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Solar Thermal Systems in District Heating Systems

UPV-EHU, Bilbao, 10-12 December 2019

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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   - Solar Thermal (ST) Systems
   - District Heating (DH) Systems
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   - Technologies
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   - Design of ST fields

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Index (Day 2)

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1. Context

1.0 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

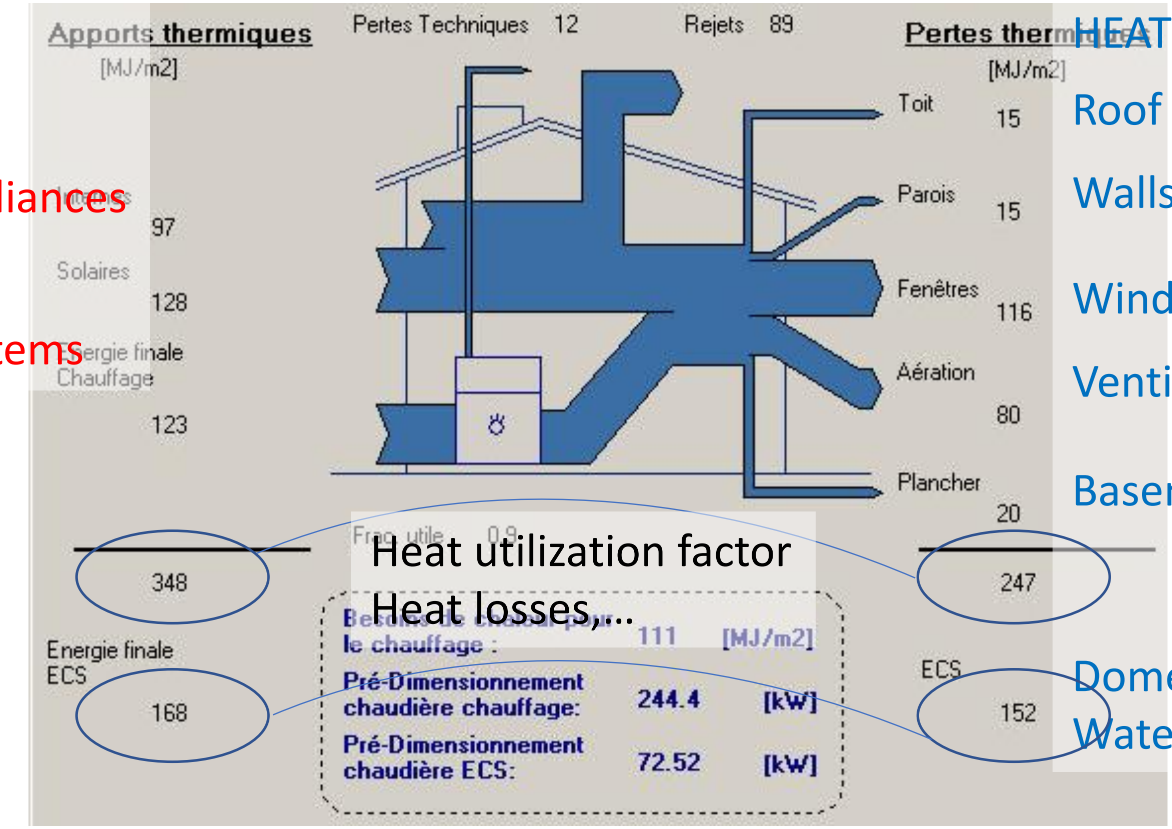
Ventilation

Basement

Domestic Hot Water

Heat utilization factor

Heat losses,…



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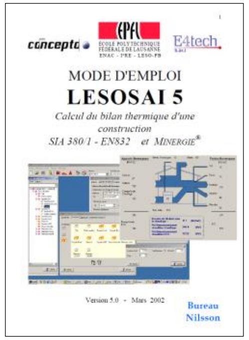

LESOSAI 5. Mode de Emploi. 2002.
https://docplayer.fr/57528916-Lesosai-5-calcul-du-bilan-thermique-d-une-construction-sia-380-1-en832-et-minergie.html

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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

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

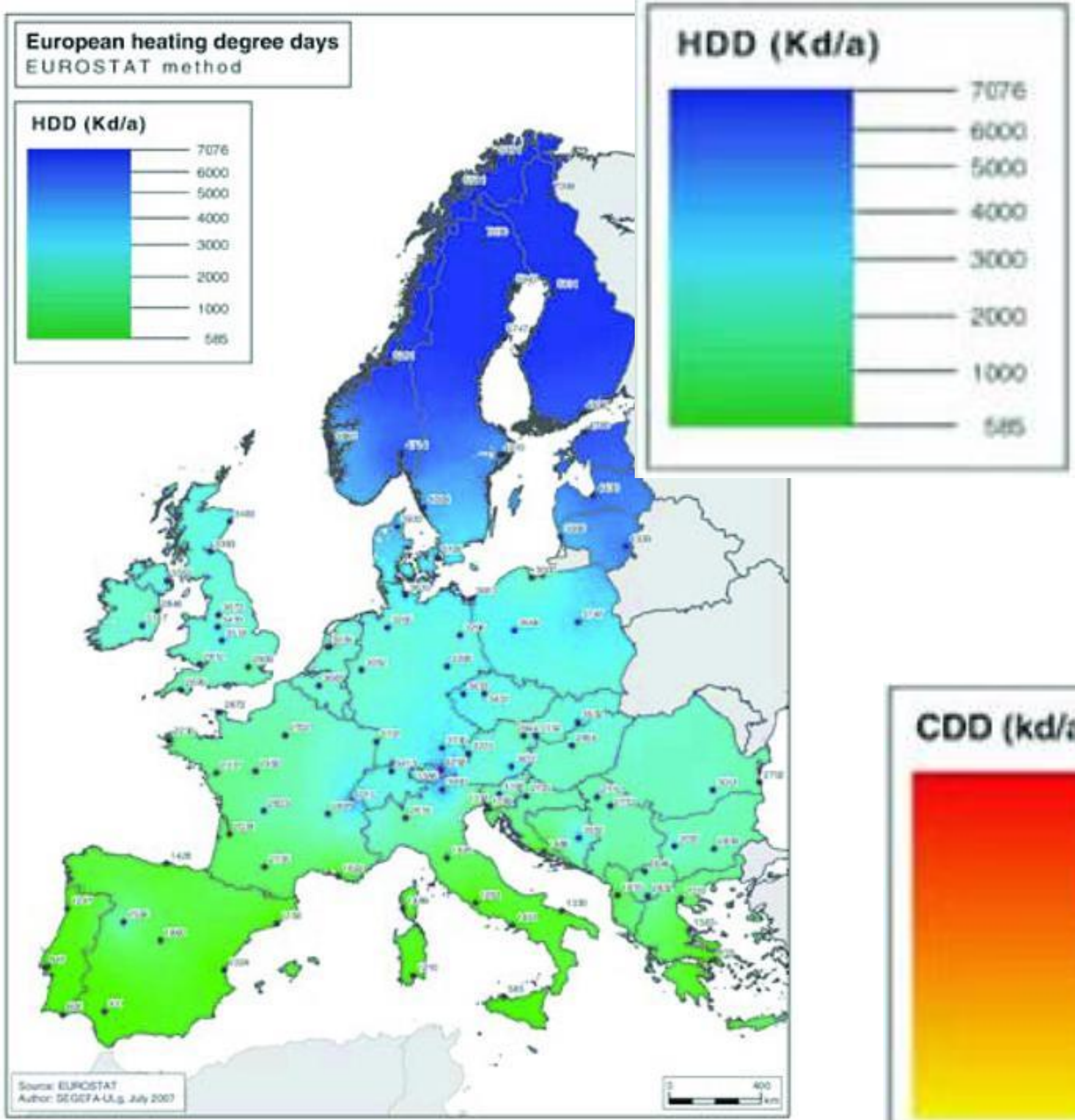
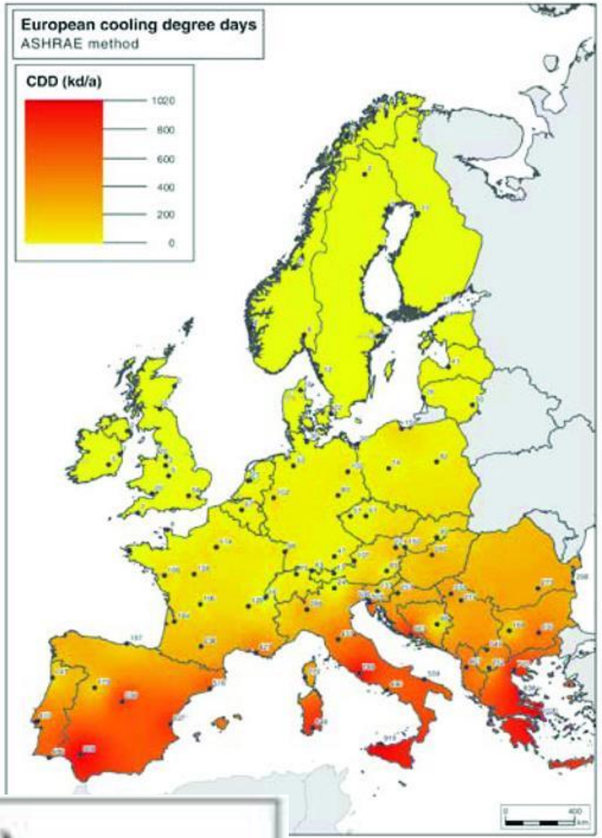
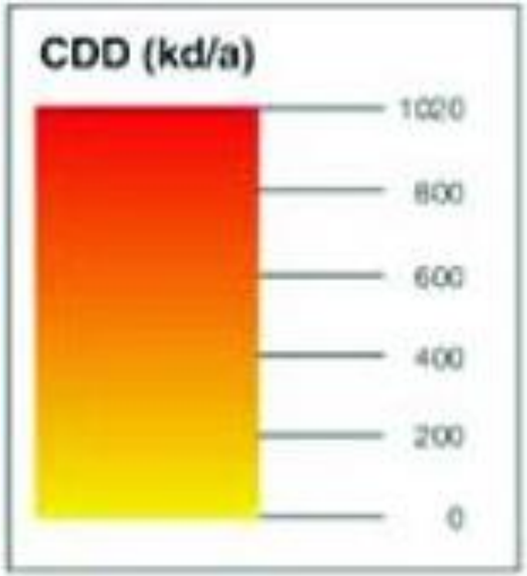


Figure 6: European cooling degree days map (ASHRAE method)





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

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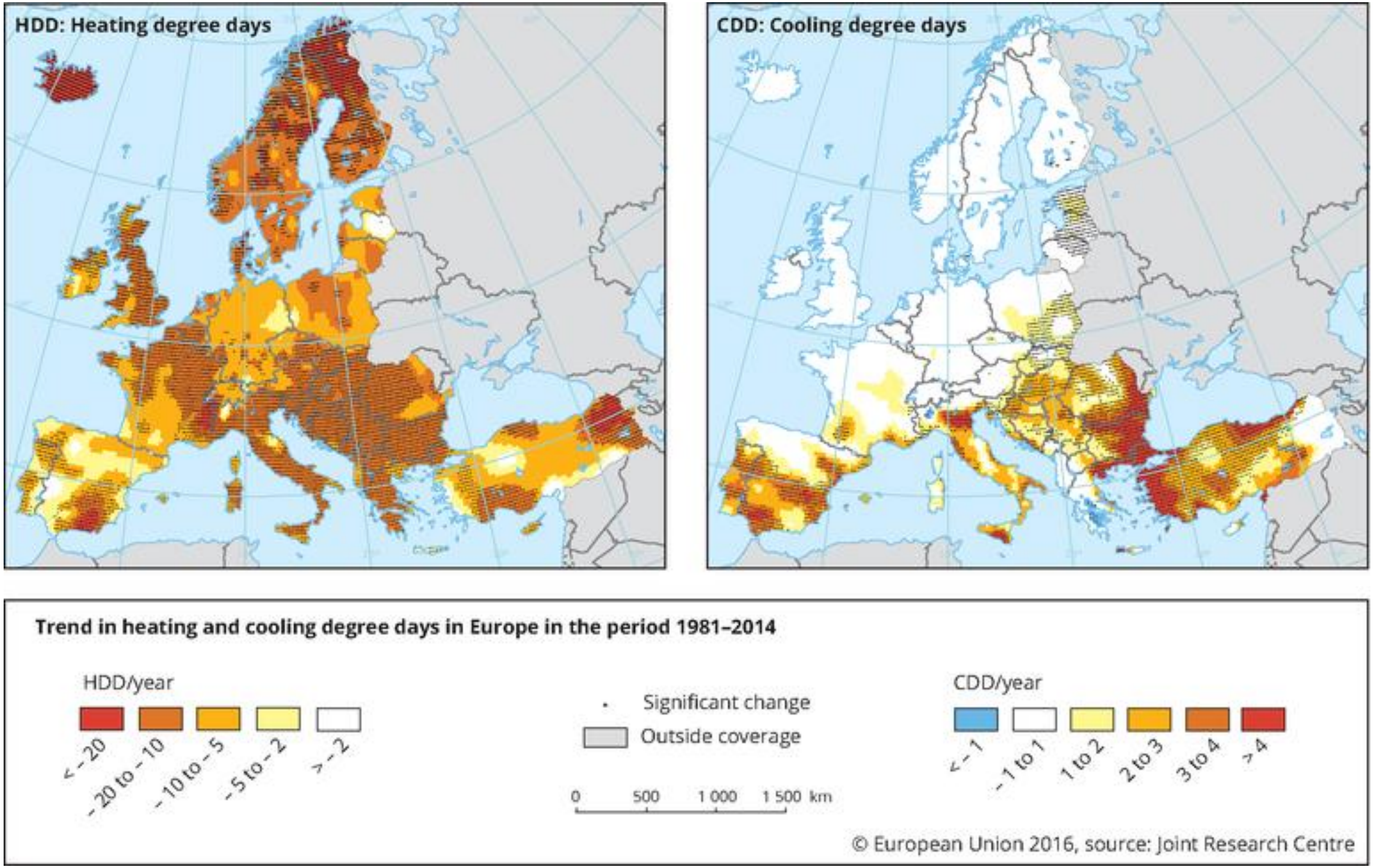

European Environmental Agency, Observed trends in heating & cooling degree days 1981-2017 https://www.eea.europa.eu/ds_resolveuid/f2a5588e42b543d4be499359c34ca617

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Provincia	Estación	Indicativo
Vizcaya	Bilbao (Aeropuerto Sondica)	1082

UBICACIÓN: ENTORNO CIUDAD

a.s.n.m. (m)	Lat.	Long.
39	43°17'53"	02°54'21" 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 (°C)	TS_99,6 (°C)	TS_99 (°C)	OMDC (°C)	HUMcoin (%)	OMA (°C)
-6,0	-0,2	1,2	10,7	89	31,4

CONDICIONES PROYECTO REFRIGERACIÓN (TEMPERATURA SECA EXTERIOR MÁXIMA)

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

CONDICIONES PROYECTO REFRIGERACIÓN (TEMPERATURA HÚMEDA EXTERIOR MÁXIMA)

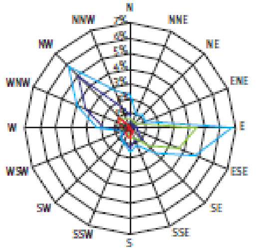
TH_0,4 (°C)	TSC_0,4 (°C)	TH_1 (°C)	TSC_1 (°C)
22,8	30,6	21,8	29,5

VALORES MEDIOS MENSUALES

HDD (15ºC) HDD (20ºC) CDD (20ºC)

Mes	TA (°C)	TASOL (°C)	GD_15 (°C)	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

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



Calmas: 20%

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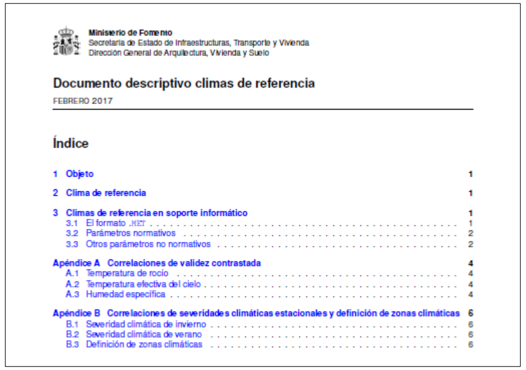
Ministerio de Fomento
Secretaría de Estado de Infraestructuras, Transporte y Vivienda
Dirección General de Arquitectura, Vivienda y Suelo

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

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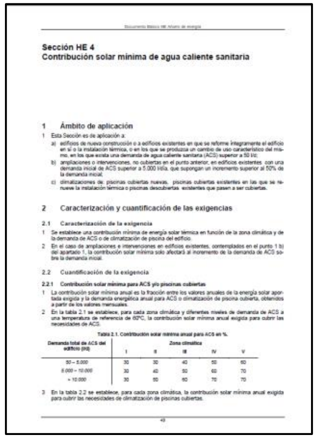
Tabla 4.1. Demanda de referencia a 60 °C[1]

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 cole		
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)

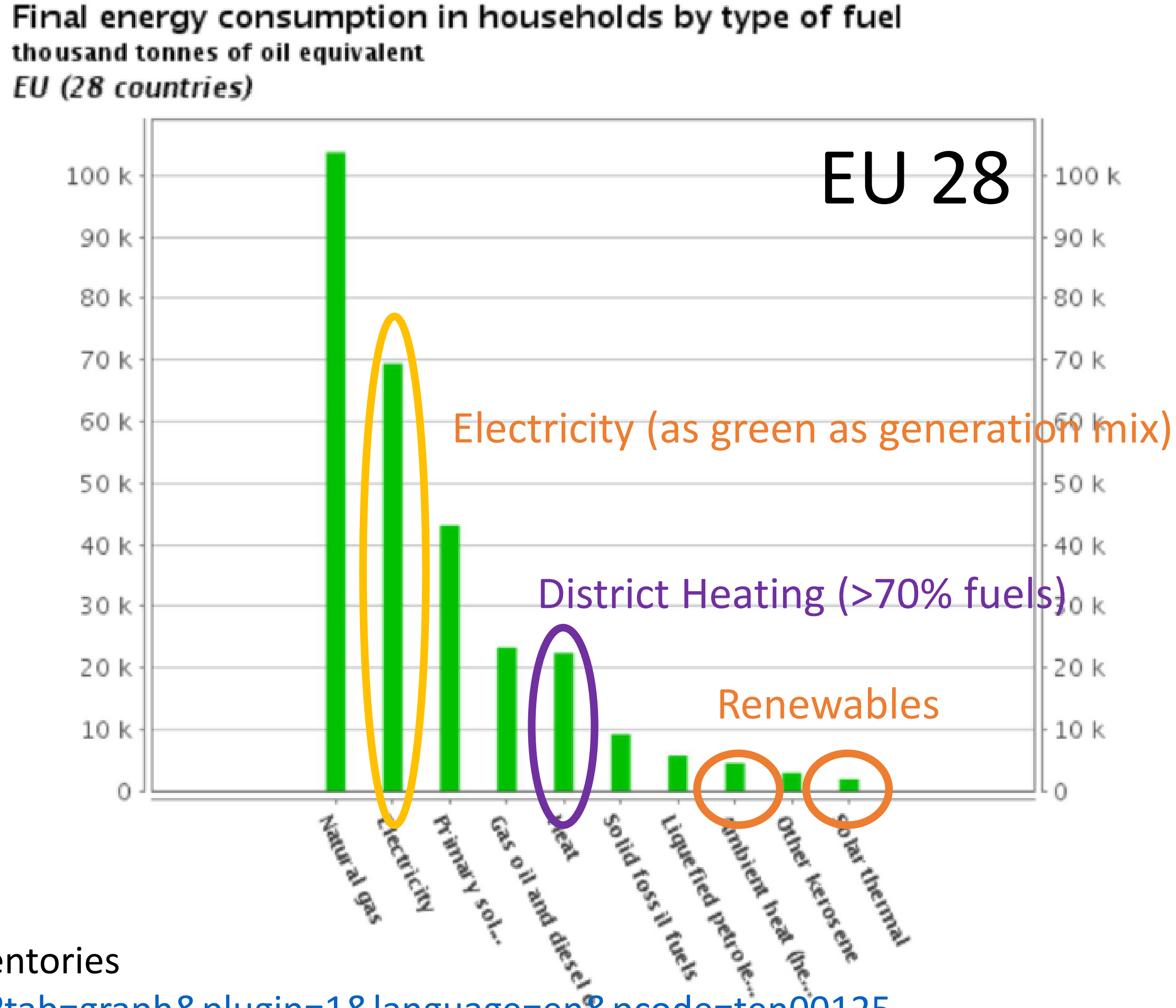
- m as defined in CTE HE4
- Cp = 4,18 kJ / (l*K)
- T_sup = 60 ºC
- T_source as per local climate

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

Energy Supply to EU households



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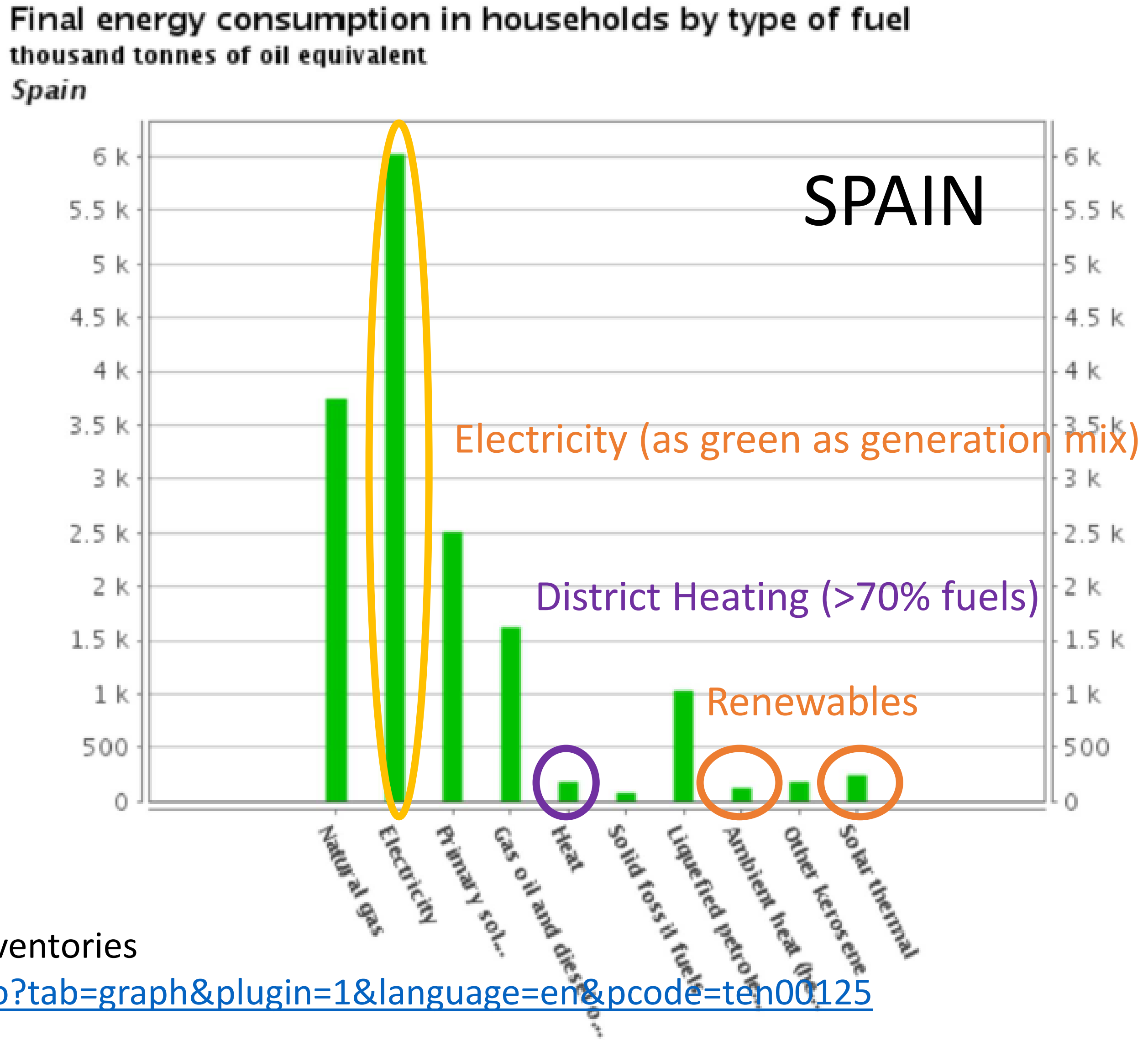
EUROSTAT. Custommized quary to energy inventories
https://ec.europa.eu/eurostat/tgm/graph.do?tab=graph&plugin=1&language=en&pcode=ten00125

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

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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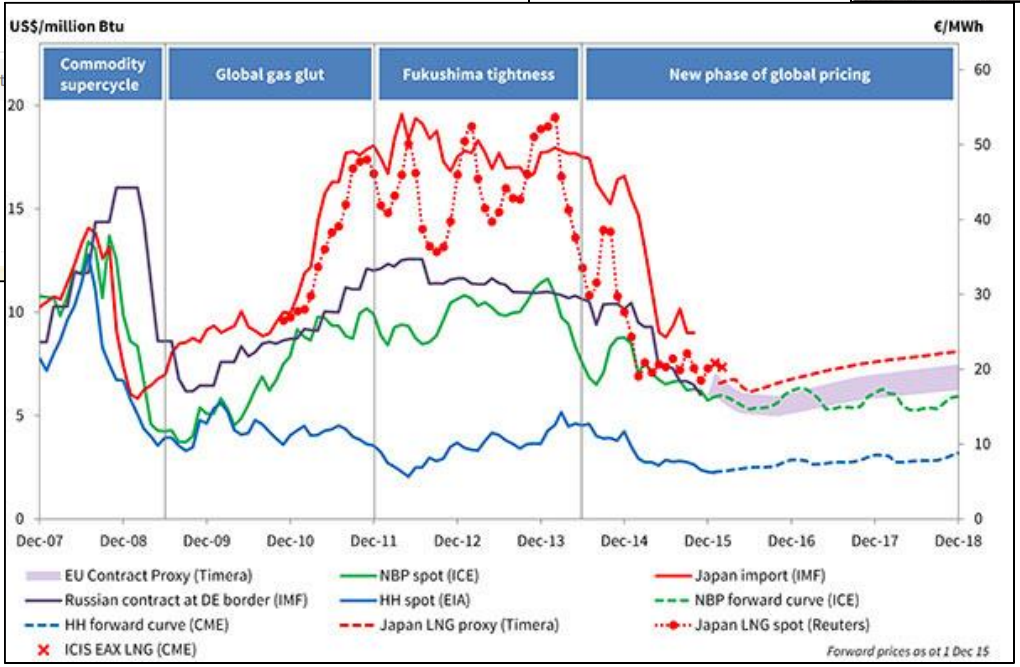

1.1 Solar Thermal (ST) Systems

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

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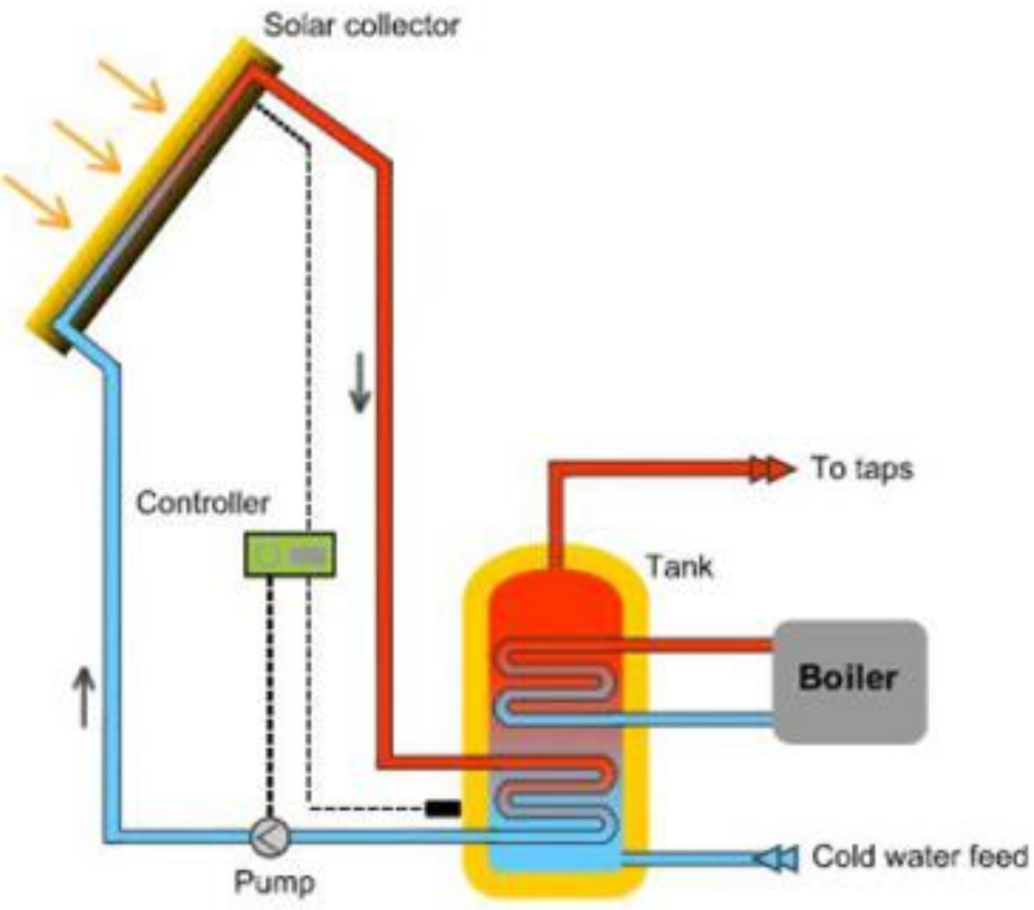
Basic Configuration(s)

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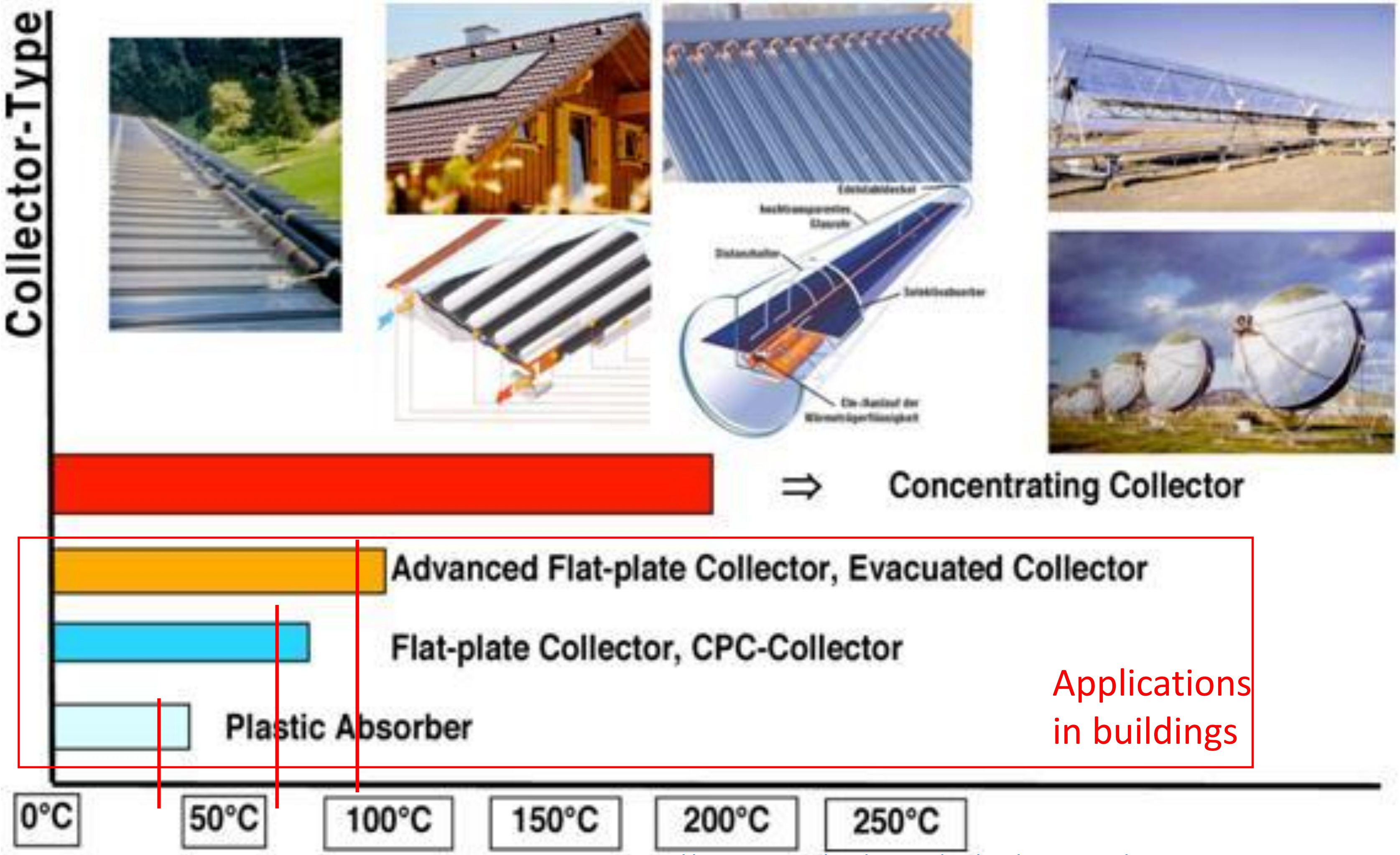
Space heating, 45-70 ºC
DHW pre-heating 20-45ºC
Swimming pool heating ~30ºC
Other low-grade app. ~20ºC



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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1.2 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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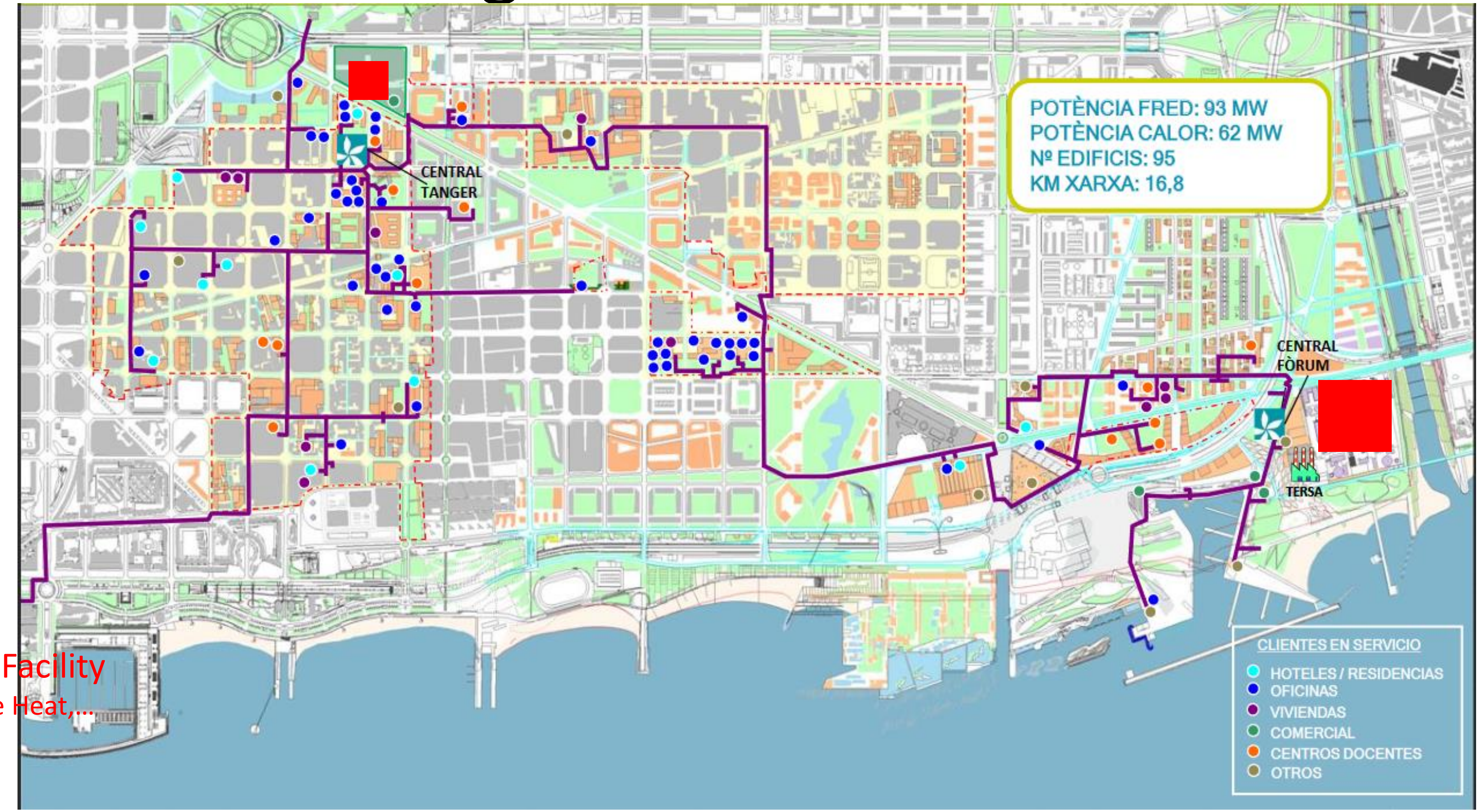

Main Heat Production Facility
Commonly CHP, 3G, Waste Heat,...

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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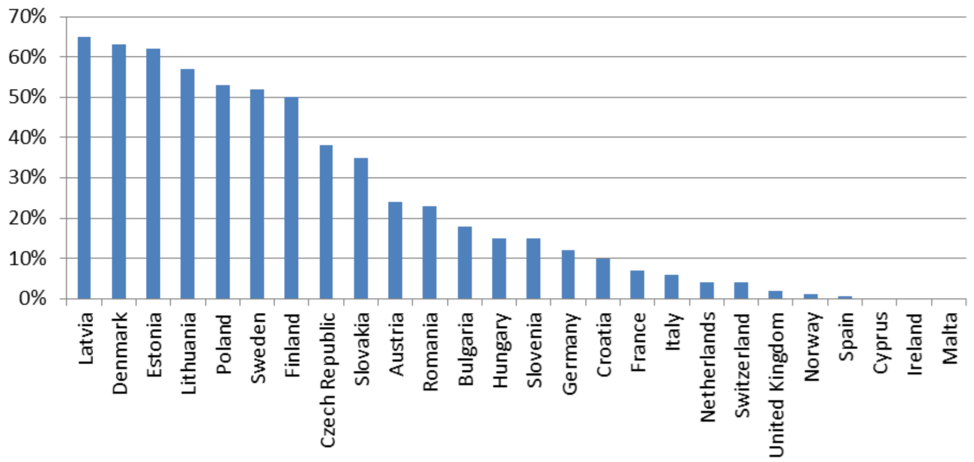
Basic Configuration

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

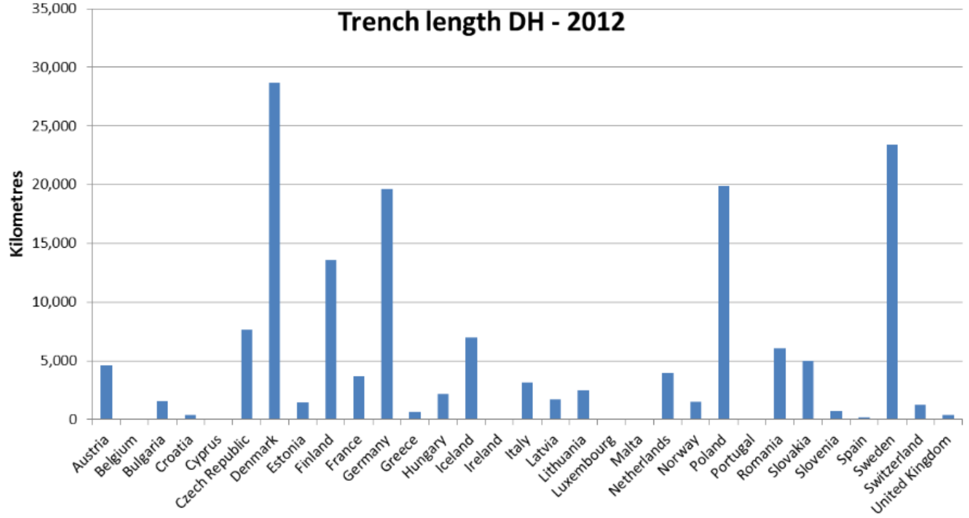
http://www.districlima.com/districlima/uploads/descargas/presentaciones%20y%20otros%20documentos/2019_06%20Presentaci%C3%B3n%20est%C3%A1ndar%20Districlima%20(CAST).pdf

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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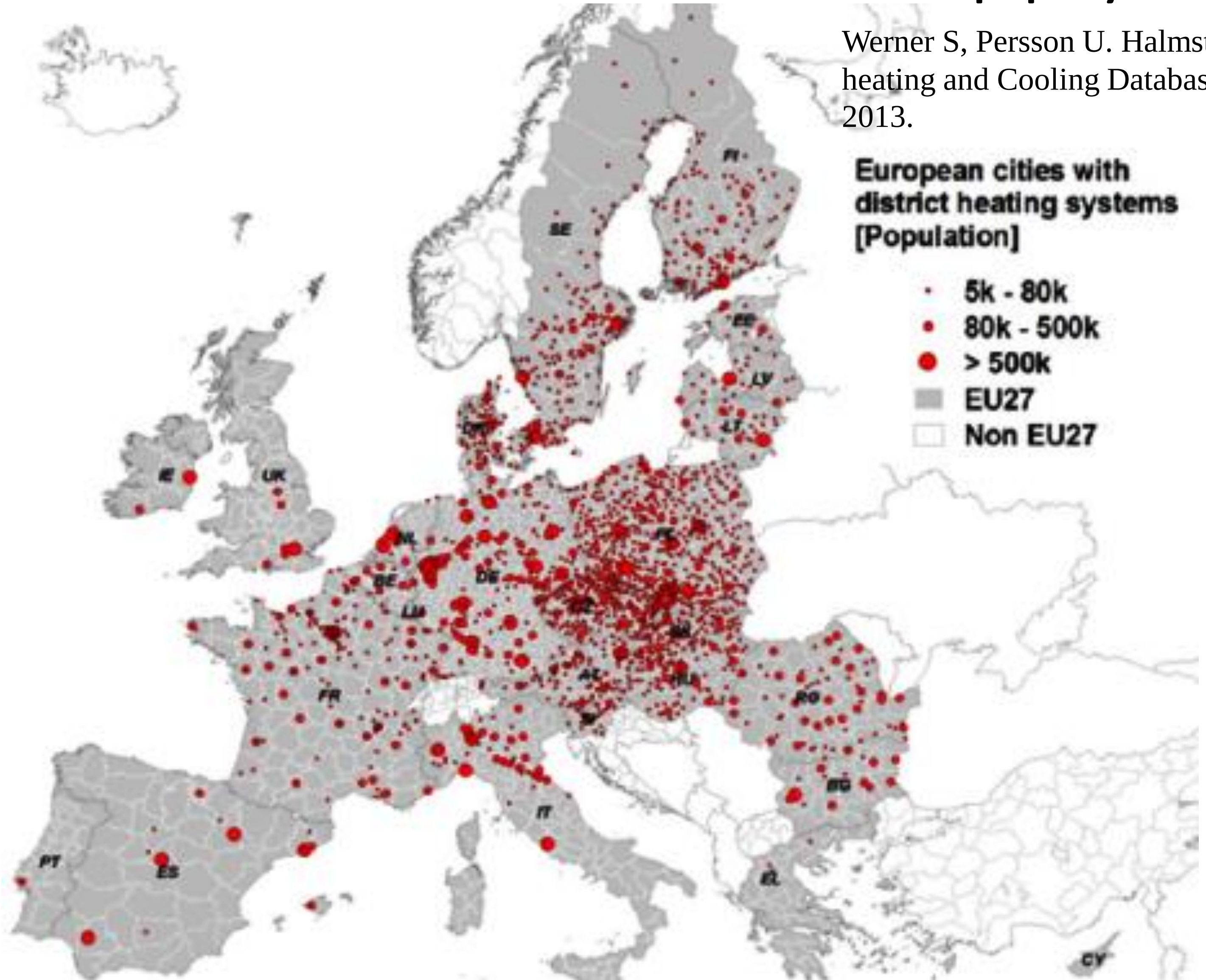
Relevance in EU heat supply

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

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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

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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2. Performance of ST systems

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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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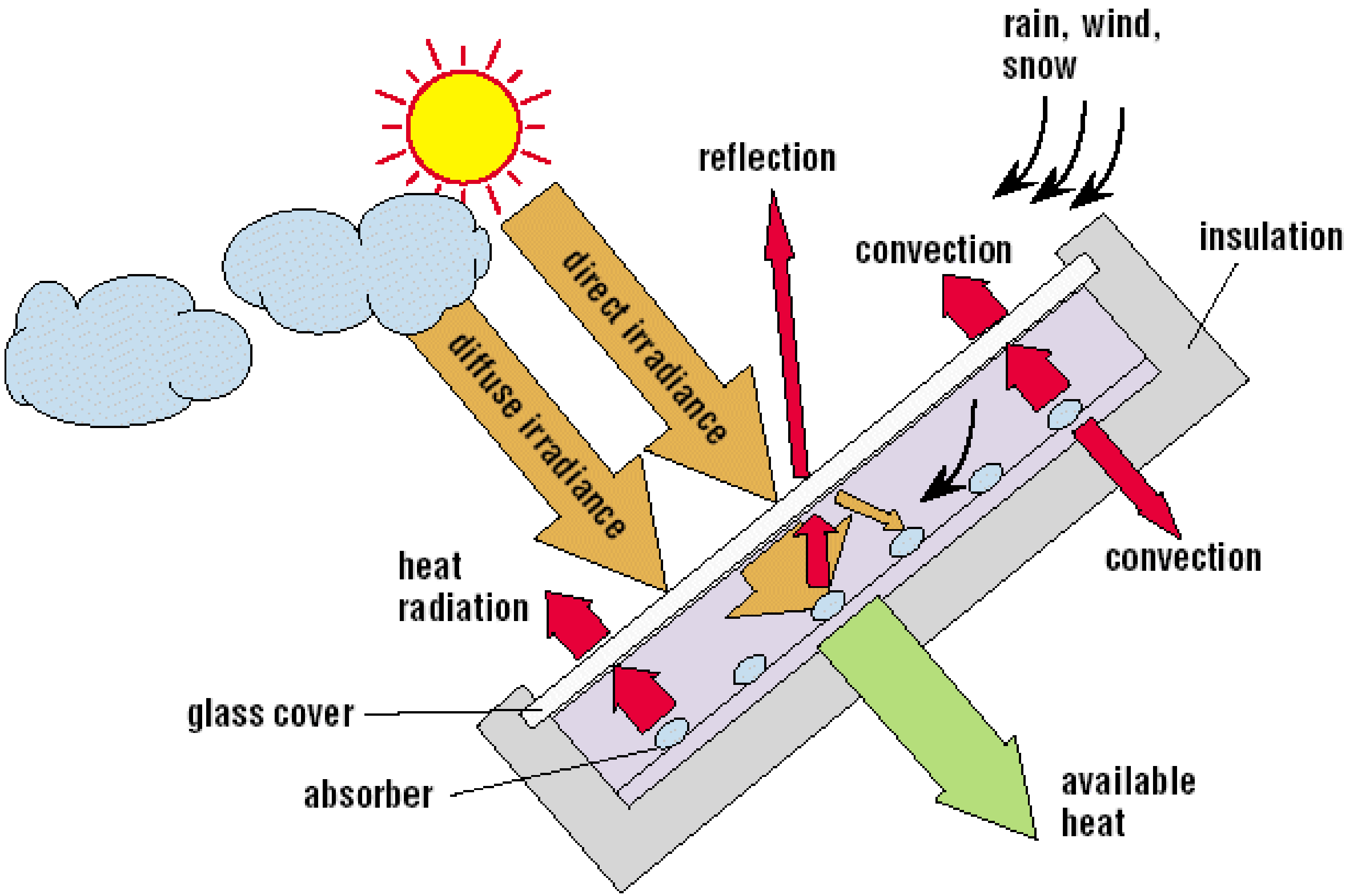

https://www.volker-quaschning.de/articles/fundamentals4/index.php

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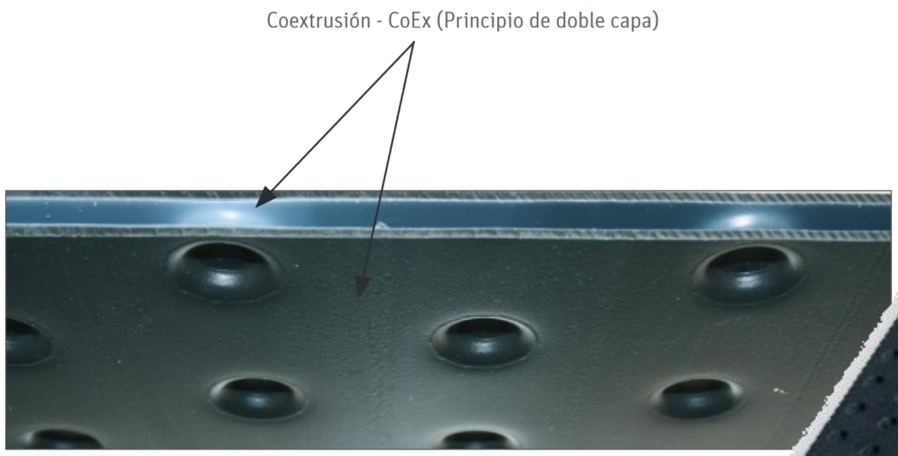
Unglazed Flat Plate



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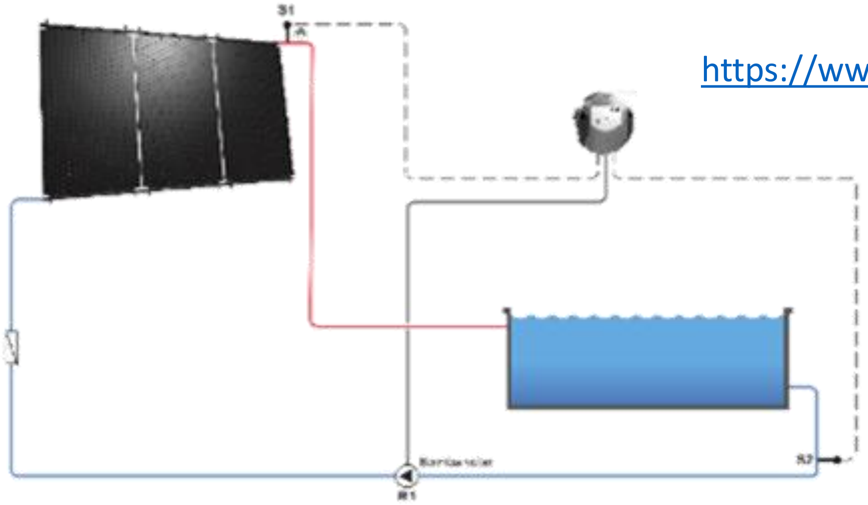
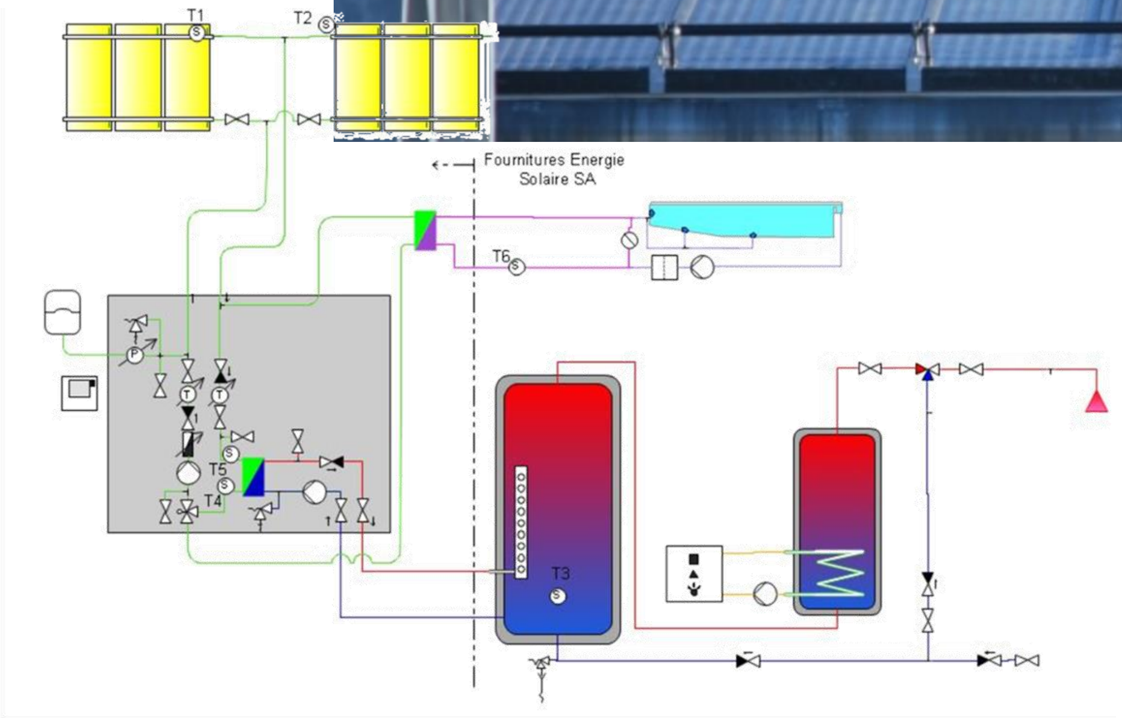


https://www.roth-spain.com/es/Captador-solar-para-piscinas-Rothpool.htm

Unglazed Flat Plate



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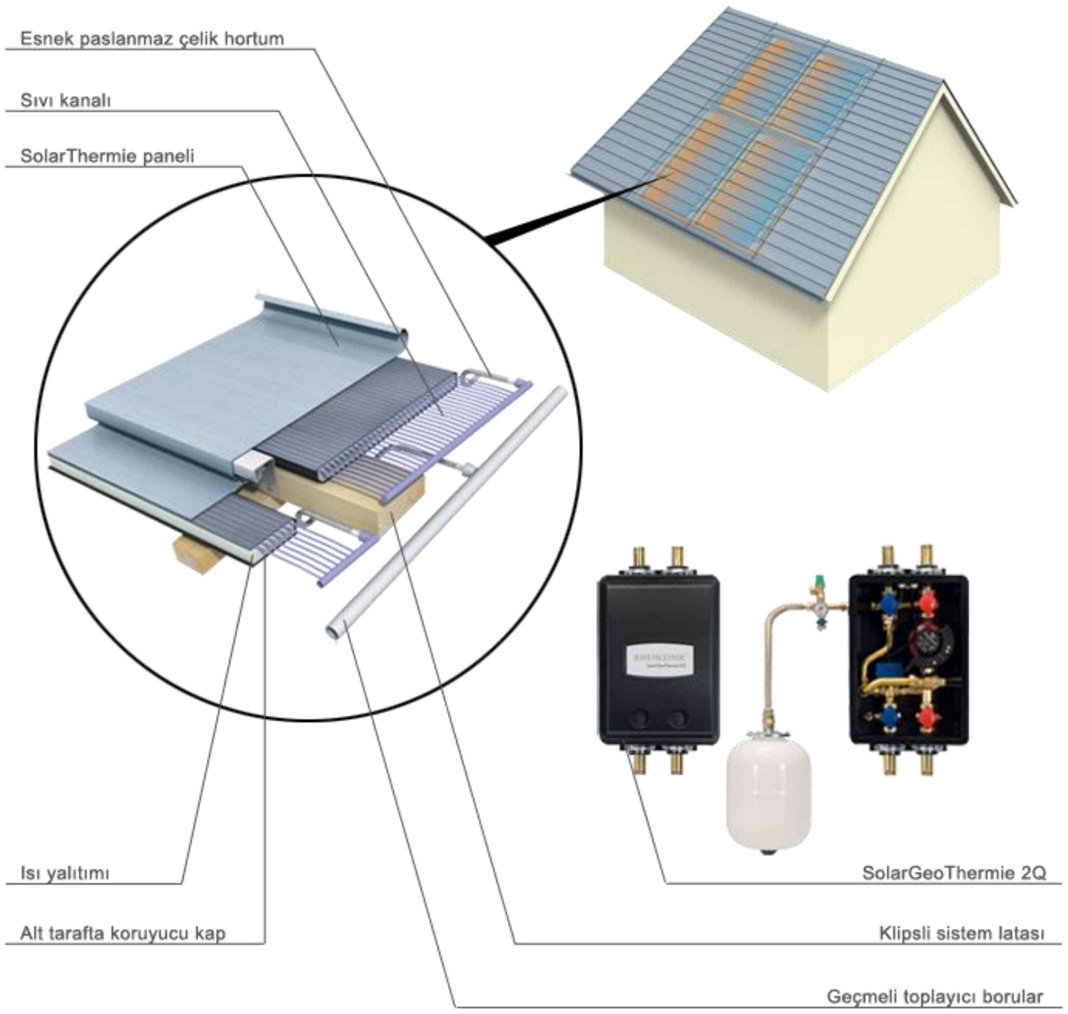
https://www.energie-solaire.com

Unglazed Flat Plate



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

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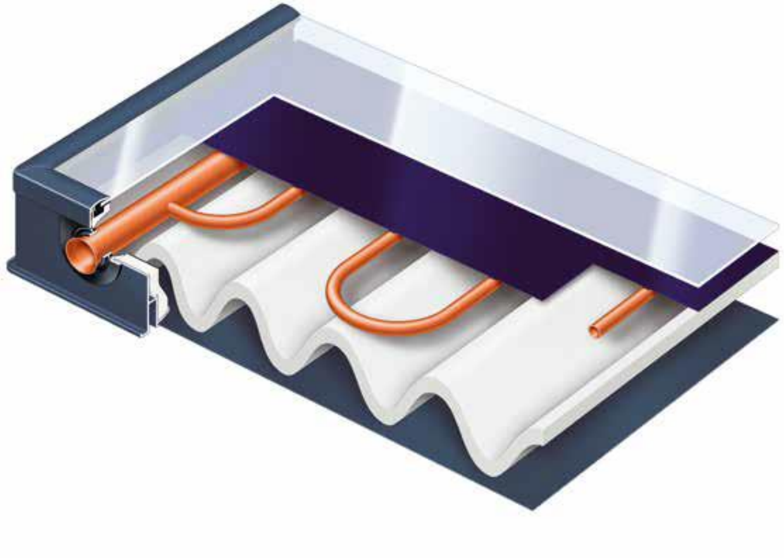
Glazed Flat Plate

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



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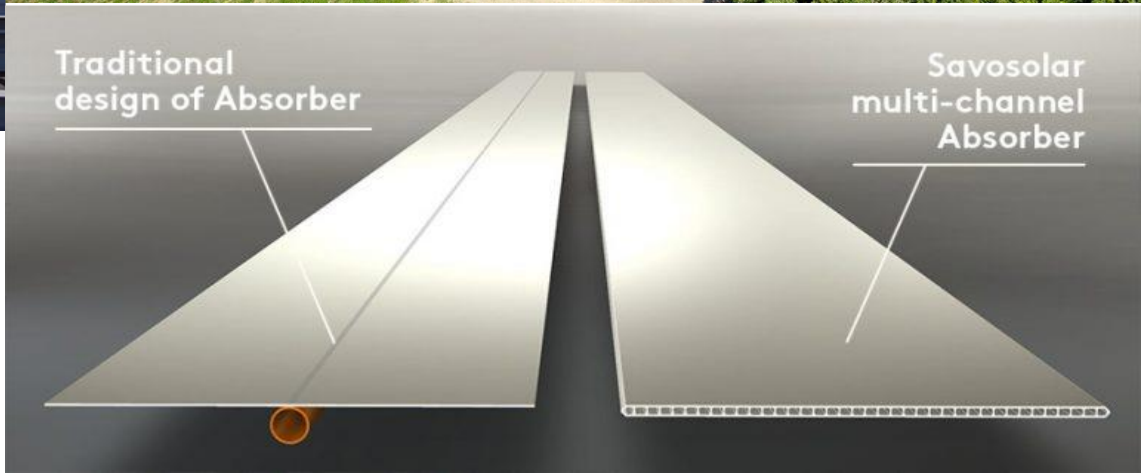
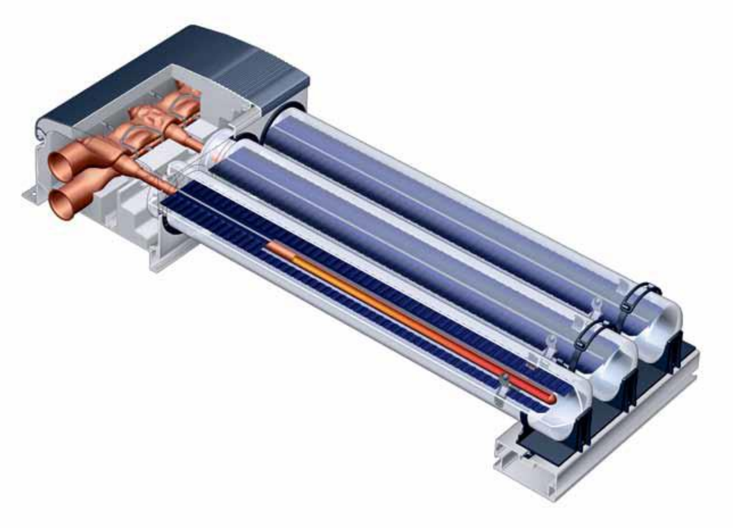
https://savosolar.com



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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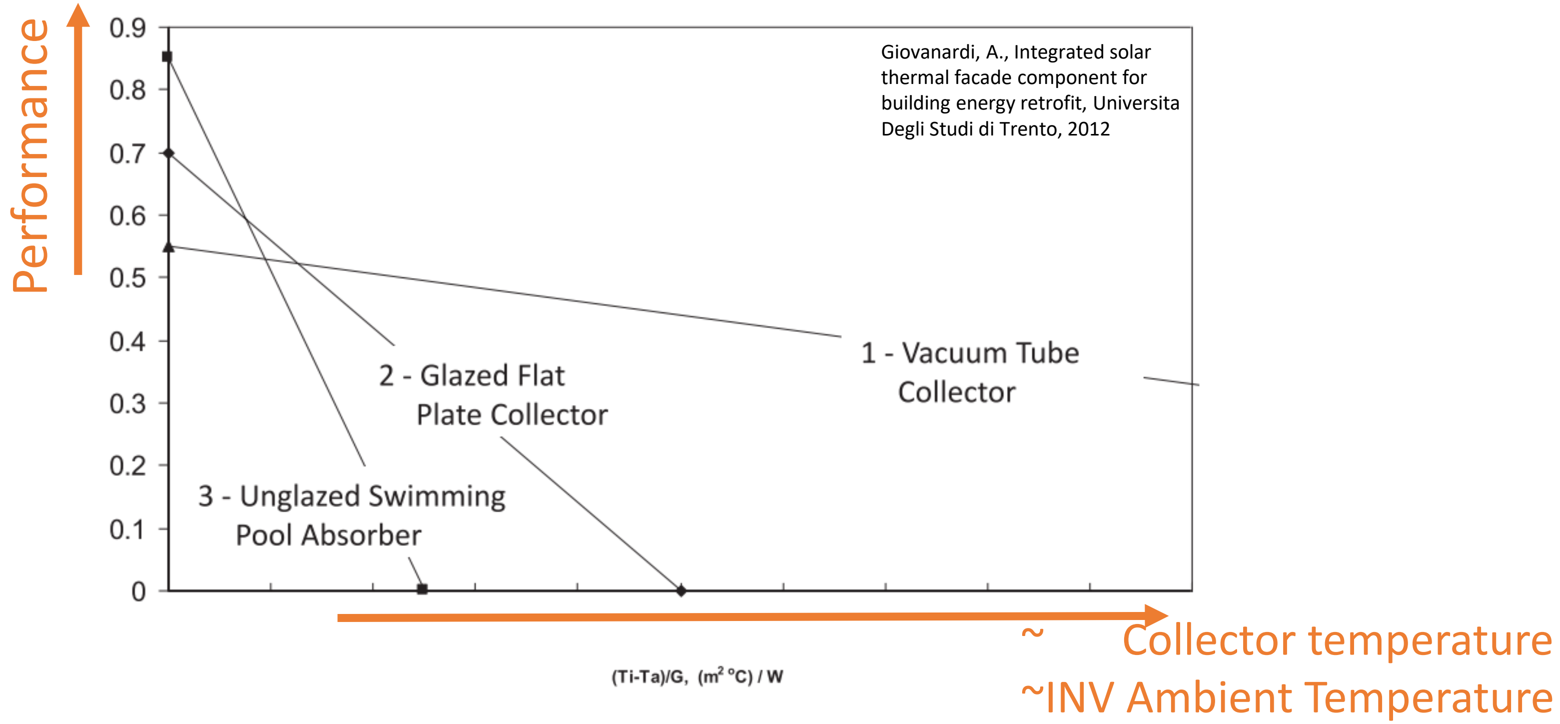
2.2 Performance characterisation



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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/m^{2}ºC)	
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

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

2.3 Design of ST fields

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

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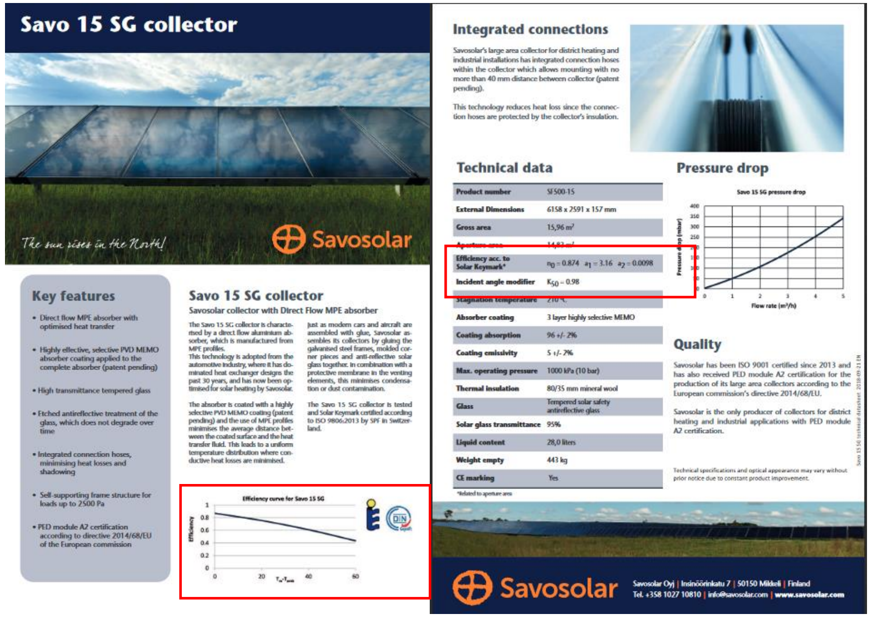
Collector Datasheet



Product number	SI 500-15
External Dimensions	6158 x 2591 x 157 mm
Gross area	15,96 m²
Aperture area	[illegible]
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

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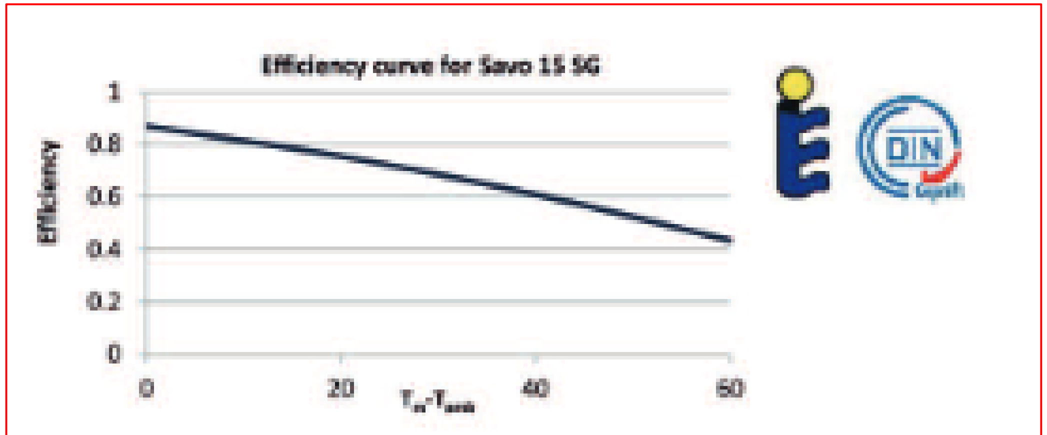

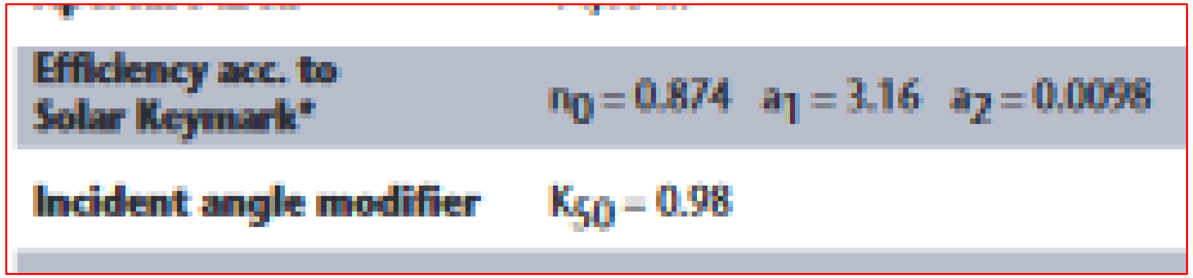

Efficiency acc. to Solar Keymark*	$\eta_0 = 0.874$ $a_1 = 3.16$ $a_2 = 0.0098$
Incident angle modifier	$K_{50} = 0.98$

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

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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

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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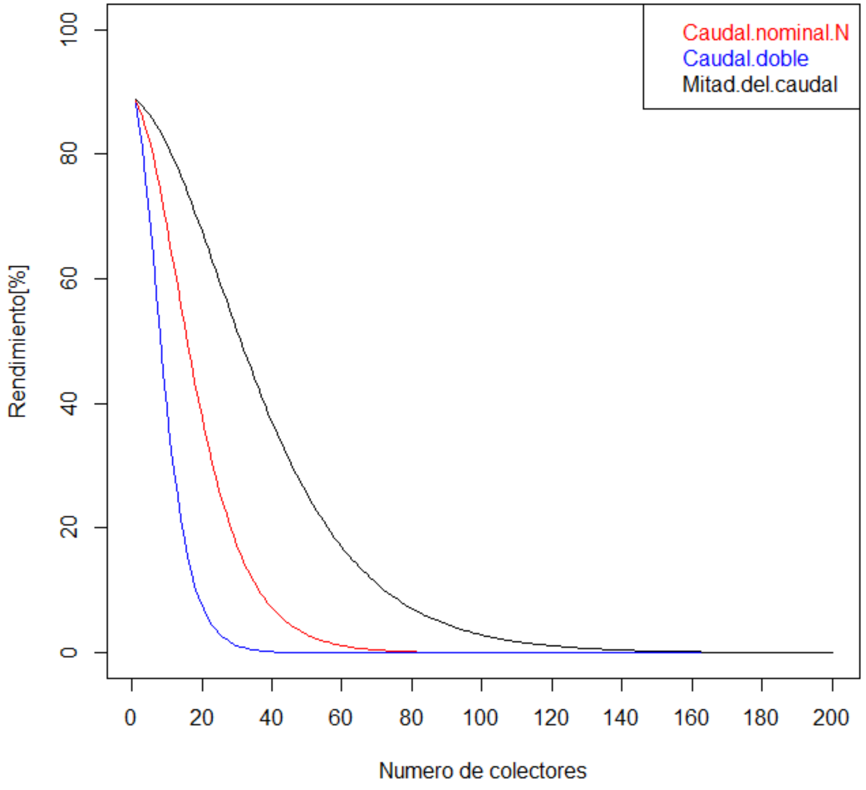
Serial connection

- 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

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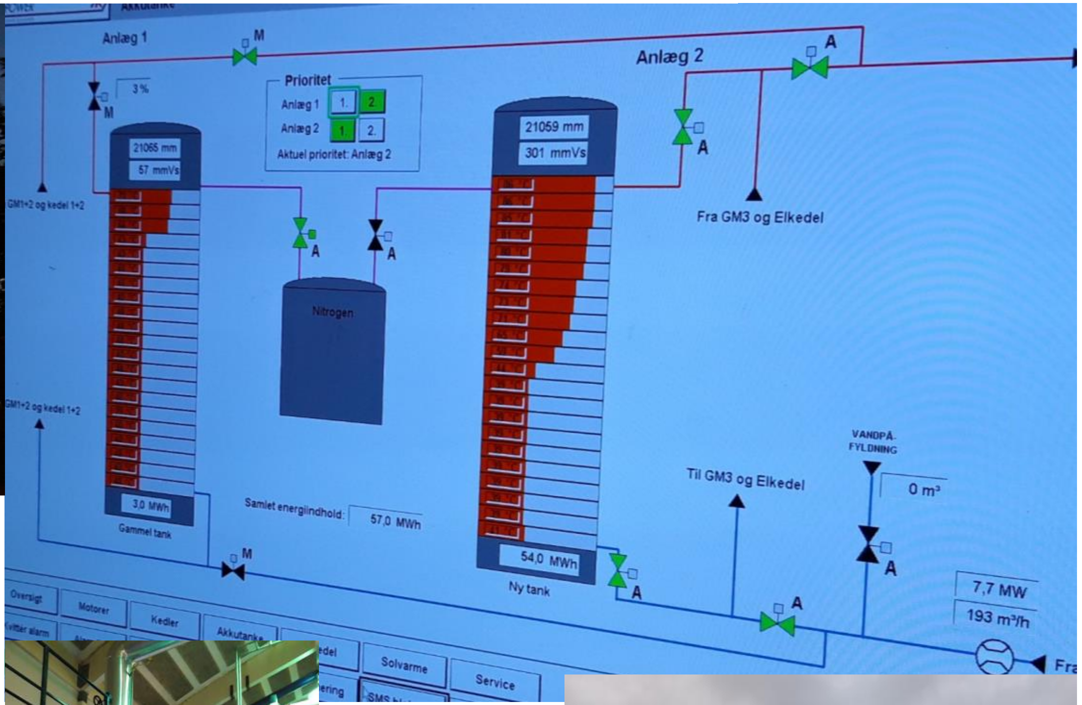
District heating plant at Helsinge (DK)



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

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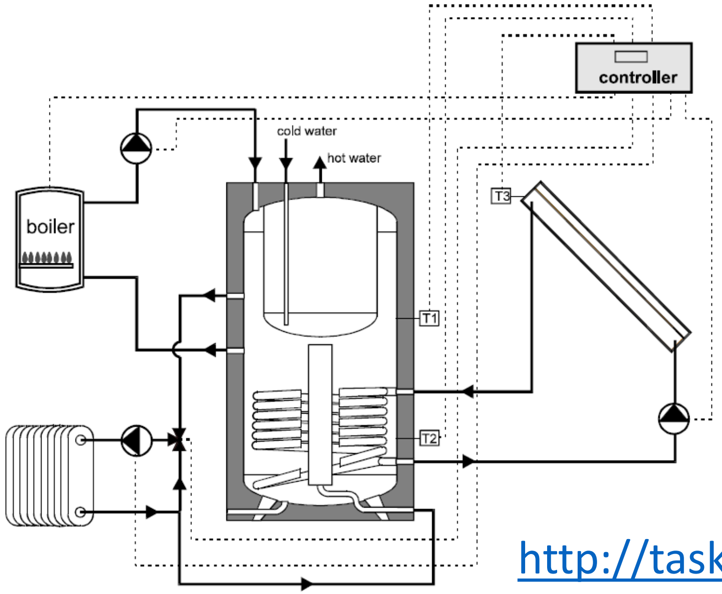
Heat Injection into Thermal Storage

- 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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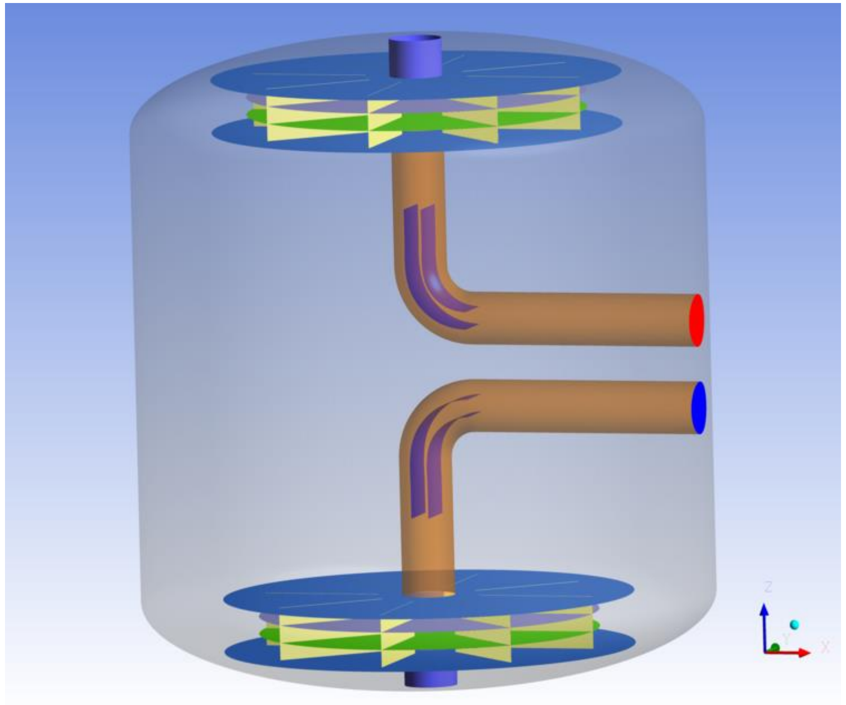
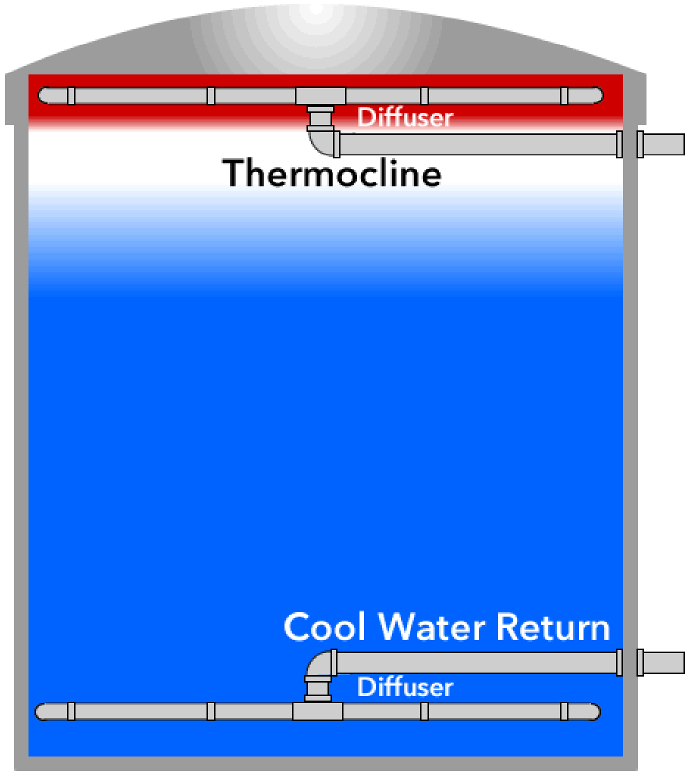
Heat Injection into Thermal Storage

- 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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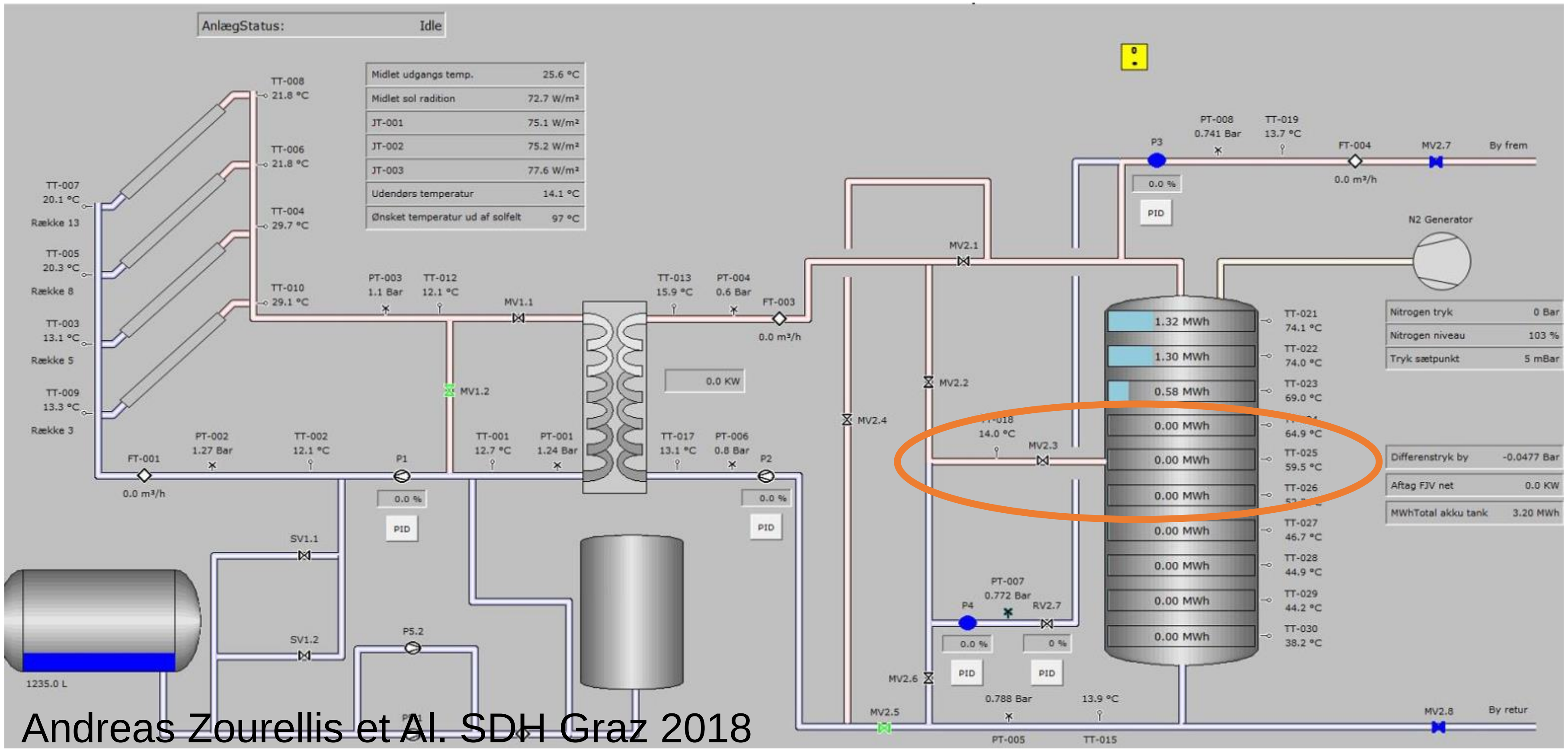
Heat Injection into Thermal Storage

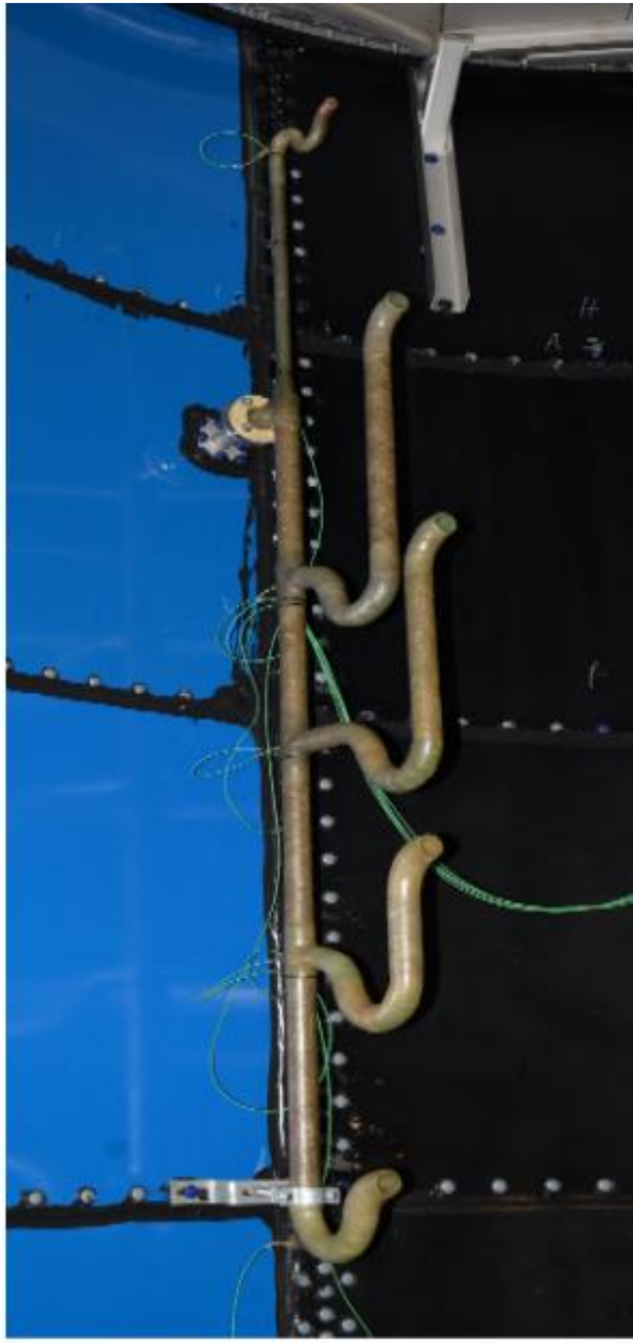
- Open systems
  - Also, injection at intermediate temperature levels



Andreas Zourellis et Al. SDH Graz 2018

Heat Injection into Thermal Storage

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



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End of Day 1

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