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Building Energy Performance Rating: Impact of the Reference Characteristics in the Notional Building Approach

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Abstract

As the energy performance regulations are getting stricter, building industry stakeholders stress the importance of a fair energy performance rating system. In Belgium, the regulations are perceived to be stricter for certain dwellings such as small apartments and row houses, while these are typically the most energy efficient building typologies. A research project was set up to propose an alternative energy performance rating for domestic buildings. The notional building approach, a methodology to normalize the primary energy use of a building, was studied, as it has recently been introduced in Belgium for utility buildings, and is used in several European countries. Energy simulations were performed on 6.000 houses of a Flemish Energy Performance database containing the characteristics of over 100.000 recently build dwellings. The results showed how dwellings of different typology or size can be significantly advantaged or disadvantaged by the notional building approach, depending on the selected set of reference characteristics. The average building approach was developed as an alternative energy performance rating to solve these problems.

Keywords – building energy performance, energy performance of buildings regulations, notional building, average building, energy performance database

1. Introduction

In order to lower the building energy use in Europe, every member state has to implement the Energy Performance of Buildings Directive of the European Commission [1]. This directive states that the energy performance of a building should include a primary energy use indicator, and an energy performance indicator. The energy performance indicator should be expressed in kWh/m².

As buildings of different size – but the same ambition level regarding energy performance – will have a different primary energy use, the latter is necessary to rate the energy performance of buildings and to allow national legislation to impose maximum levels and a transition pathway toward nearly zero-energy buildings.

The energy performance indicator, obtained through normalizing the primary energy use, should be designed in order to make a fair judgement of the energy-saving efforts made by the homeowner.

In Belgium, the Flemish Energy Agency, received feedback from several stakeholders who perceived the current domestic energy performance regulation as unfair to some building typologies. They felt apartments and row houses, and more specifically the smaller dwellings, are disadvantaged by the normalization methodology. Since these houses are known to consume few energy compared to detached, or larger houses, this is an undesirable effect.

To update the current domestic building energy regulations, a research project was launched studying different approaches to the normalization of the primary energy use of buildings [2].

One of the options studied, was the notional building approach, which is recently adopted in Flanders for utility buildings, and is used in several European countries such as Germany, UK and Hungary for domestic buildings.

In the notional building approach, the primary energy use of the actual building ($E_{prim,actual}$) is compared to the primary energy use of a notional (fictive) building with the same geometry, but with fixed properties of the building skin and HVAC systems ($E_{prim,notional}$). The resulting energy indicator (E_{not}) is thus expressed as a percentage of a reference energy use and can easily be used to lower the maximum allowed energy use compared to a baseline scenario.

$$E_{not} = E_{prim,actual} / E_{prim,notional} \qquad (1)$$

The straightforwardness of the normalization methodology is often regarded as one of the advantages, while a major disadvantage is the lacking incentive to design a more efficient geometry. This is due to the use of the same geometry in the notional building: whenever a building is designed with a large heat loss area for a specific volume, the notional building will have the same large heat loss area, thus canceling out the heat losses which could have been avoided using a more efficient geometry.

2. Method

As one of the main reasons for the research project was the indication of unfair treatment of some dwellings by the current building energy normalization methodology, the research team wanted to study the effects of its new proposals on a large, representative group of dwellings, rather than a using a small sample of fictive houses.

Since the Flemish Energy Agency collects all the building characteristics from new buildings' energy performance reports in a database, the research team had access to geometry, properties of the building skin and HVAC systems of more than 100.000 dwellings built since 2006.

The houses in the EPBD-database were clustered in different groups according to typology (apartments, row houses, semi-detached and detached) and number of sleeping rooms.

Six clusters were selected in total, and from each cluster 1.000 dwellings were randomly selected, resulting in a large set of dwellings with different characteristics (typology, size, geometry, window fraction, materials, systems…).

The largest cluster of each typology (apartments 2 bedrooms, row houses 3 bedrooms, semi-detached 3 bedrooms and detached 3 bedrooms) were supplemented with two clusters with only one bedroom to pay specific attention to smaller houses (apartments 1 bedroom, detached 1 bedroom).

As only the overall geometry (volume and heat loss area) was available in the database, and in-house built simulation tool was used to generate the corresponding detailed geometry (area of different faces and orientations) necessary for the energy calculations. For every cluster, a detailed parametric BIM-model was built in Revit, which was fitted 1.000 times to correspond to the overall geometry of each house. Based on the detailed geometry, the simulation tool calculates the energy use according to Flemish building regulations [3] [4].

Five sets of measures (building skin and HVAC systems) are defined. In this paper, set1 (up-to-date) and set2 (outdated) are used as reference characteristics to calculate $E_{prim,notional}$. Set 3 (up-to-date, $\neq$ set1), set 4 (ambitious) and set 5 (very ambitious) are applied to calculate $E_{prim,actual}$.

3. Compactness and form efficiency

During the study, stakeholders involved in energy regulations, stressed the importance of a fair treatment of dwellings with different size, but felt dwellings with an energy efficient geometry should be rewarded with a lower energy performance rating. The latter is often described by the compactness (c), which is defined as the ratio between the volume (V) and the heat loss area (A_T) of a building.

$$c = V / A_T \qquad (2)$$

Achieving a high compactness is generally regarded as a good design practice, and is promoted by building regulations. However, the definition of compactness favors larger buildings, as the following example shows. In Table 1, two volumes of the same shape (a cube), but different size are compared.

Table 1. Compactness

	small cube	large cube
dimensions	1 x 1 x 1 m	10 x 10 x 10 m
volume	1 m³	1000 m³
area	6 m²	600 m²
compactness	0.16 m	1.6 m

Although the larger cube has a higher compactness and is more energy efficient, both volumes were designed with the same effort to achieve the most efficient building form. As the volume of a building is a result of the specific needs of the home owner, and

the design of larger residential buildings should not be promoted, both cubes should be regarded as equally ambitious.

As an alternative, 'form efficiency' was defined as the ratio between the area of a sphere with the same volume as the building (A_{sphere}), and the heat loss area of a building. Note that any geometry could have been used instead of a sphere.

$$f = A_{sphere} / A_T \qquad (3)$$

The area of a sphere with a given volume can be calculated as following:

$$A_{sphere} = 4 \cdot \pi \cdot ((3 \cdot V) / (4 \cdot \pi))^{2/3} \qquad (4)$$

Table 2 demonstrates how the form efficiency describes the efficiency of the geometry, regardless of the size.

Table 2. Form efficiency

	small cube	large cube
dimensions	1 x 1 x 1 m	10 x 10 x 10 m
sphere area	4.84 m²	484 m²
area	6 m²	600 m²
form efficiency	0.81	0.81

4. Notional building approach

In the notional building approach, the primary energy use of the actual building is compared with the primary energy use of the notional building. Both the energy uses in numerator and denominator, are the result of a calculation methodology described in normative documents.

In Belgium, some energy flows required to calculate the primary energy use are based upon the heat loss area (transmission heat losses, infiltration heat losses, solar gains…) while others are based on the volume of the building (ventilation heat losses, quantity of domestic hot water, internal gains…). Note that in most other countries, some energy flows are calculated based on the floor area instead of the volume. As the volume is a result of the floor area multiplied by the floor height, the same findings are valid for other countries. Equation 1 could be written as:

$$E_{not} = (E_{prim,actual,f(At)} + E_{prim,actual,f(V)}) / (E_{prim,notional,f(At)} + E_{prim,notional,f(V)}) \qquad (5)$$

As a result, both the quality of the building skin (insulation performance, airtightness, SHGC…) and the quality of some HVAC systems (performance of the ventilation system, domestic hot water generation efficiency…) are compared between the actual building and the notional building.

The ratio between the heat loss area and the volume is defined by the building's form efficiency (either by choosing an energy efficient typology such as an apartment, or

choosing an energy efficient geometry such as a cube), and by the size of the building as paragraph 3 showed.

Consequently, buildings of a different form efficiency and size will only be rated equally by the notional building approach when the ratio of the performance of the heat loss area-based elements ($E_{prim,actual,f(At)}$ / $E_{prim,notional,f(At)}$) and the ratio of the performance of the volume-based elements ($E_{prim,actual,f(V)}$ / $E_{prim,notional,f(V)}$) is equal. In reality, this will never happen, and some buildings will inevitably be advantaged compared to others.

Example 1 shows this effect:
- Given are two dwellings with the same volume of 500 m³, the first is a row house with a heat loss area of 250 m², the second is a detached house with a heat loss area of 500 m².
- Suppose the performance of the volume-based elements is equal in both the actual and notional building. This results in an energy use of 10.000 kWh.
- Suppose the performance of the heat loss area-based elements is twice as good in the actual building as in the notional building. This results in an energy use of 10.000 kWh in the row house, and 20.000 kWh in the detached house in the actual building, while for the notional building this is respectively 20.000 and 40.000 kWh.

The energy performance rating of the row house is calculated as

$$E_{not} = (10.000 + 10.000) / (20.000 + 10.000) = 0.67$$

While for the detached house

$$E_{not} = (20.000 + 10.000) / (40.000 + 10.000) = 0.60$$

This example shows how buildings with a better form efficiency can achieve a worse energy performance rating by the notional building approach, which is an undesirable effect. Similarly, dwellings with the same form efficiency, but different size will be rated differently, which is also a negative effect.

In addition, the difference between the energy performance rating for different types of buildings (form efficiency and size) is depending largely on choice of building skin and HVAC systems in both actual building and notional building.

Example 2 shows this effect:
- Given are the same two dwellings
- Suppose the performance of the volume-based elements is, again, equal in both the actual and notional building. This results in an energy use of 10.000 kWh.
- Suppose the performance of the heat loss area-based elements in the actual building is the same as in Example 1. The performance of these elements in the notional building is half as good as in the actual building. This results in

an energy use of 10.000 kWh in the row house, and 20.000 kWh in the detached house in the actual building, while for the notional building this is respectively 5.000 and 10.000 kWh.

The energy performance rating of the row house is calculated as

$E_{not} = (10.000 + 10.000) / (5.000 + 10.000) = 1.33$

While for the detached house

$E_{not} = (20.000 + 10.000) / (10.000 + 10.000) = 1.50$

While in Example 1, the row house had a higher energy performance rating as the detached house, this is not true for Example 2. This example shows the large impact of the performance of the building skin and HVAC systems of the notional building. The performance of the building skin and HVAC systems of the actual building have a similar effect.

Both effects were observed when the results of the energy simulations were normalized according to the notional building approach.
Figure 1 shows the results of the detached dwellings with 3 bedrooms. It can be observed that the notional building approach does not always promote a better form efficiency. While the houses with the highest form efficiency are the most energy saving and should, according to the stakeholders involved in the study, receive the lowest energy performance rating, this is only slightly the case when set 4 is applied. In contrary, when set 3 and set 5 are used, the most form efficient houses get the worst energy performance rating.
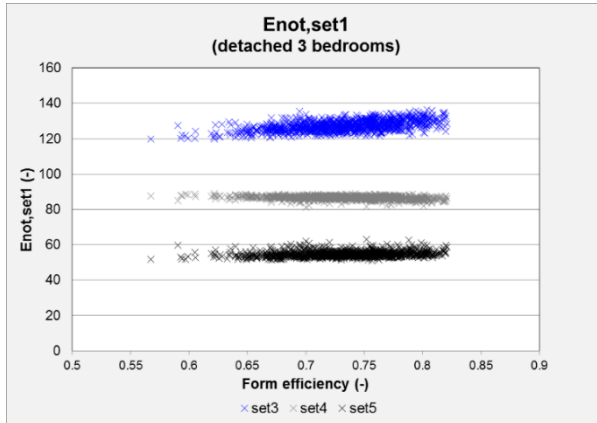
Figure 1: The chart shows the results for the notional building approach with an up-to-date set of reference characteristics when three different sets of characteristics of the actual building are applied. Houses with a higher (=better) form efficiency are advantaged or disadvantaged depending on the actual set of measures.

When in Figure 2, the previous results ($E_{not,set1}$) are compared to the results for the notional building approach with another set of characteristics for the notional building ($E_{not,set2}$), no clear correlation can be observed. This is especially the case when set 4 and set 5 are used in the actual building, where a large cloud of results is shown in the graph. Some detached dwellings with 3 bedrooms score a low $E_{not,set1}$-value but a high $E_{not,set2}$-value, while for some other dwellings a reverse effect is visible.
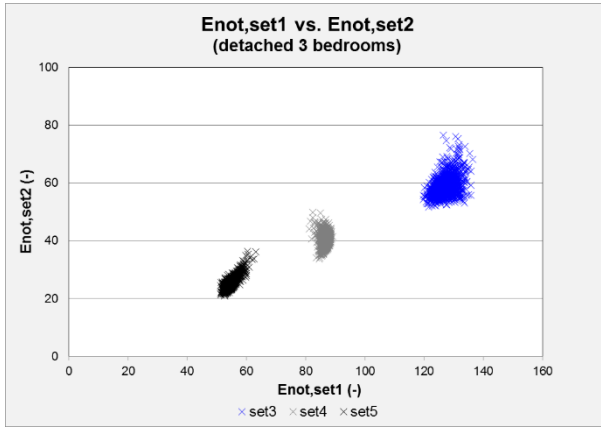

Figure 2: The chart shows the results for the notional building approach with both an up-to-date set of reference characteristics (x-axis) and outdated set of reference characteristics (y-axis) when three different sets of characteristics of the actual building are applied. The absence of any correlation stress the impact of the reference characteristics in the notional building approach.

5. Average building approach

To tackle the problems associated with the notional building approach, an alternative normalization methodology was developed. In the 'average building approach', the primary energy use of the actual building is also compared to the primary energy use of a fictional building with a predetermined set of reference characteristics. This fictional building has the same volume as the actual building, but in contrast to the notional building approach, does not have the same geometry.

$$E_{avg} = E_{prim,actual} / E_{prim,average} \qquad (6)$$

As the name suggest, in the average building approach, an average geometry is used based on a representative set of buildings. To calculate the primary energy use for the

average building according to the Flemish energy calculation methodology, three aspects besides the volume of the building are necessary: heat loss area, window area and solar gains.

The average heat loss area is calculated based on the area of a sphere with the same volume as the actual building, and an volume-weighted average form efficiency of a reference set of buildings (f_{avg}).

$$A_T = A_{sphere} / f_{avg} = A_{sphere} / (A_{sphere} / A_T)_{avg} \qquad (7)$$

To determine the average window area (A_W) of the average building, the window area of every building in the representative set of reference buildings is normalized to the volume of the corresponding building and a volume-weighted average is calculated. This average value is multiplied by the volume of the actual building to calculate the window area of the average building.

$$A_W = V \cdot (A_W / V)_{avg} \qquad (8)$$

As the distribution of the window area across different orientations in the average building cannot easily be determined, the average solar gains (Q_S) were calculated based on simulation results. Simulations on a set of reference buildings were performed using the SHGC of the glazing and shading characteristics in the predetermined set of measures. Again, the solar gains were normalized according to the building volume, and a volume-weighted average was calculated for the complete set.

$$Q_S = V \cdot (A_W / V)_{avg} \qquad (9)$$

All other energy flows (ventilation losses, internal gains) necessary to calculate the primary energy use according to the Flemish energy calculation methodology, are based on the volume of the building.

As there is a fixed rate between the volume and heat loss area of the average building, all energy flows of the average building are based on the volume of the building. Equation (6) can be written as:

$$E_{not} = (E_{prim,actual,f(At)} + E_{prim,actual,f(V)}) / E_{prim,average,f(V)} \qquad (10)$$

When the energy use of two buildings with the same volume, but different form efficiency is normalized using the average building approach, the most form efficient building will always get the lowest energy performance rating, assuming other aspects (same set of measures, same window fraction and solar gains) are identical. This is demonstrated in Figure 3, where for all three sets of characteristics, detached houses with 3 bedrooms with a better form efficiency, are rewarded with a lower $E_{avg,set1}$ energy performance rating.
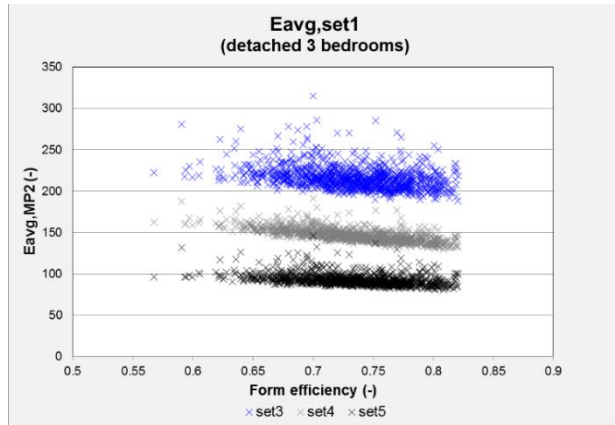
Figure 3: The chart shows the results for the average building approach with an up-to-date set of reference characteristics when three different sets of characteristics of the actual building are applied. Houses with a higher (=better) form efficiency are advantaged, independent on the actual set of measures.

This will be the case for every selected set of measures for the average building, despite the performance level of this set of measures. Whether this set of measures consists of a high performance building skin quality rather than high performance HVAC-systems is of much lesser importance compared to the notional building approach.

In Figure 4, the previous results ($E_{avg,set1}$) are compared to the results for the average building approach with another set of characteristics for the notional building ($E_{avg,set2}$). Despite the different reference characteristics, a strong correlation can be observed for all three sets of measures in the actual building.
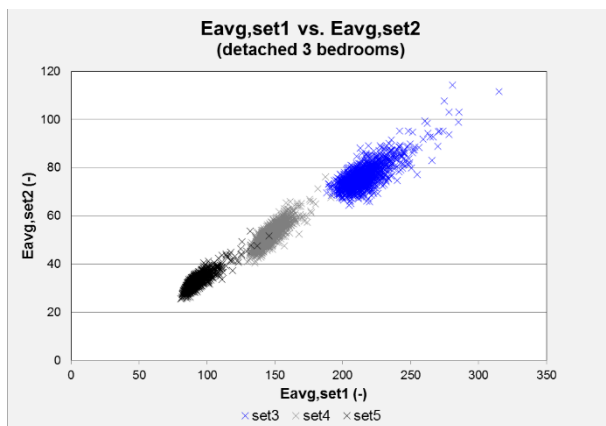
Figure 4: The chart shows the results for the average building approach with both an up-to-date set of reference characteristics (x-axis) and outdated set of reference characteristics (y-axis) when three different sets of characteristics of the actual building are applied. The strong correlation indicates the lesser importance of reference characteristics in the average building approach compared to the notional building approach.

6. Conclusion

This paper showed that the notional building approach does not only lack an incentive to design form efficient buildings, but can also favor buildings with an inefficient geometry or larger size. This undesirable effect can appear with certain combinations of both the designed and notional building properties (building skin and HVAC systems), stressing the importance of a thought out set of properties of the notional building.

The average building approach was developed as an alternative normalization methodology. In this approach, the energy use of the actual building is compared to an average building with the same volume. The average building approach leads to a lower energy performance rating for more form efficient buildings, regardless of their size. The impact of the reference characteristics is of much lesser importance, compared to the notional building approach.

Acknowledgment

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