ESTIMATION OF THE ENERGETIC REHABILITATION STATE OF BUILDINGS FOR THE CITY OF BERLIN USING A 3D CITY MODEL REPRESENTED IN CITYGML

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ABSTRACT:

We propose and describe a method for the estimation of the energetic rehabilitation state of buildings. It combines a virtual 3D city model with real measured heating energy data in order to determine energetic relevant building characteristics. Among these characteristics are, e.g., the volume, the assignable area, the building type or the surface-to-volume ratio (S/V). Using these values the energy consumption characteristic, which is normally given in kWh/m^2, can be calculated. This allows to classify a building into predefined heating classes. Additionally, an estimation of the energy consumption of buildings is calculated on the basis of building typologies and is compared to the real consumption values. Using these results, estimations of the energetic rehabilitation are derived.

1. INTRODUCTION

The discussion about the energy consumption, climate change and possible energy saving measures can be found nowadays everywhere and is one of the key problems to be solved in the future. In 2007 the Intergovernmental Panel on Climate Change (IPPC), which is a United Nation's organization, published a climate report suggesting that the increase of global temperature is likely to be caused directly by anthropogenic influences, mainly due to the burning of fossil energy sources (IPPC, 2007).

One of the major consumers of fossil energy sources within Germany are residential buildings, using 17.9 % of the total consumed final energy (Tzscheutschler et al., 2009). The biggest part - around 75 % - of this energy is used for space heating. It is a well known fact that old buildings consume considerably more energy than new buildings. Taking into account that around 75 % of the buildings in Germany are older than 30 years, a high potential of energy saving can be assumed (StaBuAmt, 2006). In many cases, though, building owners actually do not know the precise energetic rehabilitation state of their buildings. Therefore, it would be useful to have a simple method which could identify those buildings being in a bad energetic rehabilitation state simply by combining already existing data sources, in order to carry out adequate rehabilitation measures on them. Since the heating energy consumption of buildings is strongly correlated to their geometric and semantic characteristics, the idea of our approach is to combine these characteristics, which are already available with high precision within virtual 3D city models, with real heating energy consumption values of buildings. From this combination energetic relevant parameters can be calculated and the rehabilitation state of buildings can be estimated.

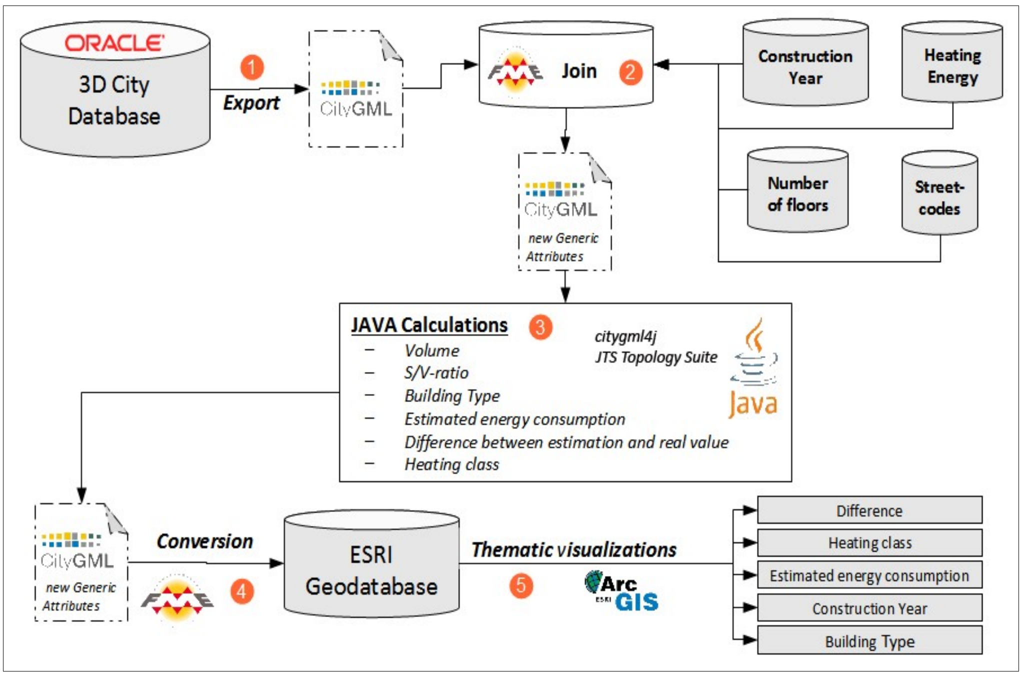

Figure 1.1: Work flow diagram

Construction Year Class	A	B	C	D	E	F	G	H	I
Building Type	**-1870**	**1850-1918**	**1919-48**	**1949-57**	**1958-68**	**1969-78**	**1979-83**	**84-94**	**95-01**
EFH	272	250	282	203	197	142	105	98	93
RDH	254	251	201	203	147	112	74	71	67
KMFH	248	178	224	169	186	135	106	96	84
GMFH	248	169	170	149	161	130	93	96	

Table 1: Exemplary building typology showing the energetic consumption characteristic of each class in kWh/m²a. (Dortmund,2005)

2. METHODS

The method which is described in the following section was developed on the basis of the 3D city model of Berlin. This model is the result of an initiative started by the Senate Departments of Economics and Urban Development in 2003, which had the goal of extending Berlin's geodata infrastructure (Döllner et al., 2006). It is modelled according to CityGML, which is an OGC standard for representing and exchanging virtual 3D city models (Gröger et al., 2008). It is implemented as an application schema for the geographic markup language (GML) and therefore based on XML. In the case of Berlin the model is stored in an Oracle relational database from which it can be exported to CityGML files. One of the strengths of CityGML is the separation of geometry and semantic information of features. That means a virtual city model represented in CityGML contains more than just geometric and appearance properties, namely semantic information describing the individual features of a city, which in the context of this work are generally buildings. There are several predefined semantic attributes for a building within CityGML among them, for instance, the self explaining attributes *yearOfConstruction*, *storeyHeightsAboveGround* or *storeysAboveGround*. Since these attributes are standardized, data exchange is getting easy. Unfortunately, in practice not all the available predefined CityGML attributes are captured during the creation process of such city models. That means other external sources are needed to obtain all those building attributes which are relevant for this work. Within this study these external sources included the German digital cadastral information system (Automatisierte Liegenschaftskarte, ALK), which was used to obtain the number of storeys above ground. Furthermore a scanned raster map containing the construction year periods of buildings in the center of Berlin. Generally, it can be stated that by using such kind of standardized data structure like CityGML provides the advantage of being able to develop a method which is not only restricted to the use within the city model of Berlin but which is easily transferable to city models of other cities.

In order to evaluate the energetic rehabilitation state of a building a quality measure is needed, which is in most cases the heating energy consumption per square meter. The reference area for this measure has been defined in Germany within the energy saving regulation (**En**ergie**E**inspar**V**erordnung, EnEV) as being the «assignable area» (Gebäudenutzfläche)[1], which can be derived directly from a building's volume (BRD, 2007). To calculate this area, as well as other geometrical characteristics, and to join the real heating energy consumption with the buildings from the city model, the work flow shown in figure 1.1 has been developed. It consists of 5 different steps: *exporting, joining, calculating, converting* and *visualizing.*

Exporting the city model from the oracle database into a CityGML file and *joining* it afterwards with additional information are the first two steps. The joining is done using the FME (Feature Manipulation Engine) which creates a new enriched CityGML data set. The additionally needed external data sources include first of all the actual heating energy consumption values for buildings within a small test area. This data has been provided by the company Vattenfall. Remarkable is the fact that the provided consumption values were only referring to the space heating within the building and did not include the energy needed for the heating of water. In comparison to other studies (Strzalka et al., 2010), this gave the advantage of not having to subtract an average value for the hot water fraction, which is normally part of the energy consumption, making the energy values more precise. Having these consumption values, the first step was to perform a time correction. This was done in a way that afterwards the consumption was referring to the period of exactly one year. It was accomplished by using a degree day table as suggested in DIN 4713. As a second step, the values were additionally corrected for climatic conditions on the basis of the directive VDI 3807 (VDI, 2007).
Furthermore, the number of storeys for the buildings within the test area was needed in order to derive the storey heights which are used in equation 1. This information was captured manually by using the ALK. The height of the building is in the case of the city model of Berlin stored as an attribute within the CityGML files. Dividing this height by the determined number of storeys leads to an average storey height.

Another important parameter is the construction year of the individual buildings. Data sources providing information about that are limited and the only available source for that was a scanned raster map from the year 1993. This map classifies every building in the centre of Berlin by using a colour code into nine different construction year classes. The major problem of this data source is the fact that it is provided in form of a raster image. Therefore, it is not possible to generate a direct connection between this image and the CityGML model. Of course, it would be possible to add the relevant construction year classes manually to every building of the city model. But considering the amount of buildings which are normally within a city, this task would be very time consuming. Therefore, a semi-automatic procedure was developed, which makes it possible to add the information contained within the raster map to the city model in a reasonable time (Carrión, 2010). After adding the construction years to the city model visualizations can be generated which can, for instance, be useful to analyze the settlement structure of a certain city district (figure 2.1).

The enriched CityGML dataset can be processed with Java using the citygml4j library providing predefined classes and

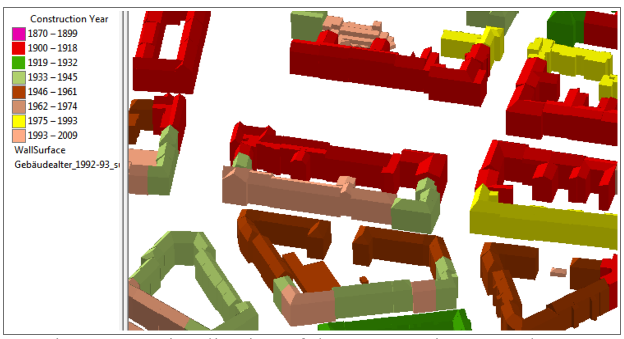

Figure 2.1: Visualization of the construction year classes

1 Translation according to VDI3807

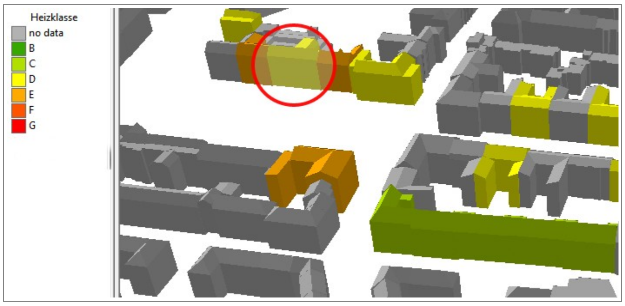

Figure 2.2: Determined heating classes.

methods for reading and writing CityGML files. Using this library and extending it with own methods makes it possible to *calculate* geometric characteristics for every building, e.g., the volume, the assignable area, the surface-to-volume ratio (S/V) or the building type. Since the buildings in the city model of Berlin are represented in a level of detail 2 (LOD2), which includes roof structures, the calculated volume is more accurate than in other studies, where the ground surface is simply multiplied by the building height (Strzalka et al., 2010).

One of the key parameters for this study is the assignable area of a building. We derive the this area - A_N - as suggested in the EnEV:

$$A_N = V_e \left(\frac{1}{h_G} - 0.04\, m^{-1}\right) \qquad (1)$$

V_e *heated building volume [m³]*
h_G *storey height in [m]*

Together with the determined building type and the construction year, an estimation of the total energy consumption over one year can be calculated. For this purpose, building typologies are used, which display the correlations between mentioned parameters in a tabular form, i.e., they provide energetic characteristic values for buildings of a certain type and age, see table 1. They are based on the fact that buildings which are built within a certain time period are constructed according to the state of the art in insulation possibilities and legal regulations at the time and have therefore similar energetic characteristics.
In addition to the construction year, typologies group buildings into different types, which have similar energetic characteristics. For instance, single family houses normally consume more heating energy per square meter than multi family houses. According to IWU (2003) five different building types can be distinguished: single family house (EFH), row houses (RDH), small multi family houses (KMFH), big multi family houses (GMFH) and multi-storey houses (HH). In the

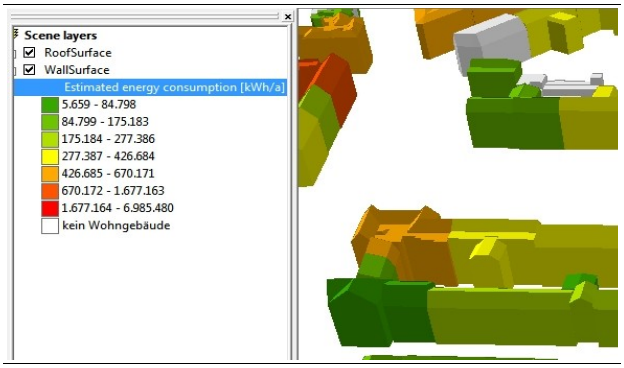

Figure 2.3: Visualization of the estimated heating energy consumption.

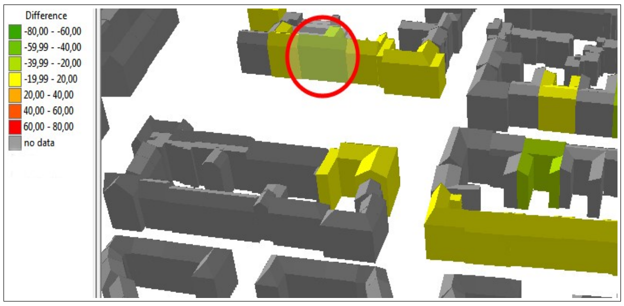

Figure 2.4: Determined deviation classes.

city model of Berlin every building is “preclassified” within the CityGML *BuildingFunctionType* attribute, which is a value according to the German digital cadastral information system (Automatisierte Liegenschaftskarte, ALK). These types are not directly assignable to the above mentioned types, but by additionally taking geometric thresholds of building characteristics into account, e.g., the height, the volume or the surface-to-volume ratio, a building can be classified automatically into one of the five different building types described above.

After the Java *calculations* are finished, the results for every building are written to new generic attributes within the CityGML file. These attributes can be freely defined and can therefore extend the predefined CityGML attributes. Consequently, a dataset is created which is again semantically enriched. *Converting* this file into an ESRI geodatabase makes it possible to generate thematic *visualizations* using ArcScene, as seen, e.g., in figure 2.3, where the estimated energy consumption is shown.
Above described procedure was implemented in a similar way already by other studies like, for instance, in the work of Neidhart and Sester (2004). Our study takes one more step by joining every building with its real consumption value. On the one hand this allows us to calculate the deviation to the estimated value, which can provide a clue on how big the difference to the historic state of the building is. On the other hand an energetic characteristic value (kWh/m²) can be determined by dividing the real consumption value by the calculated assignable area. This value can be used to classify a building into a certain heating class, which in turn allows to draw conclusions on the energetic rehabilitation state. The «Berliner Heizspiegel» defines such classes, which are shown in figure 2.5. According to their definition passive houses and low-energy houses are within class A, new buildings and very well rehabilitated buildings should normally be within class B whereas partly rehabilitated buildings are within class C and D. Unrehabilitated buildings are generally within class E and F (SenVerwaltung, 2010). Figure 2.2 shows a visualization of such a classification for some buildings within the test area.

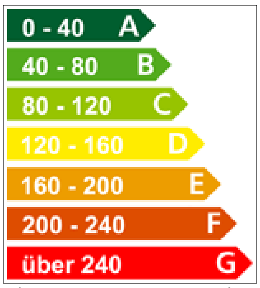

Figure 2.5: Heating classes [kWh/m²a].

By comparing figure 2.2 and figure 2.4, the difference of the two possible ways for describing the energetic rehabilitation state can be observed. For instance, the building marked with a red circle shows a large negative deviation from the estimated value, suggesting that it has been undergone certain kinds of rehabilitation measures and that it is in a good rehabilitation state. Nevertheless, the same building is classified into the heating class D, which is not considered to be a very good heating class.

Generally, the classification according to the heating classes can be described as an absolute classification independent from the construction year of the building. Calculating the difference between the estimation and the real value can be considered as a relative classification which is depending on the time epoch in which the building was constructed. A building having a large negative deviation is not necessarily in an good energetic rehabilitation state, it just means that it is in a better state than when it was built.

3. FINDINGS AND CONCLUSION

The study has shown that energetic relevant parameters including the volume, assignable area, living area or the building type, can be derived directly from the three dimensional building models contained in a virtual 3D city model. For instance, through the comparison of the calculated assignable area with the available real world reference data, it could be proved that the assignable area can be calculated with an accuracy of ±15 %. Considering that more and more cities are creating such models, they can be seen as a good starting point for energetic analysis since many important building characteristics can be derived from them easily. Using a standardized data structure like CityGML for the data modelling of such models offers a good and sustainable framework for integrating of additionally needed external data sources

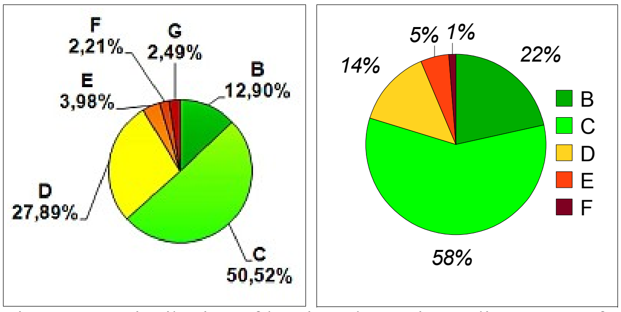

Figure 3.1: Distribution of heating classes in Berlin 2007. Left: According to the “Heizspiegel Berlin” (SenVer, 2010). Right: Result of this study.

This study tried to estimate the energetic rehabilitation state in two different ways. Figure 3.1 shows the result of the first way by comparing the distribution of the heating classes within the test area with the distribution of the heating classes of complete Berlin (according to the «Heizspiegel Berlin»). It can be seen that according to the results of this study, the buildings in the test area are in a better energetic rehabilitation state than the average of Berlin. Class B, which shows buildings in a very good rehabilitation state, is almost two times as big as the average of Berlin. Among the test buildings there are also more buildings in class C than in the average of Berlin. Generally, it can be concluded that the buildings in the test area are in a better energetic rehabilitation state than the average of complete Berlin. This can be caused by two facts. First, the test area lies within the district of Charlottenburg-Wilmersdorf, which is a rather rich part of the city, and it sounds reasonable the rehabilitation quota is a little bit bigger than elsewhere in Berlin. Second, all investigated buildings are heated by district heating which has an inherent lower energy consumption and therefore these buildings are classified into a better heating class than buildings having a heating boiler.

The second way was to calculate the difference between the estimated energy consumption and the real consumption value. This difference is supposed to help to compare the momentary energetic rehabilitation state with the historic state of a building. It was realized though, that the estimation of the energy consumption on basis of a typology value for individual buildings can be very uncertain since the underlying values are only average values. Different ways of modeling the energy consumption, for instance, as proposed in the work of Strzalka et al. (2010) could lead to a more accurate estimation, making the modeling process more complex though

Furthermore, the real measured energy values are subject to resident influences, which are mainly caused by varying room temperatures and different ventilation rates (Eikmeier et al., 2004). Because of these unknown influences, which can hardly be modelled, the uncertainties of the values taken from a building typology and the limited accuracy of the assignable area, the interpretation of the calculated difference between estimation and real value is difficult. The estimated heating energy consumption based on building typologies could be useful for different purposes though. Especially in those cases where not an individual building is of interest but many buildings, e.g., during the capacity planning of a district heating network within a whole city.

Summing up it can be stated that classifying buildings into heating classes provides an easy way of judging their rehabilitation state. Since the assignable area is available for every building within the city model, evaluations of the rehabilitation state of whole city districts can be realized easily, if the real consumption values are available. In our case these consumption values were originating from a district heating network. It should be noticed in this context, that the energy consumption for such kind of heating system is generally between 15-30 % lower than for standard boiler heatings (dena, 2010). This leads consequently to a classification into a better heating class and it remains to be proved to which extent different heating systems can be compared reasonably.

As secondary results from this study statistical information on the building stock of Berlin could be calculated since building type, living area and construction years were available. This revealed that from a quantitative point of view the single family houses are the predominant building type representing 38 % of all buildings in complete Berlin. They are followed by multi-family houses which make up for 33 % of the whole building stock. Considering that multi family houses are generally much bigger than single family houses it is understandable that the result showed that they own 75 % of the total living area, This suggests that these buildings are consuming the majority of heating energy and are therefore the most interesting building type for energetic optimization.

4. REFERENCES

Bundesrepublik Deutschland (BRD), 2007. Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden (Energieeinsparverordnung-EnEV). Bundesgesetzblatt, vol. I, no. 34, 26-07-2007.

Carrión, D., 2010. Estimation of the energetic rehabilitation state of buildings for the city of Berlin using a 3D city model represented in CityGML. Unpublished Masters thesis, Technical University Berlin, Germany

Deutsche Energie-Agentur GmbH (dena), 2010. Energieausweis für Wohngebäude. Berlin, Germany.

Döllner, J., Kolbe, T., Liecke, F., Sgouros, T, and Teichmann, K., 2006. The virtual 3D city model of Berlin - Managing, Integrating and communicating complex urban information. In Proceedings of the 25th International Synopsium on Urban Data Management UDMS, Aalborg, Denmark, 2006.

Eikmeier, B., and Pfaffenberger, W., 2004. Verbrauchskennzahlen und Fernwärmepotenziale für Wohn- und Nichtwohngebäude in Städten. In *Pluralistische Wärmeversorgung*, volume 1. AGFW, Frankfurt, 2004

Gröger, G., Kolbe, T.H., Czerwinski, A., Nagel, C., 2008. OpenGIS City Geography Markup Language (CityGML) Encoding Standard, Version 1.0.0, OGC Doc. No. 08-007r1, Open Geospatial Consortium.

Institut Wohnen und Umwelt GmbH (IWU), 2003. Deutsche Gebäudetypologie – Systematik und Datensätze. Darmstadt, Germany.

IPPC. Summary for Policymakers, 2007. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor, and H.L. Miller, editors, Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

Neidhart, H., Sester, M., 2004. Digitale Wärmekarte. In: *Pluralistische Wärmeversorgung*, volume 1. AGFW. Frankfurt, Germany.

Senatsverwaltung für Gesundheit, Umwelt und Verbraucherschutz Berlin, 2010. Berliner Heizkostenspiegel. http://www.heizspiegel-berlin.de/. [Online; accessed 15-May-2010].

Stadt Dortmund Umweltamt, 2005. Dortmunder Gebäudetypologie - Neuauflage der Hausdatenblätter. Dortmund, Germany.

Statistisches Bundesamt Deutschland, 2006. Wohneinheiten in Gebäuden mit Wohnraum nach dem Baujahr 2006. http://www.destatis.de. [Online; accessed 15-May-2010].

Strzalka, A., Eicker, U., Coors, V., Schumacher, J., 2010. Modeling energy demand for heating at city scale. Stuttgart University of applied science, Stuttgart, Germany.

Tzscheutschler, P., Nickel, M., Wernicke, I., Buttermann, H., 2009. Energieverbrauch in Deutschland. BWK Das Energie-Fachmagazin, 61(6), pp. 6-14.

Verein Deutscher Ingenieure (VDI), 2007, Energie- und Wasserverbrauchskennwerte für Gebäude. VDI 3807, VDI, Düsseldorf, 2007.

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