DataRen, a Territorial Energy Demand Modelling Tool

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Abstract. This paper presents a tool allowing for characterization of heat, electricity and cooling demand for any portion of the territory of the Canton of Geneva (Switzerland). This project is conducted in cooperation with the local energy utility company Services Industriels de Genève and its final goal is to offer to all stakeholders a uniform spatio-temporal database to be used for the purpose of territorial energy planning. The added value is to consolidate the various data and estimations models into a single data container and to share the resulting data (GIS and hourly load curves) on a web-service platform. The model behind the tool operates in two steps. First the yearly demand of the various energy services (space heating, domestic hot water production, electricity, comfort cooling and process cooling) are estimated at building level, whenever possible using energy bills. Data gaps are filled using statistical extrapolations models. In a second step, these annual aggregated demands (at district level) are characterized in terms of hourly dynamic, for a common reference year, by re-scaling monitored load curves collected on various case studies. Finally, for a chosen district the tool evaluates the impact on energy demand of some prospective scenarios, as adding of new buildings and / or retrofitting existing ones.

Nomenclature

AC air conditioning (cooling)
HDD₁₂²° heating degrees day (outside air temperature: 12 °C; inside air temperature: 20 °C)
DHW domestic hot water
FBI federal building identification
GIS geographic information system
SIG Services Industriels de Genève (local utility)
SH space heating

1. Introduction

Realization of the energy transition will require both, reduction of the energy demand in buildings and substitution of fossil fuels by renewable energy. However, strategic planning for exploiting renewable resources requires a fair knowledge of the spatial-temporal distribution of local resources and of the energy demand of the related building stock.

Such is in particular the case for the heating and cooling sectors, since transportation over large distances is prohibitive. Moreover, these issues are specifically relevant for existing and dense urban districts, once sufficient demand density makes the integration of thermal networks cost effective, and where coincident heating and cooling demand may represent an important potential for synergies.
The goal of this study is to set up a homogeneous spatio-temporal demand database for any existing district of Geneva (Switzerland). Since the construction of heat and electricity loads has already been presented before [1], in this paper we focus on the methodologies to evaluate the cooling load and to create simple prospective scenarios. Most of the demand (GIS-data for annual values) comes from various existing databases, which are compiled and completed for the sake of this study. District aggregated data (in terms of hourly dynamic over a common reference year – 2015) is obtained by re-scaling of actual, monitored load curves.

2. Energy demand evaluation

2.1. Heat demand

Annual values for SH and DHW demand are derived from the heating index database of the Canton of Geneva [2], which contains GIS information, at building level, concerning the heated floor area, the associated energy career, as well as the climate corrected final energy for heat production, measured over several years of operation. The missing data is derived from a recently developed GIS heat demand model of the Swiss building stock [3]. An average heat production efficiency per energy carrier converts the final energy demand into useful energy demand [2], and finally, SH demand is estimated by subtracting the DHW demand, itself derived from standard values for different building categories [2]. This procedure allows setting up a GIS database covering the entire Canton, Fig. 1 and Fig. 2 show SH and DHW demands of a specific urban neighbourhood in Geneva. At aggregated level, the total Canton demand sums up to 4'575 GWh of annual heat demand (3'460 GWh SH, 1'115 GWh DHW) for a total heated surface of 45.4x10^6 m².

Hourly profiles of these spatially aggregated demands are constructed by the upscaling the aggregated and normalized SH and DHW load curves of the Laurana multifamily residential complex (33.5x10³ m² of heated surface), also situated in Geneva, which is connected to a district heating network [4]. In 2015, the annual heat consumption of these buildings (measured at the level of the 6 substations), amounted to a total of 4.3 GWh (69 % SH, 31 % DHW). The representativeness of this specific building complex of the 60s, in terms of load profile, could be questioned. However, the comparison of 5 different district heating networks situated in Geneva, covering various building categories and age, shows a very homogeneous behaviour in terms of load duration curves [5], which speaks in favour of our procedure.

The resulting 2015 load curves for the Canton are presented in Fig. 3, in terms of hourly and daily average values. Hourly peak values amount to 1'460 MW SH and 330 MW DHW, for a combined 1'540 MW total heat demand (non-simultaneous peak loads). Daily average peak values amount to 1’170 MW SH and 170 MW DHW, for a combined 1’330 MW total heat demand.

Figure 1. Geo-localized SH demand for an urban neighbourhood of Geneva.

Figure 2. Geo-localized DHW demand for an urban neighbourhood of Geneva.
2.2. Cooling demand

Annual values for cooling demand are derived from authorization requests database for centralized AC units in Geneva, covering the 1980–2013 period [6], which contains information at building level of the nominal thermal load and of the building category / usage type. At Canton level, the 929 registered AC units totalize 274 MW nominal capacity (180 MW for comfort cooling and 94 MW for datacentre cooling units, Fig. 4 and Fig. 5 show comfort and datacentre cooling demand for a specific neighbourhood.

Hourly profiles of these spatially aggregated demands are reconstructed by re-scaling the aggregated annual cooling demand of the 16 MW GLN district cooling network [7], also situated in Geneva, for which hourly data of the 7 substations for the year 2015 was provided by the local utility company SIG.

In the case of the GLN district cooling network, there is no distinction between comfort and datacentre consumption. The datacentre demand is evaluated by assuming that there is no comfort cooling demand when the external temperature is below 15 °C and global irradiance on horizontal plane is below 500 W/m² (values measured at Geneva’s city-centre meteorological station [8]). During this period, we characterize the datacentre demand by way of a multilinear regression model, which takes into account external temperature, global irradiance, working versus non-working days, as well as day versus night periods. The model is applied to the entire year, which yields the annual cooling load for the datacentres. By subtraction from the total cooling load, we finally estimate the load for comfort cooling. Note that during the hot summer days we occasionally observe a strong drop of the total cooling load, which reaches the modelled datacentre demand, apparently corresponding to periods without comfort cooling (Fig. A, Appendix). This corroborates the validity of the datacentre load estimations.

The resulting load curves for the Canton are presented in Fig. 6, in terms of hourly and daily average values. Hourly peak values amount to 170MW for comfort and to 95 MW for datacentre cooling, for a combined 255 MW total cooling demand (non-simultaneous peak loads). Daily average peak values amount to 130 MW comfort and 75 MW datacentre, for a combined 205 MW total cooling demand.

Figure 3. Aggregated heat load curves for SH (red) and DHW (blue) for the Canton of Geneva, hourly values (light colors) and daily average values (dark colors).
2.3. Electricity demand

Annual values for electricity demand were provided by the local utility company SIG, with distinction between residential and non-residential purposes, totalizing an aggregated annual value of 2.9 TWh (1.1 TWh residential, 1.8 TWh non-residential). The resulting load curves for the Canton are presented in Fig. 7, in terms of hourly and daily average values. Hourly peak values amount to 425 MW and daily average peak values amount to 340 MW.

At this point, the representativeness of the aggregated Cantonal load curve for a specific district at Geneva remains an open question, which certainly speaks in favour of further studies, in particular for disaggregation of the diverse electricity usages as done in [9].
3. Database consolidation
To export the results in a faster and proper way, annual demands of the exiting building stock (cooling, heating and electricity) have been implemented on a SQL database which can be queried from a web-service using the federal building identification (FBI) as query key. From total annual demand, different load curves are straightforward exported using the previously shown re-scaling models (Fig. 8).

It is also possible to simulate new buildings or thermal building retrofit by indicating the new heated surface, additional heating demand, as well as cooling and electric power. The additional heating demand of future buildings is estimated using statistics of the existing buildings constructed in Geneva after 2010.

4. Prospective scenarios for the heat demand of Geneva
As an example of the added value of this input / output approach, three different scenarios were created in such a way to evaluate Geneva’s heat demand by 2035, taking into account demographic evolution, evolution of heating degrees-days (HDD) and different retrofit ratios. When compared to the 2015 value, by 2035 we expect 3.5 % additional heated surface (+1.6x10^6 m^2, [10]) as well as 17.7% reduction of
HDD (-215 K.day, estimation made from temperature measures at Cointrin for the period 1961–2017 [11]). For the new buildings, we further suppose that the distribution among the different categories remains the same, except for single family houses (for which we assume that the stock remains unchanged, following the Canton’s policy to densify existing neighbourhoods [12]).

Retrofit scenarios focus on multifamily buildings (52% of the Cantonal heated surface), in particular the ones constructed in the 1961 to 1980 period (15% of the Cantonal heated surface, 18% of the Cantonal heat demand for SH and DHW). For the first scenario (GE 2035), no retrofit is implemented; for the second one (GE 2035 1%), we consider a retrofit rate of 1% per year; for the third one (GE 2035 2.5%), the retrofit rate amounts to 2.5% per year. The buildings to be retrofitted are chosen as the ones with the highest specific SH consumption (kWh/m²/year), even if we are aware that retrofit decision process may be based on other criteria, for example as a response to a local policy [13]. The SH load curves for three scenarios are shown on Fig. 9 (right).

For the GE 2035 scenario (no retrofit), the expected reduction of annual heat demand is of 4% (197 GWh/year), HDD reduction over-compensating for increase in heated surface. For the 1% and 2.5% retrofit rates, the reduction of annual heat demand is of 7% (330 GWh/year) and 9% (426 GWh/year) respectively. In comparison, the total heat consumption (SH + DHW) of a dense Geneva’s neighbourhood with 17’130 inhabitants and 1.6x10⁶ m² of heated surface (Fig. 1 and 2) is estimated to 175 GWh/year [1].

5. Conclusion
By compilation of existing data from various sources, combined with simple re-scaling algorithms, we set up a homogenous demand database, comprising annual GIS-data, as well as district aggregated data on hourly basis over a common reference year.

The database should serve as a basis for evaluation of diverse strategies concerning the integration of renewable resources and the creation of prospective scenarios. With availability of further basic data and / or in combination with models developed within the SCCER FEEB&D, the methodology could possibly be extended to the Swiss territory.

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Appendix. Measures and model estimation for datacentre cooling power
Figure A shows the measured (total load) and modelled (datacentre) cooling loads. The analysis is made on hourly basis, yet the results are present on daily basis. The datacentre model is applied when the hourly external temperature is lower than 15 °C and when the global solar irradiance on horizontal plane is lower than 500 W/m².

Figure A. 2015 relative total cooling (red) and modelled datacentre cooling (blue) power on daily basis for GLN cooling district 2015. Global solar irradiance on horizontal plane (Gh) and external temperature (Text) are also shown.