A simplified calculation process of buildings’ energy saving potential

Matthias Groß¹, Angeliki Kresteniti², Manuel Lindauer¹

¹ epiqr Software GmbH, Beethovenplatz 4, Munich, Germany
² CalCon Ingenieurgesellschaft mbH, Beethovenplatz 4, Munich, Germany

m.gross@calcon.de, a.kresteniti@calcon.de, m.lindauer@calcon.de

Abstract. The real estate sector is responsible for 40 percent of the energy consumption and one third of the CO₂ emissions in Europe. Moreover one third of the European Union’s buildings are in fact older than 50 years while only one percent is being renovated each year. The building stock is therefore of great importance for the European Union in order to achieve its climate targets not only for 2020 but also long term. The difficulty however is to decide where and how to realize energy savings in the most efficient and economical way – especially for property owners with a large and heterogeneous building stock. This paper provides a simplified analysis method to evaluate real estate portfolios and estimate their buildings’ saving potential. This method has been integrated into AiBATROS®[1] software and can help to prioritize measures increasing energy efficiency. Verification and validation of the process are demonstrated comparing results with another method’s energy calculations.

1. Motivation
On June the 6th 2011, the German Federal Government adopted comprehensive measures to reduce energy consumption and increase the share of renewable energies with the primary target on improving the energy efficiency of buildings. This decision resulted in the obligation for the Institute for Federal Real Estate (BlmA), one of the biggest German real estate businesses managing all properties used for official purposes, to draw up an energetic renovation roadmap; in the medium term until 2020 and in the long term until 2050.

Therefore, the necessity to integrate the acquisition of energy assessment figures and an energy scoring model into the regular planning and decision-making processes became apparent. Moreover, the main requirement was to keep the cost and effort necessary to acquire the needed data as low as possible and make best use of the existing information.

Based on these conditions, a scoring system was developed, which shows the priority for energy improvement for each building under consideration of economic aspects. A uniform and objective procedure was designed to ensure that all buildings could easily be compared and aligned. Considering economic aspects as well as the possible future use of renewable energies, the energy saving potential of existing properties is analysed. This facilitates for each building the identification and subsequent derivation of needs for action with regard to the improvement of its energy efficiency. The objective to minimize the effort and cost for the survey of the property was succeeded by focusing on the most impacting building components that can be identified with a quick visual inspection.
The criteria of this model were revised and are being further developed on the software AiBATROS®[1].

2. Methodology
AiBATROS® is a web-based portfolio management software that automatically generates and administrates necessary maintenance and repair costs, associated refurbishment measures and important information on the building stock. The cost values collected from CalCon Group over many years serve as statistical basis for the EPIQR [2] calculation core. Work is carried out in a web interface in which all operations as surveying, building analysis etc. can be managed.

Central point of AiBATROS® is the survey and evaluation of cost intensive building components named element types (ET). Each ET refers to a reference value (e.g. area of a façade surface, number of devices, power provided by devices), which is a weighting factor for its influence on the building’s general condition. All ET are assessed according to their degradation grade resulting in four states:

- state "A" = "good condition"
- state "B" = "light deterioration"
- state "C" = "serious deterioration"
- state "D" = "end of lifespan reached"

Each of these states is associated with maintenance measures ranging, for example, from a simple surface treatment of a façade to its total replacement. The system automatically calculates the necessary costs for the implementation of the respective measure.

The level of survey detail for assessing the necessary data can be customised, resulting in varying accuracy of the calculations: rough, medium or fine. Additionally, different survey dimensions (energy dimension, building construction etc.) can be selected for a holistic inspection. Therefore, a multidimensional and individual survey model with a mixture of dimensions and levels can be defined to adapt to each user’s need for building data.

The primary idea behind AiBATROS® follows the Pareto principle, in which an accuracy of 80 % is already achieved through 20 % expenditure [3]. In this way the data collection effort can be minimised. Therefore only the energy related building elements that make up the biggest part of the building energy demand are examined for the simplified energy calculation presented here.

By considering the basic geometric data and the energy qualities of the building components, together with statistical data of similar buildings, within a few steps an approximation of the building energy demand and potential improvement can be automatically calculated [4].
This calculation, which is implemented in AiBATROS®, is based on the variables described in the following paragraphs.

The reference value \( A_{ET \, i=1...n} \) of each ET refers either to some geometric value (like façade area for building components related to the façade) or to some technical value (like heating power for components related to heating systems).

The state percentage \( P_{ET \, i=1...n, \, state \, A/B/C/D} \) of an ET defines the distribution of the degradation grades for this ET.

The state markup percentage \( p_{ET \, i=1...n, \, markup \, A/B/C/D} \) defines the influence of the ET on the energetic value for the given state.

The proportion factor \( g_{ET \, i=1...n} \) defines the overall influence of an ET on the energetic demand.

Aim of the calculation is to get a characteristic energy value (EV) for each surveyed ET and hence an assessment for the total energetic demand and the CO₂ emissions of the building.

ET that benefit the building energy demand because of energy production or concrete energy savings get negative markup percentages (Table 1). These have to be set before the calculation can be executed.

As these values will most likely differ for varying building types and usages, a dependence of all variables on the building type and usage, summarized as the AiBATROS® object class, was also implemented. This is not shown in this paper for better readability.

### Table 1. State markup percentages \( p_{ET \, i=1...n, \, markup \, A/B/C/D} \) per ET

| state [-]          | A  | B  | C  | D  |
|-------------------|----|----|----|----|
| positive state markup percentage | 1,00 | 1,25 | 1,75 | 2,00 |
| negative state markup percentage | -2,00 | -1,70 | -1,00 | -0,50 |

From these values the energetic state \( z_{ET \, i} \) per ET can be calculated:

\[
z_{ET \, i} = A_{ET \, i} \times g_{ET \, i} \times \frac{\sum_{j=1}^{D} (P_{ET \, i, \, markup \, j} \times P_{ET \, i, \, state \, j})}{100} \quad [-] \tag{1}
\]

The energetic state of an ET takes into account its reference value, its proportion factor and its distribution of the degradation states. It is therefore an auxiliary variable to represent the influence of the ET to the total building energetic state.

Using the energetic states of all ETs the total building energetic state can be calculated:

\[
z_{total} = \sum_{i=1}^{n} z_{ET \, i} \quad [-] \tag{2}
\]

The mentioned values are dimensionless because of the comparability among the ET that are surveyed in different units \( A_{ET \, i} \).

The characteristic \( EV \in [0,1] \) is calculated by the best and worst energetic state \( z_{A/D} \)

\[
z_{A/D} = \sum_{i=1}^{n} A_{ET \, i} \times g_{ET \, i} \times P_{ET \, i, \, markup \, A/D} \quad [-] \tag{3}
\]

\[
EV = \frac{z_{total} - z_A}{z_D - z_A} \quad [-] \tag{4}
\]

By choosing from statistics an average final energy demand \( Q_{final \, energy \, average} \), which represents the mean of the energy demand of buildings of this object class, and an energy range \( \alpha \),
which defines a confidence interval representing the final energy demand of such an object class in non-refurbished and refurbished state, we get the best and worst final energy demand with

\[
Q'_{\text{final energy, best/worst}} = Q'_{\text{final energy, average}} \pm Q'_{\text{final energy, average}} \cdot \alpha \quad \left[ \frac{kWh}{m^2a} \right] \quad (5)
\]

Hence the total final energy demand of the building is

\[
Q'_{\text{total}} = Q'_{\text{final energy, best}} + EV \cdot (Q'_{\text{final energy, worst}} - Q'_{\text{final energy, best}}) \quad \left[ \frac{kWh}{m^2a} \right] \quad (6)
\]

Out of that we get the energy saving potential \(Q'_{\text{potential}}\) of the object

\[
Q'_{\text{potential}} = Q'_{\text{total}} - Q'_{\text{final energy, best}} \quad \left[ \frac{kWh}{m^2a} \right] \quad (7)
\]

With a specific statistical CO\(_2\) value \(m'_{\text{CO2}}\) dependent on the energy source of the building we get the \(\text{CO}_2\)-emissions \(m_{\text{CO2}}\) and the saving potential \(m_{\text{CO2, potential}}\)

\[
m_{\text{CO2}} = m'_{\text{CO2}} \cdot Q'_{\text{total}} \quad \left[ \frac{kg}{m^2a} \right] \quad (8)
\]

\[
m_{\text{CO2, Potential}} = m'_{\text{CO2}} \cdot Q'_{\text{potential}} \quad \left[ \frac{kg}{m^2a} \right] \quad (9)
\]

Values shown in AiBATROS\(^{®}\) for a building will be the EV and the potential savings of energy and \(\text{CO}_2\)-emissions given by \(Q'_{\text{potential}}\) and \(m_{\text{CO2, Potential}}\). In addition, for each ET the state can be shown and also the potential saving achievable by bringing an ET to a better state.

3. Validation

For the validation and verification of this process, a comparison between the energy calculations of AiBATROS\(^{®}\) and EnerCalC was carried out. EnerCalC is an Excel-based tool, which enables the assessment of buildings’ energy performance based on the German norm DIN V 18599 [5]. It was developed as part of the dissertation „Vereinfachungen für die energetische Bewertung von Gebäuden“ („Simplification of the energetic evaluation of buildings“) [6]. EnerCalC was chosen for the comparison because it displays the same simplification grade with relatively little input effort while similar components are being examined resulting to comparable output data.

Four test objects with different surface (sa) to volume (vol) ratio \(\frac{sa}{vol}\) (0.2, 0.4, 0.57 and 0.8) were chosen for the comparison. Additionally, two complexities for each building construction and systems for heating, ventilation and air conditioning (HVAC) were created to get a multidimensional analysis:

- a non-refurbished or a refurbished building construction
- a technical service with only heating system (HVAC 1) or a heating system together with ventilation technology (HVAC 2).

The following figure shows the test cases for one object:
Further conditions for the comparison were set:

- $Q_{end \text{ energy, average}} = 110 \frac{kWh}{m^2a}$
- $\alpha = 20\%$
- $m'_CO_2 = 0,2 \frac{kg \ CO_2}{kWh}$
- All reference values were used consistently

The results of each test case were compared for each object individually to analyse the effect of changing building components on the calculation. Afterwards a comparison between test objects has been executed to evaluate the deviation for varying building configurations.

The evaluation of the test cases shows three major problems of the AiBATROS® energy calculation. In the next paragraphs these problems will be explained and approaches for a solution will be given.

1. **Surface-to-volume ratio**

   The biggest problem shown by the comparison is that with increasing surface-to-volume ratio, the differences of the energy demand results are growing (Figure 3). The reason therefor is that the calculation of the EV is based on each building component separately and it is does not take into account the building as whole. One cannot conclude automatically from the energetic standard of the building components the final energy demand of the object. The comparison approximation in EnerCalC integrates the loss of heat because of the decreasing compactness of the objects. In AiBATROS® this information is missing at the moment.
One solution to conclude from a building component EV to a final energy demand could be an adjustment factor based on the compactness. One empirical approach could be a linear adjustment factor:

$$Q'_{\text{total},\text{new}} = Q'_{\text{total}} \times (0.9 + \frac{sa}{vol})$$ \[ (10) \]

Figure 4 shows again the energy demand per test case but now with the adjustment factor on the AiBATROS® values. It is evident that the differences shrink significantly.

2. **Proportion of energy demand**

The proportions of energy demand of the ET mentioned before were set at the beginning out of internal reference values of the company and research. The individual evaluations of the objects showed that these proportions deviate by default (Figure 5).

A suggestion for the adaption of the energy demand proportions could be:

- Reducing of the HVAC to 15 %
- Increasing the lightning by 10 %
- Reducing of the water supply to 2 %
- Levy of the rest of 7 % on the building construction
3. State A and the energy demand
The results of test object 1 \( s_{vol} = 0.2 \) are shown in Fehler! Verweisquelle konnte nicht gefunden werden.. It becomes apparent, that with the addition of ventilation technology (HVAC 2) the differences of the energy demand increase in EnerCalC significantly. On the other hand in AiBATROS® the differences between the cases are minimal. The reason for that is the good energetic state of the ventilation technology that suggests no high energy demand in AiBATROS®. In EnerCalC though, even a good energetic state implies an increase of the energy demand in such cases. This information is not available in AiBATROS® at the moment.

A solution could be to implement a standard premium on the energy demand or EV for certain building elements.

4. Example calculation
An example calculation for the test object 3 with \( s_{vol} = 0.57 \) (case renovated HVAC 2) according to the process described in sections 2 and 3 is shown in the next paragraphs.

In this example, where the best and worst energetic state \( z_{A/D} \) and the total object state \( z \) are as following
\[
z_A = 181, \ z_D = 387, \ z = 276
\]
we get the characteristic \( EV \)
\[
EV = \frac{276 - 181}{387 - 181} = 0.46
\]
As can be seen from the result, the \( EV \) in this example is very balanced (\( EV_{best} = 0.00; EV_{worst} = 1.00 \)).

With \( EV \) and the difference of the best and the worst energy demand we get the total energy demand for our example building:
\[
Q'_{end \ energy\_best} = 110 \frac{kWh}{m^2a} \times (1 - 0.2) = 88 \frac{kWh}{m^2a}
\]
\[
Q'_{end \ energy\_worst} = 110 \frac{kWh}{m^2a} \times (1 + 0.2) = 132 \frac{kWh}{m^2a}
\]
\[
Q'_{total} = 88 \frac{kWh}{m^2a} + 0.46 \times 44 \frac{kWh}{m^2a} = 108.3 \frac{kWh}{m^2a}
\]
Out of these values we get the CO$_2$-emissions $m_{CO2}$ and the saving potentials for the energy demand and the CO$_2$-emissions:

$$m_{CO2} = 108,3 \frac{kWh}{m^2 a} \times 0,2 \frac{kg CO}{kWh} = 21,9 \frac{kg CO2}{m^2 a}$$

$$Q'_{potential} = 108,3 \frac{kWh}{m^2 a} - 88 \frac{kWh}{m^2 a} = 20,3 \frac{kWh}{m^2 a}$$

$$m_{CO2, potential} = 20,3 \frac{kWh}{m^2 a} \times 0,2 \frac{kg CO2}{kWh} = 4,1 \frac{kg CO2}{m^2 a}$$

To show the direct impacts of the adjustments the possible solutions are applied for object 3. In Figure 7 the initial values are depicted, while in Figure 8 are the values after implementing an adjustment factor for the surface-to-volume-ratio on the energy demand.

![Figure 7. Results for object 3 without adjustment factor](image)

![Figure 8. Results for object 3 with adjustment factor](image)

While in Figure 7 the deviation of the results from AiBATROS® calculation and the reference calculation is between 43.8% and 79.9 %, modifying the calculation with the adjustment factor (Figure 8) decreases the deviation to -2.2% to 22.4%. The deviation is still larger for the cases with HVAC 2, because the modification for the energy demand in state A has not yet been implemented. Moreover the total energy demand for the example building has been recalculated using the surface-to-volume-ratio factor:

$$Q'_{total,new} = 108,3 \frac{kWh}{m^2 a} \times (0,9 + 0,57) = 159,2 \frac{kWh}{m^2 a}$$

Regarding the aim of the AiBATROS® calculation to get a scoring for prioritizing energy improvements over large portfolios this remaining deviation is acceptable.
5. Conclusion & Outlook
This paper shows a couple of limitations of the linearized energy calculation in AiBATROS®. In some cases the calculation results are consistent with the results of the comparison tool EnerCalC, but some cases cannot yet be covered very well.

One problem is the evaluation of only building components information for calculating the energy indicator while not considering information about the building as a whole. This will be improved by also considering the compactness of a building for calculating the energy indicator.

Another problem is the initial definition of shares of the building components effect on the energy demand, which will be adapted in accordance with the validation results. Also the effect on the energy demand of some building components in good degradation state will be implemented.

After the implementation of these modifications, the calculation approach will be included in AiBATROS® for customer usage in pilot projects. In these projects, additional data will be collected for validating the results of the calculation and analysing additional modifications. Beside certificate data on energy performance also measured data on the energy consumption will be used. Meanwhile, the approach is being applied for ranking large building portfolios by their energy saving potential. This ranking can be utilised, beside additional information, to make an informed decision about with which buildings to start the planning of energy saving measures.

The next step will be to further validate the calculation method presented in this work using data of customer’s pilot projects and to adapt the factors and coefficients used by the calculation accordingly to the buildings used in the projects.

References
[1] CalCon Deutschland AG 2019 AiBATROS®. Available at https://www.aibatros.com/, 14.05.2019.
[2] Wetzel C 1999 EPIQR – Ein Softwareprogramm zur Grobdiagnose von Altbauten Bundesbaublatt 4 p 30-2.
[3] Nahrstedt H 2017 Excel + VBA für Ingenieure (Wiesbaden: Springer Vieweg).
[4] Gross M 2019 Plausibilisierung einer statistischen Energieapproximation - Überprüfung der Zuverlässigkeit eines vereinfachten, bauentbasierten, auf statistischen Werten und dem Pareto-Prinzip beruhenden Energiekennwert-Berechnungsverfahren für Bürogebäude Bachelor Thesis (Munich: Technische Universität München).
[5] Anon DIN V 18599-1:2018-09 Energetische Bewertung von Gebäuden - Berechnung des Nutz-, End- und Primärenergiebedarfs für Heizung, Kühlung, Lüftung, Trinkwarmwasser und Beleuchtung - Teil 1: Allgemeine Bilanzierungsverfahren, Begriffe, Zonierung und Bewertung der Energieträger (Beuth Verlag GmbH)
[6] Lichtmeß M, Voss K and Berges M 2017 Energiebilanzierung mit EnerCalC Version 5. Available at https://projektinfos.energewendebauen.de/fileadmin/user_upload/Projekte/Tools_und_Software/EnerCalC/Anleitung_Energiebilanzierung_mit_EnerCalC_Version_5.pdf, 14.03.2019.