A neural network approach for quick dimensioning of energy walls

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A neural network approach for quick dimensioning of energy walls

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Shallow geothermal energy can play a major role in the perspective of the decarbonization of heating and cooling demands in the building sector. However, the high realization cost and the large land consumption of these systems reduced the diffusion and the positive support provided to the achievement of EU climate goals. A novel system called GeothermSkin [1] fits into this context: it is a very shallow energy wall provided with a net of pipes able to transform the underground portions of buildings into geothermal collectors, thus conferring to the structural element an additional energy function. The hydraulic circuit comprises reticulated polyethylene Pe-Xa pipes fixed to the wall's external surface in contact with the ground and crossed by a heat transfer fluid. It enables to overcome the limits of traditional geothermal applications because it is characterized by low investment cost, ease of installation and applicability to existing buildings subjected to retrofitting. A prototype of such a system was installed in Torino (Italy) and coupled with an electric heat pump which, by providing hot or cold heat transfer fluid to a fan coil, allows to heat and cool a test environment.

In this study, the data collected during heating tests carried out between October 2019 and February 2020 have been processed to evaluate the heat pump's performance and the heating power supplied per unit area of GeothermSkin. The aim is to make available to the designer a tool able to ease the sizing of GeothermSkin providing an indicative estimate of the surface to be equipped with such a system to fulfil, partially or completely, the building's heating demand. By doing so, the diffusion of shallow geothermal energy would be improved and the carbon footprint of the residential sector minimized.

The data processing's results conceal the relationship between the thermal power and climate variables such as solar radiation, external temperature, temperature and moisture of the ground. The knowledge of the correlation between the performance and the variables would allow to forecast the heat power supplied by the geothermal system in different environmental and ground conditions and to evaluate the surface of GeothermSkin required to meet the heat load of the building.

To discover such correlation and maximise knowledge, a data-driven approach can be followed. In this study, an artificial neural network multilayer perceptron (ANN), belonging to supervised machine learning algorithms, has been trained for this purpose. The ANN is designed with 4 neurons for the input layer, 2 hidden layers each consisting of 64 neurons and 1 neuron for the output layer which applies a rectified linear unit (RELU) activation function to ensure a positive predicted power. During the training process, the training set originating from the performed tests on the prototype facility is completely analyzed 100 times (this hyperparameter is called epoch) in each of which the training set is splitted into 64 batches randomly sampled and analyzed with a learning rate specifically optimized. The training data, composed of environmental and ground condition inputs (i.e. external temperature, ground temperature, solar radiation and relative humidity) paired with the heat power produced during the real operation of the geothermal system, are provided to the ANN which looks for the pattern with backpropagation to minimize an error function evaluated between the forecast thermal power and the real one with gradient descent algorithms.

After training, the artificial neural network can take in new unseen inputs represented by the annual average environmental and ground condition for each Italian province (same as the ones already mentioned for the training) and estimate, as an output, the annual average heat power $Q_{forecasted}$ provided by the geothermal system in that specific location with a mean absolute percentage

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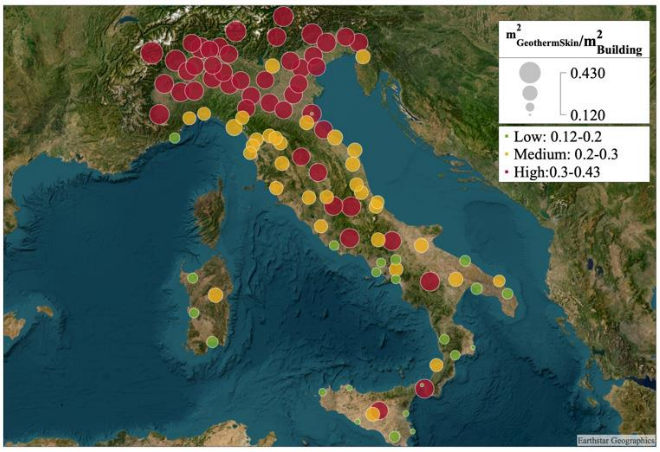
error of 7%. Average environmental and ground data of each province are available from the ERA5-Land dataset, a long-term record of our climate history generated to track the climate change within the project Copernicus launched by the European Center Medium Weather Forecast (ECMWF) [2]. The dataset is obtained by combining a weather model with observational data from satellites and ground sensors and includes several climate variables with high spatial and temporal resolution.

Knowing the average thermal power forecasted for each province normalized by the area of the GeothermSkin ($A_{GeothermSkin}$) it is referred to (i.e. 34.5 m^2, corresponding to the surface equipped with pipes during the tests carried out), in watt per square meter of equipped wall, and the maximum annual average power required by a building according to its latitude and the Italian legislation $Q_{requested}$, in watt per square meter of building, the surface of the energy wall required per unit area of building is obtained as:

$$S_{GeothermSkin\ required} = \frac{Q_{requested}}{Q_{forecasted}} \cdot A_{GeothermSkin} \quad \left[\frac{m^2_{GeothermSkin}}{m^2_{building}}\right] \tag{1}$$

The results are shown in Figure 1 and suggest that the area of GeothermSkin per unit area of building able to provide an annual average thermal power sufficient to meet the annual average heat load in Italy varies between 0.12-0.43 m^2/m^2. Table 1 shows the results concernings 8 provinces. It is possible to observe that, overall, the required area decreases from North to South because the maximum annual average power required by a building is lower and the average thermal power forecasted is higher. Indeed the warmer, sunnier and more stable weather in Southern region allows GeothermSkin to extract a higher thermal power and operate with a great coefficient of performance thanks to the smaller difference between the ground and the internal buildings' temperatures.



Province	$Q_{requested}$ [W/m²]	$Q_{forecasted}$ [W]	$\frac{m^2_{GeothermSkin}}{m^2_{building}}$	
Milano	13,2	1449	0,32	
Torino	13,2	1326	0,34	
Firenze	10,0	1465	0,24	
Ancona	10,0	1402	0,25	
Roma	10,0	1527	0,23	
Brindisi	7,8	1317	0,20	
Palermo	5,5	1423	0,13	
Cagliari	7,8	1363	0,20	

Figure 1: Required GeothermSkin surface per unit surface of building and summary for main cities.

Contributor statement

Alessandro Poveromo: data curation, formal analysis, investigation, methodology, visualization, writing – original draft; Alessandra Insana: conceptualization, supervision, writing, review and editing; Davide Papurello: conceptualization, methodology, project administration, supervision, writing, review and editing; Marco Barla: conceptualization, funding acquisition, project administration, supervision, writing, review and editing.

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