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Primary energy use in buildings in a Swedish perspective

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ABSTRACT

The building sector accounts for a large part of the energy use in Europe and is a sector where the energy efficiency needs to improve in order to reach the EU energy and climate goals. The energy efficiency goal is set in terms of primary energy even though there are different opinions on how to calculate primary energy. When determining the primary energy use in a building several assumptions are made regarding allocation and the value of different energy sources. In order to analyze the difference in primary energy when different methods are used, this study use 16 combinations of different assumptions to calculate the primary energy use for three simulated heating and ventilations systems in a building. The system with the lowest primary energy use differs depending on the method used. Comparing a system with district heating and mechanical exhaust ventilation with a system with district heating, mechanical exhaust ventilation and exhaust air heat pump, the former has a 40% higher primary energy use in one scenario while the other has a 320% higher in another scenario. This illustrates the difficulty in determining which system makes the largest contribution to fulfilling the EU energy and climate goals.

1. Introduction

The residential and service sector accounts for about 40% of the final energy consumption in the European Union [1]. According to the Energy Efficiency Directive (EED) [2] the building stock alone has the biggest potential for energy savings, and therefore measures taken in this sector are an important part of those needed in order to reach the EU climate and energy goals.

The energy efficiency goal is set in the term of primary energy. There are different ways of defining primary energy use with different system boundaries, which are addressed in Section 2 of the current paper. In general one can say that primary energy is the total energy in the form of natural resources that has been used to produce final energy in the form of, for example, electricity or district heating. Primary energy can therefore be used as a measure of resource use. Resource use is, according to WWF [3], one of the factors affecting the world's growing ecological footprint, which is now equivalent to 1.5 earths. The single largest part of our ecological footprint is the carbon component which is mainly the result of burning fossil fuels. The carbon component is strongly connected to the energy sector since, worldwide, the energy sector in 2012 consisted of 82% fossil fuels (oil, coal, natural gas) [4].

There is no unified approach in the EU regulations on how to calculate primary energy. In the directive 2010/31/EU on the energy performance of buildings (EPBD) [5], it is stated that the energy performance of a building shall include an indicator based on primary energy factors (PEFs). A PEF is a factor used to convert final energy to primary energy and is defined as the ratio between primary energy consumption and final energy consumption. The PEFs used to calculate the energy performance of a building may be based on either national or regional values according to the EPBD.

According to Johansson et al. [6] there are few studies dealing with the relation between primary energy use and delivered energy to buildings. Also Sartori & Hestnes [7] found that the factors converting final energy to primary energy vary in literature. In the articles studied by Sartori & Hestnes it was not even consistent how the results were presented as some expressed the energy as final energy, some as primary energy, and some did not specify at all.

The term primary energy is used in Sweden by e.g. district heating (DH) companies for environmental assessment of DH. The use of primary energy for environmental assessment of buildings is debated. In the current building regulations in Sweden [8] primary energy is not included. The Swedish building code is instead based on energy consumption defined as delivered energy to the building.

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There is a recent published investigation with a proposal for a new Swedish building code [9] dealing with energy consumption in nearly zero-energy buildings, which shall be applied to all new buildings from 2021 according to EPBD. Both new levels for nearly zero-energy buildings and a method for calculating the energy consumption are suggested. The system boundary proposed for calculating energy consumption is still delivered energy to the building. A weighting factor of 2.5 for electricity and 1.0 for all other energy carriers is suggested in order to avoid promotion of electrically heated buildings. These weighting factors are supposed to act as the PEFs demanded by the EPBD.

In some countries there are already weighting factors in the building regulations for comparison between different energy carriers. For example in Finland the factors are 1.7 for electricity and 0.7 for DH [10] and in Denmark the factors are 2.5 for electricity and 0.8 for DH [11]. In a report by the European Union funded project EPISCOPE [12], factors for different European countries are presented even though not all are used in building regulations. The weighting factors in Norway are presented as 1.3 for electricity and 1.5 for DH, and the average factors for the European countries included in the report are 2.6 for electricity and 1.2 for DH (these factors are from here on referred to as "European average").

Definitions and use of the term "primary energy" is further explained in Section 2 and the PEF for electricity is discussed in Section 3. In this paper Swedish methods of calculating primary energy are inventoried and described in Section 4. In order to analyze the methods, they are used to calculate the primary energy consumption of a simulated building with three different heating and ventilation systems described in Section 5. The results, discussion and conclusions are found in Sections 6–8.

2. Definition and use of the term "primary energy"

Primary energy is defined as "energy from renewable and non-renewable sources which has not undergone any conversion or transformation process" in the EPBD. A similar definition is used by the United Nations Statistics Division [13], which explains primary energy as "...energy sources as found in their natural state...".

When talking about the use of primary energy, different geographical system boundaries are sometimes included in the definitions. In the EED the primary energy consumption is defined as "... gross inland consumption...", and the International Energy Agency [14] defines primary energy demand as "... domestic demand...".

Primary energy is also defined with different system boundaries in scientific articles. In some articles primary energy is specified as energy used to produce the end-use energy including extraction, transformation and distribution losses along the entire supply chain [7,15,16]. In other articles it is calculated as the fuel input to the DH and electricity production units [17]. In some articles the system boundaries are not specified in detail [18].

Even though the definition of the term differs somewhat depending on the source, the energy efficiency goal set by the European Commission in the EED is based on primary energy. The national targets set by each member state should also be expressed in terms of primary energy.

Besides the different system boundaries used, the methods used to calculate primary energy differ as well. The different ways of calculating can give completely different results. The primary energy can, for example, be calculated using either average values or marginal values, and the primary energy can include only fossil based primary energy instead of all kinds of energy sources. For all methods there are also different ways of obtaining the data. Some use statistics from previous years [19], while others use simulation tools to simulate the primary energy use [16,20]. In cases where the simulation is for the final energy or fuels used in the production units, PEFs are used to convert it to primary energy, either without mentioning the source of the PEFs [21] or using default PEFs for different fuels or for a specific country [22,23].

The use of PEFs is discussed at EU level. In the EED a default PEF for electricity is set to 2.5 which is now discussed in the European Commission together with the overall use of PEFs. At a meeting organized by the European Commission in Brussels in 2015 [24], with both member states and stakeholders attending, different opinions were raised concerning the use of PEFs. Many member states said that from a consumer perspective final energy is the best indicator, with some different opinions depending on the usage. For the attending stakeholders a majority were in favor of using PEFs to calculate primary energy to ensure technological neutrality. A few stakeholders argued that the PEFs should be derived using a scientific method. Concerning the question whether the PEFs should be based on average or marginal values most member states were in favor of average present values in order to keep it simple. The European commission will launch a study to update the PEFs. The alternative of using regional or national PEFs according to EED and EPBD should still remain.

It is not certain that there is a consensus on how to calculate primary energy even nationally. In Sweden there are different sets of PEFs and different ways of allocating the environmental impact, both between electricity and heat in combined heat and power (CHP) plants and between the energy sector and the waste management service when waste is used as an energy source.

Even so, the primary energy per delivered energy for heating increased from 1970 to 2000 according to Nässén and Holmberg [25], mainly due to the increased use of electricity for heating. It is therefore important to have a way of calculating the environmental impact in the form of primary energy consumption since a lower amount of delivered energy does not necessarily imply a lower primary energy consumption.

3. Primary energy factor for electricity

Many assumptions are made when evaluating the environmental impact of electricity consumption. The system boundary is one of the assumptions that has to be made. The electricity grid is not a small local system like a typical district heating system; it is a huge network with connections between countries. Even so, smaller system borders such as national borders are often used. Using smaller geographical boundaries has a major impact on the results when the production mix in the smaller system differs from the production mix in the larger system.

Another important assumption when calculating the environmental impact of electricity consumption is whether to calculate using average values or marginal values. In Sweden, and in countries with a similar electricity production mix, this assumption has a huge impact on the results [26], especially with the own country as system boundaries. This because there is a large difference in the average and marginal production [26]; the electricity production in Sweden is roughly 50% hydropower which has a low PEF, while the marginal electricity production is from mostly fossil fuels [27] with a high PEF. According to Sköldberg & Unger [28] the main part of the marginal production might still be from fossil fuels until 2037 in northern Europe. Even though Sweden is a net exporter of electricity, the marginal production can still be from coal condensing power according to Sköldberg & Unger. According to Profu [27] the marginal production will probably still be mostly fossil based until 2050 even with what they in their simulations call "high climate ambitions". Sweden's large share of hydropower together with wind power is never regarded as marginal production, and the same goes for nuclear power which production is restricted for