Assessing the energy efficiency of a district’s existing building stock glazing – Case Study TU Dresden

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Abstract. Restoration of existing buildings becomes inevitable due to urbanization, population growth, conservation laws and scarcity of resources. Upgrading existing glazing could reduce building heating demand by 10% and reduce the TUD emissions by 573.4 tCO₂-eq/a. However, renovations are often postponed due to unknown energetic glazing quality. Traditional measures such as removing the glazing to a test-lab to identify the uₜ-value are often not permitted nor practical for existing (heritage-listed) occupied buildings. In this article, methods suitable for the assessment of the energetic quality of existing glazing without removing the glazing from the building, i.e. (a) the use of literature values per building age classification, (b) glazing built up measurement with uₜ-value calculations per standard and (c) direct uₜ-value measurement using a portable tool, are tested on the existing window stock of the TUD campus, compared and evaluated in terms of accuracy and easiness of application. Results show that the energetic quality can range widely from a uₜ-value of 0.5 to 3.5 W/m²K within a single building, and that method (a) is not accurate and method (b) is as accurate as method (c), but 20 minutes faster per glazing which, extrapolated to a district like TUD, can save months of work and significantly increases the chances of glazing renovations being carried out.

1. Introduction
Dresden targets to reduce CO₂ equivalent emissions by 10% every five years by 2030 and from 7 tCO₂-eq/(inhabitant*a) in 2011 to 2.5 tCO₂-eq/(resident*a) by 2050/2080. [1] Germany moreover focuses on energy-efficient building renovation and targets to achieve a virtually climate-neutral building stock by 2050. However, compared to new buildings with known energy efficiency, existing buildings are still a challenge. About 70% of the technical university of Dresden (TUD) were built before 1979 [2]. At that time there were no requirements on thermal insulation [3], and many have been undergoing successive partial renovations and do not comply with the energy requirements of the current regulations. Transparent components have among the highest heat transmission losses in the thermal building envelope. Accurate quantitative data on the glazing heat transfer coefficient i.e. uₜ-value is lacking [4], but essential to work out suitable measures for renovation. Increasing the rate of renovation of building skins can increase the CO₂-savings in Germany from 7 mill t/a to about 12 mill t/a [5, table 8] as per sustainable development goal (UN SDG) 13 and almost double the rate of improvement in energy efficiency as per UN SDG 7. Replacing TUD existing glazing with energy-efficient windows reduces heating demand by about 10% [5, table 7], which equals about 573.4 tCO₂-eq/a savings (2016).
2. Determination of the glazing heat transfer coefficient

2.1. Literature

Based on the window construction and the building age, the building is classified into a building age class and the $u_g$-value for the glazing can be determined using empirical values [6] (table 1).

| construction type | building age | EnEV 2002/2007 | EnEV 2009/2014 |
|-------------------|--------------|----------------|----------------|
| wooden frame with:| till 1978    | 1.5            | 1.1            |
|                   | 1979 till 1983 | 1.1            |                |
|                   | 1984 till from 1994 | 1.1            |                |
|                   | from 1995     |                |                |
| single glazing    | 5.8          |                |                |
| double glazing    | 2.9          | 1.4b           |                |
|                   | 2.9          | 1.4b           |                |
|                   | 2.9          | 1.4b           |                |
| a insulating glazing, box windows or composite windows | | | |
| b multi-pane glazing | | | |

2.2. DIN-standard

Low weight portable optical measurement devices like the Glassbuddy (figure 1) can measure the glazing built-up in less than a minute without removing the glazing from the existing building. Using laser beam reflection and light refraction, such devices provide information on the glass thickness, the pane built-up, and the position and type of coatings. The measurement range is limited to a glazing thickness of 100 mm and the accuracy is +/- 0.1 mm [9]. The measured glazing built-up with or without coating is then used to manually calculate the $u_g$-value per DIN EN 673 German standard.

2.3. Measurement

Portable $u_g$-measurement tools, for example the "Uglass" from NETZSCH (figure 1 right) often consist of two heatable sensors, which are attached to each side of the glazing by a suction pump to create an artificial temperature gradient, in case of the absence of a natural temperature gradient. The glazing is then heated on one side and the sensor detects the temperature increase on the other side. By analysing the time lapse of $\Delta T$, the $u_g$-value of the glazing is determined. Using such tools thermal insulation values of double and triple glazing with $u_g$-values between 0.5 and 4 W/m²K can be determined [10,11]. Measurements take about 25 minutes per glazing.

3. Results

The glazing built-up of many TUD buildings were measured (figure 2 left) and their $u_g$-values calculated according to the German standard (figure 2 right).
3.1. Window type and glazing built-up
The inventory showed that most glazing at the TUD are double-glazing, despite the fact that about 2/3 of its buildings were built before 1978 (figure 2 left) [2]. Box windows are still evident in buildings built at the beginning of the 20th century. It appears that in older buildings windows have already been replaced, as both double-glazing and box windows are apparent. Occasionally, even single glazing was found.

3.2. Uₜₐ-value according to German standard
Figure 2 (right) shows the average uₜₐ-value per building calculated according to the German standard. The classification is based on the uₜₐ-range of literature and EnEV. Buildings that have scheduled a refurbishment (grey) are not considered. Buildings displayed with a black border were also measured with the portable uₜₐ-measurement tool. Only those buildings, if built before 1994, are used in the comparison, as buildings constructed after 1994 have unlikely had many refurbishments. Buildings with a green color have highly insulated glazing as compared to red buildings. The evaluation shows there is no building at the main campus that has an average uₜₐ-value better than 1.1W/m²K. Most of the older buildings are in the orange range, newer buildings from 1990 onwards and some older buildings are in the yellow and green range. In those older buildings with a better average uₜₐ-value some windows have been replaced in the past, thus improving the average value.

4. Comparison of literature, standard and measurement
The average uₜₐ-value per glazing type (table 2) indicates a good agreement between values calculated according to standard and those measured.

Table 2. Average heat transfer coefficient (uₜₐ-value) per glazing type for TUD buildings with construction year till 1994

| glazing type     | literature | calculated average | Std. Dev. | measurement average | Std. Dev. |
|------------------|------------|--------------------|-----------|---------------------|-----------|
| single glazing   | 5.8        | 5.76               | 0.084     | 5.68                | 0*        |
| double glazing   |            | 1.53               | 0.54      | 1.62                | 0.57      |
| triple glazing   | 2.9        | 0.71               | 0.073     | 0.67                | 0*        |
| box window       |            | 3.04               | 0.36      | -                   | -         |
| composite window |            | 2.86               | 0.10      | 3.52                | 0*        |

*Only one building with this glazing type

While one-, two- and three-pane glazing have a deviation of 2 to 6%, the composite window shows a difference of 23%. The larger deviation may result from the inability of the uₜₐ-measurement device to measure windows with a large cavity, like composite and box windows, due to air movement. The analysis also showed that most of the replaced windows already have a coating. As a major difference in uₜₐ-value was apparent depending on the glazing coating, the literature method, which does not consider gas filling or glazing coating, is less accurate. A flat literature uₜₐ-value per building age for different types of glazing can lead to deviations of up to 65%, as especially older buildings often have a uₜₐ-value better than literature due to partial (undocumented) renovations with highly insulated glazing. At the Zeuner-building for example, there are seven different glazing apparent, including single glazing wire glass, box windows and triple glazing (figure 3). The uₜₐ-value ranges from 3.52W/m²K to 0.67W/m²K. Although the highlighted windows (figure 3 detail A) seem the same, closer inspection reveals that the right window is a box window (figure 3 bottom right) and the left window has triple glazing (figure 3 top right).
5. Discussion, conclusion and acknowledgements

The use of literature values is only recommended if a building is still in its original state, as partial renovations cause large deviations. If the window is not a box window and special gas filling is expected, a portable $u_g$-measurement device can be used, requiring about 20 minutes per glazing for the measurement. Portable glazing built-up measurement tools combined with manual calculations can achieve accurate results, although the influence of gas fillings in the cavity space remains unknown. This method is found more scalable since it does not take much time and still offers an accurate result.

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