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 Unige contributions for boosting the Geo Heat Pump market and engineering
Marco Fossa short CV

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 Sustainability (2022)


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

Univ. du Quebec ETS, (2022) and Polytech Montreal (2022)

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

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

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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 the 16th 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
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

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

The average UniGe position is around 360, i.e., in the world's top 1.5% universities.

UniGe is ranked fifth among big Italian universities (20-40,000 students) in terms of internationalization (Censis ranking).

UniGe’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

UniGe 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.
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 Architecture 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).
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)
1.5°C Pathway, according to Irena (2021)
The Italian Energy Plan for Climate based on EU directives (PV sector)

Plan Targets at 2030 (GW)

Photovoltaic cumulative power in Italy (GW)

Revamping
Renewable energy from Heat Pumps and other renewable sources (Italy, 2020, Mtep units)
**Heat Pumps vs Gas Furnaces** (Italy as an example)

Electricity MIX in Italy, 2020

```
E_E = 0.48 * E_chem
Q_build = COP * E_E
```

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

$$\text{COP}_{\text{min}} = \frac{(1 - 0.426)}{0.48} = 1.20$$

(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)
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 CO2 emissions.
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.
Heat Pumps in Europe (Air source vs Geothermal)

In “warm” countries ASHPs dominate the market (2019 Eurobserv’er data)

<table>
<thead>
<tr>
<th>Country</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>19,600,000</td>
<td>14,100</td>
</tr>
<tr>
<td>France</td>
<td>6,994,356</td>
<td>161,250</td>
</tr>
<tr>
<td>Spain</td>
<td>4,157,961</td>
<td>10,793</td>
</tr>
<tr>
<td>Sweden</td>
<td>1,349,857</td>
<td>551,776</td>
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<td>Portugal</td>
<td>1,160,677</td>
<td>909</td>
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<td>Germany</td>
<td>762,336</td>
<td>392,784</td>
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<tr>
<td>Finland</td>
<td>836,620</td>
<td>127,964</td>
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<tr>
<td>Netherlands</td>
<td>660,806</td>
<td>71,065</td>
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<tr>
<td>Denmark</td>
<td>380,995</td>
<td>68,997</td>
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<tr>
<td>Malta</td>
<td>425,237</td>
<td>0</td>
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<tr>
<td>Belgium</td>
<td>321,593</td>
<td>15,804</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>201,946</td>
<td>36,877</td>
</tr>
<tr>
<td>Austria</td>
<td>126,246</td>
<td>109,695</td>
</tr>
</tbody>
</table>

Total number of heat pumps in operation in 2018 and 2019.
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

![Diagram showing energy demand and heat pumps](chart-diagram.jpg)

- **Q**
- **Q_{GCHP}**
- **Q_{ASHP}**
- **Q_{build}**

Missing Heat to ASHP due to COP decrease as a function of external air temperature.
The Good Thermodynamics of Heat Pumps

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

$$Q_{\text{ground}} = Q_{\text{build}} \frac{(\text{COP}-1)}{\text{COP}}$$

The $Q_{\text{ground}}$ 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 models very often refer to heat conduction only. The thermal response of ground is described in terms of a “transient” thermal resistance, \( R_{\text{ground}} \). The inner BHE contribution is modeled as the resistance \( R_{bhe} \).

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

\[
R_{\text{ground}}(\tau) = \frac{(T_b - T_{gr})}{(\dot{Q}/L)} \quad \text{[mK/W]}
\]
Ground Thermal response and ground resistance in time

\[ \dot{Q} = 2.5 \text{ kW} \quad (\dot{Q}/L = 25 \text{ W/m}) \]

\[ R_{\text{ground}}(\text{start}) = 0 \text{ [mK/W]} \]

(initial temperature) far field temperature (10°C)

\[ R_{\text{ground}}(1\text{ day}) = \frac{(10-6.6)}{25} = 0.136 \text{[mK/W]} \]

\[ R_{\text{ground}}(1\text{ week}) = \frac{(10-4.9)}{25} = 0.224 \text{[mK/W]} \]

\[ R_{\text{ground}}(\tau) = \frac{(T_{\text{bhe}}-T_{\text{gr}})}{(\dot{Q}/L)} \]

Conditions:
- Constant Heat rate in time
- Borehole diameter = 6 inches
- Ground conductivity = 2.1 W/m-K
- Ground diffusivity = 0.08 m²/day
- Far-field (Undisturbed temperature) = 10°C

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 \( (T_{f, \text{in}}) \) 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

$T_f$ is related to the BHE wall temperature along the depth

$T_{f,\text{ave}} = \frac{(T_{f,\text{in}} + T_{f,\text{out}})}{2}$  (at the HP ports)

At a given heat transfer rate $Q$, $T_{f,\text{ave}}$ depends on $T_{\text{ground,\infty}}$ (Undisturbed temperature) and on BHE and Ground thermal resistances.

HENCE:

It’s necessary to evaluate both $R_{\text{bhe}}$ and $R_{\text{ground}}$

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)

$Q = Q_{\text{extracted}} = Q_{\text{build}} \times \frac{\text{COP}_{\text{w}} - 1}{\text{COP}_{\text{w}}}  \quad \text{Winter Mode}$

$Q = Q_{\text{extracted}} = Q_{\text{build}} \times \frac{\text{COP}_{\text{s}} + 1}{\text{COP}_{\text{s}}}  \quad \text{Summer Mode}$
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.

Those solutions, the TRF family (here denoted with the symbol $\Gamma$), includes the Infinite Line Source (ILS or E1) solution, the Infinite Cylindrical Source (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.

$$T(r^b, \tau) - T_{gr,\infty} = \frac{\dot{Q}_{ave}}{Ck_{gr}} \Gamma(Fo)$$

$C=1$ (ICS)

$C=4\pi$ (ILS)

$\Gamma=G$ (ICS)

$\Gamma=E_1$ (ILS)

$$R_{ground}(\tau) = \frac{\Gamma(Fo)}{Ck_{gr}}$$
The ILS solution for the Ground Thermal Property estimation

The ground thermal conductivity \( k_{\text{ground}} \) 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 \( R_{\text{ground}} \) 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).

\[
R_{\text{ground}}(\tau) = \frac{\Gamma(Fo)}{Ck_{gr}}
\]

\[
Fo = Fo_{rb} = \frac{\alpha \tau}{r_b^2}
\]
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 \( T_p \).

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

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 $Q_y$, the ground thermal conductivity $k_{gr}$, the BHE overall length $L$, the BHE interdistance $B$, the BHE mutual disposition.

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

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

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

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

- Rectangular or Square (R type)
- U type
- O type
- L type
- Inline type
- Slender Rectangular (Non R type)
4: The Unige contributions for boosting the Geo Heat Pump market and engineering
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, 8 BHEs, H=125 m, rated COP=4.5, rated power 48 kWt

Energy Efficiency
Class A+
23 kWp
Photovoltaic electricity

Fully automatic control of ventilation, air conditioning and lighting
SMART ENERGY BUILDING Unige (monitoring system)
**SamLab Greenhouse Unige** *(Albenga, Italy)*

**Antea Violet and Begonia cultivation at SamLab**

**Storage tank**

**Air Handling Unit**

**GCHP**
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

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 GOHP applications and refers to the Italian Patent by UniGE n. 102019000023062 (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 micro pc, 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.

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

Any Canadian collaboration is welcome for the new Ashrae25 method...
Thanks for your attention