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Update and extension of the When2Heat dataset

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Abstract. The “When2Heat” dataset comprises synthetic national time series for heat demand and heat pumps’ coefficient of performance (COP) in hourly resolution. Heat demands for space and water heating are computed by combining gas standard load profiles with spatial temperature reanalysis data and population geodata. With this update, we extend the dataset to 28 European countries and the period from 2008 to 2019, including new, state-of-the-art data sources. For the geographical extension, we propose a novel approach, shifting established German heat demand curves based on country-specific heating thresholds to account for regional differences in thermal insulation and user behavior. Using the example of Italy, we illustrate the effect of shifting heat demand curves. The dataset, scripts, and input parameters are publicly available under an open-source license on the Open Power System Data platform.

Published dataset:

This version: <https://data.open-power-system-data.org/when2heat/2022-02-22/>

Latest version: <https://data.open-power-system-data.org/when2heat/latest/>

1 Introduction

The dataset and its relevance. The When2Heat dataset provides simulated heat demand and COP time series in an hourly resolution for several European countries (Ruhnau et al., 2019b). Since its first publication in 2019, energy system technology and economic scholars have met the dataset with great interest. Heat electrification plays an important role in combatting climate change (Ruhnau et al., 2019a). Therefore, one frequent application is the analysis of heat electrification’s impacts on the power systems (Gea-Bermúdez et al., 2022; Heitkoetter et al., 2021; Siddiqui et al., 2021; Pavičević et al., 2020; Ruhnau et al., 2020).

Method and advantages. The When2Heat dataset is based on spatially resolved temperature data and uses a statistical approach to derive heat demand. In contrast to physical simulations using one national temperature time series, this approach accounts for geographical and behavioral smoothing, avoiding overestimation of the heating peak (Fajardy, Charitopoulos, and Reiner, *forthcoming*). Furthermore, Peacock et al. (2021) compared the When2Heat dataset with other approaches for simulating heating demand profiles. From all the assessed approaches, the When2Heat dataset exhibits the best fit with the validation profiles ($R^2 > 0.99$). In addition to the varying heat demand, Petrović et al. (2016) highlighted the importance of the variability in heat pump COPs.

Contribution. This paper presents an update and extension of the dataset based on new data sources and a novel approach that allows to transfer the German heat standard load profiles to European countries with different climatic conditions and, therefore, different building insulation standards.

New datasets. More precisely, the When2Heat dataset used weather data from the ERA-Interim dataset at the European Centre for Medium-Range Weather Forecasts (ECMWF), which was discontinued in September of 2019. Therefore, we switched to the new ERA5 dataset, also from the ECMWF, which allows us to extend our dataset until 2020 (Copernicus Climate Change Service, 2019). Furthermore, we replace annual numbers on final energy demand from the EU Building Database with the more recent and assumably more accurate data from the “Integrated Database of the European Energy System” by the Joint Research Centre (JRC-IDEES) (Mantzios et al., 2018).

Geographical extension. Finally, we geographically extend the When2Heat dataset from 16 to 28 European countries (Figure 1). The heating profiles are based on the German standard load profile method for the gas demand as a proxy for the heat demand in buildings. The parameters included in this method are specific to the German buildings stock, thus, the original When2Heat dataset comprised only 15 countries with similar building insulation characteristics. This limitation of standard load profiles was also stressed by Lombardi et al. (2022). To overcome this drawback and extend the dataset to all European countries, we adapt the method to local building insulation characteristics by considering national heating threshold temperatures.

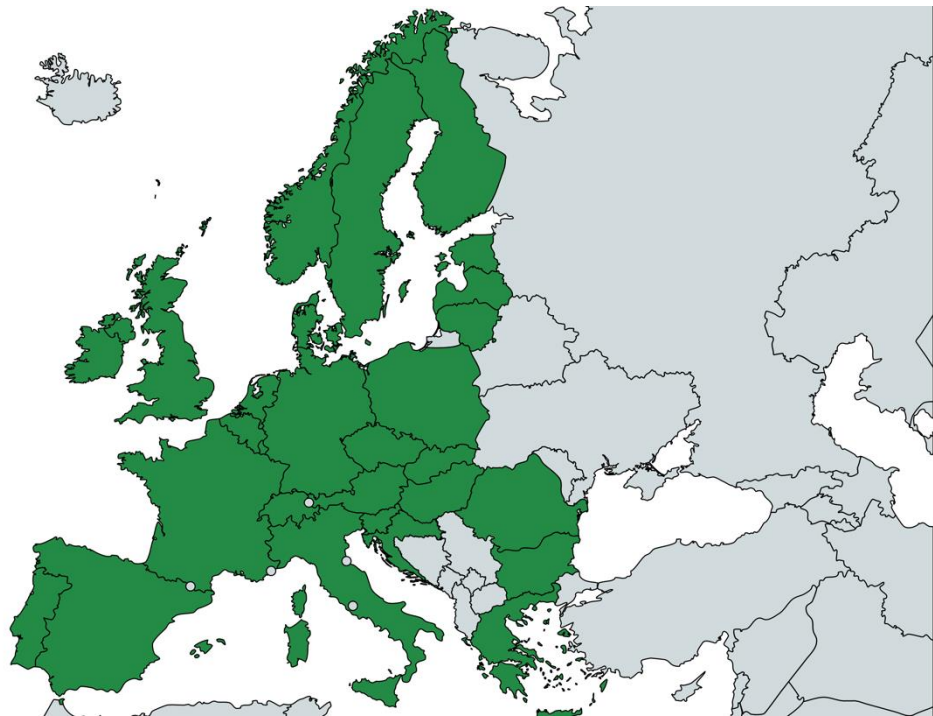


Figure 1: Countries included in the dataset (created with mapchart.net)

Outline. The remainder of this paper is structured as follows. The following section on the methodical approach explains the introduction of the new data sources, and the implementation of the geographical extension in detail. In Section 3, we summarize the results in general and illustrate the example of Italy. Furthermore, we discuss potentials for further research.

2 Method

Overview. This Section describes the data and methods applied for the update, comprising the data sources for weather and the annual national heat demand (Subsection 2.1), and extension, geographically and temporarily, of the When2Heat dataset, respectively (Subsection 2.2).

2.1 Update

Weather data. Regarding weather data, the When2Heat dataset originally used the ERA-Interim dataset from ECMWF. However, this was discontinued and replaced by the ERA5 dataset in 2019 (Copernicus Climate Change Service, 2019). Therefore, this update shifts toward ERA5 as a source for weather data. Note that the ERA-Interim dataset provided six-hourly time intervals, and interpolation was needed for our hourly COP calculations. By contrast, the ERA5 dataset features an hourly resolution, which eases the hourly COP calculations.¹ Otherwise, the utilization of the weather inputs has not changed.

Annual heating demand. The hourly heat demand profiles are scaled with annual statistics of national heat demand, which was obtained from the EU Building Database² in the previous version of the When2Heat dataset. With this version, we introduce annual heating demand data from JRC-IDEES, which is widely used for other heat-related research projects (e.g., Thomaßen et al., 2021; Zeyen et al., 2021). The JRC-IDEES database has the advantage that it includes useful heating demand, making it obsolete to estimate and apply a conversion factor to transform final to useful demand, which was necessary for the EU Building Database. Hence, results can be expected to become more accurate. The JRC-IDEES reports useful heat demand until 2015, which we use to scale the heat demand profiles to absolute values (MW).

2.2 Extension

Differentiating insulation. National standard load profiles are specific to the local physical building properties. For example, the German standard load profiles are specific to the insulation of the German building stock. The main idea on which we base the geographical extension of the When2Heat dataset is that the heat demand in countries with better insulation features similar profiles at lower ambient temperatures. Conversely, we assume that the heat demand in countries with weaker insulation features similar profiles at higher ambient temperatures. The heating threshold captures this relationship: the better the insulation, the lower the heating threshold (Figure 2). Behavioral differences and measurement errors may explain deviations from this general relationship.

¹ Because of the thermal inertia of buildings, the heat demand is based on daily average temperatures and the intra-daily temporal resolution of the underlying temperature data is not relevant.

² Available at https://ec.europa.eu/energy/eu-buildings-database_en

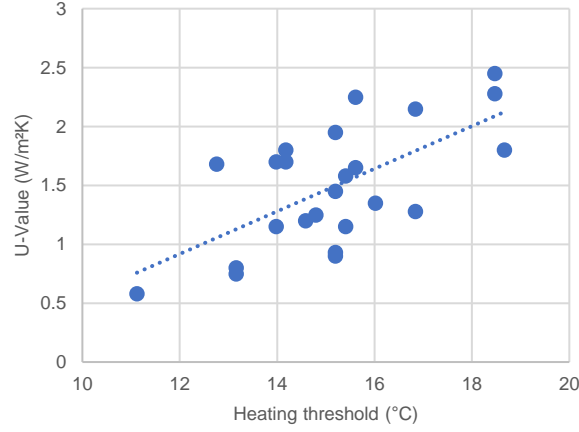


Figure 2: Building insulation (in terms of U-values) and heating thresholds in different European countries. Own illustration based on the EU Building Database and Kozarcanin et al. (2019).

Standard load profile method. Based on this rationale, we use national heating threshold temperatures as estimated by (Kozarcanin et al., 2019) to shift the profile function of the German gas standard load profile method (BDEW, 2015). For every day, d , and every location, l , the profile function defines the daily demand factor, $f_{d,l}$, as a function of the local reference temperature, $T_{d,l}^{ref}$, which is then shifted by the difference of the national heating threshold in comparison to that of Germany, ΔT_l^{th} :

$$f_{d,l} = \frac{A}{1 + \left(\frac{B \cdot ^\circ C}{T_{d,l}^{ref} - \Delta T_l^{th} - T_0} \right)^C} + D + \max \left\{ m_{space} \cdot (T_{d,l}^{ref} - \Delta T_l^{th}) / ^\circ C + b_{space}, m_{water} \cdot (T_{d,l}^{ref} - \Delta T_l^{th}) / ^\circ C + b_{water} \right\}, \quad (1)$$

Where:

$$\Delta T_l^{th} = T_l^{th} - T_{Germany}^{th} \quad (2)$$

Illustration. The parameters $A, B, C, D, m_{space}, b_{space}, m_{water}, b_{water}$ differ depending on building types, namely single-family houses, multi-family houses, and commercial buildings, while $T_0 = 40^\circ C$ for every building type. Figure 3 illustrates the shift of the profile function for the example of single-family houses in Germany, Italy, and Norway with heating thresholds at $13,98^\circ C$, $15,61^\circ C$, and $11,53^\circ C$, respectively Kozarcanin et al. (2019).

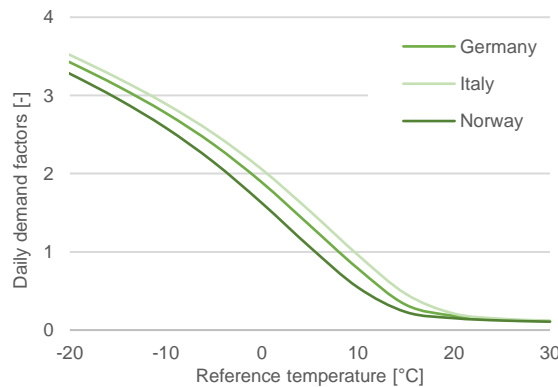


Figure 3: Daily heat demand factors as a function of the reference temperature. Exemplary profile functions for single-family houses for Italy and Norway are shifted by the difference of the national heating thresholds as compared to Germany.

3 Results

Data access. The resulting dataset is published open source at the Open Power System Data platform (see page 1). This section describes changes in the dataset due to the updated data sources and illustrates the method for geographically extending the dataset, respectively.

Updating weather data. Replacing ERA-Interim with ERA5 as a source of weather data did not yield significant differences in the results. Comparing the time series for the years 2008 to 2017 for the different dataset, we find a normalized root-mean squared error (RMSE) of 0.4% for heat demand and 1.7% for the COP³.

Updating annual demand data. Replacing the EU Building Database with the JRC-IDEES as a source for the annual heat demand has a somewhat larger effect. Interestingly, when comparing values from the EU Building Database with those from the JRC-IDEES, we find that values on annual water heating are similar. By contrast, data on space heating from JRC-IDEES is about 25% smaller than that from the European Building Database. Part of this can be explained by the distinction between final and useful heat demand, but the gap seems somewhat larger. Although we cannot fully explain this larger gap, we think that JRC-IDEES is a valid source for the reasons stated in Subsection 2.1.

Geographical extension. The impact of adjusting the profile function to the national heating threshold is illustrated in Figure 4 for the case of Italy. Compared to Germany, Italy has fewer cold days, which leads to the heat demand being more concentrated on fewer days of the year. This effect is captured by applying the unadjusted German profile function to Italian weather data (“IT not adjusted”). However, this concentrating effect is alleviated by the fact that Italy starts heating at higher ambient temperatures than Germany, mostly because buildings are less insulated. This alleviating effect is captured by adjusting the German profile function to the Italian heating threshold (“IT adjusted”). Still, the adjusted heat profile in Italy is more concentrated than the German profile.

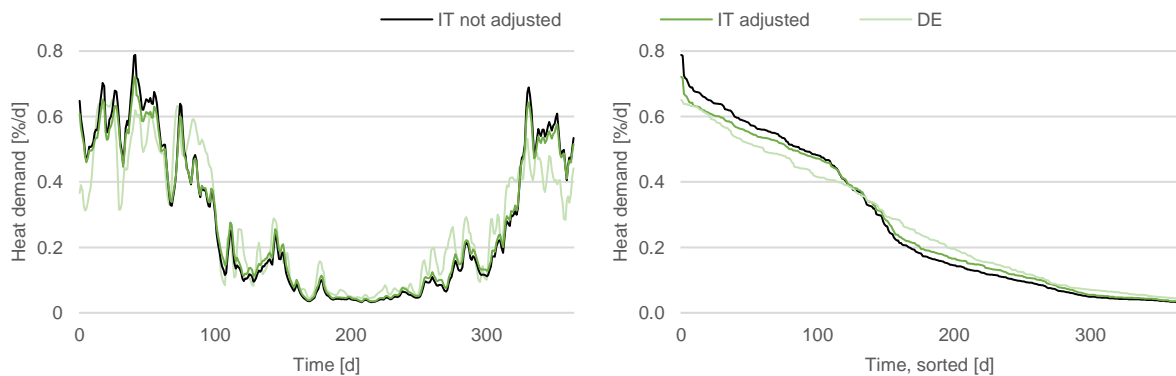


Figure 4: Modeled heat demand for space and water heating in 2013 for Italy and Germany, with and without adjusting the Italian profile function to the national heating threshold. Profiles are normalized by the annual heat demand.

³ The RMSE was normalized by the mean value of the time series.

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