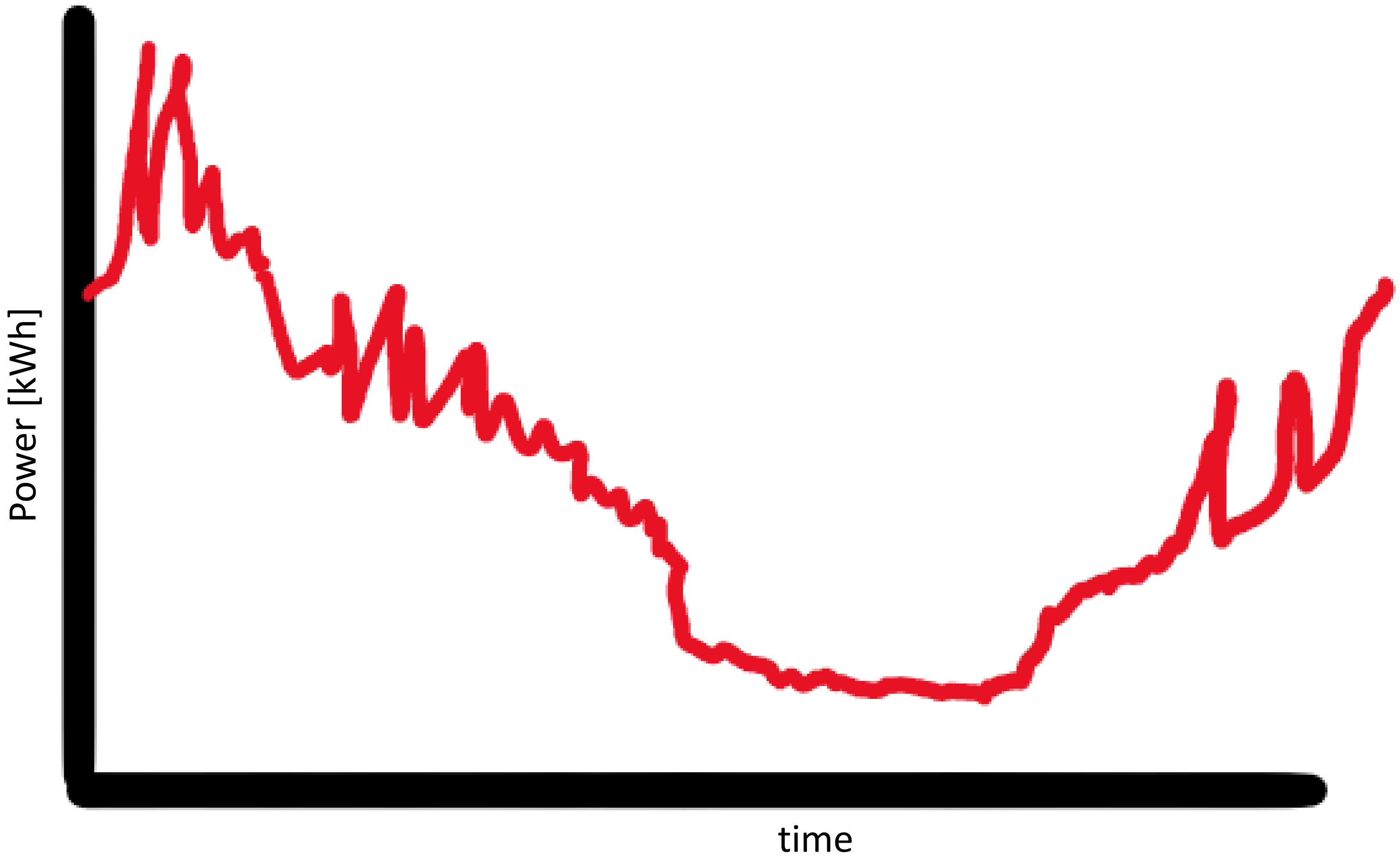

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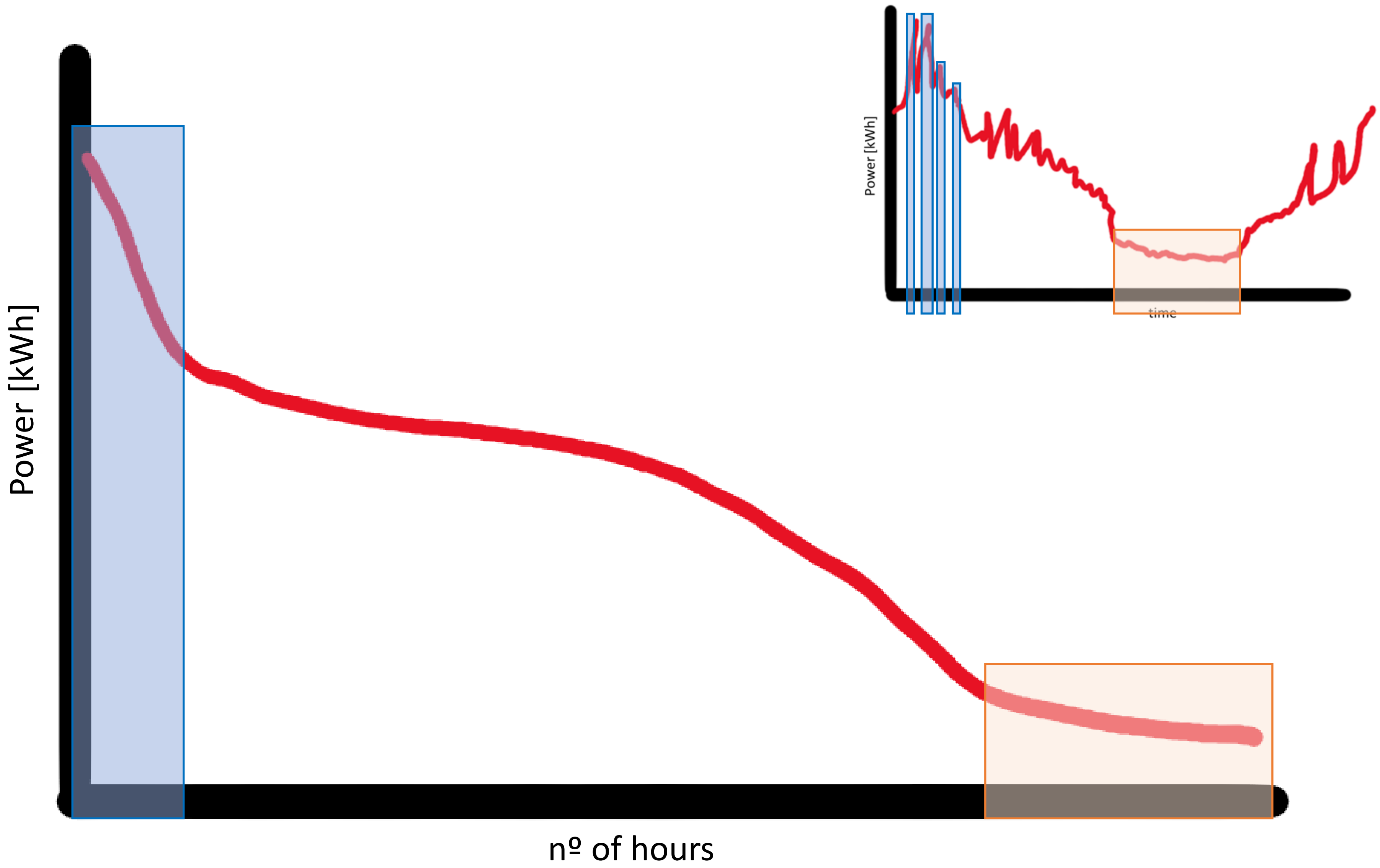

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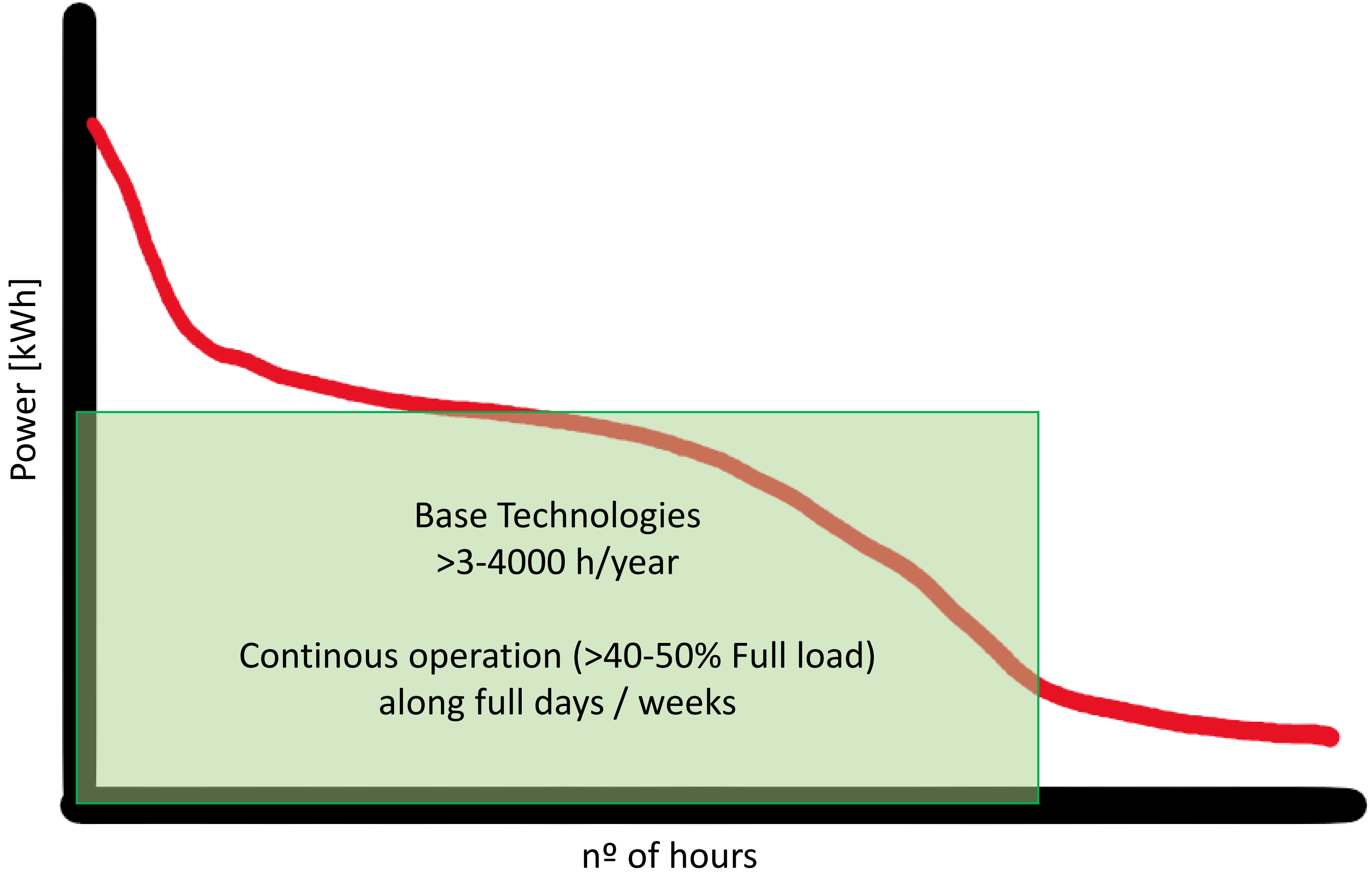

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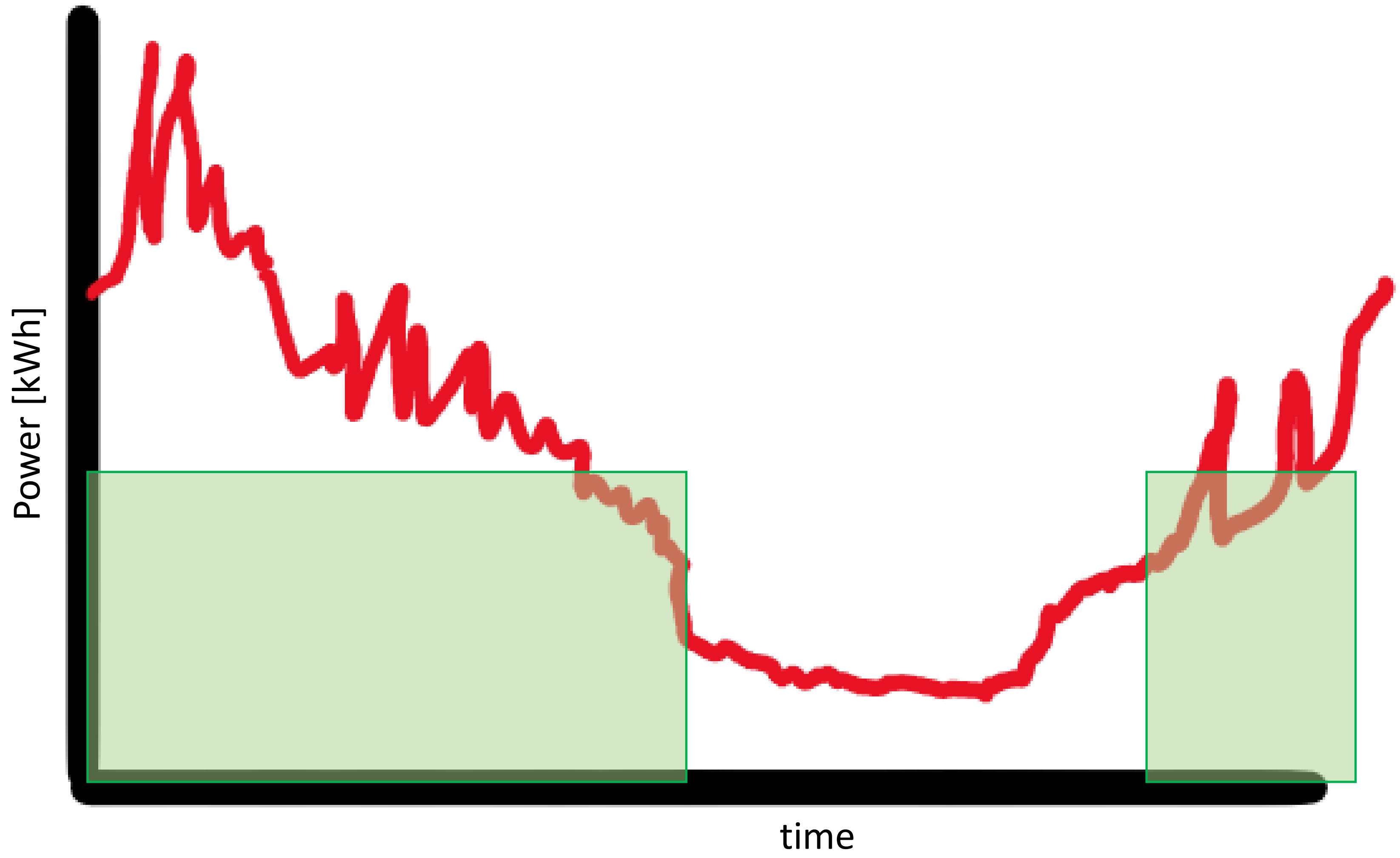

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2. Performance of ST systems

2.1 Technologies

- Basic energy concept
- Unglazed Flat Plate
- Glazed Flat Plate
- Vacuum tuve
- Parabolic concentrators (not covered)
- Other high temperature systems (not covered)

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Basic energy concept

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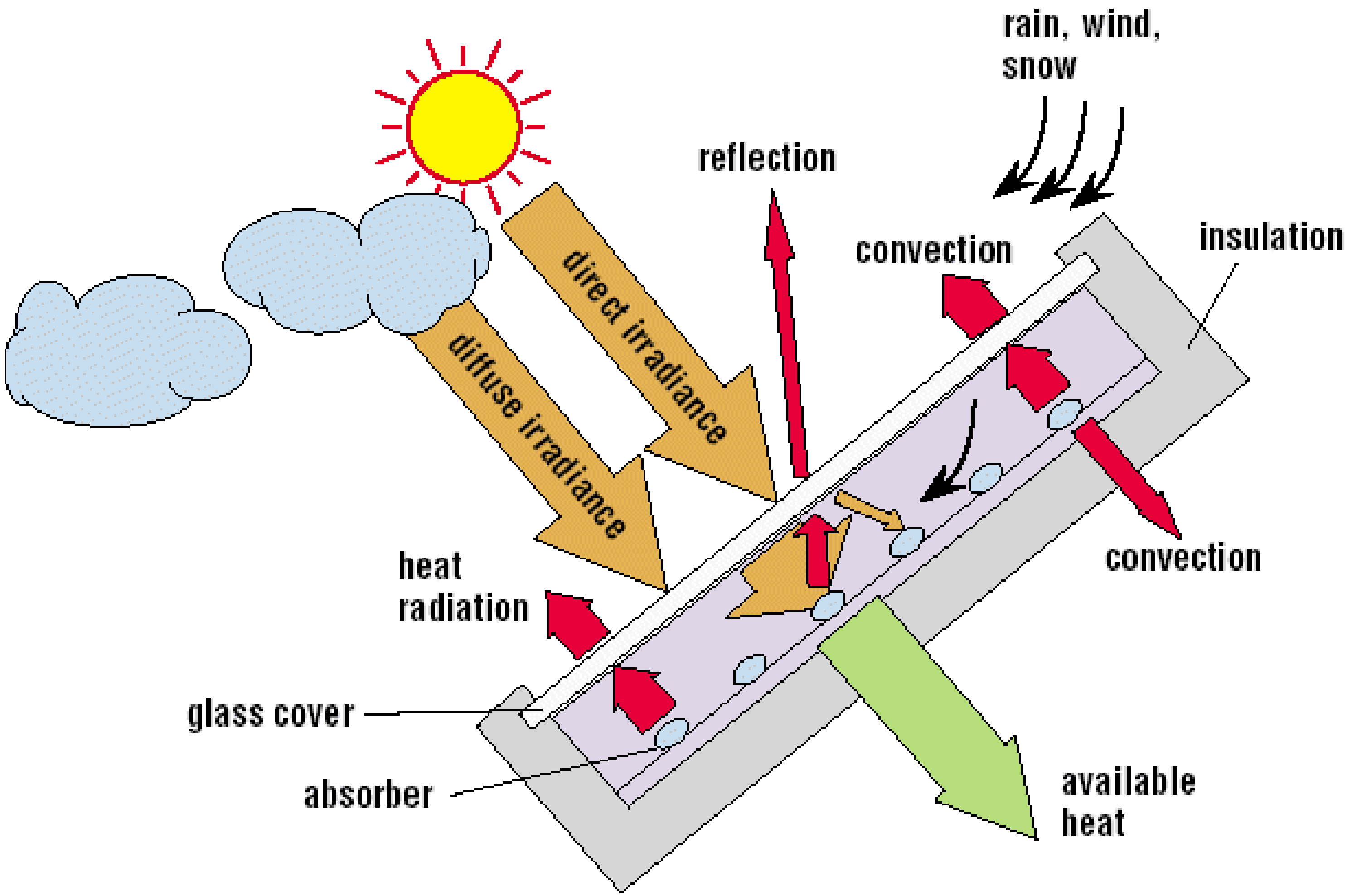
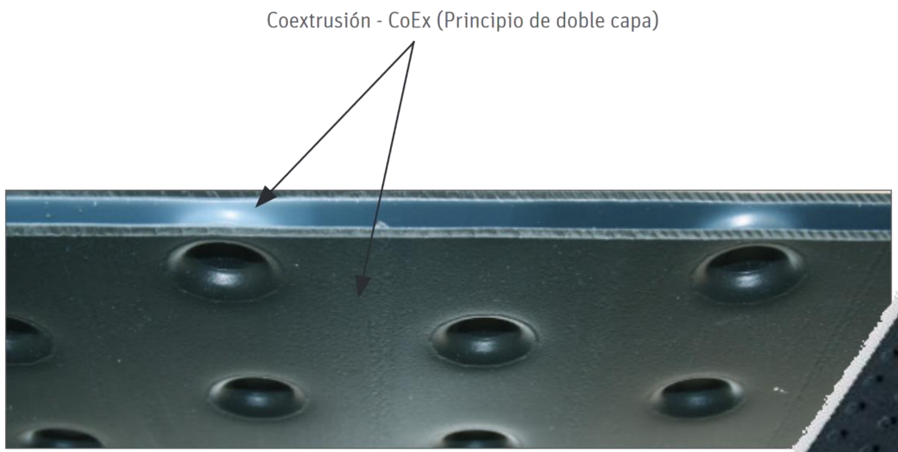


https://www.volker-quaschning.de/articles/fundamentals4/index.php

Unglazed Flat Plate



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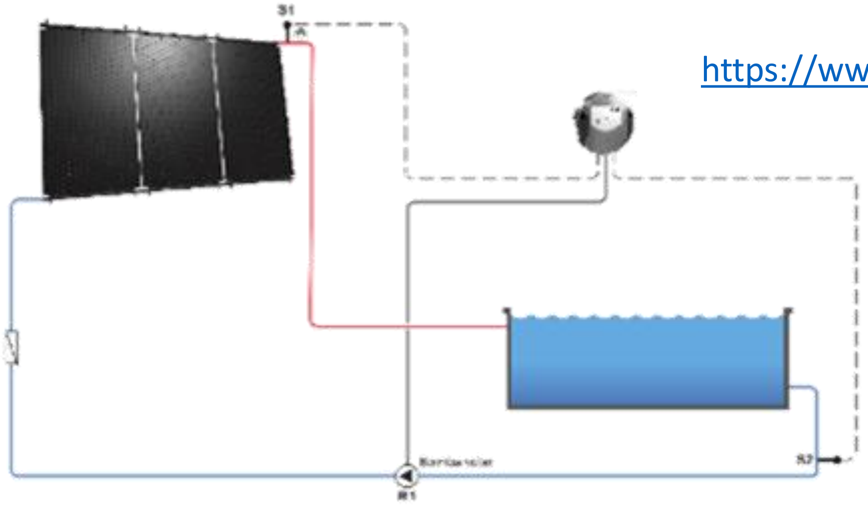

https://www.roth-spain.com/es/Captador-solar-para-piscinas-Rothpool.htm

Unglazed Flat Plate

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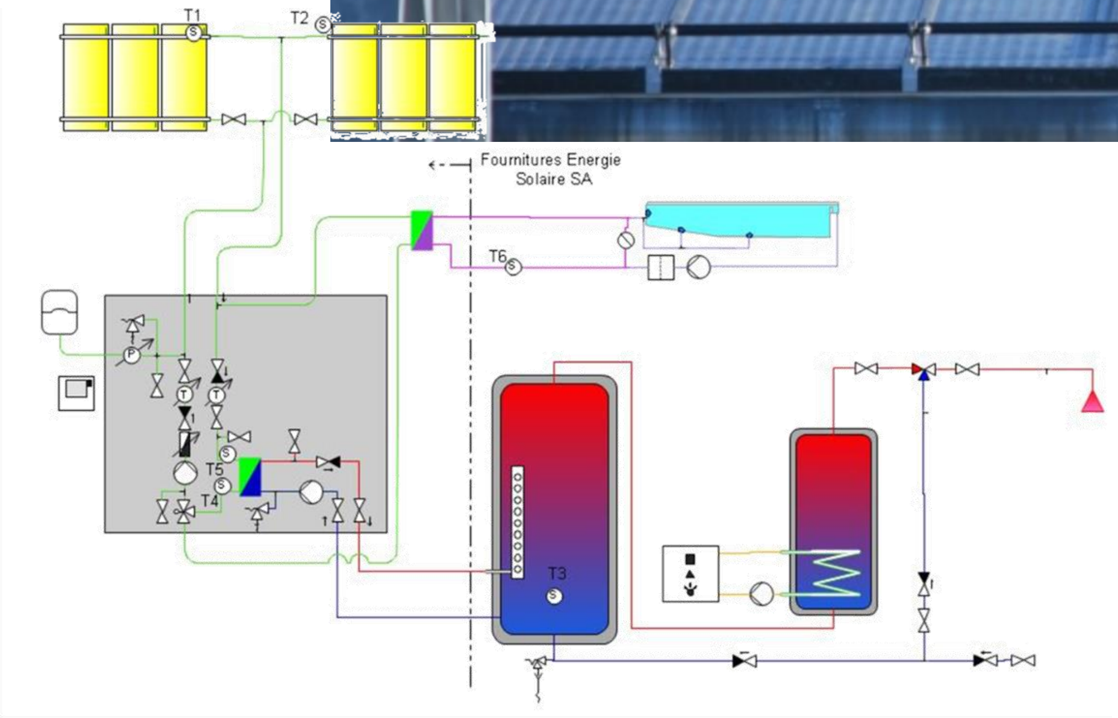
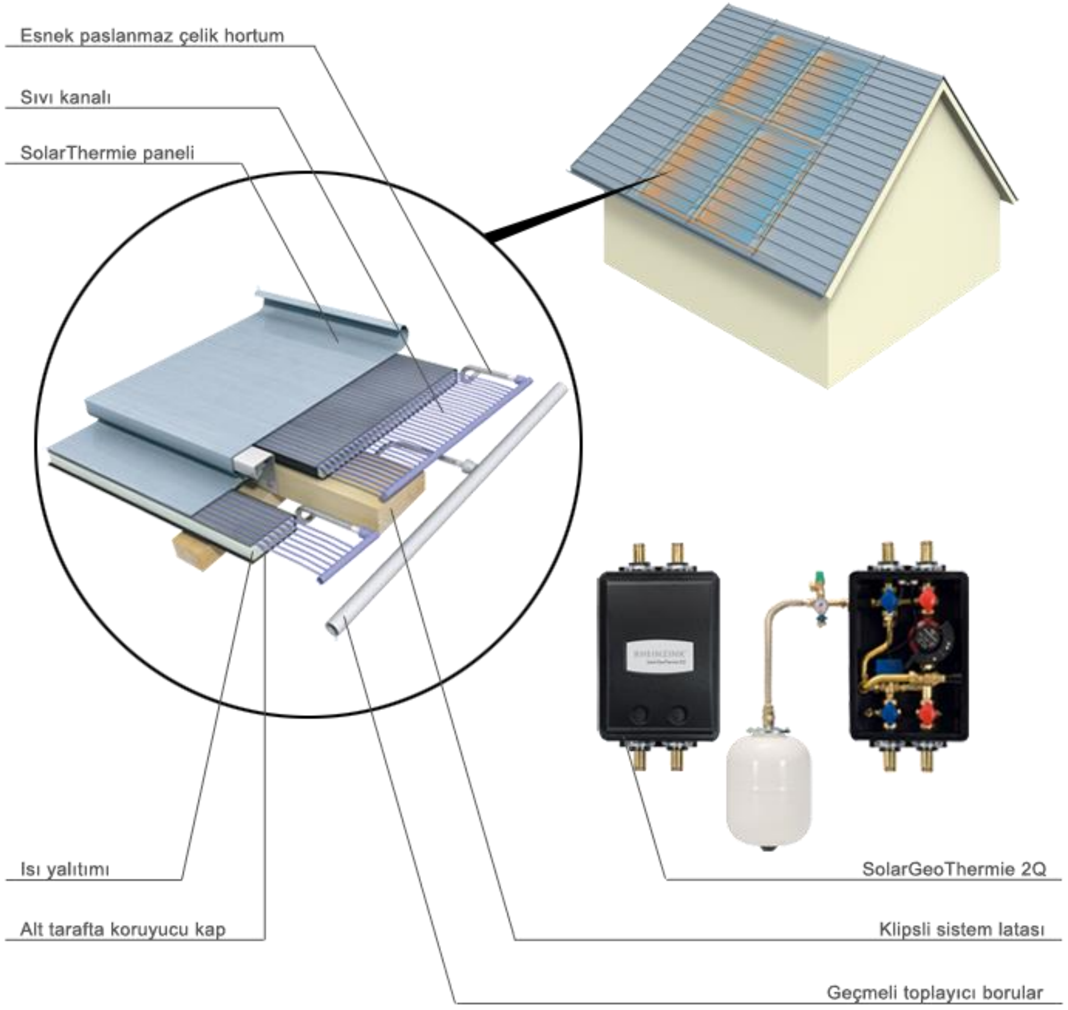


https://www.energie-solaire.com

Unglazed Flat Plate



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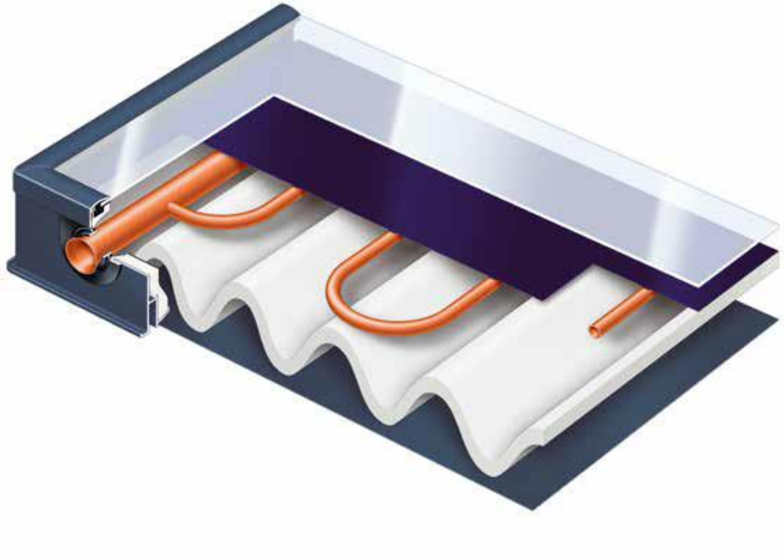
https://www.rheinzink.com.tr/ueruenler/cati-sistemleri/solar-sistemler/quick-stepr-solarthermie/tedarik-programi/

Glazed Flat Plate

https://www.viessmann.es/es/edificios-de-viviendas/sistemas-de-energia-solar/colectores-planos/vitosol-200-fm_msm_moved.html



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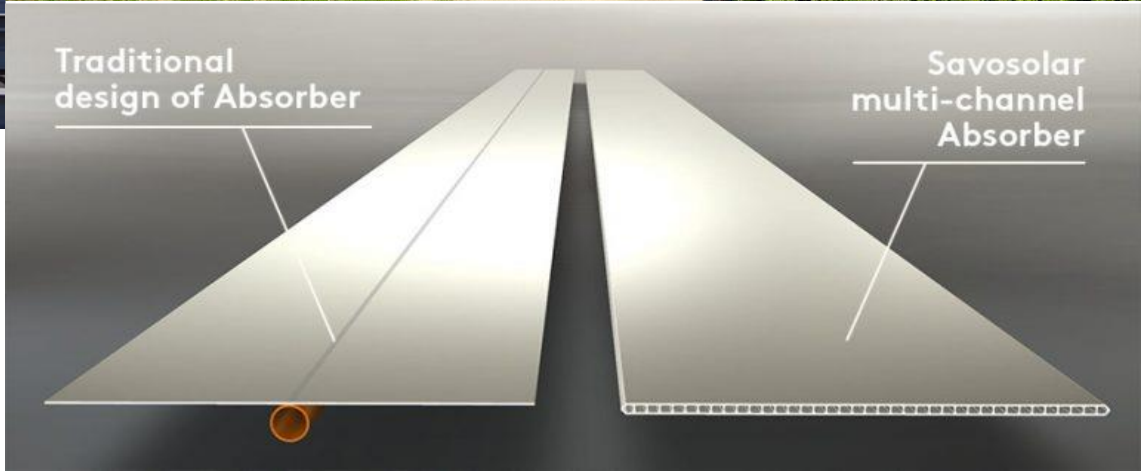
Glazed Flat Plate



https://savosolar.com

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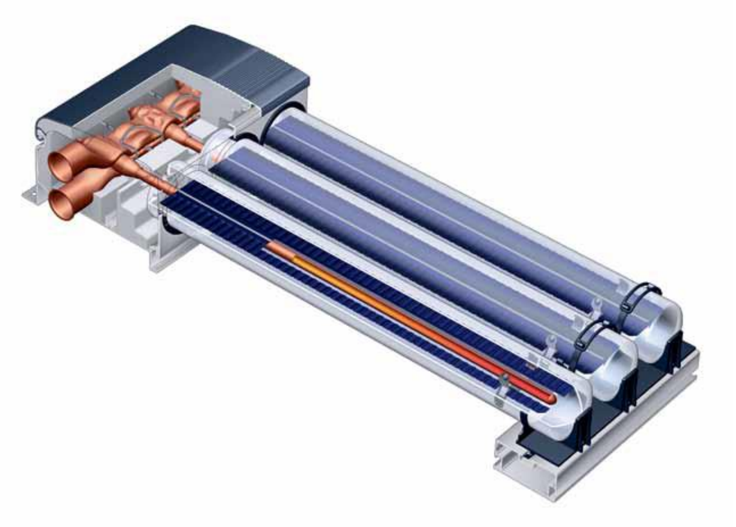
Vacuum tuve



https://www.viessmann.es/es/edificios-de-viviendas/sistemas-de-energia-solar/colectores-de-tubos/vitosol-300tm.html

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Parabolic concentrators & other high temperature systems

- NOT COVERED
- Mainly for industrial applications

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2.2 Performance characterisation

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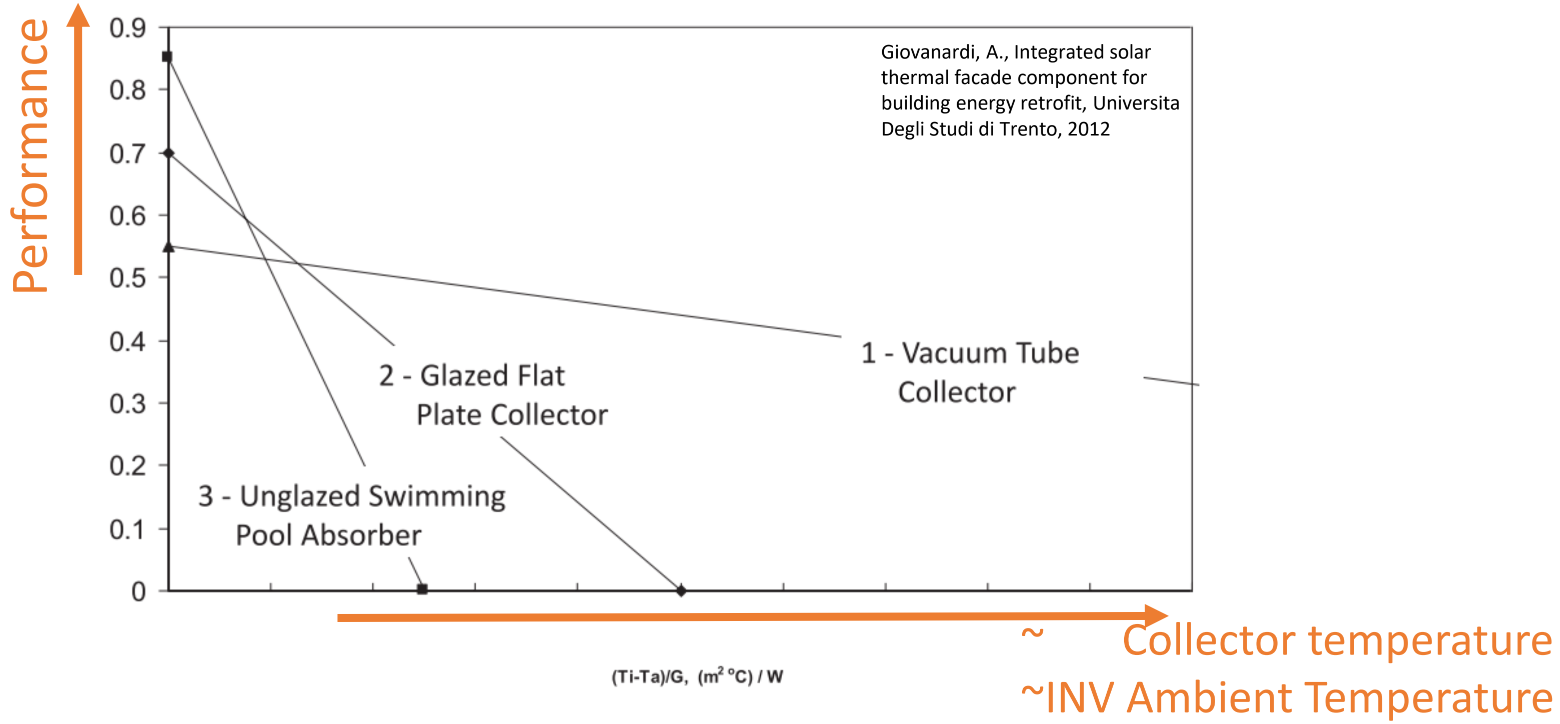

$$\eta = \frac{Q_u}{G_T \cdot A_c} \approx \left[F_R \cdot (\tau\alpha) - F_R \cdot U_L \cdot \frac{(T_m - T_{amb})}{G_T} \right]$$

#	F_R ( )$_e$	F_R U_L (W/m²ºC)	
1	0.5 - 0.75	1 - 2	Depends on tube spacing
2	0.65 - 0.8	3 - 8	Depends on # of covers and absorber coating
3	0.8 - 0.95	10 - 20	Depends on wind speed

2.2 Performance characterisation

- Simple collectors perform best for low AT
  - Greatest Surface and solar apertura
- Insulation level is increasingly relevant
  - High temperature applications
  - Low ambient temperature
- Relevant Standard: EN 12975
  - http://www.estif.org/fileadmin/estif/content/projects/QAiST/QAiST_results/QAiST%20D2.3%20Guide%20to%20EN%2012975.pdf
- Performance curve $$\eta = a_0 - a_1 * \frac{\Delta T}{I} - b_1 * \frac{\Delta T^2}{I}$$

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- For educational purposes only
- Typical issues out of the scope of this exercises
    - Logaritmic mean temperature calculations
    - Self-shading
    - Shading between arrays for flat roof/ground mounted systems
    - Issues at plant level

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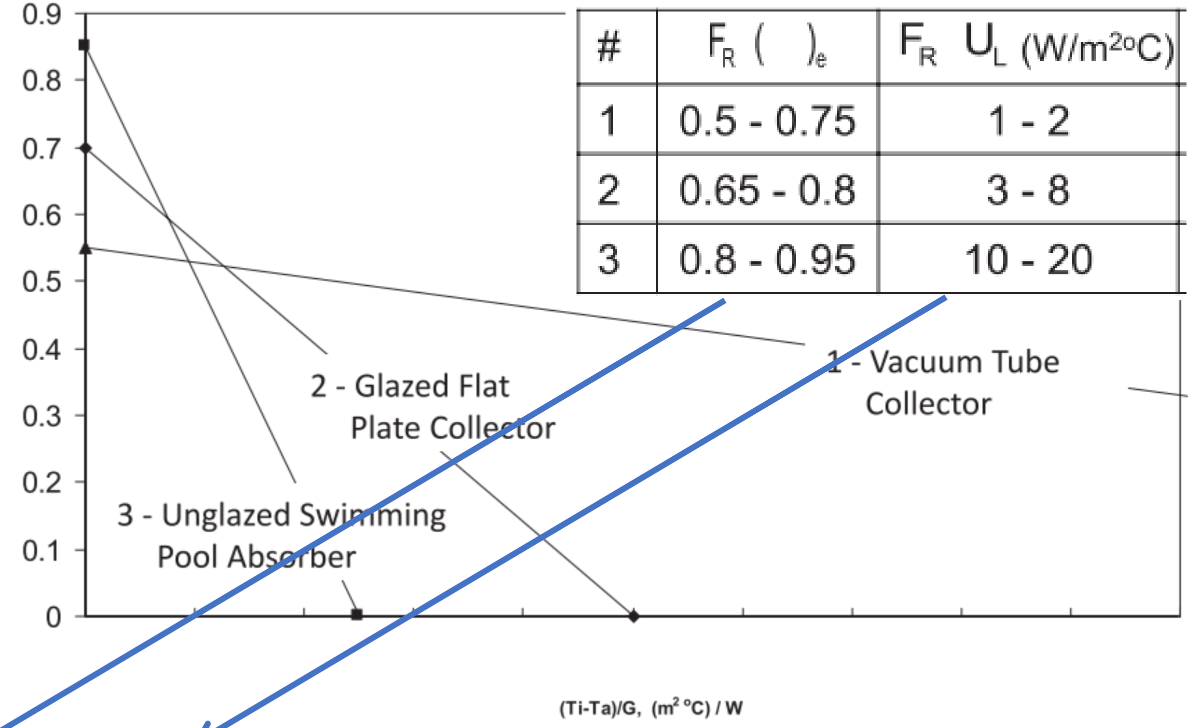
EXERCISE 3

Performance of ST collector technologies at various temperatures



#	F_R ( )$_e$	F_R U_L (W/m²°C)
1	0.5 - 0.75	1 - 2
2	0.65 - 0.8	3 - 8
3	0.8 - 0.95	10 - 20

$$\eta = \left[F_R \cdot (\tau\alpha) - F_R \cdot U_L \cdot \frac{(T_m - T_{amb})}{G_T} \right]$$

$$\eta = a_0 - a_1 * \frac{\Delta T}{I} - b_1 * \frac{\Delta T^2}{I}$$

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$$\eta = a_0 - a_1 * \frac{\Delta T}{I}$$

	a_0	A_1 W/m2K
Evacuated Tube Collectors	0,625	1,5
Glazed Collectors	0,725	5,5
Unglazed collectors	0,875	15

• Ambient temperature	5ºC	15ºC	15ºC
• Inlet temperature	40ºC	40ºC	35ºC
• Outlet temperature	50ºC	50ºC	40ºC
• Solar Irradiation	300W/m2	400W/m2	500W/m2
• Mean collector temperature	45ºC	45ºC	37,5ºC
• AT	40ºC	30ºC	22,5ºC
• Performance ET	43%	51%	56%
• Performance G	-1%	31%	48%
• Performance UG	-113%	-25%	20%

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2.3 Design of ST fields

- Collector Datasheet
- Design Temperature levels
- Thermal Storage Sizing
- Heat Injection into Thermal Storage

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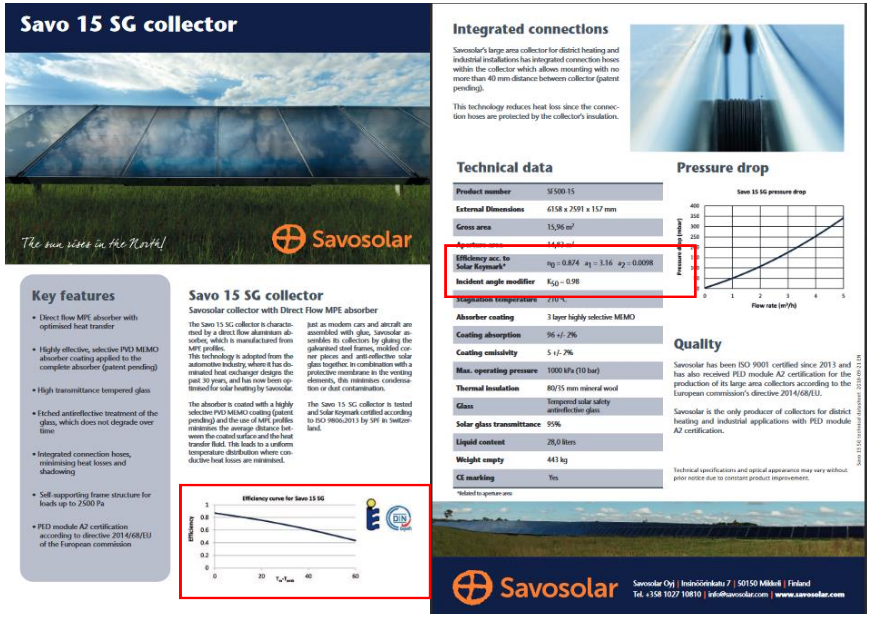
Collector Datasheet



Savo 15 SG collector

The sun rises in the North!

Savosolar

Key features

- Direct flow MPE absorber with optimised heat transfer
- Highly effective, selective PVD MEMO absorber coating applied to the complete absorber (patent pending)
- High transmittance tempered glass
- Etched antireflective treatment of the glass, which does not degrade over time
- Integrated connection hoses, minimising heat losses and shadowing
- Self-supporting frame structure for loads up to 2500 Pa
- PED module A2 certification according to directive 2014/68/EU of the European commission

Savo 15 SG collector

Savosolar collector with Direct Flow MPE absorber

The Savo 15 SG collector is characterised by a direct flow aluminium absorber, which is manufactured from MPE profiles.
This technology is adopted from the automotive industry, where it has dominated heat exchanger designs the past 30 years, and has now been optimised for solar heating by Savosolar.

The absorber is coated with a highly selective PVD MEMO coating (patent pending) and the use of MPE profiles minimises the average distance between the coated surface and the heat transfer fluid. This leads to a uniform temperature distribution where conductive heat losses are minimised.

Just as modern cars and aircraft are assembled with glue, Savosolar assembles its collectors by gluing the galvanised steel frames, molded corner pieces and anti-reflective solar glass together. In combination with a protective membrane in the venting elements, this minimises condensation or dust contamination.

The Savo 15 SG collector is tested and Solar Keymark certified according to ISO 9806:2013 by SPF in Switzerland.

Integrated connections

Savosolar's large area collector for district heating and industrial installations has integrated connection hoses within the collector which allows mounting with no more than 40 mm distance between collector (patent pending).

This technology reduces heat loss since the connection hoses are protected by the collector's insulation.

Technical data

Product number	SF500-15
External Dimensions	6158 x 2591 x 157 mm
Gross area	15,96 m²
Aperture area	[illegible] m²
Efficiency acc. to Solar Keymark*	$\eta_0 = 0.874$ $a_1 = 3.16$ $a_2 = 0.0098$
Incident angle modifier	$K_{50} = 0.98$
Stagnation temperature	210 °C
Absorber coating	3 layer highly selective MEMO
Coating absorption	96 +/- 2%
Coating emissivity	5 +/- 2%
Max. operating pressure	1000 kPa (10 bar)
Thermal insulation	80/35 mm mineral wool
Glass	Tempered solar safety antireflective glass
Solar glass transmittance	95%
Liquid content	28,0 liters
Weight empty	443 kg
CE marking	Yes

*Related to aperture area

Pressure drop

Quality

Savosolar has been ISO 9001 certified since 2013 and has also received PED module A2 certification for the production of its large area collectors according to the European commission's directive 2014/68/EU.

Savosolar is the only producer of collectors for district heating and industrial applications with PED module A2 certification.

Technical specifications and optical appearance may vary without prior notice due to constant product improvement.

Savo 15 SG technical datasheet 2018-09-21 EN

Savosolar

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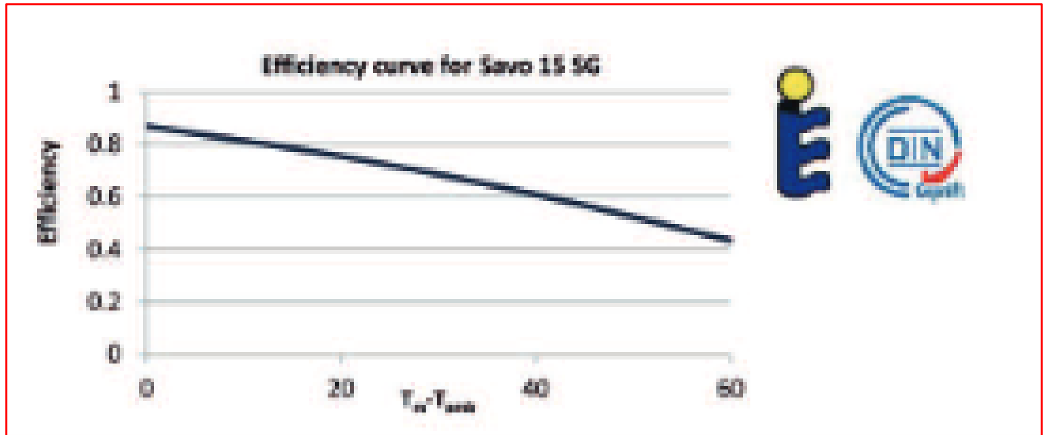

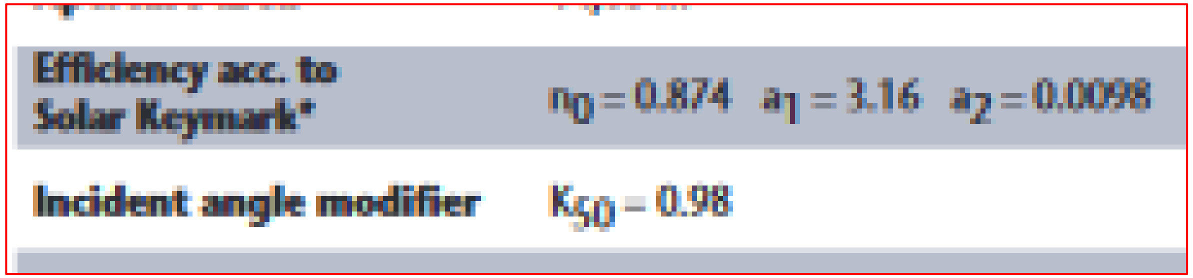

Efficiency acc. to Solar Keymark*	$\eta_0 = 0.874$ $a_1 = 3.16$ $a_2 = 0.0098$
Incident angle modifier	$K_{50} = 0.98$

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Collector Datasheet

Collector Type	Model	η_0	a_1	a_2
Unglazed	KOLLEKTOR AS	0,897	10,91	2,31
Glazed	VITOSOL 200-F	0,813	3,416	0,021
Evacuated Tube	ENERTECH ENERSOL HP 70-8	0,608	1,14	0,012

Design Temperature levels

• Space heating (hydronic)	
• Radiators	70-90ºC
• Low temperature Radiators	50-60ºC
• Underfloor heating	30-35ºC
• Air heating	
• Fan coil systems & Air Handling Units	45-55ºC
• Swimming pool heating	30-35ºC
• Domestic Hot Water	
• Service	50-80ºC
• Pre heating	~30-45ºC
• (intake)	~5-15ºC

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Thermal Storage Sizing

- Storage sizes depend on purpose
  - Smooth operation — small ammount of water
  - Intra-daily storage — 50-100 l/m2
  - Inter-daily storage — >200 l/m2
  - …
  - Seasonal

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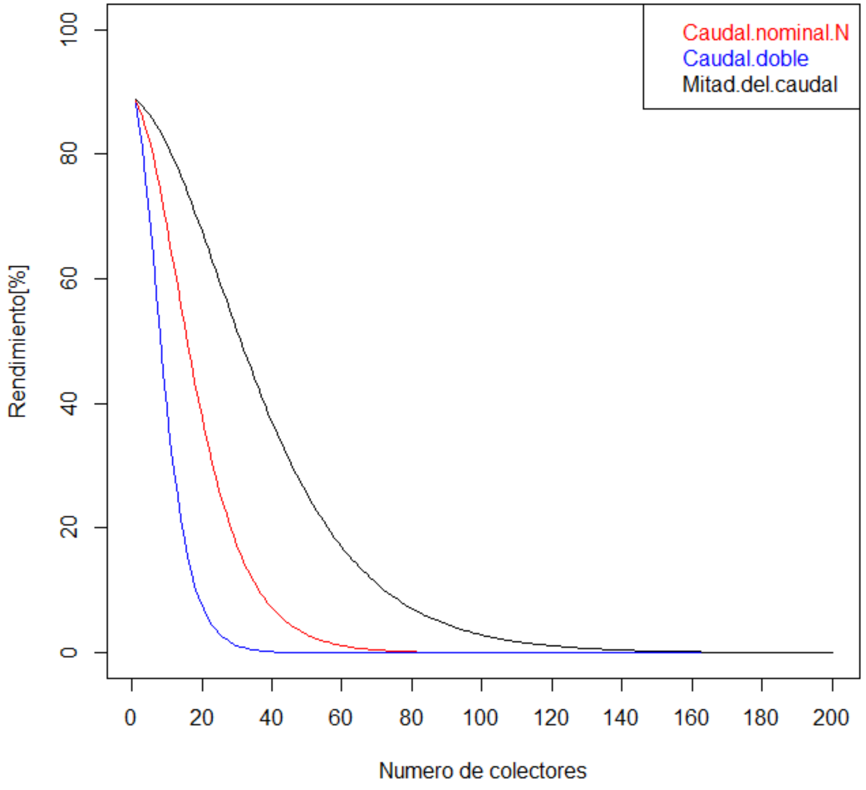
Serial connection

- Collector arrays are arranged in series to increase output temperature.
- Increased AT
  - Desired outcome
  - to be limited according to heat usage
- Increased AP
  - Greater pumping costs
- Increased heat loss
  - Lower performence
- Commonly 3-6 units in series



Thermal Storage Sizing

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https://partner.nibe.eu/Products/Accumulator-tanks/NIBE-VPA--VPAS/

https://ramboll.com/media/rgr/two-ramboll-projects-among-the-eight-most-efficient-district-heating-and-cooling-systems-in-the-eu

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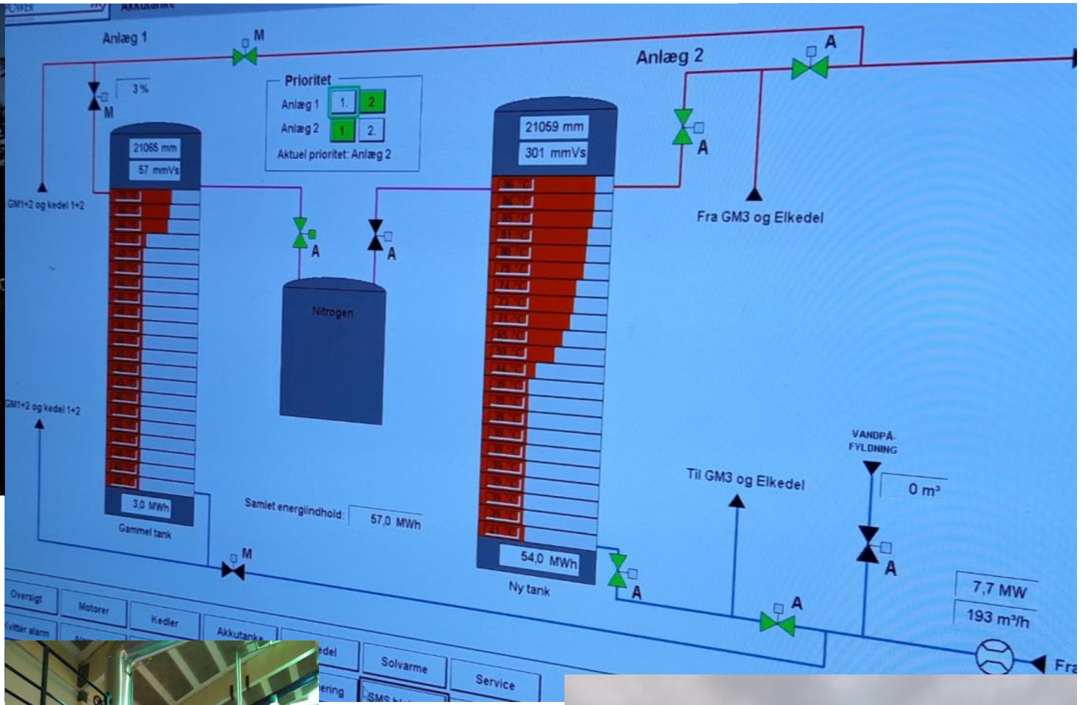
Heat Injection into Thermal Storage

District heating plant at Helsinge (DK)



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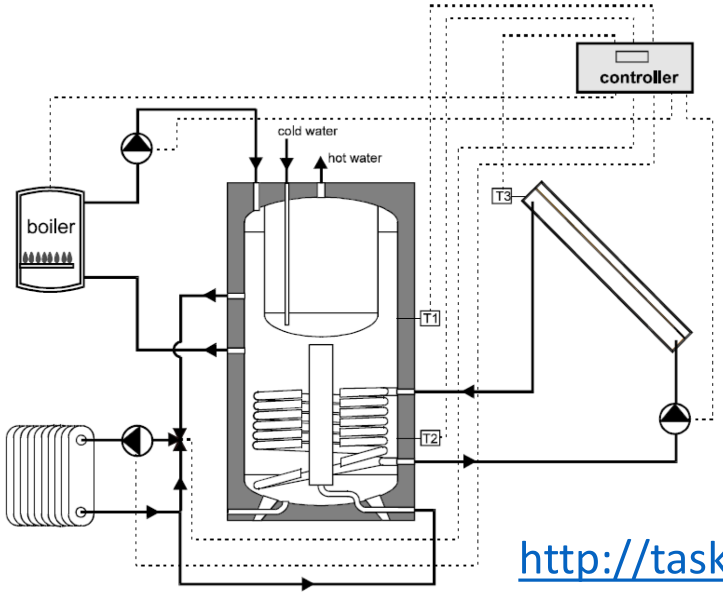
Principles of Thermal Storage

- Thermal buoyancy
- Flow to ST field at low T
- ST return to storage at T > storage
- Flow to load at high T
- Return from load at T< storage

Heat Injection into Thermal Storage

- Heat Exchange (Coil or heat exchanger)
  - Commonly cross Flow
  - If ST is only backup,
    coil at lower 1/3 of tank
  - Many designs have been tested over



http://task26.iea-shc.org/

Tank upside down!

Metro Therm production plant at Helsinge (DK)

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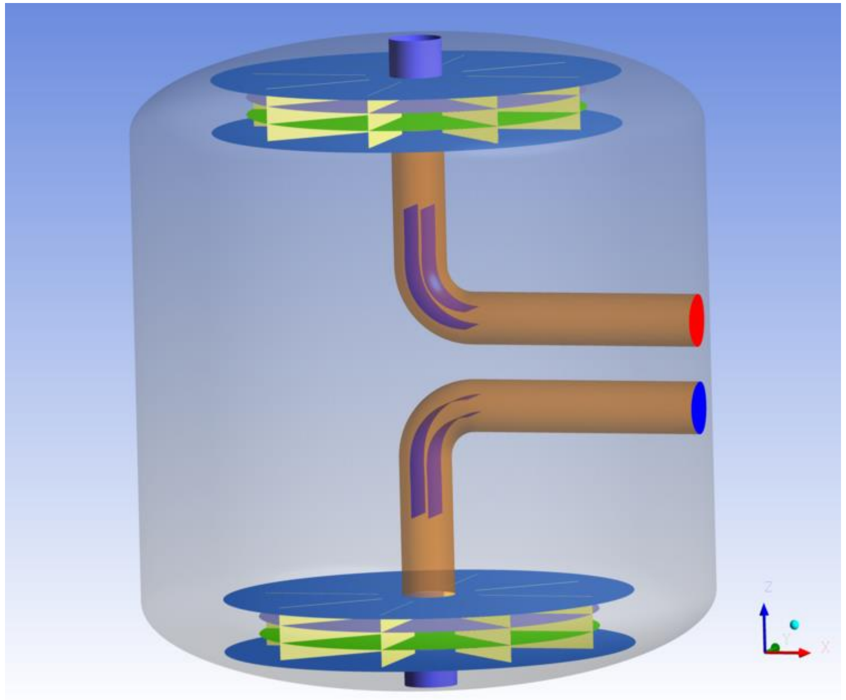
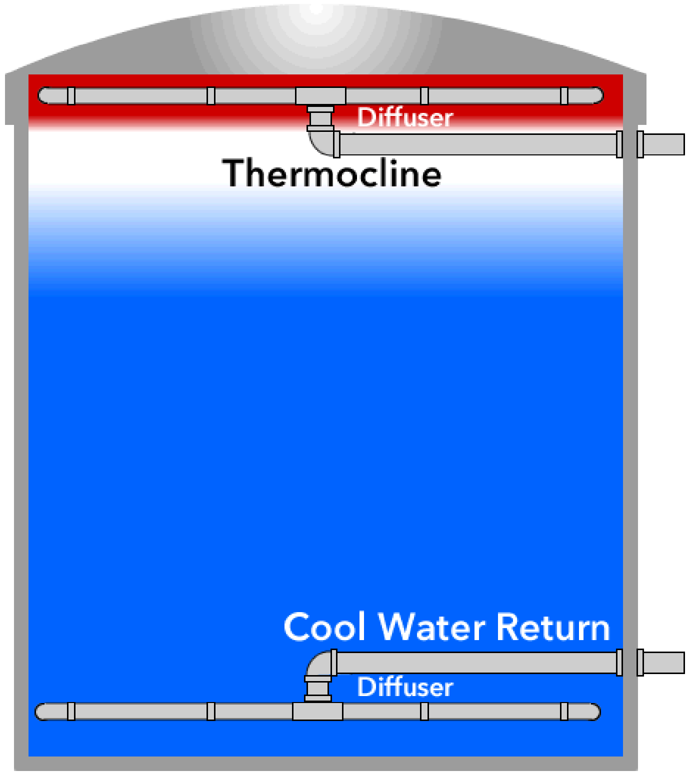
Heat Injection into Thermal Storage

- Open systems
  - Direct systems. Same fluid in tank and ST system



https://mechartes.com/case-study-thermal-energy-storage-tank



https://www.pacifictank.net/tes-tanks/

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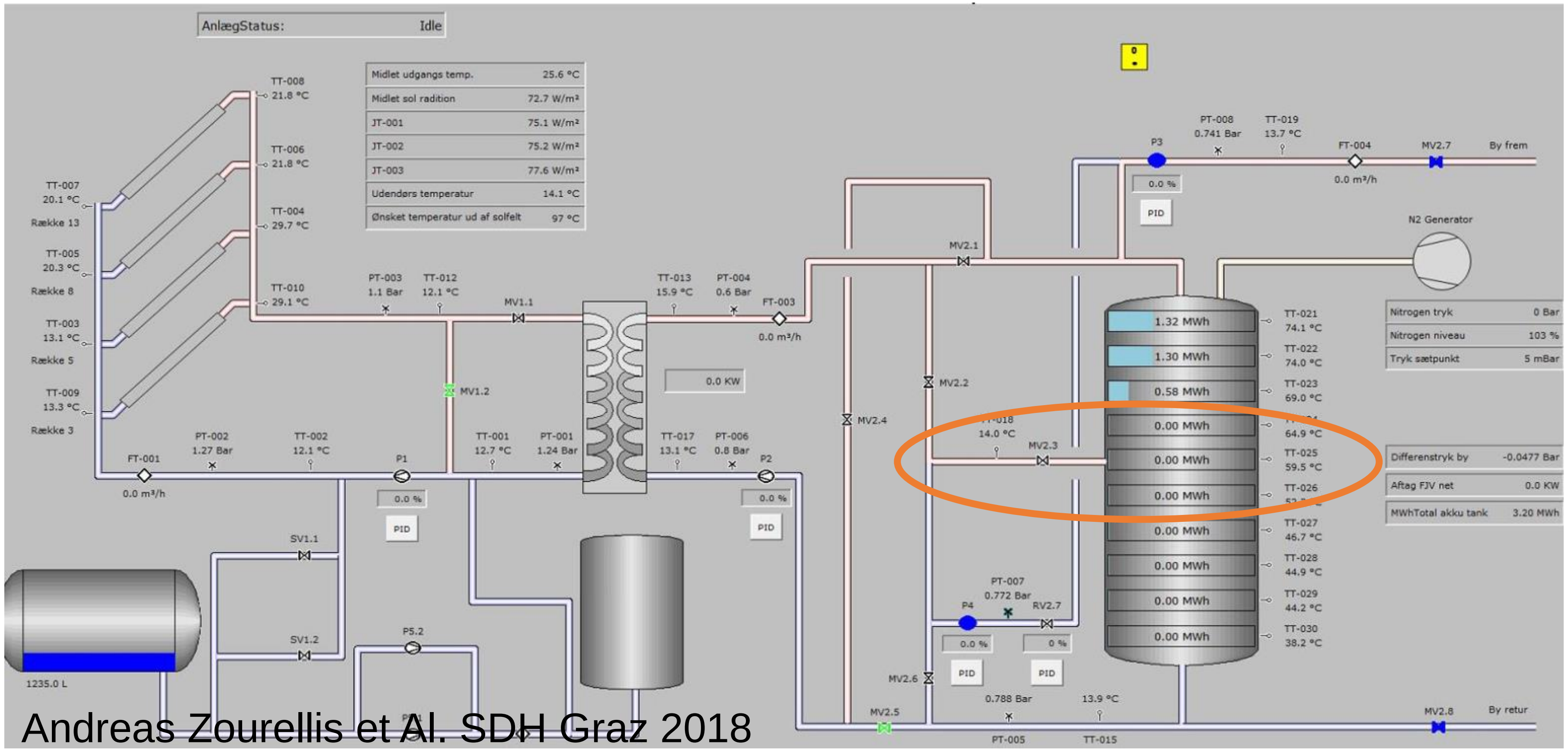
Heat Injection into Thermal Storage

- Open systems
  - Also, injection at intermediate temperature levels



Andreas Zourellis et Al. SDH Graz 2018

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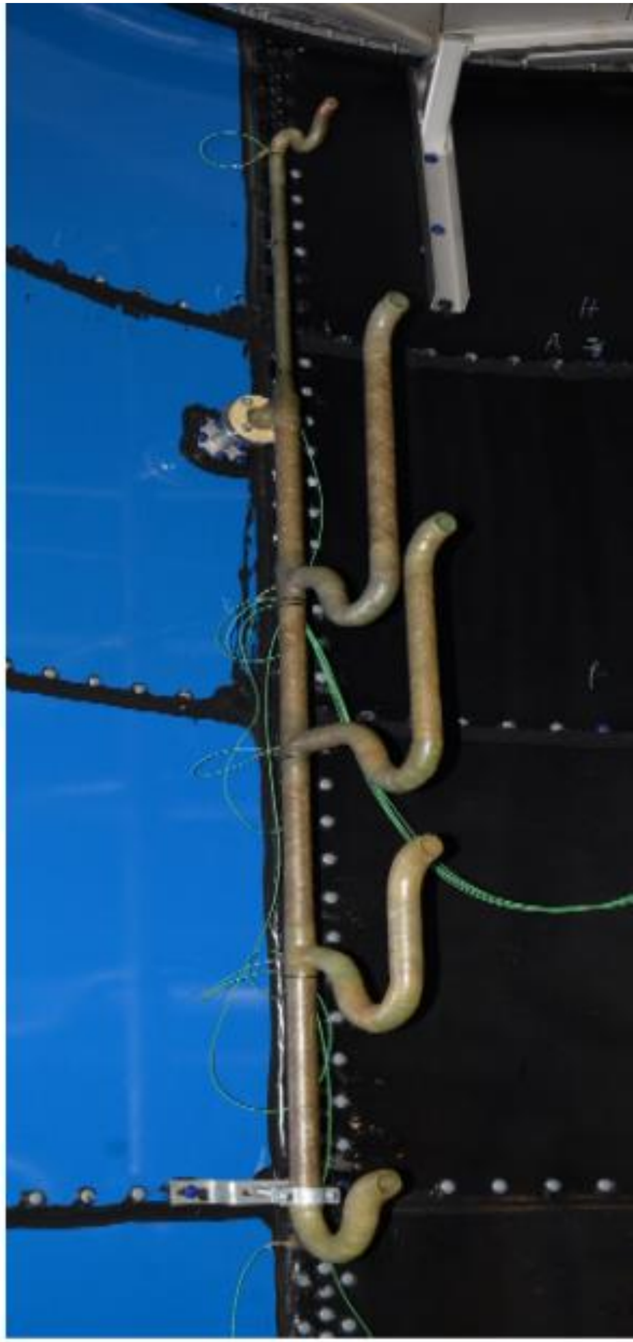
Heat Injection into Thermal Storage

- Open systems
  - Statification devices allow for beter positioning of intake at correct temperature levels



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Timo Herrmann et Al. SDH Graz 2018

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- Typical issues out of the scope of this exercises
  - Inperfect loading/unloading patterns
  - De-stratification & mixing
  - Actual values of insulation levels
  - …

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EXERCISE 4

Calculation of Thermal Store. Effective volume & Heat loss

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- Design of a thermal storage application for 200MWh
- 30ºC of Flow-return temperature difference
- How much energy can be stored in 1m3?
  - Cp = 4,2 kJ/kgK
  - Density = 1000 kJ/kg
  - factor= 3600 kJ/kWh
  - Answer?
    - Depends on the temperature rise. Let´s calculate it for 1ºC
    - 0,001166 MWh/m3K
- How large should be the tank?
  - 5714 m3
- Height of tank with 20m diameter?
  - 18,19 m

- Heat loss
  - Tank temperature: 70ºC
  - Ambient temperature: 5ºC
  - AT: 65ºC
- Coupling Coefficient

Item	Surface (m2)	U (W/m2K)	Q (kW)
Top	315	0,2	4,3325
Wall	1150	0,3	22,425
Bottom	315	0,7	14,33
Total			40,85

- Loss in 24h
  - ~1 MWh
  - ~0,5 % (over 200MWh)
- Loss in 1 week
  - ~7 MWh
  - ~3,5 % (over 200MWh)
- Loss in 1 month (31 days)
  - ~30,5 MWh
  - ~15 % (over 200MWh)

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3. District Heating Systems

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3.1 Evolution

- Some historic references
  - Roman Baths
  - Chaudes-Aigues (France)
- 1st generation. Steam Based systems (xxx – 1930)
  - Very high temperatures & presurized pipes
  - Non-optimal efficiency, reliability & safety
  - Still in use in Paris and New York
  - For areas with large heat density

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3.1 Evolution

- Some historic references
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- 1st generation. Steam Based systems (xxx – 1930)
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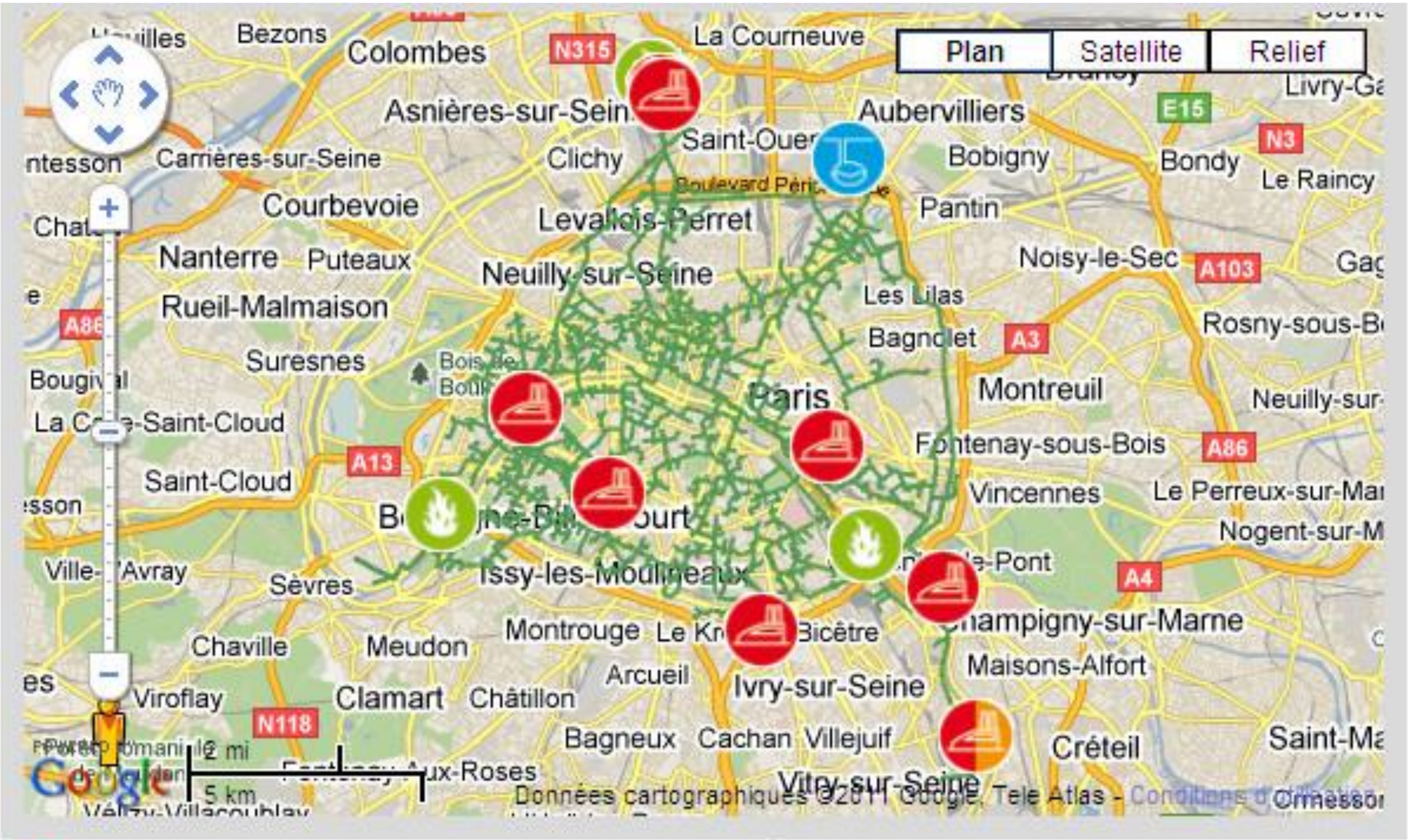

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Centre de production - Cogénération - CPCU

Centre de production - Géothermie - CPCU

Centre de valorisation des déchets ménagers du SYCTOM

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3.1 Evolution

- 2nd generation. Overheated water (1930 – 1970)
  - > 100 ºC
  - Coal and oil-based systems
- 3rd generation. Hot water (1970- today)
  - > 55-60ºC
  - Increased efficiency/sustainability of heat sources
    - CHP, Biomass, Industrial waste heat, etc.
  - Increased insulation levels

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3.2 Temperature levels

- Stable conditions for mild weather and summer
  - Compatible with DHW production
  - In some cases, service is interrupted in summer
- Increased temperature levels with cold weather
  - Increase capacity with same infrastructure
- Large Flow-Return ΔT to avoid large pumping costs

3.2 Temperature levels

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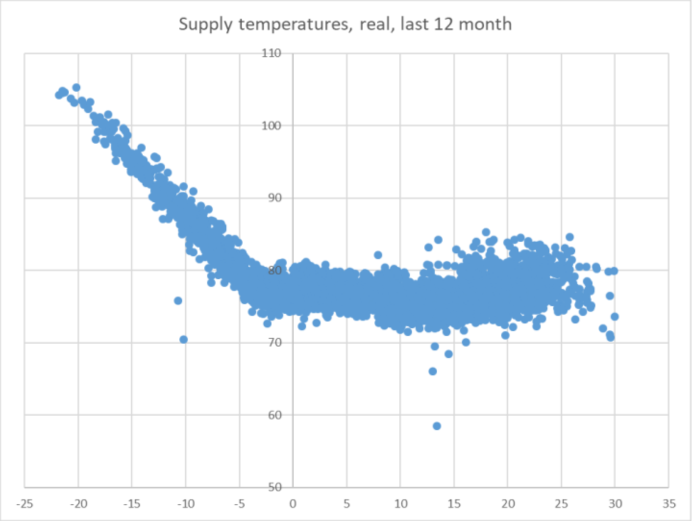

3.3 Heat production structure

- One (or various) low cost producer. As BASE HEAT PRODUCTION TECHNOLOGY
  - CHP (with additional revenue from electricity production)
  - Biomass or waste incineration
  - Industrial waste heat
  - Large boilerplant (e.g. fuel-based)
- Peak producers activated if required
  - Smaller & more expensive technologies
  - Commonly gas-fired boilerplants

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Questions 1.

Typical Full Load Operation Hours for Technologies.

- How many hours are there in a year? 8760h
- Typical length of heating season?
  - Serbia October-April, 7 months, ~5100h
  - Spain November-March, 5 months, ~3600h
- Max operating period of a plant? 11 months (1 month for maintenance)
- Meaning of Full Load Operation Hours?

FTOH (h)=Delivered energy (MWh)/Nominal power (MW)

- Typical FTOH for base technology (e.g. CHP)? 4000-6000h
  Winter at full load + partial load during summer
- Typical FTOH of peak technology (e.g. Natural Gas Boiler)?
  <1000h
  Only certain moments during coldest periods

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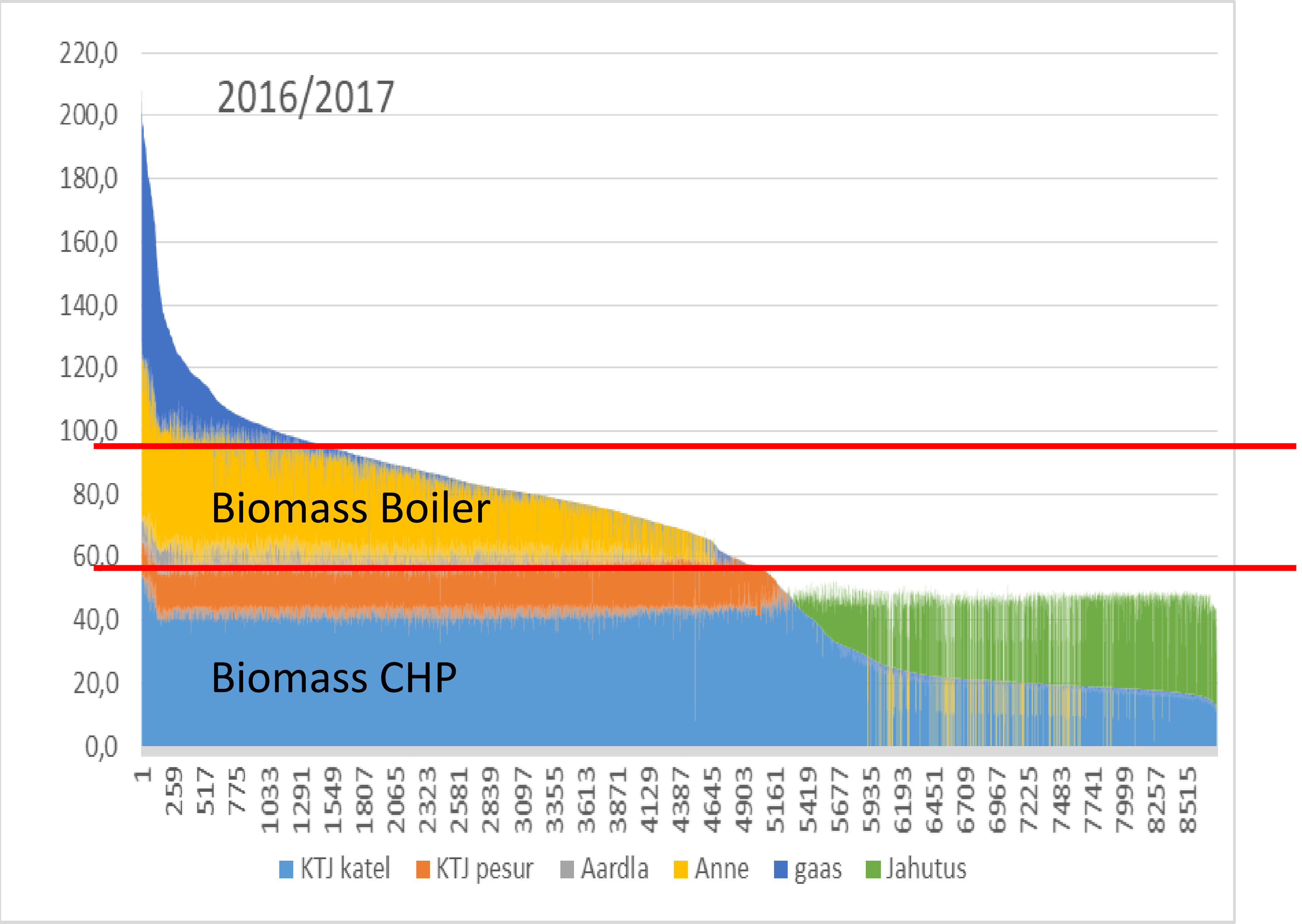

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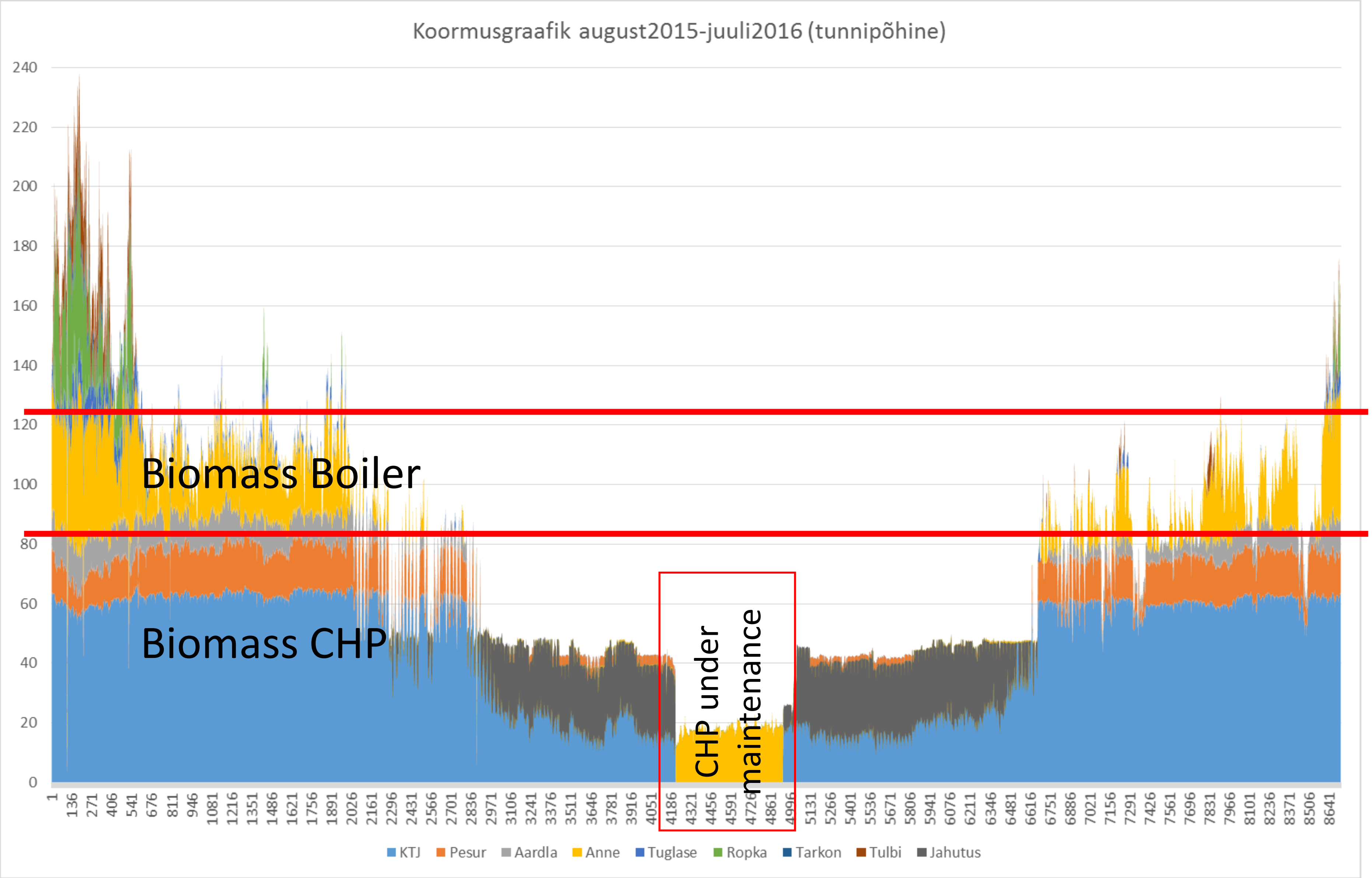

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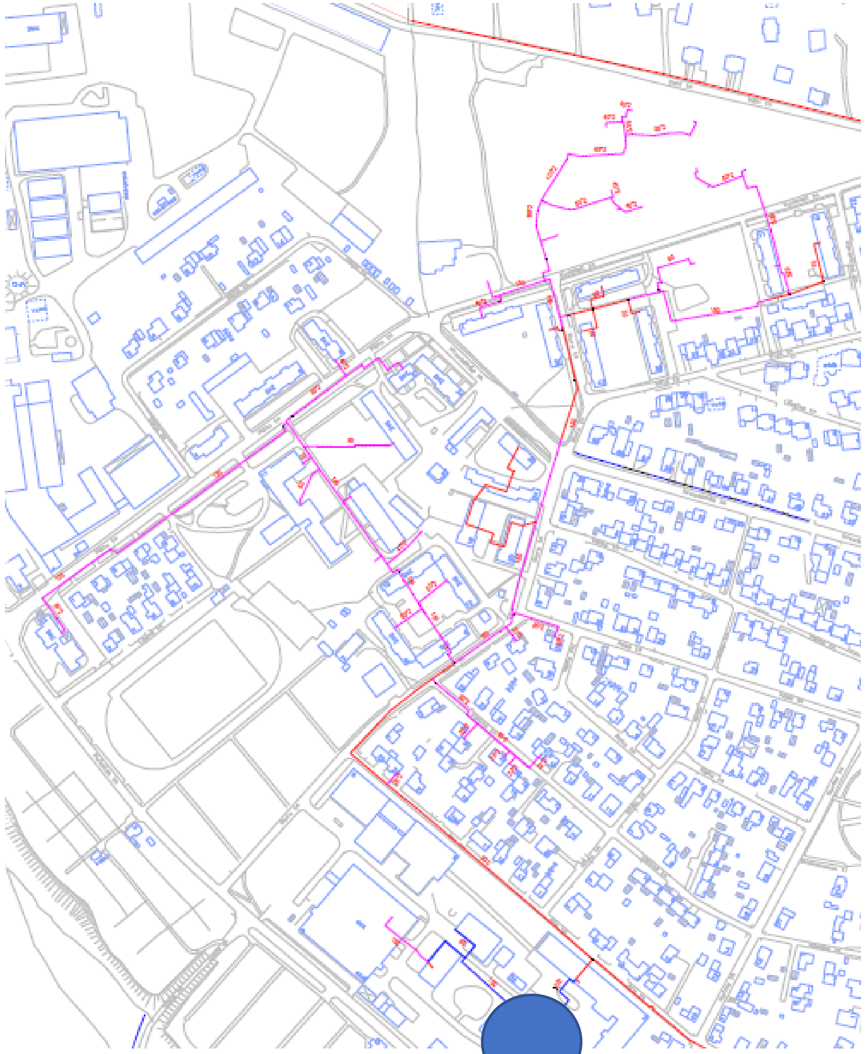
3.4 Network Structure

- Small networks:
    - One heat production facility
    - Individual branches
- Large networks:
    - One (large) heat production facility
    - Individual branches
    - Peak boilers installed in branches
    - In some cases, partially meshed system
- Very large networks
    - Transmission lines & Meshed networks

3.4 Network Structure



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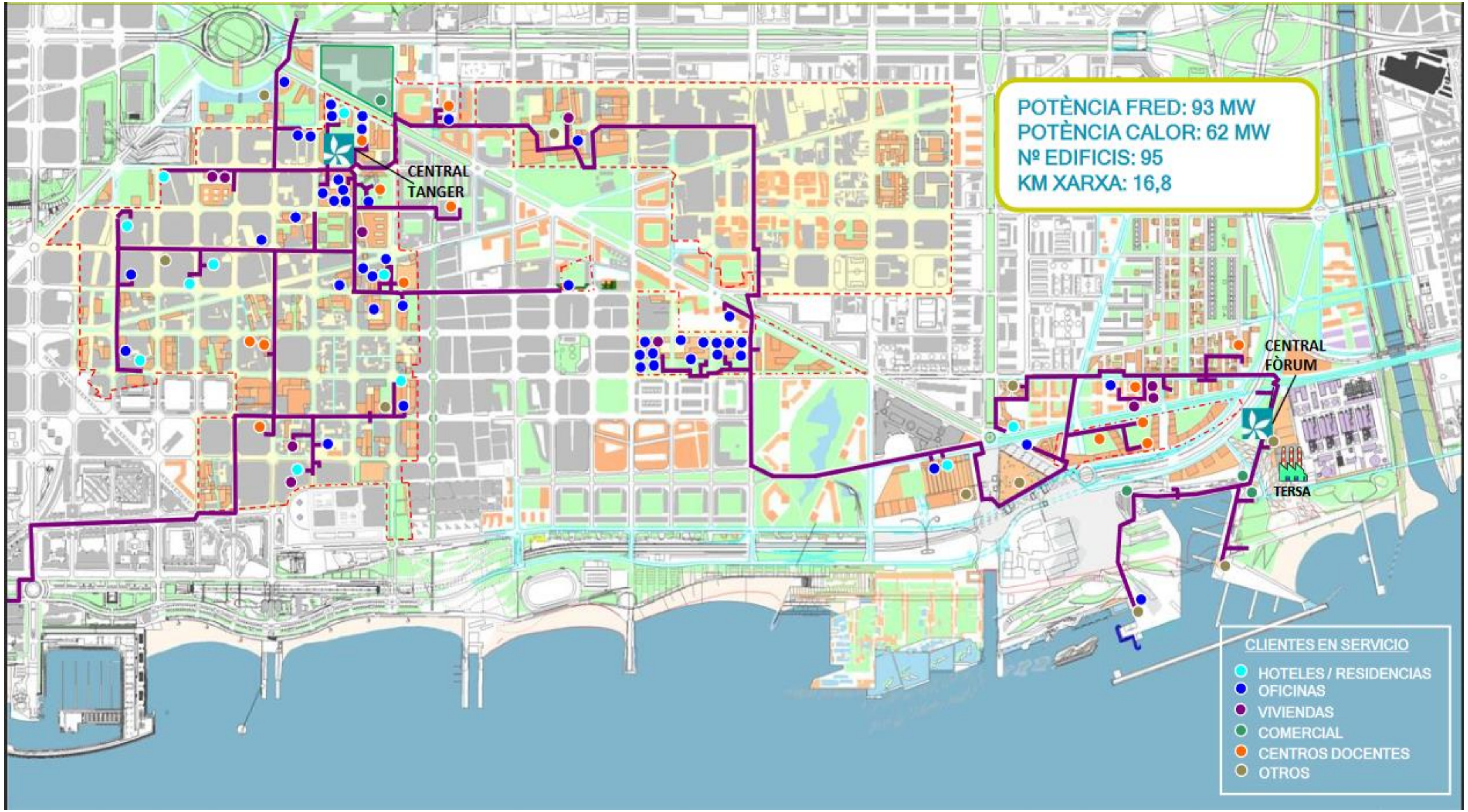
3.4 Network Structure



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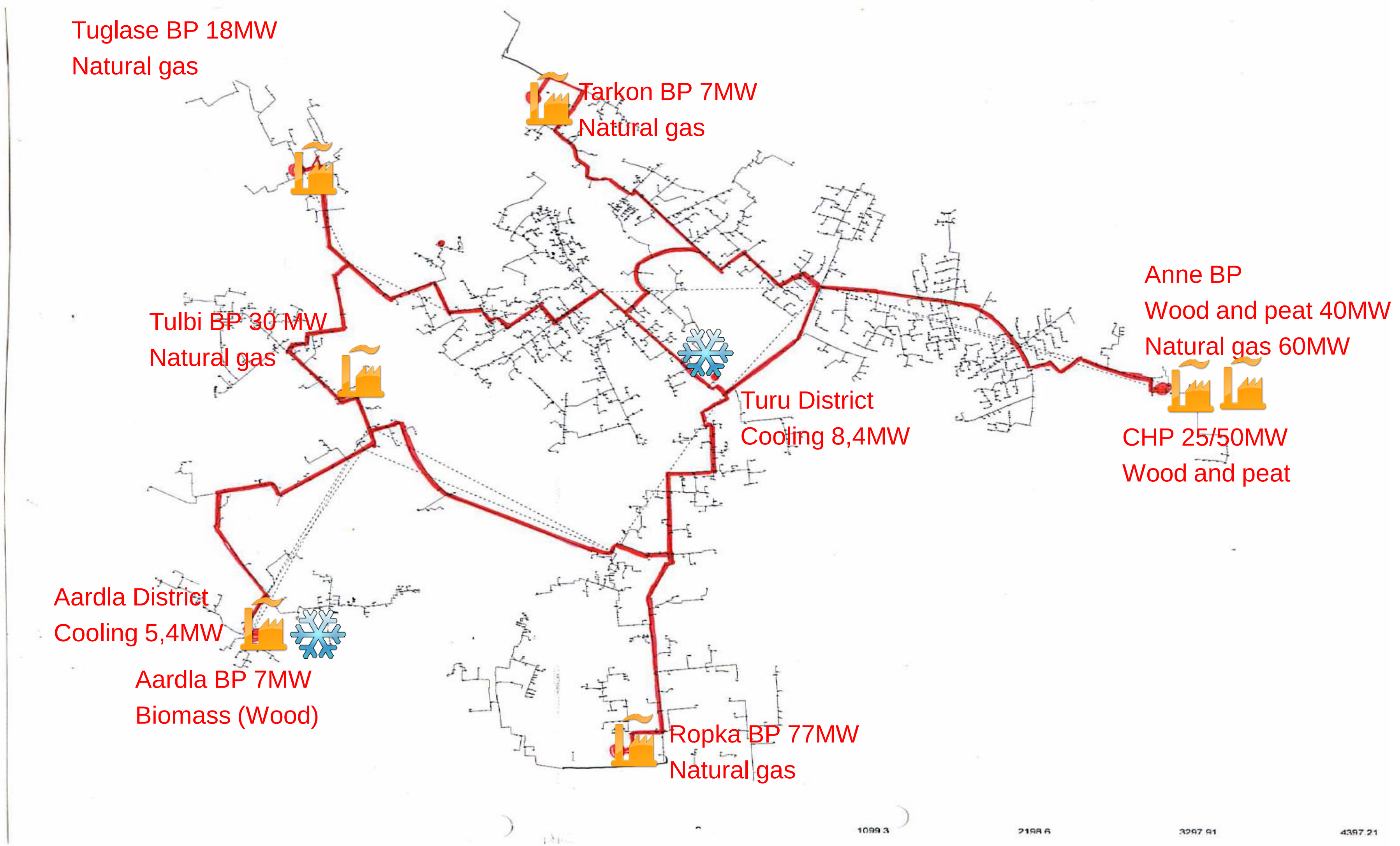

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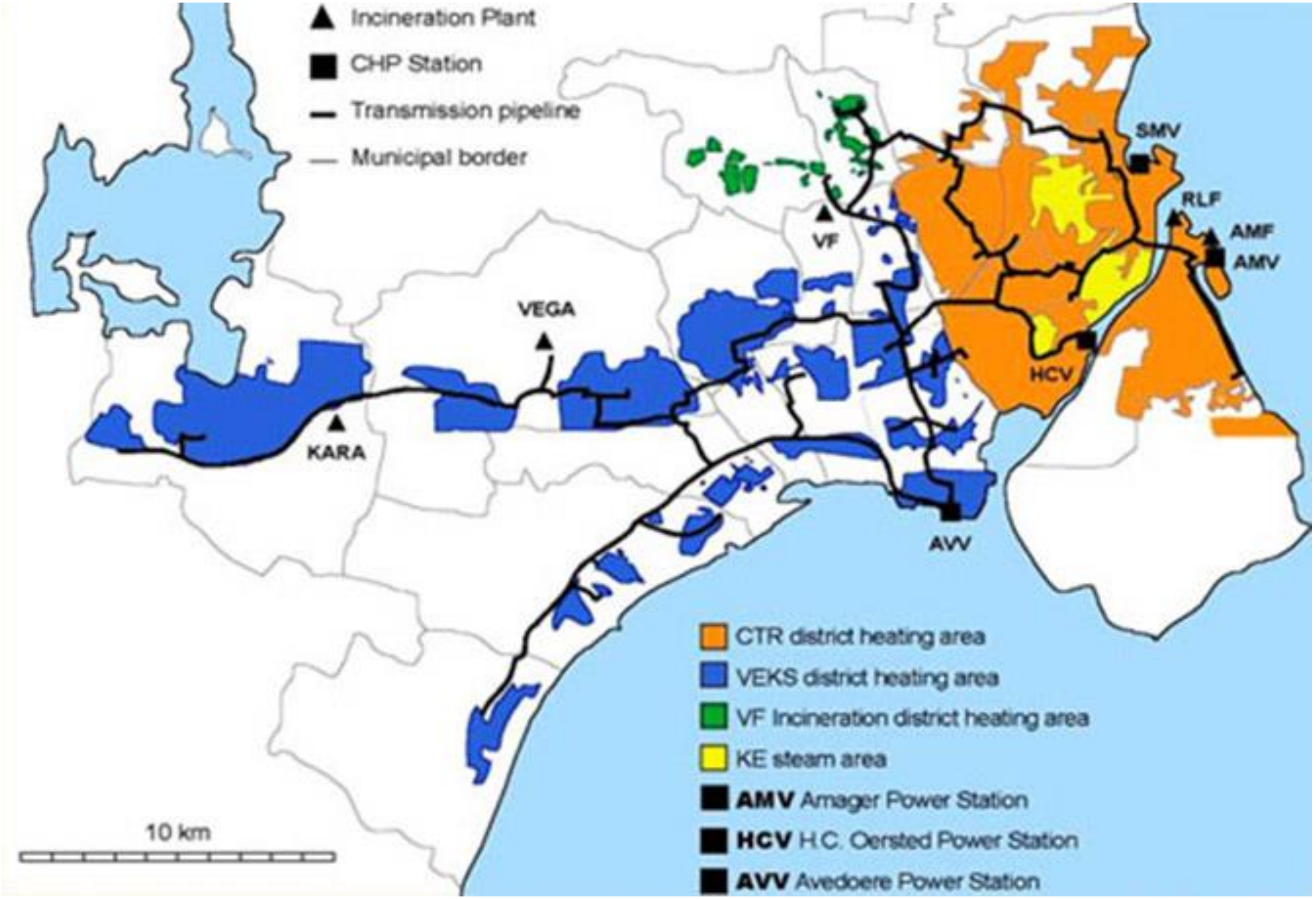

https://dbdh.dk/dhc-in-denmark/characteristics/

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Questions 2

Critical Spots for Damages/Failures.

Next spots for densification.

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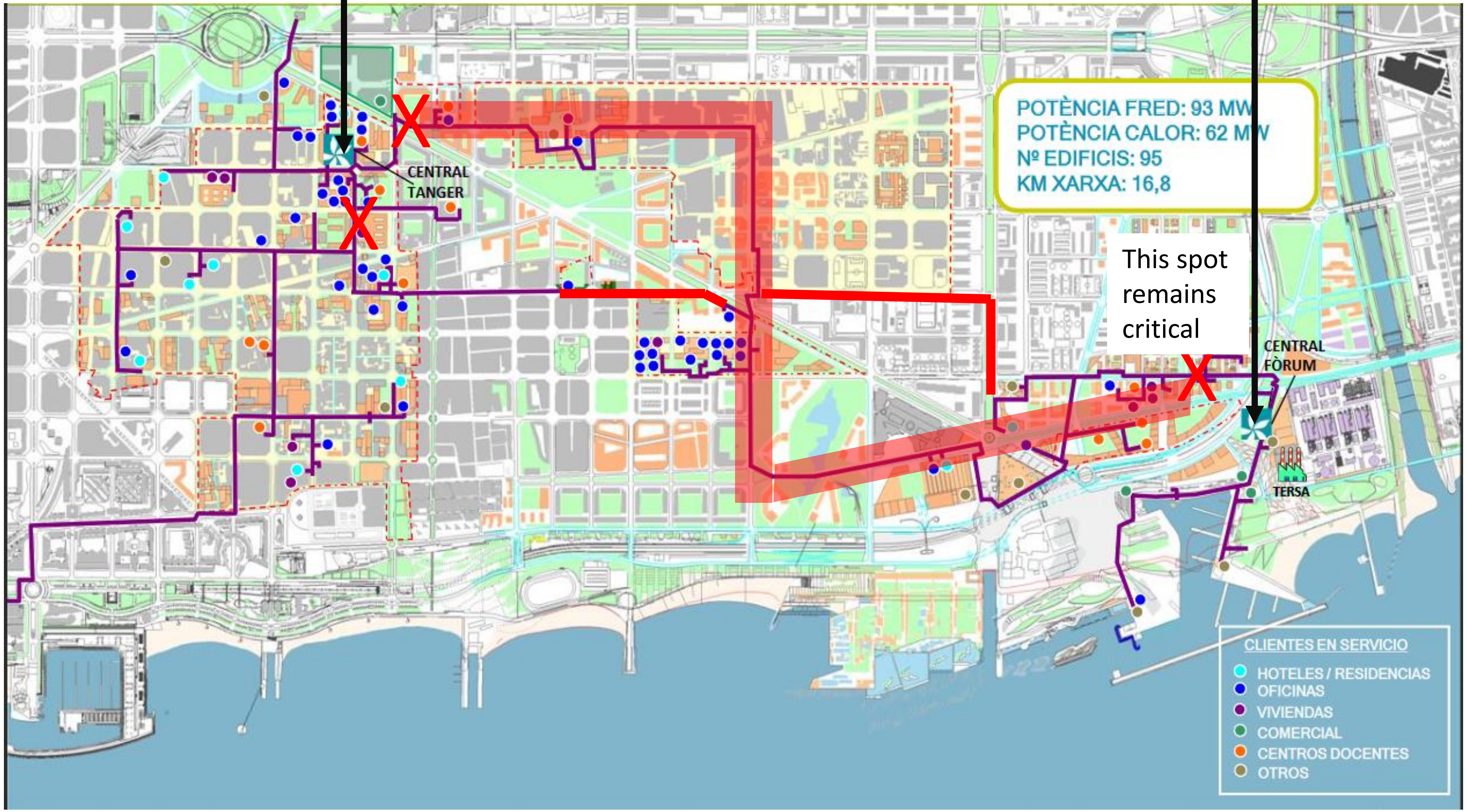
Plant 2
Large Capacity
Innefficient production

Plant 1
Largest Capacity
Most Efficient Production



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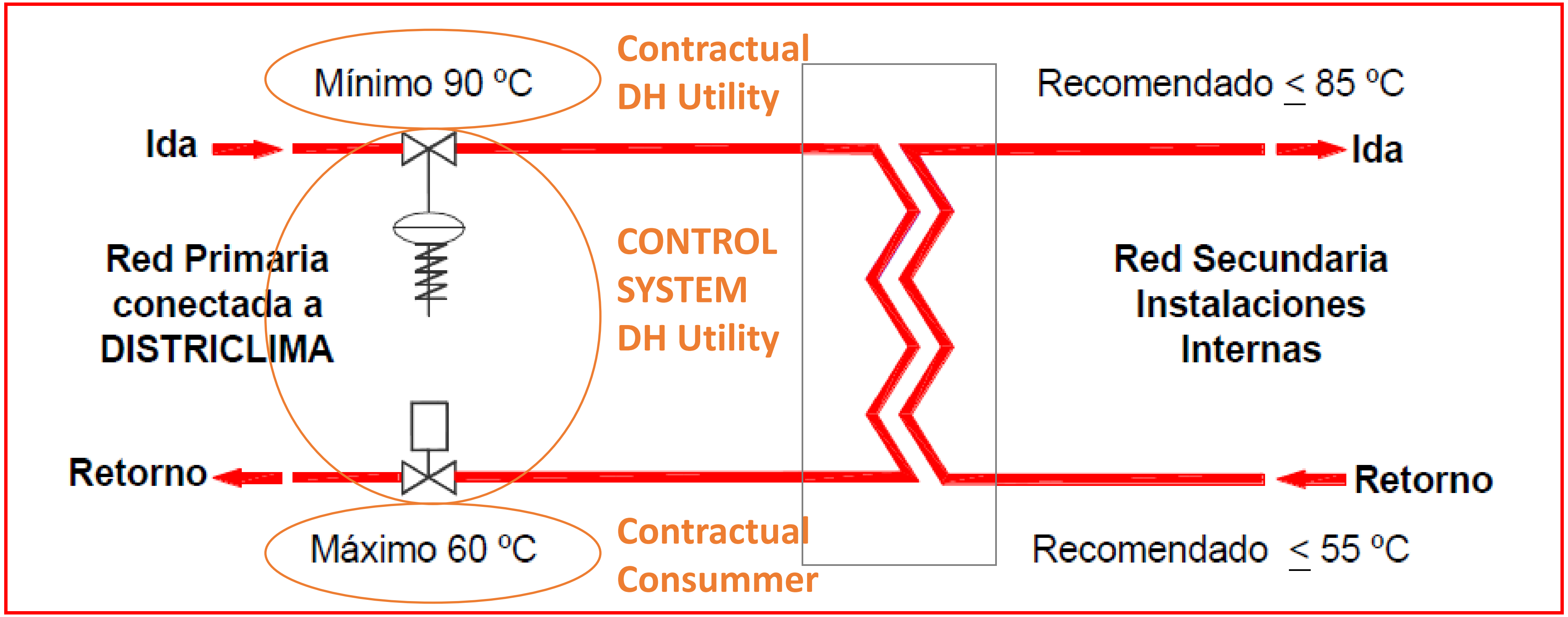
3.5 Design criteria (consumer-side)

- Deliver maximum heat at low (primary-side) Flow
- DHW sizing: temperature independent
- Space Heating sizing:
  - For typical winter conditions (at low Temperature)
  - For cold winter conditions (at high Temperature)
- Space Cooling sizing:
  - At stable DC temperature. DC already quite cold. Need to avoid frosting.
- Serviceability issues

3.5 Design criteria (consumer-side)

GUÍA TÉCNICA DEL CLIENTE	Página 4
Acometidas, subestaciones y circuitos interiores	Revisión 10 -03/11/16



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- For educational purposes only
- Typical issues out of the scope of this exercises
    - Many issues regarding fan coil unit selection

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Exercise 5

Changes in sizing of fan coil units from centralized boiler to District Heating

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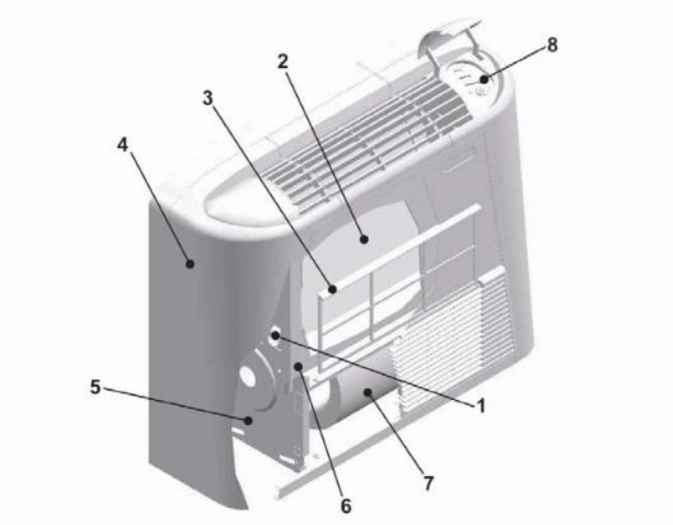

Características generales

Datos técnicos

MODELO		Uds.	16	20	30	40	50	60	80	100	120
Potencia frigorífica (1)	Vel.máx.	W	1100	1400	2100	2800	3400	4000	4900	6100	6850
	Vel.med.	W	980	1200	1850	2450	3010	3550	4350	5500	6100
	Vel.min	W	770	950	1450	1900	2390	2800	3600	4400	5000
Caudal de agua		l/h	189	241	361	482	585	688	848	1049	1178
Deshumidificación máx. vel.		g/h	230	275	500	650	750	870	930	1160	1350
Pérdida de carga lado agua		kPa	2.4	3.9	10.6	18.8	14.0	18	14.9	9.9	12.5
Potencia térmica (2)	Vel.máx.	W	2800	3650	5500	6500	7800	9400	12500	14900	15800
	Vel.med.	W	2400	2250	3400	4000	4930	5800	8300	9600	10000
	Vel.min	W	1800	2250	3400	4000	4930	5800	8300	9600	10000
Caudal de agua		l/h	241	314	478	559	671	808	1075	1281	1359
Pérdida de carga lado agua		kPa	2.9	4.9	13.2	18.5	14.0	18.1	17.7	10.8	12.1
Potencia térmica (3)		W	1700	2050	3200	3850	4590	5100	7200	8700	9300
Pérdida de carga lado agua		kPa	2.0	3.2	3.6	15.2	13.0	14.6	12.1	8.0	10.1
Potencia térmica batería un rango (3)	Vel.máx.	W	1250	1650	2550	3150	3690	4100	5050	6200	6950
	Vel.med.	W	1070	1420	2110	2640	3150	3440	4360	5200	6190
	Vel.mín.	W	860	1180	1750	2150	2820	2820	3480	4250	4800
Caudal agua		k/h	108	142	219	271	317	358	434	533	598
Pérdida de carga lado agua		kPa	1.7	3.0	3.6	13.2	3.0	4.1	6.2	12.8	16.1
Potencia térmica resistencia eléctrica		W	800	800	1500	1500	2200	2200	2200	2600	2600
Caudal aire	Vel.máx.	m^3/h	215	280	410	545	615	750	1050	1200	1350
	Vel.med.	m^3/h	170	210	310	400	510	600	850	970	1070
	Vel.mín.	m^3/h	110	140	220	290	350	410	570	670	720
N° ventiladores		Ud.	1	1	1	2	2	2	2	3	3
Presión sonora	Vel.máx.	dB(A)	32	35	39	41	44	44	48	50	52
	Vel.med.	dB(A)	24	29	32	34	37	37	45	46	47
	Vel.mín.	dB(A)	19	22	26	28	28	26	35	38	39
Potencia máxima motor		W	35	38	55	76	75	85	144	168	200
Conexión batería principal		"	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4
Conexión bat. suplementaria un rango		"	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2
Contenido agua bat. un rango		l	0.22	0.22	0.36	0.36	0.50	0.50	0.50	0.64	0.64
Contenido agua bat. tres rangos		l	0.82	0.82	1.26	1.26	1.88	1.88	1.88	2.42	2.42
Conexión salida de condensados		mm	16	16	16	16	16	16	16	16	16

NOTAS:
Alimentación: 230-1-50 (V-F-Hz)
(2) Calefacción
Temp. ambiente 20°C
Temp. agua en entrada 70°C, Δt agua 10°C a la máxima velocidad ventilador; para media y mínima velocidad ventilador caudal de agua como en la máxima velocidad.
(3) Temp. agua en entrada 50°C caudal de agua como en refrigeración.
Velocidad ventilador: máx.
(1) Refrigeración
Temp. aire ambiente: 27°C BS, 19°C BH
Temp. agua en entrada: 7°C Δt agua 5°C a la máxima velocidad ventilador; para media y mínima velocidad ventilador caudal agua como en la máxima velocidad.
Velocidad ventilador: máx.
(4) Presión sonora en ambiente de 100m³ con tiempo de reverberación de 0.5 seg.
(E) Datos certificados EUROVENT.

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Características generales

Rated power →

Datos técnicos

MODELO		Uds.	15	20	30	40	50	60	80	100	120
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	Vel.med.	W	980	1200	1850	2450	3010	3550	4350	5500	6100
	Vel.mín	W	770	950	1450	1900	2390	2800	3600	4400	5000
Caudal de agua		l/h	189	241	361	482	585	688	843	1049	1178
Deshumidificación máx. vel.		g/h	230	275	500	650	750	870	930	1160	1350
Pérdida de carga lado agua		kPa	2.4	3.9	10.6	18.8	14.0	13	14.9	9.9	12.5
Potencia térmica (2)	Vel.máx.	W	2800	3650	5500	6500	7800	9400	12500	14900	15800
	Vel.med.	W	2400	2250	3400	4000	4930	5800	8300	9600	10000
	Vel.mín	W	1800	2250	3400	4000	4930	5800	8300	9600	10000
Caudal de agua		l/h	241	314	473	559	671	808	1075	1231	1359
Pérdida de carga lado agua		kPa	2.9	4.9	13.2	18.5	14.0	13.1	17.7	10.8	12.1
Potencia térmica (3)		W	1700	2050	3200	3850	4590	5100	7200	8700	9800
Pérdida de carga lado agua		kPa	2.0	3.2	8.6	15.2	13.0	14.6	12.1	8.0	10.1
Potencia térmica batería un rango (2)	Vel.máx.	W	1250	1650	2550	3150	3690	4100	5050	6200	6950
	Vel.med.	W	1070	1420	2110	2640	3150	3440	4360	5200	6190
	Vel.mín.	W	860	1130	1750	2150	2820	2820	3480	4250	4800
Caudal agua		k/h	108	142	219	271	317	353	434	533	598
Pérdida de carga lado agua		kPa	1.7	3.0	3.6	13.2	3.0	4.1	6.2	12.3	10.1
Potencia térmica resistencia eléctrica		W	800	800	1500	1500	2200	2200	2200	2600	2600
Caudal aire	Vel.máx.	m³/h	215	280	410	545	615	750	1050	1200	1350
	Vel.med.	m³/h	170	210	310	400	510	600	850	970	1070
	Vel.mín.	m³/h	110	140	220	290	350	410	570	670	720
Nº ventiladores		Ud.	1	1	1	2	2	2	2	3	3
Presión sonora	Vel.máx.	dB(A)	32	35	39	41	44	44	48	50	52
	Vel.med.	dB(A)	24	29	32	34	37	37	45	46	47
	Vel.mín.	dB(A)	19	22	26	28	23	26	35	38	39
Potencia máxima motor		W	35	38	55	76	75	85	144	163	200
Conexión batería principal		"	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4	3/4
Conexión bat. suplementaria un rango		"	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2
Contenido agua bat. un rango		l	0.22	0.22	0.36	0.36	0.50	0.50	0.50	0.64	0.64
Contenido agua bat. tres rangos		l	0.82	0.82	1.26	1.26	1.88	1.88	1.88	2.42	2.42
Conexión salida de condensados		mm	16	16	16	16	16	16	16	16	16

NOTAS:
Alimentación: 230-1-50 (V-F-Hz)
(2) Calefacción
Temp. ambiente 20°C
Temp. agua en entrada 70°C, Δt agua 10°C a la máxima velocidad ventilador; para media y mínima velocidad ventilador caudal de agua como en la máxima velocidad.
(3) Temp. agua en entrada 50°C caudal de agua como en refrigeración.
Velocidad ventilador: máx.
(1) Refrigeración
Temp. aire ambiente: 27°C BS, 19°C BH
Temp. agua en entrada: 7°C Δt agua 5°C a la máxima velocidad ventilador; para media y mínima velocidad ventilador caudal agua como en la máxima velocidad.
Velocidad ventilador: máx.
(4) Presión sonora en ambiente de 100m³ con tiempo de reverberación de 0.5 seg.
(E) Datos certificados EUROVENT.

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MODELO		Uds.	20
Potencia térmica (2)	Vel.máx.	W	5500
	Vel.med.	W	3400
	Vel.min	W	3400
Caudal de agua		l/h	473

(2) Calefacción
Temp. ambiente 20°C
Temp. agua en entrada 70°C, Δt agua 10°C a la máxima velocidad ventilador; para media y mínima velocidad ventilador caudal de agua como en la máxima velocidad.

- Ambient T = 20ºC
- Inlet Water T = 70ºC
- Water AT = 10ºC
- Mean Water T = 65ºC
- Water-Amb AT = 45ºC
- H(W/K) = 5500/45 = 122W/K

DH →

- Ambient T = 20ºC
- Inlet Water T = 70ºC
- Water AT = **30ºC**
- Mean Water T = 55ºC
- Water-Amb AT = 35ºC
- H(W/K) 122W/K
- Power(W) = 35*122 = 4270W
- Reduction (%) = **22%**

- Power = 4270 W
- Cp = 4.2 kJ/kg.K = 1,16 W.h/l.K
- AT = 30 ºC
- Flow = 122l/h
- Reduction (%) = **75%**

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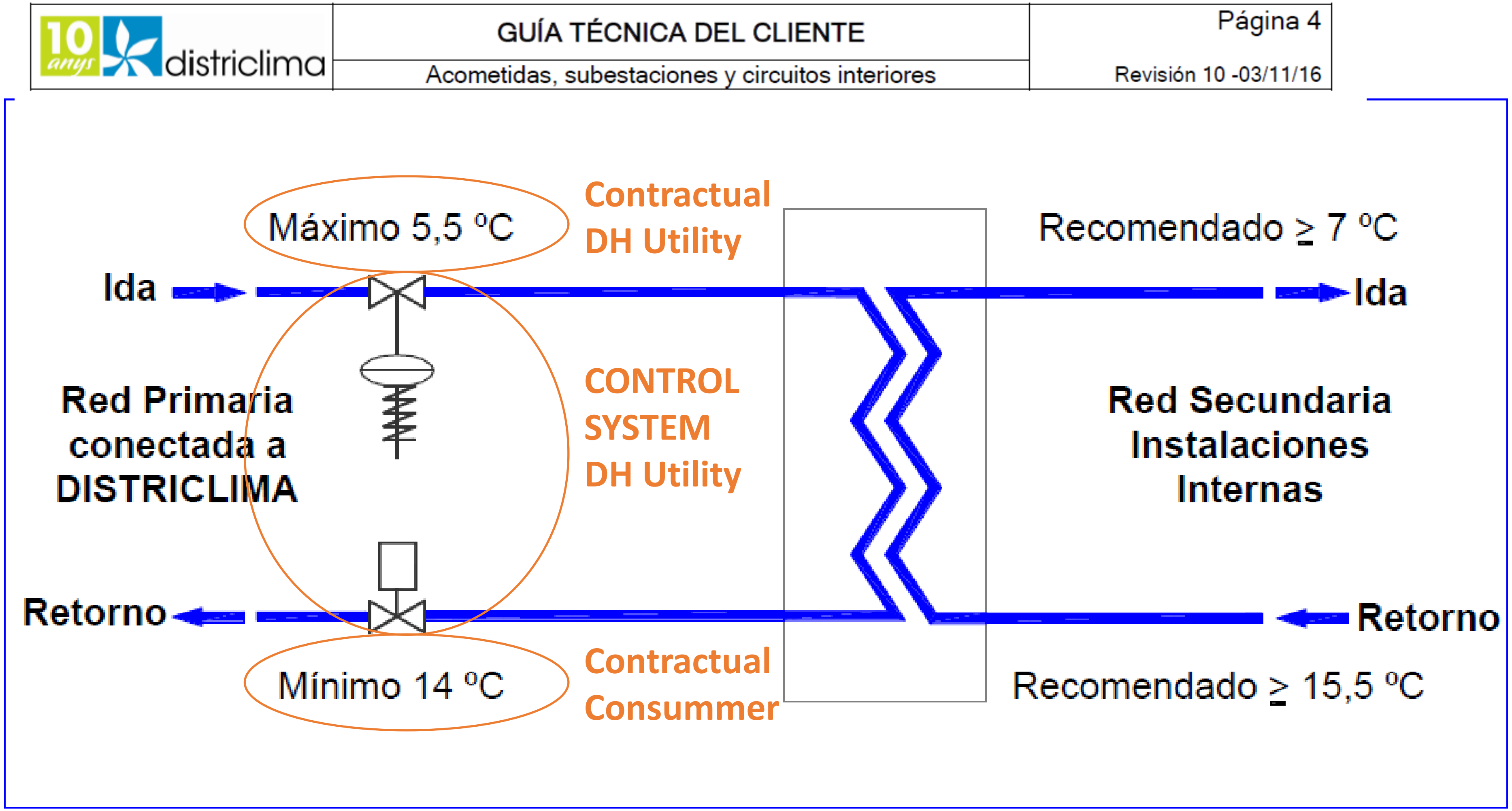
3.5 Design criteria (consumer-side)



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3.5 Design criteria (consumer-side)

- Materials & layouts standardized for the full network
- Meters standardized.
  - Data to be provided varies with capacity
    - Small buildings. Total Heat. Even manual reading
    - Large buildings/factories. Automated Reading.
      - Instantaneous power
      - Total heat
      - Instantaneous Flow
      - Total volumen
      - Inlet T
      - Outlet T
      - Secondary-side values

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3.5 Design criteria (consumer-side)

- Materials & layouts -> standardized for the full network
  - Thermal insulation
  - Operational Pressure & Temperature
  - Homogeneous devices across network
- Meters -> standardized.
  - Data to be provided varies with capacity
    - Small buildings. Total Heat. Even manual reading
    - Large buildings/factories. Automated Reading.
      - Instantaneous power
      - Total heat
      - Instantaneous Flow
      - Total volumen
      - Inlet T
      - Outlet T
      - Secondary-side values

3.5 Design criteria (consumer-side)

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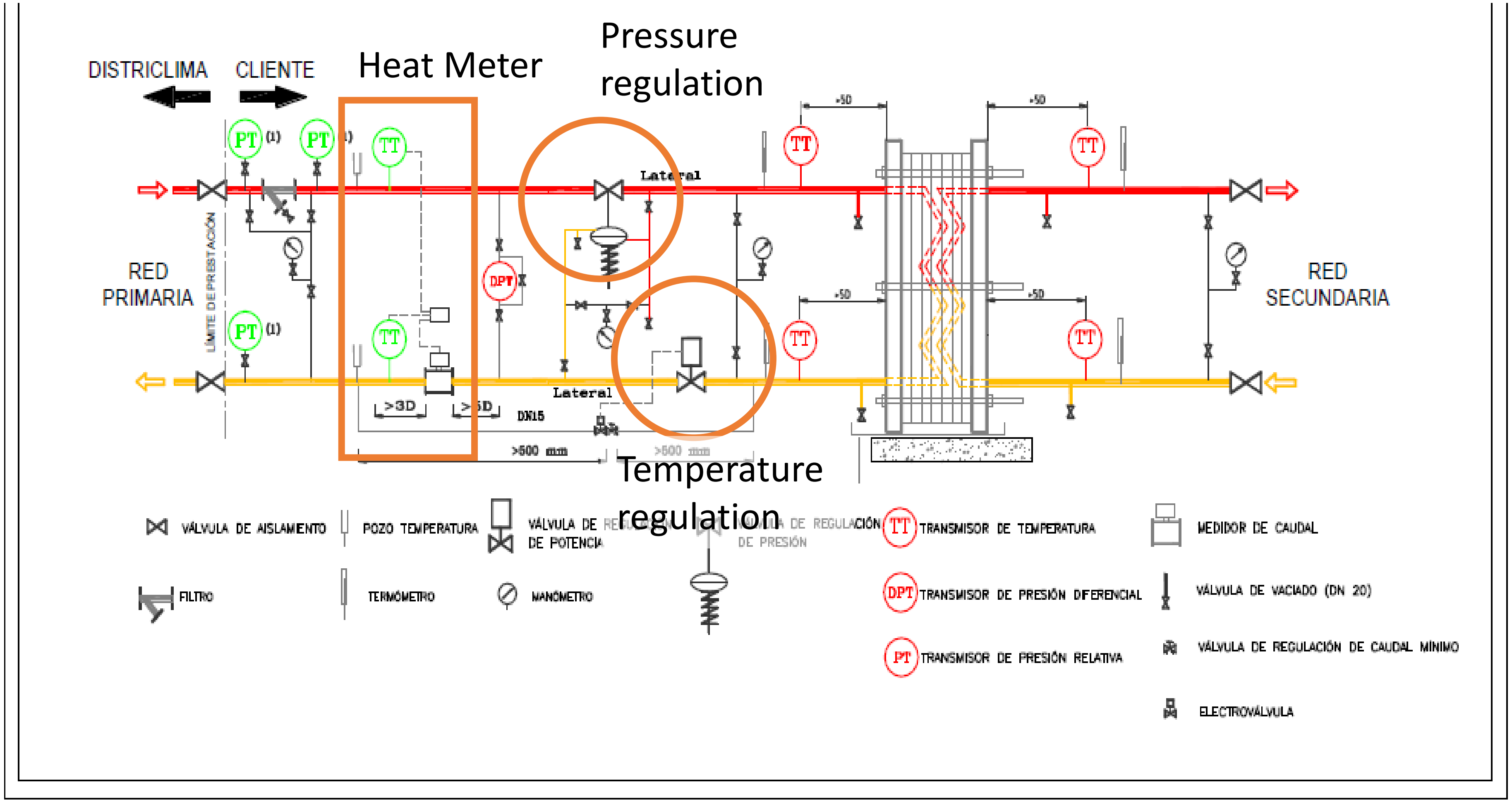
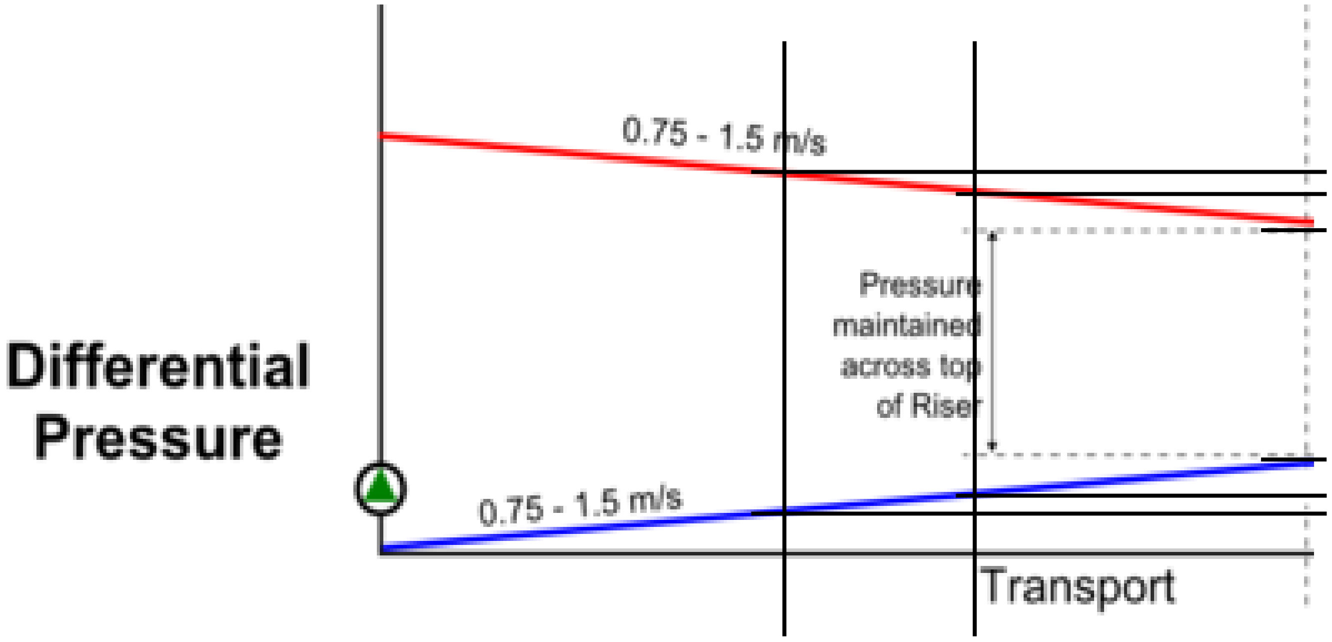
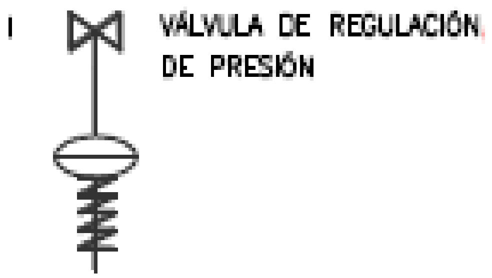


3.6 Presure diagram





- Materials specified for greatest AP
- Presure regulation valve delivers only AP under contract
  - Otherwise Flow/energy to last building in the line would be limited

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3.6 Operation criteria

- Guarantee heat supply
  - DHW temperature levels (summer)
  - Weather-dependent temperature levels (Winter)
- Heat production with lowest posible cost
  - Income from electricity production in CHP
  - CO_2 emission taxes

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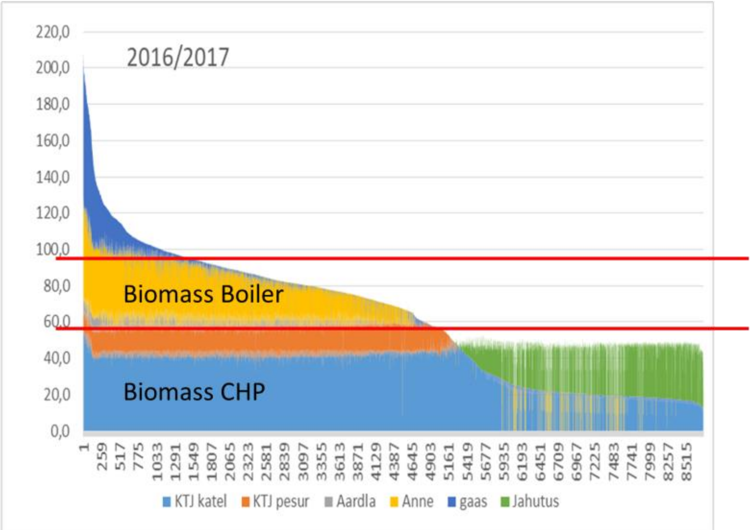
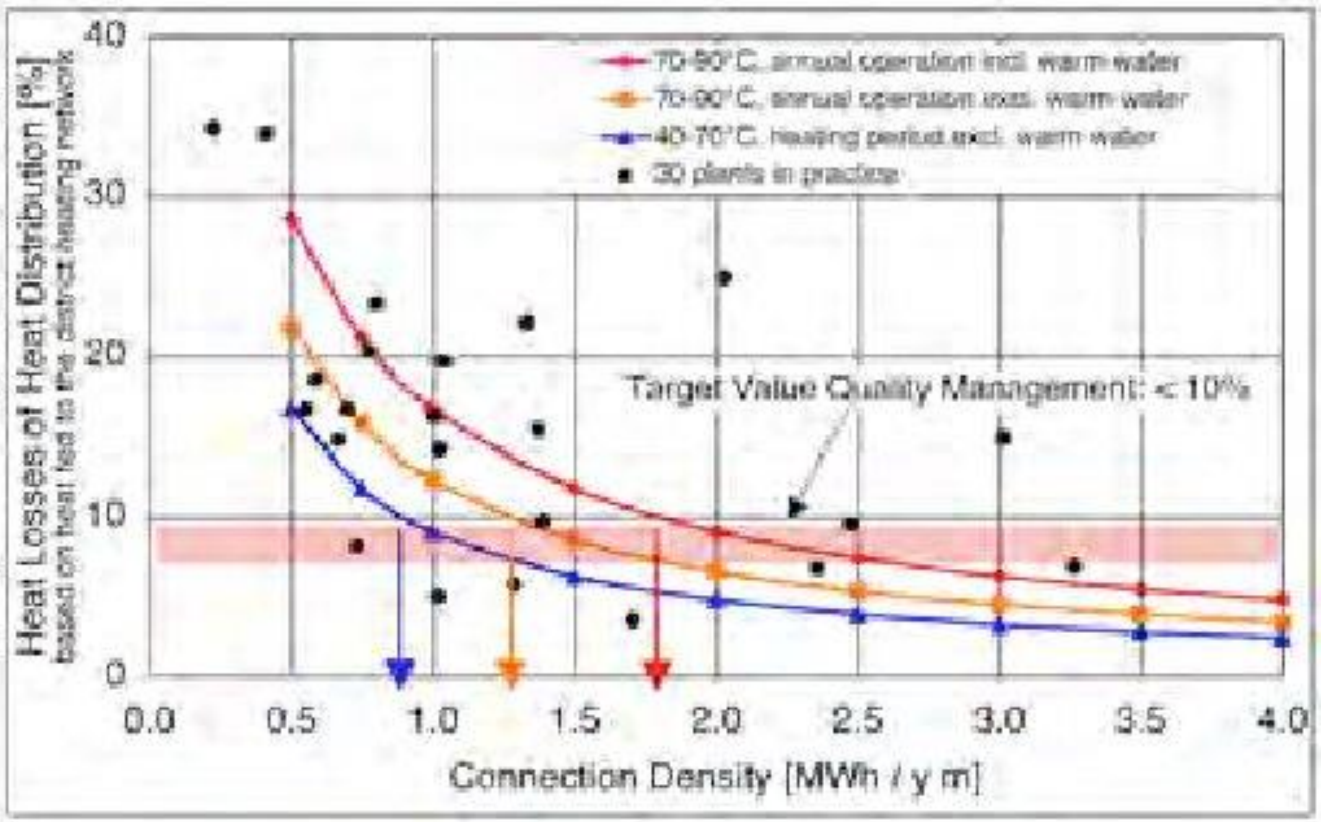


Fortum Tartu. District Heating Network of Tartu, Estonia

3.6 Operation criteria

- Reduce network loss
  - Lowest posible distribution T



J. Good et Al. Conference on Biomass for Energy, Industry and Climate Protection, Rome 2004

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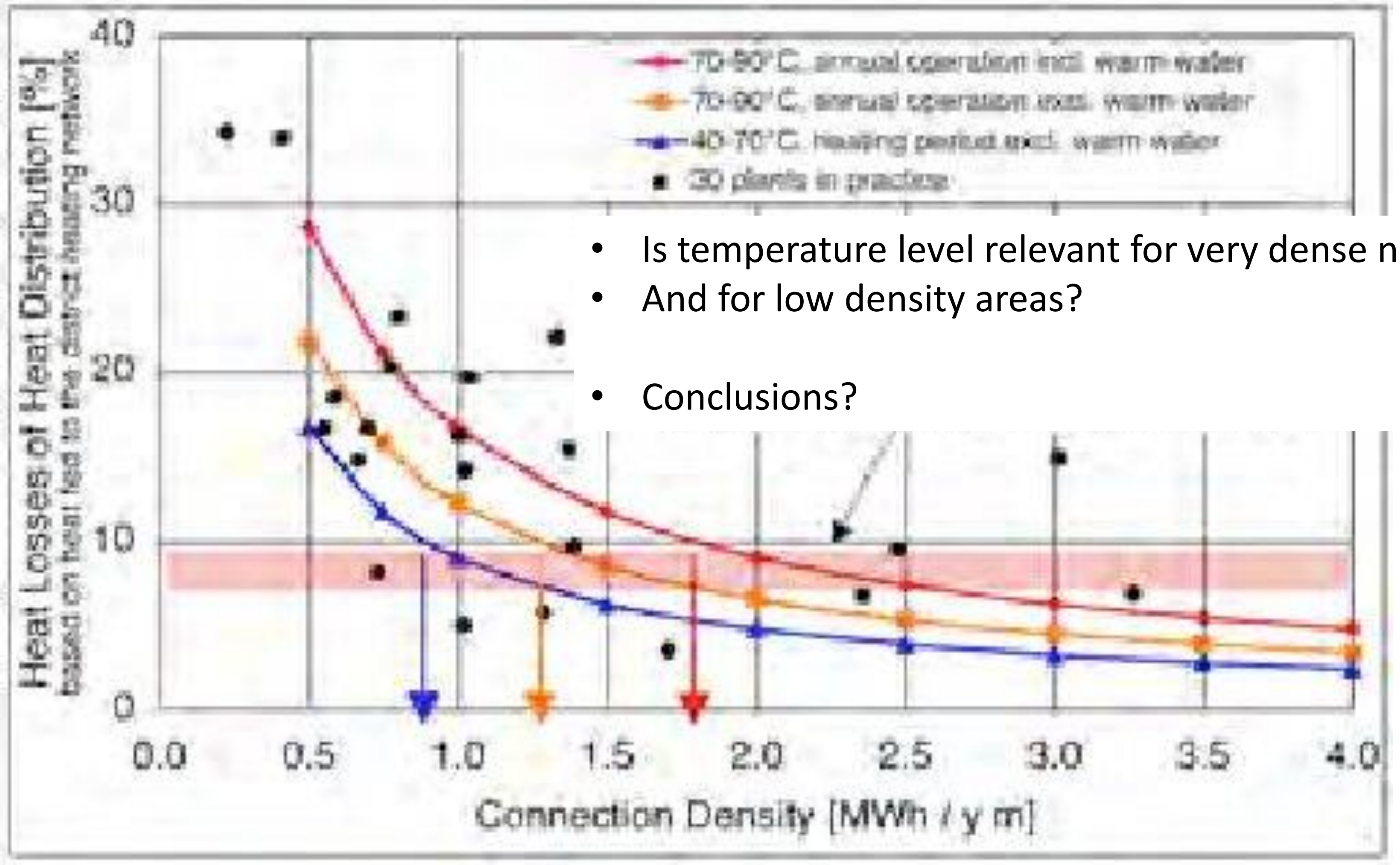
Questions 3

Network loss

- Typical distribution heat loss in 3G DH networks? ~7-15% (90/70C)
- Loss reduction due to change to 3.5-4G DH networks? 5-10% (70/40ºC)
- Loss in dense urban environments? ~5%
- Loss in small towns? **15-30%**



- Is temperature level relevant for very dense networks? Not too much
- And for low density areas? It is critical
- Conclusions?

Steam networks still in operation in Paris and New York

Low Temperature DH concepts are developed in suburban areas

3.7 Integration of Renewables & Waste Heat Sources

- Industrial waste heat
- Solar thermal Systems
- Low grade heat (heat pumps)
  - Geothermal
  - Lakes/Rivers
  - Exhaust from cooling applications (~20-30ºC)
  - Air-driven heat pumps
- Waste to heat
- CHP systems (?)

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Industrial waste heat

- Process cooling.
  - Commonly reject heat goes to atmosphere.
  - Complex systems which require maintenance & consume electricity
  - Potential (almost) free heat source for DH
- (some examples)

Industrial waste heat

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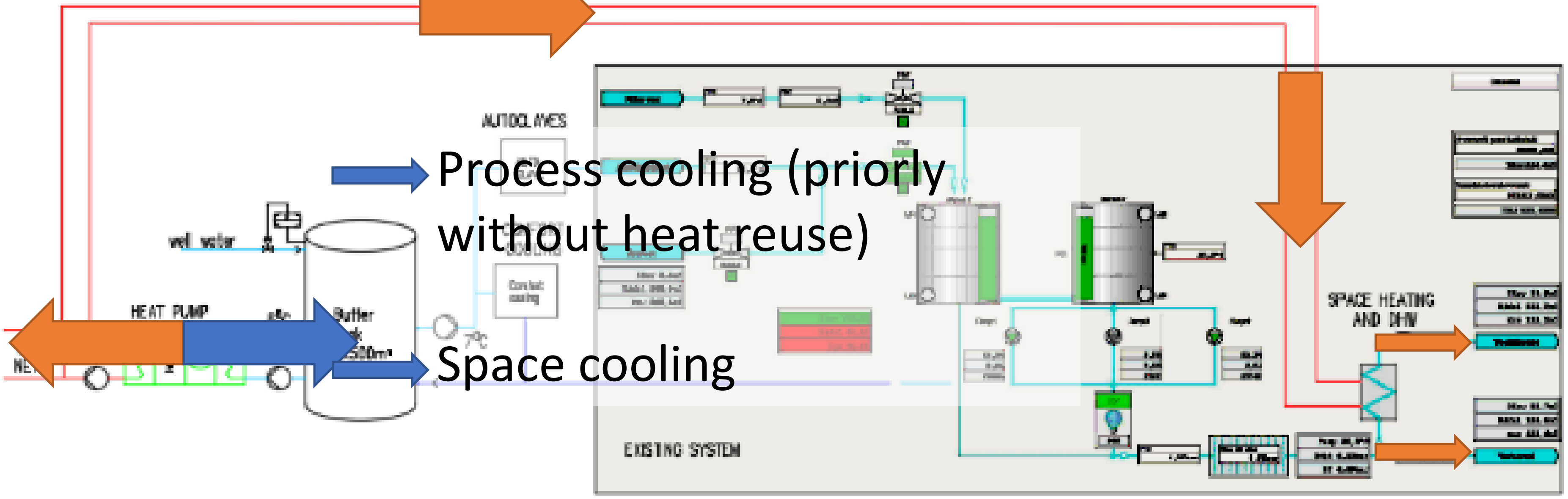
Heating from DH (space heating & DHW)



Process cooling (priorly without heat reuse)

Space cooling

High Grade heat (nat. Gas)

Industrial waste heat

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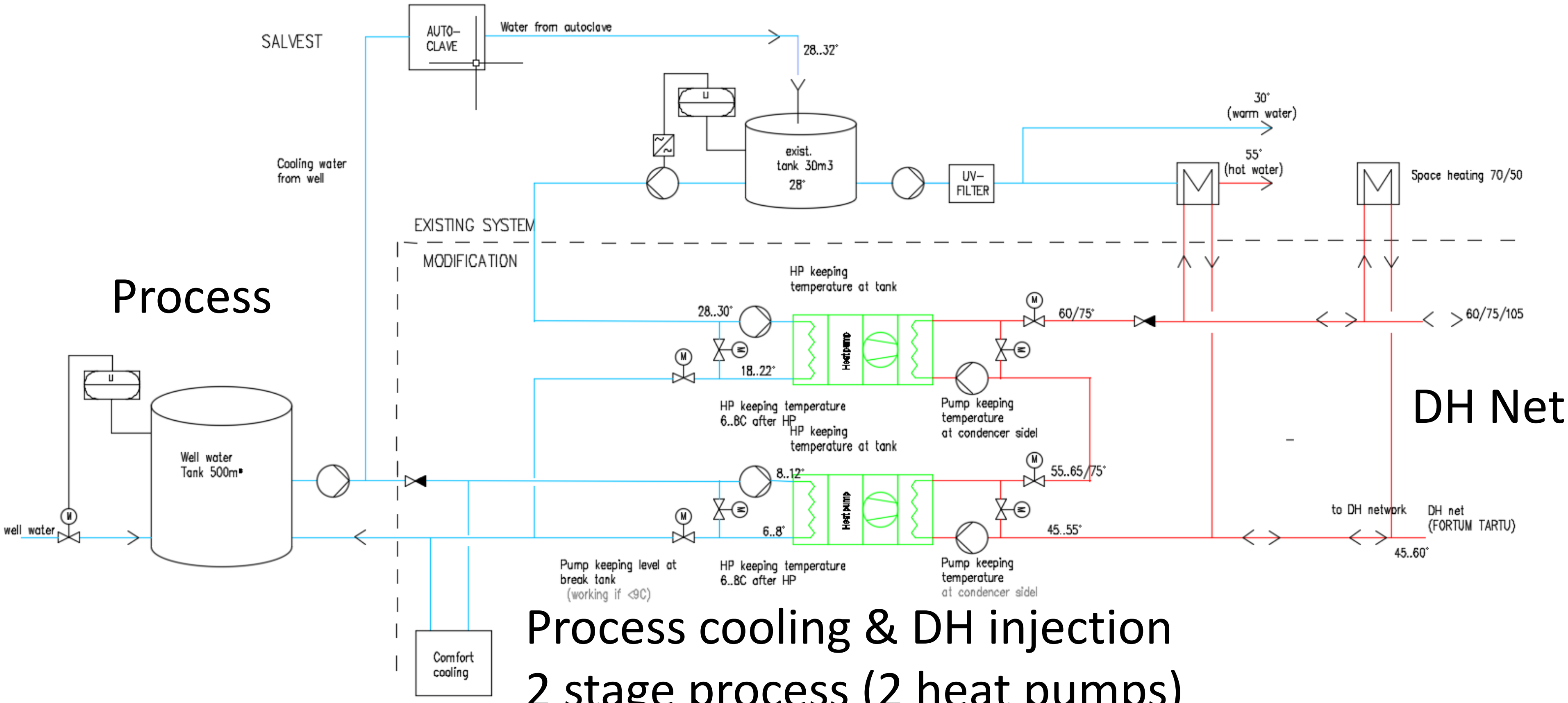
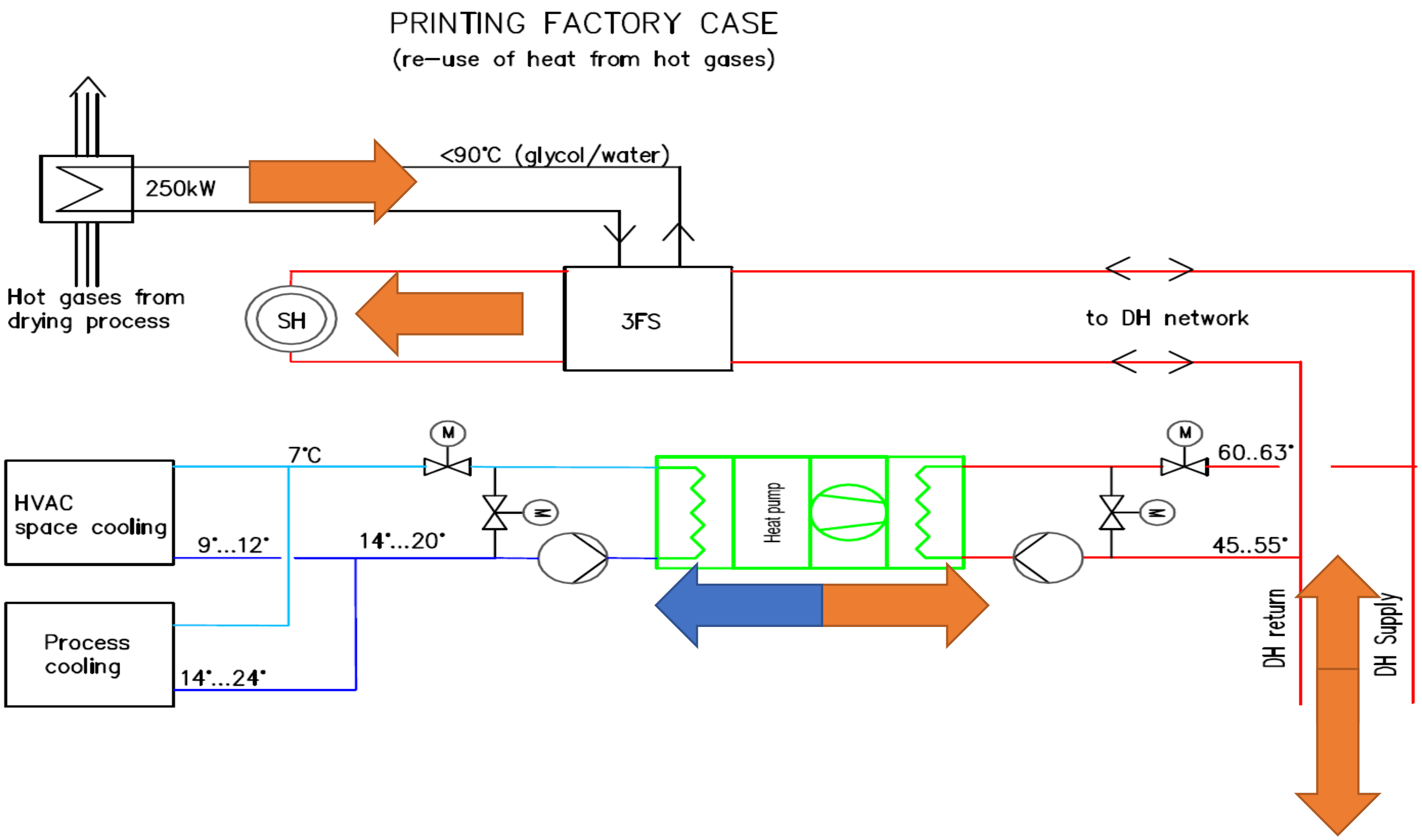


Process cooling & DH injection

2 stage process (2 heat pumps)

800 kW

Industrial waste heat



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Industrial waste heat

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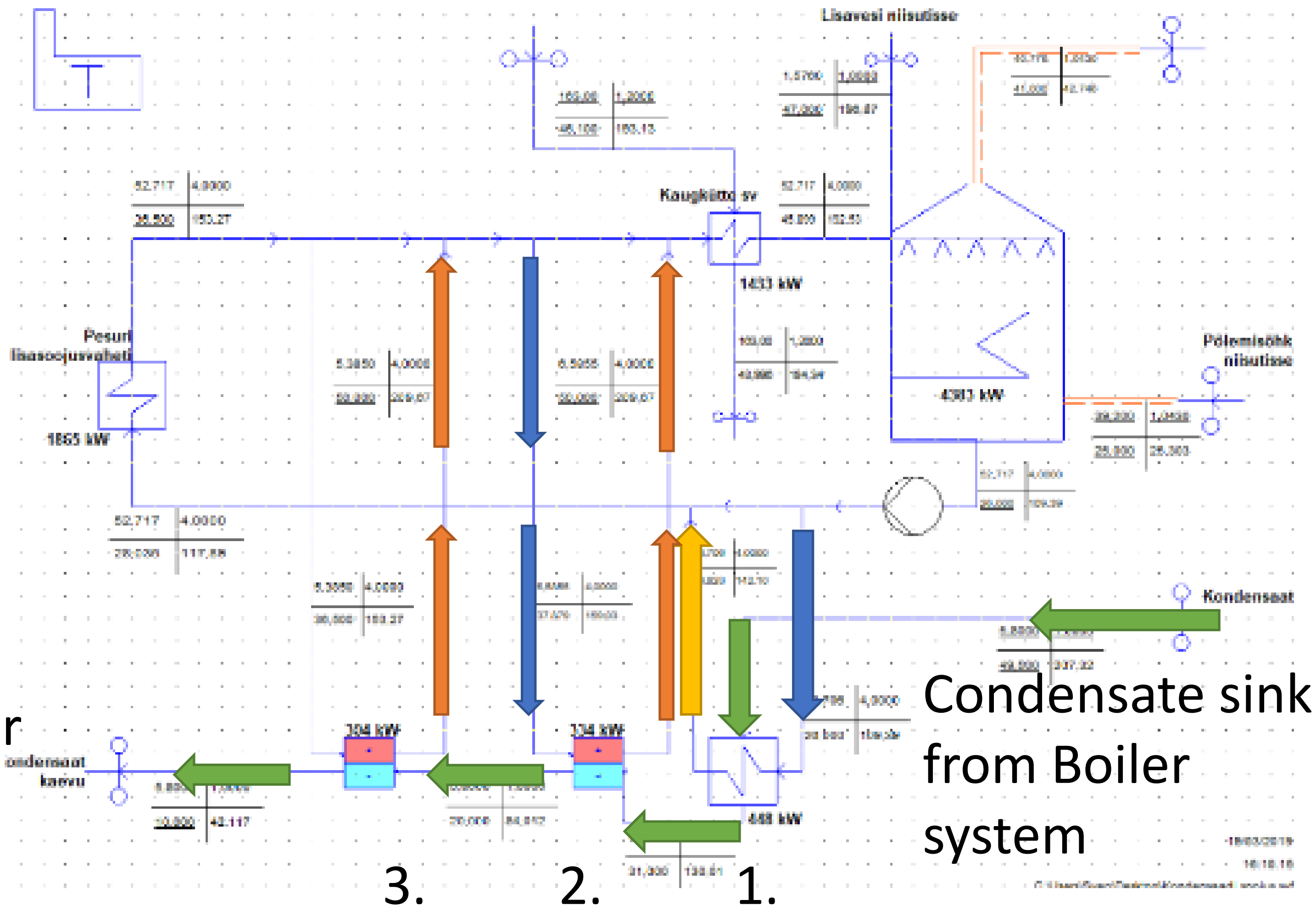
1. Direct heating of economizer water
2. Indirect heating of economizer water
3. Indirect heating of fresh water



Heat Pumps

- Typical applications.
  - Deep Geothermal
  - Shallow Geothermal
  - Air Driven
- Performance
  - Good COP levels at ~55-65ºC DH Flow
  - Economic performance requires on electricity mix
- Small DH networks
  - Fairly economic
  - Escalable
  - Only requires electric supply (virtually everywhere in EU)
  - Typical heat source in new DH networks

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Heat Pumps

- DH network in Vinge (DK)
  - New town. Presently ca 100 hab.
  - To be populated up to 20.000 hab.
  - 55ºC Flow T.
  - Portable Heat Pump System
    - In container.
    - Composition
      - 2x HP
      - Sotorage tank
      - In-line heater for peak loads
    - Additional containers to be installed in the future
    - To be superseded by larger heat source when town grows
      - Eventually biomass boiler/CHP

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Heat Pumps

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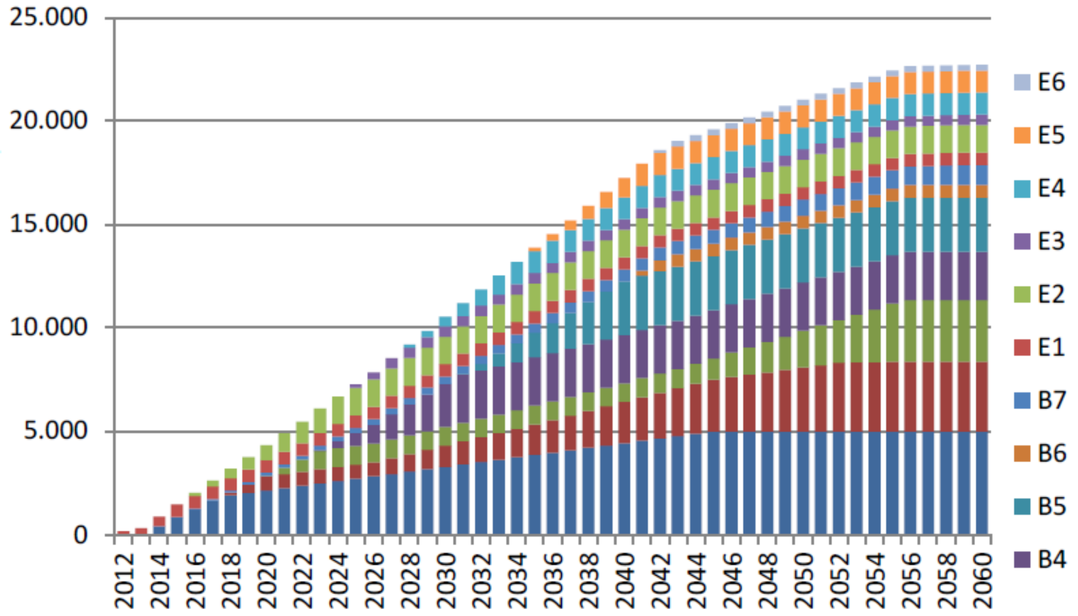
Heat Pumps



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Heat Pumps

- Innovative uses
  - Reject heat from supermarket cooling applications
  - Reject heat from data centres

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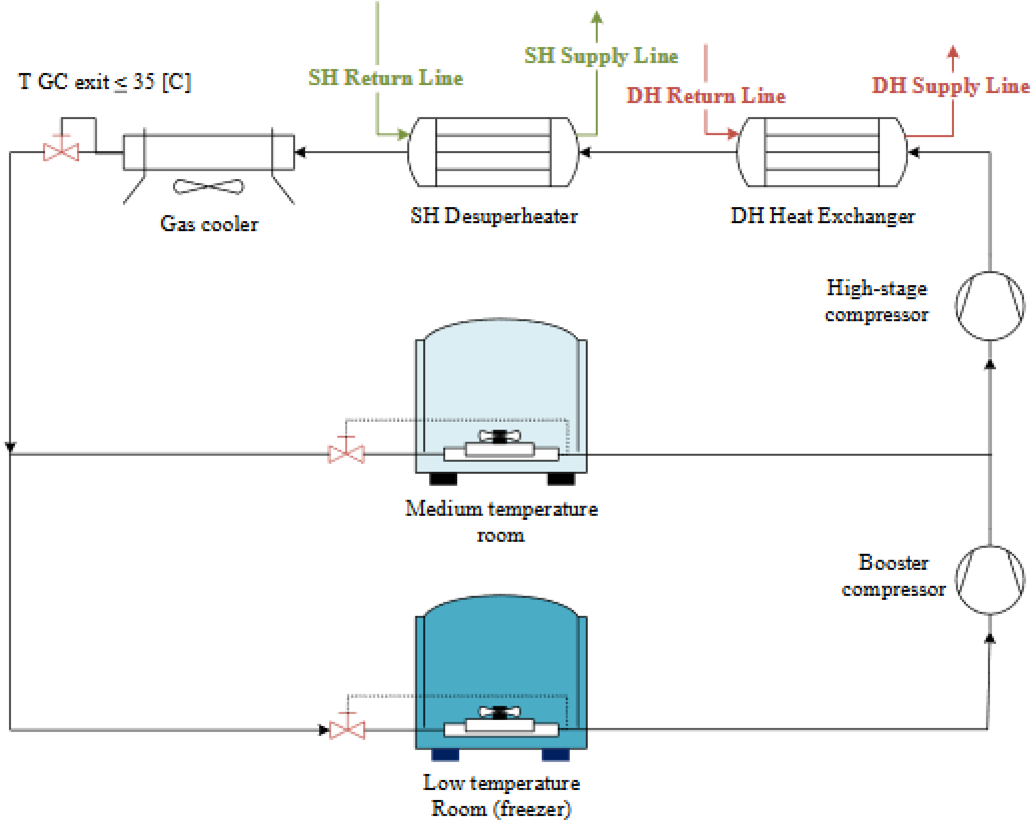
Heat Pumps

- Supermarket



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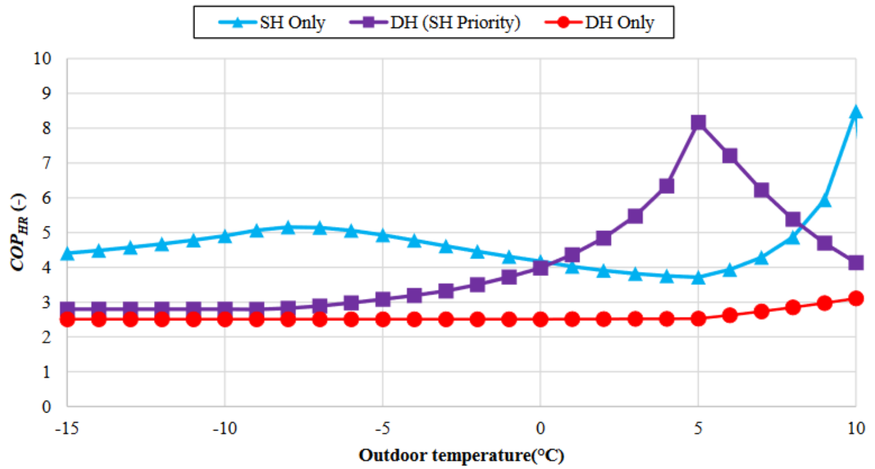

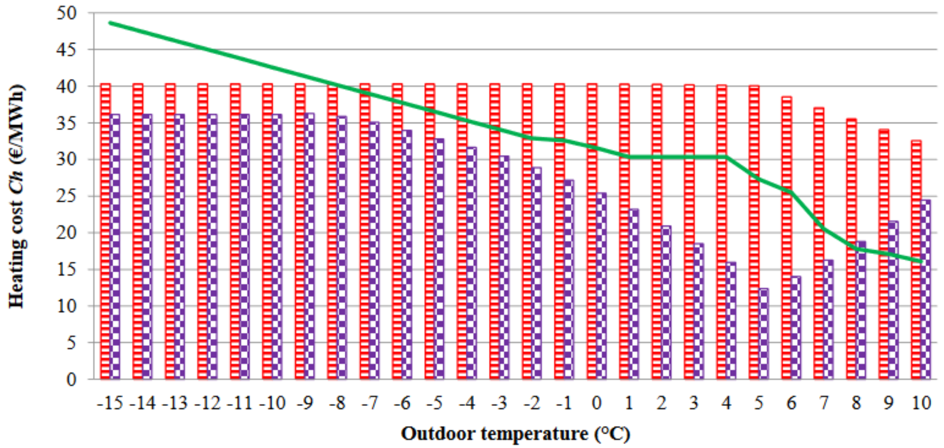

Adrianto, HeatRF Heat Recovery from CO2 Refrigeration System in Supermarkets to District Heating Network, 2018

Heat Pumps

- Reject heat from data centres
- FGH Zurich.
  - Housing Community
    - Various housing blocks, each with specificities (insulation & heating system)
  - Close to 2 main datacentres (Central DCs for Bank & Insurance companies)

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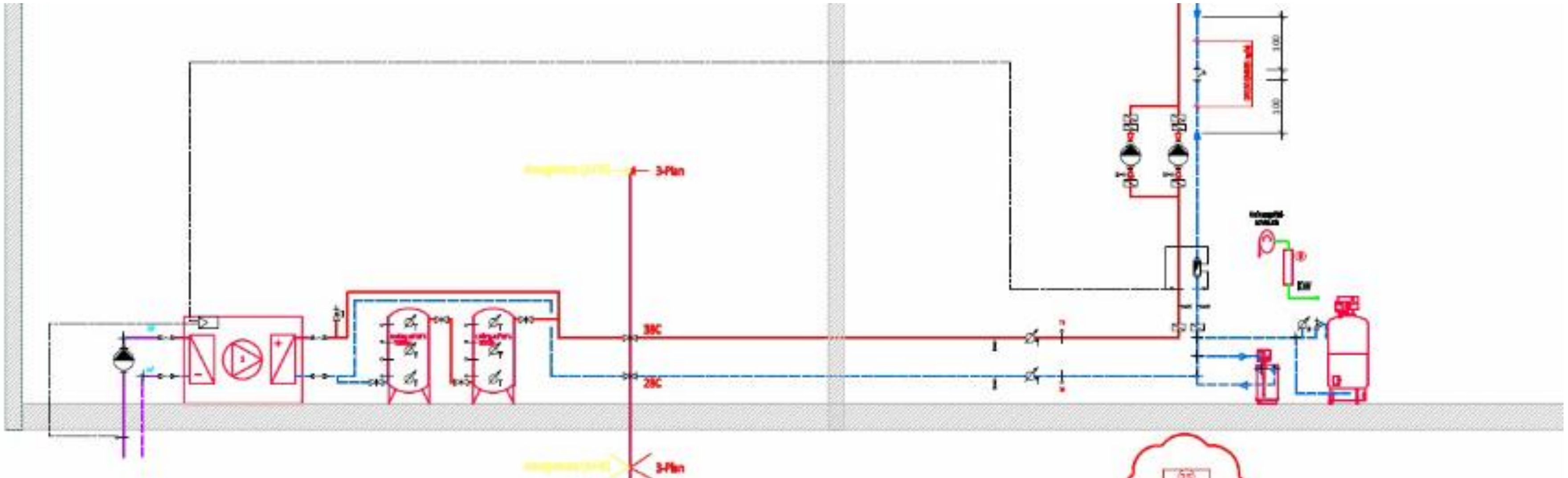
Heat Pumps

- FGH Zurich.
  - “Cold” DH network @ 20-30ºC
  - Heat pump in each block
    - Space heating T according to specific Flow T for buildings
    - DHW T according to standards
  - 1 heat pump (buildings with SH T > DH T)
  - 2 heat pumps (buildings with SH T < DH T)



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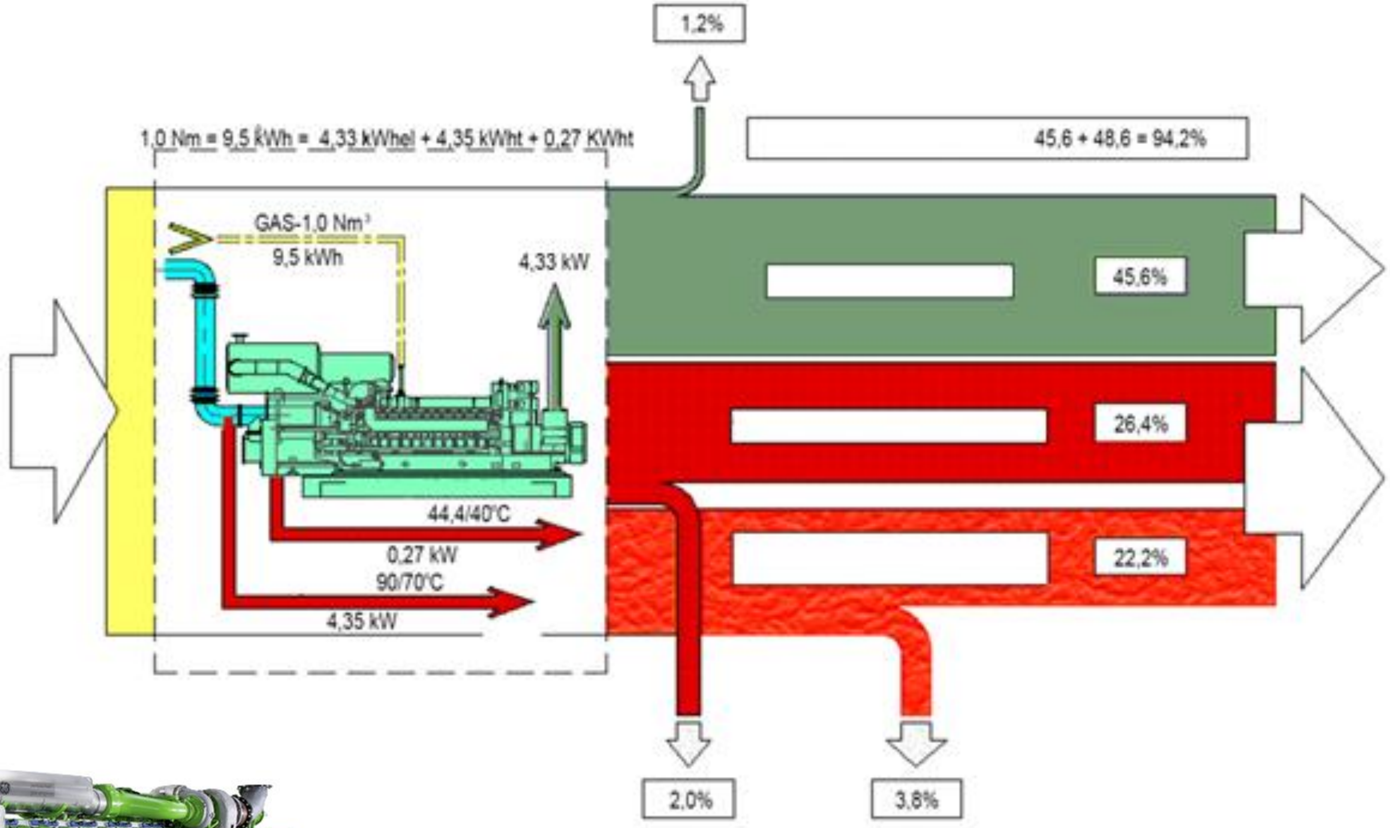
CHP



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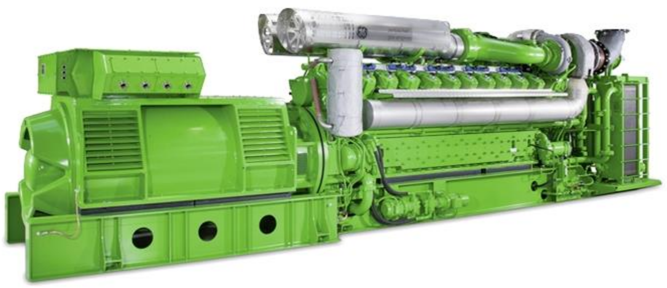
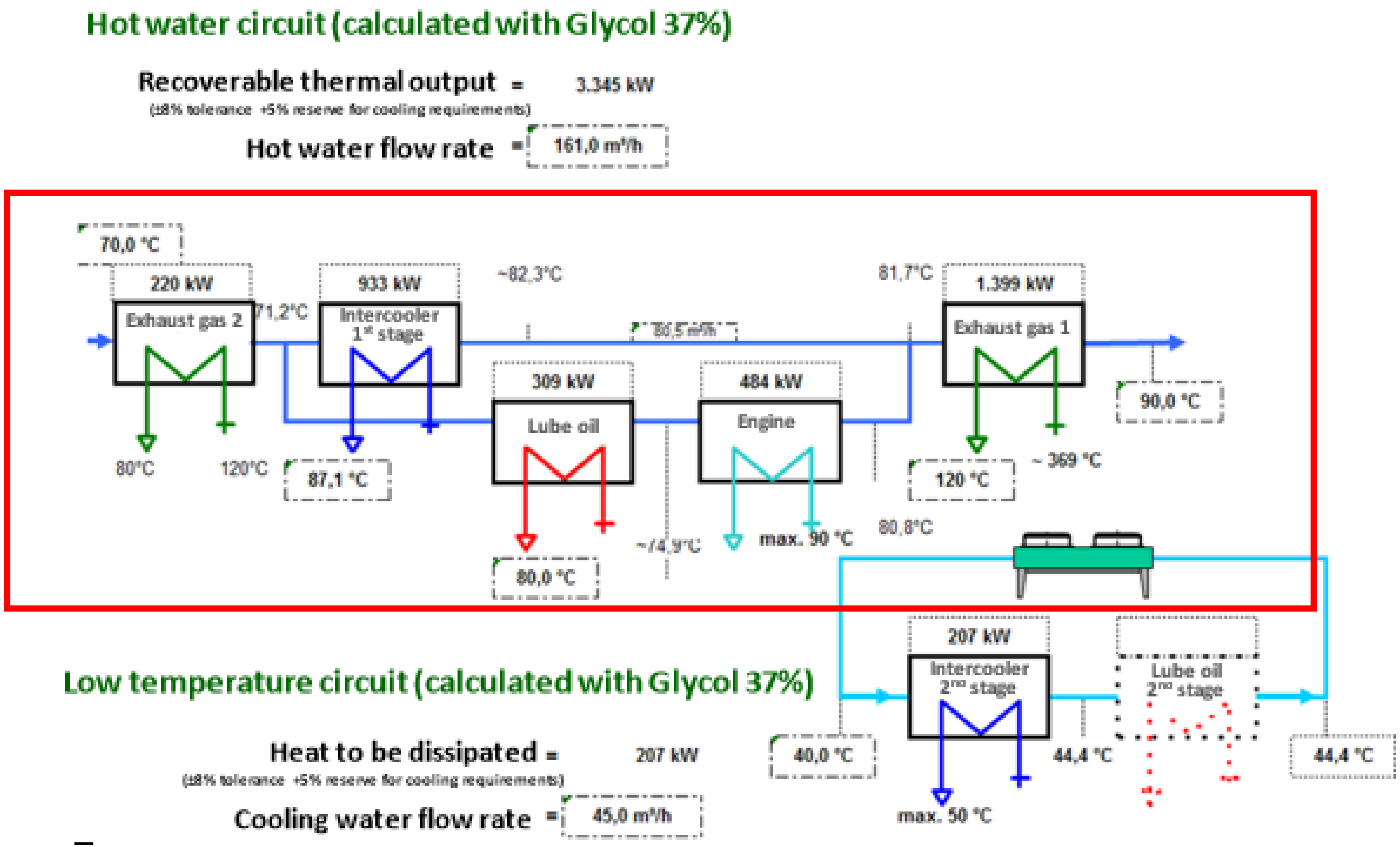


CHP



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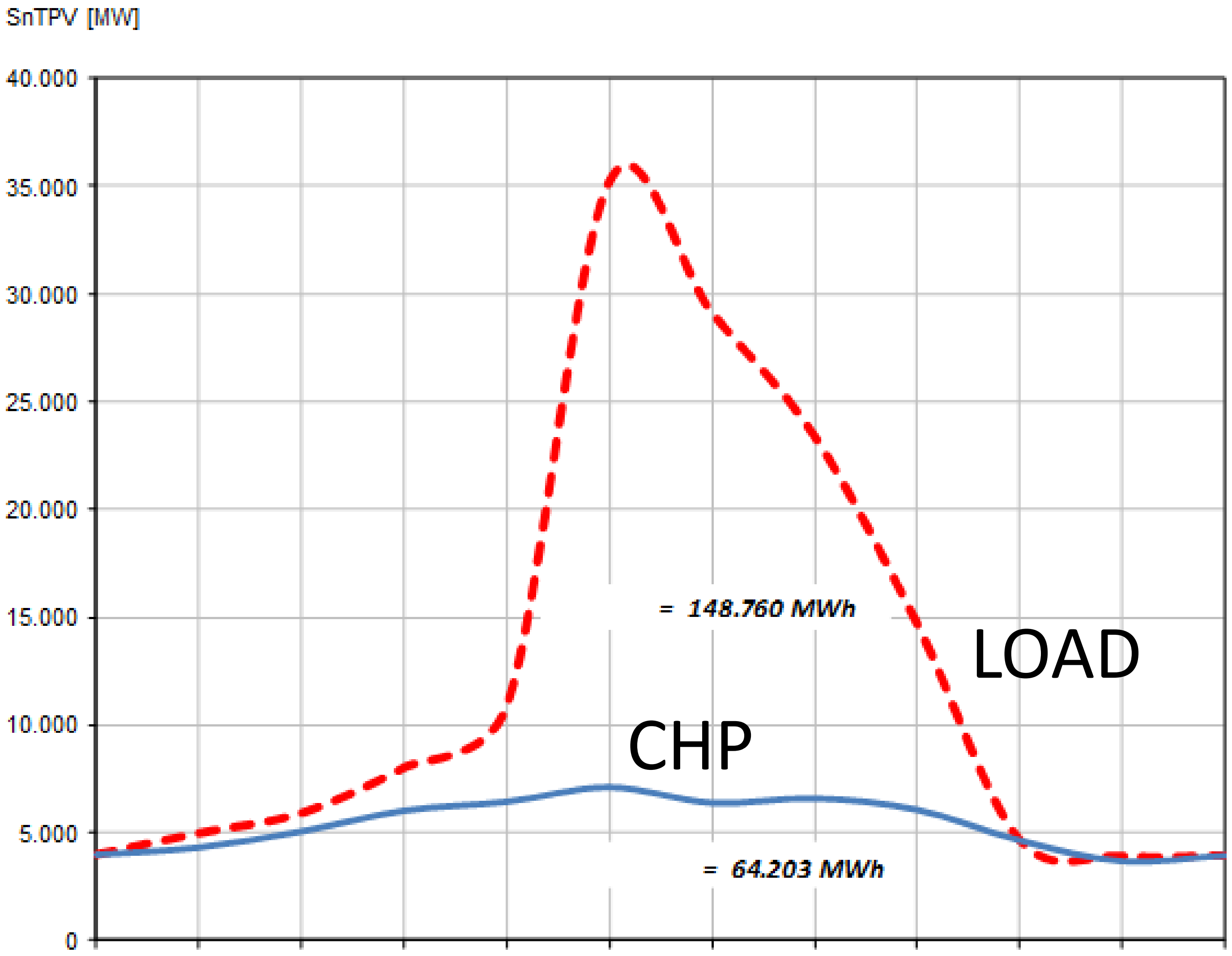
CHP



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CHP

- Nikola Tesla Power plant
  - (Belgrade, 300,000+connetions)
  - Presently electric power plant
  - Conversion to CHP
  - Connection of condenser to DH netork
  - Within a wholistic plan
    - Reduction of carbon footprint by 45%

Chinese company to build heating pipeline in Belgrade

Serbia | June 8, 2017 | Comments: 0 | Author: Balkan Green Energy News |

Mali said the EUR 200 million project is very important both because it brings annual savings of about EUR 43 million or about one third of the EUR 140 million which the Belgrade district heating company spends for gas imports.

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4. Solar Thermal in DH

4.1 Large Solar

- DHs
  - Large & continous heat loads
  - Large energy bills
- ST
  - Discontinous heat production
  - Free heat
  - (isolated systems) non optimal heat usage
  - (isolated systems) expensive to set up & mantain
- Oportunity
  - Optimal heat usage
  - Lower (specific) upfront & maintenance costs
- Drawback
  - Higher temperature levels (than in isolated systems)
  - Transmission losses

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4.1 Large Solar

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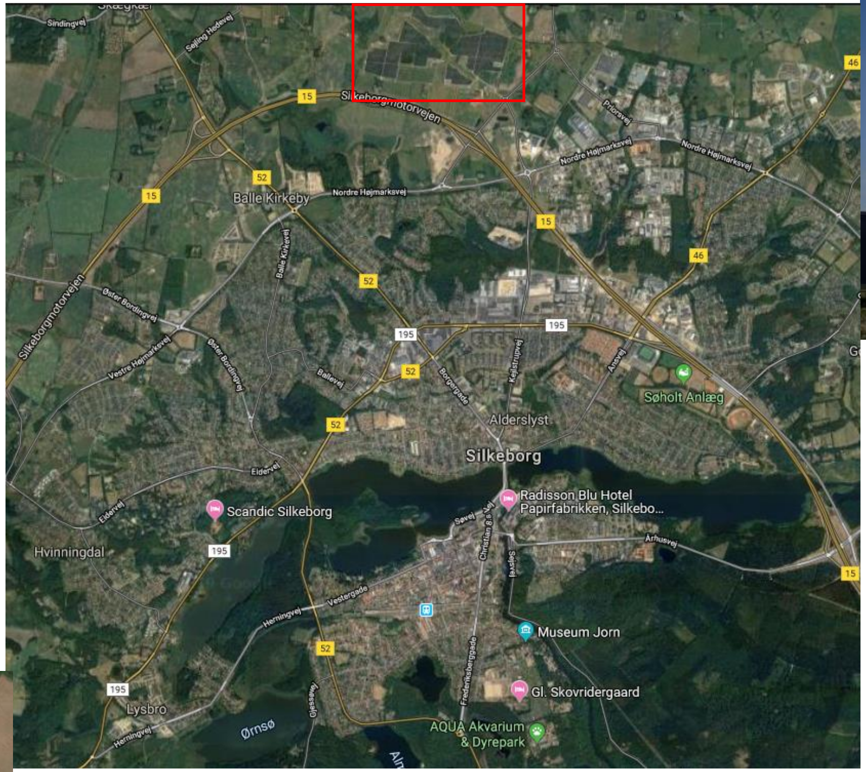


Silkeborg SDH system

http://arcon-sunmark.com

4.1 Large Solar

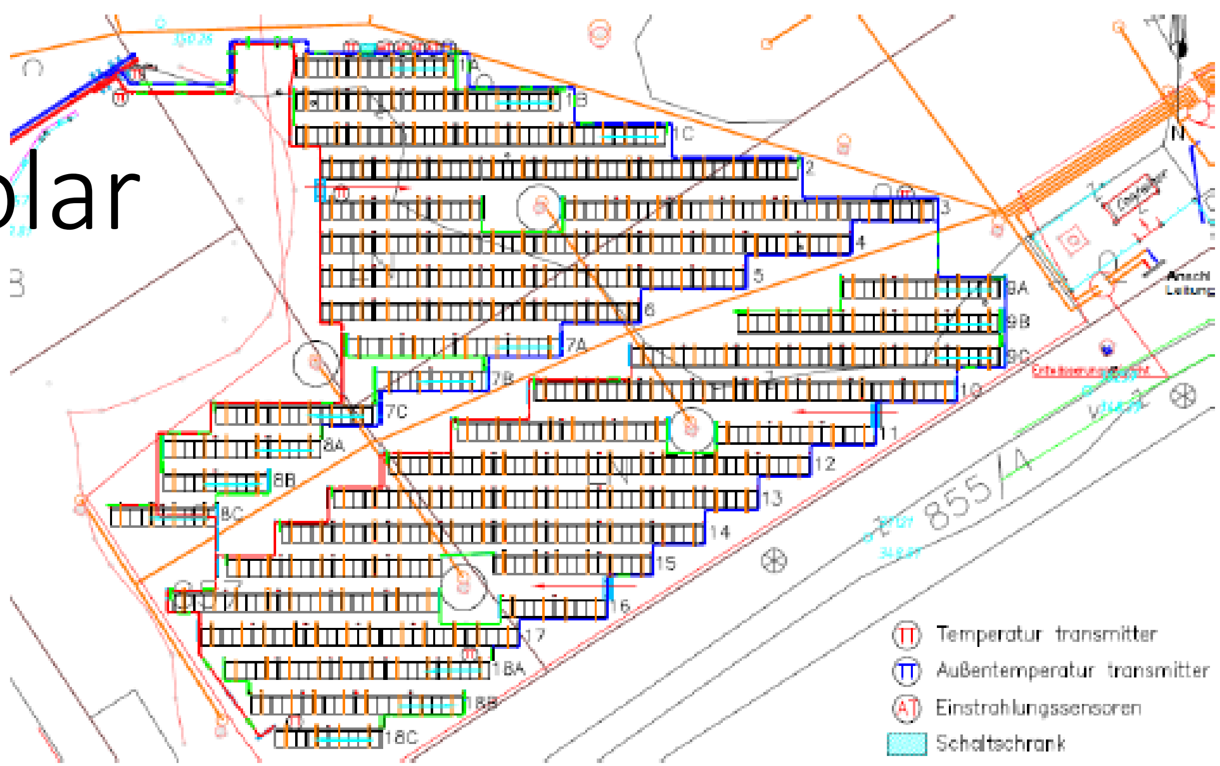
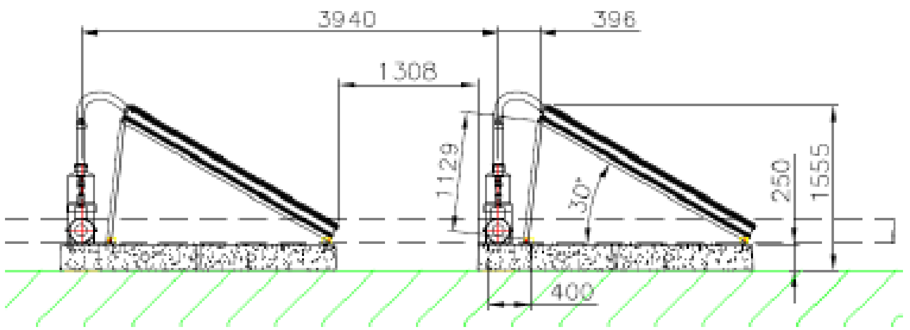


figure: planning collector field



HELIOS, SDH conference Graz, 2018

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4.1 Large Solar

- Specific ST panel systems (~15m^2)
- Systems installed over ground
- Large panel arrays
- Relevant use of land
- Substantial energy savings
- Substantial economic saving
  - Cost of heat ~20-30 €/MWh
  - (vs 40-50 €/MWh with fossil fuels)

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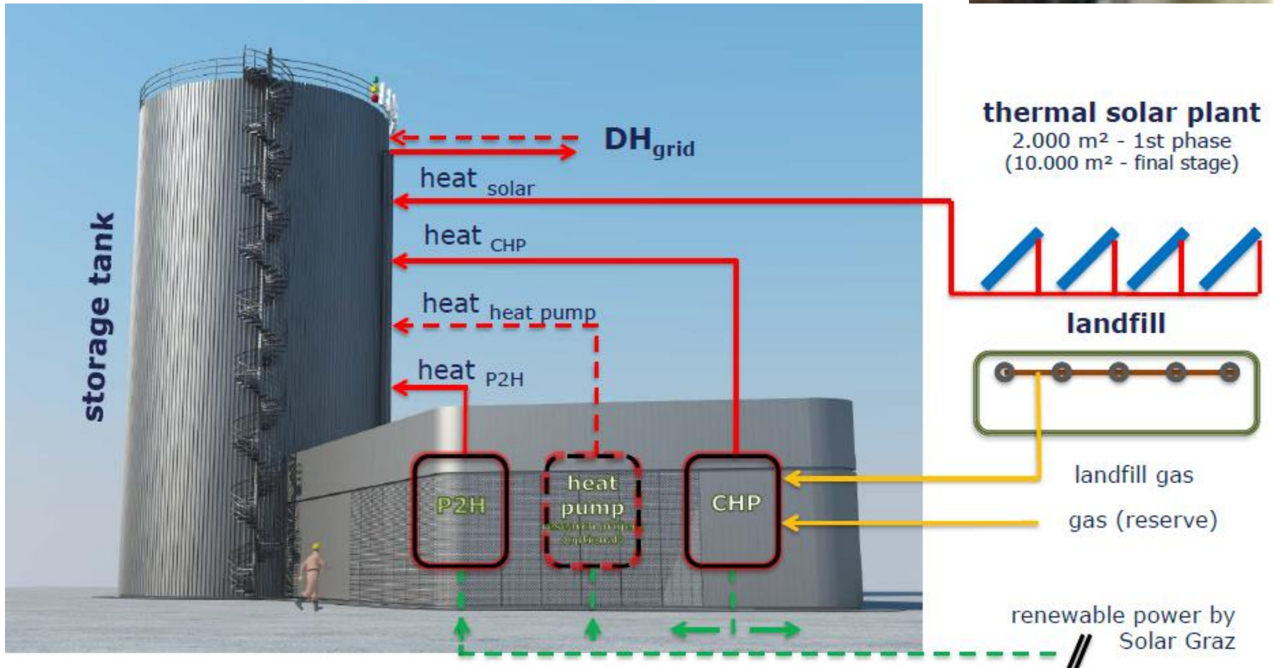
4.2 Storage

- SDH without storage
  - Limited to periods with relevant solar input (summer)
  - No production during night periods
  - Sizing limited to summer loads
- Storage
  - Increase solar fraction
  - Heating by night
  - Heating during autumn & Winter
  - Other benefits in peak shaving
    - Can store heat from other producers even without solar input

4.2 Storage

- Day/week storage
  - Stratified tanks



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Exercise 6

Storage heat loss for large volumes

- Exercise 4
  - 200MWh
    - Now something 100 times larger. 20GWh
  - 30ºC of Flow-return temperature difference
  - Size 5714 m3
    - Now ? = 571 400 m3
  - Heat Loss @ 65ºC AT in 1 month. 15%
- Pit storage (lets asume that is cubic)
  - Square floorplan
    - Side = 150 m
    - Surface? = 22 500 m2
  - Height? = 25,4 m
  - Heat Loss @ 65ºC AT? ~1700kW =~1,7MW

Item	Surface (m2)	U (W/m2K)	Q (kW)
Top	22500	0,2	~295
Side	15240	0,7	~693
Bottom	22500	0,5	~731
Total			~1700

  - Heat Loss @ 65ºC in one month? ~ 1,28 GWh
    ~ 6,4 % of 20 GWh

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4.2 Storage

- Seasonal storage
  - Pit storage

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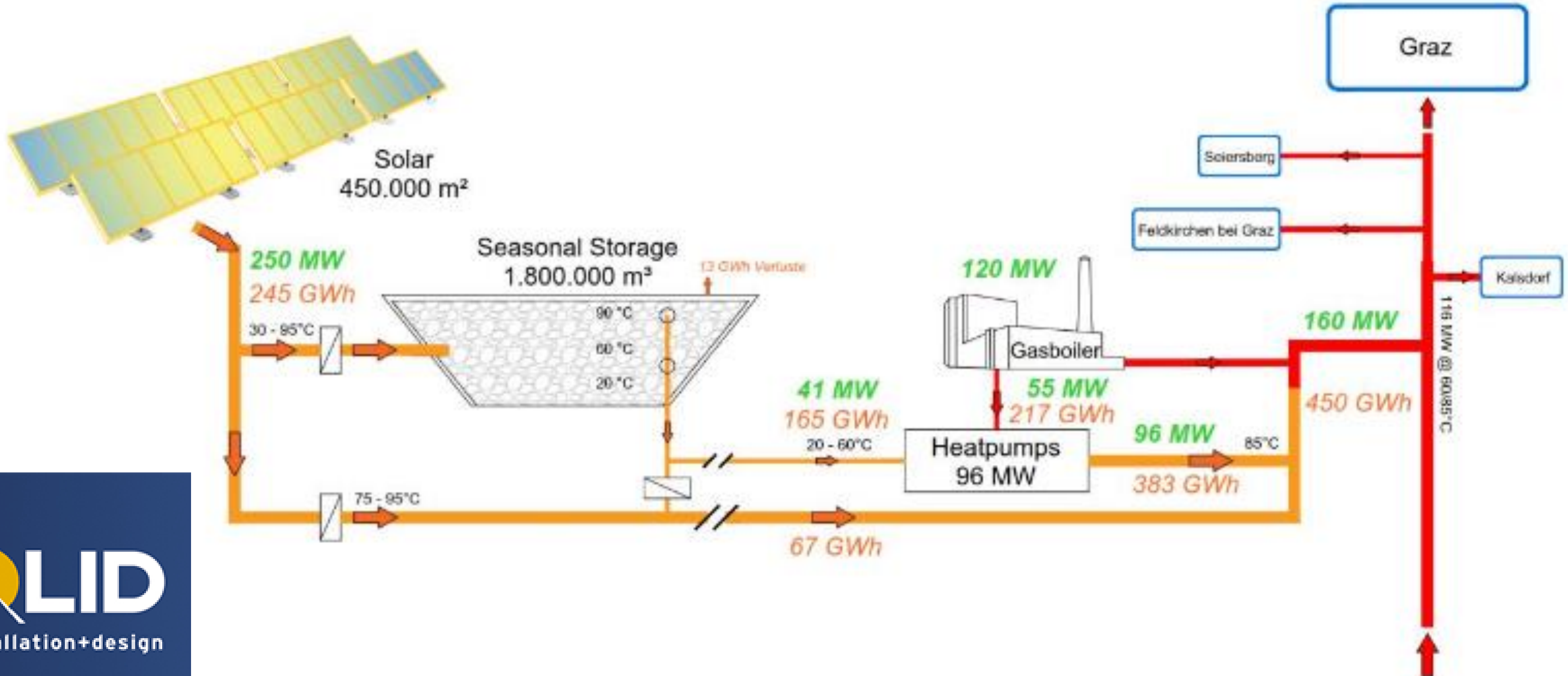
Reference project in progress – Solar district heating:

Feasibility Study BIG Solar Graz



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4.2 Storage

- Seasonal storage
  - Pit storage

planenergi.eu

ramboll.com

Dronninglund District Heating; 37,573 m2 of solar collectors and 62,000 m3 pit heat storage

~2m^3/m^2

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- Seasonal storage
  - Pit storage

planenergi.eu

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ramboll.com

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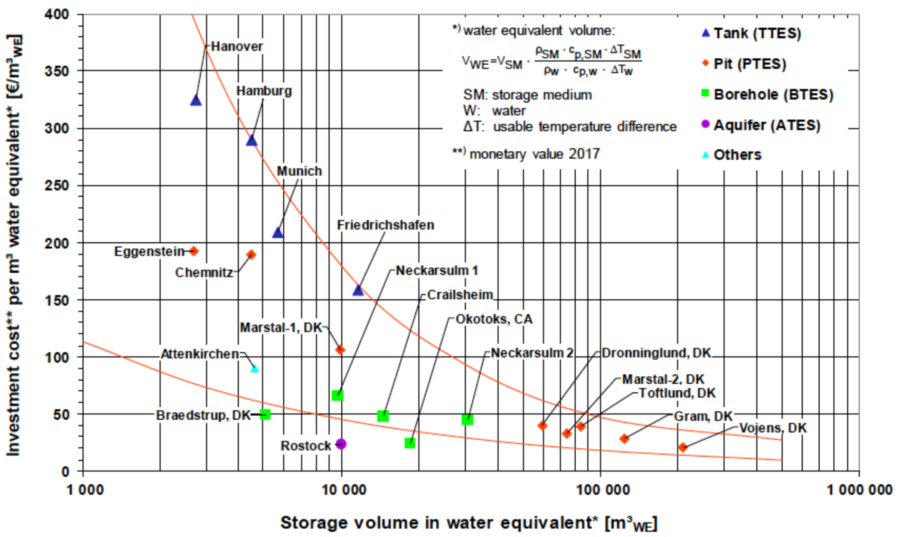
4.2 Storage

- Seasonal storage
  - Pit storage



https://www.solarthermalworld.org/news/seasonal-pit-heat-storage-cost-benchmark-30-eurm3

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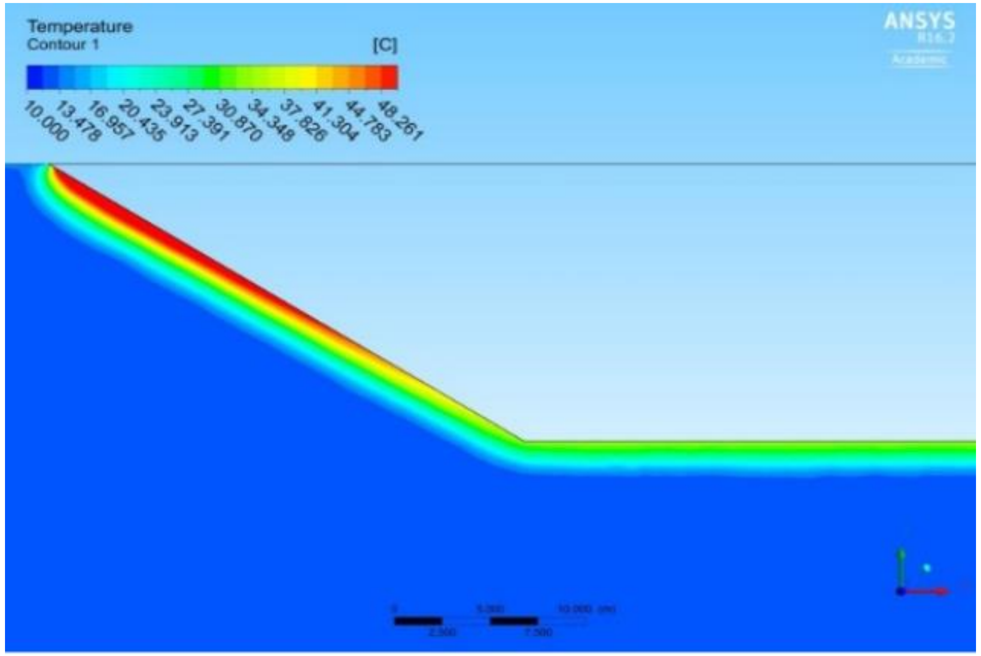

https://backend.orbit.dtu.dk/ws/files/141970828/Untitled_2.pdf

4.2 Storage

- Some tricks with heat pumps
  - Storage temperature not enough (~ by 10-15ºC)
    - Heat pump can be use at VERY LARGE COP
      - Primary-side: storage
      - Secondary-side: DH
    - Increased use of solar heat
  - Tank not sufficiently stratified
    - Heat pump can be used to better stratify tank
      - Primary-side: bottom of tank /outlet to ST
      - Secondary-side: top of tank / inlet from ST
    - Increased performance of ST field (lower inlet T)
    - Increased stratification & better use of heat in DH
  - Storage temperature not enough (~ by 20ºC)
    - Heat can be injected in return line of DH
    - Only in low share (<25% of total load)
    - Only if hydraulic design of network allows

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4.2 Storage

- Some tricks with heat pumps
  - Storage temperature not enough (~ by 10-15ºC)
    - Heat pump can be use at VERY LARGE COP
      - Primary-side: storage
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    - Increased use of solar heat

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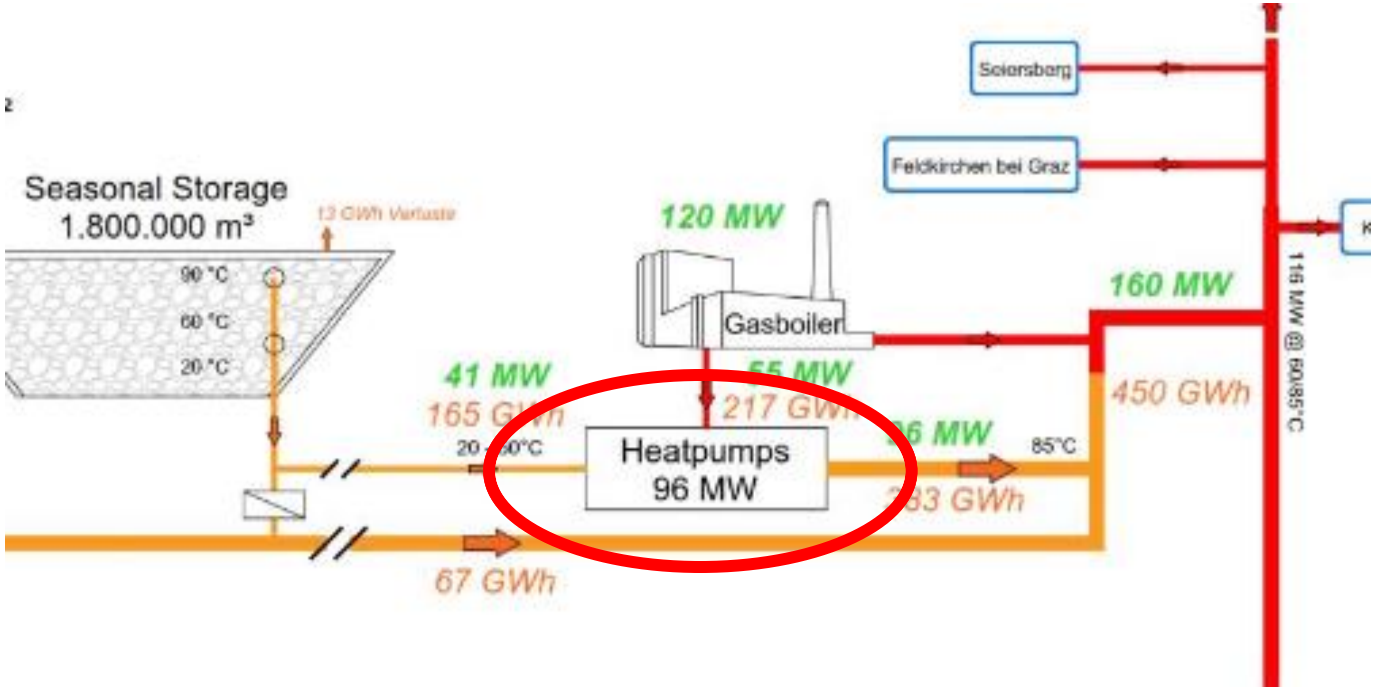

4.2 Storage

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  - Storage temperature not enough (~ by 20ºC)
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    - Only if hydraulic design of network allows

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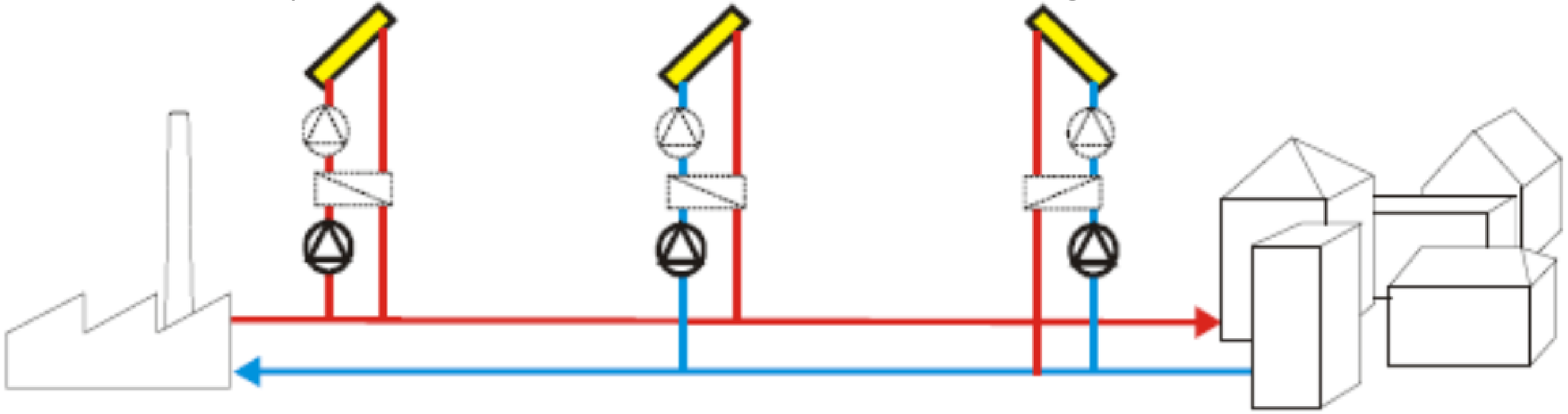
Supply-Supply (premium) | Return-Supply (standard) | Return-Return (low grade)



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4.3 Distributed Solar

- Connection of Building Integrated ST systems to DH
- Advantages
  - Greater heat production (than Isolated systems)
  - Lower transmisión loses (than Large Solar)
  - No need for storage (if ST in less tan 1/3 of buildings)
  - Injection in return line substantially increases heat production
  - Maintenance costs can be reduced (compd to Isolated systems) if performed by DH company
  - No need for land (compd to Large Solar)
- Disadvantages
  - More complex & expensive than Large Solar
  - Only small solar fractions are achievable without storage

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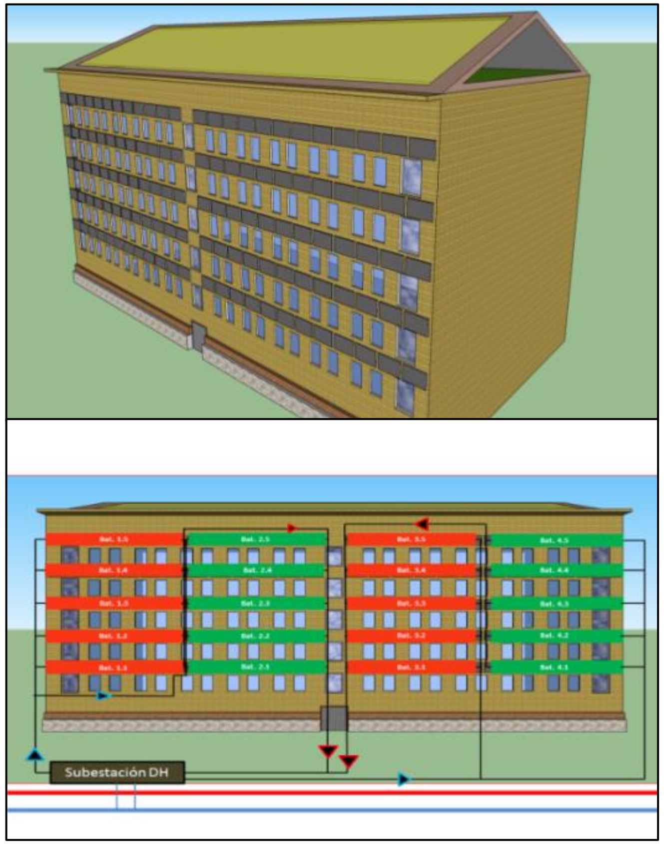
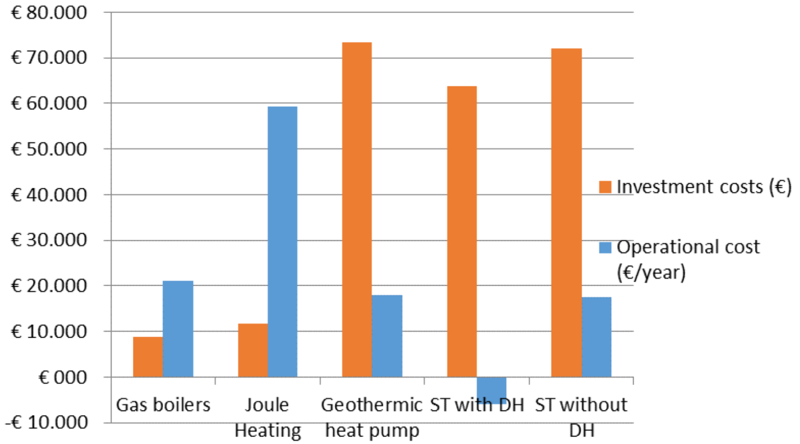
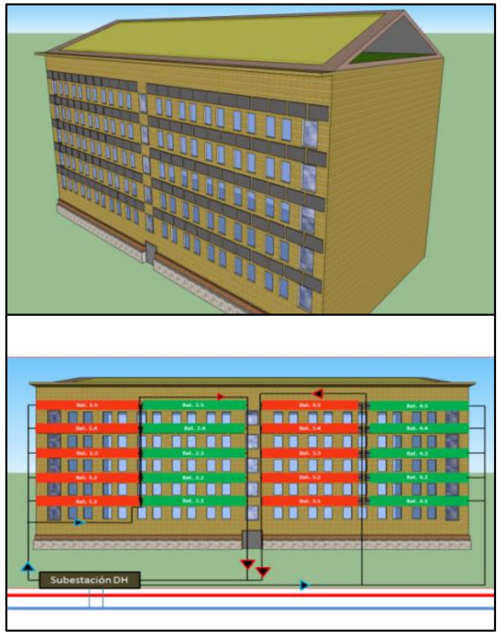
4.3 Distributed Solar

- ST systems in façades
  - (unglazed systems, mainly connected to return line)
- When ST needs to be installed
  - Connection to DH cheaper than isolated systems
  - No need for backup heat source
- Negative Operational costs
  - DH purchases heat at a fraction of DH heat cost





M. Lumbreras, et Al. Unglazed solar thermal systems for building integration, coupled with district heating systems... Journal of Facade Design and Engineering, 2018



4.3 Distributed Solar

- Technical issues to be considered
  - Preliminar study. To be refined
  - Systematic injection in return line
  - Only valid for low solar fractions
  - Only valid for a limited number of connections
- Business issues to be considered
  - Economic performance varies with DH heat price
  - DH operators make their business* on Heat production & Distribution. ¿Will they allow this kind of systems?

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M. Lumbreras, et Al. Unglazed solar thermal systems for building integration, coupled with district heating systems... Journal of Facade Design and Engineering, 2018

4.3 Distributed Solar

- Integration of ST fields over existing DH networks (2) in Barcelona
- Large ST fields (over factories)
- Connection of Building Integrated ST
- Different DH heat price in each network

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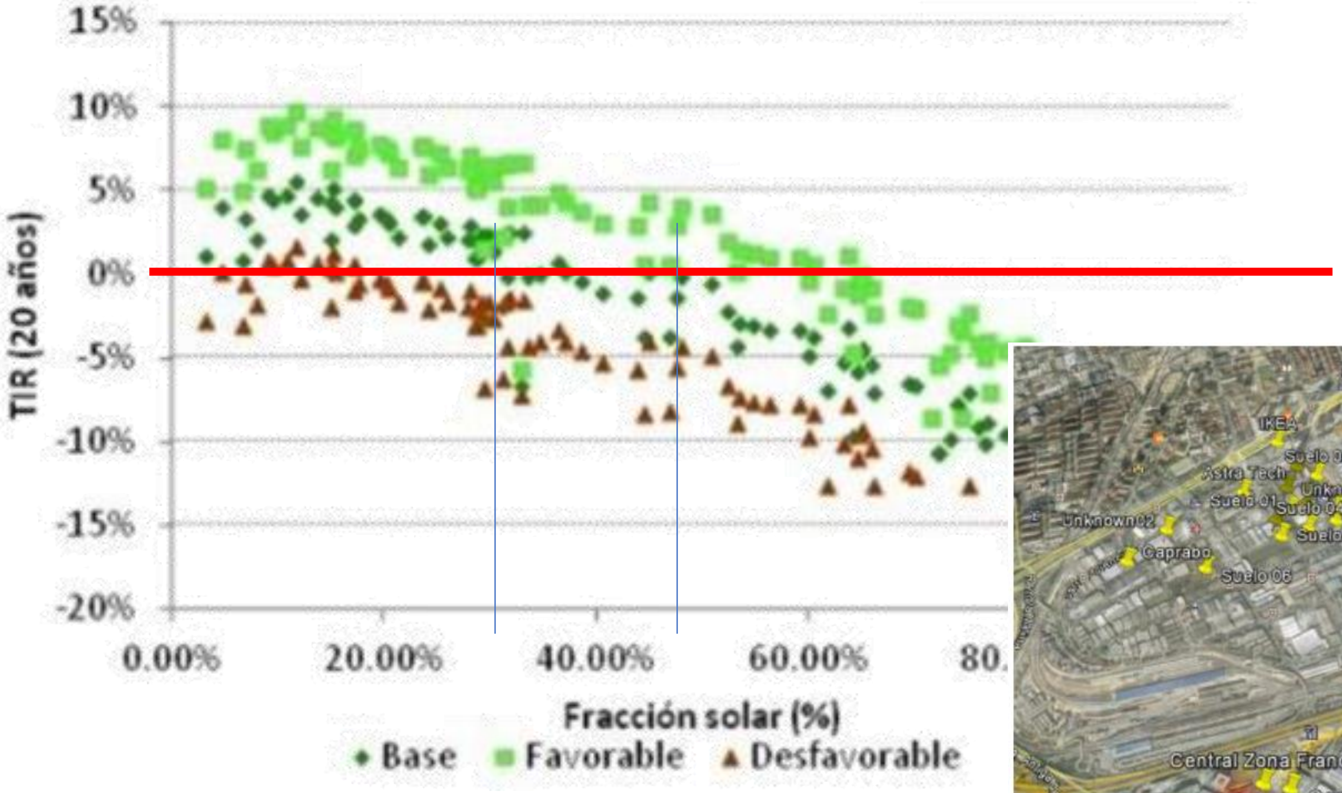
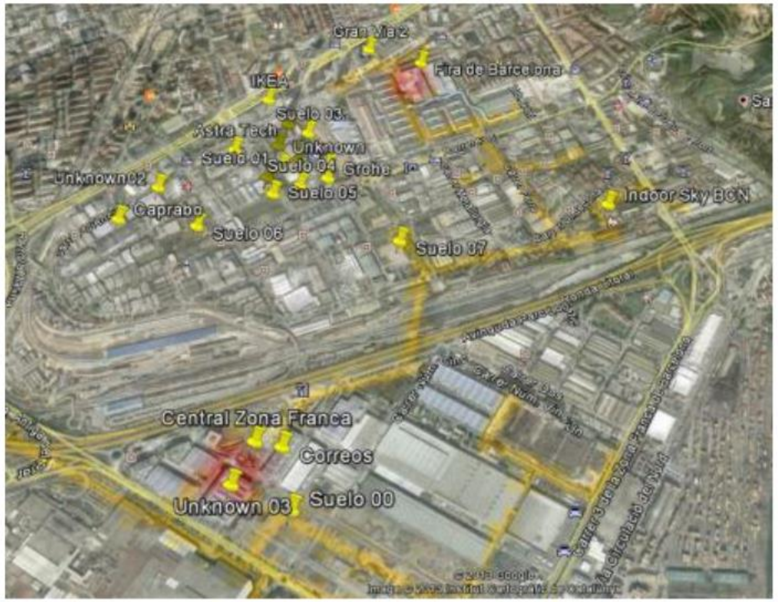
4.3 Distributed Solar

- Large Solar in Ecoenergies network (biomass)
  - Profitable Return on investment if solar fraction <~30 %





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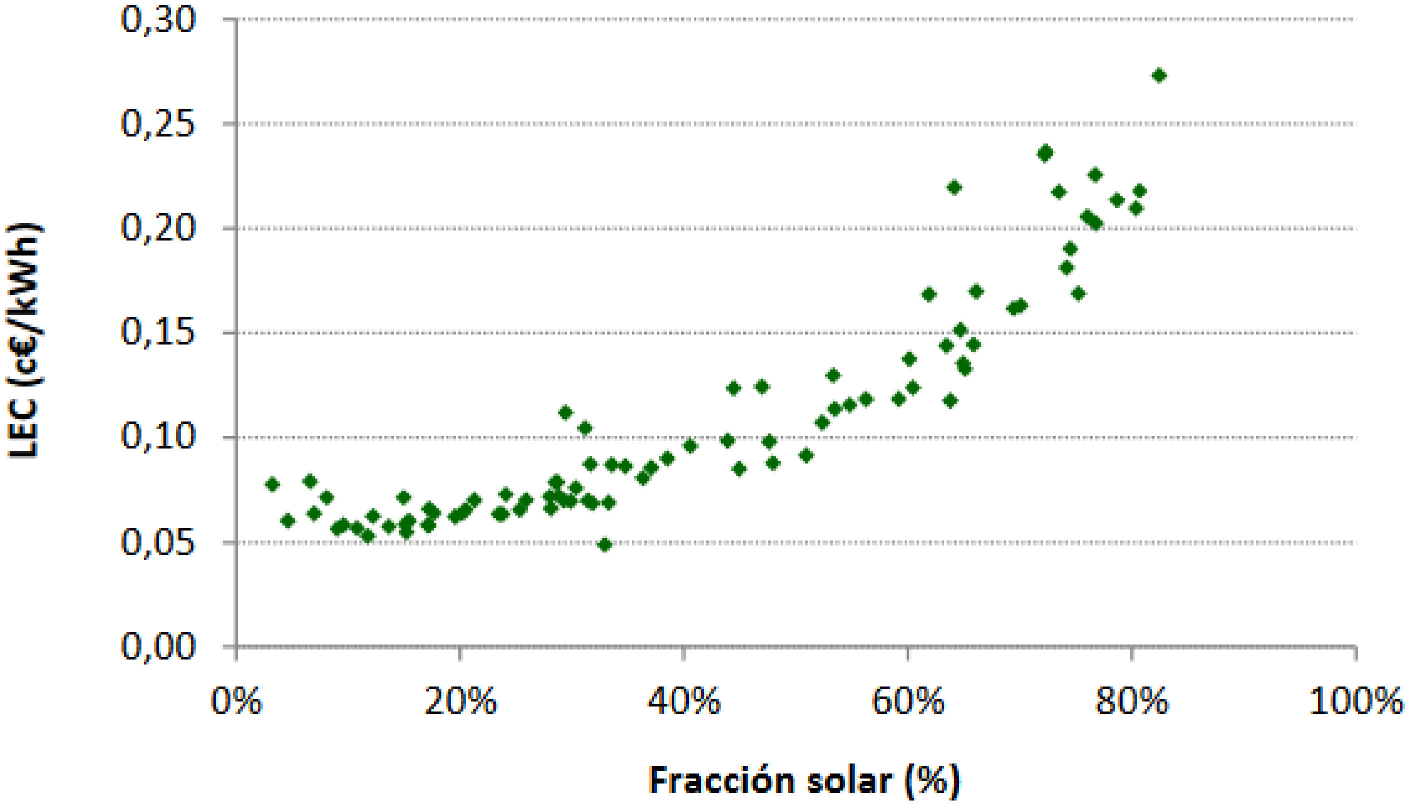
4.3 Distributed Solar

- Large Solar in Ecoenergies network (biomass)
  - Levelized Energy costs increase if Solar Fraction >30-35 %



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4.3 Distributed Solar

- Large Solar in Districlima network (waste incineration)
    - Not profitable due to low cost of heat

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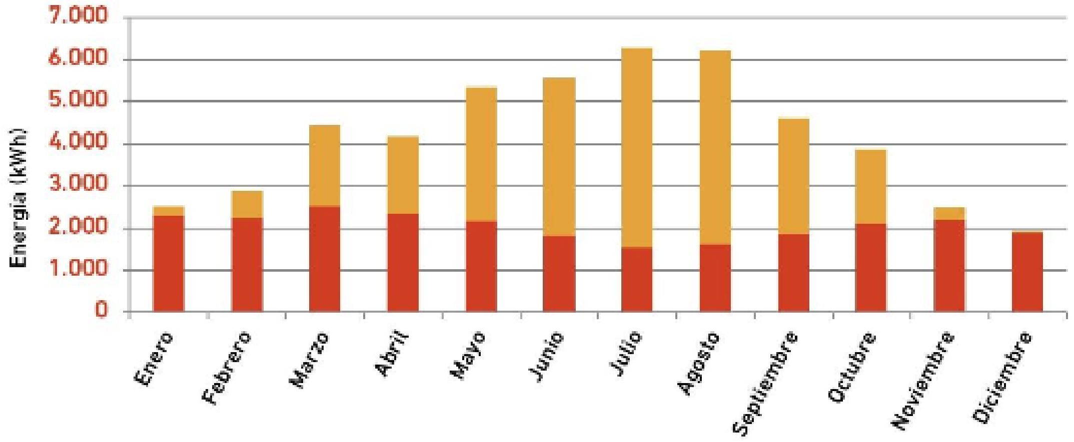
4.3 Distributed Solar

- Building Integrated Solar in Districlima network (waste incineration)
  - Heat production doubles when compared to isolated system

(kWh)	Rad. solar incidente	Producción solar campo	Aport. solar consumo	Aport. solar interna (red interior edificio)	Aport. a red de distrito
TOTAL	128.612	52.879	50.374	24.605	25.769
kWh/m²	1.644	687	654	320	335



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4.3 Distributed Solar

- Building Integrated Solar in Districlima network (waste incineration)
  - Project costs include only connection to DH
  - Positive internal return rate in many projects
  - (even for low cases with low cost of heat)

Nomenclatura	TIR 20 años
SCH1TIP1CAS1	3,20%
SCH1TIP1CAS2	6,20%
SCH1TIP3CAS1	4,30%
SCH1TIP3CAS2	14,60%
SCH2TIP1CAS1	-
SCH2TIP1CAS2	-
SCH2TIP3CAS1	-
SCH2TIP3CAS2	6,30%
SCH3TIP1CAS1	-
SCH3TIP1CAS2	3,90%
SCH3TIP3CAS1	1,10%
SCH3TIP3CAS2	12,50%

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5. Economics of Solar Thermal in DH

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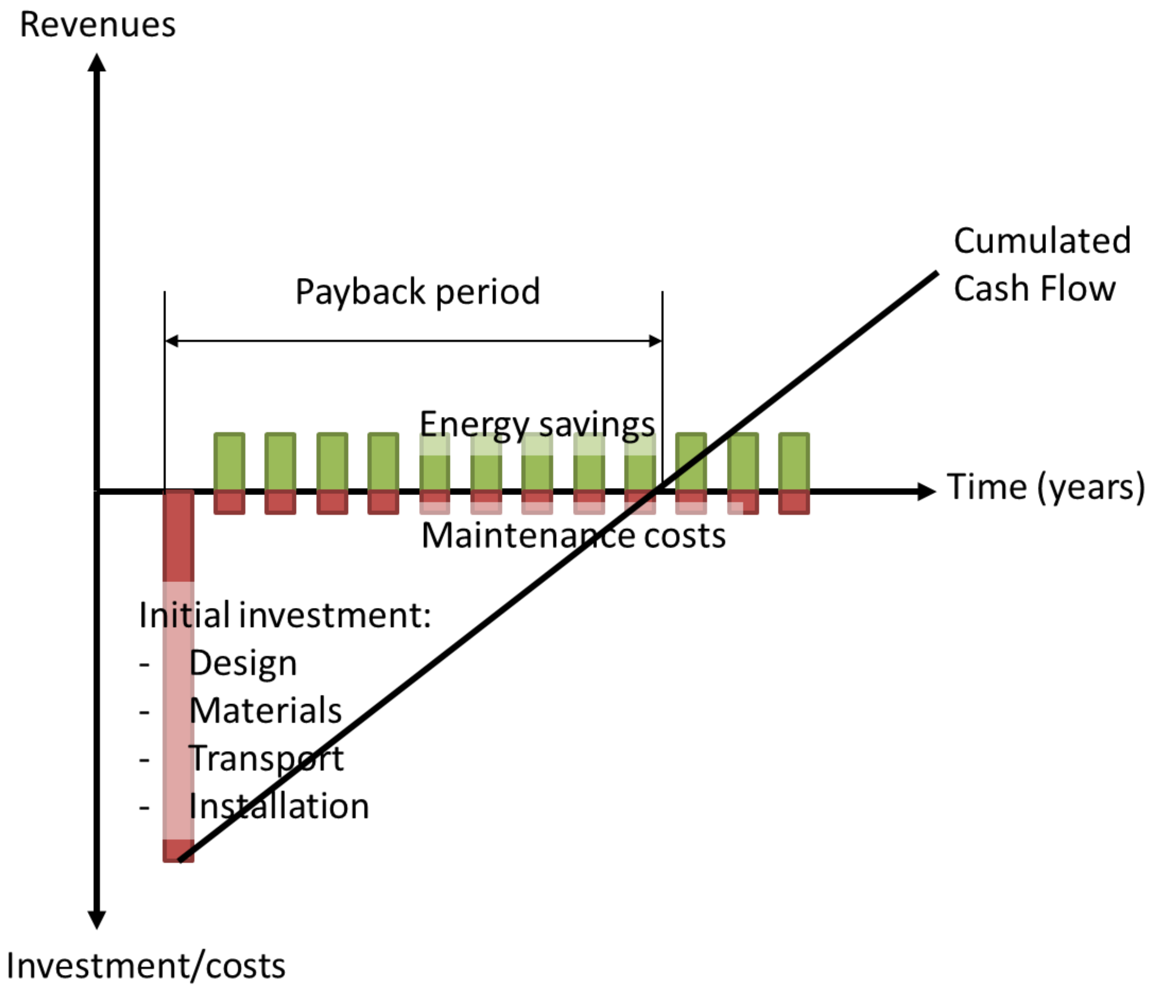
5.1 Economic Metrics

- (almost) all projects in a competitive environment are funded based on economic metrics.
- Each firm has its own criteria to accept or reject projects.
- Typical criteria include:
  - Profitability of Project
    - (internal) Return Rate, IRR. Value deemed by the Project at a yearly basis in [%/year] *
    - Return on Investment, ROI. Value deemed by the Project in total [% or UNITS]
  - Value of Project
    - (discounted) Net Present Value, (d)NPV. Present value of project [€ or UNITS]
  - Value of money
    - Interest rate, (i). [%/year] *
  - Risk
    - Payback period. PB, time until investment is recovered [years]
    - Discount rates [%/year], wich incorporate risks (country, currency, custommers) *
  - Ambitions
    - Desired revenue of projects. [%/year] *
- Commonly all ítems under * are valued in a compound discount rate

5.1 Economic Metrics



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5.1 Economic Metrics

$$NPV = \sum \frac{\text{Cn}}{(1+i)^n} - I.$$

$$ROI = \frac{NPV}{I}\ x\ 100$$

PB=n, where NPVn > 0

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5.1 Economic Metrics

- Typical values (non-profit DH company):
  - Profitability of Project
    - (internal) Return Rate, IRR. > loan interest + ~ 5 %
    - ~~Return on Investment, ROI.~~
  - Value of Project
    - discounted Net Present Value, dNPV. > 3-4
  - Value of money *
    - Interest rate, (i). Typically very low. ~0,5-1 %
  - Risk *
    - Payback period, PB. < 5-10 years (**,***)
    - ~~Discount rates [%/year]~~
  - Ambitions
    - ~~Desired revenue of projects. [%/year]~~

(*) DHs are stable systems with low risk, but depends also on reliability of each company

(**) Can be longer for very large investments

(***) Can be <1 year in some cases. If so, they are decided "on the go".

5.2 Investment Decission

- Issues to be considered at DH level
  - Heating mix
  - Multi-year evolution of heating loads
  - Facility commissioning / de-comissioning cycle
  - Status of other investments
- Space & Funding availability

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Issues to be considered at DH level

- (for the introduction of SDH)
- Heating mix
  - Number of different producers
  - Classification under Peak, Intermediate, RES & base production systems
- Base production
  - Systems with full load operational hours exceding 3000-5000 h
  - Very efficient heat production systems, CHP or large boiler systems
  - Heat production systems which require >3h of startup time

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Issues to be considered at DH level

- Intermediate production
  - Systems with full load operational hours in the range of 1000 to 3000 h
  - Efficient, medium-size systems
  - Commonly at part load (Winter and intermediate season)
  - Commonly as base generation technology when larger producers are stopped for maintenance (summer)
  - Typically biomass/natural gas boilers & heat pups
- RES
  - Renewable energy systems
  - Industrial waste heat systems
  - In some cases, without possibility to difer heat production

Issues to be considered at DH level

- Peak & Backup production
  - Inexpensive systems
  - Activated under peak conditions (coldest days in the year)
    - Or due to failure/non-availability of other systems
  - Typically natural gas boilers
    - Heat pumps not optimal for very cold days.
  - Typically geographycally distributed
    - Redundancy for pipeline failure cases

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Issues to be considered at DH level

- (for the introduction of SDH)
- Multi-year evolution of heating loads
  - Is load stable?
  - Load increase due to densification of network
  - Load increase due to extension to new neighborhoods
    - Locally deployed systems?
  - Load reduction
    - Climate change?
    - Increase in building insulation levels
    - Better heat supply alternatives

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Issues to be considered at DH level

- Facility commissioning / de-comissioning cycle
  - Are some old facilities expected to be de-commissioned?
  - How will this impact in the production mix?
  - Are new facilities to be constructed?
- Status of other investments
  - Viability of investments not yet paid back need to be guaranteed
  - Or discounted from newer investments

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Space & Funding availability

- Space
  - Land availability within DH plants (if VERY large)
    - Space for ST fields can be found in the viccinity of DH plants.
    - Not relevant ST capacity when compared to DH plant.
  - Towns < 5-20,000 hab.
    - Commonly reasonably-priced land is available.
  - Industrial areas
    - Roofs, parking áreas, etc.
  - Large cities
    - "imaginative" solutions
    - Building integrated, etc.

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Space & Funding availability

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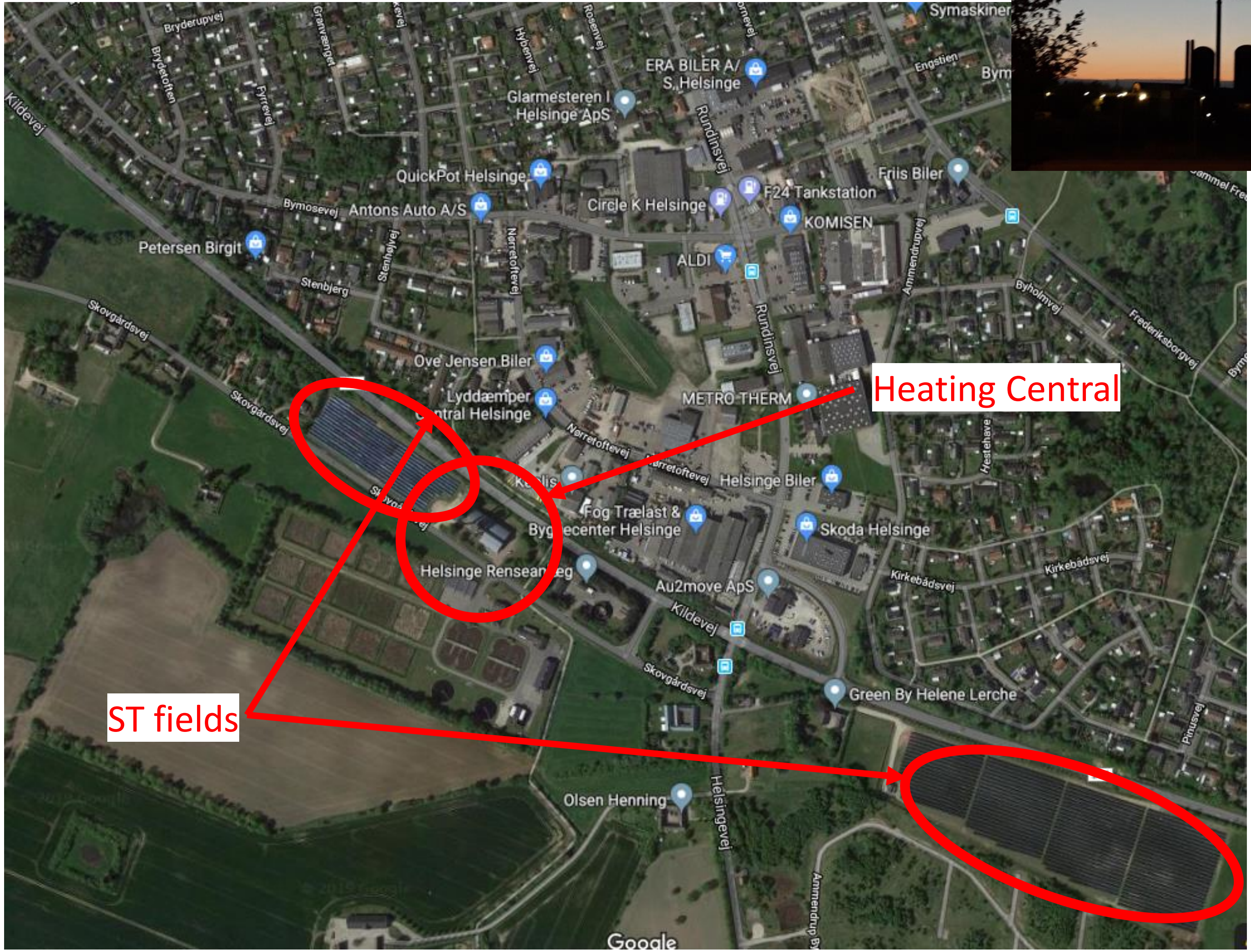
http://solarheateurope.eu/2018/06/18/big-solar-graz-the-largest-solar-district-heating-plant-is-moving-ahead/

Space & Funding availability



Google Maps. Aerial photo of Helsinge DH plant (DK)

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Space & Funding availability

SDH project

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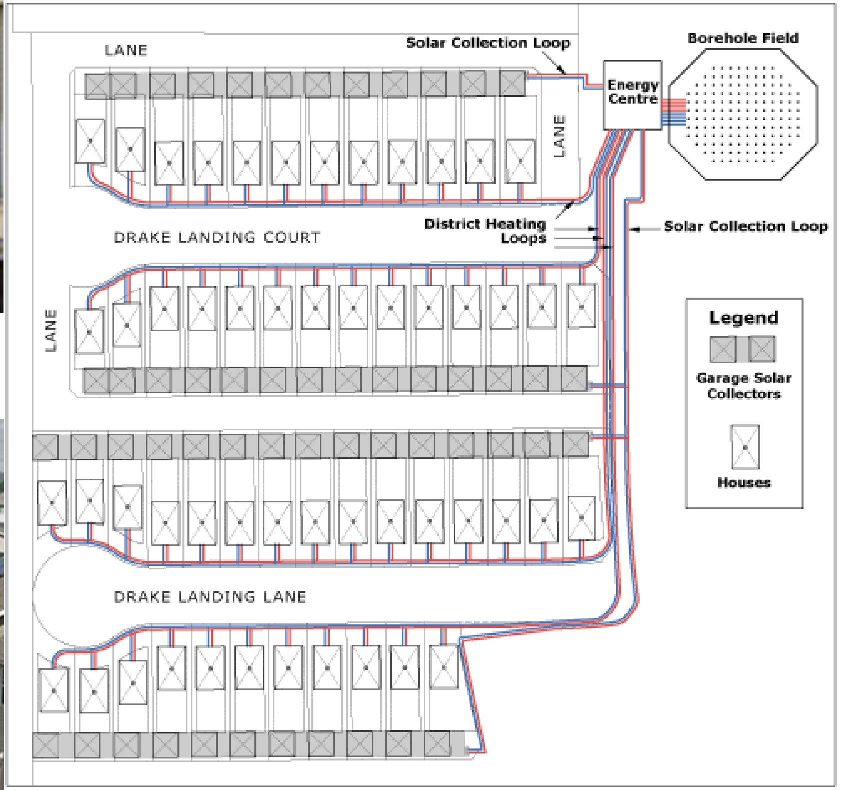
Space & Funding availability

RELaTEDproject.eu



Drake Landing Solar Community (CA)

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Space & Funding availability

- Funding
  - Own funds.
    - Commonly limited to investments < 5 % of yearly turnover.
    - Low impact at large scale
  - Multi-party agreements
    - For all large-scale investments
    - Funding from Banks & Investment funds
    - Subsidies from National & Regional government
    - Guarantees
      - Multi-year heat purchase agreements at ~fixed Price
      - Feed-in tariffs & subsidies (e.g. CHP electricity)
      - (stability of normative framework)

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5.3 Operational Criteria (high-RES)

- SDH plant is “systemic”
  - Produces a relevant share of heat in a given period (e.g. >20%)
  - Stable heat production capacity
    - Substitutes other heating technologies (e.g. other plants are stopped for maintenance)
- Criteria
  - Meet DH Flow temperature levels
  - Stabillize production, with at least daily/weekly thermal storage
  - Incorporate backup heat production system

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5.4 Operational Criteria (low-RES)

- ST produces some free heat
  - Small share heat production (e.g. <5%)
  - Variable heat production
    - Excedentary heat from a building/factory
- Criteria
  - Preferrably, production at DH Flow temperature level
    - Lower Flow temperature accepted (e.g. -5-10ºC).
  - Injection to return level is posible (in some systems)
    - Much higher performance, but higher heat los & lower price of heat
  - No storage or backup heating

5.5 Sizing

- Collector field
  - Optimal orientation: ~South
  - Optimal slope: 30-40º
- Storage

• Inertia/short-term	<0,05 m^3/m^2	
• Daily	~0,3 m^3/m^2	(vertical tank)
• Seasonal	~ $2m^3/m^2$	(borehole/pit storage)

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For educational purposes only
Proper design requires

- Basic engineering of ST plants
- Transient load & production análisis (e.g. hourly)
- CFD análisis of storage tanks
- Detailed control loops
- Cost analysis

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EXERCISE 7

Plant Sizing, Energy & Economic performance

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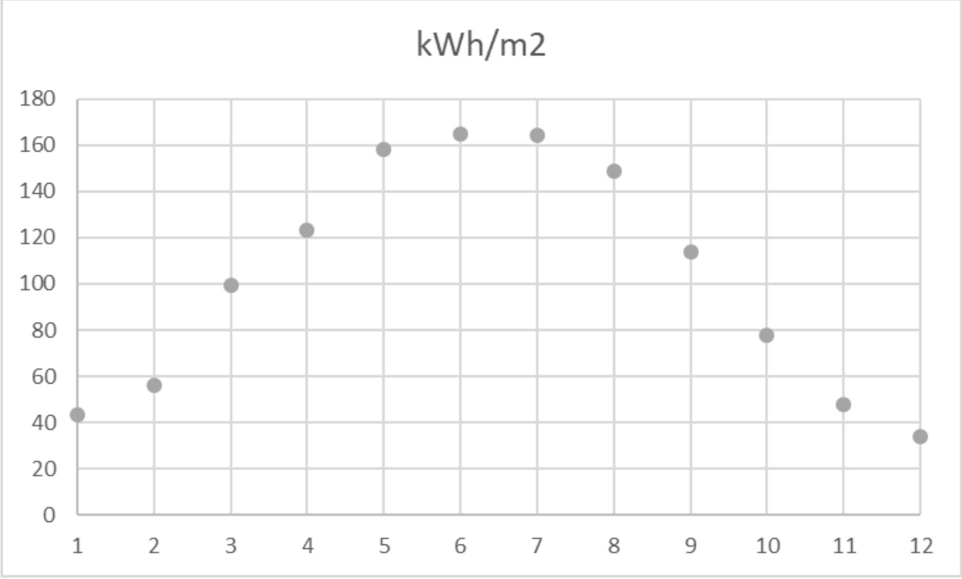
- Turning point for a collector (perf >0)
- DH temperature levels: 60/30ºC
  - Collector mean Surface temperature: 45 ºC
- Ambient temperature: 5 ºC
  - AT: 40 ºC
- perf = 0,853 - 2,71*(AT/I) - ~~0,0046*(AT²/I)~~
  - I where perf > 0 : 127 W/m²
  - Performance at 300 W/m² 49 %

- Solar energy yield
- Average collector performance: 35%
- Monthly solar energy
  - July: 5.3 kWh/m^2.d
  - Days in month

    31
  - Available solar energy

    164 kWh/m^2
  - Input to DH

    57,5 kWh/m^2



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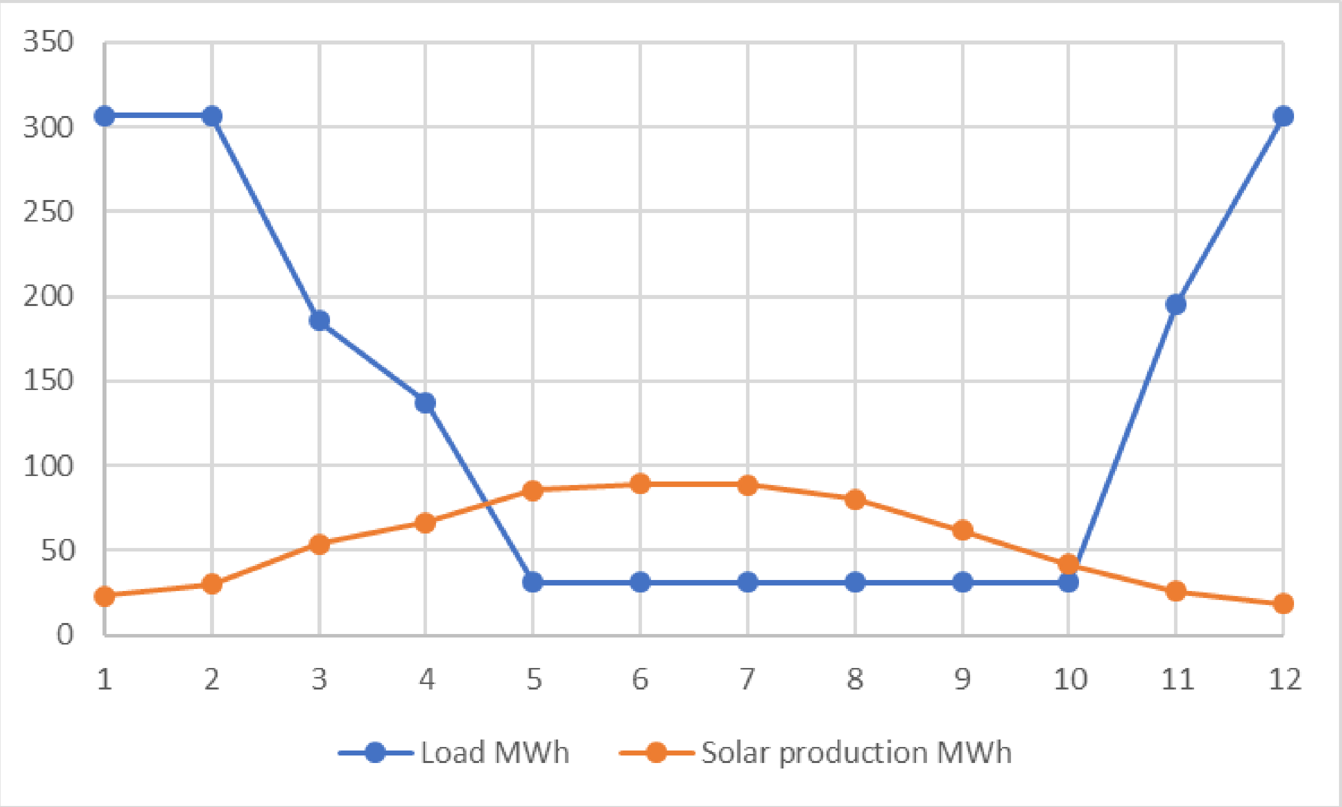
- Total DH load: 1625 MWh
- Desired solar fraction: 40 %
    - Required solar input to DH — 650 MWh
- Yearly solar energy yield: 1,2 MWh
    - Average collector performance: 35%
    - Required collector Surface — 1547 m^2
- Land-to-collector surface ratio: 3
    - Required Surface for collector field — 4642 m^2 ~0,5 ha



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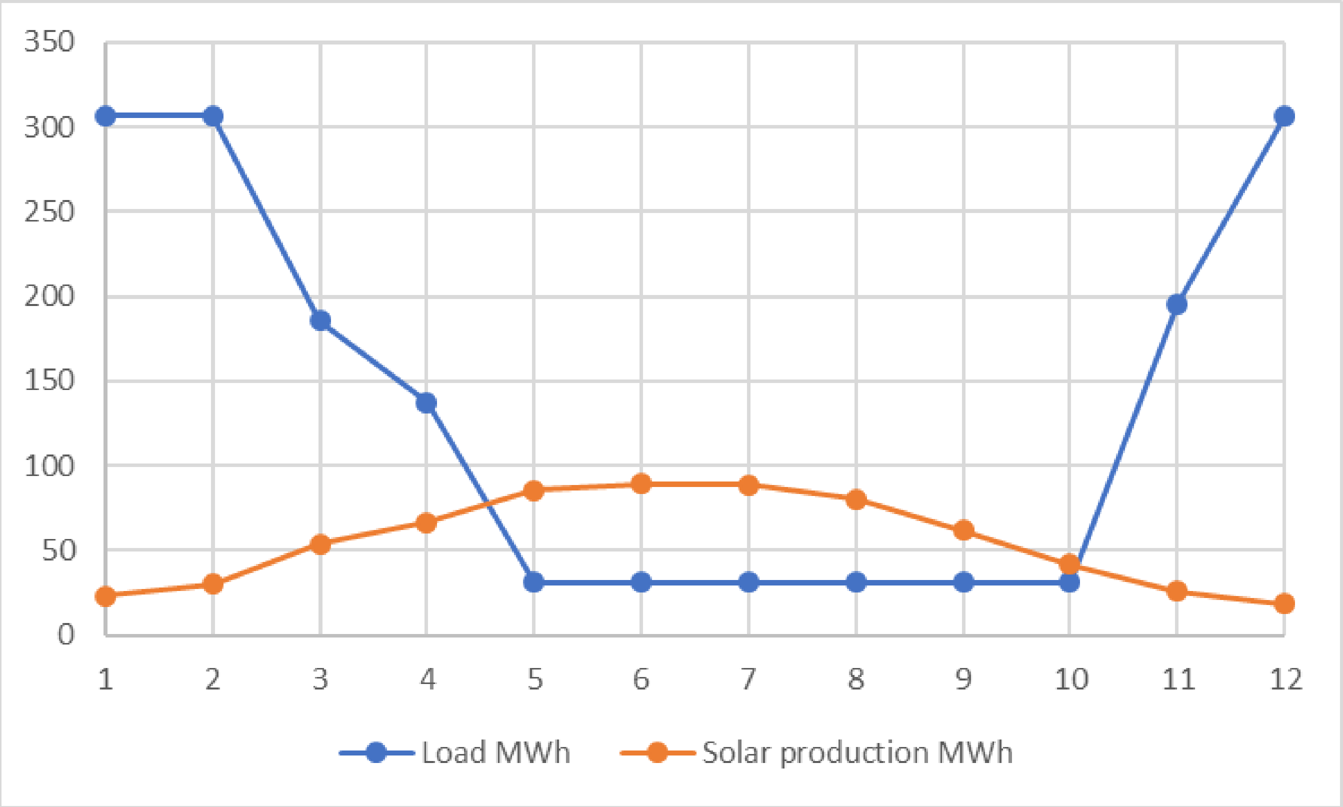
- Load & production patterns
- Storage size
  - ~60 MWh ? No
  - ~90 MWh ? No
  - ~250MWh ? Yes



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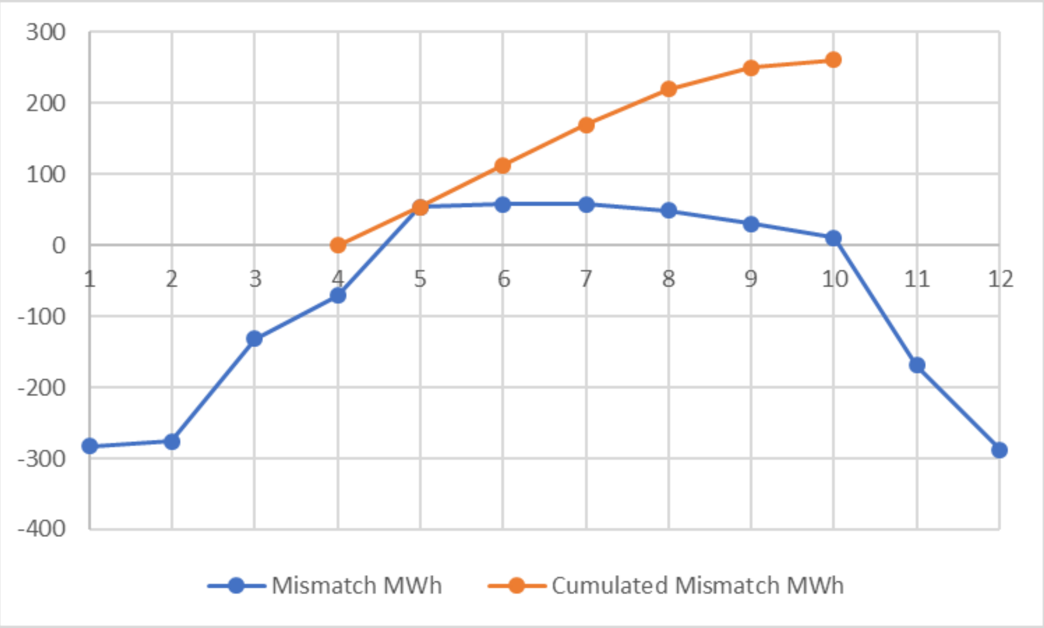

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- Storage capacity: 250 MWh
  - Cp: 4,1 kJ/kg.K
  - density: 1000kg/m3
  - AT: 30 ºC
  - 1kWh =3600 kJ
  - (effective) storage volume: 7300 m^3
- Vertical tank
  - Diam 20 m / floorplan 314 m^2
  - Height: 23 m

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- Collector Surface: 1547 m2
  - Unit cost: 300 €/m2
- Storage volumen: 7300 m3
  - Unit cost: 300 €/m3
- Total investment 2.654.100 €
- Service life: 15 years
- Yearly heat production: 667 MWh
- Cost of heat: ~265 €/MWh
- Is this profitable? No (should be ~20-30 €/MWh
- Reasons? Small field & large tank

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- Collector Surface: 1547 m2
  - Unit cost: 200 €/m2
- Storage volumen: 7300 m3 (instantaneous supply to network)
  - Unit cost: 300 €/m3
- Total investment 309.400 €
- Service life: 15 years
- Yearly heat production: 667 MWh
- Cost of heat: ~30 €/MWh
- Is this profitable? Yes

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6. Wrap-Up

Topics discussed

1. Context
2. Performance of ST systems
3. District Heating Systems
4. Solar Thermal in DH

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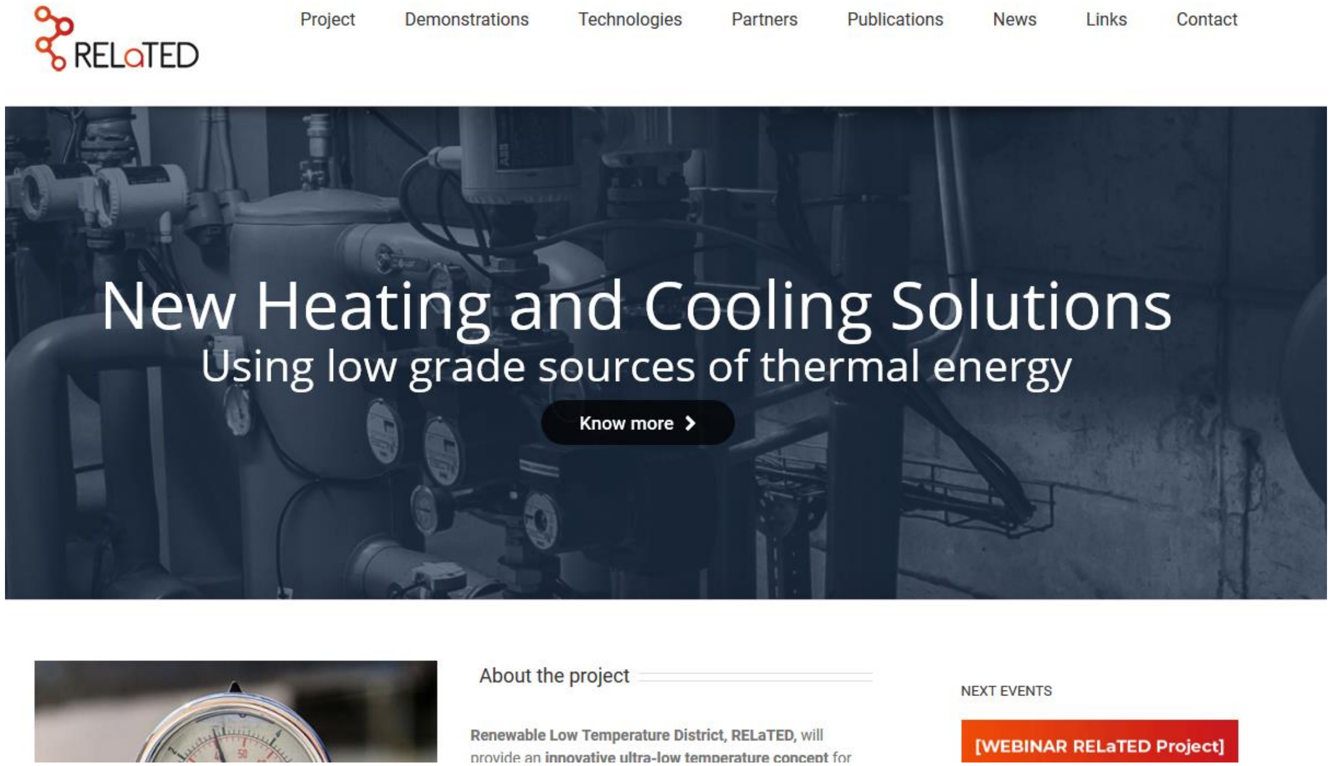
Key Issues

- Energy sector is a fast evolving system
- De-carbonisation, sustainability & security of supply are key issues
- DHs are a relevant heat supply technology
- There is an increasing need for renewables in DHs
- Solar systems are increasingly common in DH networks
- Solar systems can de-carbonize DH networks
- Solar heat is substantially cheaper than other technologies
- Sustainability & economic performance need to complement each other

acknowledgement

Renewable Low Temperature District (h2020 Project)

http://www.relatedproject.eu/



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End of Seminar

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