Relevance of renewable energy ratio indicator in describing nZEB performance

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Abstract
The energy used in nearly zero-energy buildings has to be covered to a significant extent by energy from renewable sources by the EPBD directive definition and renewable energy ratio can be used to quantify the proportion of renewable energy. It has been discussed should the Member States set requirement for minimum renewable energy ratio or would it be adequately covered by the non-renewable primary energy indicator. The purpose of this study was to assess, if setting requirements of the renewable energy ratio of nearly zero-energy buildings is relevant. We studied the energy use of 8 nearly zero-energy buildings in Europe, calculated the primary energy and renewable energy uses and analyzed grid loads of the 4 buildings that had hourly energy use data available. The primary energy uses and renewable energy ratios of the buildings varied between -1 and 96 kWh/m² and 106% and 28% respectively, whereas there was a good negative correlation. Renewable energy ratio was not particularly sensitive to the use of total and renewable or non-renewable primary energy factor or calculations without factors. Renewable energy ratio did not allow drawing conclusion about the grid load and hourly data about energy use was required to assess grid loads. This allowed concluding that renewable energy ratio did not provide useful additional information and it would be more straightforward and transparent to operate with non-renewable primary indicator only.
1. Introduction

Energy from renewable sources, including energy from renewable sources produced on-site or nearby is one part of EPBD nZEB definition stating that the energy used in nearly zero-energy buildings has to be covered to a significant extent by energy from renewable sources. It has been discussed should the Member States set requirement for minimum renewable energy ratio or would it be adequately covered by the non-renewable primary energy indicator. At least it should be possible to calculate renewable energy contribution (called also RES share or RER – renewable energy ratio). Member States have used so far twofold approach for RES share accounting. Some countries have set quantitative requirements for RES share in national nZEB applications, some countries have not set the requirements as through the non-renewable primary energy factors RES share is accounted qualitatively in the primary energy indicator.

In this paper we have applied RER equation of REHVA nZEB report [5] and FprEN 15603:2015 which both define RER as complementary indicator in addition to main primary energy indicator. Analyses for 7 nZEB office and 1 school are conducted in order to show the correlation between non-renewable primary energy and RER indicators as well as for the relevance of RER indicator in the grid load estimation.

2. Methods

Our study was conducted in the following steps:
1. Obtaining energy use and production data about the buildings
2. Calculating annual primary energy and renewable energy ratios
3. Calculating monthly renewable energy ratios and renewable energy fraction indexes and percentages of generated renewable energy that is used

A. Studied nearly-zero energy buildings

The eight studied European nZEB-s are described in Table 1. Four of them are located in Central- or Western Europe and the other four in northern part of the continent. Most cases are office buildings with one exception, which is a primary school. Most common heat sources are either ground source heat pump or district heating, but there is also one example with biofuel. All use the ground or groundwater as an efficient cooling source, whereas a few are using the heat pump to increase cooling capacity. Photovoltaic panels are the most common renewable energy source, but two cases have also solar collectors. Wind turbines and combined heat and power production were installed in two cases respectively.
Four of the buildings had only annual energy uses available and the other four had hourly data, whereas it was measured in case the office building SE1 and other buildings had only simulated data available. The energy uses and technical solutions of buildings with annual data only have been reported in the REHVA European HVAC Journal [1-4]. The hourly energy use data of the other four case studies was obtained from the representatives connected with the buildings.

Table 1. Description of nearly zero energy buildings. Code: Off – office building; Pri. Sch. – primary school; Meas – measured, Sim – simulated; GSHP – ground source heat pump; w/o – without; HP – heat pump; cool – cooling; PV – photovoltaic panels; SC – solar collectors; BioCHP – combined heat and power plant using biofuel

<table>
<thead>
<tr>
<th>Case code</th>
<th>Location</th>
<th>Type</th>
<th>Data</th>
<th>Heating</th>
<th>Cooling</th>
<th>Renewable energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE1</td>
<td>Väla Gård, Helsingborg, Sweden</td>
<td>Off</td>
<td>Meas, hourly</td>
<td>GSHP</td>
<td>Boreholes w/o HP</td>
<td>PV</td>
</tr>
<tr>
<td>SE2</td>
<td>Entré Lindhagen, Stockholm, Sweden</td>
<td>Off</td>
<td>Sim, hourly</td>
<td>District heat</td>
<td>Boreholes w/o HP</td>
<td>Wind</td>
</tr>
<tr>
<td>NL1</td>
<td>DSK-II, Haarlem, Netherlands</td>
<td>Pri. Sch.</td>
<td>Sim, hourly</td>
<td>GSHP</td>
<td>GSHP</td>
<td>PV + SC</td>
</tr>
<tr>
<td>FR</td>
<td>Elithis Tower, Dijon, France</td>
<td>Off</td>
<td>Meas</td>
<td>Biofuel</td>
<td>Free cool + chiller</td>
<td>PV</td>
</tr>
<tr>
<td>EE</td>
<td>Rakvere SBCC, Rakvere, Estonia</td>
<td>Off</td>
<td>Sim, hourly</td>
<td>GSHP</td>
<td>Open wells + GSHP</td>
<td>PV</td>
</tr>
<tr>
<td>CH</td>
<td>IUCN Headqtr, Gland, Switzerland</td>
<td>Off</td>
<td>Sim</td>
<td>GSHP</td>
<td>Boreholes</td>
<td>PV</td>
</tr>
<tr>
<td>NL2</td>
<td>UKP NESK, Hoofdrop, Netherlands</td>
<td>Off</td>
<td>Sim</td>
<td>GSHP</td>
<td>GSHP</td>
<td>BioCHP + SC</td>
</tr>
<tr>
<td>FI</td>
<td>Ympäristötalo, Helsinki, Finland</td>
<td>Off</td>
<td>Sim</td>
<td>District heat</td>
<td>Boreholes w/o HP</td>
<td>PV</td>
</tr>
</tbody>
</table>

B. Primary energy and renewable energy ratio

The primary energy indicator $E_{P_P}$ (kWh/m² a) is the sum of delivered energy multiplied with respective non-renewable primary energy factors minus exported energy multiplied with respective primary energy factors. It was calculated with equation 1:

$$
E_{P_P} = \frac{\sum_i (E_{del,i} \cdot f_{del,nren,i}) - \sum_i E_{exp,i} \cdot f_{exp,nren,i})}{A_{net}} \tag{1}
$$

The renewable energy ratio describes the share of renewable energy in delivered and exported energy, which is based on the total primary energy. $RER_{P_P}$ (-) was calculated with equation 2:
\[
RER_p = \frac{\sum_i E_{\text{ren},i} + \sum_i ((f_{\text{del,tot},i} - f_{\text{del,nren},i}) \cdot E_{\text{del},i})}{\sum_i E_{\text{ren},i} + \sum_i (E_{\text{del},i} \cdot f_{\text{del,tot},i}) - \sum_i (E_{\text{exp},i} \cdot f_{\text{exp,tot},i})}
\]  

(2)

In equations 1 and 2 $E_{\text{del},i}$ – delivered energy on-site or nearby for energy carrier $i$, kWh/a; $E_{\text{exp},i}$ – exported energy on-site or nearby for energy carrier $i$, kWh/a; $E_{\text{ren},i}$ – renewable energy produced on-site or nearby for energy carrier $i$, kWh/a; $f_{\text{del,nren},i}$ – non-renewable primary energy factor (-) for the delivered energy carrier $i$; $f_{\text{del,tot},i}$ – total primary energy factor (-) for the delivered energy carrier $i$; $f_{\text{exp,nren},i}$ – non-renewable primary energy factor (-) of the delivered energy compensated by the exported energy for energy carrier $i$; $f_{\text{exp,tot},i}$ – total primary energy factor (-) of the delivered energy compensated by the exported energy for energy carrier $i$; $A_{\text{net}}$ – useful floor area (m$^2$) calculated according to national definition.

Same primary energy factors were used for all cases to compare the buildings. The primary energy factors are described in Table 2.

**Table 2. Primary energy factors**

<table>
<thead>
<tr>
<th>Energy carrier</th>
<th>Non-renewable $f_{\text{del,nren},i}$, -</th>
<th>Renewable $f_{\text{del,ren},i}$, -</th>
<th>Total $f_{\text{del,tot},i}$, -</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biofuel</td>
<td>0.5</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>District heat</td>
<td>0.7</td>
<td>0.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Electricity</td>
<td>2.0</td>
<td>0.2</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Currently, several MS have defined the nZEB, however the methodology varies. Some countries have primary energy factors, while others calculate only delivered energy. In addition included energies vary e.g. appliances may or may not be included and few do not include exported energy in the calculations. All these factors affect the primary energy and renewable energy ratios. Therefore we made calculations with and without primary energy factors, exported energy and appliances to determine how renewable energy ratios change.

**C. Self-generation and self-consumption.**

Renewable energy fraction index (REF) describes the percentage of electricity demand covered by on-site renewable electricity and is also called self-generation [5]. Renewable energy matching index (REM) describes the percentage of the renewable electricity that is utilized by the building and is also called self-consumption [5]. Both indexes can be illustrated by Fig. 1, where REF is the ratio of the area III to the sum of demand (areas of I, III and IV). REM is the ratio of area III to the sum of onsite generated power (areas of II and III).
3. Results

D. Energy use and renewable energy production

The delivered energy, which is the basis for all calculations, is shown in Table 3. The table also gives the exported energy share of local production, which was calculated, when hourly data was available, however in some cases we had to assume the share based on experience. Appliances and heating formed the largest proportion of delivered energy, which is on average 30% and 28% respectively. However, the heating energy dominated in both cases with district heating and in only one case with ground source heat pump. The third largest energy consumer was lighting, which was followed by fans and pumps, while the cooling systems required least energy.

Table 3. Delivered energy of studied buildings

<table>
<thead>
<tr>
<th></th>
<th>SE1</th>
<th>SE2</th>
<th>NL1</th>
<th>FR</th>
<th>CH</th>
<th>NL2</th>
<th>EE</th>
<th>FI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>10.0</td>
<td>32.2</td>
<td>20.5</td>
<td>10.5</td>
<td>6.0</td>
<td>13.3</td>
<td>10.4</td>
<td>38.3</td>
</tr>
<tr>
<td>Cooling</td>
<td>0.5</td>
<td>1.3</td>
<td>3.2</td>
<td>2.4</td>
<td>6.7</td>
<td>3.3</td>
<td>1.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Fans/pumps</td>
<td>3.0</td>
<td>13.2</td>
<td>11.8</td>
<td>6.5</td>
<td>8.1</td>
<td>17.5</td>
<td>9.7</td>
<td>9.4</td>
</tr>
<tr>
<td>Lighting</td>
<td>12.6</td>
<td>16.5</td>
<td>12.5</td>
<td>3.7</td>
<td>16.3</td>
<td>21.1</td>
<td>11.3</td>
<td>12.5</td>
</tr>
<tr>
<td>Appliances</td>
<td>12.6</td>
<td>16.9</td>
<td>5.0</td>
<td>21.2</td>
<td>26.8</td>
<td>19.2</td>
<td>18.5</td>
<td>19.3</td>
</tr>
<tr>
<td>On site el.</td>
<td>39.0</td>
<td>-</td>
<td>36.5</td>
<td>15.6</td>
<td>30.9</td>
<td>73.8</td>
<td>14.2</td>
<td>7.1</td>
</tr>
<tr>
<td>Nearby el.</td>
<td>-</td>
<td>47.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BioCHP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>184</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Exported heat</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Exp./Prod., -</td>
<td>38.8</td>
<td>44.7</td>
<td>49.0</td>
<td>33a</td>
<td>40a</td>
<td>50a</td>
<td>36.2</td>
<td>25a</td>
</tr>
<tr>
<td>EP_p</td>
<td>-0.6</td>
<td>22.5</td>
<td>33.0</td>
<td>41.7</td>
<td>66.0</td>
<td>68.0</td>
<td>74.4</td>
<td>95.6</td>
</tr>
<tr>
<td>RER_p</td>
<td>105.9</td>
<td>81.8</td>
<td>82.6</td>
<td>55.0</td>
<td>59.2</td>
<td>65.4</td>
<td>49.1</td>
<td>27.8</td>
</tr>
</tbody>
</table>

a – Exported energy proportion was assumed, because hourly data was unavailable.
Based on the obtained data we calculated the primary energy indicator and renewable energy ratios for all cases. Fig. 2 presents a detailed primary energy calculation example based on the nearly-zero energy office building in Rakvere, Estonia. The energy need boundary included all energy needs taking into account solar and internal gains and heat losses, but disregarding technical systems. The next step was to calculate the delivered and exported energy considering the technical systems. Primary energy indicator was reached by summing up the annual energy flows multiplied by respective non-renewable primary energy factors.

Fig. 3 illustrates renewable energy ratio calculation example based on the same building. The renewable energy was the sum of electricity produced by PV panels, heating energy drained or cooling energy driven to the ground and the share of renewable sources in delivered energy defined by the difference of total and non-renewable primary energy factors. The heating energy drained from the ground was heating need covered by the heat pump minus compressor energy, however the delivered cooling energy was added to geothermal energy, because it was absorbed in the ground.

The calculations described in Fig. 2 and Fig. 3 were performed for all buildings and the results are presented in the bottom rows of Table 3. The primary energy ranged between -1 and 96 kWh/m², which means that the building SE1 is a net zero energy building. The renewable energy ratios ranged between 28% and 106%, whereas higher renewable energy ratios were achieved with lower primary energy. Fig. 4 illustrates a good negative correlation between primary energy and renewable energy ratio, whereas the correlation did not seem to depend on renewable energy sources.

**Fig. 2** Calculation example of the primary energy of nZEB in Rakvere, Estonia

**Fig. 3** Illustration of renewable energy ratio calculation example based on the same building.

**Fig. 4** Illustrates a good negative correlation between primary energy and renewable energy ratio, whereas the correlation did not seem to depend on renewable energy sources.
14.2 PV electricity, from which 11.0 is used in the building and 3.2 exported.

SOLAR ENERGY

17.7 + 1.0 = 18.7

GEOTHERMAL ENERGY

Energy wells connected to GSHP and free cooling heat exchanger
40.1 - 10.0 = 30.1
17.7 + 1.0 = 18.7

GEOTHERMAL ENERGY

Renewable energy ratio:

\[
RER_p = \frac{14.2 + 30.1 + 18.7 + (2.2 - 2.0) \cdot 40.2 + (1.0 - 0.7) \cdot 0.4}{14.2 + 30.1 + 18.7 + 0.4 \cdot 1.0 + 40.2 \cdot 2.2 - 3.2 \cdot 2.2} = \frac{71.2}{144.8} = 0.49
\]

Fig. 3 Calculation example of the renewable energy ratio of nZEB in Rakvere, Estonia

Fig. 4 Primary energy and renewable energy ratios depending on renewable energy source

E. Monthly energy use analysis

Fig. 5 describes the monthly renewable energy ratios of the nearly-zero energy office building in Rakvere, Estonia and using primary energy factors and including exported energy or appliances did not affect the shapes of the
graphs significantly. Highest renewable energy ratios appeared during the warm period. In the current case highest renewable energy ratios were achieved by disregarding appliances and lowest with excluding exported energy. When only non-renewable primary energy factors were used, the difference from the graph with both total and non-renewable factors was insignificant.

![Graph showing monthly renewable energy ratios of nZEB in Rakvere, Estonia. Code: RERp – RER based on total and renewable energy factors; RERd – RER based on delivered energy; RERNren – RER based on non-renewable primary energy factors; RERp w/o exp – RERp without export; RERp w/o app – RERp without appliances.](image)

Fig. 5 Monthly renewable energy ratios of nZEB in Rakvere, Estonia. Code: RERp – RER based on total and renewable energy factors; RERd – RER based on delivered energy; RERNren – RER based on non-renewable primary energy factors; RERp w/o exp – RERp without export; RERp w/o app – RERp without appliances.

![Graph showing monthly renewable energy fraction indexes for four nZEB-s.](image)

Fig. 6 Monthly renewable energy fraction indexes

Fig. 6 illustrates self-production of four nZEB-s and the graph shapes of the building with PV panels (NL1, SE1 and EE) were similar to the renewable energy ratios of EE. However SE2 had wind turbines, which reduced the variations in monthly renewable energy fraction indexes. During June and July approximately 50-70% of electricity use was covered by local or nearly production, however in January and December the majority of
electricity need had to be covered from the grid except for SE2 with wind production.

Fig. 7 illustrates self-consumption, which shows that during summer 40-60% of produced could be utilized in the building and rest had to be driven to the grid as there were no batteries. The proportion of used and sold electricity remained similar throughout the year in case of wind production (SE2). However, due to low PV panel electricity production during winter, the majority of produced electricity during that period could be used in the building in the other cases.

![Fig. 7 Monthly renewable energy matching indexes](image)

Fig. 7 Monthly renewable energy matching indexes

Fig. 8 illustrates the electricity grid loads, showing that most of the time electricity was delivered to the building. In case of PV panels (SE1, NL1, EE), electricity was exported up to 15% of the year, but in case of wind turbines (SE2). The primary energy of the buildings varied between -1 and 74 kWh/m² and renewable energy ratios between 49-106% (Table 3), however there was no remarkable distinction between the grid loads. The buildings’ renewable energy ratios decreased in the order SE1, SE2, NL1 and EE, however the maximum grid loads presented in Table 4 did not follow that order.
Fig. 8 Grid loads of nZEB-s with hourly data available

Table 4. Maximum grid loads nZEB-s with hourly data available

<table>
<thead>
<tr>
<th></th>
<th>SE1</th>
<th>SE2</th>
<th>NL1</th>
<th>EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max delivered, W/m²</td>
<td>27.0</td>
<td>24.2</td>
<td>32.6</td>
<td>25.5</td>
</tr>
<tr>
<td>90&lt;sup&gt;th&lt;/sup&gt; percentile, W/m²</td>
<td>14.8</td>
<td>10.9</td>
<td>15.0</td>
<td>10.0</td>
</tr>
<tr>
<td>10&lt;sup&gt;th&lt;/sup&gt; percentile, W/m²</td>
<td>-6.5</td>
<td>-6.2</td>
<td>-3.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Max exported, W/m²</td>
<td>-34.2</td>
<td>-12.6</td>
<td>-31.6</td>
<td>-13.4</td>
</tr>
</tbody>
</table>

4. Discussion and conclusions

Good (negative) correlation between primary energy and RER that was not very technology dependent was shown. Monthly and annual RER values did not allow to draw conclusions on the grid load. Therefore RER did not provided useful additional information and it would be more straightforward and transparent to operate with non-renewable primary indicator only.

References