Energy transition in Europe and Italy: the Renewable Energy plans and the role of geothermal heating and cooling solutions

Montreal 18th August 2022

Marco Fossa, Univ. Genova, Italy

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- The University of Genova, Italy: Facts and Figures
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- Heat Pumps: why and how to choose the Geothermal solution
- The Unige contributions for boosting the Geo Heat Pump market and engineering

Marco Fossa short CV

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Mech. Engineer, Phd, Full Professor at the University of Genova,
DIME Department of Mechanical, Energy, Management and Transportation Engineering (www.dime.unige.it)

Rector's Delegate for the International Study Programs
Director of Unige Master on Energy and Sustanability (2022)
MSc Course in Energy Engineering (En2) Coordinator (2014-2020, www.en2.unige.it)

Teaching: Applied Thermodynamics and Heat Transfer, Renewable Energies, Solar and Geothermal Energy, Clean Energy Production

Research (Scopus data): author of 170 scientific papers, 1300 citations, h index=20

Visiting appointments: Cern Geneva, CH (1990-1992, 2001-2003)
Univ. Nottingham (2001), MCI Innsbruck (2018, 2019, 2020, 2021)
UNSW Sydney (2006, 2008, 2010, 2012, 2017) as Visiting Professor
Univ. du Quebec ETS, (2022) and Polytech Montreal (2022)

Collaborations: Locie Univ. Savoie Mt Blanc, Insa Cethil Lyon
Cern Geneva, UNSW Sydney, KTH Stockholm

Areas of interest: Renewable Energies, Solar Energy, Geothermal heat pumps, Building Integrated Photovoltaics, Solar thermal and Solar Concentrati
(and even Cross Country Ski..)

1: The University of Genova, Italy: Facts and Figures

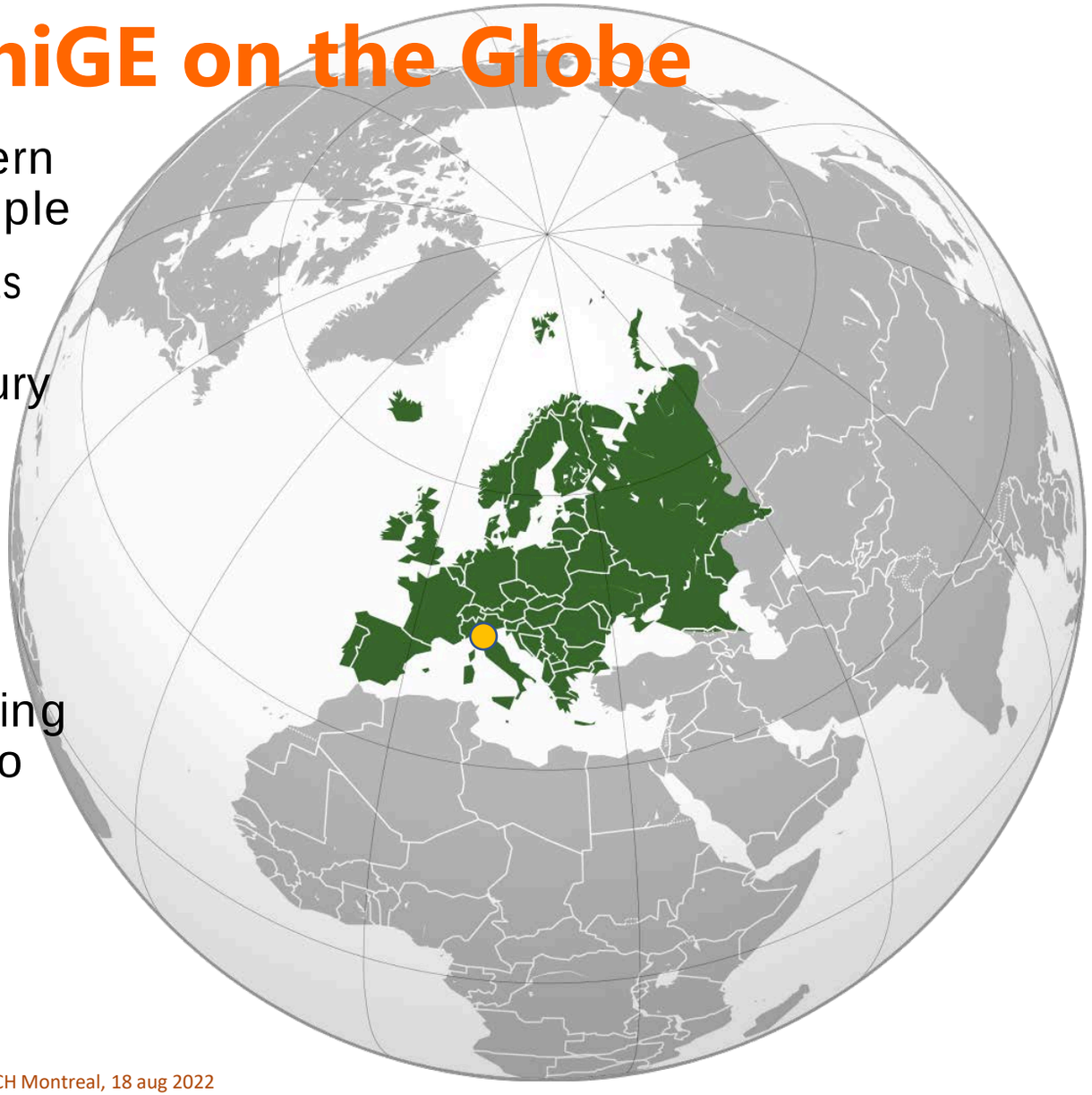
Genova and UniGE on the Globe

Genova is a city in northern Italy, with some 600k people

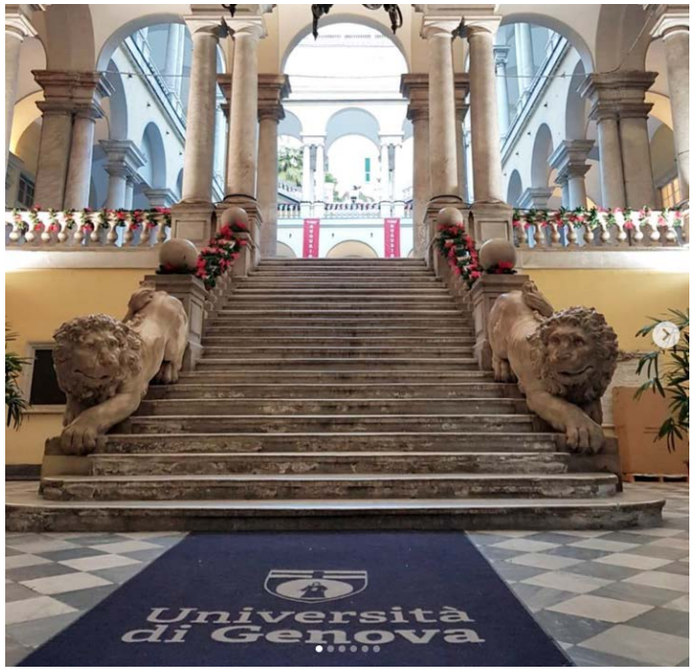
The Roman Oppidum was established in Genova ("Janua") in the 3rd century b.c.

The Republic of Genova from the 12th to the16th century a.d. played a leading role in European commerce and in financing the Spanish expeditions to the Americas

Currently, Genova is the busiest port in the Mediterranean Sea



UniGE presentation Video



UniGE Facts

Established in 1481 as School of Theology

School of Medicine established in the 16th century

Royal School of **Naval Engineering established in 1870**

1260 faculty (37% of them are female)

Four campuses along the Ligurian coast: Genova, La Spezia, Savona and Imperia

Five Schools (natural sciences, medical sciences, engineering and architecture, social sciences, humanities) organized as 22 Departments

132 BSc and MSc courses (of which **18 are international**)

28 PhD courses and 80 postgraduate courses (professional masters and specialization schools)

9 libraries

UniGE Facts

More than **33.000 students enrolled** in BSc (3yrs) and MSc (2yrs) courses

Nearly 3.200 of them (~10%) are international students

More than **1.350 student exchanges each year** (850 outgoing and 500 incoming)

200+ ERASMUS+ agreements

160+ academic cooperation agreements in more than 60 countries

20+ double degree courses

UniGE Facts

Uni**Ge** is present in all the major international rankings (QS, ARWU, THE, CWUR, US-News, Scimago).

The average Uni**Ge** position is around 360, i.e., in **world top 1.5%** universities.

Uni**Ge** is **ranked fifth** among big Italian universities (20-40.000 students) in terms of internationalization (Censis ranking).

Uni**Ge**'s MSc Engineering and ICT are ranked:

first, among all the Italian universities (Censis, global score).

second, among all the Italian universities, in terms of international outlook.

International MSc courses at UniGE (in English)

Architecture and Design (1):
Architectural composition
Engineering (10):
Computer engineering
Energy engineering
Engineering for building retrofitting
Engineering for natural risk management
Engineering technology for strategy and security
Environmental engineering
Internet and multimedia engineering
Robotics engineering
Safety engineering for transport, logistics and production
Yacht design
Medical Sciences (1):
Medical-pharmaceutical biotechnology
Mathematical, Physical, Natural Sciences (1):
Computer science
Political Sciences (1):
International Relations

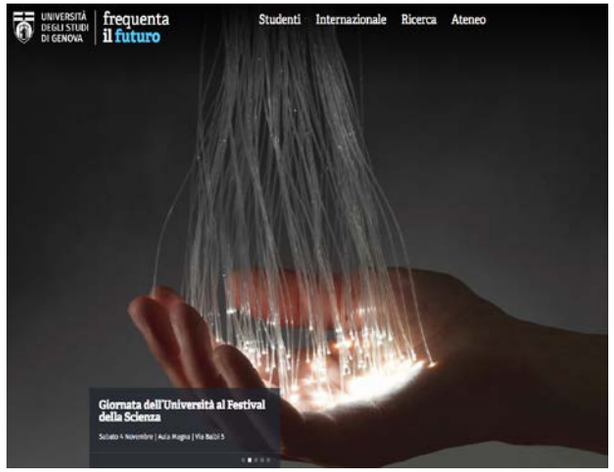
The European Alliance Ulysseus

Uni**Ge** is a member of the Ulysseus Alliance, one of the European Consortiums aimed at awarding European BSc and MSc Titles.

Currently, Ulysseus includes: Univ. Sevilla, Univ. Cote d'Azur Nice, UniGE, MCI Innsbruck, Tech. Univ. Kosice (Slovakia) and Haaga Helia Univ. Helsinki

Ulysseus
EUROPEAN UNIVERSITY

UniGE: Research and Tech Transfer



28 PhD courses and more than 100 post-graduate courses, enrolling more than 4.000 students.

Approximately 40 M€ of research-related income in 2020 (50% from industrial contracts).

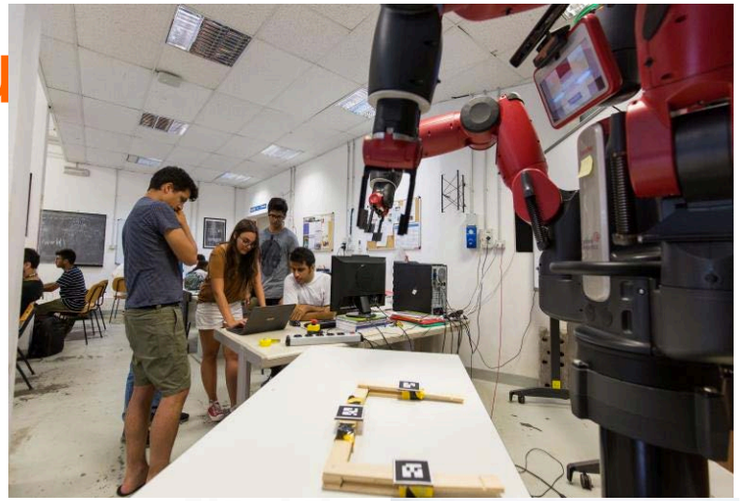
70 EC-funded H2020 active projects (5 of them coordinated by UniGe, 1 ERC starting, 2 ERC consolidator, 1 ERC advanced).

Second, among national Universities, for the number of active spinoff companies (about 50).

100+ patents deposited from 2001 (50% in Engineering).

UniGE Polytechnic School of Architectu and Engineering

Established in 1870 as the Royal Naval School.
Three campuses along the Ligurian coast: Genova, La Spezia, and Savona.
Five Departments, enrolling around 8200 BSc and MSc students.
42 BSc and MSc courses (of which 13 are international).
8 PhD courses enrolling 198 students.



UniGE Savona Campus and its Electric and Thermal Micro Grid

Savona is a small town 50km west of Genova, Italy, and some 170km from Nice, France.

Engineering is present with 1 BSc and 1 MSc course in Energy Engineering (MSc in English).

The Campus is also an Electric Micro Grid (100kWp by PV, 130kWe by cogenerative gas turbines, 100 kWhe storage) and thermal microgrid, including 230kWt from turbines.

SEB building at Campus is a Geothermal Heat Pump building (40kWt by HP), NZEB powered by 23kW PV roof.

2: Energy saving and renewable energy production in the Building Sector: an international perspective

CO2 concentration in the atmosphere and temperatures of planet Earth

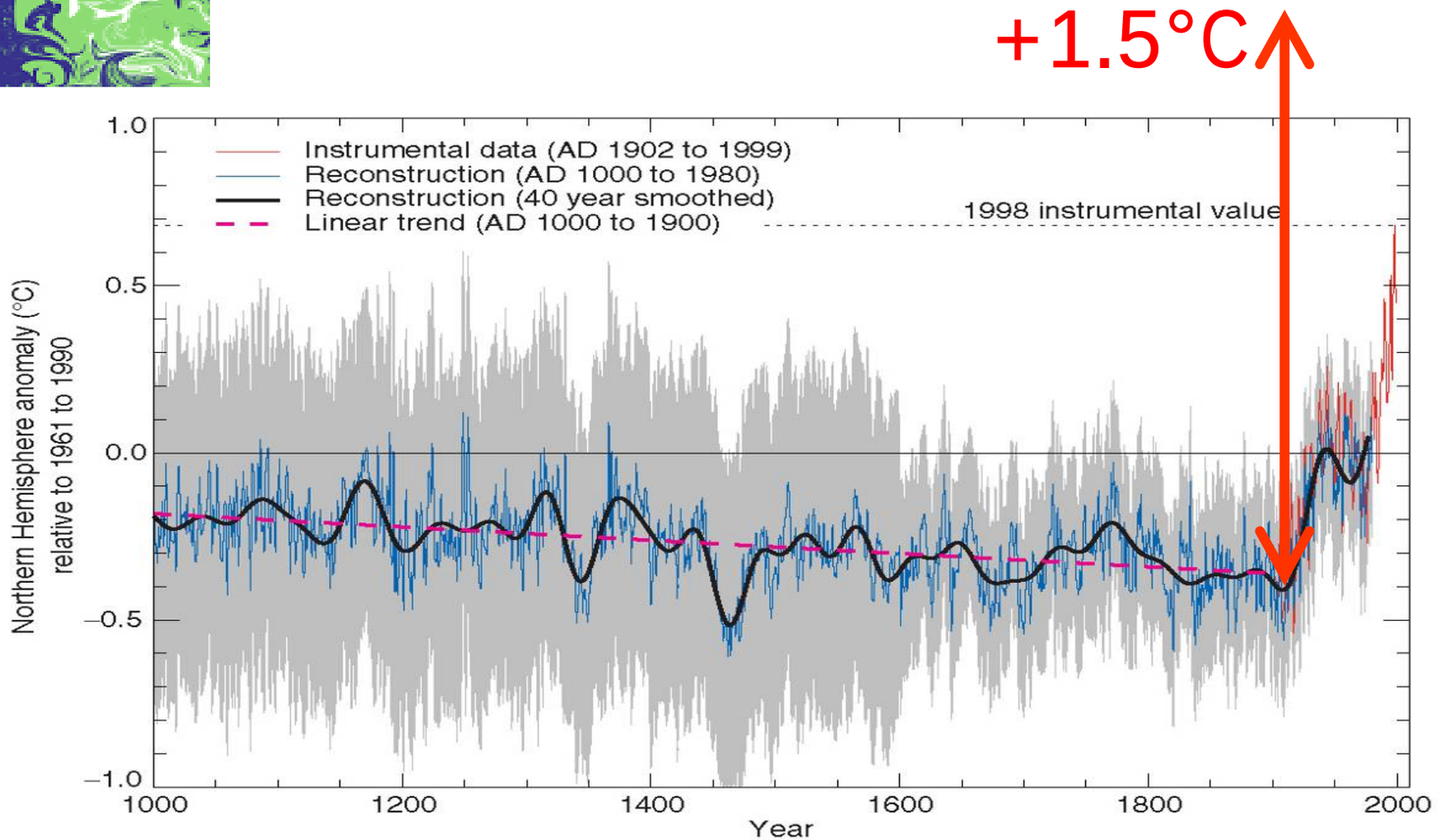
CO2 concentration in the atmosphere remained stable in the past 10000 years at 280ppm.

In the last 150 years, due to the anthropic carbon emissions, this concentration dizzily raised : 370ppm was the value in the year 2000, 414ppm in november 2021 (COP26 summit)

Targets (hopes?) at COP26, 2021

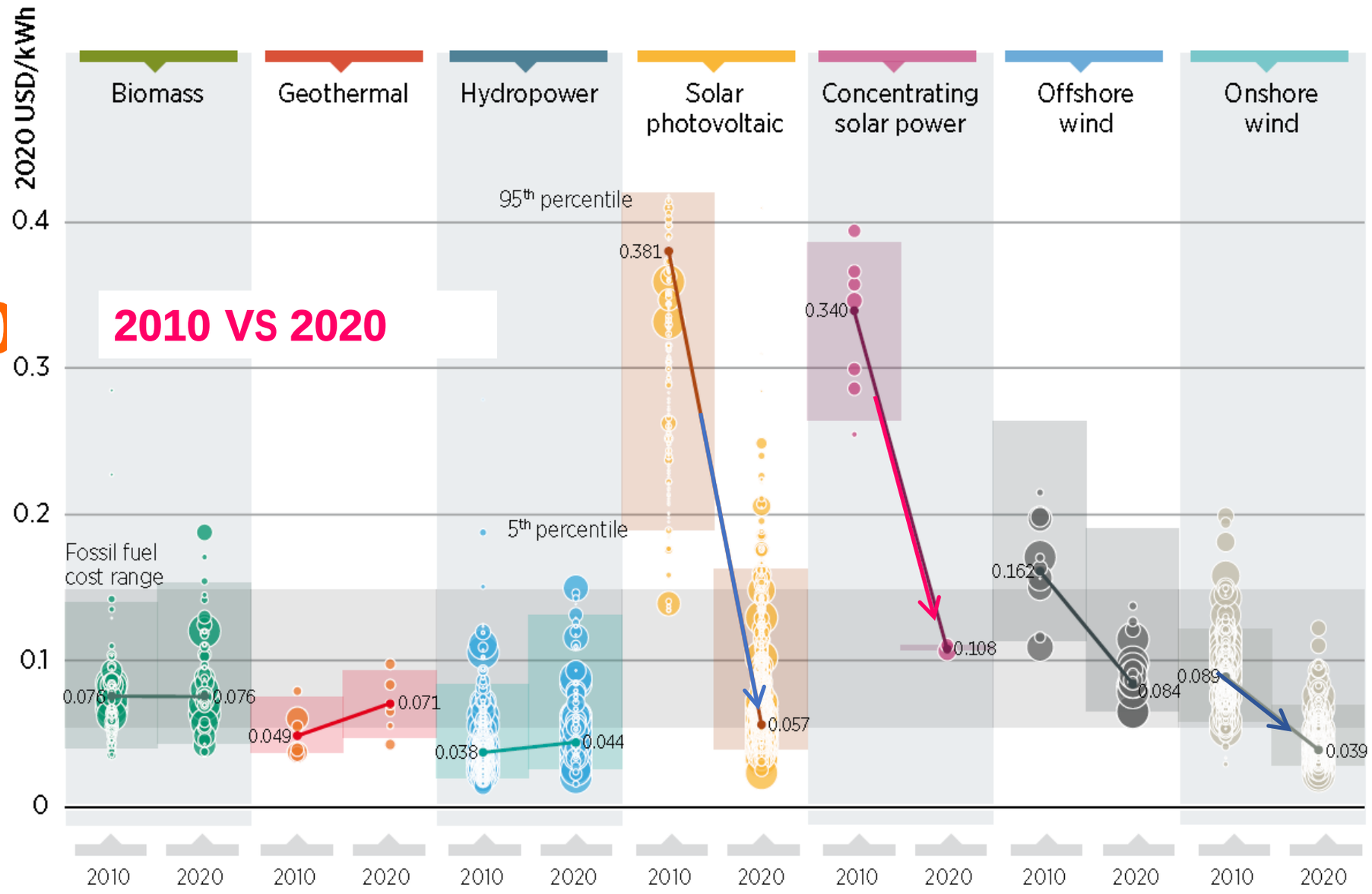
Planet temperatures are increasing at a rate never seen on Earth.

COP26 global warming mitigation targets (+1.5°C at the year 2100) require an epochal change in the Energy sector



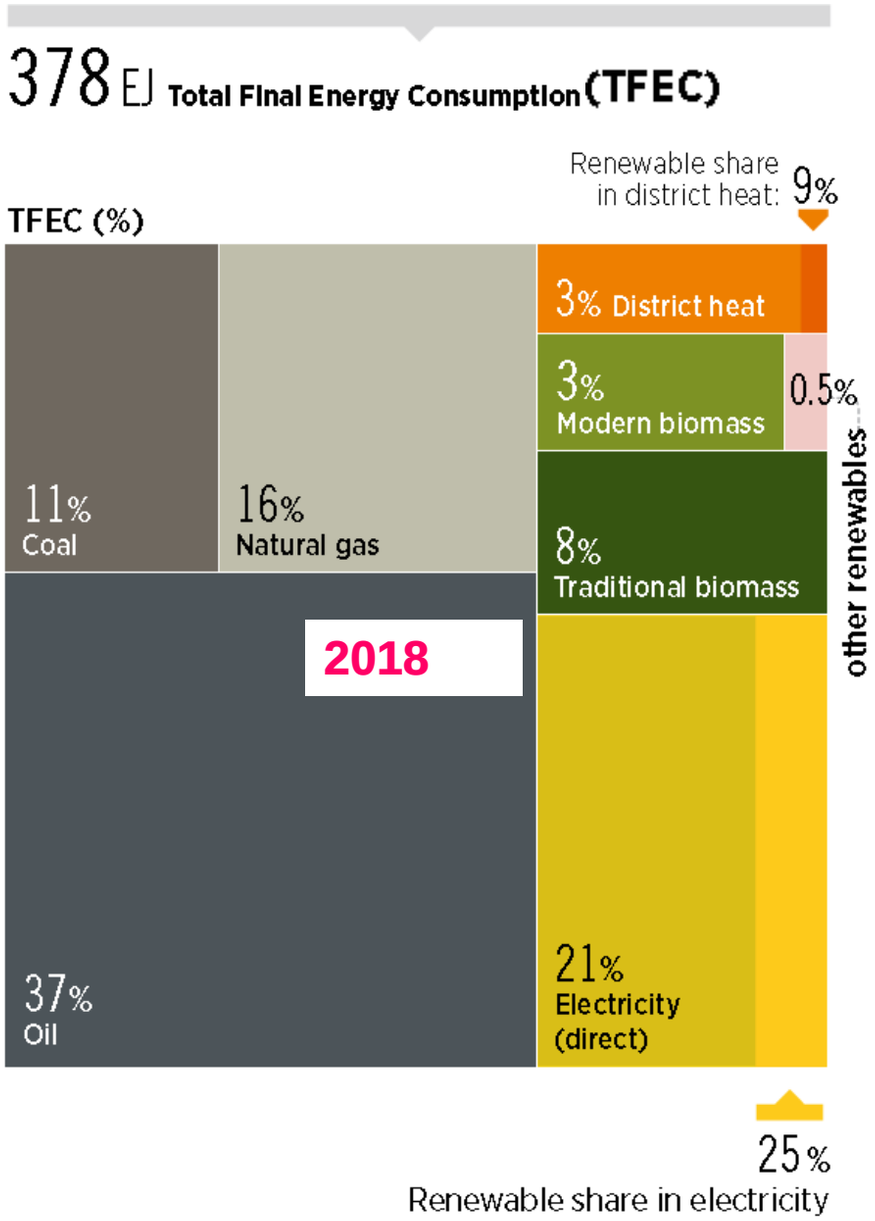
2.1: Renewable Energies and Energy savings for the "+1.5°C" global trajectory

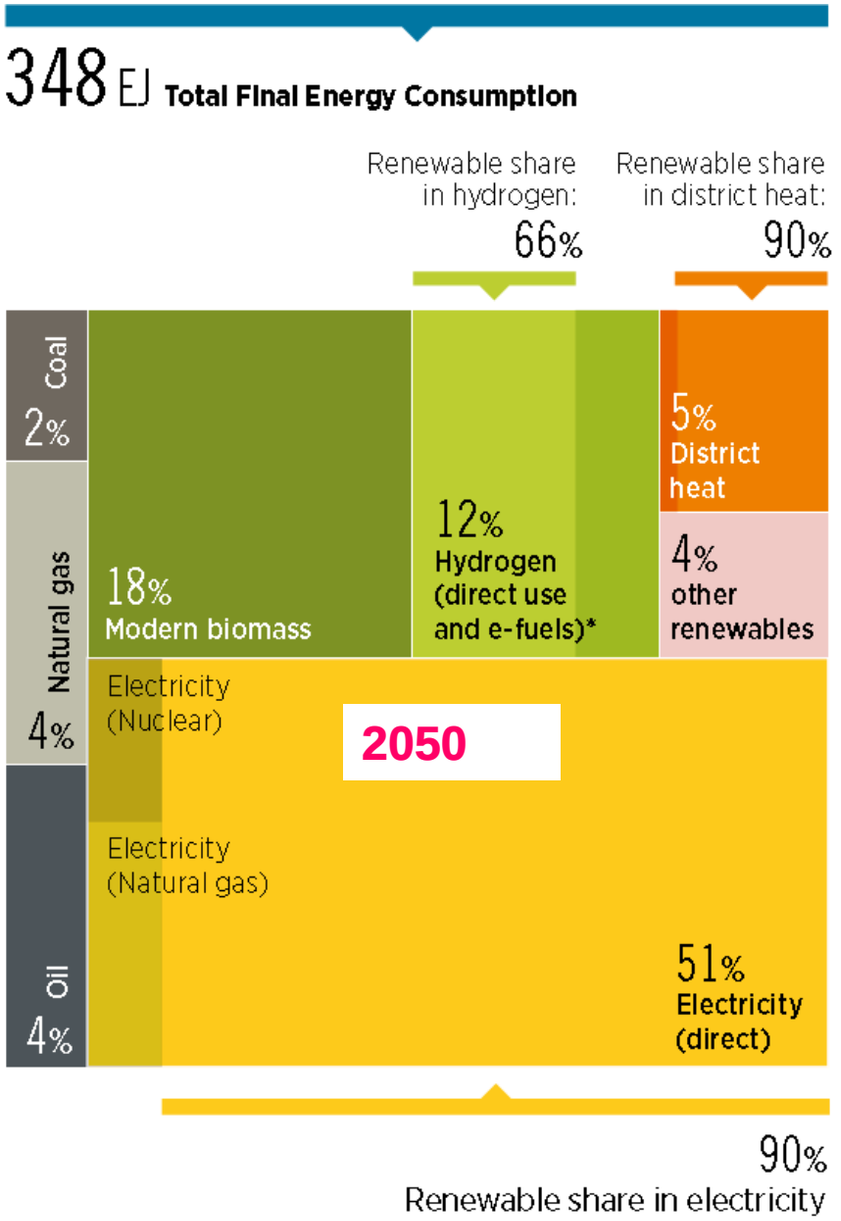
Levelized Cost Of electric Energy, Renewables, 10 years of records (US$/kWh)



IRENA
International Renewable Energy Agency

1.5°C Pathway, according to Irena (2021)

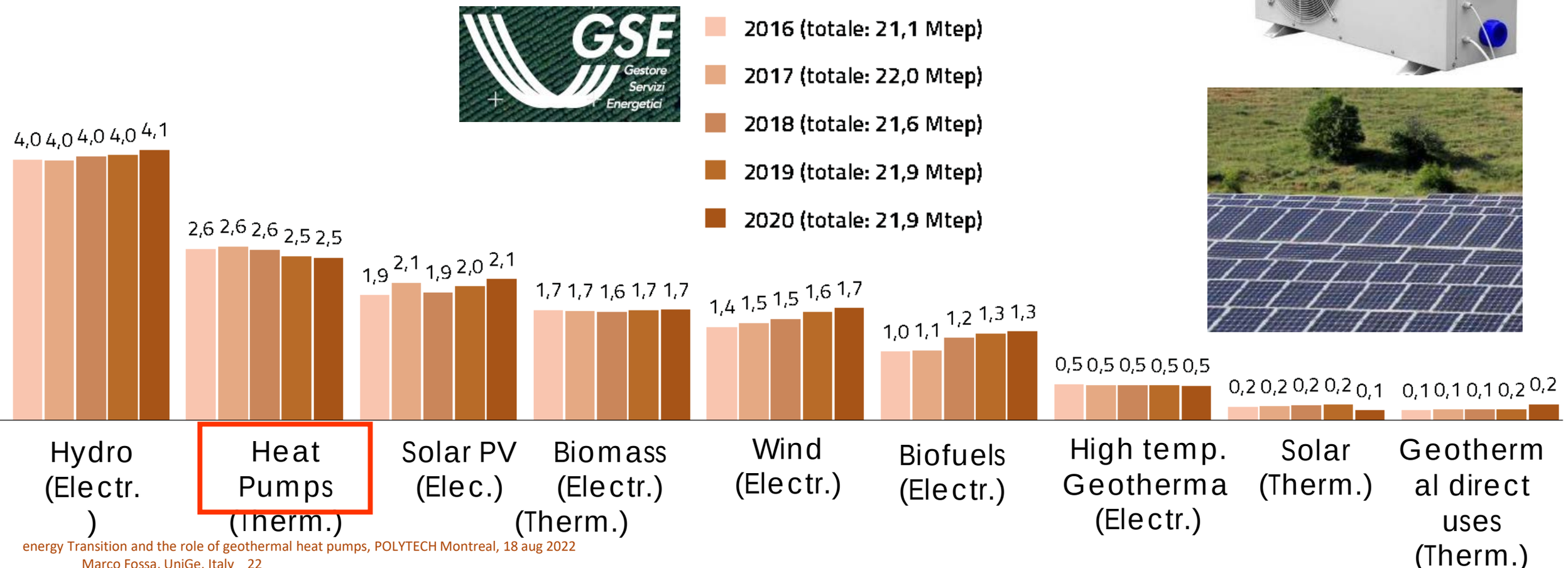




IRENA
International Renewable Energy Agency

The Italian Energy Plan for Climate based on EU directives (PV sector)

Renewable energy from Heat Pumps and other renewable sources (Italy, 2020, Mtep units)



Heat Pumps vs Gas Furnaces (Italy as an example)

$E_E=0.48*E_{chem}$

$(1-0.426)*E_E=E_{chem}*0.45$

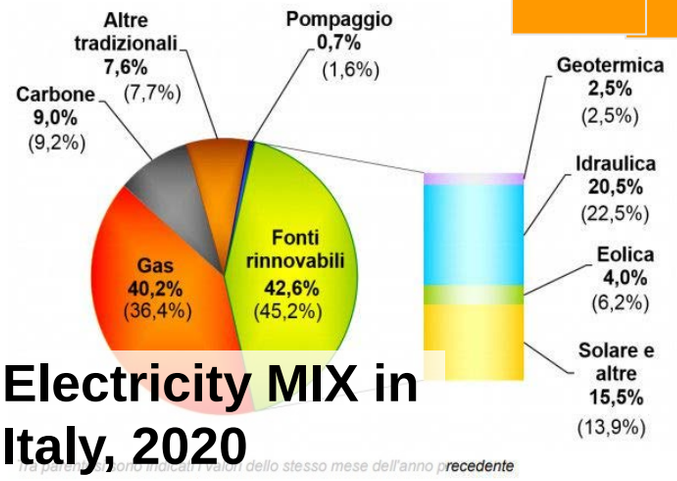
Q_{renew}

$Q_{build}=COP*E_E$

E_{chem}

E_{chem}

$Q_{build}=E_{chem}$



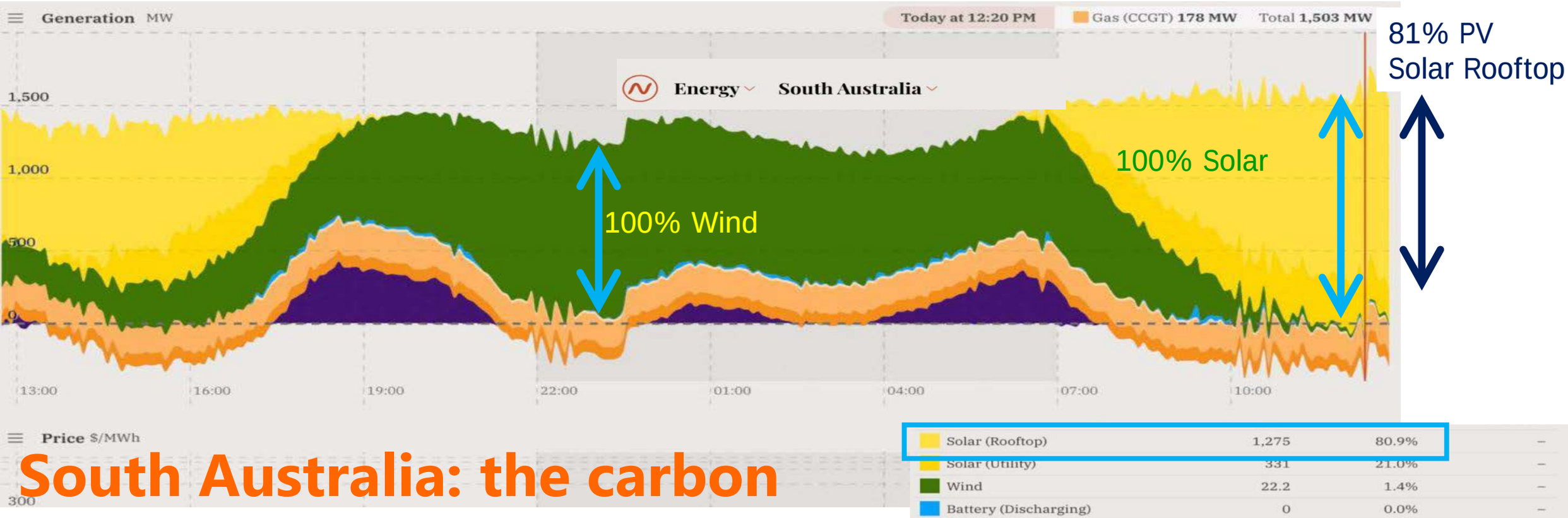
Electricity MIX in Italy, 2020

Min COP @ same Q_{build} and same E_{chem} is:

COPmin= (1-0.426)/0.48=**1.20**

(Typical COP values=**3 to 5** !)

2.2: Solar, wind, heat pumps and Energy savings: news from the world



South Australia: the carbon free future of the electricity sector is now (29 and 30 October 2021, 100% of 1500MW)

Solar (Rooftop)	1,275	80.9%	–
Solar (Utility)	331	21.0%	–
Wind	22.2	1.4%	–
Battery (Discharging)	0	0.0%	–
Gas (Reciprocating)	15.5	1.0%	–
Gas (OCGT)	0	0.0%	–
Gas (CCGT)	178	11.3%	–
Gas (Steam)	81	5.1%	–
Distillate	-0.2	-0.01%	–
Imports	0	0.0%	–
Loads	**-398**		
Exports	-326	-20.7%	–
Battery (Charging)	-72	-4.6%	–
Net	**1,503**		
Renewables	**1,628**	**103.4%**	

Energy saving and Heat Pumps to cut the Gas dependency in the EU

In Italy, Genova region, most buildings rely on NG for heating (some 20Nm3/year/m2). This consumption could be reduced to less than a third with proper insulation and heat pumps.

The EU Fit for 55% (june 2022) aims at cutting 55% of the 1990 CO_2 emissions

Press release | 18 May 2022 | Brussels

REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition*

HOME > ANALYSIS > BRIEFINGS

(march 2022)

How to cut the UK's dependency on Russian gas... permanently

More UK gas won't cut bills. Insulation and heat pumps can. National security is at stake.

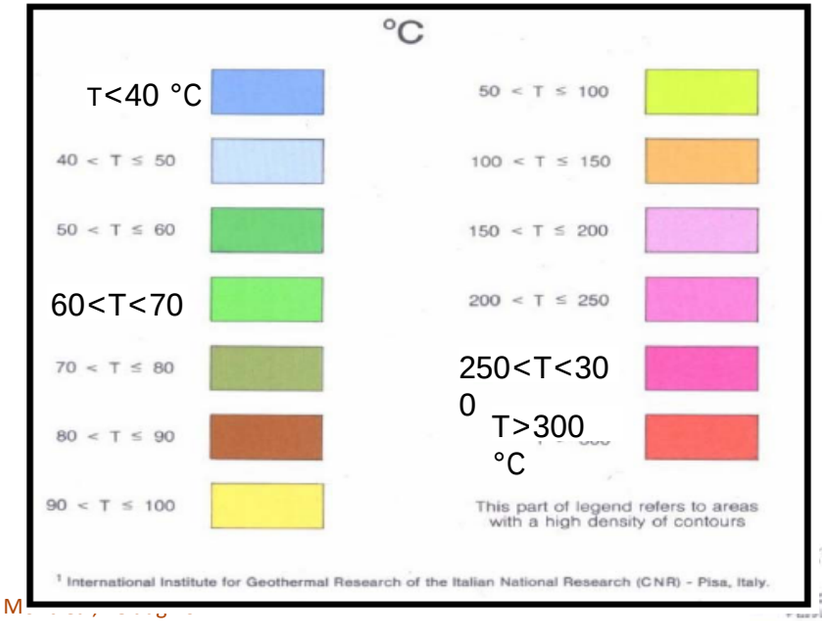
3: Heat Pumps: why and how to choose the Geothermal solution

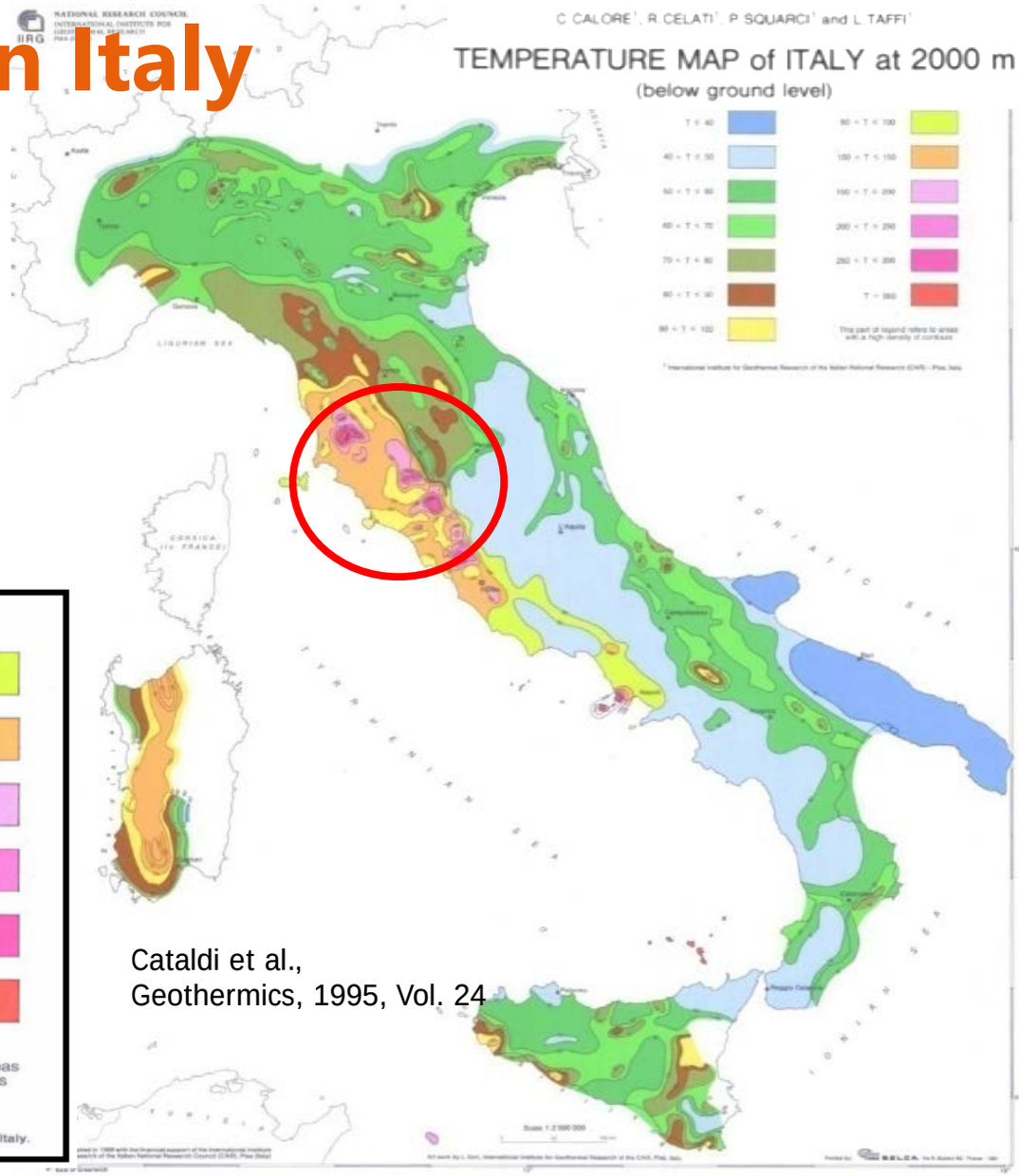
High temperature geo energy in Italy

High Enthalpy geothermal energy is exploited for electricity production since 1911 but most available reservoirs have been explored.

The Italian company Enel Green Power manages 35 power plants in 4 main areas in Tuscany.

The overall power is 810MW and 5.2TWh is yearly energy yield.





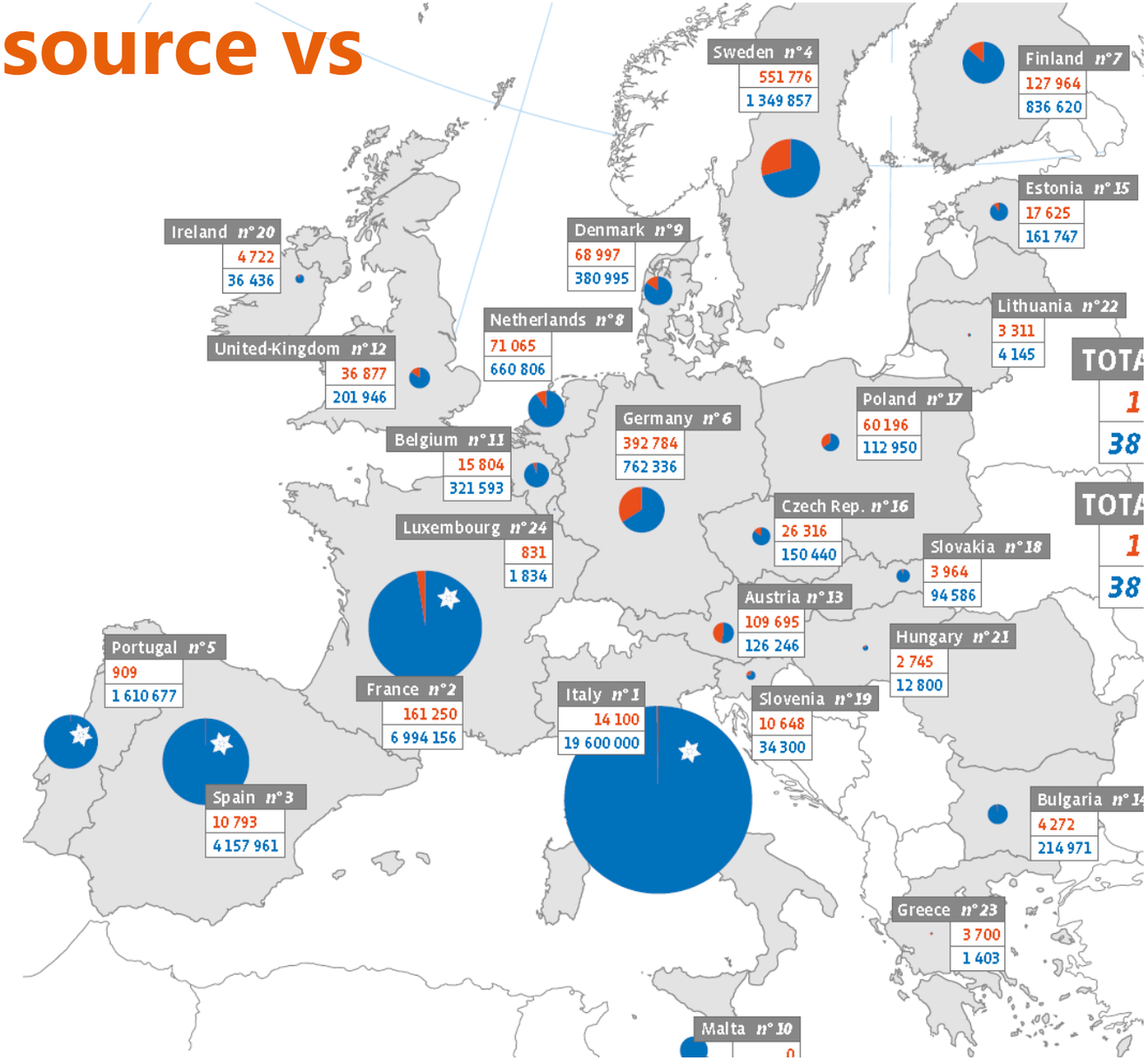
Cataldi et al., Geothermics, 1995, Vol. 24

Heat Pumps in Europe (Air source vs Geothermal)

In "warm" countries ASHPs dominate the market (2019 Eurobserv'er data)

Total number of heat pumps in operation in 2018 and 2019

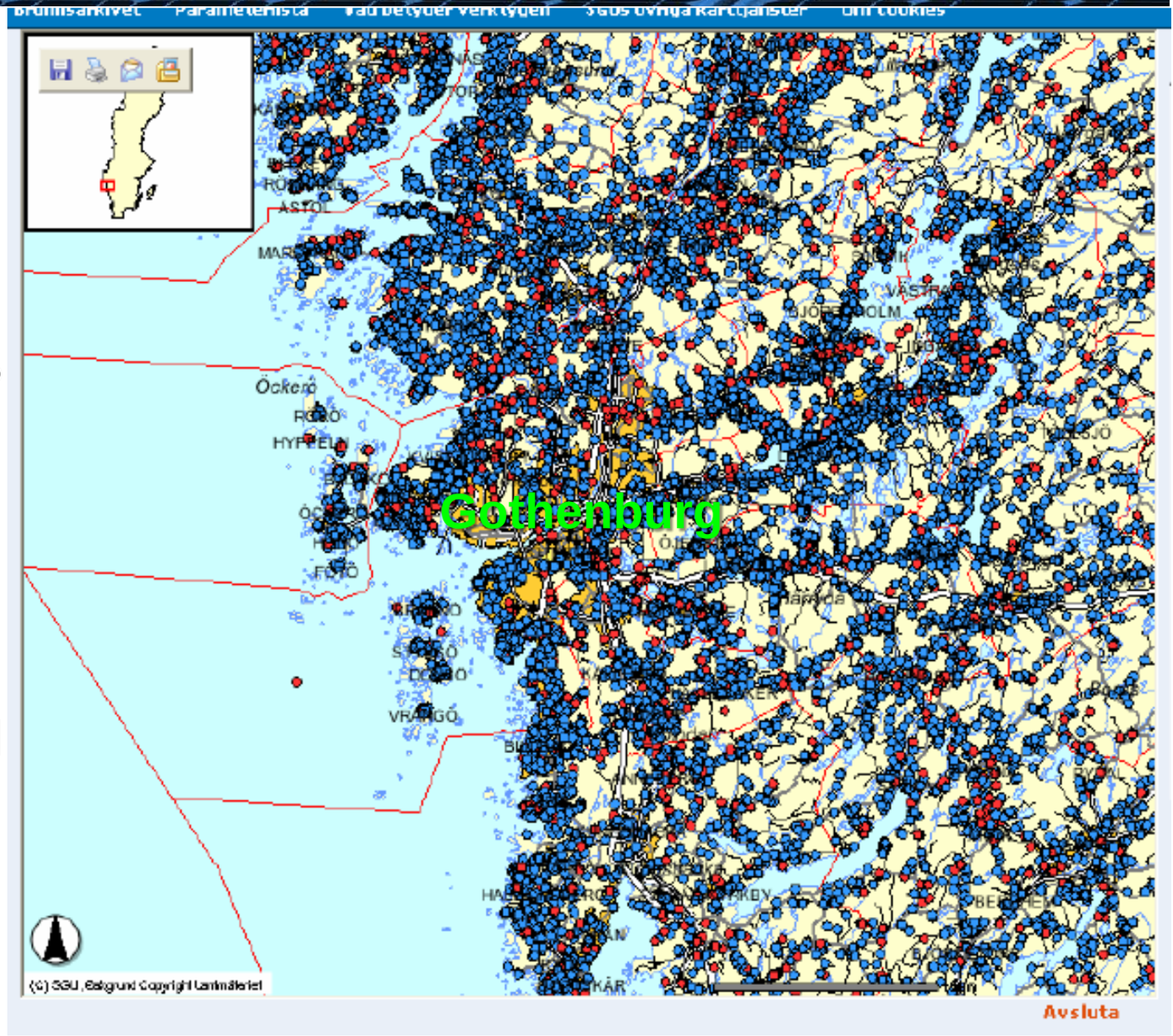
	2019	
	Aerothermal heat pumps	Ground source heat pump
Italy	19 600 000	14 100
France	6 994 156	161 250
Spain	4 157 961	10 793
Sweden	1 349 857	551 776
Portugal	1 610 677	909
Germany	762 336	392 784
Finland	836 620	127 964
Netherlands	660 806	71 065
Denmark	380 995	68 997
Malta	425 237	0
Belgium	321 593	15 804
United Kingdom	201 946	36 877
Austria	126 246	109 695



GeoHP in Sweden, Goteborg area

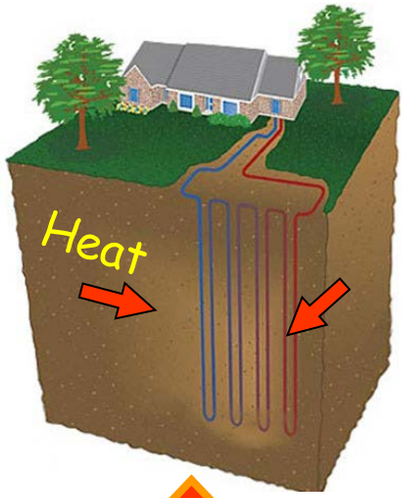
In Sweden, the diffusion of GSHP is really important.
In this image blue points represent GCHP (closed loop) units while red ones are open loop geo HPs (groundwater units).

Drilling depth is higher (200m typical) than in other EU countries thanks to geological conditions (hard granite) and long drilling experience with HP.



Air Source HP vs GeoHPs

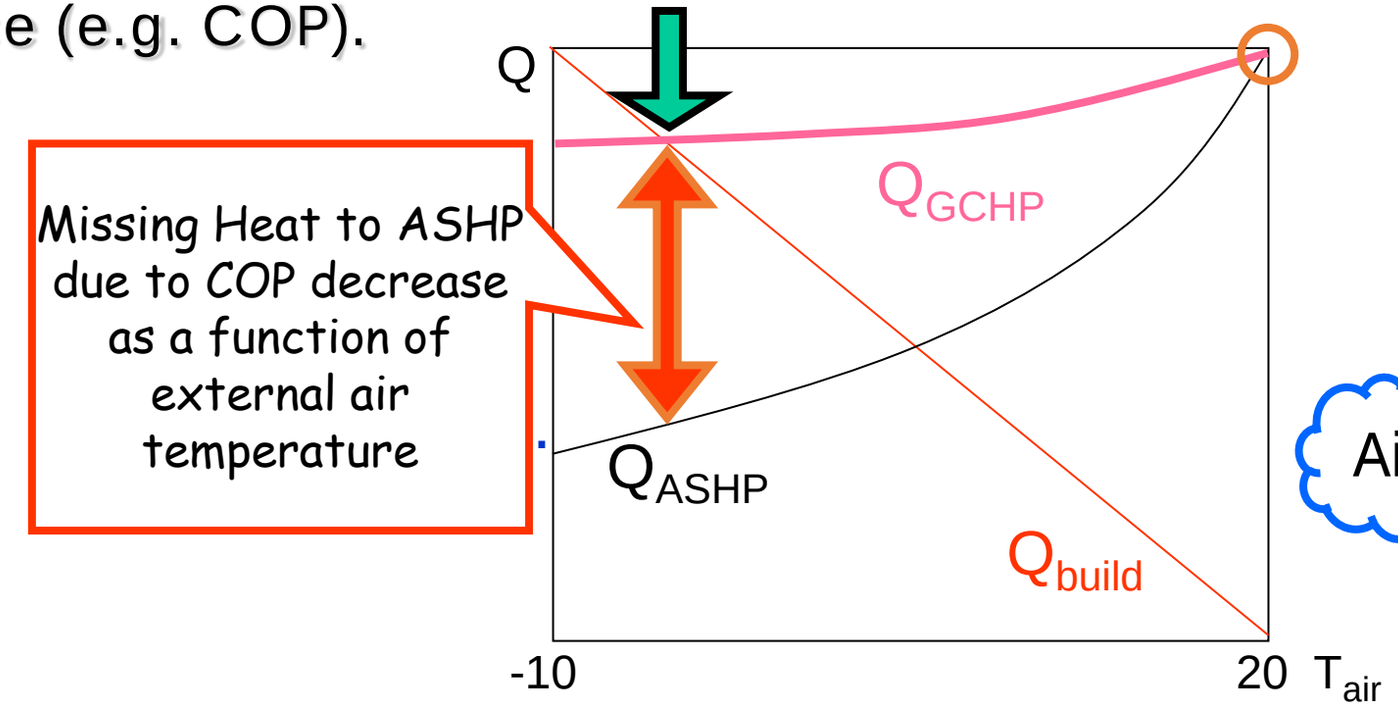
Energy Demand from buildings inevitably increases with decreasing external temperatures. In this condition, the efficiency of the air source heat pump (ASHP) decreases as well for Second Law reasons. On the other hand the favorable ground temperatures help the GCHP to be less influenced by building energy demand in terms of energy performance (e.g. COP).



Quebec City

Ave Ground Temperature (80m depth) = 7°C

Air Temperature Ave Dec to Feb = -9°C

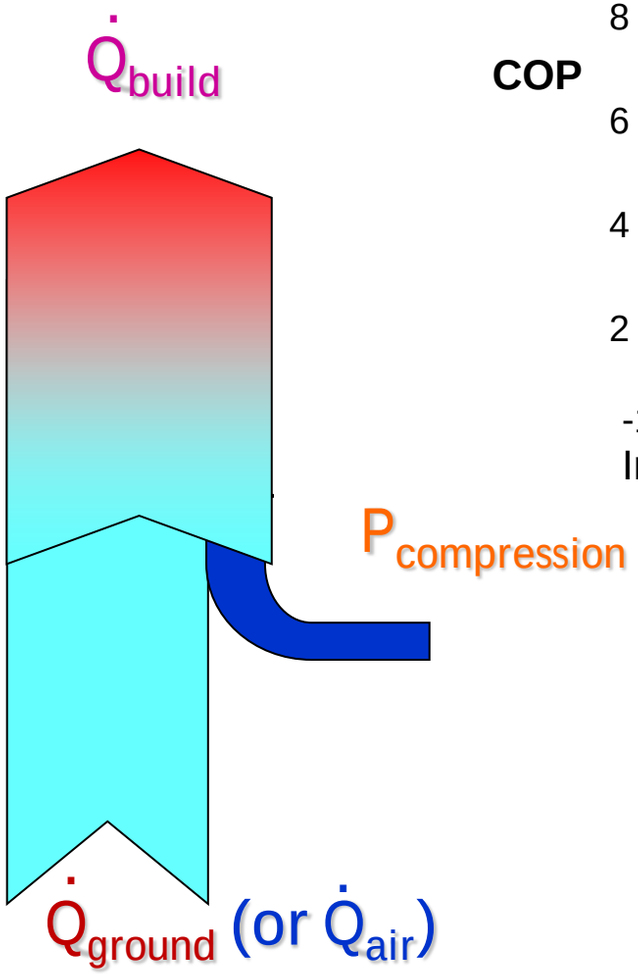


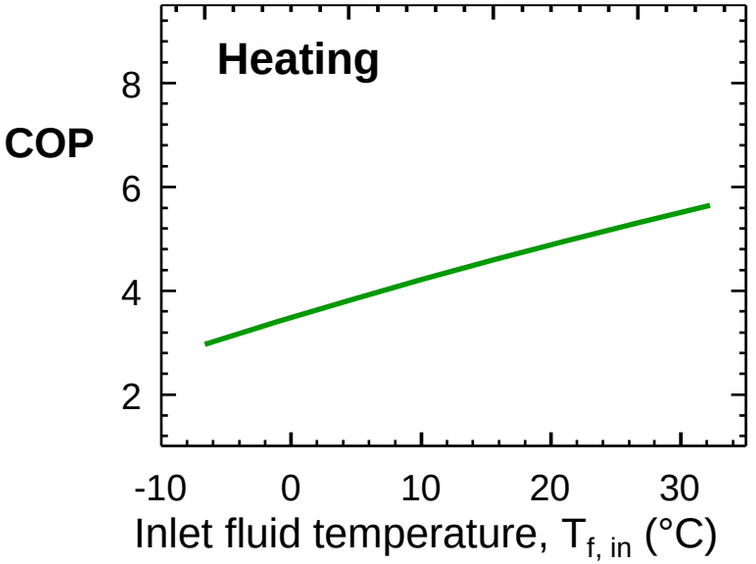
The Good Thermodynamics of Heat Pumps

Depending on the COP (Coefficient of Performance, heat pump mode) the heat supplied to the building Q_{build} [W] is in majority covered by the heat coming from the low temperature source, say the quantity Q_{ground} (or Q_{air} for ASHP).

$$\dot{Q}_{ground} = \dot{Q}_{build}(COP-1)/(COP)$$

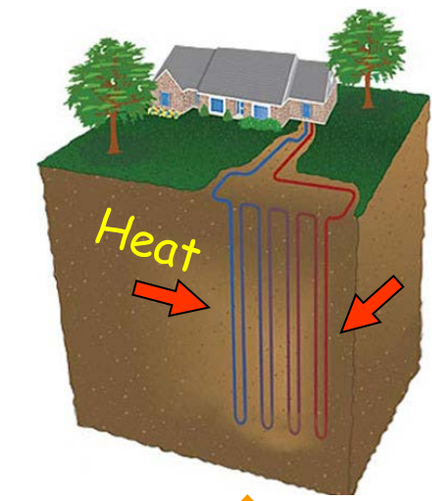
The Q_{ground} fraction is the **Renewable Energy for the building**, equal to 75% for COP=4





Air Source HP vs GeoHPs: thermal resistances

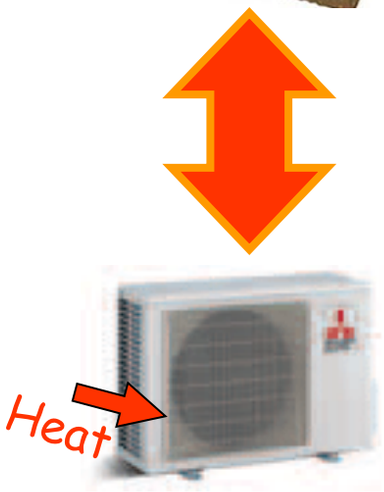
Just considering Thermodynamics Second Law issues (say no costs, no frost problems, etc) a GCHP is "COP better" than its ASHP cousin if its "Overall Thermal Resistance" (Undisturbed Ground to Carrier Fluid at Evaporator) is "small enough" for having evaporation temperatures higher than in the ASHP case.



Quebec City

Ground Undisturbed Temperature (80m depth) **= 7°C**

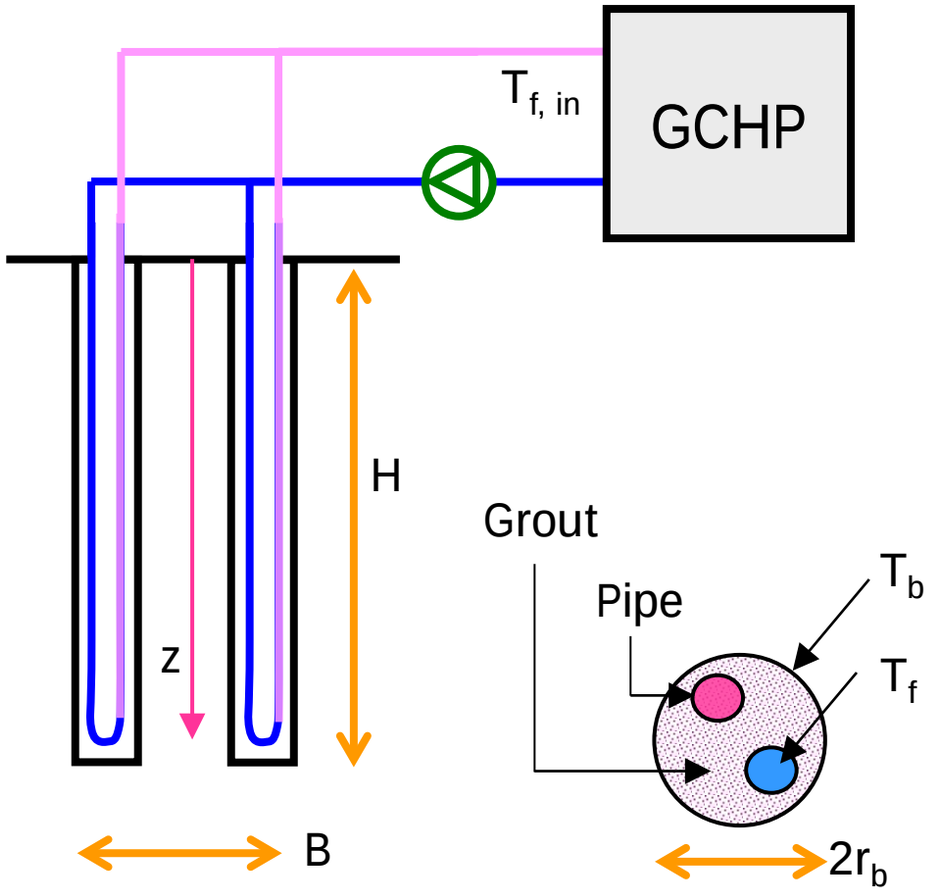
Air Temperature, Ave Dec to Feb = **-9°C**



Hence how to "maximize" the initial 16°C advantage (Quebec case) ?

The response is the Correct design of the Borehole (BHE) field also in terms of reliable estimations of the Ground Thermal Properties.

BHE Field design: the two thermal resistance approach

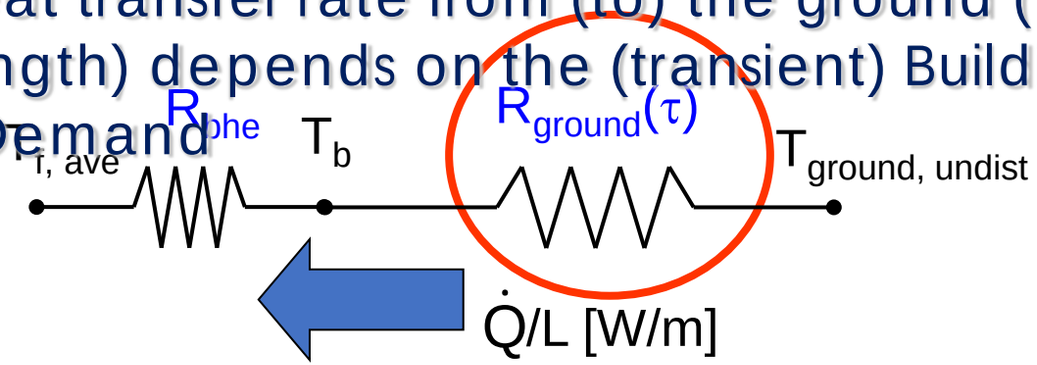


BHE models very often refer to heat conduction only.

The thermal response of ground is described in terms of a "transient" thermal resistance, Rground.

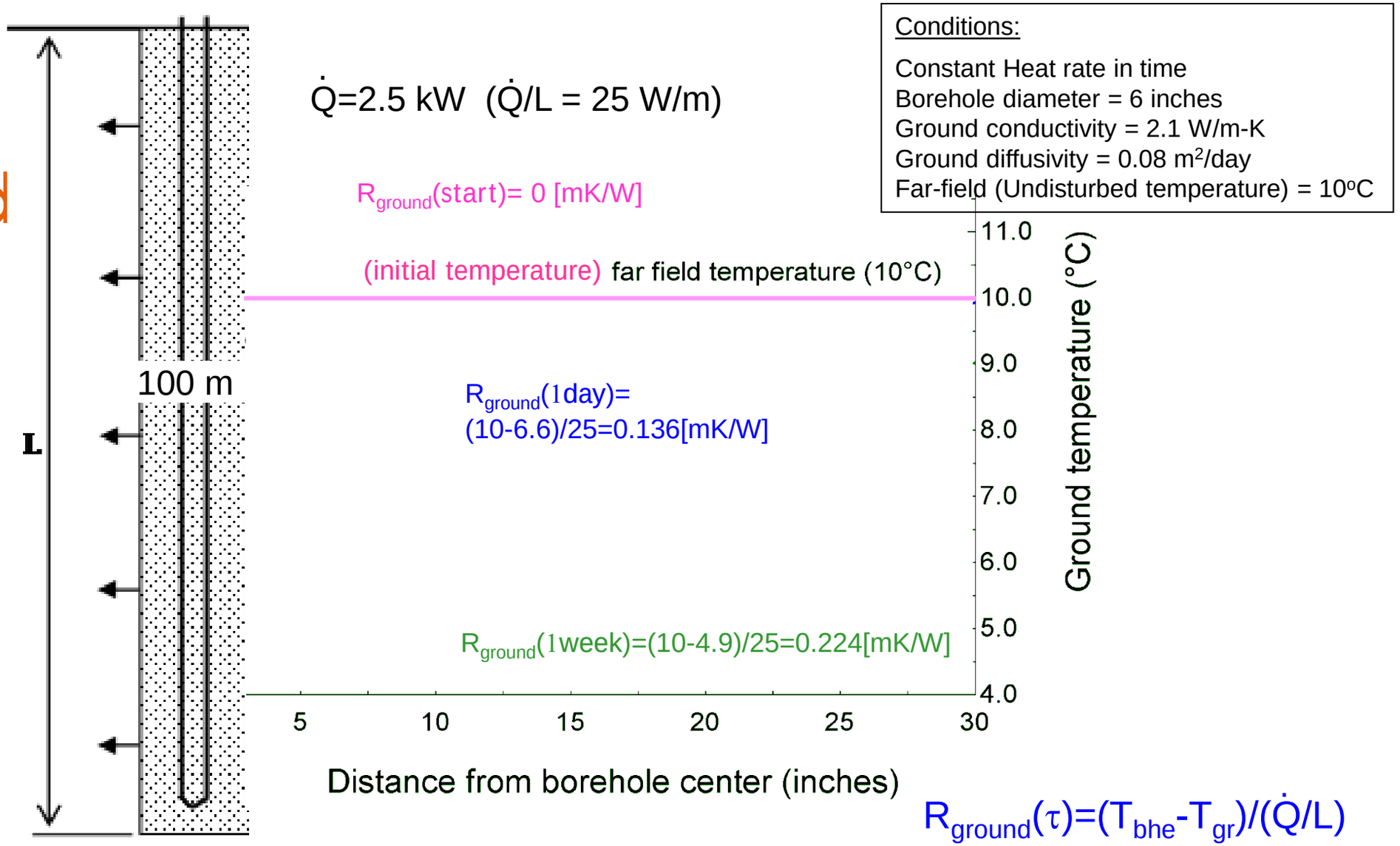
The inner BHE contribution is modeled as the resistance Rbhe.

The heat transfer rate from (to) the ground (per unit length) depends on the (transient) Building Heat Demand



$R_{ground}(\tau)=(T_b-T_{gr})/(\dot{Q}/L)$ [mK/W]

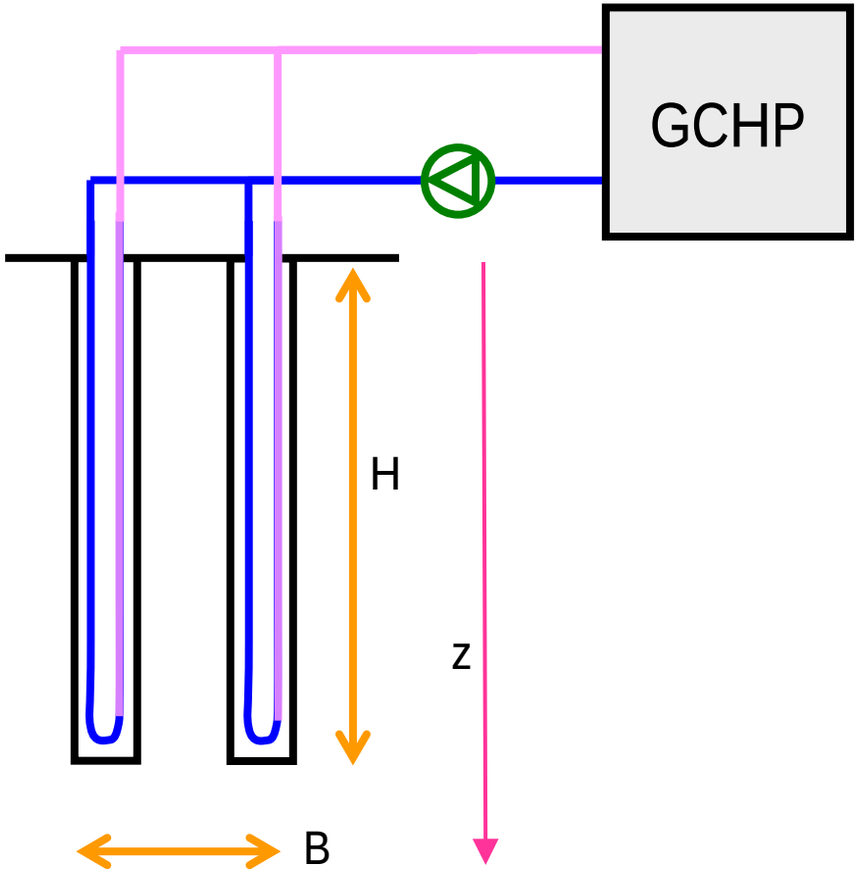
Ground Thermal response and ground resistance in time



$R_{ground}(\tau)=(T_{bhe}-T_{gr})/(\dot{Q}/L)$

Picture: Courtesy of Prof. Michel Bernier, EP Montreal (2008)

Two resistance model for BHE field design: goals

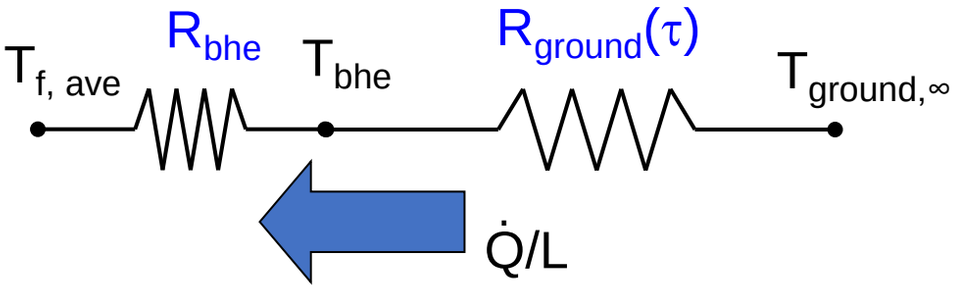


DESIGN PROBLEM AND GOALS

To find the suitable BHE overall length in order to have (in assigned working conditions and given Time) a proper return fluid temperature ($T_{f,\,in}$) for:

1) Obtaining high average seasonal COPs (SPF Seasonal Perf. factor)

2) Minimizing the Pay Back period of the Drilling/Installing Investment



BHE field design: Input information

Tf is related to the BHE wall temperature along the depth

Tf,ave=(Tf,in + Tf,out)/2 (at the HP ports)

At a given heat transfer rate Q, Tf,ave depends on Tground,∞ (Undisturbed temperature) and on BHE and Ground thermal resistances.

HENCE:

It's necessary to evaluate both Rbhe and Rground

Inputs of the problem are the heat transfer rate Q [W] extracted/injected into the ground as a function of time (hourly, daily or monthly values), the Ground Thermal Properties, the expected COP (at a conventional time, e.g. after 10yrs of operation)

Q=Qground = Qbuild(COPw -1)/(COPw) Winter Mode

Q=Qground = Qbuild(COPs+1)/(COPs) Summer Mode

Ground Thermal Resistance and Temperature Response Factors (TRF)

Analytically and numerically, the Fourier Heat Conduction Equation can be solved for estimating the ground response to a constant heat transfer rate applied along the source/sink representing the BHE.

$$T(r_b,\tau)-T_{gr,\infty}=\frac{\dot{Q}'_{ave}}{Ck_{gr}}\Gamma(Fo)$$

C=1 (ICS)

C=4π (ILS)

Γ=G (ICS)

Γ=E_1 (ILS)

Those solutions, the TRF family (here denoted with the symbol Γ), includes the Infinite Line Source (ILS or E1) solution, the Infinite Cylindrical Sorce (ICS or G function), the g-function (multi Finite Line Sources, MFLS) family (See M.Cimmino and M.Bernier works).

Temporal superposition (also in the frequency domain, see P.Pasquier works) is then used for extending the TRF solutions at variable heat transfer rates (even ''aggregated'', AGG), hence accounting for variable heat transfer to/from the building.

$$R_{ground}(\tau)=\frac{\Gamma(Fo)}{Ck_{gr}}$$

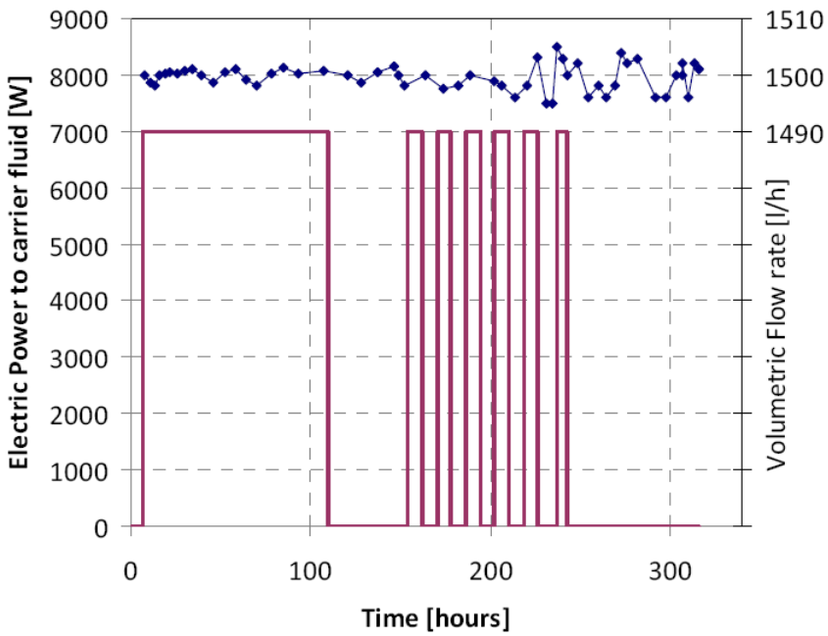
The ILS solution for the Ground Thermal Property estimation

The ground thermal conductivity kground is the most important thermal property to be estimated. It varies from rock to rock in a wide range of values (1 to 4 W/mK typically) and plays ''a double role'' inside the Rground term (it is also inside the Fourier number..).

The ILS solution (and also G), for Fo<1000, is able to accurately describe the ground response to constant heat transfer rates and it is perfect for Thermal Response Test (TRT) experiments (See M.Palne, 1982).

$$R_{ground}(\tau) = \frac{\Gamma(Fo)}{Ck_{gr}}$$

$$Fo = Fo_{rb} = \alpha\tau / r_b^2$$



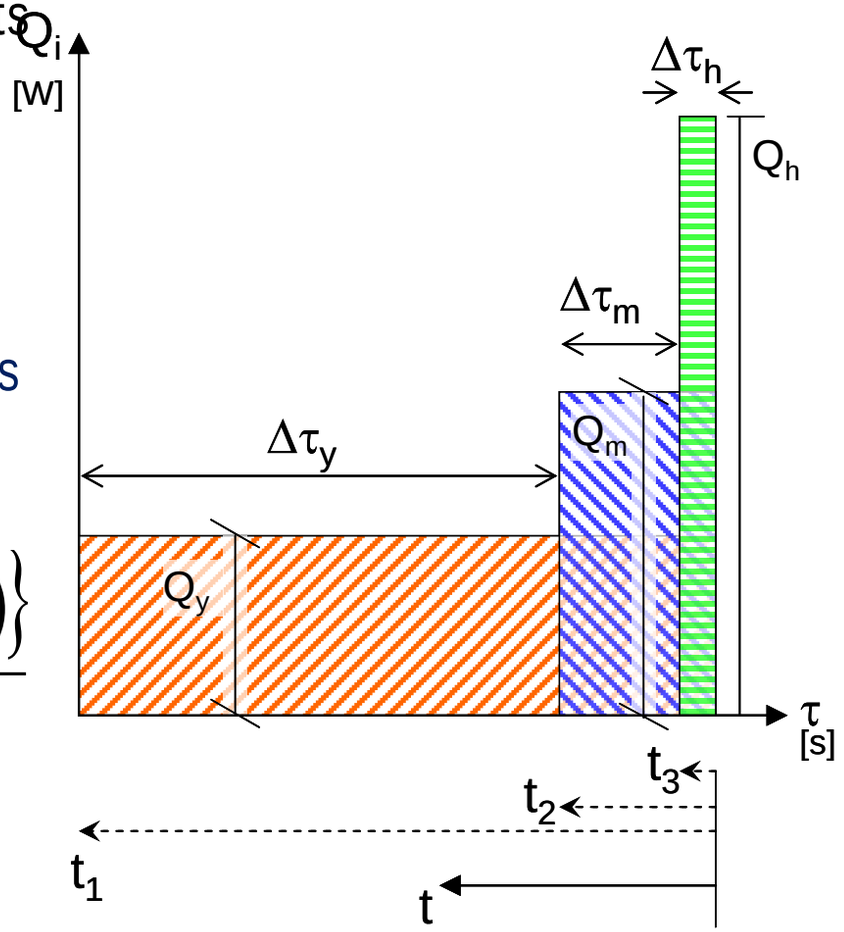
The Unige Pulsating TRT apparatus, See Fossa and Pasquier, IGHSPA 2018)

Temperature Response Factors and Temporal superposition (TS): the Ashrae Method

The Ashrae Method is the simplest TRF+TS+AGG method. Its temporal window (at which BHE field performance are expected) is 10yrs+1month+6hrs.

The Method provides the overall BHE field length L and requires the calculation of 3 ground thermal resistances based on the G (ICS) solution. By ''the G nature'' the 10yrs ground resistance requires a correction, that can be written in terms of a Temperature Penalty Tp.

$$L = \frac{\left\{\dot{Q}_y R_y + \dot{Q}_m R_m + \dot{Q}_h \left(R_h + R_{bhe}\right)\right\}}{T_{gr,\infty} - T_{f,ave}(\tau_N) - T_p}$$



M.Fossa, The Temperature Penalty Approach to The Design Of Borehole Heat Exchangers For Heat Pump Applications, Energy and Buildings, (2011)

Ashrae formula is simple, but Temperature Penalty estimation is complex

It can be demonstrated that the Temperature Penalty depends on many factors, including the 10yrs heat transfer rate Qy, the ground thermal conductivity kgr, the BHE overall length L, the BHE interdistance B, the BHE mutual disposition.

$$L = \frac{\left\{\dot{Q}_y R_y + \dot{Q}_m R_m + \dot{Q}_h \left(R_h + R_{bhe}\right)\right\}}{T_{gr,\infty} - T_{f,ave}(\tau_N) - T_p}$$

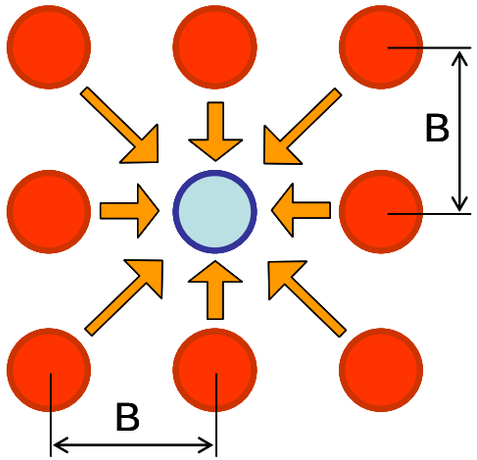
$$T_p(L) = \frac{\dot{Q}_y \Delta\Gamma_G(t_1)}{L k_{gr}}$$

(Please Refer to the paper below for further details, including the meaning of $\Delta\Gamma_G$)

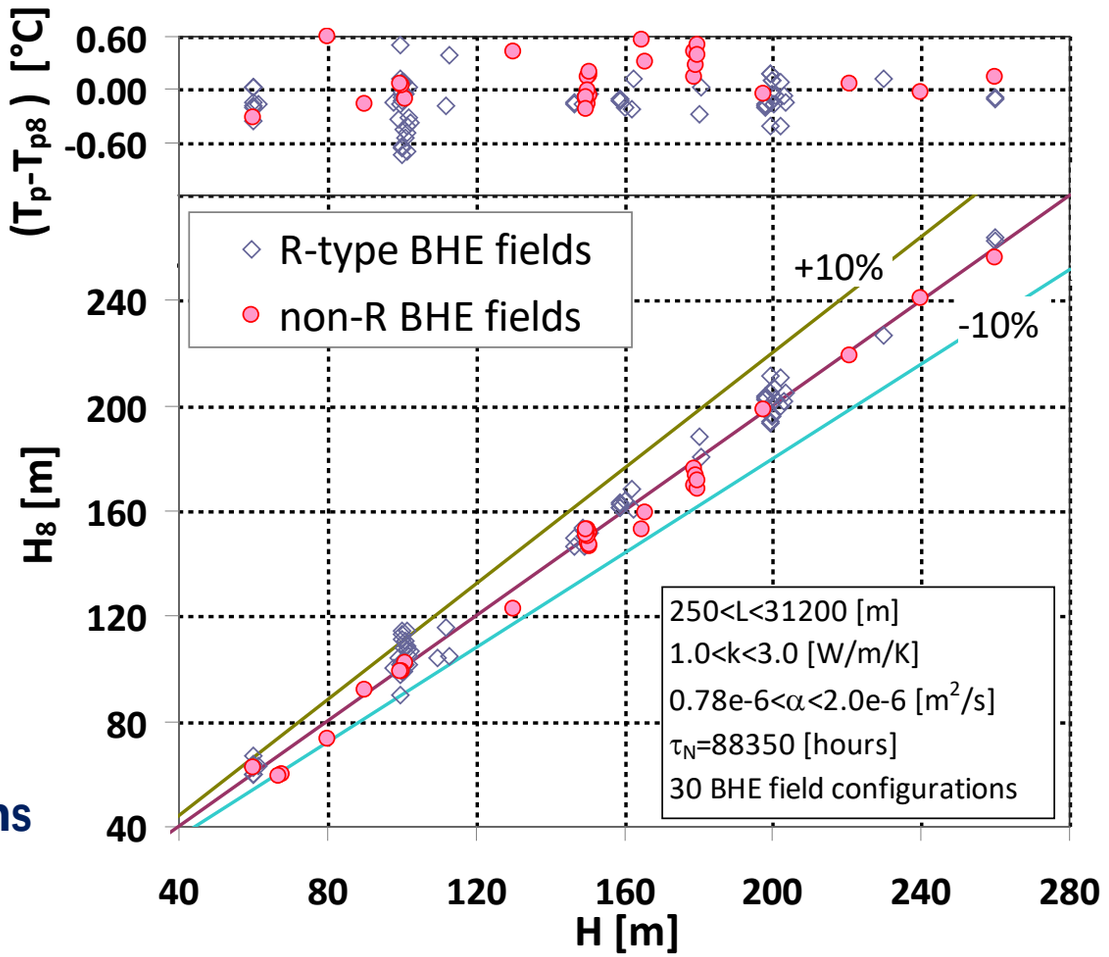
M.Fossa, The Temperature Penalty Approach to The Design Of Borehole Heat Exchangers For Heat Pump Applications, Energy and Buildings, (2011)

The Ashrae Method and its Tp8 version

The Unige research group has proposed a physically based model for estimating the Temperature Penalty and correctly design the BHE field. The Tp8 approach rivals the 12-month algorithms (e.g. EED) at the same monthly and peak loads at 10yrs. No g-functions needed !

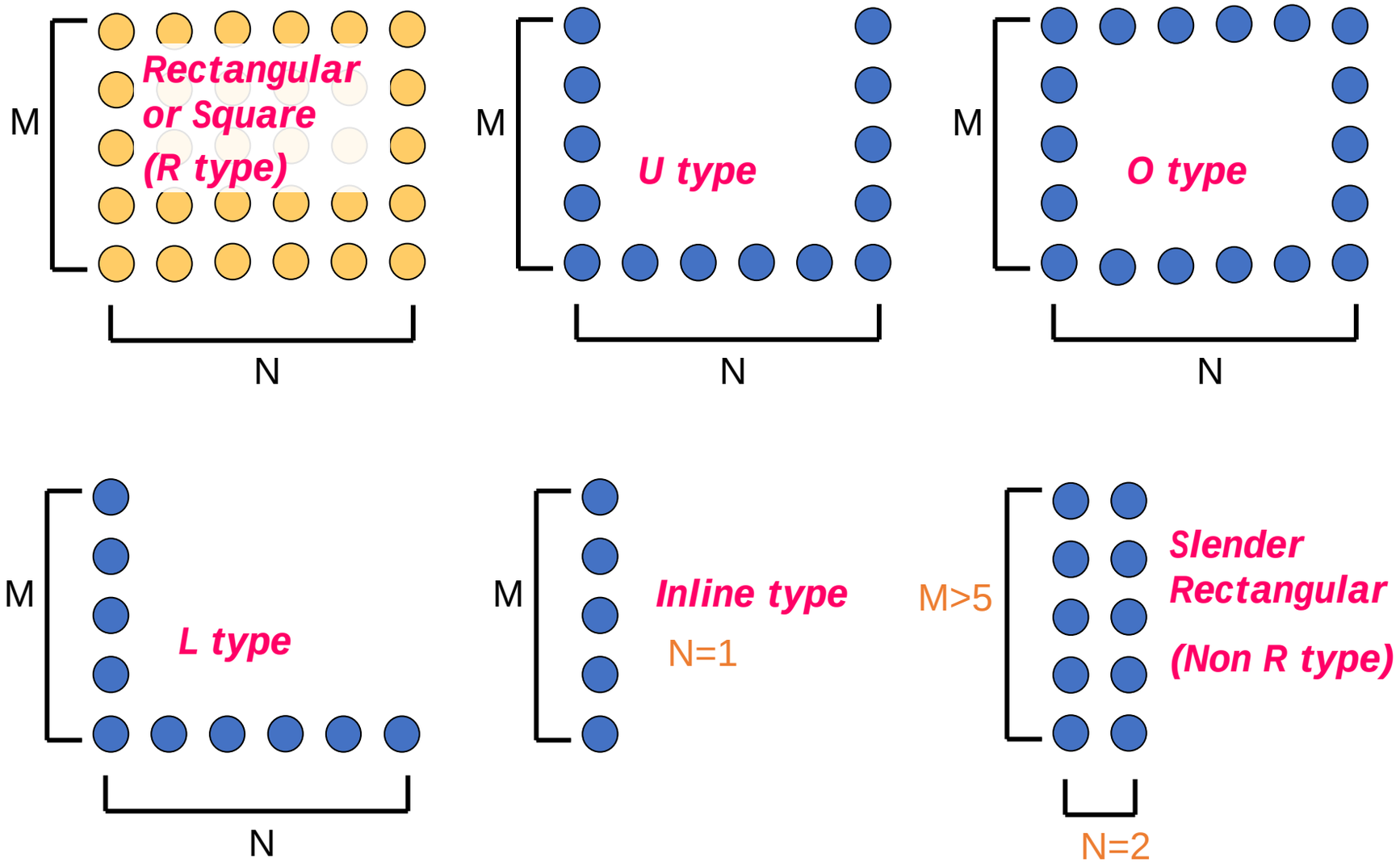


In Figure, the BHE depth values as calculated by the Ashrae/Tp8 method (H8) and by EED (H) for 30BHE field configurations



M.Fossa, Science and Technology for the Built Environment, 2017, DOI: 10.1080/23744731.2016.1208537

Ashrae/Tp8 method: the BHE field configurations



4: The Unige contributions for boosting the Geo Heat Pump market and engineering

SMART ENERGY BUILDING
Unige, Savona Campus

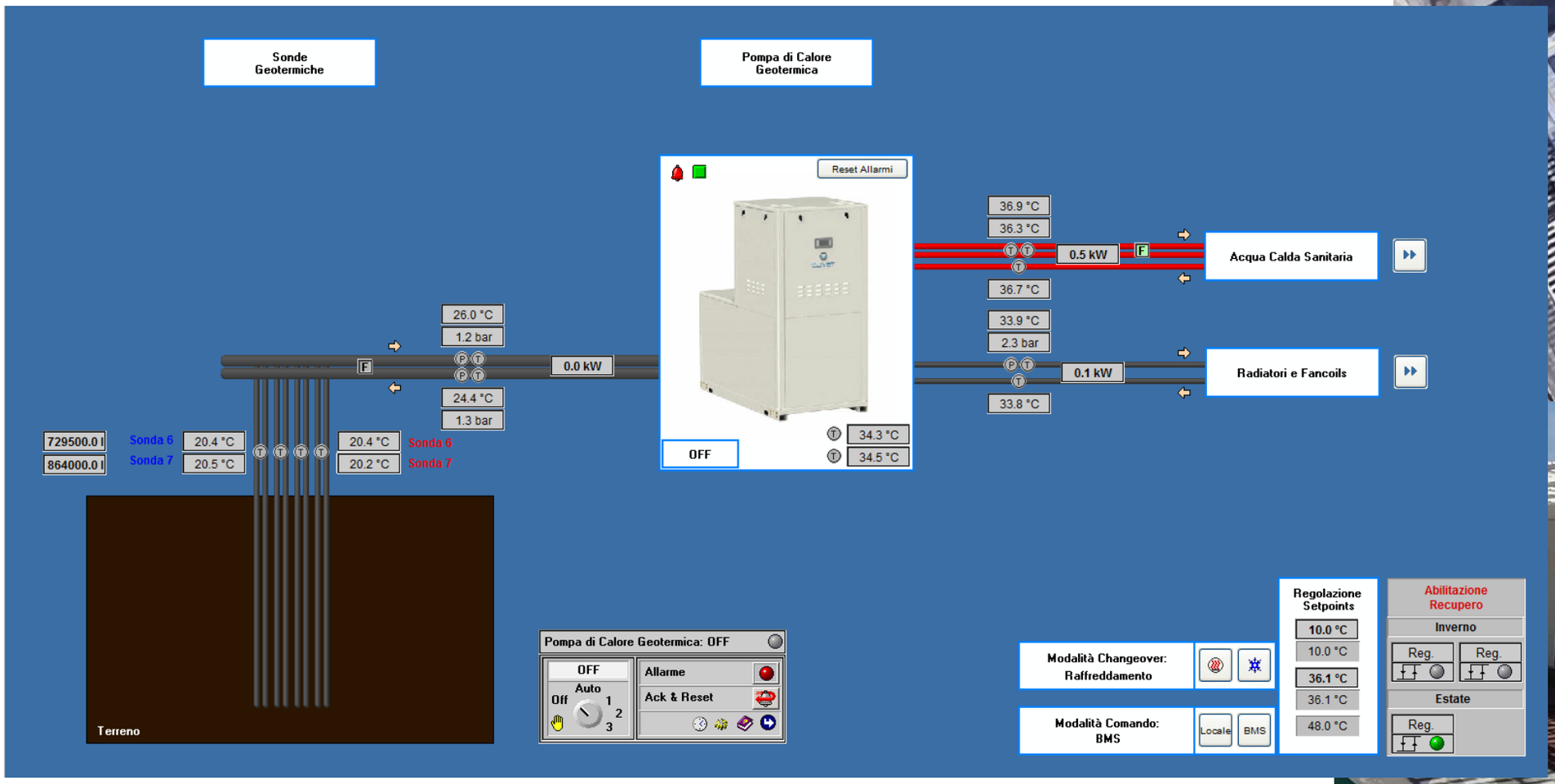
Energy Efficiency
Class A+
23kWp
Photovoltaic
electricity

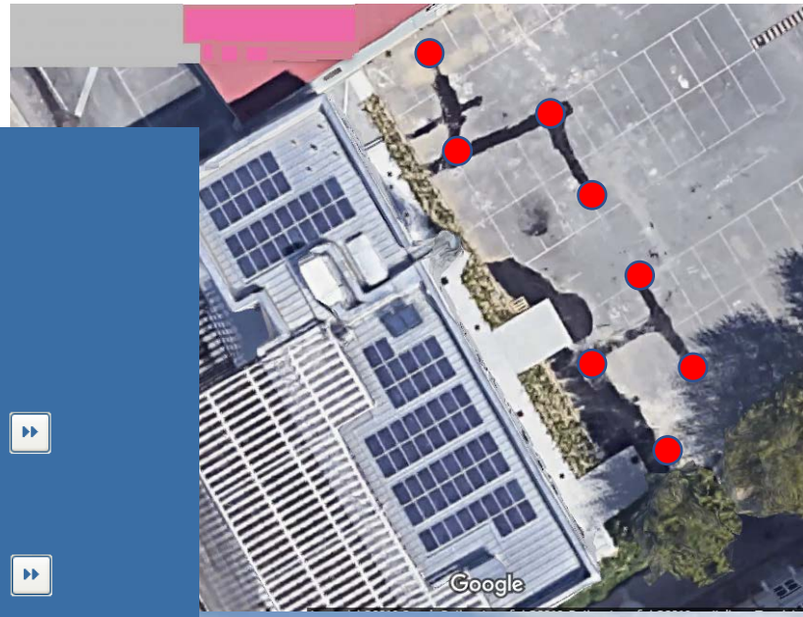
Fully automatic control of ventilation, air conditioning and lighting

Funded by: 90% Italian Ministry for the Environment and Sea, 10% UNIGE, Value of the project: 3 M€

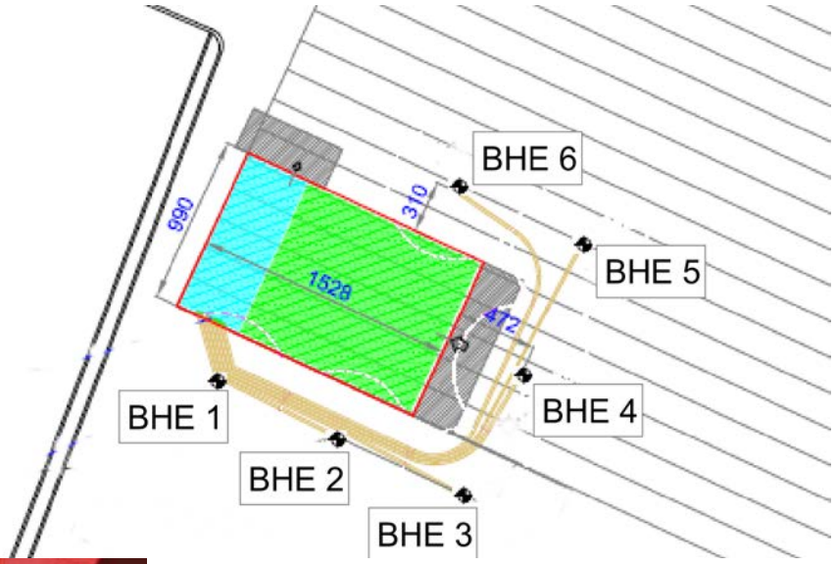
- Status: in operation since February 2017
- Smart Building interacting with local Smart Microgrid
- Surface: 1000 m2
- **NZEB building with GCHP, 8BHEs, H=125m, rated COP=4.5, rated power 48kWt**

SMART ENERGY BUILDING Unige (monitoring system)

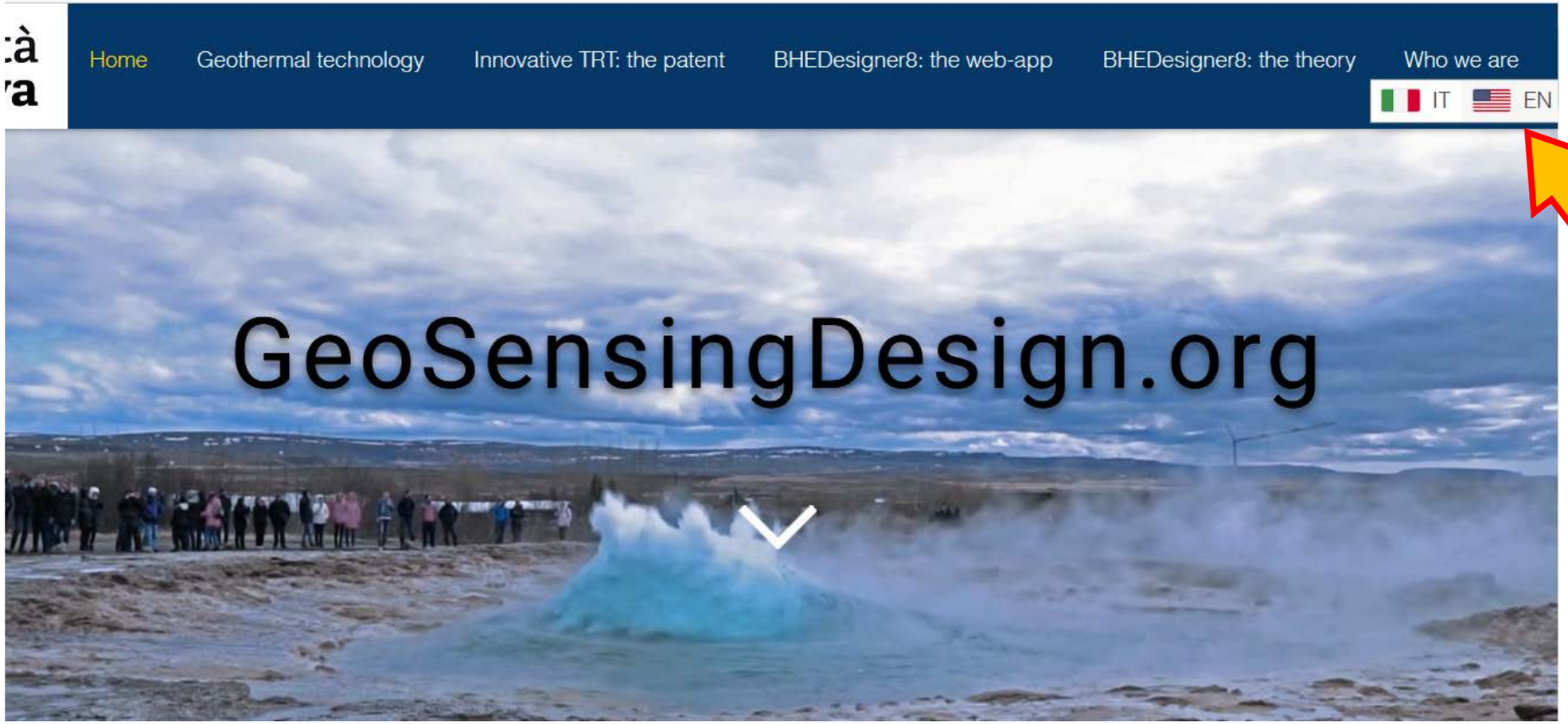




SamLab Greenhouse Unige (Albenga, Italy)



The Unige (Free !) support to BHE field Design: the GeoSensingDesign Portal and Web App



The French Canadian Flag is still missing!

Volunteers for a French version?

GeoSensingDesign Portal: the Innovative DTRT system and All-in-One BHE patent

versità enova

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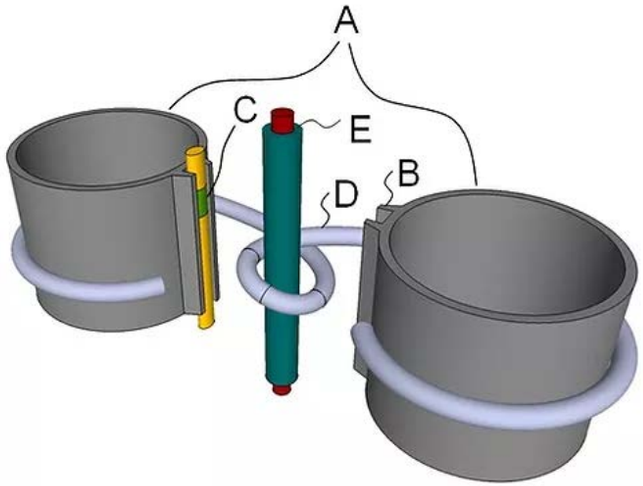
TRT Innovative: the *all-in-one* Patent

The knowledge of the thermophysical properties and in particular of the ground thermal conductivity and of the equivalent thermal resistance of the vertical geothermal heat exchanger (Borehole Heat Exchanger, BHE) is of fundamental importance in the sizing phase of the system, guaranteeing its long-term energy efficiency and economic sustainability.

The traditional method for determining the ground and BHE thermal parameters consists of an experimental procedure called Thermal Response Test (TRT). This test involves using a pilot BHE, placed in the ground to be analyzed, in which the carrier fluid, suitably heated above the ground in a controlled manner, is kept in flow circulation for a duration of about 70 hours. During the test, the fluid temperatures are measured and from the measurements analyses, it is possible to deduce the ground thermal conductivity and the effective thermal resistance of the BHE. To carry out this measurement campaign, dedicated experimental equipment is used, the so-called TRT machines, which have a particularly high construction cost (€ 10000-30000 from 2019 estimates).

The proposed invention constitutes an absolute novelty in the market of GCHP applications and refers to the Italian Patent by UniGE n. 102019000023082 ("Method and device for measuring geothermal parameters for sizing and subsequent monitoring of geothermal heat

The Distributed TRT All-in-One BHE



Traditional TRT machines are complex, heavy and costly (30k CAD). Unige All-In-One invention (Italy and Canada patented) is based on extruded ribbed pipes with embedded one-wire temperature sensors.

With the proper algorithm, a cheap Arduino as a micropc, a central electric heater, the system is able to provide:

- TRT measurements without the TRT machine
- In depth both kground and kgrout measurements
- BHE monitoring in time

Additional BHE cost:

1.5CAD per

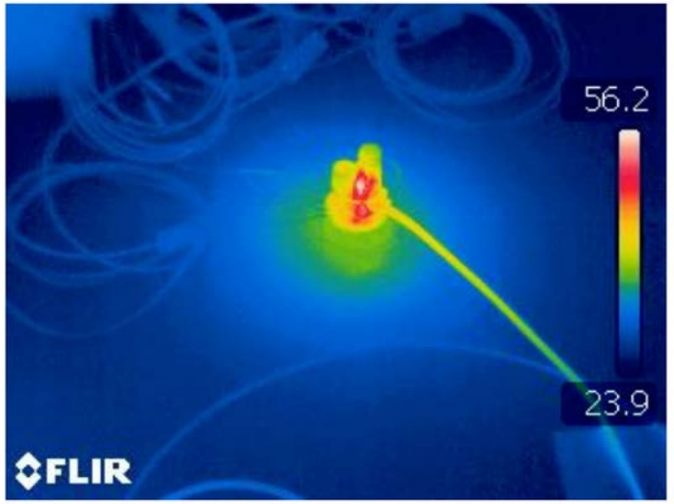
BHE meter

All-in-One BHE experimental tests

An experimental investigation (2021, Energies J., https://doi.org/10.3390/en14216955) on a reduced scale ground and BHE model (slate rock block, 1600Lbs) demonstrated the capability of the system to accurately measure both the rock and grout thermal conductivities and to perform depth temperature measurements for BHE performance monitoring, test for correct grouting, test for aquifer presence.

Is it better a standard BHE pipe for 80CAD/m or the all-in-one for just 82 ?

Any Canadian collaboration is welcome!



The BHEDesigner8 web app

Unige GeoSensigDesign.org hosts the BHEDesigner Web App for BHE field design based on the Ashrae/Tp8 method. The tool and the entire web page have been developed without any specific grant (unbelievable, but true…)

The web tool, completely free, is organized as an excel spreadsheet.

Inputs are the building monthly and peak loads, ground properties, expected COP, the desired BHE depth H

The User while inserting the data is in real time addressed to the proper BHE field configuration and BHE number

The BHEDesigner8 mask

The present web app is, to the Authors' opinion, a boosting tool for the GCHP market, education, and engineering sectors.

A fast and accurate evaluation of the geometry of the Borefield can be easily performed.

Future developments include the 25yr version of the Algorithm and its web app.

Università di Genova

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INPUT Section

Building Heat loads [kWh/month]

Month	$Q_{M,build,j}$	COP_{ave} [-]
January	60925	4,5
February	47721	4,5
March	48248	4,5
April	33943	4,5
May	25952	4,5
June	29238	4,5
July	22332	4,5
August	26721	4,5
September	28818	4,5
October	31375	4,5
November	44956	4,5
December	56623	4,5

Heat Pump data

$T_{f,in,winter,eva}$ [°C]	3
$T_{f,out,winter,eva}$ [°C]	0
$T_{gr,\infty}$ [°C]	8
$T_{f,in,summer,cond}$[°C]	36
$T_{f,out,summer,cond}$ [°C]	39
$COP_{ave,winter}$	4,5
$COP_{ave,summer}$	4
$COP_{peak,winter}$	4,5
$COP_{peak,summer}$	4

N_{tot} (suggested)	24

Ground and BHE characteristics

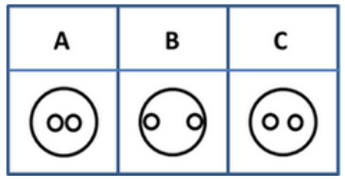
k_{gr} [W/mK]	5
α_{gr} [m²/s]	1,60e-006
$H_{expected}$ [m]	200
BHEs configuration	U-shape
R_{BHE} already known?	no
R_{BHE} (if known) [mK/W]	0,1
B [m]	10
D_b [m]	0,14
N	4
M	2
N_{tot}	6

B/H too low: increase B and/or N or M

You have to fill this table

BHE geometry

k_{pipe} [W/mK]	0,4
k_{grout} [W/mK]	1,8
h_{conv} [W/m²K]	1500
$D_{p,int}$ [m]	0,026
$D_{p,ext}$ [m]	0,032
$D_{p,ext,max}$ [m]	0,0480
N_{pipes}	4
BHE pipes arrangement	A
Calculated R_{BHE} [mK/W]	0,134



(Any Canadian collaboration is welcome for the new Ashrae25 method...)

Thanks for your attention