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DHGEN: AUTOMATED GENERATION OF DISTRICT HEATING NETWORK LAYOUTS FOR FEASIBILITY STUDIES

Authors:
Giuseppe Peronato, Jérôme H. Kämpf

Summary

District Heating Networks (DHNs) are part of the solutions towards a low-carbon energy transition for space heating, making an efficient use of renewable or waste energy sources. In early-stage planning, their potential is often evaluated at the demand side, using large-scale building energy models. However, from the financial and energy efficiency standpoints, the actual potential is also depending on the development of the physical pipework connecting the supply heating station with the substations. To this end, this work proposes a framework for the automated generation of a plausible network layout by solving a minimum spanning tree problem connecting the different stations and assigning a sizing peak power to each network element. Although fully adaptable to data available in other contexts, the current implementation relies on Swiss open geodata to provide a quick analysis for any location in Switzerland without almost any user input required.

Keywords: district heating networks; feasibility studies; software toolkit.

1. Introduction

District Heating Networks (DHNs) are energy systems distributing heat generated in a central location to multiple building consumers using an insulated pipework. By the efficient use of local waste and renewable energy resources, also withing cogeneration plants, district heating systems provide a viable solution to decarbonized heat supply to buildings.

Due to the long-term investment (Colmenar-Santos et al., 2017, Chapter 3), DHNs require careful planning. Typical regional-scale potential assessments or early-stage viability studies (Bush & Bale, 2019; Gils et al., 2013) are commonly done predicting heating densities and hence selecting locations achieving a minimum threshold for DHN viability. However, the viability of a network is also depending on the necessary pipework to connect all substations to the heating station(s) (Best et al., 2020).

Conceived as a modular toolkit, DHgeN provides easy access to existing models as well as custom ones for the generation of a plausible network path and predicting the peak power of the network nodes. Unlike existing optimization solutions (Best et al., 2020), it focuses on straightforward application of existing graph theory models from available geodata. To this end, it implements a simple building peak power demand adapted to the Swiss context (§2.1) as well as existing models (§2.2) from the popular Python library Networkx. Already at the current development stage, thanks to the presence of open data in Switzerland, the generation can be done without almost any user inputs.

2. Methodology

2.1 Model of the peak power demand

The peak power demand [W] of buildings is modeled as follows: $\mathrm{P} = A \cdot \Delta T \cdot U$, where ΔT is the difference between the indoor T_{int} and outdoor temperature T_{out} [K], U is the standard envelope U-value (W/m^{2}K), and A is the building envelope area [m^2] calculated assuming a squared footprint and a 3-m floor height using the following equation: $\mathrm{A} = 4\sqrt{area_{footprint}} \cdot 3\, n_{floors} + 2\, area_{footprint}$. In Switzerland, the $area_{footprint}$ and n_{floors} , the period of construction and xy coordinates of each building can be automatically retrieved from the Swiss Federal Register of Buildings and Dwellings (RegBL) available through an open API. The envelope U-value is set using the calibrated wall U-value for typical Swiss buildings for different periods (Perez, 2014, p. 177) and SIA Norm 380/1:2009 for the most recent values. The T_{int} and T_{out} can be set by the user, for example using standard values from the Swiss Society of Engineers and Architects (SIA). Depending on the building use, a power density of 1 to 3 $W/m^2{}_{\text{floor area}}$ is also included, while internal loads, solar gains and window losses are not considered. Current results are bounded to recommended power-to-floor-area densities for non-labeled buildings, i.e., a minimum of 25 $MW/m^2{}_{\text{floor area}}$ (i.e., for recent buildings) and a maximum of 80 $MW/m^2{}_{\text{floor area}}$ (i.e., for poorly insulated commercial buildings).

2.2 Model of the network layout and power distribution

An initial network G is modeled as a regularly spaced grid, where the width and length of the cell nodes (by default 25 m) and rotation (by default 0°) can be set by the user. If street data is added, a network S is created from the vector paths, which are densified to the same resolution as G; each node of S is then connected to the closest node of G. The minimum spanning tree connecting all heating (sub)stations is computed using Networkx's approximate Steiner tree model with the weight set to the edge length. The Steiner tree method is commonly used for optimizing electrical grids and has been already implemented in DHN layout optimization (Delmastro et al., 2016). The S edges are weighted by a [0,1] parameter set by the user, where a lower value can be used to give a priority to street over grid edges. The non-directional network is then transformed into a directional graph originating from the heating station, whose spatial location can be set by the user, resulting in a typical branched DHN. Finally, the peak power of each edge of the network is computed using NetworkX simplex network model, using as demand the substations power (calculated in §2.1) and as weight the edges' length.

2.1 Implementation

The models are coded in Python and can be called as part of an automated data-processing pipeline. For locations in Switzerland, all the input data requirements (buildings data and street paths) are automatically retrieved using the REST API from the Swiss Federal Office of Topography Swisstopo.

3. Test-case application

The model is applied to the area of the municipality of Broc (Switzerland) where a DHN is currently in operation and data is available from previous studies.

3.1 Presentation of the case study

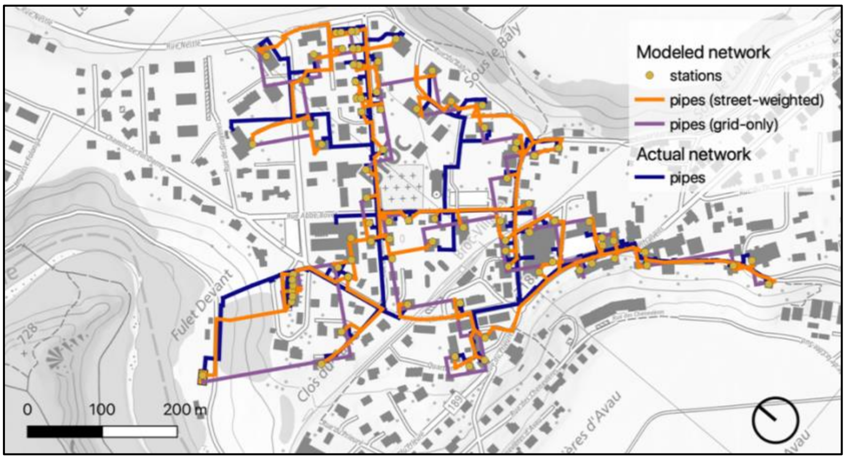
The DHN in Broc is composed of 85 substations connected to a 3.6 MW heating station located at the North-West boundaries of the village. It is to be noted that currently one of the substations, corresponding to the church, does not have an entry in the RegBL and for this reason is not included in the modeled network. In addition, since only a subset of buildings within the area is connected to the actual DHN, the application of the model was manually limited to these buildings by filtering the RegBL entries by their *egid* identifier. In addition, 4 records without some fields, were modeled using default values of n_{floors} = 2 and U =1.35 W/m^2K.

3.2 Application of the generator

The generator was applied using two different strategies: 1) a network based on a 25x25-m grid rotated by 50° and 2) a network also following the street graph with a 0.3 weight. The resulting layout solutions are compared in Table 1 and Figure 1 to the actual network. The layout and the length of the modeled networks present similar figures, while the power of the heating station (resulting from the application of the model of §2.2 to 84 out of 85 buildings) is significantly underestimated.

Tab. 1: Comparison of some relevant figures of the actual and modeled networks.

	Actual network	**Modeled network**	
		Grid-only	**Street-weighted**
Length of pipework (out)	3860 m	3984 m (+3%)	4500 m (+17%)
Peak power of the heating station	3.6 MW	2.34 MW (-35 %)	
Number of substations	85	84	



Background: Swiss Map Raster 10 ©swisstopo

Fig. 1: Results of the paths generated by the model compared to the actual path of the DHN in Broc (Switzerland).

4. Conclusions

This extended abstract has given an overview of the models at their current development stage. By using this tool, which is expected to be released soon as open-source software, the user can test different planning scenarios, notably for choosing the optimal location of the heating station, minimizing the length of the pipework and/or the maximum power of the pipes.

The output of the models has been compared to the layout of an existing DHN showing quite realistic modeled layouts. The peak power demand is underestimated, however the method for determining the subscribed power (used here as ground truth) is not known and is likely to include safety margins also for future extensions. Inclusion of a detailed physical model is expected to improve such results.

Expected on-going/future development is done on the following tracks:

- Integration of further goals/constraints, notably avoiding passing too close existing buildings;
- Simulation of hourly building demand and peak power using CitySim;
- Integration of DHgeN as part of the under-development pyDHN Python module;
- Deployment of DHgeN as part of a calculation module in a web platform.

5. References

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