Joint Activity Scenarios and Modelling

HOURLY DEMAND PROFILES FOR SPACE HEATING AND ELECTRICITY

Selin Yilmaz[a]
Portia Murray[b]
Andrew Bollinger[b]
Gianfranco Guidati[c]

[a] University of Geneva
[b] EMPA
[c] ETH Zurich

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Contents

Chapter 1

Heating demand modelling – CESAR model

> Data available at https://data.sccer-jasm.ch/demand-hourly-profile-retrofits-cesar/

1.1 Scope of the analysis

Jointly with the project SNF EnDK EnTeR (Murray et al., 2019), building level information has been collected for the overall building stock of Switzerland. Information is gathered from three main sources, which are provided by the Federal Office for Statistics (BFS), by the Swiss Competence Centre for Energy Research (SCCER), and by the Federal Office for Topography (swisstopo). Respective databases pertain to the Swiss building- and apartment-registry (für Statistik, 2013), where information on individual buildings is available. Additionally SCCER's geo-dependent energy supply/demand web service (Schneider, 2018) was used, which provides estimations of average heat demand of Swiss buildings on a per-area basis (squares of 200m by 200m) and heating demands of each individual building. Swisstopo data on geometry information is used (Swiss Federal Office of Topography, 2016) to evaluate floor area and height of buildings. After combining the different building databases and cleaning the dataset, a total of approximately 800'000 buildings are remaining. Among those, 230'000 are multi-family houses (MFH) and approximately 440'000 are single-family houses (EFH). The remaining buildings pertain to the public, industrial or commercial sector.

1.2 Identification of residential building archetypes

Switzerland's residential building stock is composed of approximately 1.8 Million buildings, 32% of which are single family homes (SFH) and 16% of which are multi-family homes (MFH) (Bundesamt für Statistik, 2013). To define representative archetype buildings, clustering techniques on various building characteristics are deployed. In order to effectively cluster, information such as building area, age of the building, energy demand, climatic region or renewable energy potential is collected. Relevant features, which are used for the clustering, are summarized in Table 1.1

In this analysis the Swiss building stock has been condensed to 50 multi-family buildings (MFH) and 50 single-family buildings (SFH). For this clustering, an algorithm was selected (further details are provided in Niffeler (2018)), which relies on the Euclidean distance as a measure of similarity between the different data points, i.e. the buildings in this case. The subset of properties, which were deemed to be most relevant to the selection of archetype SFH, are the district's location, floor area, building height, construction period, energy carrier for heating, energy carrier for hot water, and number of residents. In addition to these properties, the number of dwellings in each building is used in the selection of archetype MFH. Due to the very large data set used for clustering in this approach, this method is particularly effective since it is deterministic and will result in the same set of clustering solutions every time it is run. Other clustering methods, such as k-means or medoids, take very long times to run for large data sets and due to the number of residential buildings, the nearest neighbour clustering method was preferred.

Table 1.1: Features used for clustering of the residential buildings (Murray et al., 2019)

Features	**Databases by**		
	BFS	**SCCER**	**swisstopo**
GIS building code			x
Identifier of municipality	x	x	x
Identifier of canton	x	x	x
Postal code	x		
Building coordinates	x	x	x
Classification of construction zone			x
Building category BFS	x		
Building category SCCER		x	
Number of dwellings in building	x		
Number of residents	x		
Number of main residents	x		
Construction period	x		
Number of floors	x		
Building height			x
Ground floor area			x
Total floor area		x	x
Estimated total heated surface		x	
Heating system	x		
Energy carrier for heating	x	x	
Availability of hot water	x		
Energy carrier for hot water		x	
Heating demand		x	
Domestic hot water demand		x	
Final energy demand for heating and domestic hot water		x	

1.3 Identification of non-residential building archetypes

Non-residential buildings in Switzerland are registered in the NOGA database, which assigns to each building a business category (Bundesamt für Statistik, 2008). The most prevailing business categories are selected and assigned to the archetype categories shops, offices, restaurants and hotels, schools and hospitals (Carp, 2018). In a next step, the non-residential building stock was assigned to these categories and the floor area, building height and building period of all buildings, based on the GWS database (für Statistik, 2013) was used for the k-medoids clustering analysis. The clustering resulted in 45 archetype buildings for the non-residential building stock, which are summarized in 1.2

Table 1.2: Non-residential categories considered in the analysis, and the number of archetypes considered for each (Murray et al., 2019)

Building type	**Number of Archetypes**	**Total number of buildings represented**
Restaurants	9	6380
Schools	9	2115
Hospitals	9	4453
Offices	9	11202
Shops	9	7512
Total	45	31662

1.4 Energy demand calculations

Energy demand calculations for archetypical buildings are performed using the tool CESAR "Combined Energy Simulation and Retrofitting" (Wang et al., 2018). This tool utilizes the building simulation engine EnergyPlus (NREL, 2015) to calculate hourly electricity, heat and cooling demand profiles of buildings within a district over a period of one year. Geo-spatial information pertaining to building floorplans and their height (2.5D shape) is used to represent the geometry of buildings. Neighbouring buildings are considered as shading objects. Schedule files are derived from SIA 381/1. As additional input information for the simulations pertains to age, type, and the primarily used energy carriers for heating and domestic hot water. Internal conditions pertaining to occupancy, equipment and lighting patterns are taken from SIA 2024. Heating loads are ideal loads and do not include the heating system technology. Hourly energy demand calculations are performed for all archetype buildings for 8760 hours, whereby weather conditions of the different climatic regions are represented by 52 weather files based on SIA 2028 climate regions (SIA, 2010).

1.5 Calculating the effects of building retrofitting

An additional module of CESAR allows for evaluation of different envelope and other energy efficiency measures in addition to the current energy demand of the buildings. Thereby envelope measures such as insulating different surfaces or replacing windows can be evaluated. In case of retrofitting existing construction elements, the archetypical constructions per building age are taken and modified in order to meet current energy efficiency standards.

1.6 Hourly heating demand profiles

The analysis above entailed the simulation of 145 building archetypes (100 residential, 45 non-residential) each under 7 different retrofitting scenarios and 54 different climate zones in Switzerland. In total, this resulted in 54,810 annual, hourly-resolution energy demand profiles for heating, cooling and electricity. A selection of these results is provided on the JASM data platform[1]. As illustration, Figure 1.1 and Figure 1.2 show the overlaid hourly heating demand profiles for 2 building types – multi-family houses (50 different archetypes) and hospitals (9 different archetypes) – simulated under different retrofitting scenarios and different climate conditions.

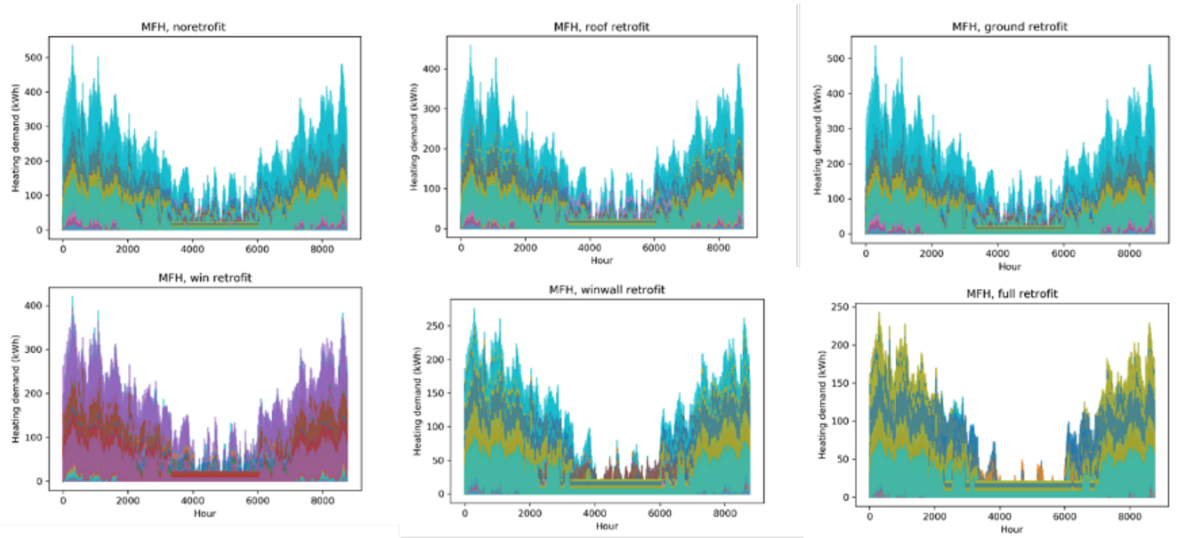


Figure 1.1: Simulated hourly heating demand profiles for 50 different multi-family house archetypes, calculated under different retrofitting scenarios and 54 different climate conditions. Retrofitting scenarios include no retrofit (noretrofit), roof retro-fit, ground retrofit, window (win) retrofit, window + wall (winwall) retrofit and full retrofit (all of the above)

[1] https://data.sccer-jasm.ch/demand-hourly-profile-retrofits-cesar/2020-02-28/

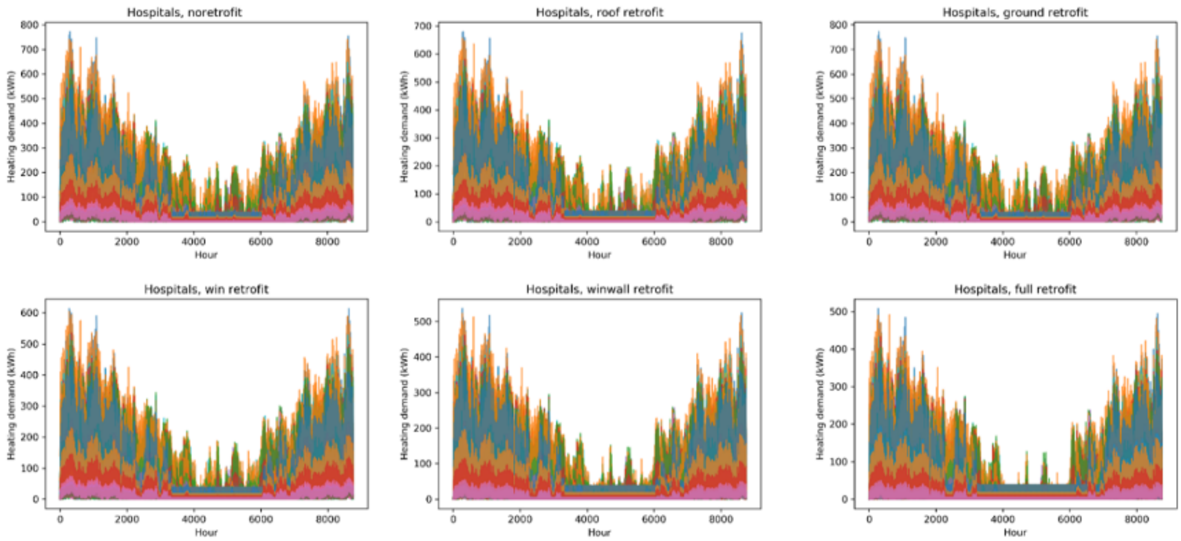


Figure 1.2: Simulated hourly heating demand profiles for 9 different hospital archetypes, calculated under different retrofitting scenarios and 54 different climate conditions.

Chapter 2

Decomposition of household electrical appliances

> Data available at https://data.sccer-jasm.ch/household-daily-load-curves/

2.1 Current household appliance electricity demand (2015)

Household electrical appliances include all those appliances typically found in homes such as 'wet' appliances (washing machines, tumble dryers, dishwashers), 'cold' appliances (fridges, freezers), cooking appliances, audio-visuals (televisions, Hi-Fi's) and many more. An existing model of the appliance stock and its electricity demand for 2015 and 2035 developed by authors (Yilmaz et al., 2019, Heidari et al., 2018, Heidari and Patel, 2020) are used for wet, cold and cooking appliances, TVs and computers (including printers), and lighting to model the electricity consumption. A bottom-up appliance electricity demand model was developed and applied that generates daily residential electricity demand profiles for appliance use in 2015. The model allows to modify key parameters (e.g. appliance ownership or average power depending on the appliance stock composition) in order to evaluate the impact of energy efficiency measures and future appliance stock on the total electricity demand profile (Yilmaz et al., 2020). The stock model was constructed based on the principles of material flow analysis (Kleijn et al., 2000, Melo, 1999). As first step, the appliance stock is determined using estimated ownership levels by type of appliance in Swiss house-holds from representative surveys VSE, 2005; VSE, 2015; SHEDS (Weber et al., 2017). The Swiss appliance stock of a given year is determined by multiplying the ownership levels by the number of households present in Switzerland. The dynamic changes in the stock are determined by the sales of appliances (entry of appliances into the stock) and the probabilities of obsolescence, allowing to represent the number of appliances which have reached their lifetime and are hence leaving the system as waste flow. This type of calculation is repeated for each product group and for each year in the period 2015–2035. The number of appliances by label class is estimated on the basis of the shares of each label class sold according to annual sales data published by FEA. It was taken into account that stricter minimum energy performance standards were introduced in Switzerland in 2015 (e.g. A++ refrigerators as opposed to A+ according to EU regulations and class A+ for tumble dryers instead of class B in the EU). After 2015, all appliances sold are assumed to be at least A++, and A+++ after 2020 depending on the rate of increase of the shares of each label (A++ and A+++). Finally, when calculating the lifespans, we use empirical parameters which were determined for the Netherlands and were also used in the United Nations University Guidelines on classification (Wang et al., 2013). To account for the latter and in view of the absence of comparable information for Switzerland, we use the French Time Use Data (TUD) survey from September 2009 to October 2010, collected by INSEE (INSEE, 2010). Due to unavailability of monitored data of individual appliances by energy efficiency label, a standard power demand is calculated depending on the weighted average of different energy efficiency labels existing in the Swiss stock. The standard consumption is defined by the authorities in accordance with Annex VII of the European Commission in which the label class was converted into electricity consumption.

Figure 2.1 presents the structure of the bottom-up model of the electricity demand profile of a household. First, appliances are stochastically assigned to a household depending on the appliance ownership. For each appliance present in a household, we assume, a set of daily activity probabilities and switch-on prob-abilities (see left of the diagram), which represent the likelihood of people performing different activities and switching on different wet appliances at different times of the day. Using this data, the appliance usage and activities are modelled via Monte Carlo simulation for one year. Then power demand profiles of the respective appliances are attributed to build the electricity demand profile of one household. This procedure is repeated to simulate whole household stock.

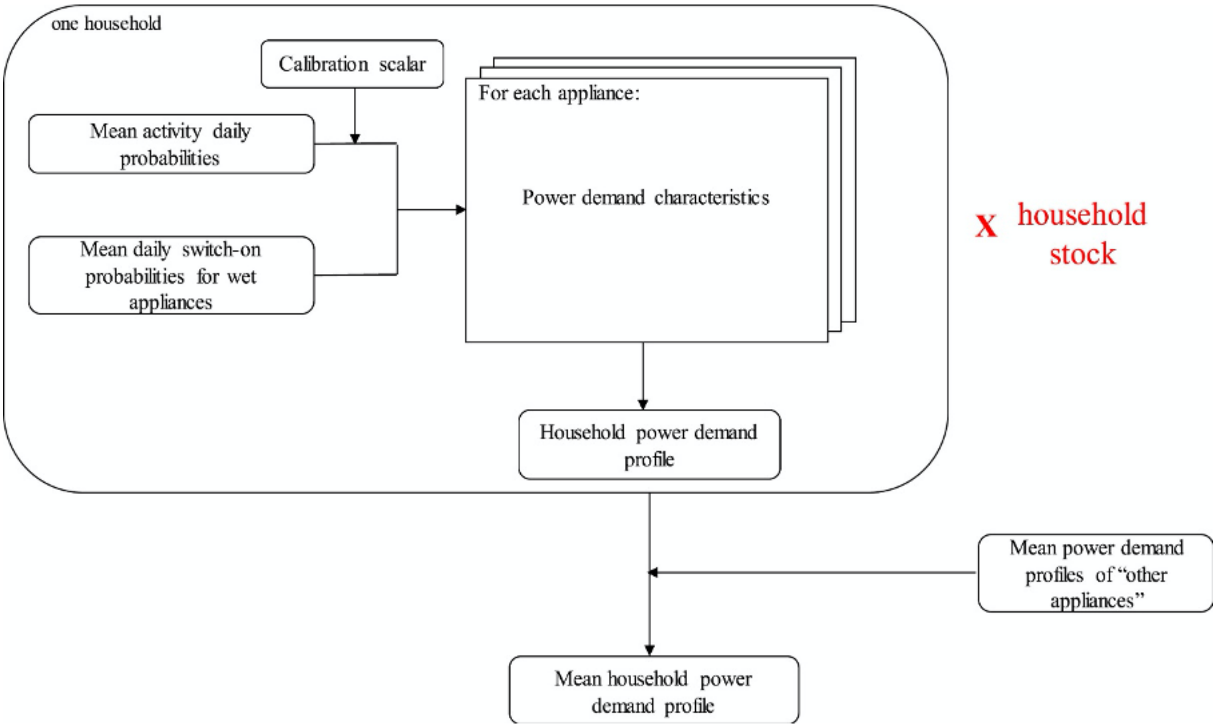


Figure 2.1: Schematic of bottom-up modelling of the household load profiles

2.2 Evolution of appliance electricity demand for 2035 and 2050

There are two distinct differences in our modelling assumptions for 2015, 2035, and 2050 i.e. ownership levels of appliances for a household and average power per appliance use/cycle. The other parameters determining energy use in 2035 and 2050 were assumed to remain unchanged: this concerns the frequency and duration of appliance use as well as the daytime at which households use their appliances. We made this choice because there was no data available to forecast any changes in habits. Figure 2.2 shows the electricity demand of the domestic appliances for 2015, 2035 and 2050.

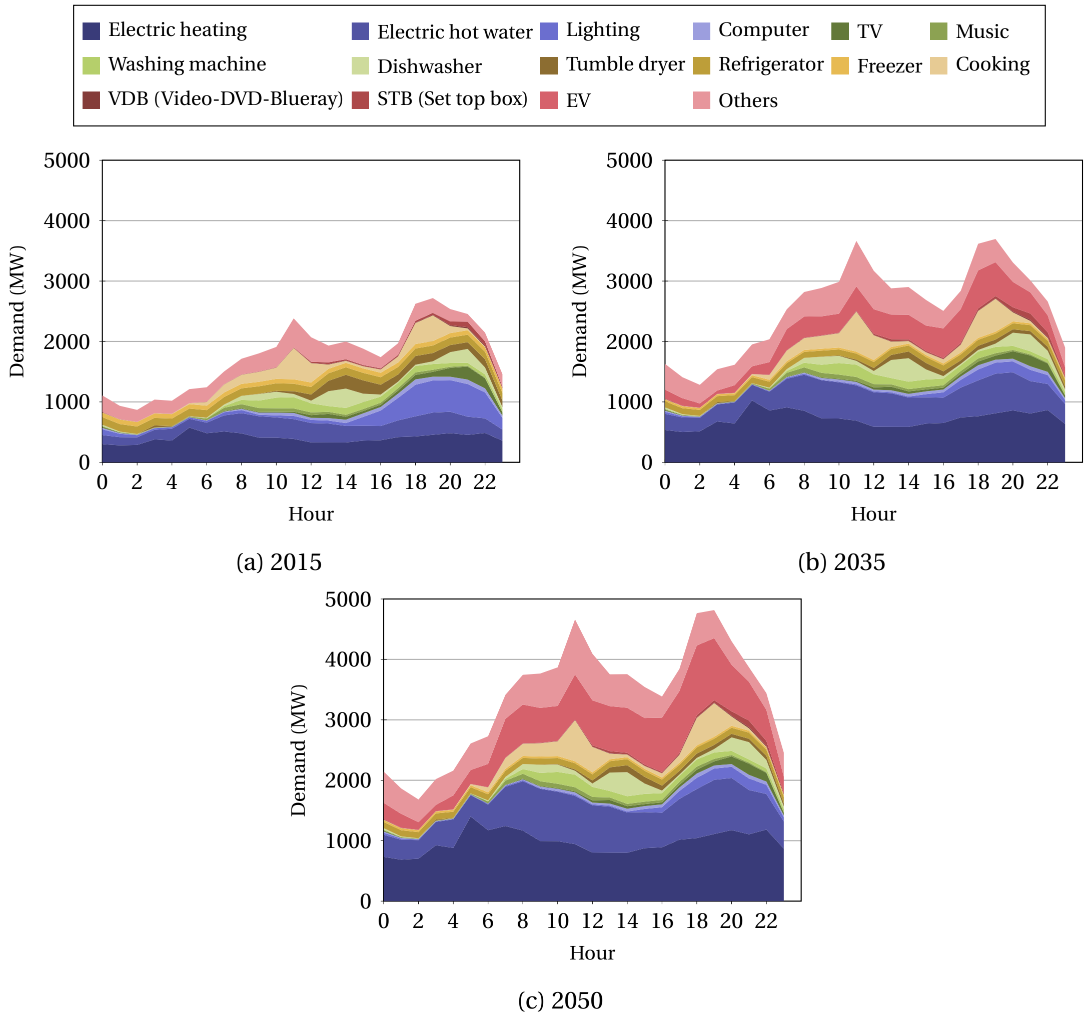
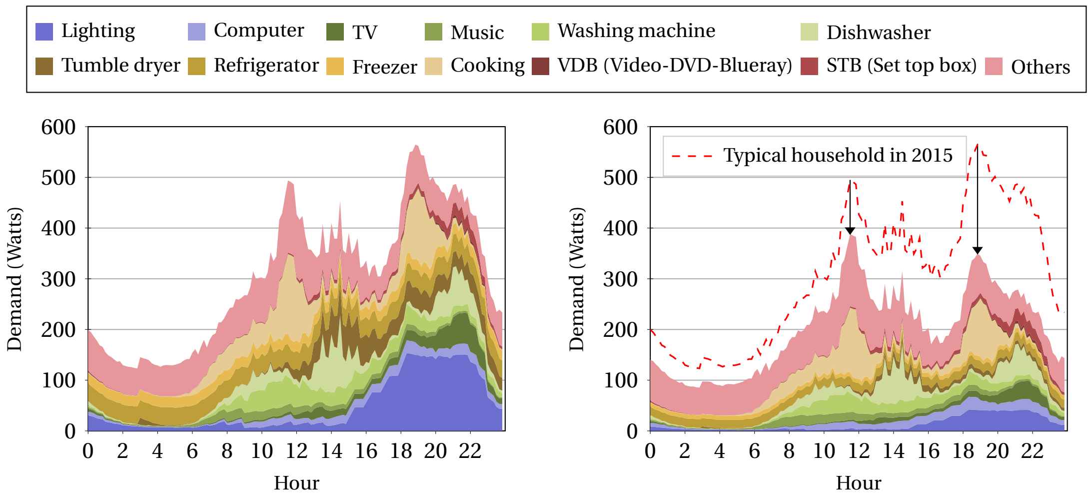


Figure 2.2: Comparison of the demand profiles of domestic appliances for the Swiss household in 2015, 2035 and 2050

To find out the potential peak demand reduction by most efficient appliances, appliances which are required to have energy efficiency labels according to the EU directive are replaced by the best energy efficiency labels which are currently on the market. TVs are replaced by LCD-LED models with the A+++ label. For electric hobs, only induction technology is used; exclusively LED light bulbs are implemented. Figure 2.3 shows the comparison of the mean electricity demand profiles of domestic appliances for a Swiss household in 2015 and best-case scenario in 2015.



(a) Current electricity demand (2015)

(b) Best-case scenario (2015)

Figure 2.3: Comparison of the mean electricity demand profiles of domestic appliances for an average Swiss household in 2015 and best-case scenario in 2015.

Chapter 3

Industry & Service sector load curves

> Results available at www.electrowhat.ch

University of Geneva collaborated with the local utility company SIG (Service Industriels de Genève) and developed the ElectroWhat platform that decomposes the yearly electricity consumption of every Swiss municipality. The estimated hourly load curves were modelled per sector branches, per day type and per month for 2015 for whole Switzerland. The results are published at www.electrowhat.ch. The electricity consumption calculations include Industry & services, common appliances and public lighting. An example of this is shown in Figure 3.1 for the total hourly electricity demand of Switzerland for different service and industry branches for a weekday and month as march for the year of 2015.

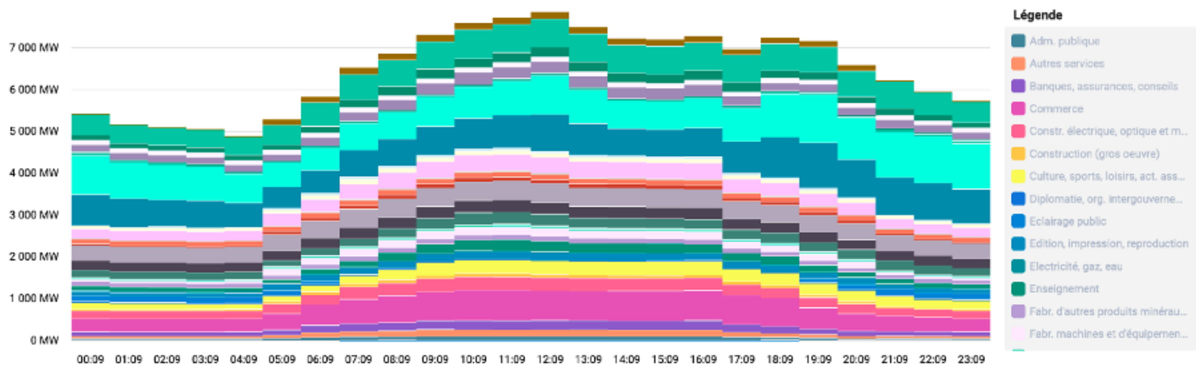


Figure 3.1: Total hourly electricity demand of Switzerland for different service and industry branches.

Industry and services: For each municipality, the estimation of the yearly consumption of the industry & services sector is based on the number of working places per NOGA activity code available in the STATENT database. This statistic is combined with unitary average consumption per working places and NOGA code. Considering the territory of Geneva and that of the EOSh group, these unitary consumptions are estimated using the total billed electricity per activity. For the remaining Swiss municipalities, the average unitary consumptions are calculated using a yearly national survey conducted for approximately 12,000 companies (Schneider et al., 2017) . Common appliances & public lighting: The number of collective dwellings is used as explanatory variable for these two demands. This assumption is based on the fact that public lighting (including traffic lights) is linked to urban density.

This approximation does not take account of specificities as for example extra urban highways and tunnels. Priority is given to unitary consumptions calibrated on local ESCO bills to take account of regional differences. For example, there are big differences between several Swiss regions in use practices of lighting in the common areas of buildings. For forecasting the future electricity demand from these branches, the development of dedicated methods and respective tools is still ongoing. Readers, modellers are encouraged to use their own economic models with the forecast of the activities (e.g. number of employees, value added) and energy efficiency potentials as well as decomposition tools to create their own scenarios for their energy system models for 2050.

Chapter 4

Heating demand modelling – HSR model

The demand for space heating is rarely measured on an hourly scale, we therefore rely on simulation results. These have been done for multi- and single-family houses, both for old and new buildings (see (Iturralde et al., 2019)). The resulting hourly time series represent the instantaneous power of the heat delivery system, e.g. a radiant floor delivered for actual buildings. Figure 4.1 depicts the normalized hourly profiles for the four archetypes (single and multi family houses, old and new).

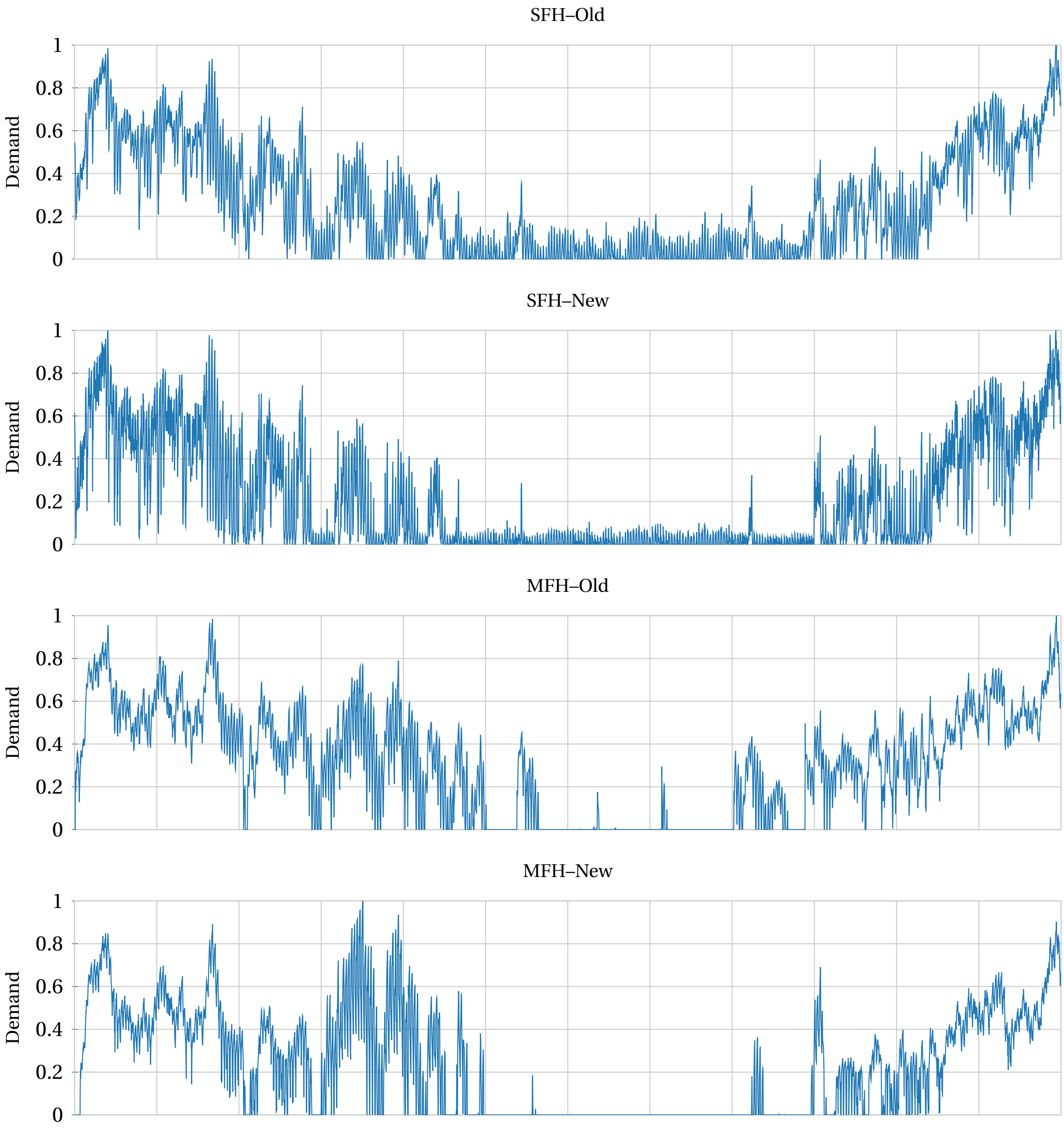


Figure 4.1: Hourly profile space heating (normalized)

Bibliography

Bundesamt für Statistik, 2008. Allgemeine systematik für wirtschaftszweige. URL: https://www.bfs.admin.ch/bfs/de/home/statistiken/industrie-dienstleistungen/nomenklaturen/noga.assetdetail.415633.html.

Bundesamt für Statistik, 2013. Swisstopogebäude und wohnungsregister. URL: https://www.bfs.admin.ch/bfs/de/home.html.

Carp, V., 2018. Quantification and Reduction Potentials of the CO2 Emissions of the Swiss Building Stock. Master's thesis. ETH Zurich.

Heidari, M., Majcen, D., van der Lans, N., Floret, I., Patel, M.K., 2018. Analysis of the energy efficiency potential of household lighting in Switzerland using a stock model. Energy and Buildings 158, 536–548. doi:10.1016/j.enbuild.2017.08.091.

Heidari, M., Patel, M., 2020. Stock modelling and cost-effectiveness analysis of energy-efficient household electronic appliances in Switzerland. Energy Efficiency 13, 571–596. doi:10.1007/s12053-020-09843-x.

INSEE, 2010. Enquête Emploi du temps. URL: https://www.insee.fr/fr/metadonnees/source/serie/s1224/.

Iturralde, J., Alonso, L., Carrera, A., Salom, J., Battaglia, M., Carbonell, D., 2019. Energy demands for multi-family buildings in different climatic zones D1.1. URL: https://doi.org/10.5281/zenodo.3763249, doi:10.5281/zenodo.3763249.

Kleijn, R., Huele, R., Voet, V.D., E, 2000. Dynamic substance flow analysis: the delaying mechanism of stocks, with the case of. PVC in Sweden. Ecol. Econ. 32, 241–254.

Melo, M.T., 1999. Statistical analysis of metal scrap generation: The case of aluminium in Germany. Resources, Conservation and Recycling 26, 91–113. doi:10.1016/S0921-3449(98)00077-9.

Murray, P., Marquant, J., Niffeler, M., Mavromatidis, G., Orehounig, K., 2019. EnTeR Project Report. chapter WP3 Measures and synthesis.

Niffeler, M., 2018. Analysis of optimum retrofit and energy systems solutions for the Swiss residential building stock. Master's thesis. ETH Zurich.

NREL, 2015. Energyplus. URL: https://energyplus.net/.

Schneider, S., 2018. Geodependent energy supply/demand web service. URL: http://wisesccer1.unige.ch/.

Schneider, S., Le Strat, P., Patel, M., 2017. Electro What: A platform for territorial analysis of electricity consumption. Energy Procedia 122, 92–97. URL: https://doi.org/10.1016/j.egypro.2017.07.376, doi:10.1016/j.egypro.2017.07.376.

SIA, 2010. Merkblatt 2028 – klimadaten für bauphysik, energie- und gebäudetechnik.

für Statistik, B., 2013. Gebäude und Wohnungsstatistik (GWS).

Swiss Federal Office of Topography, 2016. Swisstopo. URL: https://www.swisstopo.admin.ch/.

Wang, D., Landolt, J., Mavromatidis, G., Orehounig, K., Carmeliet, J., 2018. Cesar: A bottom-up housing stock model for switzerland to address sustainable energy transformation strategies. Energy and Buildings 169, 9–26.

Wang, F., Huisman, J., Stevels, A., Baldé, C.P., 2013. Enhancing e-waste estimates: Improving data quality by multivariate Input-Output Analysis. Waste Management 33, 2397–2407. URL: http://dx.doi.org/10.1016/j.wasman.2013.07.005, doi:10.1016/j.wasman.2013.07.005.

Weber, S., Burger, P., Farsi, M., Adan, L.C., Puntiroli, M., Schubert, I., Volland, B., 2017. Swiss Household Energy Demand Survey (SHEDS): Objectives, design, and implementation. Technical Report.

Yilmaz, S., Majcen, D., Heidari, M., Mahmoodi, J., Brosch, T., Patel, M.K., 2019. Analysis of the impact of energy efficiency labelling and potential changes on electricity demand reduction of white goods using a stock model: The case of Switzerland. Applied Energy 239, 117–132. URL: https://doi.org/10.1016/j.apenergy.2019.01.137, doi:10.1016/j.apenergy.2019.01.137.

Yilmaz, S., Rinaldi, A., Patel, M.K., 2020. DSM interactions: What is the impact of appliance energy efficiency measures on the demand response (peak load management)? Energy Policy 139, 2019. doi:10.1016/j.enpol.2020.111323.