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An example of thermal retrofitting for the Piedicastello tunnel

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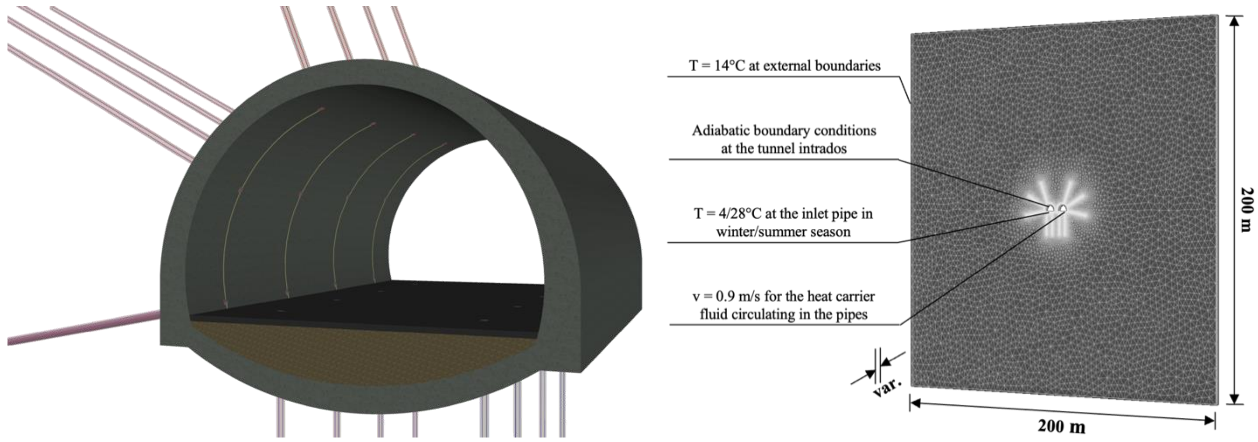
Over the last decades, global warming has become one of the major issues to cope with: as it stands, human activities are responsible for a global surface temperature increase of approximately 1.1°C since the pre-industrial age. Climate change is directly linked to the level of global warming, thus affecting different kind of regions around the world in multiple ways, leading not only to increments of heat extremes, but also to changes in rainfall patterns, sea level rise, amplification of the permafrost thawing, ocean acidification and much more [1].

In this context, carbon dioxide emissions due to heating systems are one of the main enemies in the pathway for reaching the 1.5°C Paris climate goal and energy geostructures could play a relevant role. Among them, the thermal activation of tunnels has raised interest [2, 3, 4] and recent full scale projects have demonstrated the feasibility of such technology [5, 6]. However, so far applications have been related to new tunneling projects, whereas possibilities of implementation in the existing heritage of tunnels have not yet been investigated.

The Authors are developing investigations for the thermal retrofitting feasibility of existing tunnels. In this abstract the attention is posed on the case study of the Piedicastello tunnel, located in the city of Trento, crossing the city centre through a 100 m high spur of limestone, called Doss Trento. This tunnel used to be part of the Italian roadway network but, following the construction of a new tunnel in 2007, it fell into disuse, being partly transformed into a museum one year later, i.e. the tunnel is now a closed environment.

One of the design hypotheses identified for thermal retrofitting of the Piedicastello tunnel consists in taking advantage of its 100 m overburden by drilling radial borehole heat exchangers (rBHEs), arranged along several tunnel cross sections. In Figure 1a, a 3D view of the rBHEs solution is shown. This solution leaves the lining intrados visible for future inspection and is essentially unaffected by the internal aerothermal condition of the tunnel.



(a) (b)

Figure 1: (a) 3D view of the thermal retrotting solution and (b) numerical model.

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In order to assess its thermal performance, some 3D numerical models were built with the Finite Element software Feflow [7]. The above-mentioned models are 200.0 m high and wide, with a thickness that varies as a function of the rBHEs cross section interaxis distance (Figure 1-b). The two horse-shoe shaped tubes of the Piedicastello tunnel have an external equivalent diameter of 12.7 m, with an 80 ÷ 130 cm thick concrete lining. Heat exchanger pipes, instead, were modelled through one-dimensional elements ("discrete features"), with a cross section of 201 mm^2, corresponding to an external diameter of 20 mm and a thickness of 2 mm.

Both thermal and hydraulic boundary conditions were set considering the lack of information about the groundwater regime of the Doss Trento and the internal aerothermal conditions of the Piedicastello tunnel. Nonetheless, given its unusual conditions (absence of moving vehicles and closed environment), the latter would likely have a minor role in the heat exchange process. Accordingly, setting adiabatic boundary conditions at the tunnel contour and considering a dry rock mass, a preliminary sensitivity analysis was performed with the aim of drawing some meaningful conclusions about two key design aspects of the rBHEs solution. To this purpose, three different borehole length setups (short – 12.50 m, mid – 18.75 m and long – 25.00 m) and three cross section interaxis distances (3.0 m, 5.0 m and 7.5 m) were investigated. The results of the preliminary numerical simulations are shown in Table 1.

Table 1: Computed input/output temperature difference in winter and summer seasons after 30 days of operation.

	Winter heating			Summer cooling		
	3.0 m interaxis	5.0 m interaxis	7.5 m interaxis	3.0 m interaxis	5.0 m interaxis	7.5 m interaxis
Short (5 × 12.50 m)	2.12°C	2.26°C	2.28°C	2.96°C	3.26°C	3.29°C
Mid (5 × 18.75 m)	3.00°C	3.18°C	3.20°C	4.19°C	4.45°C	4.49°C
Long (5 × 25.00 m)	3.78°C	3.99°C	4.02°C	5.29°C	5.59°C	5.63°C

From the sensitivity analysis, it seems evident that, in the considered cases and ranges: (i) as expected, the longer the rBHEs, the higher the heat that the system can exploit, accordingly the rBHEs optimal length should be designed considering also the pumping and drilling costs, (ii) two consecutive instrumented cross sections have virtually no interaction if the interaxis distance is set higher than 5.0 m.

Starting from these valuable evidences, future research will investigate: (i) the influence of the groundwater regime, as well as the internal aerothermal conditions of the tunnel, (ii) new alternatives for the thermal retrofitting of existing tunnels and (iii) the optimal rBHEs length with respect to a cost-benefit analysis that will consider both drilling and pumping costs.

Contributor statement

Simone De Feudis: conceptualization, formal analysis, visualization, writing – original draft, writing - review & editing; Alessandra Insana: conceptualization, supervision, writing - review & editing; Marco Barla: conceptualization, funding acquisition, supervision, writing - review & editing.

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