NON-RESIDENTIAL BUILDINGS: INPUT PARAMETERS FOR MODELING THE ENERGY DEMAND

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ABSTRACT

This paper investigates the categorization of non-residential buildings to calculate the heat energy demand of a large number of buildings in Germany. We applied a methodology for estimating the thermal envelope area of residential buildings, developed by the *Institut für Wohnen und Umwelt* (IWU, 2005) to a sample of 229 office buildings. Using this methodology we developed new parameters relevant to office building façade areas. We found that a consistent building depth is the decisive criterion for applying the method, leaving out building-types with heterogeneous geometries and user profiles. Regarding the study, resulting façade areas are slightly overestimated by an average 3 % with a standard deviation of 0.29.

INTRODUCTION

Germany's building stock, consisting of residential and non-residential buildings (RBs and NRBs), is responsible for 35 % of the total final energy demand, as well as for around one third of the total greenhouse gas emissions in the country (BMWi, 2015, p. 5). Of these buildings, almost three million heated NRBs account for 36 % of the final energy demand and 42 % of the primary energy demand (dena, 2015, p. 20, 22, 134). The majority of the NRB-stock was built before the first German Thermal Insulation Ordinance in 1977 (BMVBS, 2013; Krüger et al., 2013, p.6). Those buildings have a high energetic refurbishment potential, considering typical life spans of their components.

For these reasons, the NRB-sector plays a key role to meet Germany's energy efficiency targets: a nearly climate neutral building stock by the year 2050, including 80 % reduction of the primary energy demand compared with 2008 (Energiekonzept 2010, p. 22; BMWi, 2015, p. 9). But how can an effective and also realistic contribution of the NRB-sector be implemented? The Federal Ministry for Economic Affairs and Energy (BMWi) recently commissioned a research group to investigate energy demand and - via energy efficiency scenarios - the potential coverage gap for the 2050-target (Prognos et. al, 2015). On this basis, energy efficiency strategies are defined for the building sector. The BMWi-study emphasizes that no substantiated statements can be made for NRBs due to a lack of building data (BMWi, 2015, p.32).

Problem statement

Unlike other European countries (e.g. Norway, Great Britain), so far Germany missed the opportunity to establish a data base with NRB-data partly collected via political instruments: for instance using the process of building permit, energy certificate, or the national census (Zensus 2011). This causes the current lack of a national-wide NRB database (BMVBS, 2013). Using the actual federal programs for NRB energy management and efficiency (Energieaudit, Energieeffizienznetzwerke), a new chance to build up a data base rises and should be taken. On the basis of a geo information system, a NRB-geoportal could be compiled, containing building type, construction year, gross floor space, etc. At this point, one should investigate, which basic parameters are sufficient to precisely model the NRB energy demand. Analyzing the parameters sensitivity as well as the long-term effects of decisions is crucial to develop valid energy efficiency strategies for the 2050-target.

State of the Art

Several studies have been conducted to model the energetic behavior of NRBs on the basis of data samples (BMVBS, 2011 and 2013). The overall observation is that the developed parameters helped to get reliable results on total energy demand and CO_2 emissions, but cannot be used to extrapolate to the overall NRB-sector. The derived building parameters are valid specifically to their projects (BMVBS, 2013).

The Centre for Sustainable Building at the Technical University of Munich developed a model for residential buildings, showing on different scales the buildings long-term energy demand development, as well as their preservative and energetic refurbishment potential (Nemeth et al., 2012). The model uses methods to acquire input parameters needed for the heat energy demand and saving potential calculations.

Considering the development of such a model for the NRB-sector, basic input parameters and methodologies in order to gain them have to be defined.

Objective and Scope

A crucial part when modeling the energy demand of a building stock is the determination of the buildings thermal envelope areas. Facing the problem of a poor NRB data condition, geometry parameters to calculate the thermal envelope areas, such as building depth and floor height, are often missing with regard to NRB modeling on large scale.

The objective of the paper on hand is to investigate the parameterization options to estimate the thermal building envelope area of NRBs. A methodology is aimed that balances out effort (data collection and analysis) and effectiveness (accuracy of results).

THE HEAT ENERGY DEMAND

Calculating the heat energy demand of a building according to standard that means balancing heat losses and gains over time under certain utilization factors and climatic conditions (DIN V 4108-6). Thereby the transmission heat loss of the thermal envelope of a building plays a crucial role, especially for older buildings. Figure 1 shows the relative transmission and ventilation heat losses of a typical office building (net floor space: around 900 m²) over the construction year periods.

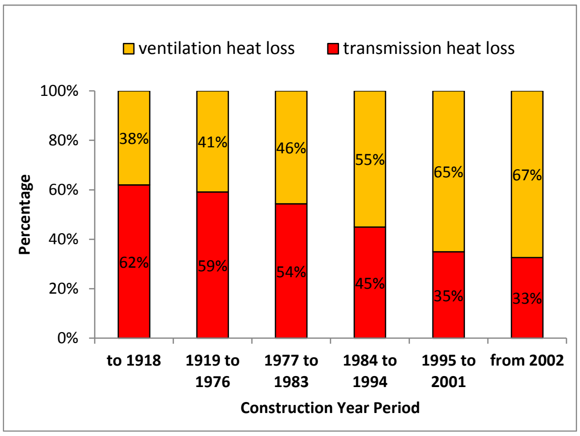

Figure 1: Transmission and ventilation heat losses for a typical office building (own diagram)

The transmission heat loss is calculated for each envelope component surface by multiplying heat transition coefficient (u-value), temperature correction factor, and surface area, considering thermal bridges (DIN V 4108-6). Dealing with large building stock data bases lacking information, standard u-values and temperature correction factors can be used instead. But if the information on building geometry is missing, the surface area cannot be calculated.

This demonstrates the need to investigate in geometry parameters for NRB-types to estimate the buildings envelope areas.

ESTIMATING THE ENVELOPE AREA

Methodology

The procedure of estimating the building component areas aims to generate a complete data set of the thermal building envelope, while being provided with a minimum data set to start with: gross floor area, number of full floors, and floor height.

Concerning the residential building sector, such a methodology has been developed and published in 2005 at the *Institut für Wohnen und Umwelt* (IWU, 2005, p. I-2 et seq.), called *'Flächenschätzverfahren'* (Methodology of Estimating Area - MEA). The study on hand investigates the applicability of the MEA to the NRB-stock.

The methodology's hypothesis implies that building envelope area and heated net floor area correlate (IWU, 2005, p. I-2 et seq.). Regarding a data sample of one building type, often a consistent parameter can be found in the building depth due to architectural principles. The 'fixed' building depth can be used to assume a proportional behavior of heated net floor space and building length. The more consistently the building depth of a sample behaves, the more reliable are the developed envelope area parameters. As the aiming result of the MEA is not the building length but the envelope area, the floor height is taken into account as a third dimension. This influence has to be considered in the MEA equations as a ratio of actual and standard floor height (see equation 3).

In the light of the above, the envelope area factors are developed on the basis of a data sample, expressing the ratio of envelope area and heated net floor area (m²/m²). Consequently, the validated parameters are used in the MEA equations to calculate the total envelope area of a building.

With due regard to the methods principle, the paper on hand investigates the implementation of MEA on one exemplary building type. The authors choose the NRB-type 'office buildings', due to its well-researched characteristics: standard user profiles and equipment requirements in offices cause typical room depths between six and seven meters, regarding area efficiency and daylight transport required in the room (Pinpoint, 2010, p. 192 et seq.; Neufert, 2012, p. 479, SIA2024:2006, p. 34, BMVBS, 2013, p. 56). Considering a typical double sequence building of cell and combined offices 'office – corridor (~ 1.50 m) – office', one can assume a standard building depth between 13.50 and 15.50 meters.

Data Basis

For the study, a basic data set of the Bavarian state's real estate is used. Fulfilling the parameter requirements, 229 office buildings are extracted of the data base (sample). In a second step the sample's data sets are completed by using the public and regional geoportal BayernAtlas (BayernAtlas, 2016). Table 1 gives the data basis overview. During the data acquisition procedure a plausibility check is conducted to ensure that the data set for each building is complete.

Table 1:
Overview of the MEA Data Basis

DATA SOURCE	PARAMETERS
data base of the Supreme Building Authority of the Bavarian State Ministry of the Interior	- construction year, - gross + net floor area, - number of full floors, - gross building volume
public geoportal	- building shape - roof shape - adjacency situation - building depth and perimeter

Definition of Basic Variables

The basic variables used for the MEA analysis are defined in this sub chapter.

First, the 229 office buildings are sorted according to their construction year. Figure 2 shows frequency and gross floor area (GFA) per construction year category (CYC). Looking at the building groups per CYC, they are similar in size with an average frequency of 23 buildings. In contrast, the GFA varies, with higher GFA in the year categories 4 and 5 (178.000 and 153.000 m²), as well as CYC 7 (205.000 m²) and lower GFA in CYC 1, 3, and 8 (76.000-78.000 m²). The low GFA in CYC 10 corresponds to the small group size of 13 buildings.

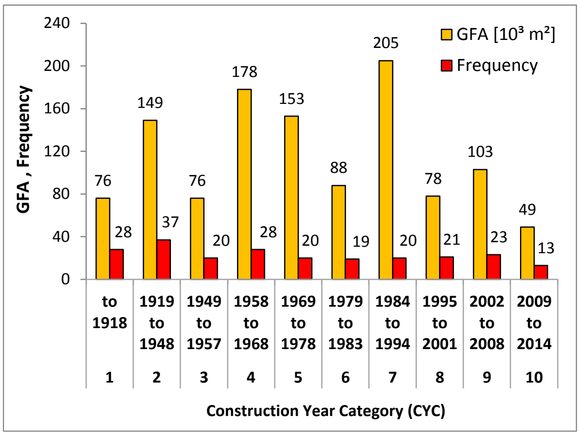

Figure 2: Basis Variable 'construction year category' (own diagram)

A further indicator to define the building sample is the number of full floors (n_{ff}). Table 2 shows the frequency distribution according to the GFA: the largest n_{ff} -shares have 4 and 5 floors, while the most frequent GFA is located in the lower segment from 0 to around 6000 m², in addition with the highest segment of > 10,000 m².

Table 2:
Basis variable 'number of full floors'

gfa [m²]	**n_{ff}** 1	2	3	4	5	6	7	8	9	10	> 10	**tot**
1000	9	14	14	11	1	1	1	0	0	0	0	51
2000	0	4	3	15	11	2	0	0	0	0	0	35
3000	0	1	3	7	13	2	1	1	0	0	0	28
4000	0	0	3	4	6	4	1	0	0	0	0	18
5000	0	0	1	2	11	2	5	0	0	0	0	21
6000	0	0	1	6	4	7	1	1	0	0	0	20
7000	0	0	1	1	3	2	1	0	1	0	0	9
8000	0	0	0	0	1	3	0	0	0	0	0	4
9000	0	0	0	2	4	1	1	0	0	0	0	8
10000	0	0	0	0	0	1	1	0	0	0	0	2
> 10000	0	0	0	4	5	7	10	1	3	3	0	33
	9	19	26	52	59	32	22	3	4	3	0	**229**

However, having a first overview of the data sample, the next step is to investigate the correlation of floor space and façade area.

As stated in the IWU publication *'Kurzverfahren Energieprofil'*, one can assume that stretched or complex floor plan geometries cause larger façade areas per floor than compact floor plans (IWU, 2005, p. I-7). The variable 'floor plan type' divides the buildings in 'compact' and 'stretched' according to their floor plan. As decisive criterion, the perimeter of the floor plan is compared to the square perimeter of the same area. If the perimeter ratio falls below 120 %, the building is designated as compact, otherwise as stretched.

Table 3 shows the frequency distribution: the sample consists of 58 % (132) compact and 42 % (97) stretched buildings. In addition, the median of the façade areas per floor is calculated for both floor plan types: the façade area per floor of compact buildings is with 254 m² significantly smaller than the façade surface of stretched buildings with 725 m². The values indicate an impact of floor plan type on façade area per floor that has to be further proven.

Table 3:
Basis variable 'floor plan type'

FLOOR PLAN TYPE	compact	stretched
Perimeter of floor plan vs. square of same area	< 120 %	≥ 120 %
Frequency	132	97
Median of façade area per floor [m²]	254	725

A further indicator that has an influence on the façade area is the adjacency situation. The study on hand splits the sample in three categories: detached buildings, buildings adjacent on one side, and those adjacent on two sides. Table 4 shows frequency and median of the façade area per floor: Detached buildings make up the largest share (143), followed by smaller groups of one- and two-sided-adjacent office buildings (57 and 29). The influence on the façade area per floor is almost a factor of two, comparing detached and adjacent situation (one-sided). Surprisingly, the median value for two-sided-adjacency exceeds the value for one-sided adjacent buildings, even though the façade surface should be decreased. The effect can be explained by the non-representative character of a small sample size, as well as an overestimated effect on the façade surface between one- and two-sided adjacent buildings. At this point, a further investigation with larger samples is necessary to validate the assumptions.

Table 4:
Basis variable 'adjacency situation'

ADJACENCY SITUATION	detached	adjacent, one-sided	adjacent, two-sided
No. of adj. walls	0	1	2
Frequency	143	57	29
Median of façade area per floor [m²]	498	263	317

Table 5 shows the statistic evaluation of building depth and floor height in order to verify the parameter's consistency and correspondence to standard values of the literature review mentioned above, in particular the BMVBS-study No 27/2013. Looking at the floor height, median, average value, and standard deviation indicate a consistent parameter of around 3.40 meters.

The statistical variance of the buildings depth may be present (5.07), but the interquartile range (50 %) of the office building sample varies between 12.00 and 15.00 meters with a median value of 13.00 meters. Thus, the parameter does not meet the optimal but sufficient consistency to conduct the MEA.

Table 5:
Basis variables 'building geometry'

BUILDING GEOMETRY	**Building depth [m]**	**Floor height [m]**
Median	13.00	3.40
Average value	14.35	3.47
Standard deviation	5.07	0.82
Average value (BMVBS No 27/2013, p. 56)	15.00	3.55

Concluding the definition of the basic variables, the boundary conditions for conducting the MEA are given. A correlation of building envelope area and heated net floor area can be assumed.

Parameter Development and Results

The MEA parameters are developed, using linear regression. The method attempts to model the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory variable X (heated net floor area), and the other is considered to be a dependent variable Y (façade area per floor) (Hedderich and Sachs, 2016, p. 128; Eckey et al. 2008, p. 189 et seq.). The equation form is defined as

$$Y = p * X + q, \qquad (1)$$

where p is the slope of the line, and q is the intercept, the value of Y when X = 0.

Figure 3 plots the 229 office buildings, showing the heated net floor area per floor on the x-axis (NFA_{floor}) and the façade area per floor on the y-axis ($A_{facade/floor}$). The buildings are categorized by geometry type and adjacency situation, leading to six following variants:

- detached | compact (det_com),
- detached | stretched (det_str),
- one-sided adjacent | compact (1s_com),
- one-sided adjacent | stretched (1s_str),
- two-sided adjacent | compact (2s_com), and
- two-sided adjacent | stretched (2s_str).

Each color represents an examined building group. Regression lines are plotted for all six variants and mathematically expressed by the regression equation on the right diagram side. Table 6 lists the values of slope factor (p) and intercept factor (q) for each variant.

Table 6:
Slope and intercept factors of the regression equations

SLOPE FACTOR	**[m²/m²]**	**INTERCEPT FACTOR**	**[m²/m²]**
p_det_com	0.15	q_det_com	238.92
p_det_str	0.46	q_det_str	252.46
p_1s_com	0.31	q_1s_com	128.10
p_1s_str	0.31	q_1s_str	402.49
p_2s_com	0.32	q_2s_com	134.15
p_2s_str	0.50	q_2s_str	253.85

The graph shows the squared correlation coefficient of Pearson, R^2, adapted to the graphs x- and y-values (x_i, y_i). The coefficient expresses the share of y-variance that is explained by the x-variance. If the factors are completely correlating, R^2 has a value of 1, meaning that the variance of y can be expressed with the variance of x by a 100 % (Eckey et al. 2008, p. 178 et seq.).

The examined sample groups (Figure 3) show a variation of R^2-values from low (0.16 – two-sided adjacent | compact) to high (0.85 – one-sided adjacent | compact). Possible reasons for this are:

First, quality and size of the sample influence the correlation coefficient. 229 buildings may be a sufficient sample size for plotting them as one group, but divided in sub groups (floor plan type and adjacency situation), the sample number per group decreases. With provided data, the variant 'adjacent on two sides | compact' has a critically low size of 7 buildings (Table 8). If additionally the few data values span a small range, the representative character of the variant and consequently the validity of its linear equation have to be treated with caution.

Second, the two factors geometry type and adjacency situation have an impact on the R^2-value. An interpretation of the parameter's mode of action is given in the following sub chapter.

Parameter Analysis

Following parameter analysis regards the results given in Table 6 and Figure 3:

One can observe that the distinction of adjacency situation leads to pairs of regression lines differing from one another with regard to starting level (intercept factor) and development (slope factor). This means, that the adjacency indicator influences the correlation of NFA_{floor} and $A_{facade/floor}$ pertaining their value level as well as their inherent relation.

Looking at each regression pair, the effect of the floor plan type can be perceived. For the detached buildings, the floor plan type plays an important role: The two regression lines (dark and light blue) start close to each other (similar intercept factor), but develop with different slopes. Hence, the floor plan type is decisive to this group, as it influences the relation of NFA_{floor} and $A_{facade/floor}$.

The regression lines of the one-sided adjacent buildings show a reverse picture: the lines run parallel to each other (same slope factor), where stretched buildings range on a higher level as compact buildings. Thus, for this group the distinction of floor plan type is also important, although the inherent relation of NFA_{floor} and $A_{facade/floor}$ is not affected.

Within the two-sided adjacent building group, both slope and intercept factors differ with regard to the floor plan type: the lines start on different levels and diverge in developing. From a mathematical point of view, the floor plan type is crucial to this group. But the result has to be restricted to a trend statement, as it is based on a critically small sample size (Table 9).

Considering given data and obtained results, adjacency situation and floor plan type need to be considered in form of their p- and q-values to estimate the façade area of an office building.

As a second part of the analysis, the p- and q-values are used to calculate $A_{facade/floor}$ for each building (recalculation). The results are compared to the buildings original $A_{facade/floor}$. This procedure validates the MEA parameters. Figure 4 shows a comparison graph of original and calculated $A_{facade/floor}$ for each building. Additionally, Table 8 lists the statistical parameters. The validation process reveals an overestimation of $A_{facade/floor}$ by an average 3 % with a standard deviation of 0.29 (Table 8).

MEA for Office Buildings

In line with the IWU MEA equations (IWU, 2005), the thermal envelope surface of office buildings can be estimated using following equations within the validity range of this study. Table 7 shows the input parameters needed to solve the MEA equations.

Table 7:
Input parameters for the MEA equations

PARAMETER	ABBR.	VALUE	UNIT
Gross Floor Area	GFA	data	[m²]
Number of full floors	n_{ff}	data	[-]
Ratio of net and gross floor area (Worm and Rathert, 2015, p. 10)	$f_{NFA/GFA}$	0,85	[-]
Factor attic / basement: (not/semi/fully heated)	f_a / $_b$	-1,0 / 0,5 / 1,0	[-]
Factor attic, usable area (IWU, 2005, p. I-10)	$f_{a,ua}$	0,75	[-]
Factor dormer (IWU, 2005, p. I-29)	f_d	1,3	[-]
Floor height	h_f	data	[m]

Calculating the net floor area per floor NFA_{floor}:

$$NFA_{floor} = \frac{GFA * 0{,}85}{n_{ff}} \quad [m^2] \tag{2}$$

Estimating the façade area per floor:

$$A_{facade/floor} = \frac{h_f}{3{,}55} * (p * NFA_{floor} + q) \tag{3}$$

Total number of heated floors:

$$n_{hf} = f_b + n_{ff} + f_a * f_{a,ua} \tag{4}$$

Attic / top floor ceiling area:

$$A_{attic} = NFA_{floor} * f_d * f_{a,ua} \quad (5)$$

$$A_{top\_floor\_ceiling} = NFA_{floor} * p_{top\_floor\_ceiling} \quad (6)$$

Basement area

$$A_{basement} = NFA_{floor} * p_{basement} \quad (7)$$

Total window façade of the thermal envelope:

$$A_{window} = A_{facade/floor} * n_{hf} * f_w \quad (8)$$

Total façade area of the thermal envelope:

$$A_{facade} = A_{facade/floor} * n_{hf} - A_{window} \quad (9)$$

Due to a lack of data, the factors for window area (f_w), basement area ($p_{basement}$), and top floor ceiling area ($p_{top\_floor\_ceiling}$) could not be developed. However, they are included to give a complete equation set.

Restrictions

As mentioned above, the MEA-parameters are specific to the investigated office building type, due to following restrictions:

- *Bavaria State's real estates:* contain a mixture of typical and specific-local characteristics (e.g. building plan structure, regulation of building height)
- *Use of geoportals*: provides estimated data, but no accurate measurements
- *Small sample size:* diminishes the quality of slope and intercept factors and therefore reduces the accuracy of the envelope area calculation
- *Lack of data:* no investigation of the factors for window area (f_w), basement area ($p_{basement}$), and top floor ceiling area ($p_{top\_floor\_ceiling}$)
- *MEA:* not applicable to all NRB-types due to their heterogeneous building geometries and user profiles.

SUMMARY

The key findings of the paper are as follows:

1. The poor data condition of NRBs requires parameterizing methods to calculate the heat energy demand of large NRB-stocks.
2. A methodology for geometry parameters per building type is needed to estimate the thermal envelope areas and subsequently calculate the transmission heat losses of a building.
3. The IWU procedure to estimate the thermal envelope of residential buildings based on few input parameters is found to be adaptable to large NRB-stocks of office buildings.
4. A consistent building depth, causing a correlation of heated net floor space and façade area, is found to be the decisive criterion for applying the MEA.
5. Building adjacency situation, floor plan type, and floor height are observed to influence the correlation of heated net floor space and façade area. They are therefore considered in the development of MEA parameters and equations.
6. Restrictions to the results application are found due to a specific and small sized data basis.
7. The values of the slope and intercept parameters in Table 6 can be applied specific to the building type with regard to the restricitons above.

CONCLUSION

Although the applicability of developed parameters is restricted by sample type and size, the methodology succeeded. This demonstrates how studies generating building parameters on few basic data contribute to the procedure of modeling large buildings stocks.

The next steps are to complete the MEA with the missing parameters (f_w, $p_{basement}$, $p_{top\_floor\_ceiling}$) and to apply the procedure to other NRB-types. At this point, the authors recognize the need for a further developed method for those NRB-types which have a heterogeneous building depth, although aligned to architectural principles. After all, input parameter sets to calculate the heat energy demand are to be compiled.

On a broader scale, the papers findings could lead to an input parameter basis for modeling the long-term energetic NRB-behavior and help closing the data gap of NRB.

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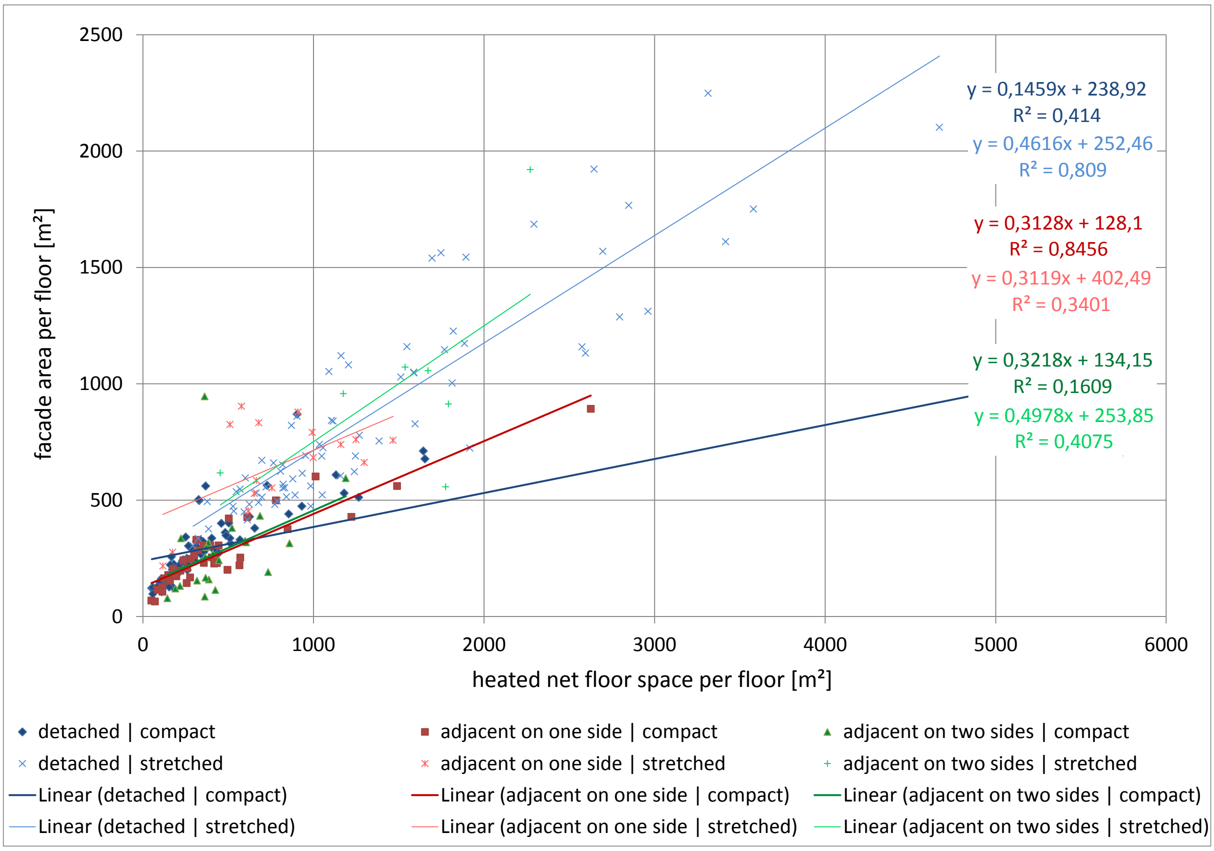

Figure 3: Correlation between facade area and heated net floor area per floor - differentiating building geometry and adjacency situation (own diagram)

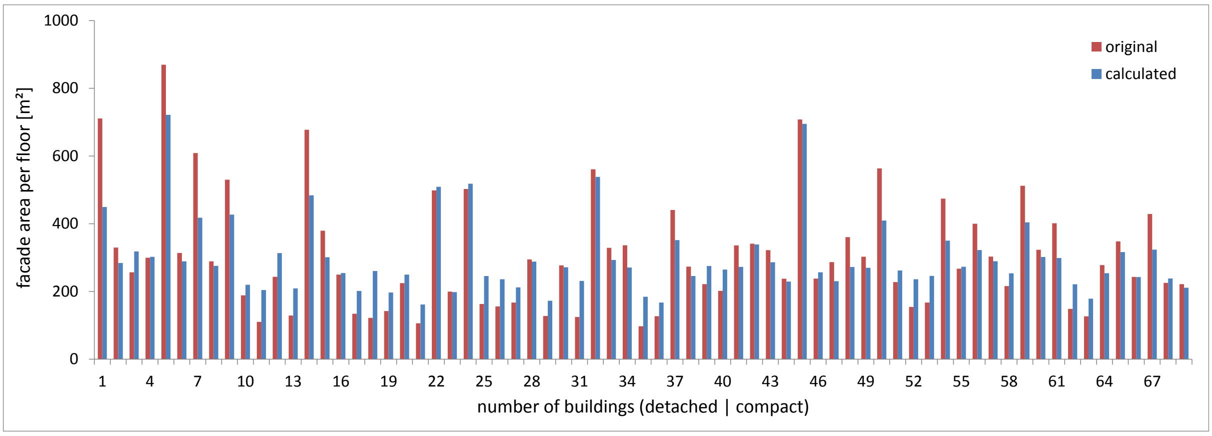

Figure 4: Comparison of original and calculated facade area per floor, shown for the building group 'detached | compact' (own diagram)

Table 8:
Statistical evaluation of the developed MEA parameters

STATISTICAL PARAMETERS	UNIT	DET_ COM	DET_ STR	1S_ COM	1S_ STR	2S_ COM	2S_ STR	AV. VALUE
no of buildings	[-]	69	74	41	16	22	7	
average value	[%]	109	99	101	108	128	107	109
median	[%]	99	99	90	103	115	113	103
standard deviation	[-]	0,33	0,16	0,31	0,23	0,49	0,25	0,29

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