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Influence of climate change on the energy performance assessment of NZEB houses

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Abstract. The Energy Performance of Buildings (EPB) regulations aim to reduce primary energy use and carbon dioxide emissions of buildings, which are the result of creating a comfortable and healthy indoor environment. In this study, the influence of climate change on the regulatory EPB calculation results is analysed for the Flanders region in Belgium. The results of the analysis may be used by authorities to better define nearly zero energy building (NZEB) requirements today. Meteonorm has been used to simulate future climate change based on IPCC scenarios and urban heat island effect. These future climates have been implemented in a Revit- and Excel-based tool that calculates the stochastic variation of energy performance for six different dwelling typologies, based on the semi-steady state energy use calculation method applied in the regional rating method. Four different packages of measures to achieve NZEB performance (thermal insulation, energy efficient ventilation, renewable energy technologies,...) have been considered. The results for primary energy use, overheating indicator and net energy use for heating and cooling have been analysed. As may be expected, climate change is found to lead to an increase in overheating risk, an increase in cooling energy use, and a decrease in heating energy use in the analysed dwellings. Since in most cases the decrease in heating energy use outweighs the increase in cooling energy use, the total primary energy use decreases in most cases for the 2050 future climate.

1. Introduction

In Belgium the implementation of the EPBD is the responsibility of the three regions (Brussels, Flanders and Wallonia). In the Flanders region, energy performance requirements came into force in 2006 through the EPB legislation (Energy Performance and Indoor Climate) [1]. The requirements relate to energy performance of the building and indoor climate, and are specified in a number of sub-requirements to which all new and renovated buildings have to comply based on regulatory calculation methods:

- thermal insulation: maximum U-value of building envelope components and overall heat loss coefficient;
- maximum E-level (measure for total primary energy use of the project);
- minimum ventilation requirements;
- maximum value of overheating indicator (summer comfort), only for residential buildings;
- minimum amount of renewable energy production.

The current EPB calculation methods use monthly mean climate variables as input (outside temperature, solar radiation) that did not change since the regulations are in place. Furthermore, these values are
based on historic climate data for Uccle, Belgium, dating back to 1958-1975 [2]. In previous decades climate has gradually become warmer in Belgium as a result of climate change, and also the number of heat waves per year has increased. There is a concern that the use of non-representative climatic data in the energy performance calculation method may lead to suboptimal and non-resilient design decisions given the on-going trends of climate change in the future. Therefore the influence of climate change on the EPB calculations results is analysed in this study. Climate projections are discussed and the simulation software Meteonorm is used to predict the future climate on different locations in Belgium, and generate new sets of climatic data that take climate change into account. Subsequently EPB calculations are performed with the new sets of climatic data to study the influence on energy performance rating and overheating. This is done with a Revit- and Excel-based tool created by Ghent University, in which the performance of a large variation of housing typologies and designs can be assessed.

The overarching requirement in the EPB calculations is the primary energy index (E-level), defined as the ratio between the calculated annual primary energy use and a reference value. The annual primary energy use is the sum of the primary energy need for space heating and cooling, domestic hot water and auxiliary devices, decreased by the primary energy production of photovoltaic energy systems and property-bound co-generation systems. The reference value of the annual primary energy use is a regression formula depending on the total area of the building envelope through which transmission heat loss occurs, the total volume of the building and a reference dedicated ventilation flow rate of the building (which is also function of the building volume) [1, 3]. The lower the E-level, the better the energy performance of the building. Nearly zero energy residential buildings (NZEB) in Flanders should have an E-level lower than E30. This requirement came into force in January 2021.

In this paper only the influence of climate change on the energy needs for space heating and cooling is studied, and how it impacts the E-level results. Both are based on the semi-steady state energy use calculation method as described in ISO 13790-2007 taking into account monthly heat losses due to transmission and ventilation, that depend on the monthly mean outdoor temperature, and monthly heat gains due to solar radiation, that are derived from the total and diffuse monthly radiation on a horizontal plane. The regulatory calculations are single-zone with a constant set-point temperature for heating and cooling of respectively 18 °C and 23°C for all the rooms. Apart from the calculation of heating and cooling energy use, the standard also defines a quasi-steady-state calculation method to assess overheating in buildings (Annex I4). However, contrary to the heating and cooling energy calculation, only few European countries have included this method in their national energy performance calculation methods or building codes. The Flemish region of Belgium has adopted the method to determine a so-called overheating indicator of a building, and set requirements. The overheating indicator (expressed in Kelvin-hours [Kh]) is based on the normalized monthly excess heat gains in relation to the indoor set-point temperature for cooling.

For the overheating indicator a threshold value and a maximum value are defined. If the indicator is below the threshold value of 1000 Kh, no overheating is expected and the probability that active cooling will be installed afterwards is assumed nihil. If the indicator is above the maximum value of 6500 Kh, the design is non-compliant, cooling is assumed to be necessary and a cooling system is taken into account in the calculations. Between the threshold and maximum value, a risk for summer overheating is assumed, and a probability that the occupant will install an active cooling system afterwards is considered. The probability increases from 0 at the lower overheating threshold value to 1 at overheating values above the maximum value. In dwellings not equipped with an active cooling system, a ‘fictitious’ energy use for cooling is included in the overall primary energy consumption in this case, depending on the predicted cooling need, the value of the overheating indicator and the associated probability of installing an active cooling system. In case the dwelling is equipped with active cooling at the moment of completion, the energy use for cooling is fully taken into account, independent of the overheating indicator value [1, 3].
2. Methods

2.1. Estimation of climate change

The emission scenarios of the Intergovernmental Panel on Climate Change (IPCC) are used in climate modelling to make projections that represent a range of possible futures. The greenhouse gas emissions of the different scenarios are used as input of Global Climate Models. These Global Climate Models are modelling tools that represent the physical processes in the atmosphere and oceans and are used to project future climate change.

By means of downscaling methods weather files may be created, which can be used in Building performance simulation (BPS) or EPB calculations. In this study, Meteonorm is used to produce these output files. Meteonorm is a stochastic weather generator, but besides that it is also a climatic database and spatial interpolation tool. The database has access to more than 8000 weather stations, five geostationary satellites and a globally calibrated aerosol climatology. This combination makes it possible to generate accurate and representative typical years for any place on earth for more than 30 parameters [4]. Besides a data provider, Meteonorm contains also algorithms to calculate extreme years and the urban heat island effect and can be used for climate change studies. Thanks to the spatial interpolation tool, data is not only available at weather station locations. Solar radiation, temperature and additional parameters can be retrieved for any place in the world.

With Meteonorm, it is possible to simulate the outdoor air temperatures and horizontal total and diffuse radiation needed for the EPB calculations for slices of 10 years in the future. From these time-periods of 10 years, one reference year is made. In this study, the Test Reference Years are used, and the SRES climate scenario A2 of the IPCC. The SRES scenarios are based on hypotheses of carbon emissions assuming various socio-economic and demographic evolutions. Nowadays these scenarios have been replaced by so-called representative concentration pathways (RCP) by IPCC, which show a strong correspondence with the SRES scenarios. The SRES climate scenario A2, which corresponds to RCP 8.5, represents a business as usual scenario leading to the largest warming compared to other climate scenarios, and is therefore selected for this study.

The mean monthly outdoor temperature and radiation in Uccle for A2 2050 are used as climate data, both the 10-year average and 10-year monthly maximum values. In what follows, these will be called the average climate and the maximum climate. These maximum values can be representative for an extreme hot summer or the higher temperatures in big cities due to the urban heat island effect. The increase in mean yearly outside air temperature compared to the currently used EPB climate is +1.2 °C for the climate with average values and +2.4 °C for the climate with maximum values, and the differences for each month are given in Figure 1.

Figure 1. Uccle 2050 average and Uccle 2050 maximum compared to EPB climate for exterior temperature (left) and total solar radiation on a horizontal plane (right).
2.2. Energy performance calculations

To study the influence of climate change on cooling and overheating, a Revit- and Excel-based tool developed at Ghent University is used. This tool makes it possible to calculate the different steps of the EPB calculation method for the E-level for different building typologies and sets of energy-saving measures that are representative for the building stock. Besides this, it is also possible to adjust the standard values of the EPB calculation method to do scenario-analyses, and even to use multi-zone calculation methods for heating instead of the single-zone calculation method of the normal EPB calculations [5, 6].

The above discussed climatic data are implemented in the tool as climate input. Not only the climate has an influence on the cooling and overheating in buildings. These are also influenced by the availability and characteristics of the sunshading, the shadowing of the building and the glazed surface areas. For the sunshading, the main options are an exterior sunshading, an interior sunshading, a sunshading in between the window glasses or no sunshading at all. In case of a sunshading, it can either be manually or automatically controlled.

Six different dwelling were made in Revit and used in this study. They are based on building characteristics from new buildings' energy performance reports in the Flemish Energy Agency’s database: apartments with 1 or 2 bedrooms, terraced and semi-detached single family houses with 3 bedrooms and detached houses with 1 or 3 bedrooms [6]. In the further discussion these types are respectively referred to as App1, App2, Closed3, Semi-detached3, Detached1 and Detached3. Of each typology, 1500 different building geometries are modelled to match the variation in geometric housing stock data in the database, resulting in a large set of dwellings with different characteristics (typology, size, geometry, window fraction etc.). Four sets or packages of measures defining the characteristics of building envelope measures (U-values, air permeability, solar heat gain coefficients,…) and technical installations (energy efficient heating and ventilation systems) were applied to the different dwellings: two so called cost-optimal sets, indicated by MP3 and MP4, and two sets based on passive house guidelines, indicated by MP5 and MP6 [6]. Table 1 lists the building envelope characteristics corresponding to these sets of measures. Two additional sets, MP1 and MP2, relate to older EPB-requirements, but are not discussed in this paper. As the Table shows, the building envelope characteristics for MP3 and MP4, and for MP5 and MP6 are identical. There is however a difference in the type of heating and ventilation system assumed. MP3 and MP5 are equipped with a natural supply and mechanical extraction ventilation system and a heat pump, while MP4 and MP6 have a balanced mechanical ventilation system with heat recovery and a gas boiler. More details are given by Vandenbussche [7].

As explained in the introduction, the regulatory EPB calculations use single-zone heating with a constant set-point temperature of 18 °C for all the rooms. In this study, two multi-zone heating user profiles are used as well, to give an indication of the variation in energy use depending on heating preferences. A first user profile assumes a constant set-point temperature of 21 °C for 24 hours in all the rooms. A second one assumes that all the rooms are heated intermittently for 5 hours. The bathroom is heated to 22 °C while the temperature in the living room and the kitchen is set on 21 °C. The set-point temperature in the bedrooms, circulation rooms and toilet is 17 °C. Hence only this second user profile is truly multi-zone.

| MP  | \( U_{\text{roof}} \) (W/m².K) | \( U_{\text{wall}} \) (W/m².K) | \( U_{\text{floor}} \) (W/m².K) | \( U_{\text{window}} \) (W/m².K) | \( U_{\text{common}} \) (W/m².K) | \( v_{SO} \) (m³/h.m²) | g-value | sunshading |
|-----|----------------|----------------|----------------|----------------|----------------|----------------|----------|
| MP1 | 0.24           | 0.24           | 0.30           | 1.80           | 1.00           | 6              | 0.63     | -          |
| MP2 | 0.24           | 0.24           | 0.24           | 1.50           | 0.60           | 4              | 0.50     | -          |
| MP3 | 0.20           | 0.20           | 0.24           | 1.40           | 0.60           | 3              | 0.38     | -          |
| MP4 | 0.20           | 0.20           | 0.24           | 1.40           | 0.60           | 3              | 0.38     | -          |
| MP5 | 0.15           | 0.15           | 0.15           | 0.80           | 0.60           | 1              | 0.50     | Manual exterior |
| MP6 | 0.15           | 0.15           | 0.15           | 0.80           | 0.60           | 1              | 0.50     | Manual exterior |
Table 2. Median values of calculated E-levels for all typologies and MPs, for 3 climates.

<table>
<thead>
<tr>
<th>E-level</th>
<th>MP3</th>
<th>MP4</th>
<th>MP5</th>
<th>MP6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EPB AV MAX</td>
<td>EPB AV MAX</td>
<td>EPB AV MAX</td>
<td>EPB AV MAX</td>
</tr>
<tr>
<td>App1</td>
<td>54 49 47</td>
<td>36 37 36</td>
<td>33 34 36</td>
<td>37 39 50</td>
</tr>
<tr>
<td>App2</td>
<td>56 52 53</td>
<td>40 41 41</td>
<td>37 38 41</td>
<td>37 40 53</td>
</tr>
<tr>
<td>Closed3</td>
<td>32 28 21</td>
<td>44 41 37</td>
<td>29 29 31</td>
<td>9  8  4</td>
</tr>
<tr>
<td>Semi-Detached3</td>
<td>35 32 26</td>
<td>47 43 41</td>
<td>31 32 32</td>
<td>14 15 10</td>
</tr>
<tr>
<td>Detached1</td>
<td>38 36 30</td>
<td>48 46 43</td>
<td>33 33 34</td>
<td>22 22 18</td>
</tr>
<tr>
<td>Detached3</td>
<td>39 36 32</td>
<td>49 46 45</td>
<td>31 34 36</td>
<td>22 24 22</td>
</tr>
</tbody>
</table>

In the regulatory calculation of the overheating indicator, the potential for ventilative cooling by means of window airing is taken into account. This potential depends on the percentage of openable windows and the position of these windows. Openable windows located on the ground floor are not considered to contribute to ventilative cooling in the regulation, because of risks for burglary. The different dwelling types have been assumed to have a different potential for ventilative cooling, with in order of increasing potential (and thus lower overheating risk) detached 1, semi-detached, detached 3, terraced, and apartments (except in case of MP4 and MP5 which have lower ventilative cooling potential for the apartments).

3. Influence of climate change on energy performance calculation results

3.1. Influence on E-level
When the E-level is calculated for the different typologies, MPs and climates according to the current single-zone heating method of the EPB calculations, the influence of the climate on the E-level depends strongly on the sets of measures applied. The median values of the E-levels for the four MPs and all the typologies are shown in Table 2 for the actual EPB climate, and for the future climates Uccle 2050 average (AV) and Uccle 2050 maximum (MAX). The cases for which the difference in E-level between the EPB climate and the maximum climate is 3 or more are shown in green for a decrease and in red for an increase in E-level. The decreases are for all typologies of MP3, for the single-family houses of MP4 and for the terraced and semi-detached buildings of MP6. The increases are the highest for the apartments with MP5 and MP6 and for the detached dwelling with 3 bedrooms with MP5. If the E-level decreases due to the changing climate, this means that the decrease in heating energy use is higher than the increase in cooling energy use for the future climate, resulting in a total decrease of E-level. The maximum decrease in E-level occurs for the terraced buildings for the maximum climate and equals -11 for MP3 and -7 for MP4. Due to a higher increase in energy for cooling than the decrease for heating, the E-levels can increase for the future climates. For the apartments with MP6, there is a small increase for the average climate (of 2 and 3) and a very big increase for the climate with maximum values, with a difference of 13 and 16 for respectively apartment 1 and 2.

For the current EPB climate, the E-levels of MP5 and MP6 are lower than those of MP3 and MP4, hence the sets of measures applied lead to a better energy performance. When the performance is assessed based on the future climates, this order in performance may change, as illustrated by the results for the single family houses (closed, semi-detached, detached). Due to the decrease in E-level of the single-family houses with MP3 and the increase for MP5, the E-levels of both cases are nearly the same in the climate with average values, and are even lower for MP3 than MP5 in the climate with maximum values, with differences between 2 and 10. This illustrates that some sets of measures which lead to improved energy performance according to the current calculations may be suboptimal when considering climate change.

For the apartments, the E-levels for MP4 are comparable to those of MP5 (maximum difference of 3) and are a lot lower than the median E-levels of MP3 and MP6. Based on the E-level, the single-family
houses with MP6 are the most energy-efficient, both for the current and the future climates. For the apartments, MP5 is the most energy-efficient in the current climate and MP4 and MP5 are the same for the maximum climate.

### Table 3. Share of buildings with $I_{\text{overh}} \geq 6500$ Kh for all typologies and MPs, for 3 climates.

<table>
<thead>
<tr>
<th>$I_{\text{overh,max}} \geq 6500$ Kh [%]</th>
<th>EPB climate</th>
<th>Uclee 2050 av</th>
<th>Uclee 2050 max</th>
</tr>
</thead>
<tbody>
<tr>
<td>App1</td>
<td>0</td>
<td>52</td>
<td>100</td>
</tr>
<tr>
<td>App2</td>
<td>0</td>
<td>68</td>
<td>100</td>
</tr>
<tr>
<td>Closed3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Semi-detached3</td>
<td>$&lt;1$</td>
<td>$&lt;1$</td>
<td>7</td>
</tr>
<tr>
<td>Detached1</td>
<td>5</td>
<td>4</td>
<td>33</td>
</tr>
<tr>
<td>Detached3</td>
<td>$&lt;1$</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

#### 3.2. Influence on overheating indicator

An overview of the percentage of building variations per building type for which the overheating indicator is higher than the maximum threshold value of 6500 Kh is given in Table 3. When this threshold is exceeded, this is an indication that summer comfort is not acceptable without active cooling system. The percentage of buildings for which summer comfort is not acceptable is clearly related to the set of measures applied, to the potential of ventilative cooling assumed. Typologies with a small potential for ventilative cooling have a larger share of buildings which need active cooling (detached 1, semi-detached, apartments with MP4 and 5). Sets of measures with better thermal insulation and air tightness of the building envelope (MP5 and MP6), also contribute to overheating.

The majority of the apartments with MP4 or MP5 (from 52 to 100 %) and a minority of the detached 1 buildings (33 and 23 %) with MP5 or MP6 need cooling for the EPB climate. When taking climate change into account, these amounts increase, as may be expected. For the average climate, besides the apartments and detached 1 buildings, also 13 to 32 % of the detached 3 buildings and 71 to 96 % of the semi-detached buildings need cooling for MP5 and MP6. For the maximum climate, cooling is needed for nearly each typology and MP, only the closed and detached 3 buildings with MP3 or MP4 will not need cooling.

#### 3.3. Influence on sum of net energy demand for heating and cooling

The median values of the sum of net energy demand for heating and cooling are shown in Table 4, for both multi-zone user profiles. Just as the E-level, the sum of net energy demand for heating and cooling increases for the average climate for MP5 and MP6 compared to the current EPB climate, because the increase in cooling energy need is not equally compensated by a reduction in heating energy need, with only a few exceptions. The opposite is true for MP3 and MP4, where the sum of net energy demand for heating and cooling in general decreases for the average climate.

In Table 4, the cases for which the sets MP3 or MP4 have a lower total net energy demand than MP5 are shown in green, when they are also lower than MP6 they are dark green. The building envelope U-values and air permeability’s applied in MP3 and MP4 have higher values than in MP5 and MP6. For the average climate, it can be concluded that the packages MP3 and MP4 result in a lower total energy use for heating and cooling for the apartments than MP5. For the single-family houses with the second user profile, the energy use of MP4 with sunshading is only slightly higher than that of MP5, and lower for the detached 3 buildings. For the maximum climate, the median net total energy use of MP4 with sunshading is always lower than that of MP5. For the apartments and terraced building, the energy use for heating and cooling for MP4 is even lower than MP6, both with and without sunshading. This is only the case for the user profile with intermittent and zonal heating. In case all the rooms of the buildings have a heating set-point of 21 °C, heating is still more important than cooling in the future.
climates, and improving thermal insulation and airtightness still leads to a reduction of the total net energy demand also for the maximum climate. The terraced building typology is the only exception here.

4. Conclusions
Many methods are available to estimate climate change. Meteonorm can be a good choice for Building Performance Simulations, as it combines climate projection with different IPCC scenarios, downscaling and spatial interpolation, it has its own database and it generates both monthly and hourly values. The future climates developed and used in this study are the 10-year average and the 10-year maximum in Uccle for 2050 based on the SRES climate scenario A2 of the IPCC, with specific monthly values for outside temperature, and global and diffuse solar radiation on a horizontal plane. The maximum values may be representative for an extreme hot summer or the higher temperatures in big cities due to the urban heat island effect. The increase in mean yearly outside air temperature compared to the currently used EPB climate is +1.2 °C for the average climate and +2.4 °C for the maximum climate.

These future climates have been implemented in a Revit- and Excel-based tool that calculates the stochastic variation of energy performance for six different dwelling typologies, based on the semi-steady state energy use calculation method. Four different packages of measures to achieve NZEB performance (thermal insulation, energy efficient ventilation, renewable energy technologies,…) have been considered. Climate change not only has an influence on the absolute value of the E-level, it also influences the package of measures with the lowest E-level. MP5 has a lower median E-level than MP3 in the current climate, but in the future climates the E-level of MP3 may be lower than MP5 with median differences between 4 and 10 for the maximum climate for single family houses. Although the E-level of the apartments with MP6 is in the same range of those for the other MPs for the current climate, the E-levels become much higher in the maximum climate, with median differences of 12 and 14 compared to MP4 and MP5.

Table 4. Median of the sum of net energy demand for heating and cooling for all typologies and MPs, for 3 climates. MP3* and MP4* are with manual exterior sunshading. Top table for user profile 1 (heating set-point 21°C in all rooms), bottom table for user profile 2 (intermittent and zonal heating).
When the predicted sum of net energy demand for heating and cooling are compared, it can be concluded that the sets of measures MP3 and MP4 with less thermal insulation can be more energy efficient in the future than the well isolated MP5 and MP6 houses, especially if MP3 and MP4 are combined with exterior sunshading. This is already the case in the average climate for the apartments, and can be the case for single family buildings in the maximum climate. This is a result of the fact that cooling of buildings will become more important than heating in the future, depending on building design. In the current climate, it is rather exceptional that the cooling energy demand is higher than the heating energy demand in buildings in the Belgian climate. This is only the case for apartments with MP5. For a temperature increase of 1.2 °C (average climate), this becomes the case for all apartments with MP5 and MP6 and the detached houses with MP5 and MP6 with intermittent and zonal heating profiles. For a temperature increase of 2.4 °C (maximum climate), all buildings with MP5 and MP6 have higher energy needs for cooling than for heating, with as result that some less isolated buildings become more energy efficient.

In summary, since in most cases the decrease in heating energy use outweighs the increase in cooling energy use, the total primary energy use decreases in most cases for the 2050 future climate. The apartment typology appears to be more sensitive to overheating. As a result, the primary energy use in NZEB apartment buildings may increase in the future as a result of climate change, particularly when NZEB is mainly achieved by reducing the net energy demand for heating. Other typologies may behave similarly, depending on the potential for ventilative cooling. Authorities should therefore carefully consider which thermal insulation requirements are imposed in current energy performance regulations or update the climatic data used as input in energy performance calculation methods, to avoid regulations lead to suboptimal and non-resilient design decisions given the evolution of climate change.

Acknowledgments
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