Analysis of Residential Heat Consumption and Building Data

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1. Introduction
In Germany, private households account for a large share of national energy consumption (Fig. 1a). The energy consumption of households, and especially the heating of residential buildings, plays a major role in achieving the goal of reducing CO2 output and saving energy. In Fig. 1b energy from sources other than electricity is mainly used for heating. Our objects of investigation are heat consumption in categories of buildings and the building structure of towns.

Energy consumption for heating depends on various parameters which may be divided into soft parameters, like personal preferences for room temperature, and hard parameters, like size of dwelling or insulation. In this approach the soft parameters are not examined although their effects influence the results. Two hard parameters, namely the kind of building and the age of the building, will be used to calculate the spectrum of specific energy consumption. Specific energy consumption is energy consumption per square meter (kWh/m²) and provides information about the quality of the buildings. The various Heat Insulation Ordinances target this characteristic of buildings.

a) 

Fig. 1: End-point energy in households

b) 

End-Point Energy (GWh)
Share of Households

Fuel oil 28%
Natural gas 39%
Electricity 18%
Other 15%

Source of Energy (GWh)

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2. Basic data

The basic data we use is of two kinds, consumption data and descriptions of the buildings. In this paper we consider only buildings which are supplied with natural gas. The restriction to this kind of supply has several advantages:

- The time of measuring the consumption is usually one year
- The measurement of the consumption is exact
- One supplier usually serves all the consumers in a town

The last point has two advantages. First, the supplier of the data covers the respective region, and secondly, and at least as important, the data is delivered in an identical and consistent way with respect to both the format and the background of the data, such as the temperature correction according to the severity of the winter or the geographical position of the town. On the other hand, the restriction to natural gas is not a real sacrifice because, as shown in Fig. 1, natural gas covers about half of the energy consumption of households for heating. During the first study we had the advantage that the gas supplier attached descriptions of the buildings to the consumption data.

2.1 Data specification and format

The data is given in two tables, one for the description of the building and the second for consumption per year. They are combined into Tab. 1, whose condensed structure allows optimal usage of the grouping and sorting capabilities of the underlying relational database. This table may have more columns when data for several years is available.

<table>
<thead>
<tr>
<th>Building identification</th>
<th>Building age class</th>
<th>Building type class</th>
<th>Number of apartments</th>
<th>Living space</th>
<th>Consumption of year n</th>
<th>Consumption of year n+1</th>
</tr>
</thead>
<tbody>
<tr>
<td>address</td>
<td>character</td>
<td>string</td>
<td>number</td>
<td>number</td>
<td>number</td>
<td>number</td>
</tr>
</tbody>
</table>

Tab. 1: Basic building parameters

2.2 Building typology, size and age classes

The thermal properties of a building are determined by two parameters:

- The building age, due to the materials available, the renovation cycles and the standards in force during the year of construction and/or renovation.
- The size or type of the building. Due to thermal losses, large houses with a low ratio of surface to volume have a lower specific energy demand than small houses with a high ratio.

The building age classification comprises nine classes (Tab. 2). Each class is characterized by a certain time period, which is an indicator of the thermal quality of a building. The first three classes mark historical periods while the following classes cover the phases of various regulations or laws in Germany concerning the level of heat insulation. The last three classes describe ordinances which set maximal values for energy consumption. A more up-to-date ordinance is now in force, the so-called "German Energy Savings Act" (EnEV). The thermal requirements of this new ordinance are about 20% more stringent compared to the previous ordinance.

The classification for the kind of buildings only has four classes (Tab. 3). They are broken down according to the ratio of the outer surface to the volume of the building, namely single- or double-occupancy houses, small or large apartment blocks. The one- and two-family houses are in the same class but a distinction is made between detached and row houses because of the different performance in heat transition.
### Class Year of Construction Rules and Laws

<table>
<thead>
<tr>
<th>Class</th>
<th>Year of Construction</th>
<th>Rules and Laws</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&lt;= 1900</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1901-1918</td>
<td>Um value (medium heat transition coefficient)</td>
</tr>
<tr>
<td>C</td>
<td>1919-1948</td>
<td>DIN 4108 (heat insulation of buildings)</td>
</tr>
<tr>
<td>D</td>
<td>1949-1957</td>
<td>1st Heat Insulation Ordinance (max. 200 kWh/m²)</td>
</tr>
<tr>
<td>E</td>
<td>1958-1967</td>
<td>2nd Heat Insulation Ordinance (max. 150 kWh/m²)</td>
</tr>
<tr>
<td>F</td>
<td>1968-1977</td>
<td>Energy Conservation Ordinance 1995 (max. 100 kWh/m²)</td>
</tr>
<tr>
<td>G</td>
<td>1978-1984</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>1985-1995</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>&gt;= 1996</td>
<td></td>
</tr>
</tbody>
</table>

Tab. 2: Building age classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>Ratio Surface to Volume (1/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>det.</td>
<td>Detached one- or two-family house</td>
<td>0.6 – 1.1</td>
</tr>
<tr>
<td>row</td>
<td>Row houses for one or two families</td>
<td>0.37 – 0.75</td>
</tr>
<tr>
<td>small</td>
<td>Buildings with 3 – 6 apartments</td>
<td>0.32 – 0.81</td>
</tr>
<tr>
<td>large</td>
<td>Buildings with more than 6 apartments</td>
<td>0.26 – 0.49</td>
</tr>
</tbody>
</table>

Tab. 3: Classes of house types

### 3. Results on basic data

The results are based on the data of a large German town covering about 60,000 buildings which use gas as the only heating energy. In summary, these buildings comprise a little less than 200,000 apartments of an average size of about 69 m². The average specific consumption amounts to 198 kWh/m². The specific consumption is related to one year and one square meter of living space.

In the following evaluations, the results concerning size and specific energy consumption are calculated with respect to the classes according to size and age introduced in the last chapter.

The selected data in the database fulfills the following criteria:

- The living space is given (>0 m²)
- The number of apartments is given (>0)
- Gas is the only heating source
- The type of building is known

The conditions must be set because even within a good data source there are undefined parameters. When a value is given we usually believe in it. On the one hand, this confidence is due to the huge amount of data which just cannot be verified. On the other hand, there are tests to strengthen this position which additionally produce nice statistics.

#### 3.1 Tests on the amount of living space per apartment

The following test on the size of the living space documents the implementation of one such test. The apartment area is classified and a frequency distribution illustrates the plausibility (Fig. 2).

The apartment area is grouped in a frequency class by the following calculation:

\[ \text{Area Class} = \text{Round} \left( \frac{\text{living space}}{10} \right) \times 10 \]

The function "Round" delivers the rounded integer of the living space divided by ten, multiplication by ten provides the class. In this example, the functions of the database system finally deliver the frequency and the total area by grouping with the class value and counting the buildings or adding up the square meters.
We see that the majority of apartments fall into the classes from 30 to 160 m². The remaining apartments represent a total of 311,000 m² out of 15,000,000 m², i.e. about 2% of the space, which is negligible. Considering the number of buildings, the percentage is slightly higher at 2.4%, but is still insignificant. On the basis of the identification of the buildings we checked some of the buildings with an extraordinarily large floor space and it appeared that at least some of them were small castles or mansions. Some data might be faulty, however.

Similar tests are also performed on other parameters such as consumption.

### 3.2 Area and energy consumption by type of building

Given the parameters of the buildings, the examination was performed according to the types of buildings. Each class includes all age classes.

<table>
<thead>
<tr>
<th>Type of building</th>
<th>Apartment area</th>
<th>kWh / m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>det.</td>
<td>98</td>
<td>297</td>
</tr>
<tr>
<td>row</td>
<td>93</td>
<td>230</td>
</tr>
<tr>
<td>small</td>
<td>66</td>
<td>191</td>
</tr>
<tr>
<td>large</td>
<td>60</td>
<td>172</td>
</tr>
</tbody>
</table>

Tab. 4: Results for types of buildings

The results about floor space and consumption (Tab. 4) confirm expectations: apartments in large buildings have on the average the smallest space with slightly larger apartments in small apartment buildings. Living in row houses offers more space than apartments. Detached houses offer the occupant the most space.

The consumption is reciprocally proportional, following the more unfavorable ratio of the outer surface to the volume. What may be observed is that the upper limit of 200 kWh / m² from 1978 for detached houses (Tab. 2) is just met on average by apartment buildings, for which, on the other hand, lower limits are defined.

The next step is therefore the examination of the average consumption according to the year of construction.

### 3.3 Area and energy consumption by year of construction

The results of grouping buildings by year of construction provides a more complex picture. The size of the apartments varies between 61 and 81 m². The maximum is reached in the period 1978 and 1984. This pe-
Period is characterized by relatively high economic growth. Afterwards the size declines again, possibly due to the declining economy.

The development of the average specific consumption shows a fluctuating level which cannot be explained precisely. A more detailed analysis and a breakdown into size classes is necessary. This is presented in the next chapter.

3.4 Apartment area and energy consumption by type of building and year of construction

The development of the living space has grown constantly and significantly, especially in one- and two-family houses (det. and row). Only in large apartment buildings does the trend seem to be broken (Fig. 3).

Fig. 3: Floor size by type and age

The energy consumption figures exhibit a different picture. While the specific consumption of apartment buildings fluctuates between 150 and 220 kWh / m², particularly detached houses reduced their consumption dramatically from more than 300 kWh / m² to less than 200 kWh / m². The general decline in consumption after 1984 is due to the fact that the regulations became more stringent.

Fig. 4: Specific energy consumption by type and age

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4. Less perfect data

In a subsequent project the data was less than perfect. The data for two other smaller towns comes from three different sources:

- accounting data for each gas meter (address, consumption, class of consumer – no cost data)
- building data with class of age and type of building
- statistical data from statistics departments concerning number of buildings with one, two or more apartments and total living space for each group. These data are town-specific.
The problem with data from different sources is inconsistency, e.g. a one- or two-family house should not have many gas meters, which, however, was sometimes the case. All buildings with such identifiable inconsistencies have been excluded. In other aspects, too, the building data was not really trustworthy and no interpretations according to the building age were made. Another point is the generalized statistical data, e.g. the number for the living space could be calculated for one-, two- and multi-family houses but not for detached or row houses.

The specific consumption was calculated and compared to the results from the first study (Tab. 5). Overall the results are very satisfactory, especially considering that, for example, the differences for apartment buildings can be explained by differences in the generalized living space.

<table>
<thead>
<tr>
<th>Type of building</th>
<th>Average living space (m²)</th>
<th>kWh / m²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Town 1</td>
<td>Town 2</td>
</tr>
<tr>
<td>det.</td>
<td>139</td>
<td>113</td>
</tr>
<tr>
<td>row</td>
<td>139</td>
<td>113</td>
</tr>
<tr>
<td>small</td>
<td>70</td>
<td>66</td>
</tr>
<tr>
<td>large</td>
<td>70</td>
<td>66</td>
</tr>
</tbody>
</table>

Tab. 5: Comparison of consumption

5. Outlook

In this paper, we have shown that in towns in North Rhine – Westphalia the specific energy consumption is comparable while the building structure differs. We have shown one difference in the building structure by a comparison of the living space, which differs above all for one- and two-family houses. However, this could have been similarly revealed for the proportion of one- and two-family houses in the towns.

The specific energy consumption is very high, particularly in comparison to the ordinances. This is due to at least two reasons, namely the fraction of old houses and the landlord/tenant dilemma. The landlord/tenant dilemma means that the energy saving of a better insulated house benefits the tenant while the investment is borne by the landlord. We showed the reduction in energy demand in new detached one-family houses, which are built for owner-occupiers. With respect to old houses, investment in energy savings is made when the necessary building renovations are done. Because of long life cycles, this takes a long time.

The last point to be mentioned is the increasing average living space. We showed the increasing living space for single apartments, but it should be seen that the number of persons per apartment is decreasing. This strengthens the need for buildings with a reduced demand for energy.

A clear drop in energy consumption in the household sector is not to be foreseen in the near future.

Bibliography