Design guidelines for direct ground cooling systems in different climates

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Outline

- introduction to direct ground cooling systems – research scope
- methodology
- system layout, reference building, climates
- dynamic simulations in different climates, by varying the building size and the envelope thermal properties
- GHEX design criteria and discussion

Direct ground cooling systems

Cooling is achieved through water circulation between radiant panels in the building and a ground heat exchanger

The ground heat exchanger sizing is a critical issue:

- oversizing → high costs
- undersizing → low performance

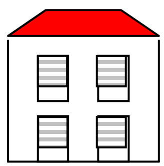
Existing guidelines and methods focus on ground coupled heat pumps and heating use [VDI 4640, Kavanaugh..] → application to direct ground cooling systems not straightforward (sensitivity to ground temperature levels…)

In this study: dynamic simulations → preliminary criteria for direct ground cooling systems sizing in the Italian climates (influencing the ground temperature and the building cooling demand)

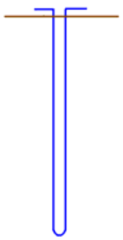
Methodology 1/3

	<T> (°C)	Tmin (°C)	Tmax (°C)
Milano	11.8	-10.0	32.6
Roma	15.8	-4.0	31.8
Palermo	18.8	4.8	34.0

Modifying the envelope (A, B, C)

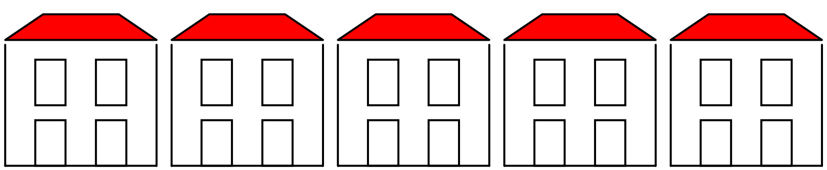


Varying the climate

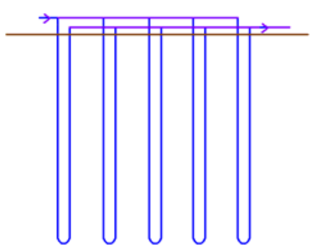


Finding the GHEX size

Scaling the building size x10, x100

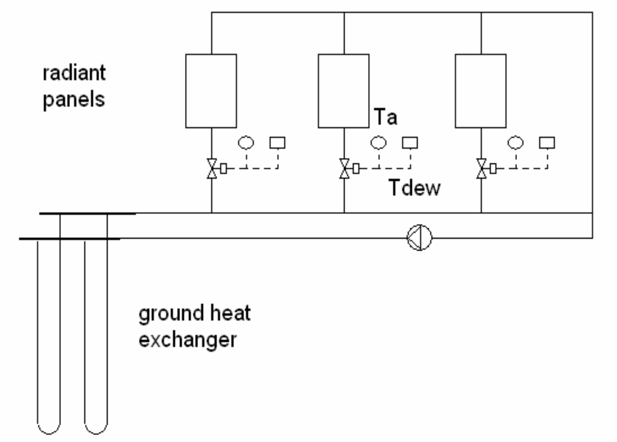


Scaling the GHEX size…



Methodology 2/3

- **Direct ground cooling system**:
  - ✓ vertical GHEX (one U pipe per borehole - average ground thermal properties)
  - ✓ chilled floors;
  - ✓ room thermostats and dew point sensors;
  - ✓ operating from June to September **for 30 years**.



	Envelope A	
	U W/m²K	g
External walls	0.46	
Roof	0.82	
Floor on ground	0.64	
Windows	3.28	0.76
Shading	Not present	

- **Reference building**: two storey single family house

Methodology 3/3

Long term evaluation of summer comfort conditions through TRNSYS simulations:

- for each summer calculation of <PMV> and mean standard deviation Δ

- adjusting the GHEX size (N, H, d) in order to have, throughout the 30 years:

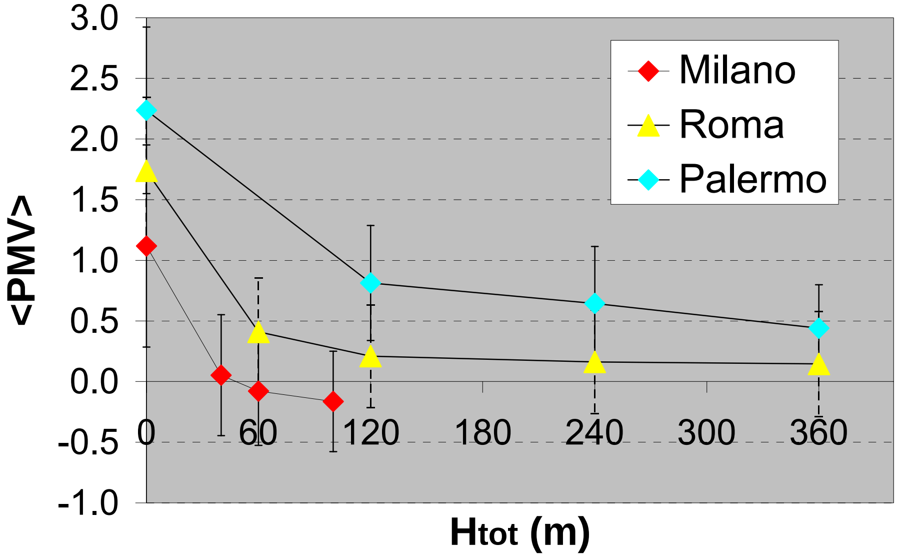
$$\langle PMV \rangle + \Delta \leq 0.5$$ comfort level (1)

(Class B environment EN 7730)

or, if the previous condition is too hard to reach,:

$$\langle PMV \rangle + \Delta \leq 0.8$$ comfort level (2)

Simulations / building x1



- in Milano N=1 H=60 m is enough; Q_{30y}/Q_{1y}= 96%
- in Roma and Palermo H_{tot}=360 m is not enough! Condensation prevention is partially responsible for that!

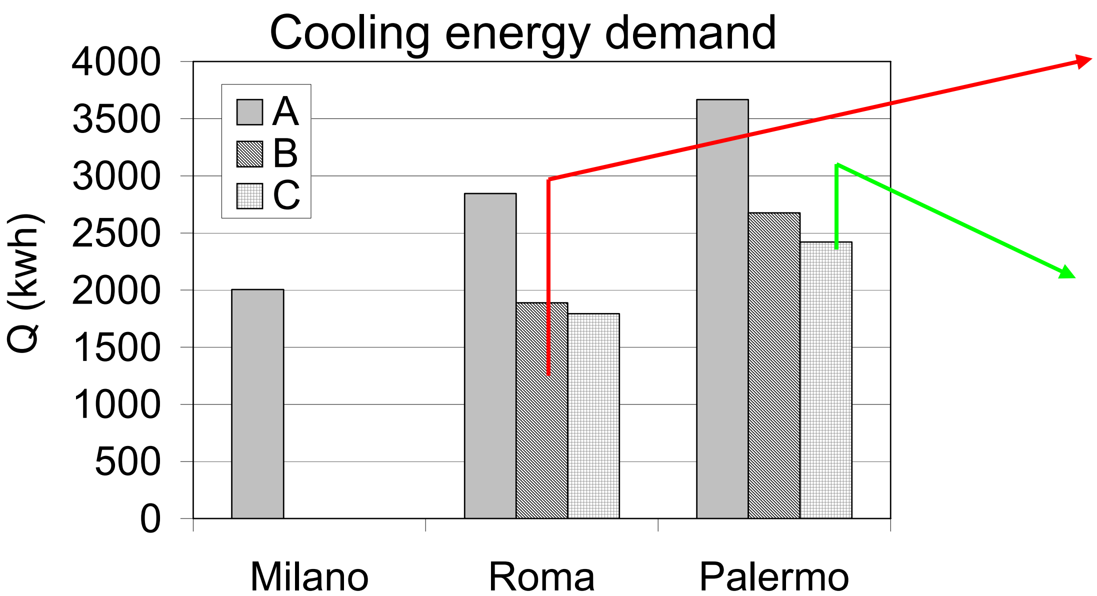
- What happens if we:

 - apply a solar control strategy (*envelope B*)

 - and increase the thermal insulation? (*envelope C*)

	Envelope A		Envelope B		Envelope C	
	U W/m²K	g	U W/m²K	g	U W/m²K	g
External walls	0.46		0.46		0.24	
Roof	0.82		0.82		0.24	
Floor on ground	0.64		0.64		0.64	
Windows	3.28	0.76	1.74	0.39	1.74	0.39
Shading	Not present		Overhangs		Overhangs	

Simulations / building x1



Roma envelope B c.l.(1):

N=1 H=70 m

Palermo envelope C c.l.(1):

H_{tot}=450 m not enough!

moving to c.l.(2):

N=2 H=90 m d≥2 m

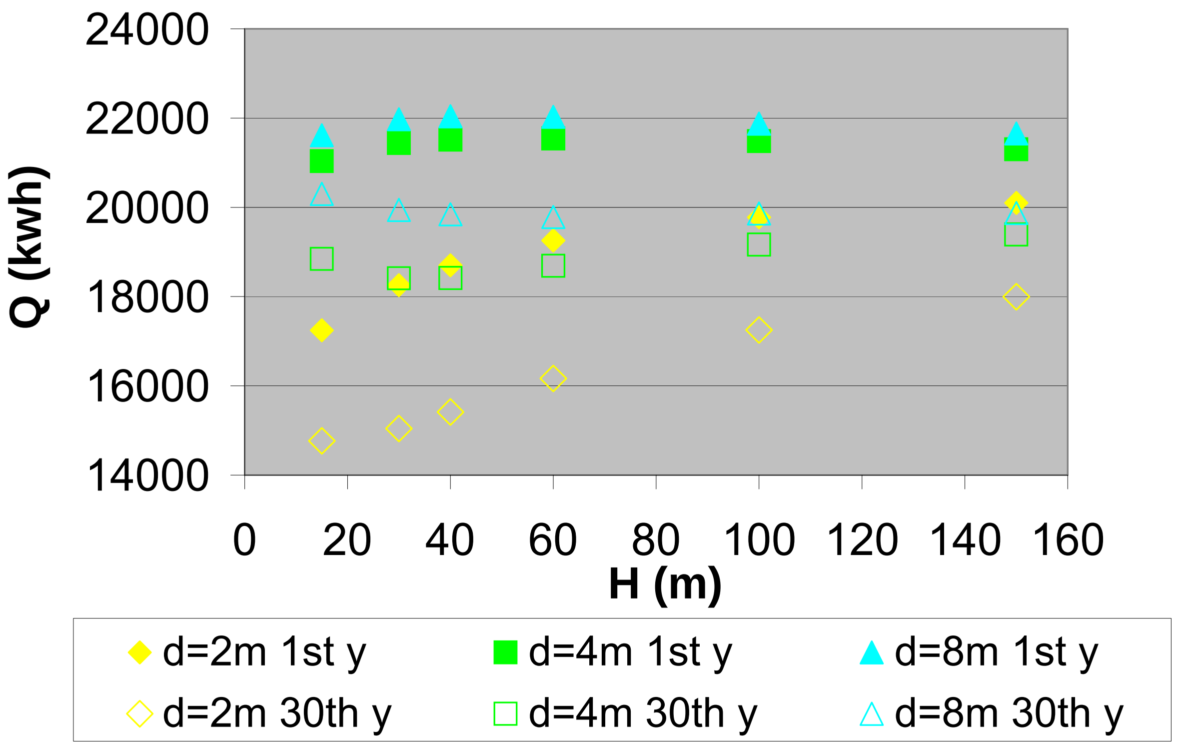
Climate	envelope	comfort level	H_{tot}(m)	Configuration
Mi	A	(1)	60	N=1 H=60m
Ro	B	(1)	70	N=1 H=70m
Pa	C	(2)	180	N=2 H=90m d≥2 m

Simulations / building x10

<u>Milano</u>: envelope A c.l. (1)

H_{tot}=60m x10= 600 m is ok but…if the boreholes distance d is too short the system performance decreases significantly with time!

Heat injected Q for different GHEX configurations with H_{tot}=600 m



Simulations / building x10

<u>Roma</u> envelope B c.l.(1):

H_{tot}=70 m x10=700 m is found to be insufficient, even if d=20 m!

→ H_{tot}=1000 m with d≥8 m

<u>Palermo</u> envelope C c.l.(2):

H_{tot}=180 m x10=1800 m is ok if:

- d≥8 m, H=15 m
- d≥16 m, H=150 m

climate	env.	comf. level	H_{tot} (m)	configurations	
				d	H, N
Mi	A	(1)	600	≥8 m	H=15÷150m N=40÷4
				4 m	H=15m N=40; H=100m N=6; H=150m N=4;
Ro	B	(1)	1000	≥8 m	H=20÷150m N=50÷7
Pa	C	(2)	1800	≥8 m	H=20m N=90
				≥16 m	H=90m N=20
			3000	≥8 m	H=120m N=25
				≥8 m	H=90m N=33

Simulations / building x100

climate	env.	comf. level	H_{tot} (m)	Configurations	
				d	H, N
Mi	A	(1)	6000	≥8 m	H=15m N=400
				≥16m	H=100m N=60
			9000	≥8 m	H=30m N=300 H=60m N=150
Ro	B	(1)	10.000	≥8 m	H=20m N=500
				≥20m	H=100m N=100
			15.000	≥12 m	H=100m N=150
Pa	C	(2)	18.000	≥12 m	H=20m N=900
				≥20 m	H=90m N=200
			30.000	≥16 m	H=120m N=250
				≥ 8 m	H=30m N=1000

In order to scale the GHEX size according to the buildings', large d or little H are required

Conclusions

- in warm-humid climates the need to avoid condensation on chilled surfaces may limit the cooling system performance
- the direct ground cooling system size strongly depends on the envelope thermal properties
- the GHEX size is very sensitive to the ground temperature level
- <u>in small scale</u> GHEX with few boreholes the system long term operation is stable
- <u>in medium and large scale</u> GHEX thermal interactions between neighbour boreholes and heat injection year after year may reduce the system performance:
    - ✓ a larger interaxial distance is required;
    - ✓ total boreholes length being equal, best long term behaviour is found for shallow configurations, since their aspect ratio permits natural ground recharge in winter by heat transfer with outside air.