Estimated Versus Actual Heating Energy Use of Residential Buildings

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Abstract

The energy demand of buildings plays an important role with regard to energy conservation objectives as well as reduction of greenhouse gas emission. The well-established building energy certificates provide essential information concerning the thermal quality and resulting energy demands of buildings in general. Hence, related Austrian regulations and standards specify a demand-orientated calculation method based on construction and material data together with standardized usage profiles, as well as a location-related weather data set. This method is also applied in the case of existing buildings, which differs from some other European countries, where certificates represent real energy usage and provide a comparison with similar buildings in terms of construction period and usage. However, it is not guaranteed that an energy demand certificate according to Austrian standards is able to represent the actual energy use of existing buildings, a circumstance that is typically referred to as 'energy performance gap'. In this context, we conducted a comprehensive comparison of real energy consumption and the certificate-based energy demand predictions for a number of buildings located in and around the city of Vienna, Austria. Specifically, 15 residential building complexes with nearly 1400 units were selected, involving a large variety of building construction dates and their thermal quality. The buildings were analyzed in detail based on historic energy consumption data from 2011 to 2017. The paper provides an overview of the real energy performance together with a detailed analysis of the discrepancies between actual energy use and certificate-based estimations. Generally speaking, the buildings with a higher energy standard and lower demand displayed higher discrepancies (expressed in terms of relative deviations) than older buildings with higher energy demand.

1. Introduction

Over the past decades, increasing efforts have been made to reduce energy consumption in all sectors. The building sector requires an average of 40 % of the total energy demand of the European Union (EU, 2010). Great saving potentials were identified for buildings and this resulted in extensive energy efficiency measures. As a result, not only new buildings are now better insulated, but also the existing building stock is to be significantly improved with necessary thermal retrofitting measures. Other additional tools for higher energy efficiency are better building systems that could contribute to further reduction of the energy requirements of the buildings. But how effective are these measures and how much can energy consumption actually be reduced?

In Austria, the Energy Performance Certificate Submission Act of 2012 mandates the following: "... the obligation of the seller or inventor to present and hand over an energy certificate to the buyer or existing customer when selling or in-stocking a building or object of use, as well as the obligation to provide certain indicators on the energy quality of the building ...)" (EAVG, 2012).

The basic idea of an energy certificate lies in the possibility of verifiability of the energy demand and better estimation of running costs. Furthermore, this is expected to influence the market prices according to the thermal quality and the predicted future energy needs and costs. Hence, an energy certificate should not be merely a project description with vague information about the energy demand and thermal quality to fulfil the requirements defined by law. Rather, it should act as a purchase or sales argument and should motivate owners to improve the energy performance. In this context, the present contribution examines the validity of energy

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certificates based on information from a set of building complexes.

2. Method

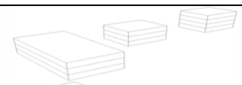
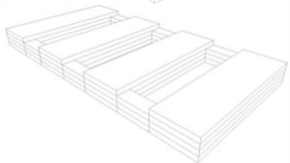
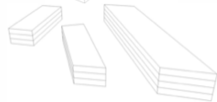
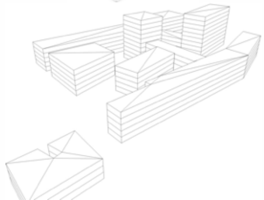
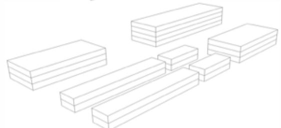
Recorded energy usage data of nearly 1400 apartments over a period of seven years (2011 to 2017) was analyzed with focus on the verifiability of the energy demand as entailed in the building energy certificates. To this end, energy consumption data from annual accounting bills were collected and compared with certificates to assess differences between the predicted and the real energy usage both at the building complex level and at the level of individual units. An initial quality check of the available data showed that 12 complexes with a total of 1043 units could be used for a detailed comparison between the estimated heating demands and the real energy usage.

3. Used Building Sampling

The building sample consists of a total of 15 complexes with nearly 1400 units, as shown in Table 1. From the schematic drawings of the cubature, it is the fact that the sampling includes different types of building complexes with single buildings as well as blocks of attached buildings may be seen. The buildings are mainly located in the city of Vienna (see Fig. 1). Buildings referred to as BH and KF are close to near to the border of the Vienna municipality, whereas AS is near Wiener Neustadt (approximately 45 km from Vienna).

Table 2 shows the variety of the buildings in terms of construction and size. Detailed information about the number of units, the building class, the heated and total area, as well as the ratio of volume and area are also included in the overview. The buildings are sorted from high to low energy demand with energy labels from C to A+. Buildings with limited data that show accounting units (relative dimensionless fraction of energy use) instead of kWh in the reporting bills are marked in red.

Table 1 – Overview of building sample, including the object code, number of units, and illustration of cubature

Object	Units/flats	Cubature
AL	28	
JB	46	
ZS	231	
UZ	23	
FM	47	
DP	148	
RA	41	
KE	324	
VG	52	
AS	45	
AB	108	
KT	90	
KF	47	
BH	73	
KW	45	

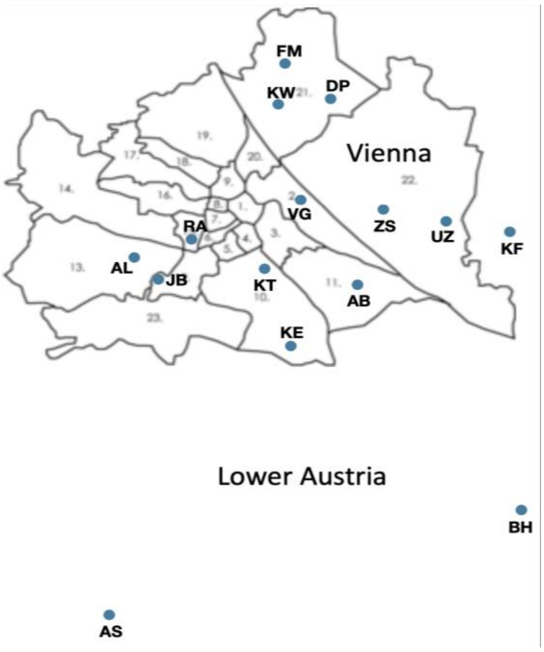


Fig. 1 – Location of the analyzed building complexes

The energy class variety of the analyzed 15 complexes included buildings from C to A++ in a range of 11 to 57 kWh/(m² a) as mentioned in Table 2 and illustrated in Fig. 2.

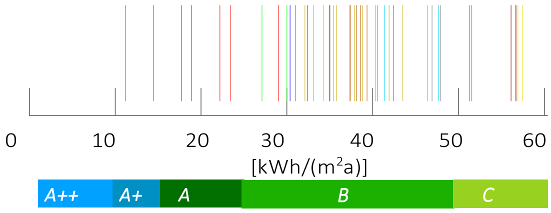


Fig. 2 – Distribution of certificate-based heating demand prediction and the building energy efficiency label from the analyzed building complexes

4. Heating Degree Days and Data Normalization

The calculation of the building energy certificate values depends on the location and its climate conditions and shows a strong dependence on the magnitude of local heating degree days (HDD). Standardized values for the different climate regions and altitudes of buildings in Austria are specified in the related OIB-RL6 regulation (OIB, 2015). The values of heating degree days are calculated as the difference between the room air temperature, which is specified as 20 °C, and the outside temperature, if it is below 12 °C. When calculating the number of heating degree days in a year, all days with daily average outside temperatures below 12 °C are specified as heating days and are considered in the calculation.

The general trend for calculated annual heating degree days for Vienna (Fig. 2), based on real temperature data from the public weather station at "Hohe Warte" (ZAMG, 2018), shows, with 2295.1 K d, the lowest value of heating degree days for 2014 and the highest value of 2940.4 K d for 2015. The mean value of 2720.4 K d is significantly lower than the standard defined value (3355 K d) for "Wien Döbling" as documented in the OIB-RL6 regulation. Hence, the recoded energy usage of the sample buildings could be expected to be significantly lower for these years when compared with the values in the certificates. The analyzed weather data showed, for the study period (2011 to 2017), approximately 19 percent lower heating degree days for Vienna.

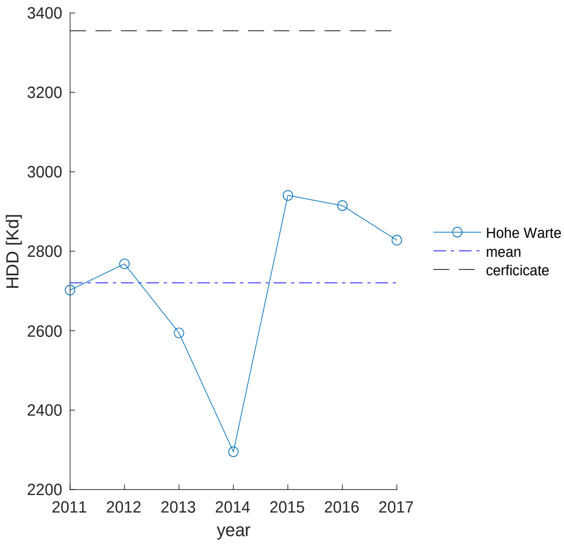


Fig. 3 – Heating degree days for the years 2011 to 2017 based on measurements from the ZAMG weather station ("Hohe Warte") in Vienna

In the following analysis, an HDD-normalization of the data was performed with a yearly factor considering the HHD-difference, and increases the yearly energy usage accordingly. Due to the proximity to Vienna (same climate zone), a separate evaluation of heating degree days in Lower Austria was not considered.

5. Results of Energy Usage Evaluation

In total, 15 residential building complexes with nearly 1400 units were evaluated on the basis of energy consumption data over a period of seven years (2011-2017). For twelve of the complexes with nearly 1050 units, a detailed comparison between the heating demand displayed in the certificate and the recorded heating energy usage was performed with a detailed discussion of the variety. The remaining three other complexes with data showing cost profiles as accounting units are limited in their analyzing possibilities and resulted in an analysis of the variation only.

5.1 Total Energy Consumption for Heating, Ventilation and Hot Water Production

The trends of the total annual energy consumption for heating, ventilation and hot production (Fig. 4) shows, as expected, a general correlation with the variation of the real heating degree days as presented before.

Fig. 4 – Total annual energy consumption for heating, ventilation, and hot water production recorded in the years 2011 to 2017

Fig. 5 illustrates the variation of annual total energy usage for the years 2011 to 2017. As expected, some of the complexes (KE and KF) show a much higher variation than the others. This could be partly explained with energy partly used for hot water preparation, which generally does not depend on the heating degree days, but depends rather on user behavior.

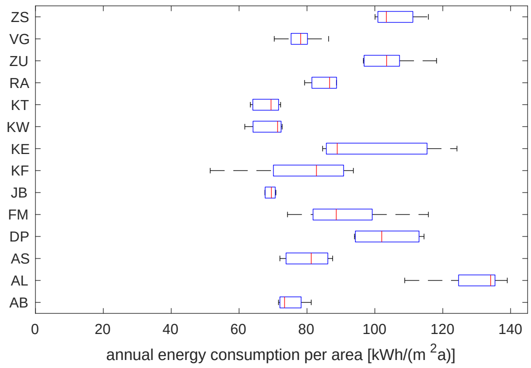


Fig. 5 – Distribution of the total annual energy consumption for heating, ventilation, and hot water production recorded in the years 2011 to 2017

5.2 Energy Demand vs Real Energy Consumption Used for Room Heating

A detailed comparison of the certificate-based energy demand for heating and the real measurements from the year 2011 to 2017 recorded by individual submeters for each unit was possible for 12 of the 15 complexes. An initial comparison of HDD-normalized annual average energy usage for heating (40 buildings and 1043 units) showed much higher usage than expected (Fig. 6). Note that not even a single building in the sample was performing equally or better than estimated in the certificate. A more detailed evaluation of the data was carried out to identify possible tendencies in relation to the building class in the certificate. Fig. 7 shows the variation of the annual HDD-normalized energy usage for heating sorted from high (at the top) to low heating energy demands (marked with blue X in the plot).

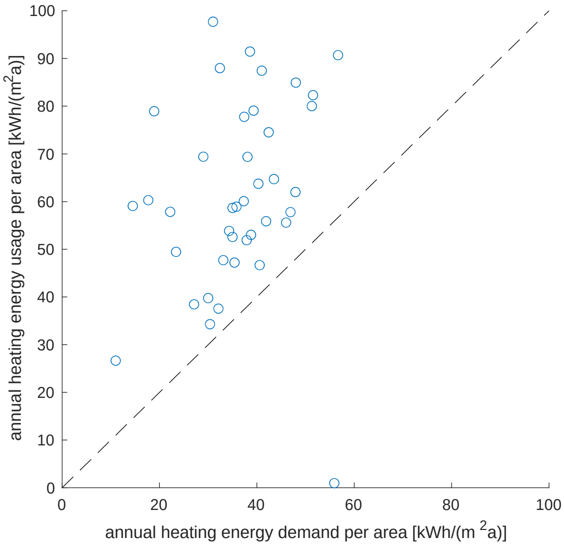


Fig. 6 – Annual certificate-based energy demand versus average annual HDD-normalized energy usage for heating recorded in the years 2011 to 2017

It may be seen that not all instances have a similar variety over time, suggesting a possible role of other influencing parameters other than the outside temperature and the related HDD influence.

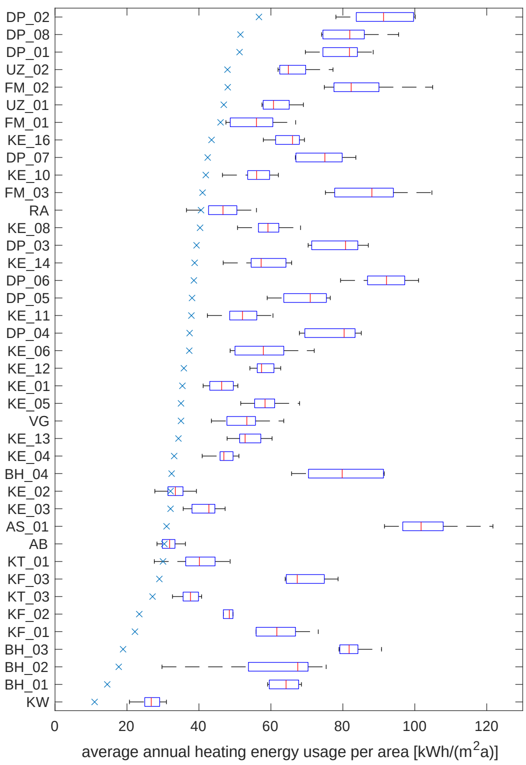


Fig. 7 – Distribution of building average (2011 to 2017) HDD-normalized annual heating energy usage together with the certificate-based heating demand (marked with a blue x)

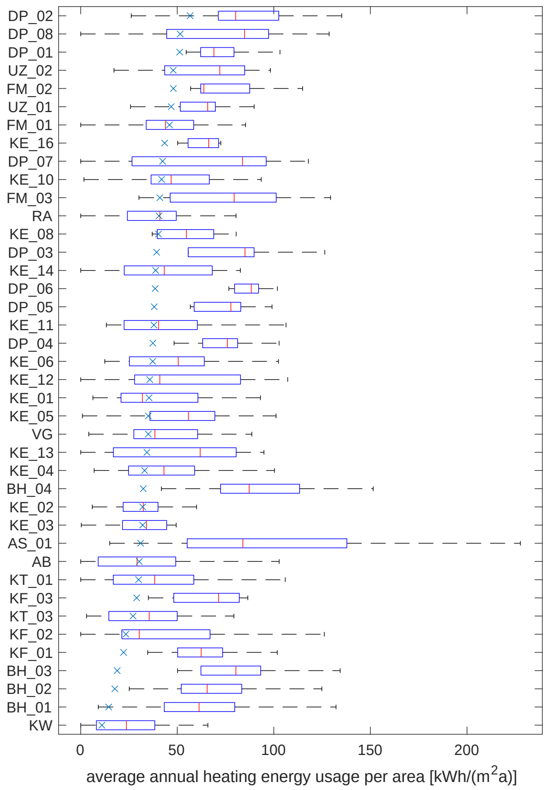


Fig. 8 – Distribution of units' HDD-normalized annual heating energy usage in the year 2016 together with the certificate-based heating demand (marked with a blue x)

Especially in the high-rated buildings (according to certificates), such as AS_01, KF_03, KF_01, BH_03, BH_02 and BH_01, rather high measured energy use values can be observed. A closer look into the variation of the units' HDD-normalized annual heating energy usage was carried out for the year 2016 and is presented in Fig. 7. It may be seen that the variation between the units is very large and could be thought of as having been caused by the occupants' influence. Again, high-ranked buildings display a wide variation. The buildings KW, BH_01, BH_02, BH_03, and BH_04 with a controlled ventilation system show much higher and wider distributed values than expected. These buildings were designed as passive houses. Hence, it could have been expected that the ventilation system would significantly reduce the heating energy use. For three complexes and the respective 9 buildings, a detailed comparison was not possible, but the variation of the energy usage documented with the related accounting units of the annual bills was analyzed in a similar way as above. Fig. 9 shows a similar variety of the units' HDD-normalized annual heating energy usage in groups of accounting units for each sampling object as for the rest of the building sample.

The main task of the study was to examine the validity of energy certificates and to evaluate how future energy usage and running costs can be predicted. The recorded data of the real energy usage in the years 2011 to 2017 for sampled buildings suggest that the real energy usage for heating is significantly higher.

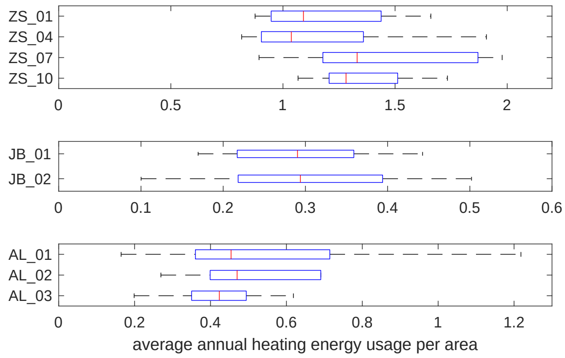


Fig. 9 – Distribution of units' HDD-normalized annual heating energy usage for buildings with heating usage data in accounting units only in the year 2016

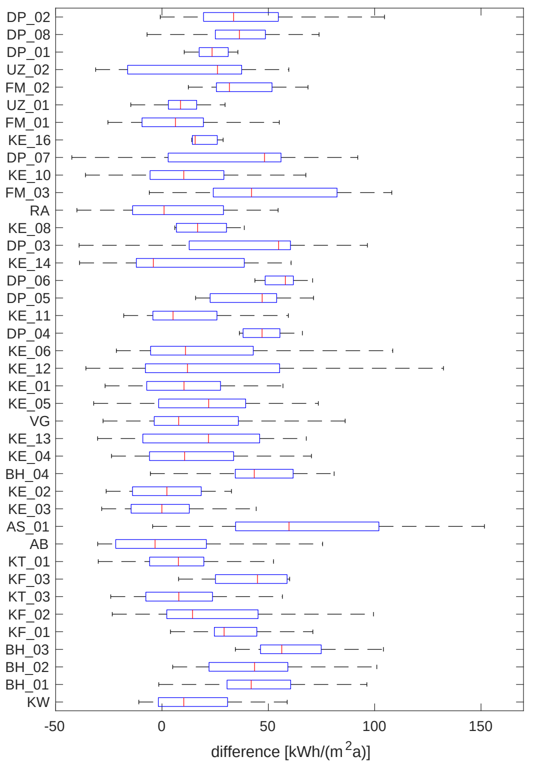


Fig. 10 – Difference distribution of unit average (2011 to 2017) HDD-normalized annual heating energy usage and the certificate-based heating demand

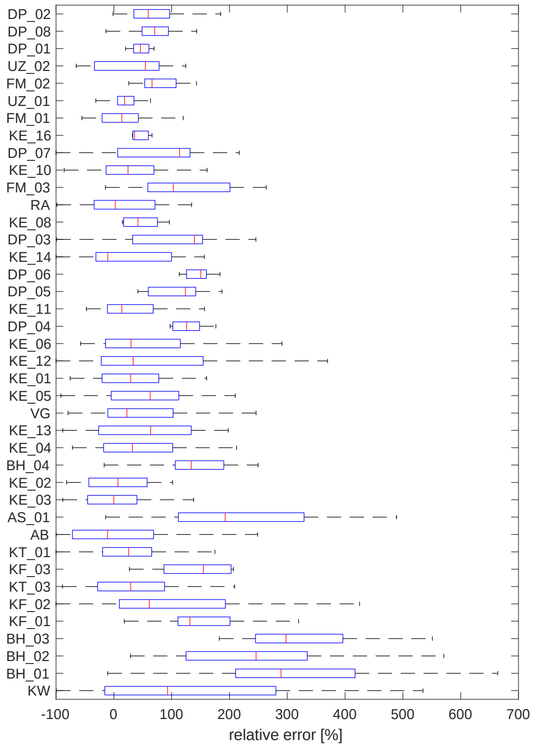


Fig. 11 – Relative error distribution of unit average (2011 to 2017) HDD-normalized annual heating energy usage and the certificate-based heating demand

Fig. 10 illustrates this for example with overview of the unit average (2011 to 2017) HDD-normalized annual heating energy usage and the certificate-based heating demand. It is clearly visible that especially the higher rated buildings at the bottom show similar or, in some cases higher, differences to the predicted heating demand. The unsatisfactory performance of those buildings is even more visible in the calculation of a relative error to the heating demand, as illustrated in Fig. 11.

6. Conclusion

The evaluation of energy consumption data (years 2011 to 2017) from 15 residential building complexes with nearly 1400 units facilitated an examination of the reliability of energy certificates in view of the prediction of building future energy use and related costs. The available data showed much higher energy consumption when compared with the values in energy certificates. This could be shown for the total energy use for heating, domestic hot water, and ventilation in cases with controlled ventilation,

as well as for the heating energy usage itself.
Buildings with higher thermal standards showed in relative terms a larger energy performance gap when compared with buildings with lower energy certificate ratings. This may be a consequence of the high potential for the influence of building occupants in total energy use.

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