NEARLY ZERO-ENERGY BUILDING DEFINITIONS IN SELECTED COUNTRIES

by

Margaux CARLIER

Master's dissertation submitted in order to obtain the academic degree of Master of Science in de industriéle wetenschappen: bouwkunde

Supervisors
Prof. Jarek Kurnitski (Aalto University)
Kaiser Ahmed (Aalto University)
Prof. Patrick Ampe (Ghent University)
Anthony Tetaert (Ghent University)

Faculty of Structural Engineering
Chair: Prof. dr. ir. Luc Taerwe
Faculty of Engineering and Architecture

Academic year 2015–2016

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Margaux Carlier

Abstract

In 2002 gaf het Energy Performance of Buildings Directive (EPBD) doelstellingen om het aandeel Bijna Energieneutrale Woningen (BEN), ook wel Nearly Zero-Energy Buildings (nZEB) genaamd, te verhogen tot dat in 2020 alle nieuwe gebouwen nZEB wonigen zijn. Het document gaf de omkadering voor dit doel, maar liet de specifieke invulling aan de lidstaten zelf over. Dit resulteerde in verschillen tussen de manier waarop de deelstaten onder meer het maximaal primair energieverbruik, de primaire energie factoren en de calculatiemethoden definieerden. Verder benvloedt ook het klimaat van de landen de eisen.

Deze thesis zoekt eerst een overzicht te geven van de belangrijkste verschillen van geselecteerde landen en dan een methode voor te stellen om de eisen tussen verscheidene landen te kunnen vergelijken, zodoende een idee te krijgen van strengheid van de desbetreffende eisen. De vooropgestelde landen zijn Estland, Finland, Frankrijk en Belgié. Binnen Belgié zijn de eisen een bevoegdheid van de gewesten, dus wordt de regelgeving per gewest besproken: het Vlaams Gewest, het Waals Gewest en het Brusselijk Hoofdstedelijk Gewest. De voorgestelde methodiek bestaat er in een vergelijking naar $delivered\ energy$ te maken, en in het geval van een grondwarmtepomp naar $net\ energy\ need$ van drie types referentiegebouwen:een alleenstaande woning, een appartementsgebouw en een kantoorgebouw. Voor elk van de gebouwen werden twee types generator voor de gecombineerde levering van warm tapwater en verwarming in beschouwing genomen.

Uit de resultaten kon over het algemeen afgeleid worden dat Frankrijk en Brussel op kop lopen wat betreft de strengheid van de eisen. Het moet opgemerkt worden dat deze landen dan ook reeds de nZEB-eisen al implementeerden in de huidige regelgeving en Frankrijk richting plus energy wil evolueren. Verder viel op dat bepaalde landen strengere eisen stelden naargelang type gebouw en dat de verschillen tussen de verschillende Gewesten aanzienlijk zijn. Dit laatste heeft voornamelijk te maken met eisen, aangezien calculatie methoden grotendeels overeenkomen.
Daarnaast werd ook duidelijk dat de vergelijking sterk bemoeilijkt wordt door verschillen in opstellen van de eisen, zo zal volgens de Belgische regelgeving in een appartementsgebouw elk appartement een specifieke eis hebben naargelang geometrie en ligging, terwijl Estland een eis geeft die geldt voor elk apartement, ongeacht de werkelijke situatie. Verder werden ook de verschillen in gewoonten tussen de landen duidelijk: stadsverwarming blijkt veel minder in gebruik in Belgié dan in Finland, waardoor de regelgeving vrij beperkt is. Andersom zal in de Noordelijke landen veel minder gas gebruikt worden om een woning te verwarmen. Dit bemoeilijkt een eenduidige conclusie.

Het standaardgebruik van de gebouwen die aan de basis ligt van de berekening verschilt ook naargelang de landen. Echter, dit normaliseren past niet binnen het kader van de verenvoudigde berekening die uitgevoerd wordt in deze thesis, maar zou interessant zijn naar een latere simulatie toe.

Abstract

In 2002 the Energy Performance of Buildings Directive (EPBD) issued objectives to raise the share of nearly Zero-Energy Buildings (nZEB), so that by 2020 all new buildings would be nZEB. The general background is provided by this directive, but the member states are free to fill in the specifics on how to realize the demand. This resulted in differences in how the countries defined for example maximum primary energy use, the primary energy factors and the calculation methods. These demands were further also influenced by the climate of each region.

This thesis will firstly discuss the significant differences between the selected countries, then a method for comparing the different countries will be provided as to achieve an overview of the strictness of said objectives. Belgium, Estonia, Finland and France are the chosen countries for this thesis. For Belgium the objectives are regulated by the regions, so this will be discussed per region (Flemish, Walloon and Brussels region). The provided method makes an equation based on the $delivered\ energy$, and, in case of a groundwater pump, on the $net\ energy\ need$, of three building types, namely a detached single family house, an apartment building and an office building. For each building two types of generators are taken into account to provide heating and domestic hot water (DHW).

The results of the analysis conclude that France and the Brussels Capital Region defined the strictest requirements. It is however noted that both France and the Brussels Capital Region already implemented the nZEB-requirements in their current regulation and France wants to comply with the plus-energy requirements in the future. The comparison of the different countries showed that some defined a stricter regulation based on building type and that regulation of the Belgian regions differs significantly. The latter can be explained by the various objectives as the calculation methods are similar.
The analysis was complicated by the differences in the requirements: according to the Belgian regulation an apartment unit in an apartment building needs to satisfy a specific requirement based on geometry and position, while Estonian regulation defines a general requirement for an apartment unit irrespective of its geometrical characteristics.
Furthermore, it became clear that different countries resulted to different habits: district heating is far less present in Belgium compared to Finland. In the Northern countries, however, natural gas is far less used than district heating.

Standard use of the discussed buildings differs depending on the countries. However it is not within the scope of the simplified calculations of this thesis to normalise this standard use, but can be interesting for future simulations.

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List of Acronyms

C

CEP	Coefficient dEnergie Primaire
COP	Coefficient Of Performance

D

DHW	Domestic Hot Water

E

EPB	Energy Performance of Buildings

F

VEA	Flemish Energy Agency

N

nZEB	nearly Zero-Energy Buildings

S

SEER	Seasonal energy efficiency ratio

1 Introduction

Since the formulation of the nZEB goal for new buildings in the Energy Performance of Buildings Directive (EPBD), the need arose to compare the regulations and calculation methods for energy performance set by the European Union Member States to attain this goal. However, this is complicated by differences in definitions of primary energy indicators (e.g. the use of a reference building in the definition), the energy flows incorporated (e.g. lighting and/or appliances are not included for all types of buildings), basic input data and different climates amongst other things. This thesis seeks to make a comparison of the maximal primary energy use in selected countries, namely Finland, Estonia, Belgium and France, according to both current and nZEB regulations.

The first chapter gives a general background on energy calculation in buildings, mentioning the overarching European EPBD standard and explaining basic ideas and concepts related to the energy calculation of buildings.

The second chapter describes energy calculation on a national level: the different countries are introduced and their methods are briefly explained. In the case of Belgium the explanation goes one step lower, to the regional level, as in Belgium energy performance regulations are the responsibility of the three regions: the Flemish Region, the Brussels Capital Region and the Walloon Region. A first brief comparison is also made. At the end of the chapter, the chosen reference buildings are introduced and the basic assumptions are mentioned.

The third chapter seeks to find a calculation method which allows for the comparison of the regulation of the different countries for the three reference buildings. In doing so, the relevant parts of each countries calculation method are explained in detail. The chosen calculation method is that of maximal allowed delivered energy, with the exception of net needed energy when using a ground source heat pump.

The fourth chapter gives the outline of the actual calculation, mentioning the most important intermittent results, assumptions and the end result. The general idea is to give more insight into the why and how of the end results.

The last chapter discusses the attained results an the reasoning behind them. The difference in set standards between the countries are looked at in detail and the values are linked back to different assumptions and calculation steps used. At the end of this chapter an overall conclusion is reached.

2

Energy calculation in buildings

2.1 Energy Performance of Buildings Directive

In order to reduce energy dependence and to limit the results of the greenhouse effect the European Union searched for a reduction of energy consumption of buildings. To this end the Energy Performance of Buildings Directive (EPBD) took effect in 2002. The eventual goal of this directive is to attain nearly zero- energy building standards, more specifically, all buildings must be nearly zero-energy buildings (nZEB) by 31 December 2020 and after 31 December 2018 all new public buildings must be nearly zero-energy buildings [The10]. A nZEB building is defined by the EPBD recast as

a building that has a very high energy performance [...]. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. [The10]

The directive does not specify details of energy performance calculation or requirements, which are defined by the Member States themselves. The implementation of the nZEB aim is discussed in a national plan, which amongst others contains a definition of nZEB in accordance with the local conditions. This includes the definition of a maximal primary energy index (other energy performance indicators may also be specified), primary energy factors and requirements for the energy performance of buildings within the framework provided by the EPBD recast. The requirements are updated regularly (every 2-3 years in most countries) in order to eventually attain the nZEB-goal. [KGR]). [The10]

2.2 System boundaries and energy flows

The calculation of the national primary energy indicators are based upon the system boundaries and energy flows defined by REHVA (figure 2.1). System boundaries can be defined as

a boundary that includes within it all areas associated with the building (both inside and outside of the building) where energy is used or produced (EN 15603:2008)

The general calculation workflow as shown on the figure is the following. First of all there are the building energy needs for heating, cooling, ventilation, domestic hot water (DHW), lighting and appliances which are within the first system boundary. As shown on the figure, heating need is influenced by amongst others solar gains. The inclusion of the specific energy flows may vary according to the Member State's national definitions, especially energy flows of electricity and/or appliances are left out in certain types of buildings (e.g. Belgian regulations do not include appliances in both residential and office buildings, but do include lighting in office buildings) [KAB+12] .

Secondly, the energy use for the before mentioned needs is provided by the building's systems (energy use system boundary). In producing this energy, there are losses related to the nature of the system [KAB+12].

Thirdly there is the delivered energy system boundary.Delivered energy is brought to the site in the form of district heating or cooling, electricity and fuels (these could be either renewable or non renewable) to supply energy for these technical systems. Any exported energy is subtracted from this value (net delivered energy). As shown on figure 2.1 is renewable energy that is produced on site not seen as delivered energy, on the contrary, the renewable energy that is already produced on site, reduces the delivered energy need. Any excess renewable energy can also be be exported [KAB+12].

The last step is the primary energy use, which is crude energy that has not been conversed or transformed in any way. The Member states define primary energy factors which account for the rate of this conversion [KAB+12].

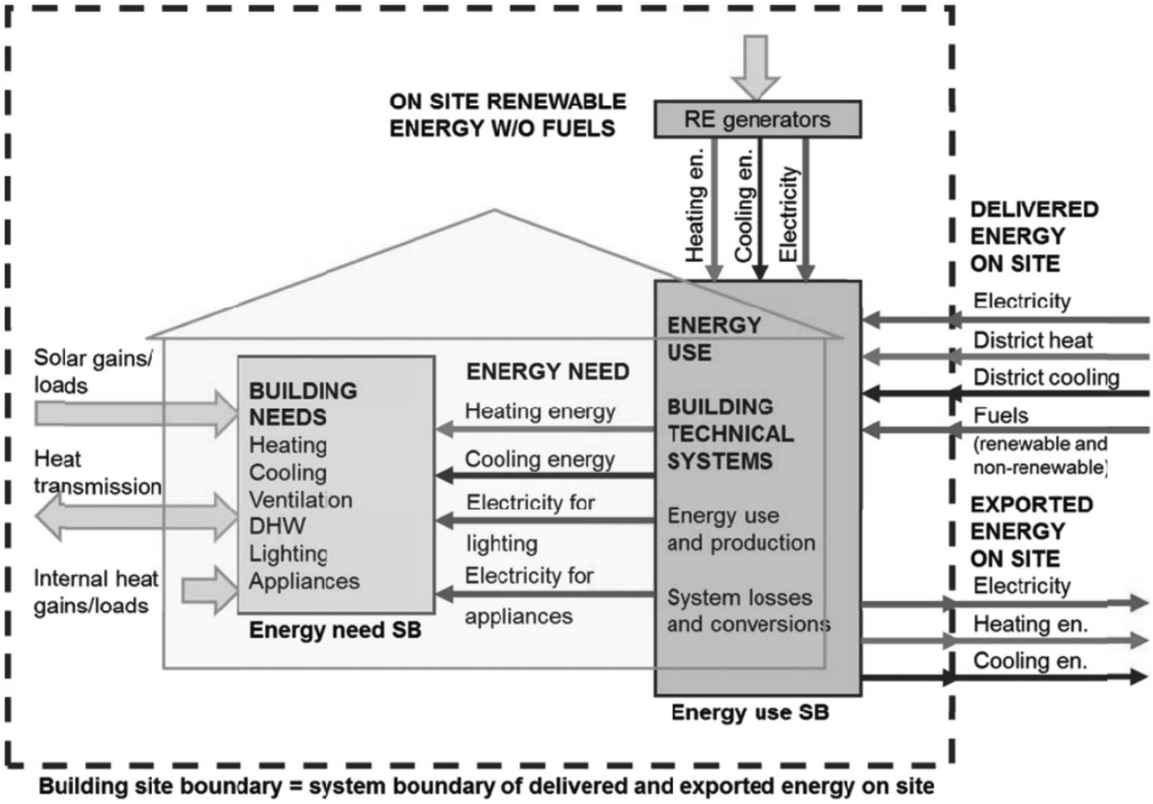

Figure 2.1: Definition of three system boundaries for on site assessment: a system boundary for energy need, energy use and delivered ad exported energy on site [REH13]

3

Energy calculation methods for selected countries

3.1 Introduction

This chapter aims to give an overview of national calculation methodologies and both current and nZEB requirements for new buildings (3.2 and 3.3). It also tries to compare the different methods and thus give a first impression of existing difference between countries, which will be handled more in depth in the following chapters. The chapter also introduces the reference buildings that form the base for the primary energy use comparisons described in chapter 2 and 3: general characteristics and the basic assumptions in relation to these building are described in section 3.4.

3.2 National calculation methodologies for new buildings

3.2.1 Belgium

The requirements and calculations to be followed depend on the building category. If parts of a mixed use building belong to different categories, the building is split into separate volumes, called V_{EPR} volumes, accordingly. This volume can be further divided into smaller parts according to the presence of one or multiple ventilation systems or heating systems. All three Belgian regions (the Walloon, Flemish and Brussels Capital Region), incorporate the energy use of space heating,cooling, domestic hot water and auxiliary devices when calculating the primary energy use of residential buildings. When calculating office buildings the energy use of lighting is also considered.The energy use due to the production of hot tap water is omitted (except for Flemish and Walloon regulations after 01/01/2017).
The basic steps of the calculations are the same in all three regions and depend on a monthly calculation of the energy flows [De 16]. The 5 steps are listed below:

1. Calculation of the monthly net energy need for space heating and domestic hot water (DHW)
2. The monthly net energy need is divided by the system efficiencies to get the monthly gross energy need.

3. The monthly final energy use for space heating and DHW is determined by subtracting the monthly contribution of a thermal solar energy system and dividing the rest by the efficiency of the generator. The monthly final energy use for auxiliary devices and cooling, if there is any, is also calculated. The characteristic monthly energy production of a photovoltaic solar energy system or property-bound co-generation system is calculated.

4. Each of the monthly final energy uses are multiplied with the corresponding primary energy factor and summed up over a period of a year to get the characteristic yearly primary energy use, $E_{char\ ann\ prim\ en\ cons}$. The already calculated self-generated energy is to be subtracted from this value.

5. The primary energy index is calculated.

The main difference between regions lies in the conception of the last step: the Flemish Region uses a value dependant on a reference building whereas the Brussels Capital Region uses an absolute value. The Walloon Region defines both relative and absolute primary energy indicators for residential buildings, but only an absolute primary energy index for office buildings. [De 16]

The details of the calculations of the other steps vary slightly for residential buildings and office buildings before 2017: sometimes an equation is formulated differently, still resulting in the same values in most cases. The suggested standard values in the region specific documents also tend to vary. Such is the case for the DHW calculation. From 01/01/2017 on the Flemish and Walloon calculation method for office buildings changes with regards to the determination of the maximal primary energy index. Again the calculation methods of both regions are very much alike [De 16] [De 15c] [Gou15b] [Gou13] [Gou15e].

Flemish Region

The maximum primary energy consumption is expressed by the primary energy indicator, E, the ratio of the yearly primary energy consumption of the building ($E_{char\ ann\ prim\ en\ cons}$) to that of a reference building with the same volume and compactness as the original building. The value of the E-level varies according to the building categories shown in table 3.1. Note that the fourth category has several subclasses. [De 16]

For office buildings with a building permit dated later then 01/01/2017 a significant change in calculation,based on the division of the building in parts with a certain function, is introduced. Some of the changes include [De 15c]:

- Determining of certain parameters, such as indoor temperature, per functional part of the building.
- Incorporation of the energy use due to the production of domestic hot water
- The calculation of the primary energy use of reference building is no longer done using a single equation incorporating a number of constants and parameters, but is done through a complete calculation of the reference building.

Brussels Capital Region

Brussels' primary energy index, CEP, depends upon the compactness (ratio of volume to heat loss area) of the bulding.The index is equal to $E_{char\ ann\ prim\ en\ cons}$ defined in Flemish regulations. Therefore calculation of the first 4 steps is very similar to the Flemish calculation, with a few exceptions such as the efficiency calculation of DHW and space heating. Different standard values are given for both generator and system efficiencies and calculations vary only slightly, so that in most cases, especially when the specifics of the building (e.g. length of the piping for DHW) are known, the results are the same. The building categories are shown in table 3.1 [Gou15b] [Gou15a].

Walloon Region
The Walloon Region defines two primary energy indicators: E_w and E_{spec}. The first value is defined in relation to a reference building and takes the volume and compactness into account. The latter value is the $E_{char\ ann\ prim\ en\ cons}$ used in all Belgian regulations, but converted to kWh/m^2a. Again, the efficiency calculation of the DHW and space heating generators such as gas condensing boiler and ground source heat pumps is different in terms of suggested standard values for efficiency. The building classes are shown in table 3.1. The calculation of office buildings changes from 2017 on with regards to the reference building calculation. As is the case for the Flemish Region the method shifts from one equation to a whole building calculation. [Gou13] [Gou15e] [Gou16]

3.2.2 Estonia

The energy performance indicator ETA is determined by subtracting the total exported energy from the total delivered energy and dividing the result by the net heated area. The indicator incorporates the energy flows of space heating, domestic hot water, auxiliary devices and, unlike the Belgian Regions, also those of lighting and appliances. The calculation is done on an hourly basis, though this can be simplified to a monthly calculation for residential buildings without cooling. The calculation process is carried out in the following steps [gov12]:

1. The calculation of the summertime indoor temperatures.
2. The energy need of space heating, the heat recovery from ventilation air, the heating of the ventilation air, domestic hot water and if present, cooling is calculated.
3. The electricity use of the ventilation system is determined.
4. Approximate calculation of the heating system, taking into account the efficiency of the generator or the performance coefficient (COP) of the heat pump. The electricity use of any auxiliary devices is also calculated.
5. The same is done for the cooling system, taking into account the condensate and heat losses of the cooling system and the production of cold.
6. The calculation of the electricity use of lighting and appliances, starting from standard values and parameters concerning the use of the equipment.
7. Presentation of calculation results.

Energy calculation is made in regards to the standard use of the building: several input parameters are given according to this standard use [oeac14c]. Similar to the Belgian Regions a division into several parts of the building volume may be in order for larger buildings with different purposes or periods of use. Small residential buildings on the other hand can be seen as a single zone.
The maximum ETA-level is dependant on the building category the building belongs to. There are 9 categories, shown in table 3.1. [gov12]

3.2.3 Finland

The primary energy indicator, E, is derived from the net purchased energy times the relevant primary energy factors. The indicator incorporates the energy use of space heating, cooling, domestic hot water, auxiliary devices and, unlike the Belgian Regions, also those of lighting and appliances. The calculations are made using an hourly time-step, except for residential buildings without cooling where a monthly time step can be used. The calculation is based on default input data related to the standard use of the building, e.g. the operation time of the ventilation system. These values are described in the regulations [Min10a]. The following steps are followed in the calculation process:

1. The net heating energy needs for space, ventilation and domestic hot water heating are calculated. If the building has a cooling system, the net needed energy for cooling is also determined.
2. The energy consumption of appliances and lighting is determined.
3. Heating system, ventilation system and cooling system energy consumption.
4. Calculation of the renewable, self-produced energy.
5. Calculating the buildings consumption of purchased energy, the energy supplied elsewhere and the buildings net consumption of purchased energy.
6. The primary energy index (E) is determined by multiplying the buildings net consumption of purchased energy by the primary energy factors.

The maximal value of the primary energy index is determined by the building categories, which are shown in table 3.1 [ME10].

3.2.4 France

The primary energy index C_{ep} takes into account energy use of space heating,domestic hot water, cooling, auxiliary devices and lighting. The calculation method is based on an hourly time step and uses a a set of standard use scenario's to determine the occupation and use of the water, heating, and lighting. Next to these there are only a minimum amount of standard values, therefore having detailed information or making assumptions is more necessary than is the case in the other methods. The method distinguishes three levels on which calculations are made. The first level is concerned with the needs of the occupants, the emission. The second level is related to distribution and the third level is occupied with production/-generation. [Cen12]

French regulations divide a building into different levels: a building- , zone-, group- and room-level, and ties specific calculations to each level. The regulatory requirements such as the consumption of primary energy index C_{ep} and the main building characteristics (e.g. location) are linked to the whole building-level. The zone level groups part of the building with the same use together. The group level is used for lighting, DHW and space heating/cooling calculations: parts of the building with different heating/ cooling needs or different access to natural lighting are separated in order to make detailed calculations. The room level makes a further distinction in use of the spaces and calculates heat gain and humidity according to them. The number of different volumes used in the calculation is again dependant on the complexity of the building. For instance, in a single family dwelling the building-, zone-, group- and rooms-level all coincide so that the calculation can be significantly simplified. An office building on the other hand has at least the following subdivisions on the room-level: offices, meeting rooms, circulation spaces and bathrooms. These are used in the lighting calculation. Depending on the exact organisation of the HVAC installations more divisions might be in order.

In this case the maximum C_{ep} index is not only dependant on the type of building but also on the building's location, altitude, the heating system and surface (in the case of a residential building). The categories are shown in table 3.1 [Cen12]

Table 3.1: Calculation method of new buildings

Country or region	Primary energy indicator	Building categories	Time step	Main reference
Brussels capital region	CEP	1. Residential buildings such as an apartment building or house 2. Communal residential buildings such as a boarding school 3. Offices and services 4. Schools 5. Health care facilities 6. Culture and entertainment buildings 7. Restaurants and cafes 8. Commercial buildings 9. Sport facilities 10. Common parts of a building 11. Other buildings	monthly	Annexe IX: méthode PER pour les unités PEB habitations individuelles [Gou15a]. Annexe X: méthode PEN pour les unités PEB bureaux et services enseignement [Gou15b].
Flemish region	E-level [1]	1. Residential building 2. Offices and school 3. Industrial buildings 4. Other specific destinations	monthly	Bijlage V: Bepalingsmethode van het peil van primair energieverbruik van woongebouwen [De 15a].Bijlage VI: EPN methode (from 01/01/2017 on) [De 15c]. Bijlage VI: bepalingsmethode van het peil van primair energieverbruik van kantoor- en schoolgebouwen (until 31/01/2016) [De 15a].

Continued on next page

Table 3.1 – *Calculation method of new buildings (Continued from previous page)*

Country or region	**Primary energy indicator**	**Building categories**	**Time step**	**Main reference**
Walloon region	E_{spec} E_w[1]	1. Single family homes and apartments 2. Offices, services, schools, hospitals, hotels, restaurants, cafes, commercial buildings, collective accommodation, ... 3. Industrial buildings	monthly	Arrête du gouvernement Wallon du 19/11/2015, annexe A1: méthode PER 2016 [Gou15e]. Annexe A2: mêthode BSE (until 21/01/2016) [Gou16].Annexe A3: mêthode PEN (from 01/01/2017) [Gou15b].
Estonia	E	1. Small residential buildings 2. Multi-apartment buildings 3. Office buildings, libraries and research buildings 4. Business buildings 5. Public buildings 6. Commerce buildings and terminal 7. Educational buildings 8. Pre-school institutions for children 9. Healthcare buildings	hourly/monthly (1)	Methodology for calculating the energy performance of buildings [oeac14b]. Minimum requirements for energy performance [gov14].

Continued on next page

Table 3.1 – *Calculation method of new buildings (Continued from previous page)*

Country or region	**Primary energy indicator**	**Building categories**	**Time step**	**Main reference**
Finland	E	1. Separate small houses, terraced and linked houses, building blocks 2. Office buildings 3. Commercial buildings 4. Commercial accommodation buildings 5. School buildings and day care centres 6. Large gyms, excluding indoor swimming pools and ice sports centres. 7. Hospitals 8. Other buildings	hourly/monthly (1)	Finnish Building code D3 [ME10] and D5 [Min10h]
France	C_{ep}	1. Residential buildings • Individual homes • Apartment buildings • University campus' 2. Office buildings 3. Primary and secondary schools 4. Nurseries/ daycare	hourly	RT2012 [Cen12]

(1) The general calculation method has an hourly time step, but residential buildings without cooling use a monthly method .

3.3 National requirements

Flemish Region

- Residential buildings: Current regulations state a maximal primary energy index E of 30 [het15]. nZEB regulations set a maximal primary energy index $E50$.
- Office buildings: Current regulations give a maximal primary energy index of 55. Office buildings built for public organisations have a stricter maximal primary energy requirement of 50 [het15]. nZEB regulations set a maximal primary energy index of 40. From 01/01/2017 on the building is divided into functional parts for which a maximal primary energy index is set according to type. The building's overall primary index is the weighted average of these different parts [het16a]. Again, slightly different values are specified for buildings built by public organisations. [De 15g]
- The form coefficients are 2,5 for electricity and 1,0 for fossil fuels [De 10c]. The primary energy factor for district heating is either a default value of 2,0 used for external heat systems or is obtained through the procedure of equivalence. The latter involves the calculation of the factor with an Excel sheet given by the Flemish Energy Agency (VEA) and applying for equivalence. The value can only be used if equivalence is granted [het16b].

Brussels Capital Region

- Residential buildings: nZEB regulations are already enforced since 2015. The a maximal primary energy use CEP for residential buildings is determined with

$$45 + max(0; 30 - 7.5C) + 15 \cdot max(0; \frac{192}{V_{EPR}} - 1) \tag{3.1}$$

  where the compactness of the building $C = \frac{V_{EPR}}{A_s}$, the ratio of the EPR-volume to the heat loss area. . [Ins16] [Bui15]

- Office buildings: If the net needed energy for heating X is less then 15 kWh/m^2a the maximal primary energy is calculated with

$$95 - (2,5C) \tag{3.2}$$

  If not it is determined with

$$95 - (2,5C) + 1,2 \cdot (X - 15) \tag{3.3}$$

  calculated with restrictions for certain parameters. [Ins16]

- The form coefficients are 2,5 for electricity and 1,0 for fossil fuels [Ins16]. The same equivalent factor of 2,0 for district heating is used for all Belgian Regions [het16b].

Walloon Region

- Residential buildings: Current regulations state a maximal primary energy use index E_w of 80 and a yearly maximal specific primary energy consumption E_{spec} of 130 $\frac{kWh}{m^2a}$. In the following calculations the strictest value is used. nZEB regulations set a maximal E_w of 45 and E_{spec} of 85 kWh/m^2a [Goud].
- Office buildings: A maximal primary energy index E_w of 80 kWh/m^2a is set in current regulations. For nZEB requirements E_w is 90/45 kWh/m^2a depending on the different functions of parts of the building. A weighted average of these different requirements gives the overall requirement [Goud]. Note that the same demands are valid for public buildings [Goue].

- The form coefficients are 2,5 for electricity and 1,0 for fossil fuels [Gou15d]. The same equivalent factor of 2,0 for district heating is used for all Belgian Regions [het16b].

Finland

- Residential buildings: Current regulations state the following maximal primary energy use for a separate small house with $A_{net} \geq 150m^2a$

  $$173 - 0,07A_{net} \tag{3.4}$$

  nZEB regulations set a maximal primary energy use of

  $$116 - 0,04A_{net} \tag{3.5}$$

  The maximal primary energy use of an apartment building is 130 according to current regulations . An apartment building with up to two storeys has a maximal primary energy use of 105 kWh/m^2a, whereas a building with at least 3 storeys must have a lower primary energy use then 82 kWh/m^2a. [Hel16] [Min16] [ME10]
- Office buildings: Current regulations state a maximal primary energy use of 190,0 kWh/m^2a, nZEB requirements set 64,0 kWh/m^2a as the requirement. [Hel16] [ME10]
- The current form coefficients are 1,7 for electricity, 0,7 for district heating and 1,0 for fossil fuels [ME10]. The nZEB regulations state new form factors: 1,2 for electricity, 0,5 for district heating and 1,0 for fossil fuels. [Min16]

Estonia

- Residential buildings: Current regulations state a maximal primary energy use of 160 kWh/m^2a for small residential buildings and 150 kWh/m^2a for multi-apartment buildings. nZEB regulations set a maximal primary energy use of 50 kWh/m^2 for small residential buildings and 100 kWh/m^2a for multi-apartment buildings [gov14].
- Office buildings: Current regulations state a maximal primary energy use of 160,0 kWh/m^2a, nZEB requirements set 100,0 kWh/m^2a as the requirement [gov14].
- The form coefficients are 2,0 for electricity, 1,0 for solid fuels, 1,0 for natural gas, 1,0 for liquid fuel and 0,9 for district heating [gov14].

France

- Residential buildings and office buildings: The nZEB regulations are already enforced [Cen12] . The maximal primary energy use of a building is found using the following equation:

$$C_{ep,max} = 50 \cdot M_{c,type} \cdot (M_{c,geo} + M_{c,alt} + M_{c,surf} + M_{c,ges}) \tag{3.6}$$

  where $M_{c,type}$ depends on the type of building, $M_{c,geo}$ depends on location,$M_{c,alt}$ expresses the influence of altitude,$M_{c,surf}$ is determined in relation to the average surface of the housing (=0 in the case of office buildings) and $M_{c,ges}$ incorporates the CO_2 emissions of the chosen heating system. Note that office buildings that have a cooling system and are exposed to a certain amount of noise coming from the environment (proximity to roads) have a significantly higher maximum primary energy index [dldldddedlm10].

- A definition for plus energy buildings is being made. This will be included in the Thermal Regulation of 2020 [Bui15].

- The form coefficients are 2,0 for electricity, 1,0 for gas and 1,0 for co-generation [Cen12].

Country or region	Primary energy indicator	Energy flows	Requirements				Primary energy factors	
			Single family dwellings		Apartment buildings			
			2016	nZEB	2016	nZEB	2016	nZEB
Brussels Capital Region	CEP $[\frac{kWh}{m^2a}]$	DHW, heating, ventilation, cooling and auxiliary	45 + max(0 ; 30-7.5C) +15max(0 ; $\frac{192}{V_{EPR}} - 1)$		45 + max(0 ; 30-7.5C) +15max(0 ; $\frac{192}{V_{EPR}} - 1)$		electricity 2,5 district heating 2,0 (1) natural gas 1,0	same as 2016
Flemish Region	E [%] (2)	DHW, heating, ventilation, cooling and auxiliary	50	30	50	30	electricity 2,5 district heating 2,0 (1) natural gas 1,0	same as 2016
Walloon Region	E_{spec} $[\frac{kWh}{m^2a}]$ E_w[%] (2)	heating, ventilation, cooling and auxiliary	130 80	85 45	130 80	85 45	electricity 2,5 district heating 2,0 (1) natural gas 1,0	same as 2016
Estonia	E $[\frac{kWh}{m^2a}]$	DHW, heating, ventilation, cooling, auxiliary, lighting and appliances	160	50	150	100	electricity 2,0 district heating 0,9 natural gas 1,0	same as 2016
Finland	E $[\frac{kWh}{m^2a}]$	DHW, heating, ventilation, cooling, auxiliary, lighting and appliances	173-0,07A_{net} (3)	116-0,04 A_{net} (3)	130	105/82 (5)	electricity 1,7 district heating 0,7 natural gas 1,0	electricity 1,2 district heating 0,5 natural gas 1,0
France	$C_{ep,max}$ $[\frac{kWh}{m^2a}]$	DHW, heating, ventilation, cooling, auxiliary and lighting	(4)				electricity 2,58 district heating 1,0 natural gas 1,0	same as 2016

(1) suggested equivalent primary energy factor, can also be determined by applying for equivalence
(2) ratio of the primary energy consumption of the building to the primary energy consumption of a reference building
(3) where $600m^2 > A - net > 150m^2$
(4) depending on building type, location, altitude and heating system (equation 3.3 <400m)
(5) depending on the number of floors

Table 3.2: Comparison of national requirements for new residential buildings

Country or region	Primary energy indicator	Energy flows	Requirements		Primary energy factors	
			Office buildings			
			2016	**nZEB**	**2016**	**nZEB**
Brussels Capital Region	CEP $[\frac{kWh}{m^2a}]$	heating, ventilation, cooling, auxiliary and lighting	Net needed energy for heating W $< 15\ \frac{kWh}{m^2a}$: CEP =$95 - 25C$ if not: CEP= $95 - (2,5C) + 1,2(X - 15)$		electricity 2,5 district heating 2,0 (1) natural gas 1,0	same as 2016
Flemish Region	E [%] (2)	heating, ventilation, cooling, auxiliary and lighting	55/50 (3)	40	electricity 2,5 district heating 2,0 (1) natural gas 1,0	same as 2016
Walloon Region	E_w[%] (2)	heating, ventilation, cooling, auxiliary and lighting	80	90/45 (4)	electricity 2,5 district heating 2,0 (1) natural gas 1,0	same as 2016
Estonia	E $[\frac{kWh}{m^2a}]$	DHW, heating, ventilation, cooling, auxiliary, lighting and appliances	160	100	electricity 2,0 district heating 0,9 natural gas 1,0	same as 2016
Finland	E $[\frac{kWh}{m^2a}]$	DHW, heating, ventilation, cooling, auxiliary, lighting and appliances	190	64	electricity 1,7 district heating 0,7 natural gas 1,0	electricity 1,2 district heating 0,5 natural gas 1,0
France	C_{ep} $[\frac{kWh}{m^2a}]$	DHW, heating, ventilation, cooling, auxiliary and lighting	(5)		electricity 2,58 district heating 1,0 natural gas 1,0	same as 2016

(1) suggested equivalent primary energy factor, can also be determined by applying for equivalence. This implies calculating the district heating efficiency and primary energy factor in a standardized way and applying for governmental approval.
(2) ratio of the primary energy consumption of the building to the primary energy consumption of a reference building
(3) buildings of public organizations have a stricter requirement of 50
(4) depending on the function of part of the building
(5) depending on building type, location, altitude and heating system (equation 3.3 <400m)

Table 3.3: Comparison of national requirements for new office buildings

3.4 Discussion of reference buildings and assumptions

The regulations of the selected countries are based on the specific climate of the country. Therefore the heating and cooling energy use needs to be degree day corrected in order to apply these regulations to one and the same reference building.

The degree day corrections are done in relation to Finland, as this has the coldest climate and has the most heating degree days and the least cooling degree days. The heating degree days of 2015 of each country's capital are: Brussels Capital, Flemish and Walloon Region: 2418 Cd, Estonia: 3540 Cd, Finland: 3689 Cd, France: 2085 Cd. The cooling degree days of 2015 are: Brussels Capital, Flemish and Walloon Region: 410 Cd, Estonia: 190 Cd, Finland: 181 Cd, France: 657 Cd. [DD16]

3.4.1 Detached singly family house

The first reference building considered is a detached house. The building has a net heated area of 171,10 m^2 and a heat loss surface area of 410 m^2. The floor height is assumed to be 2,6 m, which when multiplied with the net heated area gives a volume of 444,9m^3 [KSK$^+$13].

It is assumed that the building is heated with one generation device, has one ventilation system and no cooling system. The generator heats both DHW and the building's spaces. The building has two showers and one kitchen sink. The auxiliary devices' electricity use is assumed to be 5 kWh/m^2a for the ventilation fans and 3 kWh/ m^2a for the circulation pump of water based heating. Domestic hot water heating is normalized to an energy use of 25 kWh/m^2a. This value is based on the Estonian energy need; according to Estonian regulations, only generation efficiency is accounted for and thus the energy use for DHW only slightly varies from the energy need. This makes it easy to use as normalization value.

The calculations are made for a gas condensing boiler and a ground source heat pump. The generation efficiency of the condensing boiler is estimated by using equation 4.14, the calculation method described in the regulations of the Walloon region. When using a 97 $\%$ efficiency under 30$\%$ load (default value French regulations [lCC12]) a generation efficiency of 0,99 is found. The ground source heat pump is assumed to have an average coefficient of performance of 2,5 for domestic hot water (DHW) heating and 3,5 for space and ventilation heating. A storage system of 200 l is present. It is assumed that the building uses no renewable energy. Although this is not in line with regulations for the different countries, this allows for a simplified calculation and comparison. An overview of these characteristics can be found in table 3.4.

3.4.2 Apartment building

The calculations in the follow chapter are made for a 4 storey apartment building with 22 apartments. It has a net heated area of 1796 m^2 and heat loss surface area of 1922 m^2 [KSK$^+$13].. The floor height is assumed to be 3 m, which when multiplied with the net heated area gives a volume of 5388 m^3. More information on the apartment is given in A.It is assumed that there is one ventilation system and no cooling system. Each apartment has one shower and one kitchen sink.

The calculation is done on apartment level. The choice of apartment is more elaborately discussed under 5.3The apartment is calculated with both district heating and gas condensing boiler for the production of domestic hot water and space heating. The generation efficiency of the gas condensing boiler is again estimated at 0,99. It is assumed that a gas condensing boiler with a storage unit of 100l is placed in each apartment.The generation efficiency of district heating is assumed to be 0,97; the default value used in the Belgian Regions. No storage is present in the case of district heating. The auxiliary devices electricity is assumed to be 7 kWh/m^2a for the ventilation fans and 2 kWh/m^2a for the circulation pump of water based heating. Domestic hot water heating is normalized to an energy use of 30 kWh/m^2a, based on the Estonian value for DHW energy need, and degree-day corrected. Again no renewable energy is used for current or nZEB calculations. Although this is not in line with regulations for the different countries, this allows for a simplified calculation and comparison.An overview of these characteristics can be found in table 3.4. An overview of these characteristics can be found in table 3.4.

3.4.3 Office building

The reference building has a net heated area floor area of 2750 m^2 and a heat loss area of 3040 m^2(of which 715 m^2 are windows). The floor height is assumed to be 3 m, which when multiplied with the net heated area gives a volume of 8250 m^3 [KSK$^+$13].. Depending on the country specific regulations, the building may need to be divided into certain volumes for calculations to be done correctly. Therefore a number of spaces and their respective floor area's are defined: offices 1650 m^2, meeting rooms 275 m^2, circulation 715 m^2 and public bathrooms 110 m^2. The floor areas are assumptions based on ratio's of total net heated area for a standard office building, mentioned in French regulation RT 2012. [Cen12].

The office building's DHW and spaces heating is done with either district heating or a gas condensing boiler. The generation efficiency of the gas condensing boiler is again estimated at 0,99. The generation efficiency of district heating is assumed to be 0,97; the default value used in the Belgian Regions. It is assumed that no storage is present in both cases. The auxiliary devices electricity use is assumed to be 11,5 kWh/m^2a for the ventilation fans and 2 kWh/m^2a for the circulation pump of water based heating. Domestic hot water heating is normalized to an energy use of 6 kWh/m^2a,based on the Estonian value for DHW energy need, and degree-day corrected. The net needed energy for cooling in Helsinki is assumed to be 11 kWh/m^2a and the SEER of the cooling system is assumed to be 3,0 (combined distribution, generation and emission efficiency) [AKS15].The value is degree-day corrected.

No renewable energy is used for current or nZEB calculations. Although this is not in line with regulations for the different countries, this allows for a simplified calculation and comparison. An overview of these characteristics can be found in table 3.4.

Table 3.4: Summary of reference building geometry and basic assumptions

Parameters	Detached single family dwelling	Apartment building	Office building
Net heated area (m^2)	171,10	(1)	2750
Heat loss area (m^2)	410	(1)	3040
Normalized energy use for DHW ($\frac{kWh}{m^2a}$)	25	30	6
Net energy need for cooling ($\frac{kWh}{m^2a}$)	-	-	11
Electricity use of ventilation fans ($\frac{kWh}{m^2a}$)	5	7	11,5
Electricity use of circulation pumps ($\frac{kWh}{m^2a}$)	3	2	2
Generator efficiency (-)	gas condensing boiler: 0,99 ground source heat pump: 2,5/3,5	gas condensing boiler: 0,99 district heating: 0,97	gas condensing boiler: 0,99 district heating: 0,97 cooling: 3,0 (3)
Storage for DHW and space heating (l)	200	100 (2)	-

(1) The apartment building has a range of apartments with different net heated area and heat loss area
(2) No storage in the case of district heating
(3) Combined distribution, generation and emission efficiency [AKS15]

4
Methodology

4.1 Introduction

To be able to make a comparison between the selected countries, the existing differences, which are discussed in chapter 3, need to be eliminated. This chapter suggests a calculation method based on delivered energy, thus eliminating the influence of country-specific primary energy factors. The only exception is the calculation of the reference detached house with a ground source heat pump, where net energy need is chosen to compare the results. In this way the different generation efficiencies for DHW and space heating and the losses through distribution, emission and storage (if accounted for in national regulations) are left out of the acquired value. This makes for a better comparison for the ground source heat pump.

This chapter describes calculation methodologies for the reference buildings described in section 3.4: a family house,an apartment building and an office building. In the residential reference buildings ventilation heating is assumed to be equal to 0, since this is not accounted for in Belgian regulations. The office building incorporates both ventilation heating and cooling in the calculation. Each country's specific calculation methods, used standard values and assumptions will be discussed.

4.2 Single family dwelling

4.2.1 Maximum allowed delivered energy for space and domestic hot water heating with a gas condensing boiler

The general methodology for determining delivered energy in such a way that the value is comparable between countries is the same for all countries. The calculation starts from the national maximal primary energy requirement in KWh/m^2a , from which primary energy use for appliances and/or lighting is subtracted 4.1. Note that for countries where these energy flows are not taken into account, the value is simply equal to 0. Secondly, the DHW use is normalized by adding or subtracting the difference between the calculated country-specific DHW use and the chosen normalization value, 25 KWh/m^2a to the maximal primary energy 4.2. Thirdly the primary energy use for space heating is found by subtracting the primary energy use for (normalized) DHW and auxiliary devices from the normalized maximal primary energy use 4.3. Fourthly, a degree day correction of heating energy is done in relation to the degree day value of Finland to make up for the differences in climates between countries. Dividing the obtained value by the relevant primary energy factor gives the corrected energy use for heating (equation 4.4). Finally the delivered energy is determined by adding up the energy uses for heating, DHW and auxiliary devices (equation 4.5).

$$E_{wo\ light} = E - f_e \cdot Q_{Light/Appl} \tag{4.1}$$

$$E_{norm} = E_{wo\ light} + f_p \cdot (Q_{DHW,norm} - Q_{DHW}) \tag{4.2}$$

$$E_{heating} = E_{norm} - f_p \cdot Q_{DHW,norm} - f_e \cdot (Q_{aux,v} + Q_{aux,c}) \tag{4.3}$$

$$E_{heating,dd\ corr} = E_{heating} \cdot \frac{DD_{Fi}}{DD_x} \tag{4.4}$$

$$Q_{heating,dd\ corr} = \frac{E_{heating,dd\ corr}}{f_p}$$

$$Delivered\ energy = Q_{heating} + Q_{DHW,norm} + Q_{aux,v} + Q_{aux,c} \tag{4.5}$$

where

$\frac{DD_{Fi}}{DD_x}$	the ratio of Finland's degree days to the specific country's degree days (-)
$Delivered\ energy$	the maximal allowed delivered energy for space and DHW heating $\frac{kWh}{m^2a}$)
E	the maximal primary energy use according to national requirements, ($\frac{kWh}{m^2a}$)
$E_{heating}$	the primary energy use for heating ($\frac{kWh}{m^2a}$)
$E_{heating,dd\ corr}$	the degree day corrected primary energy use for heating ($\frac{kWh}{m^2a}$)
E_{norm}	the primary energy use with normalized DHW ($\frac{kWh}{m^2a}$)
$E_{wo\ light}$	the maximal primary energy use without lighting and/or appliances ($\frac{kWh}{m^2a}$)
f_e	the primary energy form factor for electricity (-)
f_p	the primary energy form factor for fuel used by generator (-)
$Q_{aux,c}$	the assumed energy use of circulation pumps ($\frac{kWh}{m^2a}$)
$Q_{aux,v}$	the assumed energy use of ventilation fans ($\frac{kWh}{m^2a}$)
$Q_{heating,dd\ corr}$	the degree day corrected energy use for heating ($\frac{kWh}{m^2a}$)
$Q_{Light/Appl}$	the energy use for lighting and/or appliances according to the country's regulations ($\frac{kWh}{m^2a}$)
Q_{DHW}	the energy use for DHW according to the country's regulations ($\frac{kWh}{m^2a}$)
$Q_{DHW,norm}$	the normalized energy use for DHW ($\frac{kWh}{m^2a}$)

The energy use calculation for electricity, appliances and DHW used in equation 4.1 - 4.5 are described in section 4.2.1.1 - 4.2.1.6 according to the national method. The Flemish and Walloon Region's primary energy index' needs to be converted to KWh/m^2a before starting calculations.

4.2.1.1 Flemish Region

Primary energy index

The E index is calculated as the ratio of the characteristic primary energy use of the EPR-volume $E_{char\ ann\ prim\ en\ cons}$ to a reference value $E_{char\ ann\ prim\ en\ cons,ref}$, times 100 (4.6). The characteristic primary energy use of a buiding is calculated with equation 4.7. It is assumed that none of the reference buildings has photovoltaic panels or property-bound cogeneration devices, otherwise the primary energy produced by these needs to be subtracted from the equation. The reference value, $E_{char\ ann\ prim\ en\ cons,ref}$ is determined by equation 4.8. The values of the constants a_1, a_2 and a_3 are stipulated in the Energy Decree of 19-11-2010. [De b]

$$E = 100\frac{E_{char\ ann\ prim\ en\ cons}}{E_{char\ ann\ prim\ en\ cons,ref}} \tag{4.6}$$

$$E_{char\ ann\ prim\ en\ cons} = \frac{1}{3,6 \cdot A_{net}} \sum_{m=1}^{12} (E_{heating,m} + E_{DHW,m} + E_{aux,m} + E_{cooling,m}) \tag{4.7}$$

$$E_{char\ ann\ prim\ en\ cons,ref} = \frac{1}{3,6 \cdot A_{net}} \cdot (a_1 \cdot A_{T,E} + a_2 \cdot max(V_{EPR}; \frac{V_{EPR} + 192}{2}) + a_3 \cdot V_{hyg,ref}) \tag{4.8}$$

where

a_1	115 (-) [De b]
a_2	70 (-) [De b]
a_3	105 (-) [De b]
$A_{T,E}$	the total area of the enveloping surfaces through which heat loss to the outside occurs (m^2)
A_{net}	the net heated area of the building (m^2)
E	the maximal primary energy level (-)
$E_{aux,m}$	the monthly primary energy use for auxiliary devices ($\frac{kWh}{m^2a}$)
$E_{char\ ann\ prim\ en\ cons}$	the characteristic annual primary energy use of the considered EPR-volume ($\frac{kWh}{m^2a}$)
$E_{char\ ann\ prim\ en\ cons,ref}$	the annual primary energy use of a reference building with the same geometrical characteristics and use as the considered EPR- volume ($\frac{kWh}{m^2a}$)
$E_{cooling,m}$	the monthly primary energy use for cooling ($\frac{kWh}{m^2a}$)
$E_{DHW,m}$	the monthly primary energy use for DHW ($\frac{kWh}{m^2a}$)
$E_{heating,m}$	the monthly primary energy use for heating ($\frac{kWh}{m^2a}$)
$V_{hyg,ref}$	$= 1,5(0,2 + 0,5e^{\frac{-V_{EPR}}{500}})V_{EPR}$, the reference hygienic ventilation rate ($\frac{m^3}{h}$)
V_{EPR}	a building or part of a building for which the energy performance will be determined. (m^3)

Energy use for DHW heating

The monthly primary energy use for DHW heating is based upon the final energy uses for any baths, showers or kitchen sinks in the building (equation 4.9). Note that other sinks are not taken into account. The formulas mentioned in the Belgian regulation are formulated in such a way that they can be used for both buildings with multiple devices generating DHW in parallel and buildings with only one generator. Since the reference building only has one generating unit, the simplified version of the calculation is explained in 4.9-4.22. [De 10b]

$$E_{DHW,m} = \frac{1}{3,6 \cdot A_{net}} \sum_i (f_p \cdot Q_{DHW,bath\ i,final\ m} + \sum_i (f_p \cdot Q_{DHW,sink\ i,final\ m}) \tag{4.9}$$

$$Q_{DHW,bath/sink\ i,final\ m} = \frac{f_{DHW,bath/sink\ i,m} \cdot (1 - f_{as,DHW,bath/sink\ i,m}) \cdot Q_{DHW,bath/sink\ i,gross,m}}{\eta_{gen,DHW,bath/sink\ i} \cdot \eta_{stock,DHW,bath/sink\ i}} \tag{4.10}$$

$$Q_{DHW,bath/sink\ i,gross,m} = r_{DHW,bath/sink\ i,gross} \frac{Q_{DHW,bath/sink\ i,net,m}}{\eta_{sys,bath/sink\ i}} \tag{4.11}$$

$$Q_{DHW,bath\ i,net,m} = r_{DHW,bath\ i,net} \cdot f_{bath\ i} \cdot max(64; 64 + 0,220(V_{EPR} - 192)) \cdot t_m \tag{4.12}$$

$$Q_{DHW,sink\ i,net,m} = r_{DHW,sink\ i,net} \cdot f_{sink\ i} \cdot max(16; 16 + 0,055(V_{EPR} - 192)) \cdot t_m \tag{4.13}$$

where

$E_{DHW,m}$	the primary energy use for DHW ($\frac{kWh}{m^2a}$)
$f_{as,DHW,bath/sink\ i,m}$	the fraction of total monthly heat supply delivered by a solar energy system used to prepare the hot water for shower/bath i or sink i (-)
$f_{bath/sinki}$	the fraction of the total net energy need for shower/bath i or sink i (-)
$f_{DHW,bath/sink\ i,m}$	the fraction of total monthly heat supply for water delivered by a certain bath/shower or sink (-)
f_p	the primary energy factor relevant for DHW production (-)
$Q_{DHW,bath/sink\ i,final\ m}$	the monthly amount of final energy the generating device uses to prepare the hot water for shower/bath i or sink i (MJ)
$Q_{DHW,bath/sink\ i,gross,m}$	the monthly gross energy need for heating the water for shower/bath i or sink i (MJ)
$Q_{DHW,bath/sink\ i,net,m}$	the monthly net energy need for for heating the water for shower/bath i or sink i (MJ)
$r_{DHW,bath/sink\ i,gross}$	a reduction related to the effect of preheating of the supply water to the water generator (-)
$r_{DHW,bath/sink\ i,net}$	a reduction related to the effect of preheating of the cold water supply to the shower/bath i or sink i by recovering heat from the used water. It is assumed that no preheating is used (-)
t_m	the length of the specific month (Ms)
$\eta_{gen,DHW,bath/sink\ i}$	the generation efficiency of water for shower/bath i or sink i (-).
$\eta_{stock,DHW,bath/sink\ i}$	the storage efficiency of water for shower/bath i or sink i (-).
$\eta_{sys,bath/sink}$	the average system efficiency for heating the water shower/bath i or sink i (-)

The generation efficiency of a gas condensing boiler can be calculated with equation 4.14. The combined storage and generation efficiency of a ground source heat pump is given as a default value (1,40). The combined storage and generation efficiency default values are replaced by a general assumption mentioned under section 3.4.1 to make calculations comparable. The assumption for generator efficiency (0,99) is found using equation 4.14, assuming that η_{wh}=0,97 [lCC12].

$$\eta_{gen,DHW} = \frac{\eta_{wh}}{100} \cdot f_{stock>gen,DHW} \cdot f_{dim,gen,DHW} \tag{4.14}$$

where

$\eta_{gen,DHW}$	the production performance for water heating . (-)
η_{wh}	the generation efficiency for DHW of the gas condensing boiler. This value can be given by the manufacturer or found as a default value, dependant on boiler efficiency class.(-)
$f_{stock>gen,DHW}$	a correction factor that takes into account the influence of storage on the performance (-)
$f_{dim,gen,DHW}$	a correction factor that takes into account the sizing of the DHW generation system. the default value is 1,0 (-)

If no storage is present, the default values specified under equation 4.15 are used. If there is DHW storage, or it is simply unclear whether the generating efficiency incorporates storage losses, the default values (4.16) are used . The storage efficiency is then determined with equation 4.17, 4.18,4.19 and 4.20.

$$f_{stock>gen,DHW} = 1,0 \text{ and } \eta_{stock,DHW} = 1,0 \quad (4.15)$$

$$f_{stock>gen,DHW} = 1,02 \quad (4.16)$$

$$\eta_{stock,DHW} = \frac{Q_{stock,DHW,gross,m}}{Q_{stock,DHW,gross,m} + Q_{loss,stock,DHW,m}} \quad (4.17)$$

$$Q_{stock,DHW,gross,m} = \sum_{bath\ j} Q_{DHW,bath\ j,gross,m} + \sum_{sink\ k} Q_{DHW,sink\ k,gross,m} \quad (4.18)$$

$$Q_{loss,stock,DHW,m} = S \cdot t_m \quad (4.19)$$

$$S = 31 + 16,66 \cdot V^{0,4} \quad (4.20)$$

where

$Q_{stock,DHW,gross,m}$	the monthly gross energy need of the connected baths/showers and kitchen sinks determined with equation 4.11 (MJ)
$Q_{loss,stock,DHW,m}$	the monthly storage losses of the DHW storage unit.(MJ)
S	the static loss of the DHW storage unit (W)
t_m	the length of the month (Ms)
V	the volume of the DHW storage unit (l)

If the building has no circulation pipe, equations 4.21 and 4.22 are used to find the average system efficiency, $\eta_{sys,bath/sink\ i}$. These equations incorporate the length of the piping for which regulations give 2 options: either use the standard value or make a rough estimation of the actual length using a floor plan of the building. [De 10b]

$$\eta_{sys,bath\ i} = \frac{25}{25 + \frac{l_{tubing,bath\ i}}{r_{DHW,bath\ i\ net}}} \quad (4.21)$$

$$\eta_{sys,sink\ i} = \frac{9,5}{9,5 + \frac{l_{tubing,sink\ i}}{r_{DHW,sink\ i\ net}}} \quad (4.22)$$

where

$r_{DHW,bath/sink\ i,net}$	a reduction related to the effect of preheating of the cold water supply to the shower or bath/sink i by recovering heat from the used water. It is assumed that no preheating is used
$l_{tubing,bath/sinki}$	the length of the tubing to the shower or bath/sink. Standard values are 10 m for baths or showers and 20m for the sink

4.2.1.2 Brussels Capital Region

Energy use for DHW heating

The calculation method is similar to the Flemish method. A first exception is the definition of the primary energy index: no reference value is used. Instead, the CEP-level used by Brussels regulations gives an absolute value for the calculation of the maximal primary energy use. This value can be determined in the same way as the $E_{char\ ann\ prim\ en\ cons}$ in Flemish regulations (equation 4.7).
Another exception is the calculation of generation, storage and system efficiency. A combined generation and storage efficiency for a gas condensing boiler can be calculated starting from the 30% part load efficiency. However, no default values are provided for this. In the case of a ground source heat pump with storage a default value is suggested (1,40). The country-specific combined storage and generation efficiency is replaced by the general assumptions mentioned under section 3.4.1 to make calculations comparable.The generation efficiency is 0,99 (basic assumption) and the storage efficiency is determined with equation 4.17. The default value for the distribution efficiency when there is no circulation pipe present is given below.

$$\eta_{sys,bath\ i} = 0,72$$
$$\eta_{sys,sink\ i} = 0,24$$

4.2.1.3 Walloon Region

Primary energy index

The strictest of the two maximal primary energy requirements is used in the calculation. The first index, E_{spec}, directly gives the maximal primary energy use in $\frac{kWh}{m^2a}$ and can be calculated with equation 4.7.

The latter index, E_w, gives the maximal primary energy use in relation to a reference building with the same geometry as the 'real' building through equation 4.6. The maximal primary energy use of the reference building is determined with equation 4.23-4.28.

$$E_{char\ ann\ prim\ en\ cons,ref} = \frac{1}{3,6}(E_{char\ ann\ prim\ en\ cons,ref,heat} + E_{char\ ann\ prim\ en\ cons,ref,DHW} + E_{char\ ann\ prim\ en\ cons,ref,aux}) \tag{4.23}$$

$$E_{char\ ann\ prim\ en\ cons,ref,heat} = \frac{Q_{heat,net,ann,ref}}{0,728} \tag{4.24}$$

$$Q_{heat,net,ann,ref} = Q_{L,heat,ann,ref} - \frac{4500}{A_{ch}} - 100 \tag{4.25}$$

$$if\ \frac{V_{EPR}}{A_{T,E}} \leq 1 : Q_{L,heat,ann,ref} = \frac{407}{\frac{V_{EPR}}{A_{T,E}}} + 248 \cdot \beta_{hyg,ref}$$

$$if\ 1 < \frac{V_{EPR}}{A_{T,E}} \leq 4 : Q_{L,heat,ann,ref} = \frac{289}{\frac{V_{EPR}}{A_{T,E}}} + 109 + 248 \cdot \beta_{hyg,ref}$$

$$if\ \frac{V_{EPR}}{A_{T,E}} > 4 : Q_{L,heat,ann,ref} = \frac{735}{\frac{V_{EPR}}{A_{T,E}}} + 248 \cdot \beta_{hyg,ref}$$

$$\beta_{hyg,ref} = 1,5\ (0,2 + 0,5 \cdot exp(\frac{-A_{ch}}{167}) \tag{4.26}$$

$$E_{char\ ann\ prim\ en\ cons,ref,DHW} = max(\frac{9793,36}{A_{ch}}; \frac{3324,5}{A_{ch}} + 100,95) \tag{4.27}$$

$$E_{char\ ann\ prim\ en\ cons,ref,aux} = 53 \tag{4.28}$$

where

A_{ch}	the total heated surface area, assumed to be equal to A_{net} (m^2)
$A_{T,E}$	the total area of the enveloping surfaces of the (real) building through which heat loss occurs (m^2)
$E_{char\ ann\ prim\ en\ cons,ref}$	the annual primary energy use of a reference building with the same geometrical characteristics and use as the considered EPR-volume ($\frac{kWh}{m^2a}$)
$E_{char\ ann\ prim\ en\ cons,ref,aux}$	the reference annual primary energy use for auxiliary devices ($\frac{MJ}{m^2a}$)
$E_{char\ ann\ prim\ en\ cons,ref,DHW}$	the reference annual primary energy use for DHW o($\frac{MJ}{m^2a}$)
$E_{char\ ann\ prim\ en\ cons,ref,heat}$	the reference annual primary energy use for heating ($\frac{MJ}{m^2a}$)
$Q_{heat,net,ann,ref}$	the reference annual net energy need for heating($\frac{MJ}{m^2a}$)
$Q_{L,heat,ann,ref}$	the annual net energy needs due to transmission and ventilation heat losses for the reference building($\frac{MJ}{m^2a}$)
V_{EPR}	the volume of the (real) building or part of the building for which the energy performance will be determined. (m^3)
$\beta_{hyg,ref}$	the reference hygienic ventilation rate of the EPR volme (h^{-1})

Energy use for DHW heating
The calculation is the same as the Flemish method described under 4.2.1.1. This also applies to efficiencies and default values.

4.2.1.4 Finland

Electricity use of lighting and appliances
The annual energy use of lighting and devices can be found by calculating the heat gain. This equals the annual energy use by appliances and lighting (4.29). [Min10a]

$$Q_{Light+appl} = kP\frac{\tau_d}{24}\frac{\tau_w}{7}\frac{8760}{1000} \tag{4.29}$$

where

k	a utilisation factor defined for lighting and appliances in the specific building type, given as a default value (-)
P	the thermal load of lighting and appliances, given as a default value ($\frac{W}{m^2}$)
τ_d	the number of hours of use of the building per 24 hours depending on the building use (h)
τ_w	the number of days of use of the building per week depending on the building use ($days$)

Energy use for DHW heating
The net heating energy for domestic hot water is given as a default value: $35\frac{kWh}{m^2a}$ [Min10b]. The losses due to storage, transfer and circulation are taking into account with equation 4.30 and 4.31. The energy use for DHW is found by dividing the resulting value by the generation efficiency (equation 4.32). [Min10h]

$$Q'_{DHW} = \frac{Q_{DHW,net}}{\eta_{DHW}} + Q_{DHW,storage} + Q_{DHW,circulation} \tag{4.30}$$

$$Q_{DHW,circulation} = \frac{W_{DHW,circ}}{1000} L_{DHW} \cdot t_{DHW} \cdot 365 + W_{DHW,heating} \cdot n_{heating,device} \tag{4.31}$$

$$Q_{DHW} = \frac{Q_{heating,DHW}}{\eta_{gen}} \tag{4.32}$$

where

L_{DHW}	the length of the DHW circulation pipe (m)
Q_{DHW}	the energy use for DHW heating ($\frac{kWh}{m^2a}$)
$Q_{DHW,circulation}$	the DHW circulation loss ($\frac{kWh}{m^2a}$)
$Q_{DHW,net}$	the net energy need for DHW ($\frac{kWh}{m^2a}$)
$Q_{DHW,storage}$	the DHW storage loss ($\frac{kWh}{m^2a}$)
t_{DHW}	the running time of DHW circulation pump ($\frac{h}{day}$)
$W_{DHW,circ}$	the specific power of DHW circulation pipe heat loss ($\frac{W}{m}$)
$W_{DHW,heating}$	the specific power of heaters connected to the circulation pipe for DHW (W)
η_{DHW}	the efficiency of the DHW transfer (-)
$n_{heating\ device}$	the number of heaters connected to the circulation pipe for DHW (-)

4.2.1.5 Estonia

Electricity use of lighting and appliances
The annual energy use of lighting and appliances calculation is very similar to the one of Finland, except that to find the electricity use of the appliances their heat gain is divided by 0,7 (4.33) [gov12].

$$Q_{Light+appl} = kP\frac{\tau_d}{24}\frac{tau_w}{7}\frac{8760}{1000} \tag{4.33}$$

where

k	a utilisation factor defined for lighting and appliances in the specific building type, given as a default value (-)
P	the thermal load of lighting and appliances, given as a default value ($\frac{W}{m^2}$)
τ_d	the number of hours of use of the building per 24 hours depending on the building type (h)
τ_w	the number of days of use of the building per week depending on the building type ($days$)

Energy use for DHW heating
The energy need for water heating is given as a default value based on the type of building. No storage, distribution or emission losses are taken into account in Estonian regulations. However, generation efficiency is accounted for with equation 4.34. [ME10]

$$Q_{DHW} = \frac{Q_{DHW,net}}{\eta_{gen}} \tag{4.34}$$

$$Q_{DHW,net} = 25\frac{kWh}{m^2a}$$

4.2.1.6 France

Electricity use of lighting
The hourly electricity use is determined on room level, with equation 4.35. The formula takes into account both the electricity used by the lamps under normal usage and the electricity used by the operation of certain devices when the lights are off (e.g. devices that detect if a threshold value of illuminance is reached). In the calculations each type of room has a certain electrical power, one way of switching on and of the lighting as translated in the C1-coefficient and either has access to natural lighting or not. However, if the depth of the room exceeds a certain value, part of the room is assumed to be naturally lit and part of it is not. The room is then split into two different areas where the lighting control (C2-coefficient) is determined according to access to natural light.

Instead of calculating the value for each room , the whole house is considered by using A_{net} and an average C2 -coefficient. The hourly use is turned into a yearly use by multiplying the value with the number of hours the lighting is used in a year: 2695h. [le 12a] (4.36). RT 2012 defines standard values for most of the coefficients in the case of a residential building. [Cen12]

$$
\begin{aligned}
Q_{lighting,room\ i,h} = \frac{1}{1000} max[(&P_{light,tot\ i} \cdot A_{room\ i} \cdot C1 \cdot I_{light}) \cdot (Ratio_{nat\ light\ i} \cdot C2_{dl,i} \\
&+ (1 - Ratio_{nat\ light\ i}) \cdot C2_{ndl,i}) + P_{light,aux\ i} \cdot A_{room\ i}(1 - I_{light}); \\
&P_{light,aux\ i} \cdot A_{room\ i}] \qquad (4.35)
\end{aligned}
$$

$$
\begin{aligned}
Q_{lighting} = (\frac{1}{1000} max[(&P_{light,tot} A_{net} \cdot C1 \cdot I_{light}) \cdot (Ratio_{nat\ light} \cdot C2) \\
&+ P_{light,aux} \cdot A_{net}(1 - I_{light}); P_{light,aux} \cdot A_{net}] \frac{2695 \frac{h}{year}}{3,6 \cdot A_{net}} \qquad (4.36)
\end{aligned}
$$

where

$C1$	a factor that indicates the way the lighting is turned on and off (-)
$C2$	a factor taking into account the dependence of the lighting control on the level of natural light if the rooms are fully day-lit (-)
$C2_{dl,i}$	a factor taking into account the dependence of the lighting control on the level of natural light of the day-lit part of the room (-)
$C2_{ndl,i}$	a factor taking into account the dependence of the lighting control on the level of natural light of the part of the room which hasn't got access to daylight (-)
I_{light}	a factor that indicates whether the lighting is on at the specific hour. RT 2012 gives hourly standard values for I_{light} , based on default scenario for the use of the specific type of building. 1=on, 0= off (-)
$Ratio_{nat\ light}$	the surface of a (part of) the room that has access to natural light (m^2)
$P_{light,aux}$	the power of auxiliary devices that help in the regulation of the lights. Regardless of the use of the lights this residual power remains present. ($\frac{W}{m^2}$)
$P_{light,tot}$	the total power of the lighting installed in the room ($\frac{W}{m^2}$)
$Q_{lighting,room\ i,h}$	The hourly electricity use of the lighting of a specifc room (kWh)
$Q_{lighting}$	The annual electricity use for lighting per net heated area ($\frac{kWh}{m^2 a}$)

Energy use for DHW heating
The calculation of the DHW energy use is done following the steps suggested in the RT2012 document, using the standard values suggested and making extra assumptions when needed. The first step is calculating the energy need corresponding with the heating, the so-called emission (4.37), the second step is determining the distribution losses (4.37) and the third step the generation losses (4.40). [Cen12]

Emission

Since the reference building is a residential building the water usage is determined by way of the equivalent number of adults $N^{gr,em-e}_{adeq-e}$ and the surface of the house serviced by the heating $A^{gr,em-e}_{home} = A_{net}$. For residential buildings a distinction is made between single family dwellings and multi-apartment buildings. The total hourly DHW need for a singly family home is given by equation 4.37

$$Q_{em,h} = \rho_w c_w V_{uw}(\theta_{uw} - \theta_{cw}) \tag{4.37}$$

$$\begin{aligned} V_{uw} &= V^{gr,em-e}_{uw,weekly}\ ah \\ V^{gr,em-e}_{uw,weekly} &= a^{gr,em-e} Nu^{gr,em-e} \\ a^{gr,em-e} &= min(500; 40\frac{A_{net}}{N^{gr,em-e}_{adeq-q}}) \\ if\ A_{net}\ &\geq\ 70m^2 : \\ &N^{gr,em-e}_{max} = 0,025\ A_{net} \end{aligned} \tag{4.38}$$

$$\begin{aligned} if\ N^{gr,em-e}_{max}\ &\geq\ 1,75 : \\ &Nu^{gr,em-e} = N^{gr,em-e}_{adeq-q} = Nb^{gr,em-e}_{home}\ 1,75 + 0,3 \cdot (Nb^{gr,em-e}_{home} - 1,75) \end{aligned} \tag{4.39}$$

where

$a^{gr,em-e}$	weekly amount of water at temperature θ_{uw} for the DHW emission system (l)
ah	an hourly repartition key of the DHW use. The values can be read of of a daily schedule for homes given in RT 2012.
c_w	the specific heat capacity of water: 1,163 $\frac{Wh}{kgK}$
$N^{gr,em-e}_{adeq-q}$	the number of equivalent adults corresponding to the part of the group served by one DHW emission system. In a single family dwelling the whole building is considered. (-)
$N^{gr,em-e}_{max}$	the maximum number of occupants corresponding to the part of the group served by one DHW emission system. In a single family dwelling the whole building is considered. (-)
$Nb^{gr,em-e}_{home}$	the number of residential units served by the DHW emission system (-)
$Nu^{gr,em-e}$	the number of characteristic units served by the DHW emission. For a the single family dwelling this equals $Nb^{gr,em-e}_{home}$. (-)
$Q_{em,h}$	the total hourly DHW need (Wh)
V_{uw}	the volume of water that is tapped (at temperature θ_{uw}) by the household (l)
$V^{gr,em-e}_{uw,weekly}$	the weekly volume of water that is tapped (at temperature θ_{uw}) by the household, per DHW emission system (l)
ρ_w	the mass density of water: 1 $\frac{kg}{l}$
θ_{cw}	the temperature of the cold water entering the system (°C)
θ_{uw}	the temperature of the mixed water used at the tap: 40 °C

Distribution losses

It is assumed that no pipes of the distribution system are outside of the heated volume of the building, so that equation 4.40 can be used.

$$Q_{distr,h} = \rho_w c_w V_{2nd-e}(\theta_{2nd-e} - \theta_{i,h}) \cdot nb_{bouchons} \cdot Is_{successive,h} \cdot nb_{distr} \tag{4.40}$$

$$\begin{aligned} Is_{successive,h} &= 1\ if\ Q_{distr}(h) = 0\ and\ Q_{distr}(h-1) \neq 0 \\ &= \frac{nb_{bouchons} - 1}{nb_{bouchons}}\ if\ Q_{distr}(h) \neq 0 \text{ and } Q_{distr}(h-1) \neq 0 \\ &= 0 \text{ if no (re)starting} \\ V_{2nd-e} &= (L_{2nd-e}\frac{\pi \cdot D^2_{int,2nd-e}}{4}) \cdot 1000 \\ L_{2nd-e} &= 6 \cdot \frac{A_{net}}{80} \end{aligned}$$

where

$D_{int,2nd-e}$	the internal diameter of the distribution pipes (m)
$Is_{successive,h}$	a factor incorporating the influence of the generator turning off and restarting on the distribution losses. The loss is less if the water does not cool down entirely opposed to not cooling down (-)
L_{2nd-e}	the length of the distribution network that lies wholly within the heated volume (m)
$nb_{bouchons}$	a factor indicating the number of times the cold water is stagnated/stands still per hour (-)
nb_{distr}	a factor that accounts for the number of identical distribution systems (-)
$Q_{distr,h}$	the hourly distribution losses (Wh)
$Q_{distr}(h)$	the distribution losses during the current hour (Wh)
$Q_{distr}(h-1)$	the distribution losses during the previous hour (Wh)
V_{2nd-e}	the volume of the DHW distribution group, part of the heated volume (m^3)
θ_{2nd-e}	the temperature of the water distribution system ($°C$)
$\theta_{i,h}$	the average inside air temperature at time h ($°C$)

Generation losses

The losses related to generation are calculated under full load with equation 4.41. Q_{prov} is assumed to be equal to P_{max} so that $R_{fonct,DHW}$=1 and the calculation can be simplified to equation 4.42.

$$\begin{aligned} Q_{gen,h} &= R_{fonct,DHW}(100 - \frac{\eta_{eff}}{PCSI})\frac{Q_{prov}PCSI}{\eta_{eff}} + id_{DHW}(1 - R_{fonct,DHW})Q_{p0} \\ R_{fonct,DHW} &= \frac{Q_{prov}}{P_{max}} \end{aligned} \tag{4.41}$$

$$Q_{gen,h} = R_{fonct,DHW}(100 - \frac{\eta_{eff}}{PCSI})\frac{Q_{prov}PCSI}{\eta_{eff}} \tag{4.42}$$

where

id_{DHW}	an index related to the type of production: DHW=3 (-)
$PCSI$	the ratio between the higher calorific value and the lower calorific value for the fuel of the generator (-)
$R_{fonct,DHW}$	the functioning time of the generator (h)
$Q_{gen,h}$	the hourly generation losses (Wh)
Q_{p0}	the loss at zero load (W)
Q_{prov}	the power provided by the generator (Wh)
η_{eff}	the efficiency of DHW generation (%)

Storage losses

RT 2012 defines a detailed way to determine the energy needed for DHW storage by using an iterative hourly calculation based on the type and workings of the storage system. However,due to the complexity of the calculations and the number of extra assumptions needed, the default values in table [le 12j] are used. The storage losses defined for a storage unit larger than 75l are given by equation 4.43.

$$Q_{stock,d} = 0,224 + 0,0663V_{tot}^{\frac{2}{3}} \tag{4.43}$$

where

V_{tot}	the total volume of the storage unit (l)
$Q_{stock,d}$	the daily storage losses ($\frac{kWh}{day}$)

Energy consumption of DHW

The total energy consumption of DHW can then be found as the sum of the energy need and the distribution, storage and generation losses (4.54). Before using this equation, all of the values need to be turned into an annual value, by multiplying them with the appropriate time related parameter. This is explained in more detail in the calculation section. The values are also converted to $\frac{kWh}{m^2a}$.

$$Q_{DHW} = \frac{1}{1000 \cdot 3,6}(Q_{em} + Q_{distr} + Q_{stock} + Q_{gen}) \tag{4.44}$$

4.2.2 Maximum allowed net energy need for space and domestic hot water heating with ground source heat pump

The general method for the calculation of the maximum allowed energy need for space and DHW heating with a ground source heat pump is the same for all countries. The first step is determining the energy use for DHW according to each country's regulations. An average coefficient of performance of 2,5 for DHW heating is used.

The second step is to calculate the maximum allowed delivered energy such as described in section 4.2.1 (equations 4.1-4.5) while using an average coefficient of performance of 3,5 for space heating.

The third and last step is to determine, starting from the energy uses for DHW and maximum allowed delivered energy for heating, the net energy need for DHW and space heating. The particulars of this calculation is described in the following section. The maximum net energy need is then found by adding up these two values (equation 4.45). Note that it is assumed that ventilation heating is zero for residential buildings.

$$Net\ energy\ need = Q_{heating,net} + Q_{DHW,net} \tag{4.45}$$

4.2.2.1 Belgian regions

Net needed energy for DHW
The net needed energy for DHW is found as the sum of the net energy needs (4.46) of the showers and kitchen sink, calculated with equation 4.12 and 4.13 as part of the process of determining the primary energy needed for DHW production .

$$Q_{DHW,net} = \sum_i (Q_{DHW,net\ bath\ i} + Q_{DHW,net\ sink\ i}) \tag{4.46}$$

Net needed energy for space heating
The maximum net heating energy need for space and ventilation heating is determined in the same way for the three regions by using equations 4.47 and 4.48. [De 10b]

$$Q_{heating,final} = \frac{f_{heating}(1 - f_{as,heating}) \cdot Q_{heating,gross}}{\eta_{gen,heating}} \tag{4.47}$$

$$Q_{heating,gross} = \frac{Q_{heating,net}}{\eta_{sys,heating}} \tag{4.48}$$
$$\eta_{sys,heating} = \eta_{em,heating} \cdot \eta_{distr,heating} \cdot \eta_{stock,heating}$$

where

$f_{as,heating}$	the fraction of total monthly heat supply for DHW delivered by a solar energy system (-)
$f_{heating,pref}$	the fraction of total monthly heat supply for DHW delivered by the preferential device (-)
$Q_{heating,final}$	the annual amount of final energy the generating device uses for heating ($\frac{kWh}{m^2}$)
$Q_{heating,gross}$	the annual gross energy need for heating ($\frac{kWh}{m^2}$)
$Q_{heating,net}$	the annual net energy need for heating ($\frac{kWh}{m^2}$)
$\eta_{distr,heating}$	the efficiency of DHW distribution (-)
$\eta_{em,heating}$	the efficiency of DHW emission (-)
$\eta_{gen,heating}$	the efficiency of DHW generation. For a heat pump this is the COP factor. (-)
$\eta_{stock,heating}$	the efficiency of DHW storage (-)

4.2.2.2 Finland

Net needed energy for DHW
The net needed energy is given as a tabulated value depending on building type [Min10b]. For a single family dwelling the default value is the following

$$Q_{DHW,net} = 35\frac{kWh}{m^2a}$$

Net needed energy for space heating
The net needed energy for heating of spaces is similarly found by starting from the maximal heating energy and then using equations 4.49, 4.50 and 4.51. It is assumed that the ventilation heating for a residential building is zero, so only the relevant equations for space heating are shown. [Min10h]

$$E_{HP,heating} = \frac{Q_{HP,heating}}{\eta_{heating,gen}} \tag{4.49}$$

$$Q_{HP,heating} = Q_{heating\ sp} - Q_{suppheat,spaces} \tag{4.50}$$

$$Q_{heating} = \frac{Q_{heating,net}}{\eta_{heating}} + Q_{distribution,out} \tag{4.51}$$

where

$E_{HP,heating}$	the electric energy consumption for space heating by a heat pump ($\frac{kWh}{m^2a}$)
$Q_{distribution,out}$	the heat loss in a non-heated room during heat distribution ($\frac{kWh}{m^2a}$)
$Q_{HP,heating}$	the energy consumption for space heating by a heat pump ($\frac{kWh}{m^2a}$)
$Q_{suppheat,heating}$	the supplemental energy needed for the heating of spaces ($\frac{kWh}{m^2a}$)
$\eta_{heating}$	the system efficiency of space heating (-)
$\eta_{heating,gen}$	the efficiency of domestic hot water generation. For a heat pump this is the COP factor (-)

4.2.2.3 Estonia

Net needed energy for DHW
The net needed energy for DHW heating by a heat pump $Q_{HP,heatingDHW}$ is found by 4.52. [gov12]

$$E_{DHW} = \frac{Q_{DHW,net}}{\eta_{DHW,gen}} \tag{4.52}$$

where

$\eta_{DHW,gen}$ the efficiency of domestic hot water generation. For a heat pump this is the COP factor (-)

Net needed energy for space heating
The net needed energy for heating of spaces is determined by using a very similar equation (4.53) [gov12].

$$E_{heating} = \frac{Q_{heating,net}}{\eta_{heating,distr} \cdot \eta_{heating,distr}} \tag{4.53}$$

where

$\eta_{heating,distr}$	the efficiency of the distribution and output of heat.
$\eta_{Dheating,gen}$	the efficiency of generation for space heating. For a heat pump this is the COP factor (-)

4.2.2.4 France

The order of calculation (emission,distribution, generation) is reversed. First generation, then distribution and lastly emission are calculated. The losses belonging to each step are subtracted from the heating or DHW energy use to finally get the net space and DHW heating energies. [Cen12]

Calculation of DHW and heating generation by a ground source heat pump according to RT 2012 are done by first making full load calculations under non nominal circumstances and then part load using results of the first calculation. The COP and the needed energy of the ground source heat pump is determined hourly for each of these steps by using elaborate calculation methods. These are hugely simplified by assuming that a COP of 3,5 for space heating and 2,5 for DHW heating is a reasonable yearly average of the hourly calculated COP's. [Cen12]

Net needed energy for DHW
Q_{DHW} is found by rearranging equation 4.54 and 4.55 into 4.57 . The losses due to emission, distribution and storage of domestic hot water are calculated in the same way as explained in section 4.2.1.6 (equation 4.37, 4.40 and 4.43)

$$Q_{DHW} = \frac{Q'_{DHW}}{\eta_{DHW,gen}} \tag{4.54}$$

$$Q'_{DHW} = Q_{DHW,net} + Q_{DHW,em} + Q_{DHW,distr} + Q_{DHW,stock} \tag{4.55}$$

$$\text{so that } Q_{DHW,net} = E_{DHW} \cdot \eta_{DHW,gen} - Q_{DHW,em} - Q_{DHW,distr} - Q_{DHW,stock} \tag{4.56}$$

where

Q_{DHW}	the annual electricity consumption for DHW heating of a heat pump, including emission, distribution, storage and generation losses ($\frac{kWh}{m^2a}$)
Q'_{DHW}	the annual energy consumption for DHW heating of a heat pump, including emission, distribution and storage losses ($\frac{kWh}{m^2a}$)
$Q_{DHW,net}$	the annual net energy need for DHW heating of a heat pump($\frac{kWh}{m^2a}$)
$Q_{DHW,em}$	the annual loss caused by DHW emission ($\frac{kWh}{m^2a}$)
$Q_{DHW,distr}$	the annual loss caused by DHW distribution. The distribution occurs completely within the heated volume ($\frac{kWh}{m^2a}$)
$Q_{DHW,stock}$	the annual loss caused by DHW storage ($\frac{kWh}{m^2a}$)
$\eta_{DHW,gen}$	the generation efficiency for DHW. For a ground source heat pump this is the average yearly COP (-)

Net needed energy for space heating
The heating energy use without the generation and distribution losses is found by equations 4.57 and 4.58. The distribution loss is found by solving the formula with 'average values' for the parameters, in the same way as was done for the COP, and then multiplying this by the amount of hours of heating.

$$Q'_{heating} = Q_{heating} \cdot \eta_{heating,gen} - Q_{heating,distr} - Q_{heating,stock} \tag{4.57}$$

$$Q_{heating,distr} = \frac{1}{A_{net}}(Mod_{losses} \cdot (h) \cdot U_{mean,hv} \cdot L_{hv} \cdot MAX(0, \theta_{mean}(h) - \theta_{i,mean}(h))) \tag{4.58}$$

where

L_{hv}	the length of the distribution network within the heated volume (m)
$Mod_{losses}(h)$	a coefficient related to the operation of the system. Can either be 0 or 1(-)
$Q_{heating}$	the annual electricity consumption for heating of a heat pump ($\frac{kWh}{m^2a}$)
$Q'_{heating}$	the annual energy consumption for heating by a heat pump without generation and distribution losses ($\frac{kWh}{m^2a}$)
$Q_{heating,distr}$	the annual loss caused by distribution of heated water to the heated spaces. The distribution occurs completely within the heated volume ($\frac{kWh}{m^2a}$)
$Q_{heating,stock}$	the annual loss caused by storage of heated water. It is assumed that this is equal to $Q_{DHW,stock}$ (equation 4.43 ($\frac{kWh}{m^2a}$)
$U_{mean,hv}$	the average losses of the distribution network within the heated volume ($\frac{kW}{mK}$)
$\eta_{heating,gen}$	the generation efficiency for heating. For a ground source heat pump this is the average yearly COP (-)
$\theta_{mean}(h)$	the mean value of return and departure temperatures of the heating system for time step h (° C or K)
$\theta_{i,mean}(h)$	the average indoor air temperature for time step h (° C or K)

Equation 4.59 calculates both heating energy need and the emission losses related per emission device (in this case floor heating) for a time step h. By summing up the heating energy for all the emission devices and using the annual values the formula can be rewritten as 4.60.

$$Q'_{heating}(h) = id^{em}_{em,heating} \frac{Rat^{em}_{eff,heating} MAX(0, \varphi_{util}(h)}{1 - P^{em}_{loss}} \tag{4.59}$$

$$Q'_{heating} = 1 \frac{1 \cdot MAX(0, \varphi_{util}(h)}{1 - P_{loss}}$$

$$Q_{heating,net} = \varphi_{util} = Q'_{heating}(1 - P^{em}_{per}) \ (\frac{kWh}{m^2a}) \tag{4.60}$$

where

$id^{em}_{em,heating}$	a boolean indicating whether there is a heating function (1) or not (0) at the current time step (-)
$Rat^{em}_{eff,heating}$	ratio indicating the contribution of each emission system to the total emission system, dependant on the net heated area served (-)
P^{em}_{per}	the ratio of the emission losses to the emitted heating energy (-)
$Q'_{heating}$	the annual energy consumption for heating of a heat pump without generation and distribution losses ($\frac{kWh}{m^2a}$)
$Q_{heating,net}$	the annual net energy need for heating ($\frac{kWh}{m^2a}$)
$\varphi_{util}(h)$	the average power drawn by the group (kW)

4.3 Apartment building

4.3.1 Maximum allowed delivered energy for space and hot water heating with a gas condensing boiler

4.3.1.1 Flemish Region

The calculation method is the same as mentioned under section 4.2.1.1.

4.3.1.2 Brussels Capital Region

The calculation method is the same as mentioned under section 4.2.1.2.

4.3.1.3 Walloon Region

The calculation method is the same as mentioned under section 4.2.1.3.

4.3.1.4 Finland

The calculation method is the same as described under section 4.2.1.4.

4.3.1.5 Estonia

The calculation method is the same as described under section 4.2.1.5.

4.3.1.6 France

Electricity use of lighting
The calculation method is the same as for a single family dwelling (4.2.1.6)

Energy use for DHW heating
The calculation of the energy use for DHW is done in the same way as for the single family dwelling with a gas condensing boiler (4.2.1.6), except for the emission calculation. Due to the difference in residential building type, the equations are slightly different. The emission is calculated with the group of equations 4.61 [Cen12].

Since the reference building is an apartment building the DHW usage is determined by way of the equivalent number of adults $N^{gr,em-e}_{adeq-e}$ and the surface of an average apartment served by the same DHW emission system $A^{gr,em-e}_{ap} = A_{net}$. Only the equations relevant for the reference building are shown below. [Cen12]

$$Q_{em,h} = \rho_w c_w V_{uw}(\theta_{uw} - \theta_{cw}) \tag{4.61}$$

$$\begin{aligned}
V_{uw} &= V^{gr,em-e}_{uw,weekly}\; ah \\
V^{gr,em-e}_{uw,weekly} &= a^{gr,em-e} Nu^{gr,em-e} \\
N^{gr,em-e}_{max} &= 0,035\; A_{net} \text{ for } A_{net} > 50m^2 \\
Nu^{gr,em-e} &= Nb^{gr,em-e}_{ap} = N^{gr,em-e}_{adeq-e} \\
&= \; 1,75 + 0,3(Nb^{gr,em-e}_{max} - 1,75) \text{ for } N^{gr,em-e}_{max} > 1,75 \\
a^{gr,em-e} &= min(500; 40\frac{A_{gr,em-e}}{N^{gr,em-e}_{adeq-e}})
\end{aligned}$$

where

$a^{gr,em-e}$	the weekly amount of water at temperature θ_{uw} for the DHW emission system (l)
ah	an hourly repartition key of the DHW use. The values can be read of of a daily schedule for apartment buildings given in RT 2012.
c_w	the specific heat capacity of water: 1,163 $\frac{Wh}{kgK}$
$N^{gr,em-e}_{adeq-q}$	the number of equivalent adults corresponding to the part of the group served by one DHW emission system. In the apartment building only one apartment is considered. (-)
$N^{gr,em-e}_{max}$	the maximum number of occupants corresponding to the part of the group served by one DHW emission system. In the apartment building only one apartment is considered. (-)
$Nb^{gr,em-e}_{ap}$	the number of residential units served by the DHW emission system (-)
$Nu^{gr,em-e}$	the number of characteristic units served by the DHW emission. (-)
$Q_{em,h}$	the total hourly DHW need (Wh)
V_{uw}	the volume of water that is tapped (at temperature θ_{uw}) by the household (l)
$V^{gr,em-e}_{uw,weekly}$	the weekly volume of water that is tapped (at temperature θ_{uw}) by the household, per DHW emission system (l)
ρ_w	the mass density of water: 1 $\frac{kg}{l}$
θ_{cw}	the temperature of the cold water entering the system (°C)
θ_{uw}	the temperature of the mixed water used at the tap: 40 °C

4.3.2 Maximum allowed delivered energy for space and domestic hot water heating with district heating

4.3.2.1 Flemish Region

The calculation method is the same as mentioned under section 4.2.1.1. Some default values are provided for district heating in Flemish legislation:

- Efficiency for DHW or space heating generation: 97 %
- Primary energy factor: 2
- Portion of the production coming from renewable energy sources: 0%. This value is defined because district heating with more than 45% part of renewable energy counts as the obligatory part of renewable energy. In this comparison the RES are not taken into account, so this is of less relevance.

The Flemish Region purposely sets unfavorable values as default value to encourage energy efficiency professionals to apply for equivalence and calculate the values through a provided Excel Sheet. However, the equivalence principle is only valid when the calculation is approved by the Flemish Region. [het16b]

4.3.2.2 Brussels Capital Region

The calculation method is the same as mentioned under section 4.2.1.2. The same equivalent values as in the Flemish method are used in practice.

4.3.2.3 Walloon Region

The calculation method is the same as mentioned under section 4.2.1.3. The same equivalent values as in the Flemish method are used in practice.

4.3.2.4 Finland

The calculation method is the same as described under section 4.2.1.4.

4.3.2.5 Estonia

The calculation method is the same as described under section 4.2.1.5.

4.3.2.6 France

The calculation is similar to the method already explained in section 4.3.1.6. Only in the last step , the generation, the calculation differs due to the use of district heating instead of a gas condensing boiler. RT2012 gives a way to calculate the generation losses of a sub-station depending on it's power and the way the substation and the network is conceived. However, a second equation is also mentioned (equation 4.62). Provided that an assumption of the efficiency of the district heating is made, the second equation results in a simpler calculation. Therefore equation 4.62 is used [Cen12].

$$Q_{gen} = \frac{Q_{net,gen}}{\eta_{DH}} \tag{4.62}$$

where

η_{DH}	the efficiency of generation (district heating) (-)
Q_{gen}	the energy consumed by generation ($\frac{W}{m^2}$)
$Q_{gen,net}$	the energy delivered by generation ($\frac{W}{m^2}$)

4.4 Office building

Unlike the other reference buildings, the office building has a cooling system. To incorporate this in the calculation method, the original equation 4.1-4.5 is slightly changed. The residual value after subtracting the electricity use for lighting and/or appliances, normalizing the DHW and subtracting electricity use for auxiliary devices now also incorporates the energy use for cooling. More so, the energy uses of space and ventilation heating and cooling both need to be degree day corrected to neutralize the influence of the different climates of the countries. To not overly complicate the calculation it is assumed that the cooling net energy need for an office building in Helsinki,is 11,0 $\frac{kWh}{m^2a}$ [AKS15] and that the SEER is 3,0 so that the energy use for cooling $Q_{cooling,Fi}$ is 3,7 $\frac{kWh}{m^2a}$. The cooling system is powered by electricity. This value is degree day corrected according to the cooling degree days of each country, multiplied by the primary energy factor of electricity and subtracted from the energy use for heating and cooling. The remaining heating energy use is degree day corrected to the Finnish degree days. Lastly, the maximum allowed delivered energy is found as the sum of the energy uses for cooling, the degree day corrected heating, DHW heating and auxiliary devices.

$$E_{wo\ light} = E - f_e \cdot Q_{Light/Appl} \tag{4.63}$$

$$E_{norm} = E_{wo\ light} + f_p \cdot (Q_{DHW,norm} - Q_{DHW}) \tag{4.64}$$

$$E_{heating+cooling} = E_{norm} - f_p \cdot Q_{DHW,norm} - f_e \cdot (Q_{aux,v} + Q_{aux,c}) \tag{4.65}$$

$$E_{heating} = E_{heating+cooling} - f_e \cdot \frac{DD_{cooling,x}}{DD_{cooling,Fi}} \cdot Q_{cooling,Fi} \tag{4.66}$$

$$E_{heating,dd\ corr} = E_{heating} \cdot \frac{DD_{heating,Fi}}{DD_{heating,x}} \tag{4.67}$$

$$Q_{heating,dd\ corr} = \frac{E_{heating,dd\ corr}}{f_p}$$

$$Delivered\ energy = Q_{cooling,Fi} + Q_{heating} + Q_{DHW,norm} + Q_{aux,v} + Q_{aux,c} \tag{4.68}$$

where

$\frac{DD_{heating,Fi}}{DD_{heating,x}}$	the ratio of Finland's heating degree days to the specific country's degree days (-)
$\frac{DD_{cooling,x}}{DD_{cooling,Fi}}$	the ratio of the specific country's cooling degree days to Finland's degree days (-)
$Delivered\ energy$	the maximal allowed delivered energy for space, ventilation and DHW heating ($\frac{kWh}{m^2a}$)
E	the maximal primary energy use according to national requirements, ($\frac{kWh}{m^2a}$)
$E_{heating}$	the primary energy use for heating ($\frac{kWh}{m^2a}$)
$E_{heating+cooling}$	the primary energy use for both heating and cooling ($\frac{kWh}{m^2a}$)
$E_{heating,dd\ corr}$	the degree day corrected primary energy use for heating ($\frac{kWh}{m^2a}$)
E_{norm}	the primary energy use with normalized DHW ($\frac{kWh}{m^2a}$)
$E_{wo\ light}$	the primary energy use without lighting and/or appliances ($\frac{kWh}{m^2a}$)
f_e	the primary energy form factor for electricity (-)
f_p	the primary energy form factor for fuel used by generator (-)
$Q_{aux,c}$	the assumed energy use of circulation pumps ($\frac{kWh}{m^2a}$)
$Q_{aux,v}$	the assumed energy use of ventilation fans ($\frac{kWh}{m^2a}$)
$Q_{cooling,Fi}$	the energy use for cooling in Finish climate ($\frac{kWh}{m^2a}$)
$Q_{heating,dd\ corr}$	the degree day corrected energy use for heating ($\frac{kWh}{m^2a}$)
$Q_{Light/Appl}$	the energy use for lighting and/or appliances according to the country's regulations ($\frac{kWh}{m^2a}$)
Q_{DHW}	the energy use for DHW according to the country's regulations ($\frac{kWh}{m^2a}$)
$Q_{DHW,norm}$	the normalized energy use for DHW ($\frac{kWh}{m^2a}$)

4.4.1 Maximum allowed delivered energy for space, ventilation and domestic hot water heating and cooling with a gas condensing boiler

4.4.1.1 Flemish Region

Calculation of office building undergoes major changes after 2016. Since the reference building will be calculated for both current and nZEB regulations, both are explained. [De 15b]

Calculation method for 2016

The E index is calculated as the ratio of the characteristic primary energy use of (part of) the building $E_{char\ ann\ prim\ en\ cons}$ to a reference value $E_{char\ ann\ prim\ en\ cons,ref}$, times 100. Therefore $E_{char\ ann\ prim\ en\ cons}$ can be found through (**??**) [De 15b]

$$E = 100\ \frac{E_{char\ ann\ prim\ en\ cons}}{E_{char\ ann\ prim\ en\ cons,ref}}$$

$$E_{char\ ann\ prim\ en\ cons} = E \cdot \frac{E_{char\ ann\ prim\ en\ cons,ref}}{100} labelFLa \tag{4.69}$$

The reference value, $E_{char\ ann\ prim\ en\ cons,ref}$ is determined by equation 4.70 (kWh/m^2a). The values of the constants b_1, b_2, b_3, b_4 and b_5 are stipulated in the Energy Decree of 19-11-2010.

$$E_{char\ ann\ prim\ en\ cons,ref} = \frac{1}{3,6\ A_f}(b_1 \cdot A_f + b_2 \cdot A_{T,E} + b_3 \sum_r V_{hyg,min,mr} + b_4 \sum_r (V_{hyg,mr} - V_{hyg,min,mr}) + b_5 \cdot L^{0,8}_{m,r} \sum_{m=1}^{12} (t_{day,m} + t_{night,m}) \cdot A_{f,mr} \tag{4.70}$$

where

A_f	the total floor surface of the EPU-volume, assumed to be equal to A_{net} (m^2)
$A_{f,rm\ r}$	the surface of specific room r (m^2)
$A_{T,E}$	the total area of the enveloping surfaces through which heat loss occurs (m^2)
b_1	105 (-) [De b]
b_2	175 (-) [De b]
b_3	50 (-) [De b]
b_4	35 (-) [De b]
b_5	0,7 (-) [De b]
$E_{char\ ann\ prim\ en\ cons,ref}$	the maximal primary energy use of the volume (kWh/m^2a)
$L_{rm,r}$	500 (constant) (-) [**?**]
$t_{day,m}$	the amount of hours per month when the lighting is used during the day. (h) =69,76 t_m [De 10d]
$t_{night,m}$	the amount of hours per month when the lighting is used during the night. (h) =4,76 t_m [De 10d]
$V_{hyg,min,rm\ r}$	the design outside air flow rate per room type (m^3/h)
$V_{hyg,min,rm\ r}$	the minimal design outside air flow rate per (none-smoking) room type, dependant on occupation. [Vla14] (m^3/h)
V_{EPR}	a building or part of a building for which the energy performance will be determined. (m^3)

The primary energy use for DHW production is not taken into account for office buildings in the current regulation. The primary energy use of lighting is determined with equation 4.71, 4.72 and 4.73. [De 15b]

$$Q_{p,light\ m} = \frac{1}{A_{net}}(f_p \cdot W_{light\ m}) \tag{4.71}$$

$$W_{light\ m} = \sum_i W_{light,sec\ i,m} \tag{4.72}$$

$$W_{light,sec\ i,m} = \sum_r A_{f,mr} \cdot p_{light,def} \cdot (t_{day,m} + t_{night,m}) \tag{4.73}$$

where

$A_{f,rm\ r}$	the surface of the specific room r (m^2)
$p_{light,def}$	the specific power of the lighting. The regulations suggest a default value of 0,02 $\frac{kW}{m^2}$
$Q_{p,light\ m}$	the monthly energy use for lighting ($\frac{kWh}{m^2 a}$)
$t_{day,m}$	The amount of hours per month lighting is used during the day. (h) = 69,76 t_m (the length of the month in Ms)
$t_{night,m}$	The amount of hours per month lighting is used during the night. (h) 4,76 t_m (the length of the month in Ms)
$W_{light\ m}$	The monthly energy use for lighting (kWh)
$W_{light,sec\ i,m}$	The monthly energy use for the lighting of energysector i. An energysector is a part of a building heated with one emission system and generation device. For the reference building it is assumed there is only one energysector (kWh)

The further calculation is the same as described under section 4.2.1.1.

Calculation method from 2017 on

From 2017 on the concept of functional parts is introduced: the building is divided into areas with the same function such as offices, common areas, circulation, bathrooms etc. and the calculations are made for each of these functions. This division into zones was already present in 2016 regulation to a degree, e.g. the calculation of the minimal design outside air flow rate, but is now used throughout the whole method [De 15c].

The reference value is calculated by making a complete calculation of the reference building similar to the one made for the real building, using suggested standard values and the characteristics of the real building. The calculation also takes the energy use for the production of DHW into account unlike the current regulations. Due to the complexity of the calculations these are not described here nor calculated [De 15c].

4.4.1.2 Brussels Capital Region

The calculation method is the same as described under section 4.4.1.1, except for the calculation of the reference building (the maximal primary energy index CEP is not related to a reference building). [Gou15b]

4.4.1.3 Walloon Region

The calculation method is the same as described under section 4.4.1.1. The reference value $E_{char\ ann\ prim\ en\ cons,ref}$ used in the determination of the primary energy index E_w is calculated according to equation 4.70. . [Gou16].

Calculations according to nZEB regulations also use the method of the fully calculated reference building. Again, this will not be discussed due to the complexity. [Gou13]

4.4.1.4 Finland

The calculation method is the same as described under section 4.2.1.4.

4.4.1.5 Estonia

The calculation method is the same as described under section 4.2.1.5.

4.4.1.6 France

The calculation method is similar to the residential method (described under section 4.2.1.6), drawing on the same basic calculations. The differences are discussed below.

Electricity use of lighting
The first step of calculating the lighting of an office building is dividing it into volumes consisting of certain types of rooms. The following types must be considered: offices, meeting rooms, circulation and public bathrooms. The second step is to calculate equation 4.35 for each room. Unlike for residential buildings, no standard values are given for these rooms, so the values of the different parameters have to be based upon the real design or estimated. As mentioned before, RT2012 does give a default ratio of the surface of each of these rooms to the whole building, so that the area's do not have to be determined in detail. The surface ratio for offices is 0,6; for meeting rooms 0,1; for circulation 0,26 and for public bathrooms 0,04. [le 12c]

Energy use for DHW heating
The water usage in an office building is calculated with equation 4.74.

$$Q_{em,h} = \rho_w c_w \cdot V_{uw} \cdot (\theta_{uw} - \theta_{cw}) \tag{4.74}$$

$$V_{uw} = V_{uw,weekly}^{gr,em-e} \cdot ah$$
$$V_{uw,weekly}^{gr,em-e} = a^{gr,em-e} \cdot Nu^{gr,em-e}$$

where

$a^{gr,em-e}$	the weekly amount of water at temperature θ_{uw} for the DHW emission system (l). For non-residential buildings this value is given as a default value dependant on building type
ah	an hourly repartition key of the DHW use. The values can be read of of a daily schedule for office buildings given in RT 2012.
c_w	the specific heat capacity of water: 1,163 $\frac{Wh}{kgK}$
$Nu^{gr,em-e}$	the number of characteristic units served by the DHW emission. For an office building this equals A_{net}. (-)
$Q_{em,h}$	the total hourly DHW need (Wh)
V_{uw}	the volume of water that is tapped at temperature $\theta_{uw}(l)$
$V_{uw,weekly}^{gr,em-e}$	the weekly volume of water that is tapped (at temperature θ_{uw}), per emission system (l)
ρ_w	the mass density of water: 1 $\frac{kg}{l}$
θ_{cw}	the temperature of the cold water entering the system (°C)
θ_{uw}	the temperature of the mixed water used at the tap: 40 °C

The distribution losses are calculated with equation 4.40. The length of the distribution network, $L_{2nd)e}$ is calculated differently, using formula 4.75. The equation assumes that for the reference building $A^{gr,em-e} = A_{net}$. The suggested default values also differ according to the use (for more detail, see calculations).

$$\begin{aligned} L_{2nd)e} &= 0,05 \cdot A^{gr,em-e} \\ &= 0,05 A_{net} \end{aligned} \tag{4.75}$$

The generation and storage losses are calculated as explained under section 4.2.1.6.

4.4.2 Maximum allowed delivered energy for space, ventilation, domestic hot water heating and cooling with district heating

4.4.2.1 Flemish Region

The calculation method is the same as described under section 4.4.1.1. The equivalent values for district heating (section 4.3.2.1) are used.

4.4.2.2 Brussels Capital Region

The calculation method is the same as described under section 4.4.1.2. The equivalent values for district heating (section 4.3.2.1) are used.

4.4.2.3 Walloon Region

The calculation method is the same as described under section 4.4.1.3. The equivalent values for district heating (section 4.3.2.1) are used.

4.4.2.4 Finland

The calculation method is the same as described under section 4.2.1.4.

4.4.2.5 Estonia

The calculation method is the same as described under section 4.2.1.5.

4.4.2.6 France

The calculation method is the same as described under section 4.4.1.6. The generation losses when using district heating are mentioned in section 4.3.2.6.

5
Results

5.1 Calculation background, assumptions and standard use values

The basic assumptions and geometry of the reference building are discussed in table 3.4. The requirements of each country can be found in 3.2 for residential buildings and in 3.3 for office buildings.

Each calculation method uses a country-specific set of standard use values as the starting point of the calculation. To be able to fully compare the different countries' regulations, these values should be normalized when the calculation is made. This is however beyond the scope of the simplified calculation method used in this thesis and only the energy use by DHW will be normalized. Nevertheless the values are summarized in tables 5.1 to get a full understanding of the calculation.

Country or region	**Room type**	**Lighting** ($\frac{W}{m^2}$)	**Appliances** ($\frac{W}{m^2}$)	**Occupants** ($\frac{W}{m^2}$)	**Operation time of ventilation system** (h)	**Outdoor air flow rate** ($\frac{l}{s \cdot m^2}$)	**Heating setpoint** ($°C$)	**Cooling setpoint** ($°C$)	**DHW-use**	**DHW-use** $\frac{kWh}{m^2 a}$
Belgium	No room types specified	(1)			24h/24h, 7d/7d (2)	1 [het16c]	Not specified	23 [Goua] [De a] [Gouc]	(3)	(3)
Estonia	Single family dwelling Apartment building	8 8 [oeac14c]	2,4 3 [oeac14c]	2 3 [oeac14c]	24h/24h, 7d/7d [oeac14c]	0,42 0,5	21 [gov14]	27 [gov14]	430 $\frac{dm^3}{m^2 a}$ 520 $\frac{dm^3}{m^2 a}$ [gov12]	25 30 [gov12]
Finland	Single family dwelling Apartment building	8 11(4) [Min10a]	3 4	2 (4) 3 (4) [Min10a]	24h/24h, 7d/7d [Min10a]	0,4 0,5 [ME10]	21 [ME10]	27 [ME10]	600 $\frac{dm^3}{m^2 a}$ 685/582 $\frac{dm^3}{m^2 a}$ (5)	35 40/30 (5)
France	Single family dwelling and apartment building	14 [le 12c]	1,14 [le 12c]	5,7 [le 12c]	24h/24h, 7d/7d, except for 2 weeks in august and one in December [le 12c]	(6)	21 [le 12c]	27 [le 12c]	(7)	(7)

(1) Belgian regulations estimate internal heat gains with a standard value depending on building volume [De 10b].
(2) Belgian regions define a factor that indicates the fraction of the time the ventilation system is running. For the residential reference buildings this is 1, so the system is constantly running [De 10a].
(3) Belgian calculation for DHW is done by estimating the DHW use of a specific bath/shower or sink, based on the volume of (part of) the building for which the calculation is made (equation 4.12 and 4.13).
(4)Only includes sensible but not latent heat. To incorporate this the value must be divided by 0,6.
(5) The latter value assumes the measurement of water per flat [Min10b].
(6) The value is dependant upon the specific room types that are part of the residential building [Edi15].
(7)the weekly DHW use at 40 $°C$ is calculated for a number of equivalent adults, see equations 4.37.

Table 5.1: Country specific calculation background for residential buildings

Country or region	Room type	Lighting	Appliances	Occupants	Operation time of ventilation system	Outdoor air flow rate	Heating setpoint	Cooling setpoint	DHW-use	DHW-use $\frac{kWh}{m^2a}$
Belgium	Offices Meeting rooms, reception Main entrance	20 (1)	3	(1)	0,3 (2)	4,1 (3) 1,7 (3) 0,6 (3)	19 [De 15d]	23 [De 15d]	0 (4)	0 (4)
Estonia	No room types specified	12 [oeac14c]	12 [oeac14c]	5 (5) [oeac14c]	7:00h-18:00h, monday to friday [oeac14c]	2 [gov14]	21 [gov14]	25 [gov14]	100 $\frac{dm^3}{m^2a}$ [gov12]	6 [gov12]
Finland	No room types specified	12 [Min10a]	12 [Min10a]	5 (5) [Min10a]	7:30h-18:00h, monday to friday [Min10a]	2 [ME10]	21 [ME10]	25 [ME10]	103 $\frac{dm^3}{m^2a}$ [Min10b]	6 [Min10b]
France	Offices Meeting rooms Circulation/reception Public bathrooms	no value specified	1,6 0 0 0 [le 12c]	16 10 0 0 [le 12c]	8:00h-18:00h, monday to friday [le 12c]	(6)	21 [le 12c]	25 [le 12c]	1,25 $\frac{l}{m^2}$ weekly [Cen12]	2,1

(1) Belgian regulations do not specify absolute values for the heat gain due to occupants. Note that the heat gain for lighting is not used in calculation: a value of 7 $\frac{W}{m^2}$ is used instead [De 15f].

(2) Belgian regulations give the default operation time as a fraction of hours in a year [De 15e].

(3) Values found by multiplying the occupancy rates with an air flow of 22 $\frac{m^3}{h}$ per person (for rooms were smoking is not allowed) [Vla14] [het16c].

(4) Current Belgian regulations doe not include domestic hot water for office buildings. Note that this changes after 2017 for Flemish and Walloon Regions, however this is not calculated further on and thus left outside of the table [De 15a] [Gou15c] [Gou16].

(5) Only includes sensible but not latent heat. To incorporate this the value must be divided by 0,6.

(6) The value is dependant upon the specific room types that are part of the residential building [Edi15].

Table 5.2: Country specific calculation background for office buildings

5.2 Single family dwelling

5.2.1 Maximum allowed delivered energy for space and hot water heating with gas condensing boiler

5.2.1.1 Flemish Region

Primary energy use
The 2016 maximal primary energy use is 150. For nZEB the value is 100. Using equation 4.6 the primary energy index can be rewritten as primary energy consumption in $\frac{kWh}{m^2a}$, unrelated to any reference building. The reference value (4.8) was calculated for

$$A_{T,E} = 410,0\, m^2 \tag{5.1}$$
$$V_{EPR} = 444,9\, m^3 \tag{5.2}$$
$$V_{hyg,ref} = 1,5(0,2 + 0,5e^{\frac{-V_{EPR}}{500}})V_{EPR} = 270,5\frac{m^3}{h} \tag{5.3}$$

resulting in

$$86,6\frac{kWh}{m^2a} \quad (2016)$$
$$52,0\frac{kWh}{m^2a} \quad (nZEB)$$

Energy use for DHW
The monthly energy use by DHW can be found using equations 4.9-4.22. However, a yearly value is required. This is obtained by using a yearly value fort_m; the length of a year in Ms, instead of the length of each month. Thus t_a = 31,54 Ms [De 10d].

The calculations start of separately for each bath/shower or kitchen sink. The reference building has 2 bath/showers and 1 kitchen sink. The first step is to find the net energy need for DHW heating with equations 4.13. The following assumptions are made:

- $r_{DHW,bath/sink\ i,gross}$=1, since there is no pre-heating
- $f_{bath\ i}$= 0,5 and $f_{sink\ i}$= 1
- t_m=t_a = 31,54 Ms

The second step is the calculation of the gross energy for heating for each bath/shower or kitchen sink (equation 4.12. To this end, the system efficiencies also need to be determined with formula's 4.21 and 4.22. The following assumptions are considered:

- $l_{tubing,bath\ i}$ is 10 m and $l_{tubing,sink\ i}$ is 20m, the suggested standard values in Flemish regulation [De 10c]
- $r_{DHW,bath/sink\ i,net}$ =1 as it is assumed no pre-heating of the supply water takes place.

The calculated efficiency values are shown below.

$$\eta_{sys,bath\ i} = 0,71$$
$$\eta_{sys,sink\ i} = 0,32$$

The third step is to find the amount of final energy each bath/shower or kitchen sink require (equation 4.10). The influence of the 200l storage unit is accounted for through the storage efficiency $\eta_{stock,DHW}$. Using equations 4.17-4.20 an efficiency of 0,85 is found. To calculate the final energy the following assumptions are made:

- $f_{DHW,bath/sinki,m}$ =1, since there is only one DHW generator
- $f_{as,DHW,bath/sinki,m}$=0, no solar energy system
- $\eta_{gen,DHW,bath/sink\ i,m}$=0,99 (basic assumption)

The final step is adding up the final energy uses of the different devices (equation4.9) so that the yearly energy use of DHW is found as

$$Q_{DHW} = 15,8\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation-2016
The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5 . The degree day correction factor is 1,52.

$$\begin{aligned}
E_{char\ ann\ prim\ en\ cons,norm} &= 86,6\frac{kWh}{m^2a} + 1,0 \cdot (25,0\frac{kWh}{m^2a} - 15,8\frac{kWh}{m^2a}) \\
&= 95,8\frac{kWh}{m^2a} \\
E_{heating} &= 95,8\frac{kWh}{m^2a} - 1,0 \cdot (25,0\frac{kWh}{m^2a}) - 2,5 \cdot (5,0\frac{kWh}{m^2a} + 3,0\frac{kWh}{m^2a}) \\
&= 50,8\frac{kWh}{m^2a} \\
E_{heating,dd\ corr} &= 50,8\frac{kWh}{m^2a} \cdot 1,52 = 77,5\frac{kWh}{m^2a} \\
Q_{heating,dd\ corr} &= \frac{77,5\frac{kWh}{m^2a}}{1,00} \\
Delivered\ energy &= 77,5\frac{kWh}{m^2a} + 25,0\frac{kWh}{m^2a} + 5,0\frac{kWh}{m^2a} + 3,0\frac{kWh}{m^2a} = 110,5\frac{kWh}{m^2a}
\end{aligned}$$

Maximum allowed delivered energy calculation-nZEB
The delivered energy according to nZEB regulations is calculated entirely in the same way, but starting from the nZEB primary energy index.

$$Delivered\ energy = 57,7\frac{kWh}{m^2a}$$

5.2.1.2 Brussels Capital Region

Primary energy use
The 2016 and nZEB maximal primary energy use is 66,89 $\frac{kWh}{m^2a}$, which is calculated with equation 3.1.

Energy use for DHW
The energy use by DHW is found using the same method and assumptions as mentioned under the previous section. The same generation and storage efficiencies are used as in the Flemish calculation: 0,99 and 0,85. The system efficiencies are default values ([Goub]):

$$\eta_{sys,bath\ i\ m} = 0,72$$
$$\eta_{sys,sink\ i\ m} = 0,24$$
$$\text{so that } Q_{DHW} = 17,6\tfrac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5 .

$$Delivered\ energy = 77,6\frac{kWh}{m^2a}\ \ (2016\ and\ nZEB)$$

5.2.1.3 Walloon Region

Primary energy use
In order to know which of both primary energy indicators has to be used, the primary energy indicators have to be made comparable. Therefore E_w, an index that relates the primary energy use of the building to that of a reference building and is determined with equation 3.1, is transformed into $E_{char\ ann\ prim\ en\ cons}$, the characteristic annual primary energy use. This is done by first multiplying the index with $E_{char\ ann\ prim\ en\ cons,ref}$ and then dividing the result by 100 (equation 4.6). The reference value $E_{char\ ann\ prim\ en\ cons,ref}$ is determined with equations 4.23-4.28 so that

$$E_{char\ ann\ prim\ en\ cons,ref} = 123327,1MJ$$
$$E_{char\ ann\ prim\ en\ cons,2016} = 160,2\frac{kWh}{m^2a}\ > E_{spec} = 130$$
$$E_{char\ ann\ prim\ en\ cons,nZEB} = 90,1\frac{kWh}{m^2a}\ > E_{spec} = 85$$

The maximum specific primary energy consumption E_{spec} is the strictest of both primary energy indicators and will serve as the base for the calculations.

Energy use for DHW
The DHW energy use is calculated the same way as described in Flemish regulations, so the system efficiency are again 0,71 for baths/showers and 0,32 for sinks [De 10c], the storage efficiency is 0,85 and the generation efficiency is 0,99.

$$Q_{DHW} = 15,8\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5 .

$$Delivered\ energy = 176,7\frac{kWh}{m^2a}\ \ (2016)$$
$$Delivered\ energy = 108,1\frac{kWh}{m^2a}\ \ (nZEB)$$

5.2.1.4 Finland

Primary energy use
The 2016 maximal primary energy use is 161,0 $\frac{kWh}{m^2a}$, determined with equation 3.4. For nZEB the value is 109,0 $\frac{kWh}{m^2a}$, determined with equation 4.43.

Electricity use of lighting and appliances
The annual energy use by devices and lighting is determined with equation (4.29), using the values suggested for 'separate small houses' in National Building code D3: $k_{lighting}$=0,1; $k_{devices}$=0,6;$P_{lighting}$ =8,0 $\frac{W}{m^2}$; $P_{devices}$ =3,0 $\frac{W}{m^2}$; τ_d=24 h and τ_w=7 d. [Min10a] The result is shown below

$$Q_{Light+appl} = 22,8\frac{kWh}{m^2a}$$

Energy use for DHW
The net heating energy for domestic hot water is $35\frac{kWh}{m^2a}$. [Min10b]. To obtain storage, transfer and circulation losses equations 4.30 and 4.31 are used. The following assumptions are considered:

- L_{DHW} =0,043A_{net}=7,4 m , 'for a single small house'. [Min10g]
- t_{DHW} =24$\frac{h}{day}$, reasonable assumption based on practice
- $Q_{DHW,storage}$ = 500 kWh, based on a 200 l storage tank [Min10e]
- $W_{DHW,circ}$= 8$\frac{W}{m}$, for a housing pipe with an insulation level of 0,5 times the diameter [Min10f]
- $W_{DHW,heating}$ =200W, default value [Min10f]
- η_{DHW} = 0,89, assuming there is a basic level of insulation [Min10d]
- $n_{heating\ device}$ =1, since there is only one heater

The generation losses are incorporated with equation 4.32 so that the heating energy use by DHW is found as

$$Q_{DHW} = 46,9\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5 .

$$Delivered\ energy = 94,8\frac{kWh}{m^2}\ \ (2016)$$
$$Delivered\ energy = 58,1\frac{kWh}{m^2}\ \ (nZEB)$$

5.2.1.5 Estonia

Primary energy use
The 2016 maximal primary energy use is 160,0 $\frac{kWh}{m^2}$. For nZEB the value is 50,0.

Electricity use of lighting and appliances
The annual energy use of lighting and devices is found with equation (4.33), using the values representing the standard use of 'small residential buildings': $k_{lighting}$=0,1; $k_{devices}$=0,6;$P_{lighting}$ =8,0 $\frac{W}{m^2}$; $P_{devices}$ =2,4 $\frac{W}{m^2}$;τ_d=24 h and τ_w=7 d [oeac14a]. In residential buildings the heat load of devices is divided by 0,7 in order to find their electricity use.

$$Q_{Light+appl} = 25,0\frac{kWh}{m^2a}$$

DHW
The net heating energy for domestic hot water is 25$\frac{kWh}{m^2a}$ [oeac14b], so that incorporating the generation losses with equation 4.34 the energy use for DHW becomes

$$Q_{DHW} = 25,8\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5 .

$$Delivered\ energy = 104,0\frac{kWh}{m^2}\ \ (2016)$$
$$Delivered\ energy = \ -10,6\frac{kWh}{m^2}\ \ (nZEB)$$

5.2.1.6 France

Primary energy use
The 2016 maximal primary energy use is 55,7 $\frac{kWh}{m^2}$, found with equation 3.6. The following values are considered for parameters [ÉD15]:

- $M_{c,type}$ =1, since the building is a detached house
- $M_{c,geo}$ =1,2, since the building is assumed to be situated in Paris, zone H1a
- $M_{c,alt}$ =0, since it is assumed that the altitude is between 0 and 400 m
- $M_{c,ges}$ =0, since a gas condensing boiler is used. The same goes for a ground source heat pump and district heating
- $M_{c,surf}$ =-0,1, since the building is larger then 200 m^2

As mentioned before, the intention for the future is plus energy. However, since the document that formulates these requirements still is being drafted, the nZEB value is also set at 55,7 $\frac{kWh}{m^2}$.

Electricity use of lighting

The hourly electricity use of lighting is determined with equation 4.37. The hourly use, $Q_{lighting,room\imath,h}$ is turned into a yearly use by multiplying the value with the number of hours the lighting is used in a year: 2695 h. [le 12a] This is represented in equation 4.36. The other values, such as C2 are also estimated on a yearly basis. The following values are used in the calculation:

- C1 =0,9, default value for residential buildings [le 12d]

- C2 =1, the value is found on a graph ([le 12f]) by a assuming that the average yearly level of natural light is 100 lux.

- I_{light}= 1, the lighting is on during the 2695 hours calculated from the standard scenario. Also, no $P_{light,aux}$ is present, so no power is used when the lighting is off. So these hours are not taken into account. [le 12d]

- $Ratio_{nat\ light\ i}$=1. It is assumed that since the reference building is a single family home all the rooms have access to natural light.

- $P_{light,aux}$= 0 $\frac{W}{m^2}$, default value for residential buildings [le 12d]

- $P_{light,tot}$= 1,4 $\frac{W}{m^2}$, default value for residential buildings [le 12d]

The annual use of electricity is found to be

$$Q_{lighting} = 3,4\frac{kWh}{m^2y}$$

Energy use by DHW heating

<u>Emission</u>

Again the leap from hourly to yearly calculation is made by using yearly values based on default values (e.g. weekly standards use timetables can be added up to find a yearly value) and making assumptions for certain values.The energy need and emission losses are calculated with equation 4.37.

$$Q_{em} = 12,0\frac{kWh}{m^2a}$$

The following assumptions and default values are used to come to this result:

- ah = 49,05: this is a summation of the hourly/weekly and monthly repartition key tables given in the standard use section of RT2012 [le 12d]

- c_w = 1,163 , $\frac{Wh}{kgK}$ [le 12h]

- ρ_w = 1 $\frac{kg}{l}$ [le 12h]

- θ_{cw} = 11,4°C, an assumption based on a report on the characteristics of the supplied water in Paris [CII+16]

- θ_{uw} = 40 °C [le 12h]

Distribution losses
It is assumed that no pipes of the distribution system are outside of the heated volume of the building so that the distribution losses can be determined with 4.40.

$$Q_{distr} = 0,02 \frac{kWh}{m^2 a}$$

The following assumptions are considered to obtain this result:

- $D_{int,2nd-e}$ =0,022 m, an assumption for the internal diameter of a distribution pipe based on practice

- $nb_{bouchons}$ =3,a default value for a residential building [le 12i]

- nb_{distr} =1, it is assumed that there is only one distribution system (-)

- θ_{2nd-e} =60 °C, assumption made with respect to the danger of legionella

- $\theta_{i,h}$ =19 °C [le 12k]

Generation losses
The losses related to the generation are calculated under full load with equation 4.40 and 4.41.

$$Q_{gen} = 1,4 \frac{kWh}{m^2 a}$$

- id_{DHW} =3, default value for DHW (-)

- $PCSI$ =1,11 for natural gas

- $R_{fonct,DHW}$=1 or Q_{prov}=$P_{max} = 11,96 + 0,0082$

- Q_{p0} = no assumption needed, second part of equation =0 due to the choice of $R_{fonct,DHW}$

Storage losses
The storage losses are determined with equation 4.43 for a 200 l storage unit.

$$Q_{stock} = 5,0 \frac{kWh}{m^2 a}$$

Energy use for DHW
The energy use by DHW heating is found by adding up the previously calculated values.

$$Q_{DHW} = 18,4 \frac{kWh}{m^2 a}$$

Maximum allowed delivered energy calculation

The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5 .

$$Delivered\,energy = 59,5\frac{kWh}{m^2}\ \ (2016\,and\,nZEB)$$

5.2.2 Maximum allowed net energy need for space and hot water heating with a ground source heat pump

5.2.2.1 Flemish Region

Primary energy use
The maximal primary energy index is 150 for 2016 and 100 for nZEB. The following value is found with the calculations described under section 5.2.1.1:

$$86,6\frac{kWh}{m^2a} \quad (2016)$$
$$52,0\frac{kWh}{m^2a} \quad (nZEB)$$

Net needed energy for space heating
First the energy use by DHW needs to be recalculated for a ground source heat pump. This is done in the same way as before using equations 4.9-4.22 but with a generation efficiency $\eta_{gen} = 2,5$ and the primary energy factor of electricity for DHW. The storage efficiency $\eta_{stock} = 0,85$ remains the same. The DHW energy used is normalised to 25 and the primary energy use of the auxiliary devices and normalized DHW energy (electricity) are subtracted from the primary energy values for each country. The primary energy use for heating is degree day corrected and divided by the primary energy factor, electricity (equations 4.1-4.5)

$$Q_{DHW,Fl} = 6,2\frac{kWh}{m^2a}$$

$$Q_{heating,dd\ corr,Fl} = 31,1\frac{kWh}{m^2a} \quad (2016)$$
$$= 10,0\frac{kWh}{m^2a} \quad (nZEB)$$

The maximum net heating energy need is determined with equation 4.47, 4.48 and 4.46.

$$Q_{heating,net} = 80,8\frac{kWh}{m^2a} \quad (2016)$$
$$= 25,9\frac{kWh}{m^2a} \quad (nZEB)$$

The following values were used in the calculation

- $f_{as,heating}$ = 0 as there is no solar energy system.
- $f_{heating,pref}$ =1 as there is only one generator
- $\eta_{distr,heating}$ =1, default value for which it is assumed that the heating system is centralized and is entirely within the insulated volume of the building [De 10f]
- $\eta_{em,heating}$ =0,87, default value for which it is assumed that the heating system is centralized,the temperature can be controlled per room and the temperature setpoint is constant [De 10e]

- $\eta_{gen,heating}$ =3,5 (basic assumption)
- $\eta_{stock,heating}$ =0,85, the storage efficiency for heating is assumed to be equal to the efficiency for DHW storage

Net needed energy for DHW
The net needed energy for DHW is found as the sum of the net energy needs of the showers and kitchen sink. These values are already calculated as part of the process of finding the DHW energy use (equation 4.12 and 4.13) and only need to be summed up.

$$Q_{DHW,net} = 7,7\frac{kWh}{m^2a} \quad (2016\ and\ nZEB) \tag{5.4}$$

Maximum allowed net energy need
The maximum allowed net energy need is determined with equation 4.45.

$$\begin{aligned} Net\ energy\ need &= 88,5\frac{kWh}{m^2a} \quad (2016) \\ Net\ energy\ need &= 33,5\frac{kWh}{m^2a} \quad (nZEB) \end{aligned} \tag{5.5}$$

5.2.2.2 Brussels Capital Region

Primary energy use
The 2016 and nZEB maximal primary energy use is 66,89 $\frac{kWh}{m^2a}$, which is calculated with equation 3.1.

Net needed energy for space heating
The calculation for the net needed energy for space heating is made as described under section 5.2.2.1

$$Q_{heating,net} = 46,6\frac{kWh}{m^2a} \quad (2016\ and\ nZEB)$$

Net needed energy for DHW
The calculation for the net needed energy for space heating is made as described under section 5.2.2.1

$$Q_{DHW,net} = 7,7\frac{kWh}{m^2a} \quad (2016\ and\ nZEB)$$

Maximum allowed net energy need
The maximum allowed net energy need is determined with equation 4.45.

$$Net\ energy\ need = 54,3\frac{kWh}{m^2a} \quad (2016\ and\ nZEB)$$

5.2.2.3 Walloon Region

The maximum specific primary energy consumption E_{spec} is the strictest of both primary energy indicators and will serve as the base for the calculations. For 2016 the maximal primary energy use is thus 130 $\frac{kWh}{m^2a}$ and for nZEB the maximal primary energy use is thus 85 $\frac{kWh}{m^2a}$

Net needed energy for space heating
The calculation for the net needed energy for space heating is made as described under section 5.2.2.1

$$Q_{heating,net} = 149,6\frac{kWh}{m^2a} \quad (2016)$$
$$= 78,3\frac{kWh}{m^2a} \quad (nZEB)$$

Net needed energy for DHW
The calculation for the net needed energy for space heating is made as described under section 5.2.2.1

$$Q_{DHW,net} = 7,7\frac{kWh}{m^2a} \quad (2016\ and\ nZEB)$$

Maximum allowed net energy need
The maximum allowed net energy need is determined with equation 4.45.

$$Net\ energy\ need = 157,2\frac{kWh}{m^2a} \quad (2016)$$
$$Net\ energy\ need = 85,9\frac{kWh}{m^2a} \quad (nZEB)$$

5.2.2.4 Finland

Primary energy use
The 2016 maximal primary energy use is 161,0 $\frac{kWh}{m^2}$, which is determined with equation 3.4. For nZEB the value is 109,0. $\frac{kWh}{m^2}$, which is calculated with equation 3.5.

Net needed energy for DHW
Finnish building code D53 provides a standard value for the net energy for DHW for a single family dwelling [Min10b].

$$Q_{DHW,net} = 35\frac{kWh}{m^2a}$$

Net needed energy for space heating
To obtain the net needed energy for heating of spaces equations 4.49, 4.50 and 4.51.

$$Q_{heating,net} = 54,5\frac{kWh}{m^2a} \quad (2016)$$
$$Q_{heating,net} = 42,4\frac{kWh}{m^2a} \quad (nZEB)$$

The following assumptions are considered:

- $Q_{suppheat,heating}$ =0 since there is no supplemental heating (assumption)
- $Q_{distribution,out}$ =0 since no pipes are located in a non-heated room (assumption)
- $\eta_{heating}$ =0,89, a tabulated default value found by making the assumption that there is a hot-water floor heating system 40/30 °C and that the building butts are against a warm space [Min10c].

Maximum allowed net energy need
The maximum allowed net energy need is determined with equation 4.45

$$Net\ energy\ need = 89,5\frac{kWh}{m^2a}\ \ (2016)$$
$$Net\ energy\ need = 77,4\frac{kWh}{m^2a}\ \ (nZEB)$$

5.2.2.5 Estonia

Primary energy use
The 2016 maximal primary energy use is 160,0 $\frac{kWh}{m^2}$. For nZEB the value is 50,0.

Net needed energy for DHW
The net needed energy for DHW heating by a heat pump is found by 4.52.

$$Q_{DHW,net} = 62,5\frac{kWh}{m^2a}\ \ (2016\ and\ nZEB)$$

Net needed energy for space heating
The net needed energy for heating of spaces is found with equation 4.53. It is assumed that the manner of heating is 'floor heating of slab floors' so that $\eta_{heating\ water}$ = 0,85. [oeac14c]

$$Q_{heating,net} = 68,1\frac{kWh}{m^2a}\ \ (2016)$$
$$Q_{heating,net} = \ -102,4\frac{kWh}{m^2a}\ \ (nZEB)$$

Maximum allowed net energy need
The maximum allowed net energy need is determined with equation 4.45

$$Net\ energy\ need = 130,6\frac{kWh}{m^2a}\ \ (2016)$$
$$Net\ energy\ need = \ -39,9\frac{kWh}{m^2a}\ \ (nZEB)$$

5.2.2.6 France

Primary energy use
The 2016 maximal primary energy use is 55,7 $\frac{kWh}{m^2}$.he 2016 maximal primary energy use is 55,7 $\frac{kWh}{m^2}$, found with equation 3.6. As mentioned before, the intention for the future is plus energy. However, since the document that formulates these requirements still is being drafted, the nZEB value is also set at 55,7 $\frac{kWh}{m^2}$. The assumptions are described in detail in section 5.4.1.6.

Net needed energy for DHW
First the energy need of DHW heating by a ground source heat pump is determined with equations 4.35-4.54.A COP of 2,5 for DHW generation is used (basic assumption).

$$Q_{DHW,gen} = 17,3\frac{kWh}{m^2a}$$

Secondly the net needed energy for DHW is obtained by first multiplying the value by the COP for DHW heating and then subtracting emission, distribution and storage losses (equation 4.57) . The losses due to emission and distribution of domestic hot DHW are calculated in section 5.2.1.6.

$$Q_{DHW,net} = 11,9\frac{kWh}{m^2a}$$

Net needed energy for space heating
First the energy use for space heating is determined with equations 4.1 - 4.5. The value is negative, which is related to the large primary energy form factor of electricity in French regulations.

$$Q_{heating} = -9,7\frac{kWh}{m^2a}$$

Secondly the net needed energy for heating is obtained by first multiplying the value by the COP for space heating (3,5) and then subtracting distribution and storage losses (equation 4.57). The distribution loss is normally calculated with equations 4.58, however due to the difficulty of estimating the different parameters (for example the length of the piping), the Finnish distribution efficiency for floor heating $\eta_{distr} = 0,89$ is used [Min10c]. So after multiplying the net needed energy with the COP, the storage losses are subtracted and the resultant value is multiplied by $\eta_{distr} = 0,89$.
The storage loss is calculated with equation 4.43 and multiplied by the amount of hours of heating in a year. The assumption is made that the heating season lasts 20 weeks. Lastly the net energy need is found with equation 4.60.

$$Q_{heating,net} = -40,0\frac{kWh}{m^2a} \tag{5.6}$$

The following assumptions are considered to obtain this value

- $id^{em}_{em,heating}$ =1, there is a heating function during the hours for which the calculation is made
- $Rat^{em}_{eff,heating}$ = 1, the reference building has only one emission system
- P^{em}_{per} = 0, the losses can assumed to be negligible according to RT 2012 when no emission systems are positioned in outdoor walls or floors to unheated spaces.

Maximum allowed net energy need
The maximum allowed net energy need is determined with equation 4.45

$$Net\ energy\ need = -27,8\frac{kWh}{m^2a}\ \ (2016\ and\ nZEB)$$

5.3 Apartment building

The reference building consists of a total of 22 apartments which can be divided into 11 apartment types (Reference apartment building plan, Annexe 1). Since Belgian regulations for residential buildings incorporate this geometry in the determination of the maximal primary energy index, a variety of maximal primary energy uses is found. More specifically Belgian regulations use the following geometrical characteristics: the Flemish Region uses the net heated area, heat loss area and volume to obtain the reference value for the E-index, the Brussels Capital Region incorporates the compactness (volume over heat loss area) directly in the determination of the CEP-index and the Walloon Region uses both net heated area and compactness in the reference value calculation for E_w.

To give an idea of the exact differences, the geometries are summarized for the 9 distinct apartment types in A.1 in Annex A. For the calculation in the next section a fictional apartment is used, with as primary energy for each of the Belgian Regions the weighted average of the possible primary energy index' of the apartment for that region. The net heated floor area is 66,5 m^2 and the heat loss area is 57,3 m^2. A more detailed description of the influence of apartment geometry can be found in section 6.3.1.

5.3.1 Maximum allowed delivered energy for space and hot water heating with a gas condensing boiler

5.3.1.1 Flemish Region

Primary energy use
The weighted averages of the Flemish primary energy index' are the following values

$$84,7\frac{kWh}{m^2a} \quad (2016)$$
$$50,8\frac{kWh}{m^2a} \quad (nZEB)$$

Energy use for DHW
The energy use by DHW can be found with equations 4.9, using the same method and mostly the same assumptions as for the single family dwelling described under section 5.2.1.1. A few parameters are different. Since the reference apartment building only has one shower/bath and one kitchen sink, $f_{bath\ i}$= 1 and $f_{sink\ i}$= 1 is used in the calculation of the monthly energy use by DHW (equations 4.9-4.22)

The influence of the 100 l storage unit is accounted for through the storage efficiency $\eta_{stock,DHW}$. Using equations 4.17-4.20 an efficiency of 0,78 is found. The generation efficiency is 0,99 (basic assumption).

The energy use for the generation of DHW is:

$$Q_{DHW} = 24,5\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation-2016
The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5 . The degree day correction factor is 1,52.

$$
\begin{aligned}
E_{char\ ann\ prim\ en\ cons,norm} &= 84,7\frac{kWh}{m^2a} + 1,0 \cdot (30,0\frac{kWh}{m^2a} - 24,5\frac{kWh}{m^2a}) \\
&= 90,2\frac{kWh}{m^2a} \\
E_{heating} &= 90,2\frac{kWh}{m^2a} - 1,0 \cdot (30,0\frac{kWh}{m^2a}) - 2,5 \cdot (7,0\frac{kWh}{m^2a} + 2,0\frac{kWh}{m^2a}) \\
&= 37,7\frac{kWh}{m^2a} \\
E_{heating,dd\ corr} &= 37,7\frac{kWh}{m^2a} \cdot 1,52 = 57,4\frac{kWh}{m^2a} \\
Q_{heating,dd\ corr} &= \frac{57,4\frac{kWh}{m^2a}}{1,00} \\
Delivered\,energy &= 57,4\frac{kWh}{m^2a} + 30,0\frac{kWh}{m^2a} + 7,0\frac{kWh}{m^2a} + 2,0\frac{kWh}{m^2a} = 96,4\frac{kWh}{m^2a}
\end{aligned}
$$

Maximum allowed delivered energy calculation-nZEB
The delivered energy according to nZEB regulations is calculated entirely in the same way, but starting from the nZEB primary energy index.

$$Delivered\,energy = 44,7\frac{kWh}{m^2a}$$

5.3.1.2 Brussels Capital Region

Primary energy use
The weighted average of the Brussels primary energy index is 55,8 $\frac{kWh}{m^2}$ (2016 and nZEB).

Energy use for DHW
The energy use by DHW can be found with equations 4.9, using the same method and mostly the same assumptions as for the single family dwelling described in section 5.2.1.2. Note that the system efficiencies for the Brussels Capital Region are default values that differ from the Flemish ones. This is also described in section 5.2.1.2. The energy use for the generation of DHW is:

$$Q_{DHW} = 27,4\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5.

$$Delivered\,energy = 48,0\frac{kWh}{m^2a} \quad (2016\ and\, nZEB)$$

5.3.1.3 Walloon Region

Primary energy use
The weighted averages of the Walloon primary energy index' are the following values

$$119,4\frac{kWh}{m^2a} \ \ (2016)$$
$$73,4\frac{kWh}{m^2a} \ \ (nZEB)$$

Energy use for DHW
The DHW energy use is calculated with the same method and assumptions as described in Flemish regulations (section 5.2.1.3.).

$$Q_{DHW} = 24,5\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5.

$$Delivered\ energy = 149,4\frac{kWh}{m^2a} \ \ (2016)$$
$$Delivered\ energy = 79,2\frac{kWh}{m^2a} \ \ (nZEB)$$

5.3.1.4 Finland

Primary energy use
The 2016 maximal primary energy use is 130. For nZEB the value is 82, since the building has 4 storeys.

Electricity use for appliances
For an apartment building$k_{lighting}$=0,1, $k_{devices}$=0,6, $P_{lighting} = 11,0\frac{W}{m^2}$ and $P_{devices}$ = 4,0 , τ_d=24 h and τ_w=7 d$\frac{W}{m^2}$ [Min10a] , so that by using equation 4.29 the household electricity and lighting is found.

$$Q_{Ligh/appl} = 30,7\frac{kWh}{m^2a}$$

Energy use for DHW
The net energy need of a residential housing block, given that the measurement of water is done per flat is 34 $\frac{kWh}{m^2a}$. [Min10b] Incorporating the circulation, storage, transfer and generation losses with equation 4.30, 4.31 and 4.32 the value becomes:

$$Q_{DHW} = 49,1\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5 .

$$Delivered\ energy = 52,4\frac{kWh}{m^2a} \ \ (2016)$$
$$Delivered\ energy = 24,3\frac{kWh}{m^2a} \ \ (nZEB)$$

5.3.1.5 Estonia

Primary energy use
The 2016 maximal primary energy use is 150. For nZEB the value is 100.

Electricity use for appliances
For an apartment building $P_l = 8,0\frac{W}{m^2}$ and $P_d = 3,0\frac{W}{m^2}$, so that by using equation 4.29 the household electricity and lighting is found.

$$Q_{Ligh/appl} = 29,5\frac{kWh}{m^2a}$$

Energy use for DHW
The energy use of DHW of a multi-apartment building is

$$Q_{DHW} = 30,3\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5 .

$$Delivered\, energy = 83,4\frac{kWh}{m^2a} \quad (2016)$$
$$Delivered\, energy = 31,3\frac{kWh}{m^2a} \quad (nZEB)$$

5.3.1.6 France

Primary energy use
The 2016 maximal primary energy use is 60. The following values are considered for the parameters [ÉD15]:

- $M_{c,type}$ =1, since the building is an apartment building
- $M_{c,geo}$ =1,2, since the building is assumed to be situated in Paris, zone H1a
- $M_{c,alt}$ =0, since it is assumed that the altitude is between 0 and 400 m
- $M_{c,ges}$ =0, since a gas condensing boiler is used. The same goes for a ground source heat pump and district heating
- $M_{c,surf}$ =0, calculated for an average apartment determined according to RT2012 so that the surface is between 80 and 100

Electricity use for appliances

The hourly electricity use of lighting is determined with equation 4.35. The same assumptions are considered as as described in section 5.2.1.6.

$$Q_{Ligh/appl} = 3,1 \frac{kWh}{m^2 a}$$

Energy use for DHW

The energy use of DHW of a the volume is calculated in three steps, emission, distribution and generation losses. The same assumptions are considered as as described in section 5.2.1.6.

$$Q_{DHW} = 35,0 \frac{kWh}{m^2 a}$$

Maximum allowed delivered energy calculation

The maximum allowed delivered energy for space and hot water heating with a gas condensing boiler is calculated using equations 4.1 - 4.5 .

$$Delivered\ energy = 40,9 \frac{kWh}{m^2 a} \quad (2016 and nZEB)$$

.

5.3.2 Maximum allowed delivered energy for space and hot water heating with district heating

5.3.2.1 Flemish Region

Primary energy use
The weighted averages of the Flemish primary energy index' are the following values

$$84,7\frac{kWh}{m^2a} \ \ (2016)$$
$$50,8\frac{kWh}{m^2a} \ \ (nZEB)$$

Energy use for DHW
The energy use by DHW can be found using equations 4.9-4.22. No storage unit is present, so only the generation efficiency has to be taken into account:
$\eta_{gen,DHW,bath/sink\ i}$=0,97 (basic assumption) when calculating the final energy (equation 4.10). The other assumptions are the same as for the apartment building with a gas condensing boiler (section 5.3.1.1)

Finally, by 4.9, the yearly energy use of DHW is found as

$$Q_{DHW} = 19,4\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation-2016
The maximum allowed delivered energy for space and hot water heating heating with district heating is calculated using equations 4.1 - 4.5. The form factor is found in section 4.3.2.1.

$$\begin{aligned}
E_{char\ ann\ prim\ en\ cons,norm} &= 84,7\frac{kWh}{m^2a} + 2,0\cdot(30,0\frac{kWh}{m^2a} - 19,4\frac{kWh}{m^2a}) \\
&= 105,3\frac{kWh}{m^2a} \\
E_{heating} &= 105,3\frac{kWh}{m^2a} - 2,0\cdot(30,0\frac{kWh}{m^2a}) - 2,5\cdot(7,0\frac{kWh}{m^2a} + 2,0\frac{kWh}{m^2a}) \\
&= 23,4\frac{kWh}{m^2a} \\
E_{heating,dd\ corr} &= 23,4\frac{kWh}{m^2a}\cdot 1,52 = 35,6\frac{kWh}{m^2a} \\
Q_{heating,dd\ corr} &= \frac{35,6\frac{kWh}{m^2a}}{2,00} \\
Delivered\ energy &= 17,8\frac{kWh}{m^2a} + 30,0\frac{kWh}{m^2a} + 7,0\frac{kWh}{m^2a} + 2,0\frac{kWh}{m^2a} = 56,8\frac{kWh}{m^2a}
\end{aligned}$$

Maximum allowed delivered energy calculation-nZEB
The maximum allowed delivered energy for space and hot water heating with district heating according to nZEB regulations is

$$Delivered\ energy = 31,0\frac{kWh}{m^2a} \ \ (nZEB)$$

5.3.2.2 Brussels Capital Region

Primary energy use
The weighted average of the Brussels primary energy index is 55,8 $\frac{kWh}{m^2a}$.

Energy use for DHW
The energy use by DHW can be found using equations 4.9, using the same method and mostly the same assumptions as for the single family dwelling described in section 5.2.1.2. No storage unit is present, so only the generation efficiency has to be taken into account:
$\eta_{gen,DHW,bath/sink\ i}$=0,97 (basic assumption) The energy use for the generation of DHW is:

$$Q_{DHW} = 21,7\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with district heating is calculated using equations 4.1 - 4.5 .

$$Delivered\ energy = 31,3\frac{kWh}{m^2a}\ \ (2016\ and\ nZEB)$$

5.3.2.3 Walloon Region

Primary energy use
The weighted averages of the Walloon primary energy index' are the following values

$$119,4\frac{kWh}{m^2a}\ \ (2016)$$
$$73,4\frac{kWh}{m^2a}\ \ (nZEB)$$

Energy use for DHW
The DHW energy use is calculated with the same method and assumptions as described in Flemish regulations (section 5.2.1.1), but without storage unit. The generation efficiency is 0,97.

$$Q_{DHW} = 19,4\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with district heating is calculated using equations 4.1 - 4.5 .

$$Delivered\ energy = 85,6\frac{kWh}{m^2a}\ \ (2016)$$
$$Delivered\ energy = 50,5\frac{kWh}{m^2a}\ \ (nZEB)$$

5.3.2.4 Finland

Primary energy use
The 2016 maximal primary energy use is 130. For nZEB the value is 82, since the building has 4 storeys.

Electricity use for lighting and appliances
The electricity use for lighting and appliances is the same as calculated in section 5.3.1.4

$$Q_{Ligh/appl} = 30,7\frac{kWh}{m^2a}$$

Energy use for DHW
The net energy need of a residential housing block, given that the measurement of water is done per flat is 34 $\frac{kWh}{m^2a}$. [Min10b] Incorporating the circulation, transfer, generation losses but no storage losses with equation 4.30, 4.31 and 4.32 the value becomes:

$$Q_{DHW} = 42,0\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with district heating is calculated using equations 4.1 - 4.5 .

$$Delivered\ energy = 86,3\frac{kWh}{m^2a} \quad (2016)$$
$$Delivered\ energy = 65,8\frac{kWh}{m^2a} \quad (nZEB)$$

5.3.2.5 Estonia

Primary energy use
The 2016 maximal primary energy use is 150. For nZEB the value is 100.

Electricity use for lighting and appliances
The electricity use for lighting and appliances is the same as calculated in section 5.3.1.5

$$Q_{Ligh/appl} = 29,5\frac{kWh}{m^2a}$$

Energy use for DHW
The net energy need of DHW of a multi-apartment building is a default value, and Estonian regulations do not incorporate storage losses [oeac14b]. So the absence of a storage unit has no influence on the energy use by DHW. Generation efficiency (0,97) however does have an influence, so that

$$Q_{DHW} = 30,9\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating heating with district heating is calculated using equations 4.1 - 4.5 .

$$Delivered\ energy = 100,3\frac{kWh}{m^2a} \quad (2016)$$
$$Delivered\ energy = 36,7\frac{kWh}{m^2a} \quad (nZEB)$$

5.3.2.6 France

Primary energy use
The 2016 maximal primary energy use is 60. In section 5.3.2.6 more explanation is given on how this value is found.

Electricity use for appliances
The hourly electricity use of lighting is determined with equation 4.35. The same assumptions are considered as described in section 5.2.1.6.

$$Q_{Ligh/appl} = 3,4\frac{kWh}{m^2a}$$

Energy use for DHW
The energy use of DHW of the volume is calculated in three steps, emission, distribution and generation losses. The same assumptions are considered in each of these three steps as is described in section 5.2.1.6 The generation losses when using district heating are obtained with equation 4.62 for η_{DH}=0,97 and $Q_{net,gen} = Q_{em} + Q_{distr}$.

$$Q_{DHW} = 24,9\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space and hot water heating with district heating is calculated using equations 4.1 - 4.5 .

$$Delivered\, energy = 59,7\frac{kWh}{m^2a} \quad (2016\; and\; nZEB)$$

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5.4 Office building

5.4.1 Maximum allowed delivered energy for space, ventilation heating, hot water heating and cooling with a gas condensing boiler

5.4.1.1 Flemish Region

Primary energy use
By using equation 4.6 and 4.8 the maximal primary energy use is found. The minimal design outside air flow rate is calculated by dividing the building into different zones based on occupation rate (offices, meeting rooms,bathrooms and circulation), calculating the standard occupation by multiplying the occupation rate with the area of the zones and again multiplying this with the minimal flow rate per person of 22 $\frac{m^3}{h}$ per person [Vla14]. The summation of the different zones gives $V_{hyg,min,rmr\ r}$. It is assumed that $V_{hyg,rmr\ r}$=$V_{hyg,min,rmr\ r}$

$$96,0\frac{kWh}{m^2a} \quad (2016)$$

Electricity use for lighting
The energy use by DHW is not included in the office building calculations, the lighting however needs to be calculated (equation 4.71, 4.72 and 4.73). The suggested default value of 20 $\frac{W}{m^2}$ for lighting results in a very large and overall unrealistic electricity use for lighting, so 7 $\frac{W}{m^2}$ is used instead for the Belgian Regions (assumption based on practice).

$$Q_{DHW} = 0,0\frac{kWh}{m^2a}$$
$$Q_{lighting} = 16,4\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space, ventilation heating, hot water heating and cooling with a gas condensing boiler is calculated using equations 4.63 - 4.68

$$\begin{aligned}
E_{char\ ann\ prim\ en\ cons,wolight} &= 96,0\frac{kWh}{m^2a} - 2,5 \cdot 16,4\frac{kWh}{m^2a})\\
&= 54,9\frac{kWh}{m^2a}\\
E_{char\ ann\ prim\ en\ cons,norm} &= 54,9\frac{kWh}{m^2a} + 1,0 \cdot (6,0\frac{kWh}{m^2a} - 16,4\frac{kWh}{m^2a})\\
&= 60,9\frac{kWh}{m^2a}\\
E_{heating+cooling} &= 60,9\frac{kWh}{m^2a} - 1,0 \cdot (6,0\frac{kWh}{m^2a}) - 2,5 \cdot (11,5\frac{kWh}{m^2a} + 2,0\frac{kWh}{m^2a})\\
&= 21,1\frac{kWh}{m^2a}\\
E_{heating} &= 21,1\frac{kWh}{m^2a} - 2,5 \cdot 3,6\frac{kWh}{m^2a} \cdot 2,3\\
&= 0,3\frac{kWh}{m^2a}
\end{aligned}$$

$$E_{heating,dd\ corr} = 0,3\frac{kWh}{m^2a} \cdot 1,5 = 0,5\frac{kWh}{m^2a}$$
$$Q_{heating,dd\ corr} = \frac{0,5\frac{kWh}{m^2a}}{1,00}$$
$$Delivered\ energy = 0,5\frac{kWh}{m^2a} + 3,7\frac{kWh}{m^2a} + 6,0\frac{kWh}{m^2a} + 11,5\frac{kWh}{m^2a} + 2,0\frac{kWh}{m^2a} = 23,7\frac{kWh}{m^2a} \quad (2016)$$

5.4.1.2 Brussels Capital Region

Primary energy use
It is assumed that the net needed energy for heating is 15 $\frac{kWh}{m^2a}$ so that maximal primary energy index CEP equals 88,2$\frac{kWh}{m^2a}$.

Electricity use for lighting
The same value as for the Flemish calculation is obtained:

$$Q_{lighting} = 16,4\frac{kWh}{m^2a}$$

The maximum allowed delivered energy for space, ventilation heating, hot water heating and cooling with a gas condensing boiler is calculated using equations 4.63 - 4.68

$$Delivered\ energy = 112,1\frac{kWh}{m^2a} \quad (2016)$$

5.4.1.3 Walloon Region

Primary energy use
The 2016 maximal primary energy use is 80 $\frac{kWh}{m^2a}$

Electricity use for lighting
The same value as for the Flemish calculation is obtained:

$$Q_{lighting} = 16,4\frac{kWh}{m^2a}$$

The maximum allowed delivered energy for space, ventilation heating, hot water heating and cooling with a gas condensing boiler is calculated using equations 4.63 - 4.68

$$Delivered\ energy = 90,3\frac{kWh}{m^2a} \quad (2016)$$

5.4.1.4 Finland

Primary energy use
The 2016 maximal primary energy use is 190 $\frac{kWh}{m^2a}$. For nZEB the value is 6 $\frac{kWh}{m^2a}$.

Electricity use for lighting and appliances
For an office building $P_l = 12,0\frac{W}{m^2}$, $P_d = 12,0\frac{W}{m^2}$, k_l = 0,65, t_d =11 ans t_w =5 so that by using equation 4.29 the household electricity and lighting is found.

$$Q_{Ligh/appl} = 44,7\frac{kWh}{m^2a}$$

Energy use for DHW
The net energy need of an office building is 6 $\frac{kWh}{m^2a}$. Incorporating the circulation, distribution and generation losses with equation 4.30, 4.31 and 4.32 the value becomes:

$$Q_{DHW} = 8,1\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space, ventilation heating, hot water heating and cooling with a gas condensing boiler is calculated using equations 4.63 - 4.68

$$Delivered\,energy = 99,8\frac{kWh}{m^2a}\ \ (2016)$$
$$Delivered\,energy = 4,8\frac{kWh}{m^2a}\ \ (nZEB)$$

5.4.1.5 Estonia

Primary energy use
The 2016 maximal primary energy use is 160 $\frac{kWh}{m^2a}$. For nZEB the value is 100 $\frac{kWh}{m^2a}$.

Electricity use for lighting and appliances
For an apartment building $P_l = 12,0\frac{W}{m^2}$, $P_d = 12,0\frac{W}{m^2}$, k_l = 0,55, t_d =11 ans t_w =5 so that by using equation 4.29 the household electricity and lighting is found.

$$Q_{Ligh/appl} = 37,9\frac{kWh}{m^2a}$$

Energy use for DHW
The energy use of DHW of a multi-apartment building is

$$Q_{DHW} = 6,1\frac{kWh}{m^2a}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space, ventilation heating, hot water heating and cooling with a gas condensing boiler is calculated using equations 4.63 - 4.68

$$Delivered\,energy = 68,5\frac{kWh}{m^2a}\ \ (2016)$$
$$Delivered\,energy = 6,0\frac{kWh}{m^2a}\ \ (nZEB)$$

5.4.1.6 France

Primary energy use
The 2016 maximal primary energy use is 110,0 $\frac{kWh}{m^2}$.The following values are considered for the parameters [ÉD15]:

- $M_{c,type}$ =2,2, since the building is an office building

- $M_{c,geo}$ =1,2, since the building is assumed to be situated in Paris, zone H1a
- $M_{c,alt}$ =0, since it is assumed that the altitude is between 0 and 400 m
- $M_{c,ges}$ =0, since a gas condensing boiler is used. The same goes for a ground source heat pump and district heating
- $M_{c,surf}$ =0, this parameter is only used when a residential building is being discussed

As mentioned before, the intention for the future is plus energy. However, since the document that formulates these requirements still is being drafted, the nZEB value is also set at 110,0 $\frac{kWh}{m^2}$.

Electricity use of lighting
The building is divided in 4 types of rooms (offices, meeting rooms, circulation/reception and public bathrooms), for each of which the hourly electricity use of lighting is determined with equation 4.35. For each of the types the conditions and parameters must be determined. Again, yearly average values will be used instead of hourly values. The room area's are estimated by using the following the ratio's mentioned under section 4.4.1.6 : offices: 0,6, meeting rooms: 0,1, circulation/reception: 0,26 and public bathrooms: 0,04.
<u>Offices</u>

- A_{room} = 1650 m^2
- $C1$ = 0,9, it is assumed the room's lights are operated with a light switch and thus have to be put on and off manually. [le 12l]
- $C2_{ae,i}$ =$C2_{pae,i}$ = 1, assuming that the lighting system is not divided into separate parts. The value is found on a graph ([le 12e]) by assuming that the average yearly level of natural light is 100 lux.
- I_{light}= 1, the lighting is on during the 2695 hours calculated from the standard scenario. Also, no $P_{light,aux}$ is present, so no power is used when the lighting is off. So these hours are not taken into account. [le 12d]
- $Ratio_{nat\ light\ i}$= 0,5. Only half of the area of the offices are assumed to be day-lit
- $P_{light,aux}$= 0 $\frac{W}{m^2}$, default value when a manual light switch is present
- $P_{light,tot}$= 7,0 $\frac{W}{m^2}$, reasonable assumption for power in an office building based on practice

Meeting rooms

- A_{room} = 275 m^2
- $C1$ = 0,7, it is assumed the room's lights are operated with a light switch and thus have to be put on and off manually. [le 12l]
- $C2_{ae,i}$ =$C2_{pae,i}$ = 1, the room is not divided into parts (fully day-lit). The value is found on a graph ([le 12e]) by assuming that the average yearly level of natural light is 100 lux.
- I_{light}= 1, the lighting is on during the 2695 hours calculated from the standard scenario. Also, no $P_{light,aux}$ is present, so no power is used when the lighting is off. So these hours are not taken into account. [le 12d]
- $Ratio_{nat\ light\ i}$= 1. The room is assumed to have full access to natural lighting.
- $P_{light,aux}$= 0 $\frac{W}{m^2}$, default value when a manual light switch is present
- $P_{light,tot}$= 7,0 $\frac{W}{m^2}$, reasonable assumption for power in an office building based on practice

Reception/circulation

- A_{room} = 715 m^2
- $C1$ = 0,8, it is assumed the room's lights are operated with a light switch and thus have to be put on and off manually. [le 12l]
- $C2_{ae,i}$ =$C2_{pae,i}$ = 1, the room is not divided into parts (fully day-lit). The value is found on a graph ([le 12e]) by assuming that the average yearly level of natural light is 100 lux.
- I_{light}= 1, the lighting is on during the 2695 hours calculated from the standard scenario. Also, no $P_{light,aux}$ is present, so no power is used when the lighting is off. So these hours are not taken into account. [le 12d]
- $Ratio_{nat\ light\ i}$= 1. The room is assumed to have full access to natural lighting.
- $P_{light,aux}$= 0 $\frac{W}{m^2}$, default value when a manual light switch is present
- $P_{light,tot}$= 7,0 $\frac{W}{m^2}$, reasonable assumption for power in an office building based on practice

Public bathrooms

- A_{room} = 110 m^2
- $C1$ = 0,7, it is assumed the room's lights are operated with a light switch and thus have to be put on and off manually. [le 12l]
- $C2_{ae,i}$ =$C2_{pae,i}$ = 1, the room is not divided into parts (no daylight access). The value is found on a graph ([le 12e])
- I_{light}= 1, the lighting is on during the 2695 hours calculated from the standard scenario. Also, no $P_{light,aux}$ is present, so no power is used when the lighting is off. So these hours are not taken into account. [le 12d]
- $Ratio_{nat\ light\ i}$= 0. The room is assumed to have no access to natural lighting.
- $P_{light,aux}$= 0 $\frac{W}{m^2}$, default value when a manual light switch is present
- $P_{light,tot}$= 7,0 $\frac{W}{m^2}$, reasonable assumption for power in an office building based on practice

The hourly use, $Q_{lighting,room_1,h}$ is turned into a yearly use by multiplying the value with the number of hours the lighting is used in a year: 2695. [le 12a]

$$Q_{lighting} = 11,7\frac{kWh}{m^2a}$$

Energy use for DHW
Emission
The water usage in an the reference building is calculated with equation 4.74. To this end, the following values are used:

- $a^{gr,em-e}$ = 1,25 l, default value found in table. [le 12g]
- ah =53,90 , found by adding up the hourly repartition key of the DHW use unto a yearly value. [le 12b]
- c_w = 1,163 $\frac{Wh}{kgK}$ [le 12h]
- ρ_w= 1 $\frac{kg}{l}$ [le 12h]
- θ_{cw} = 60°C, chosen in relation to the danger of legionella
- θ_{uw} = 40 °C [le 12h]

Distribution losses
The distribution losses are calculated with equation 4.40. The pipe length is determined with equation 4.75. The same assumptions are used as mentioned under 'emission'. A default value of 2 for nb_{distr} is used. [le 12i]

Generation losses
The calculation is made the same way as done for a single family home (section 4.2.1.6 for equations). The same assumptions are made. These are found in section 5.2.1.6.

Energy use for DHW
The total energy consumption is found to be

$$Q_{DHW} = 2,5 \frac{kWh}{m^2} \tag{5.7}$$

Maximum allowed delivered energy calculation
The maximum allowed delivered energy for space, ventilation heating, hot water heating and cooling with a gas condensing boiler is calculated using equations 4.63 - 4.68.

$$Delivered\ energy = 47,4 \frac{kWh}{m^2 a} \text{ (2016 and nZEB)}$$

.

5.4.2 Maximum allowed delivered energy for space, ventilation heating, hot water heating and cooling with gas district heating

The calculation is done in the same way as described in the previous section, 5.4.1 The only difference lies in the use of primary energy factor for space and DHW energy use. Therefore only the final result is mentioned.

5.4.2.1 Flemish Region

The following maximal delivered energy for space, ventilation and DHW heating and cooling is obtained. The details of the calculation are described in section 5.4.1.1.

$$Delivered\ energy = 23,4\frac{kWh}{m^2a}\ \ (2016)$$

5.4.2.2 Brussels Capital Region

The following maximal delivered energy for space, ventilation and DHW heating and cooling is obtained. The details of the calculation are described in section 5.4.1.2.

$$Delivered\ energy = 67,6\frac{kWh}{m^2a}\ \ (2016\ and\ nZEB)$$

5.4.2.3 Walloon Region

The following maximal delivered energy for space, ventilation and DHW heating and cooling is obtained. The details of the calculation are described in section 5.4.1.3.

$$Delivered\ energy = 56,7\frac{kWh}{m^2a}\ \ (2016)$$

5.4.2.4 Finland

The following maximal delivered energy for space, ventilation and DHW heating and cooling is obtained. The details of the calculation are described in section 5.4.1.4

$$Delivered\ energy = 136,0\frac{kWh}{m^2a}\ \ (2016)$$
$$Delivered\ energy = -5,7\frac{kWh}{m^2a}\ \ (nZEB)$$

5.4.2.5 Estonia

The following maximal delivered energy for space, ventilation and DHW heating and cooling is obtained. The details of the calculation are described in section5.4.1.5

$$Delivered\ energy = 74,1\frac{kWh}{m^2a}\ \ (2016)$$
$$Delivered\ energy = 4,7\frac{kWh}{m^2a}\ \ (nZEB)$$

5.4.2.6 France

The following maximal delivered energy for space, ventilation and DHW heating and cooling is obtained. The details of the calculation are described in section 5.4.1.6

$$Delivered\ energy = 58,3\frac{kWh}{m^2a}\ \ (2016\ and\ nZEB)$$

6
Comparison of Results

6.1 Objective of comparison

The comparison and discussion of the results has two goals. Firstly, it aims to give an idea of the strictness in requirements of the different countries for the specified building types. By discussing both current and nZEB regulations the evolution from current to nZEB goals is also visible. Secondly this chapter aims to look critical at the results and to explain certain tendencies or values. In order to do this the results are linked back to certain calculation steps, parameters and circumstances.

6.2 Single family dwelling

6.2.1 Maximum allowed delivered energy for space and hot water heating with a gas condensing boiler

The results are shown in figure 6.1 The maximum allowed delivered energy in the Walloon Region is clearly larger than in the other regions/countries, both for current as nZEB requirements, as was expected based on the large values for the primary energy index. The Brussels Capital Region and France are on the lower end of the 2016 results, since they have already implemented the nZEB requirement. Note that the Finland, Estonia and the Flemish Region nevertheless set a lower nZEB goal than France or the Brussels Capital Region. It must be remarked that the French nZEB value is an assumption, since it is the intention to go towards plus energy. However, the regulations are not yet drafted (RT2020).

Finland, Estonia and Flanders have similar values according to 2016 regulations, but the nZEB values show a significant difference for Estonia. This is as expected, as the Estonian regulation defines a strict nZEB value in comparison with the current regulations. The fact that the value is negative, might be caused by the choice of not taking renewable energy into account.

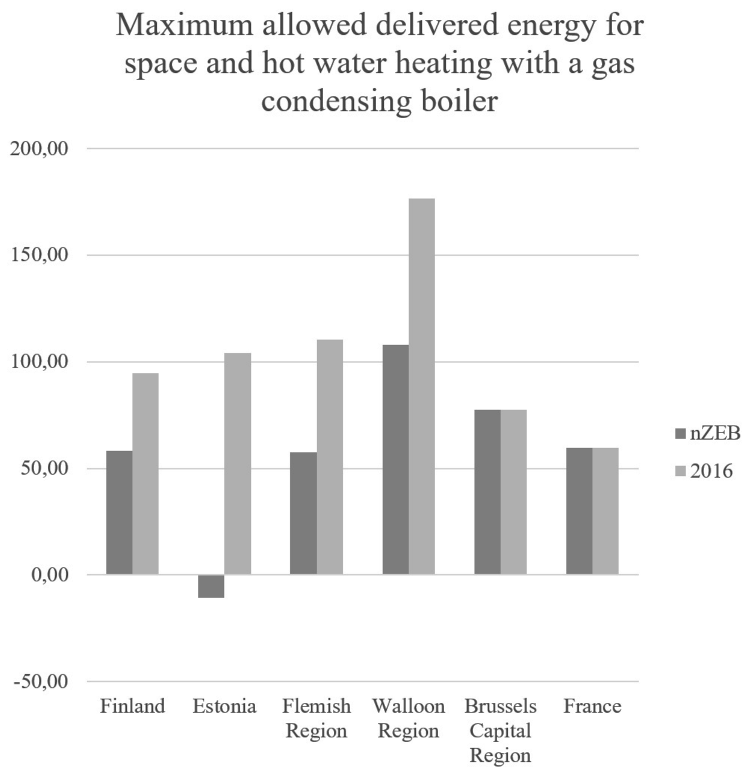

Figure 6.1: Delivered energy for a reference single family dwelling when using a gas condensing boiler

6.2.2 Maximum allowed net energy need for space and hot water heating with a ground source heat pump

The results are shown in figure 6.2 Similar to the delivered energy results for 2016, the Walloon Region still stands out as the largest value. The rest of the values show a different tendency than for the gas condensing boiler, e.g. Estonia surpasses the Flemish Region. It is probable that this is the influence of the primary energy factor for electricity, which varies a lot according to country. This opposed to the primary energy factor of natural gas, which is the same for every country. It must be noted that Finnish regulations define a change in the electricity factor (lowered) for nZEB regulations, which explains why nZEB and 2016 are so similar. The French value is negative, presumably because of the influence of the primary energy factor for electricity (2,58).

Estonia's result is even more negative than for the gas condensing boiler. Again, the strict regulations together with not incorporating a renewable energy system might be the reason for this.Brussels Capital Region and France already implemented the primary energy demand for nZEB in the current regulation so their value remains the same.

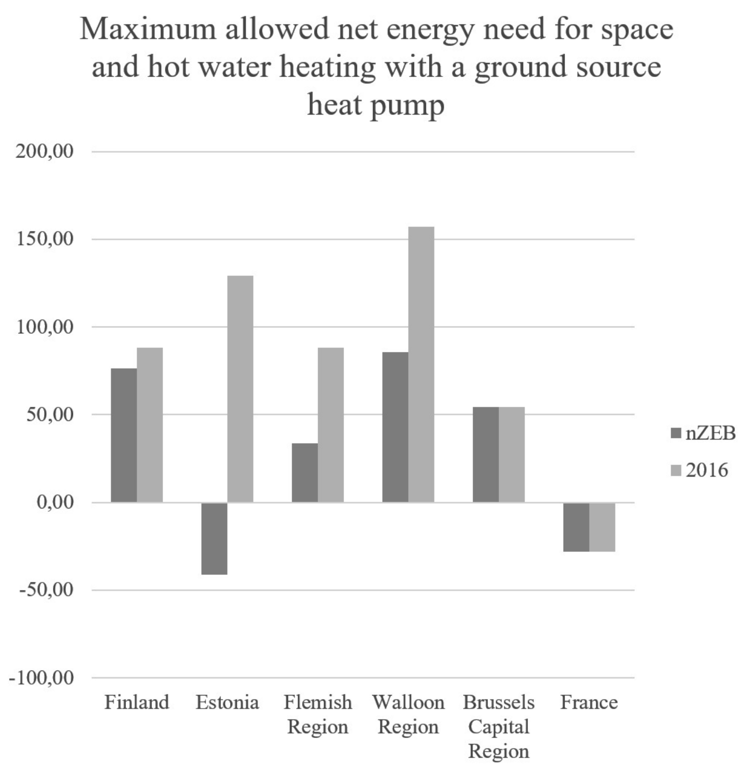

Figure 6.2: Net energy need for a reference single family dwelling when using a ground source heat pump

6.3 Apartment building

6.3.1 Influence of choice of apartment on Belgian primary energy index

The reference building consists of 11 apartments, which can be divided into 9 types as far as geometry is concerned (Reference apartment building plan, Appendix A). In Estonian and Finish regulations all of these apartments have to comply to the same primary energy index regardless of geometry or location within the building. French regulations do define the surface as one of the parameters influencing the primary energy index, but it is clearly stated that this i the surface of an average apartment.

Only in Belgium is geometry (net heated area, heat loss area and volume depending on region) used to determine the maximal primary energy index in such a way that varies according to compactness of the apartment . Since the compactness is defined as volume divided by heat loss area to the outside in the case of the apartment building this factors the fact in that a corner apartment will have more heat loss to the outside than an apartment in the middle of the building. This leads to a variety of possible primary energy index' for the apartment building, as shown on figure 6.3, 6.3, 6.5 (recalculated to $\frac{kWh}{m^2a}$. As a result each type of apartment has to be calculated separately in Belgium.
Moreover, two apartments with the same net heated area can have a different maximum primary energy indexes. For example apartment 2/27 and 2/33 have different primary energy index' in Flemish and Brussels regulation. Note that this is not the case in the Walloon Region, because for a E_w value of $130\frac{kWh}{m^2a}$ and higher, E_{spec} becomes the determining index. This value is not calculated in relation to compactness.

Overall, this difference in calculation methods makes the comparability of results questionable: through the choice of apartment maximal delivered energy for the Belgian Regions differs and so will the conclusion drawn from the comparison. Therefore it is proposed to use a fictional average apartment, with an average net heated area and heat loss area. The primary energy index' of the Belgian Region are assumed to be the weighted average of the variety of index' of the different apartments.

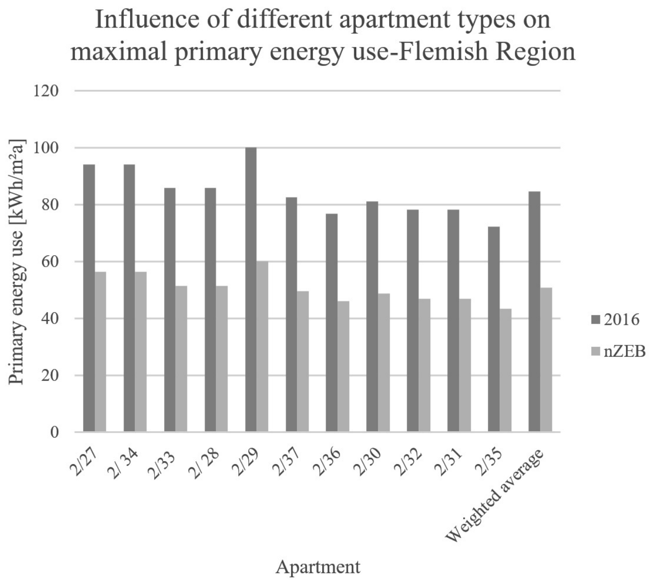

Figure 6.3: Variation of maximal primary energy index' ($\frac{kWh}{m^2a}$) for reference apartment building according to Flemish regulations

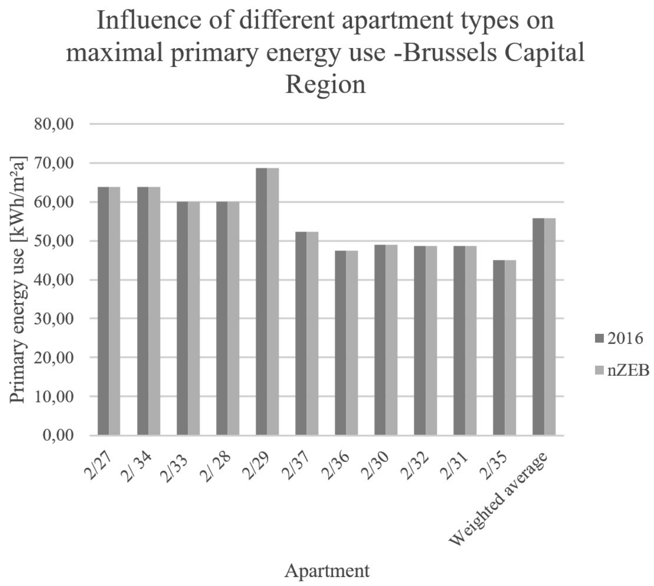

Figure 6.4: Variation of maximal primary energy index' ($\frac{kWh}{m^2a}$) for reference apartment building according to Brussels regulations

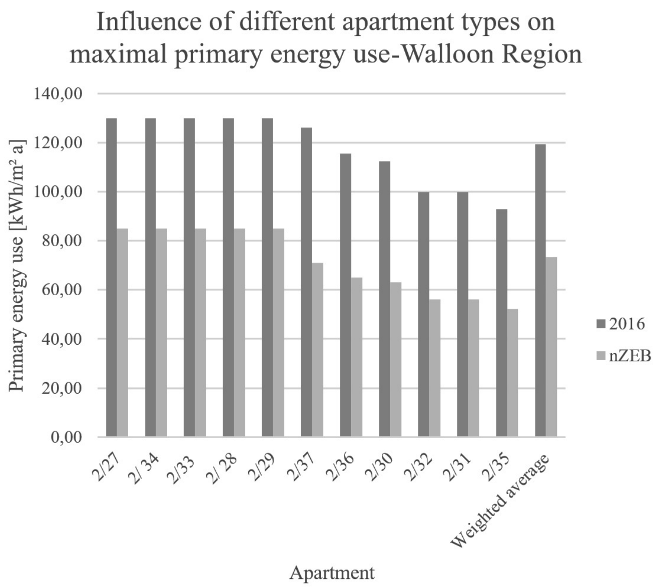

Figure 6.5: Variation of maximal primary energy index' ($\frac{kWh}{m^2a}$) for reference apartment building according to Walloon regulations

6.3.2 Maximum allowed delivered energy for space and hot water heating with a gas condensing boiler

The results are shown on figure 6.6. They show a similar pattern as for the single family dwelling. Again Brussels and France are at the lower end of the comparison and the Walloon Region has the largest value. The differences between the results are bigger than was the case for the single family dwelling: the maximal allowed delivered energy of the Walloon Region is roughly three times as high as the delivered energy of the Brussels Capital Region and France. It is also apparent that Estonian regulations set less strict nZEB requirements for the apartment building, than for the single family dwelling.

The influence of the choice of apartment on Flemish regulations complicates the comparison. This is more elaborately discussed under 6.3.1. When calculating he apartment building with both a gas condensing boiler and district heating it must be noted that gas heating is not common at all in Finland, as opposed to the Belgian Regions, where district heating is rather uncommon. The influence of the latter is visible in the next comparison.

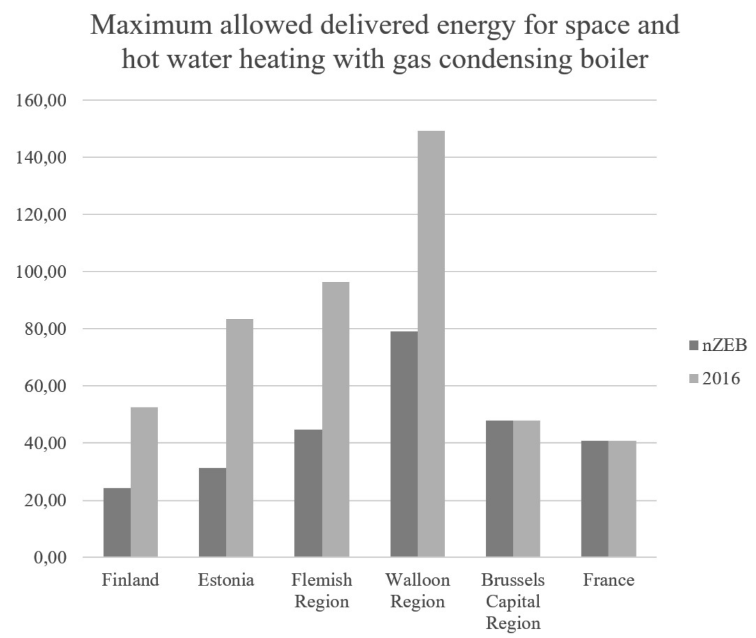

Figure 6.6: Delivered energy for a specific apartment (2/36) from a reference apartment building when using a gas condensing boiler

6.3.3 Maximum allowed delivered energy for space and hot water heating with district heating

The results for the Flemish region have lowered in comparison with the results for the gas condensing boiler. The French regulations seems less strict. In the calculation of the maximum allowed delivered energy for space and hot water heating with district heating two influences warp the results.

The first is the influence of choice of apartment. This is more elaborately discussed under section 6.3.1. The latter influence is a consequence of the fact that in Belgium less district heating is used than for instance in Finland. In Belgium it is more common to use a gas condensing boiler per apartment. This translates to the regulations; no detailed standardized method is yet developed for the three Regions.Instead, the Belgian Regions use an equivalent primary energy factor for DH of 2,0. As mentioned before, this factor is purposely kept high to encourage the use of the equivalency calculation method in practice to obtain a lower factor and therefore lower results. However, since this method specifically requires governmental approval for any new form factors, no reasonable assumptions can be made with certainty. The Belgian results are therefore not representative. Unlike for fossil fuels, there are also differences between the other countries primary energy factors (in the case of Finland, the factor even varies from 2016 to nZEB regulations). The values found for the gas condensing boiler provide a better option for discussion on the delivered energies of the selected countries, bearing in mind the influence of apartment type.

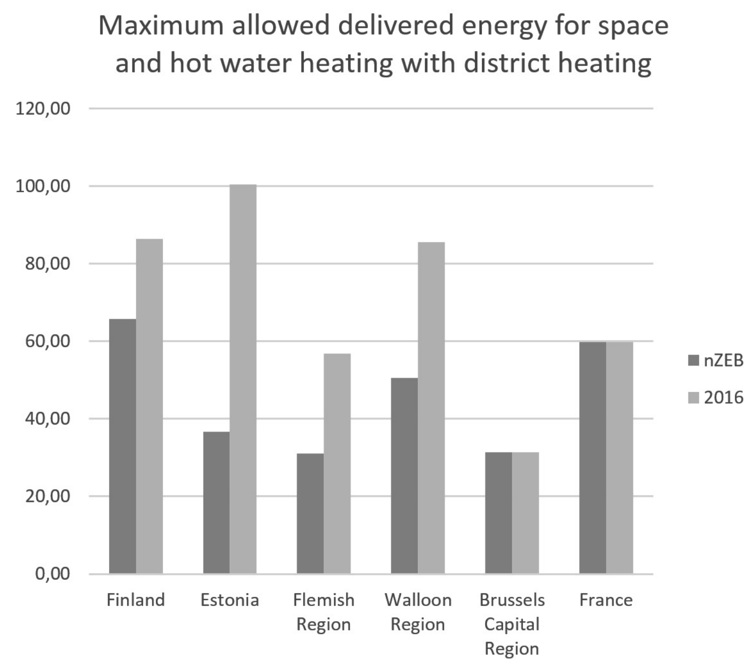

Figure 6.7: Delivered energy for a specific apartment (2/36) from a reference apartment building when using district heating

6.4 Office building

6.4.1 Maximum allowed delivered energy for space, ventilation and hot water heating and cooling with a gas condensing boiler

The results are shown on figure 6.9. The results differ quite a bit from the previous results. The maximal allowed delivered energy according to Brussels Capital Region's requirements is the largest value, followed by Finland and the Walloon Region. The Flemish Region's result is considerably smaller than was the case for residential buildings. Both Finland and Estonia's results vary considerably according to 2016 regulations or nZEB.

The change in Brussels' result compared to residential buildings may be explained by the change in how the maximal primary index is calculated. The maximal primary energy index for office buildings is related to the net needed energy used in the equation. For this value an assumption had to be made. However, this complicated the calculating method and may have resulted in errors.

Also note the change in the way the requirement is set in the case of the Walloon Region. Instead of two primary energy index', only one is specified for office buildings: E_w. Whereas the E_{spec} index limited the maximal primary energy for residential buildings, this is not the case for office buildings. The reference building used in both Flemish and Walloon calculations is also defined differently than in the residential regulations.

A few remarks have to be me made on the comparability of these results. For further research it would be interesting to also calculate the nZEB results for the Flemish and Walloon Region using a more advanced calculation method in order to improve the comparison. Secondly, the calculations are made assuming that the cooling system is powered by electricity, so the influence of the large primary energy factor of electricity might explain variation in results. Especially for France (primary energy factor of 2,58) and the Belgian Regions (2,50) the influence should be visible. Thirdly, the calculation is done using a standard value for Helsinki cooling and degree day correcting this instead of calculating the cooling country with the country-specific methods. Calculating the cooling needs is perhaps also an improvement to the method that can be made.

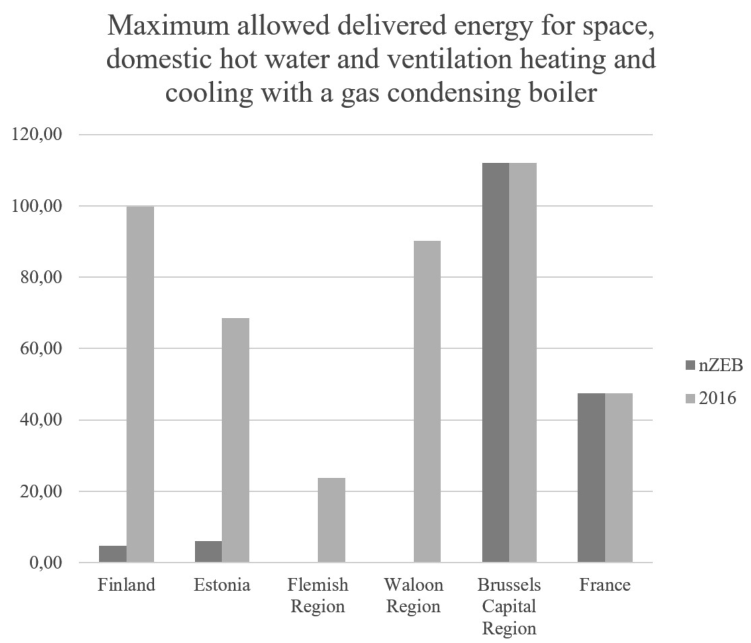

Figure 6.8: Delivered energy for a reference office building when using a gas condensing boiler

6.4.2 Maximum allowed delivered energy for space, ventilation and hot water heating and cooling with district heating

The result is shown on figure 6.9. The same conclusions can be drawn as described under section 6.4.1. Due to the influence of the various district heating primary energy factors, the results show less extreme values. This is especially the case for the Belgian Regions, as discussed before in section 6.3.2. Again it may be concluded that the gas condensing boiler provides better results to base the comparison on.

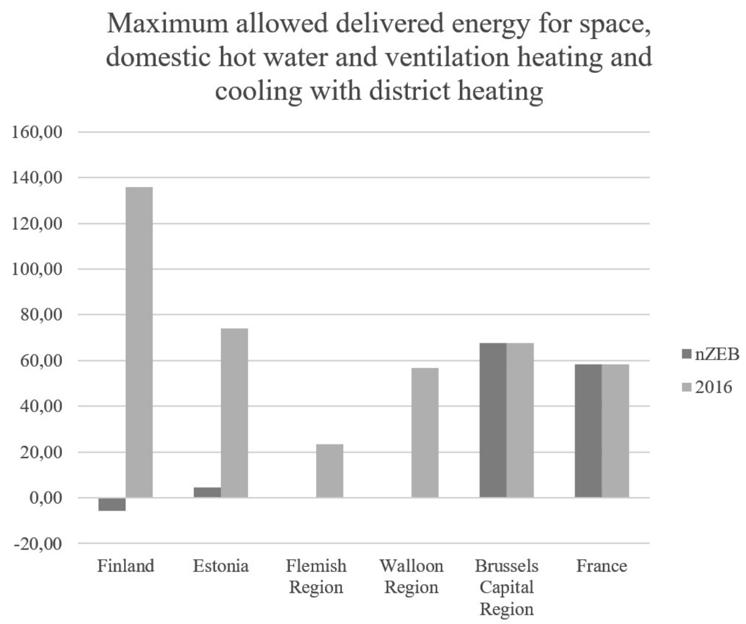

Figure 6.9: Delivered energy for a reference office building when using district heating

6.5 Conclusion

After analyzing the results, the conclusion can be made that requirements, definitions and calculation methods differ quite a lot between countries, and even between the Belgian regions. Some general tendencies could be found; the Walloon Region allows for the largest value delivered energy, and France and the Brussels Capital Region where on the lower ends of the comparison, especially for current regulations. Values varied according to the type of building, especially in the case of Estonia, which sets strict nZEB requirements for a single family home. The same goes for Finland in the case of office buildings.

While analyzing the results, the difficulties of making a comparison became apparent. Even after following the suggested calculation method and trying to normalize the differences between countries, the results were still influences and warped. A few of the factors that influenced the results are listed below.

Firstly, in order to make a comparison assumptions must be made. The amount of assumptions differed hugely between the selected countries, especially in the case of France there were significantly less default values. Sometimes there were also differences in detail of the calculations provided by the different countries. This added uncertainty to the calculations.

Secondly, the influence of how the requirements are set is visible, especially in the case of the apartment building. Results showed that for the Belgian Regions, that relate the maximal primary energy index to the net heated area, heat loss area and compactness (either by using the reference building method and a set index or by directly giving an equation for the index), the choice of precise apartment influences the final results. Whereas for Estonia and Finland the primary energy index is a fixed value not related to the specific apartment's geometry or heat loss area. In the case of France the variation in geometry is ignored by only considering an average apartment.

Thirdly, the calculation was also influenced by the the national habits concerning the heating or cooling of buildings. This was especially clear in the case of the Belgian regions. The calculation method for district heating is not standardized yet, since this is not as widespread in Belgium as it is in for example Finland, so default values had to be used. Calculation showed clearly that these were very strict. In the case of district cooling there are simply no values.

Lastly it can be stated that further research could be done on using the standard values suggested or different values for the efficiencies. Also, better results can be obtained when differences in national input data are also normalized. This is perhaps reserved for a more advanced calculation method (simulation of the building).

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A
Reference apartment building

The floor plans of the chosen reference apartment building are shown on A.1 and A.2. Information on the geometry of the different apartments is shown in table A.1. Note that in determining the heat loss area only surfaces in contact with the outside air are considered, assuming that the inside of the building is heated and heat loss through these surfaces can be neglected. For more information on the building's specifics, see [KSK+13].

Table A.1: Geometry of different types of apartments

Apartment	**Net heated area**	**Heat loss area**	**Compactness**
2/27 and 2/34	87,0	175,6	1,5
2/33 and 2/38	87,0	130,9	2,0
2/29	36,5	46,5	2,3
2/37	54,9	49,0	3,4
2/36	70,8	57,7	3,7
2/30	50,7	34,3	4,4
2/35	67,9	34,6	5,9
2/31 and 2/32	51,6	26,6	5,8

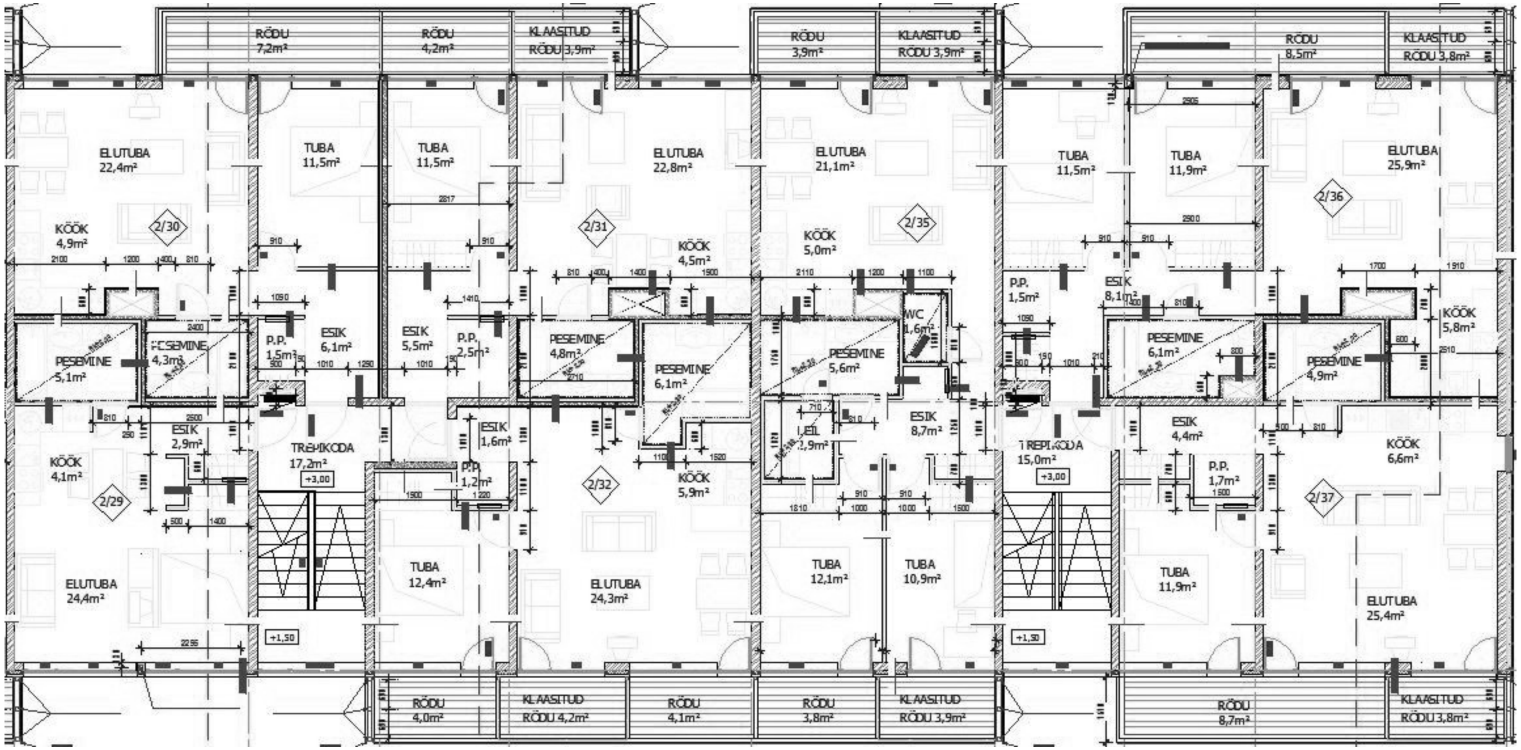

Figure A.1: Ground floor and third floor plan of the four storeys reference apartment building, containing 7 apartments

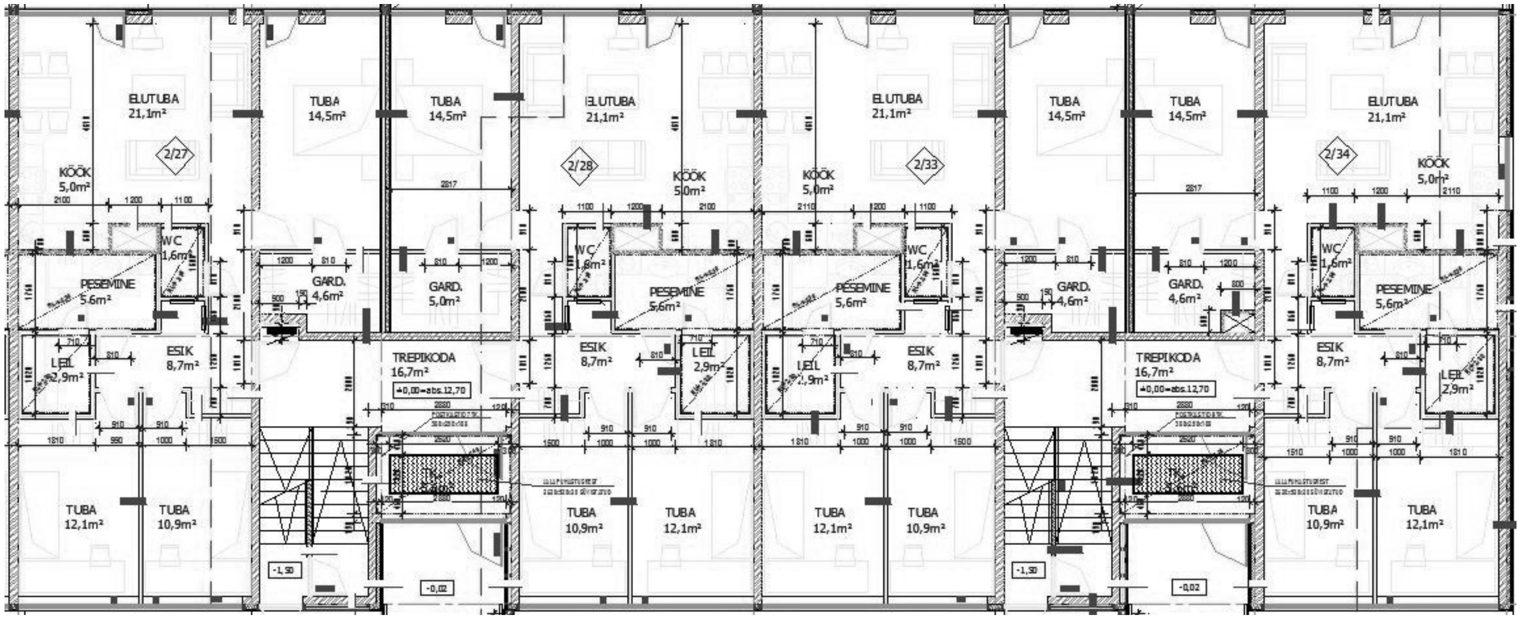

Figure A.2: First and second floor plan of the four storeys reference apartment building, containing 4 apartments