The Effect Of Dynamic Primary Energy Factors On Building Energy Performance

Kjartan Van den Brande¹, Sam Hamels²,
Marc Delghust¹, Jelle Laverge¹, Michel De Paepe¹, Arnold Janssens¹
¹Architecture and Urban Planning, Ghent University, Belgium
²Economics, Ghent University, Belgium

Abstract

In the context of increasing environmental awareness, specific methodologies have been proposed for the definition, modelling and assessment of the buildings' energy performance. These Building Energy Assessment Methods (BEAMs) are still far from accurate, when applied on actual individual buildings. New detailed data allows to further optimize the BEAM. This paper presents a preliminary study on the influence of primary conversion factors, applied to two different calculation methods: one with an hourly time interval and one with a monthly time interval. The added value of hourly data is evaluated and the two methods, provided by the new ISO 52000 standard series, are tested. The total energy needs for space heating for both methods coincide quite well. For poorly insulated buildings the monthly calculation method showed higher results, compared to the monthly calculation method. For the well insulated buildings, the opposite became clear. The added value of hourly data on Primary Energy conversion Factors (PEFs), proved to be minimal.

Introduction

This paper was written in the context of strategic basic research NEPBC (FWO, 2016)

Next generation building energy assessment methods towards a carbon neutral building stock.

The main goal of the NEPBC research is to investigate the possibilities and practical application of BEAM in the legislative context of Flanders. The application purpose of BEAM is to evaluate the energy performance of a building in terms of used resources and accommodated user comfort level. In general BEAM consists of four steps:

- 1) Definition of the building and boundary conditions
- 2) Calculation of the energy needs
- 3) Conversion from energy needs to delivered energy
- 4) Evaluation of the building based on total delivered energy compared to a reference

The exact methodology for each of these four steps can differ a great deal. Which also means that the energy performance of a building can be evaluated in many different ways. The methods used are function of the purpose of the BEAM. It is up to the users to define them. Throughout the NEPBC project each aspect of the BEAM will be thoroughly investigated.

The building stock is responsible for approximately 40% of Europe's energy use. With about 75% of the buildings being energy inefficient, a lot can change by enforcing a more energy efficient way of building. In practice this has led to the 2002 Energy Performance of Buildings Directive (recast in 2018) and the 2012 Energy Efficiency Directive (European Commission, 2010).

In Flanders, Belgium, an EPB framework has been in force since 2006. The legislation requires new building owners to file a report on the energy performance of their building, meeting preset requirements. The specific BEAM behind the report is based on the monthly quasi-steady state calculations for the heating and cooling needs, outlined in NBN EN ISO 13790. Although the BEAM has evolved since 2006, with new ways of evaluating the energy performance and stricter requirements, the current Flemish BEAM is far from accurate. One major reason for this is the lack of detailed input data (weather data, system efficiencies, user behaviour and other model simplifications). A study by Majcen et al. (2016), showed a CO₂-emission saving potential of 70% when retrofitting a house from label G to label A, while looking at actual consumption this potential was only 26%.

Recently, a lot of attention is given to the possibilities of more detailed BEAMs, which apply thermal balance calculations on a finer time resolution. In 2017 the International Organisation of Standardization (ISO), published the ISO 52000 standard series (ISO, 2017). The main goal for the 52000 series is to establish a systematic, comprehensive and modular structure for assessing the energy performance of new and existing buildings in a holistic way. Since the new ISO 52000 standard series includes guidelines for constructing an hourly BEAM, this hourly time resolution will be adopted in this paper as representative for these developments. In the first part of this paper, the influence of the monthly and hourly calculation method, provided by ISO 52016, will be compared in terms of energy needs for space heating.

To evaluate the energy performance, a specific parameter must be chosen. This parameter is called an indicator and it reflects the goals of the authorities. Usually, the indicator chosen is the overall primary energy delivered to the building. It is calculated as the energy needs, multiplied by a Primary Energy Factor (PEF) per input. The last years the PEF grows in importance because of the increasing influence of elektrification on a buildings

energy demand (heat pumps, photovoltaics, ...). This leads to the need for quantification of the PEF's influence on the energy performance of the building. In the second part of this paper, the added value of using hourly, time varying values for the PEF instead of yearly average values is investigated.

All technologies that consume fuel to generate electricity have a particular efficiency. The conversion from electricity used by the building to the primary energy sources (e.g. biomass, nuclear, coal, gas,...) is done via the overall primary energy conversion factor (PEF). This is calculated by taking the weighted average of the PEFs of each technology and their respective shares in the electricity generation during the given period. As an example, the following table shows the PEF per generation type used for this research.

Table 1: PEF values

Technology	PEF	Relevant source
Biomass	3.33	(ISI, 2016)
Fossil Gas	2.10	(ENTSO-E, 2018)
Fossil Hard coal	2.17	(ENTSO-E, 2018)
Fossil Oil	2.86	(ENTSO-E, 2018)
Hydro Pumped Storage	1.5	(ENTSO-E, 2018)
Hydro Run-of-river and poundage	1	(ISI, 2016)
Nuclear	3.03	(ENTSO-E, 2018)
Other	2.3	(EIA, 2017)
Solar	1	(ISI, 2016)
Waste	3.33	n/a
Wind Offshore	1	(ISI, 2016)
Wind Onshore	1	(ISI, 2016)

Since each country has a unique mix of electricity generation technologies, the overall PEF of electricity generated in a particular country can vary considerably. In Europe, from 1.15 up to 4.45 (IEA Annex 56, 2017).

Since the definition of the PEF and the used method are a responsibility of the national authorities, they can be used to influence the energy demand on a national level. In general, the buildings using generation technologies with a lower PEF (e.g. biomass) will benefit from this. For instance, they could achieve NZEB standards more easily.

Within this context, the European Commission contracted a study on PEF calculation methods (European Commission, 2016). The study discusses four potential calculation methods. While the first and most conventional calculation method reflects the method used by Eurostat, the three others reflect some of the additional considerations that can go into a PEF calculation. These include the way CHP plants are handled and the possibility of including life-cycle analyses (LCAs) to the PEFs of fossil fuels. The research on different PEF calculation methods and their outcome are out of scope for this research paper, however are part of the NEPBC goals. The focus of this paper lies in the added value of hourly energy calculation methods, allowing to convert calculated energy need to primary energy use on an hourly time scale, using dynamic PEF's instead of only monthly or yearly average PEF's.

To get a realistic overall energy need output, a case building was chosen for the application of the BEAMs on different time resolutions. The building is a terraced house in the Venning neighbourhood, a recent social housing development part of the Eco-Life project (EcoLife, 2009). The actual building is a very well insulated (nearly passive) masonry building, however, the simulated model will be varied, to evaluate the sensitivity of the results to e.g. different insulation levels, thermal mass, ... The model of the building was constructed in the object-oriented modelling language, Modelica, with the aid of the Dymola software. Components were used from the Modelica Standard Library, version 3.2.2. (Modelica, 2017). The Belgian climate was considered, using the weather data for Uccle from IDEAS 2.0 library (IDEAS v2.0, 2018) (ENTSO-E, 2018).

BEAM

The focus of this paper, is the energy use for heating, for which an hourly and monthly calculation method is proposed in ISO 52016 (ISO, 2017).

The relative importance of different inputs in the total energy use varies with each building, meaning that the influence of a specific choice concerning the application of a PEF differs from building to building. For this purpose, a variety of buildings was simulated. The parameters that were changed during each simulation were chosen specifically because of their influence on the heating profile of the building.

A series of simulations were performed and the following paragraphs will explain which parameters were varied during the simulations.

Insulation level and capacity of the building

The heating profile is largely influenced by the insulation level and the thermal capacity of the building. Two options were simulated for the insulation level: a well insulated house, corresponding to the actual insulation of the Venning building, and a poorly insulated house, using a standard from before 1975. ISO 52016 provides 5 default capacities in accordance with the thermal mass of the building elements. Two options were simulated: 'very heavy', which largely corresponds to the actual building and 'very light', representative for light-weight timber frame constructions.

Solar heat gains

Another influence to the heat demand is the solar gains. Every building element in contact with the exterior is subject to solar absorption of direct and diffuse solar radiation. The level of solar energy absorbed depends on the color of the exterior layer. In ISO 52016 there are three options: light, dark and medium color, each with corresponding solar absorption coefficients. All three options were tested.

For windows, part of the incoming solar irradiance is transmitted directly to the interior, depending on the tilt and orientation angle of the window and on the shading by external obstacles. In this paper no shading is

presumed. The effective solar energy transmittance factor described in ISO 52016, depends on the window type, going from single glazing to triple glazing with coating. Three options are simulated: single glazing, the actual high efficiency double glazing and triple glazing.

Temperature set points

Another important boundary condition is the set point temperature of the room. There are a lot of ways to define this temperature. For this paper, the building is simulated as a single zone and a heating set point of 20°C and cooling set point of 26°C were assumed. Three options for a reduced set point temperature for heating are taken into account in the different simulations: the normal constant set point temperature of 20°C, a reduced night set point temperature and a weekend reduction of 16°C. In the monthly quasi-steady state method, the set point temperature of 20°C is multiplied by a reduction factor for intermittent heating as described in ISO 52016.

Ventilation

The last parameter taken into account is the supply temperature of the ventilation system. The ventilation system is presumed to provide a constant flow of 220m³/h. The first option assumes a mechanical exhaust (MEV) system, meaning that air at exterior temperature enters the bedrooms and living area via air inlets in the façade. The second option is a central balanced heat recovery system (MHRV), assuming a heat exchanger with 80% efficiency.

An overview of the varied parameters is given in table 2.

Table 2: parameter variations

Parameters Categories	Values
insulation level	
well insulated	27cm EPS (Venning)
poorly insulated	3cm EPS
solar absorption factor	
light color	0.3
medium color	0.6
dark color	0.9
temperature set point reduction	
no reduction	0
night reduction	8hours x 7days
capacity	
very heavy	250 000 (+Venning)
very light	50 000
solar transmittance factor	
single glazing	0.765
double glazing	0.675
triple glazing	0.45
ventilation supply temperature	T _{supply} [K]
system C (MEV)	T _{exterior}
system D (MHRV)	T _{ext} x 0.2 + T _{int} x 0.8

Analysis

216 different cases were simulated in total. To compare these different cases, the total energy need for space heating was used. Figure 1 shows an overview of the total of yearly energy needs for space heating per simulation case. The graph has been sorted so that the values for the monthly method are in ascending order.

Figure 1: Yearly energy needs for heating in kWh.

In general the results coming from the two methods coincide. The maximum difference is 2243 kWh. However, for well insulated buildings the maximum difference is 1400 kWh, as we will see in the next graph.

Figure 2 shows the influence of insulation level on the different outcomes produced by the hourly and monthly calculation method (hourly energy needs minus monthly energy needs).

Figure 2: Division of simulations according to insulation level.

Figure 2 shows that, in contrast to the monthly calculation method, the hourly calculation method overestimates the energy needs and for poor insulated buildings the hourly method underestimates the energy needs.

The difference in energy needs for well insulated and poorly insulated buildings reaches the same maximum (around 1400 kWh) except for a small number of simulations, containing poorly insulated houses. These we will call the outliers.

Figure 3 makes the same analysis for the influence of the thermal mass. The graph shows that there is no clear influence of the thermal mass on the different outcomes of both methods. Both high and low thermal mass buildings appear equally on the positive and on the negative side of the y-axis. Also there is no influence on the 20 outliers.

Figure 3: Division of simulations according to thermal mass.

The influence of the ventilation system on the different outcomes between the two methods is visible in figure 4. For well insulated buildings, buildings with a ventilation system with heat recovery (MHRV) account for the highest differences. For poorly insulated houses, the buildings with a mechanical exhaust ventilation system (MEV) account for the highest differences. The outliers are all buildings with a MHRV system.

Figure 4: Division of simulations according to ventilation system.

The same analysis was made for the other 3 parameters (figure 5 to 7). These analyses show that there is no correlation between the difference in outcomes of both methods and the parameters solar absorption (figure 5), window type (figure 6) and temperature reduction (figure 7). However, for the window type, we see that the outliers are all buildings with single glazing.

Figure 5: Division of simulations according to solar absorption.

Figure 6: Division of simulations according to glazing type.

Figure 7: Division of simulations according to temperature set back regime.

Primary energy conversion factor

The following part looks into the effect of the Primary energy Conversion Factors on the calculated yearly primary energy use for space heating. As explained in the introduction, there is no consensus on how a PEF should be calculated or how it should be applied to evaluate the total energy delivered to the building. The different shares of each production technology in the energy mix have a significant influence on the overall average PEF. For this research the energy mix of three countries have been taken into account. To maintain validity of the boundary conditions, such as weather data, three neighbouring countries are chosen: Belgium, the Netherlands and Germany. Data collected for the energy mix is provided by Entso-E, an online platform for the collection of electricity generation, transportation and consumption data. The following figure shows the different energy mixes for the three countries for the year 2018.

Figure 8: Energy mix for Belgium, the Netherlands and Germany.

The previous graph shows the total yearly generated energy share per generation type. In reality the fractions of these parts are not constant in time. As an example, the following graph shows the hourly fluctuation of Belgiums four main sources of energy:

Figure 9: Generation energy sources for Belgium.

Looking at Figure 9 it is clear that the overall PEF will fluctuate in time. There are three possible methods to incorporate these fluctuations:

Method 1

Weighting the individual PEFs by their total share in the total energy per year. This simplified method is currently used in the Flemish EPB framework. The resulting overall averaged PEF is applied as a constant to the total energy demand of the building.

$$\sum_{CARR} \left[\frac{E_{PROD,YEAR,CARR}}{E_{PROD,YEAR,TOT}} \times PEF_{CARR} \right] \times E_{DEMAND,TOT} \quad (1)$$

Method 2

Weighting the individual PEFs by their share in the energy mix per hour. Next, all the hourly weighted PEFs are averaged. The resulting overall PEF is also applied to the total yearly energy use of the building as a constant. However, the weighting will be different.

$$av \left(\sum_{CARR} \left[\frac{E_{PROD,HOUR,CARR}}{E_{PROD,HOUR,TOT}} \times PEF \right] \right) \times E_{DEMAND,TOT} \quad (2)$$

Method 3

Weighting the individual PEF by their share in the energy mix per hour and applying these hourly PEFs to the hourly energy use of the building.

$$\sum_{HOUR} \sum_{CARR} \left[\frac{E_{PROD,HOUR,CARR}}{E_{PROD,HOUR,TOT}} \times PEF_{CARR} \times E_{DEMAND,TOT} \right] \quad (3)$$

Figure 10 shows the results for method 1, 2 and 3 and the 3 countries, Belgium (blue), the Netherlands (red) and Germany (green).

Figure 10: Averaged PEF for Belgium, the Netherlands and Germany.

The results show the highest PEF for Belgium, due to the large share of Nuclear energy production. The significant share of renewable energy, produced in the Netherlands and Germany, result in an overall lower PEF.

Looking at the PEF values for method 1 and 2 and the mean value for method 3, we see that countries with a bigger share of non-renewable energy, like Belgium, are penalized with a higher PEF value, in contrast to method 1 and 2.

The values for Method 3 in figure 10 are the values for the first building that was simulated. Over the different varying 216 simulations the PEF for method 3 varies, in function of the building's energy needs.

Figure 11 shows the value ranges for the three countries and for each month. The figure shows that during the winter the PEF is quite constant. In the summer, the PEF is influenced by the solar energy produced.

Figure 11: PEF range for method 3
Belgium, the Netherlands and Germany.

Figure 12 show the shift of the PEF value for method 3, for the three countries and the 216 simulations.

Figure 12: Average PEF, method 3, offset
Belgium, the Netherlands and Germany.

Although the monthly values for the PEF, method 3, can shift up to 0.5, when looking at the average value of method 3, the difference between method 1, 2 and 3 seems to be negligible.

Discussion & conclusion

The results presented in this paper shows that the yearly energy needs for space heating, calculated with the monthly and hourly ISO 52016 method coincide quite well. For poorly insulated buildings the difference can reach 2243kWh. Interestingly, the thermal mass of the building did not show any impact. It is important to note that in these simulations no thermal mass of internal walls and floors was taken into account. During the analysis process it became clear that small assumptions in the calculation method can have a big impact on the total energy needs. For instance, reducing the bandwidth between the heating and cooling set points from 6°C to 1°C increases the total energy needs for space heating up to 6000 kWh. In future research the different heat flows going in and out of the building (by transmission, ventilation, solar heat gains, ...) will be further investigated.

The added value of hourly PEFs showed to be minimal. On a monthly basis the impact of solar energy production can be quite large when taking into account the PEF on an hourly basis (method 3). Looking at the average PEF over a year, the difference between lumping the PEF on yearly basis and taking the PEF into account on an hourly basis is negligible. However, it is important to note, that in the context of comparing the hourly method to the monthly method, a nominal heating capacity was assumed. The next step in this research is to take part load into account. Also effects of partial heating (multi-zone modeling) will be considered.

Depending on the desired level of accuracy and practicality of the PEF calculation as well as the availability of the necessary data, it is possible to take additional factors into account like (A) more detailed characteristics of individual power plants, (B) the full energy supply chain of each power plant or technology and (C) grid losses. In theory, these factors also influence the amount of primary energy corresponding to a particular amount of electricity consumption.

Acknowledgments

We gratefully acknowledge the financial support received for this work from the Fund for Scientific Research (FWO) in the frame of the strategic basic research (SBO) project "NEPBC: Next generation building energy assessment methods towards a carbon neutral building stock" (S009617N).

References

- European Commission. (2010). Energy Performance of Buildings Directive
- European Commission. (2012). Energy Efficiency Directive
- European Commission. (2016). Evaluation of primary energy factor calculation options for electricity
<https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings>
- EcoLife. (2009). Venning
<http://www.ecolife-project.eu/ProjectResults.html>
- ENTSO-E. (2018). TYNDP 2018: Scenario Report.
- IEA Annex 56. Methodology for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation. 2017. doi:10.1007/12_003.
- Fonds Wetenschappelijk Onderzoek. (2016). Next generation building energy assessment methods towards a carbon neutral building stock
- Fraunhofer ISI. (2016). Evaluation of primary energy factor calculation options for electricity.
- IEA Annex 56. (2017). Methodology for Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation. doi:10.1007/12_003.
- International Organization for Standardization. (2017). Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads - Part 1: Calculation procedures (ISO 52016-1:2017)
- IRENA. (2018). Renewable Energy Statistics 2018
- Modelica. (2017). Modelica Standard Library
<https://doc.modelica.org/>
- openIdeas v2.0. (2018). IDEAS v2.0
<https://github.com/open-ideas/IDEAS>
- United States Environmental Protection Agency (EIA). (2017). Methods for Calculating Efficiency Key Terms Used in Calculating CHP Efficiency 2017.
<https://www.epa.gov/chp/methods-calculating-chp-efficiency>.