Nearly Zero Energy Buildings (nZEB): definition and comparative analysis in selected EU countries

MASTER THESIS

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This thesis is dedicated to my beloved mother: Nina Lucia, and the memory of my father: Luis Fernando.

Abstract

Since buildings account for 40% of total energy consumption[1] and 36% of CO2 emissions in the EU, the directive 2010/31/EU "Energy Performance of Buildings Directive (EPDB)"among other key laws concerning the reduction of energy consumption of buildings has been enforced. According to this legislation all new buildings must be nearly zero energy buildings "nZEB" by 31 December 2020 (public buildings by 31 December 2018). Nonetheless the assessment of the "high energy performance" of a building is ambiguous and a cross country comparison seems to be intricate as far as the different national building codes employ different energy indicators.

This thesis delves into the question of how do the "nZEB" definition and the transposition of the Directive 2010/31/EU into national law change in four selected EU Countries: Austria, Germany, Spain and England. The energy performance of some exemplary buildings is assessed by means of a simplified MATLAB model based on the norm DIN V-18599. The results drawn from this work show how diverse are building codes scopes and national "nZEB" definitions. Only 9 of the 36 studied cases of residential buildings obtain consistently the "nZEB" status in all four selected countries. Different climate conditions, energy requirements, primary energy factors, ambition levels and calculation methodologies lead to the problem of an uneven cross-country comparison. Moreover, primary energy consumption $[kWh/m^2a]$set as the main quantitative energy indicator by the directive 2010/31/EU might not be the most suitable one for an EU level comparison.

An EU level nZEB definition grounded on the combination of two measures, namely (1) the set of an absolute value for the maximum energy need for heating and cooling in $[kWh/m^2a]$ with a correction factor depending on the climate zone at EU level and (2) the set of a relative maximum value [%] for the primary energy consumption in regard to a reference building, could support and ease the task of the projects and initiatives intended to provide data and input on how to reach the nZEB standard and hence encourage the compliance of the proposed energy consumption reduction and CO2 emission reduction targets.

[1] Directive 2010/31/EU recast (3)

Contents

Abbreviations

AB	Apartment building
BEP	Building energy performance
CHP / KWK	Combined heat and power
DHW	Domestic hot water
EPBD	Energy performance of buildings directive
EU	European Union
GEN_1	Scenario 1. Original building
GEN_2	Scenario 2. Building subjected to normal renovation
GEN_3	Scenario 3. Building subjected to ambitious renovation
KfW	Kreditanstalt für Wiederaufbau Bank
MS	Member State
MFH	Multi-family house
NGF	Total net area
nZEB	Nearly Zero Energy Building
SCI	Winter climate severity
SCV	Summer climate severity
SFH	Single-family house
WE	Heat producer

Symbols, units, sets and subscripts

Nomenclature

A	Area $[m^2]$
A_B	Reference Area $[m^2]$
a	Year
B	Width $[m]$

C_{wirk}	Effective bulding thermal capacity $[Wh/K]$
d	Day
Δ	Difference
F_f	Form factor solar radiation (building element partialy shadowed)
F_F	Reduction factor for window frame
F_S	Reduction factor for shadowing
F_V	Reduction factor for contamination /pollution
F_w	Reduction factor due to non-vertical insiding solar radiation
f_{NA}	Correction factor for reduced operation at night (heating system)
f_{we}	Correction factor for reduced operation on weeken/ holidays
g_{eff}	Effective energy transmittance (transparent building element)
g_{tot}	Effective energy transmittance considering sun protection
H	Heat transfer coefficient $[W/K]$
h	Hour / height
I_S	Monthly average radiation intensity ´irradiance’ $[W/m^2]$
κ	Roomindex
L	Length $[m]$
m	Month
η	Performance ratio, efficiency, utilization ratio
n	Air change rate $[1/h]$
P	Power $[W]$
P_{SFP}	Specific ventilatior power $[kW/(m^3/s)]$
Q	Energy $[kWh]$
τ	Building zone time constant $[h]$
θ_e	Exterior air temperature $[°C]$

θ_i	Internal balance temperature [$°C$]
U	Thermal transmittance [W/m^2K]
V	Volume [m^3]
$\dot{V}$	Airflow rate[m^3/h]
W	Auxiliary energy [kWh]

Subscripts (MATLAB model)

a	Yearly
c	Cooling
ce	Control and emission
d	Distribution / daily
dhw	Domestic hot water
eff	Effctive
el	Electric
ETA/ABL	Outlet air, extracted air
f	Final energy
fac	Devices
g	Generation
h	Heating / hour
i,j,k	index
inf	infiltration
l	Lighting
max	Maximum
min	Minimum
mth	Monthly
NA	Reduced operation

op	Operation
outg	Output generator - Energy use
p	Primary / persons
S	Solar
s	Storage
set	Set-value , set-point
Sink	Sink
Source	Source
SUP/ZUL	Inlet air, supply air
ve	Ventilation
we	Weekend, holidays (out of main time of operation)
win	Window

Bulding Tags (EPISCOPE – TABULA WEBTOOL)

COUNTRY_REGION_BUILDING.TYPE_ID.NUMBER_SCENARIO

(for example: AT_N_SFH_08_GEN_1)

COUNTRY:	AT (Austria)
	DE (Germany)
	ES (Spain)
	UK (United Kingdom / England)
REGION:	N (Default national)
	ME (Mediterranean)
	E (East)
	ENG (England)

BUILDING.TYPE:	SFH (Single Family House)
	MFH (Single Family House)
	AB (Apartment block)
	PHS (Passive house)
ID.NUMBER:	2 Digits XX (TABULA web tool)
	4 Digits XXXX (Passiv house database)
SCENARIO:	GEN_1 (Original building)
	GEN_2 (Building subjected to normal renovation)
	GEN_3 (Building subjected to ambitious renovation)

1. Introduction

The European Union has formulated the 2020 Energy Strategy in order to keep energy affordable for consumers and business, decrease the dependence on foreign fossil fuels and help to combat climate change and air pollution. Three main targets are pursued by the Energy Strategy: (a) reduction of greenhouse gas emissions by at least 20% (b) increase the share of renewable energy to at least 20% of consumption and (c) achieve energy savings of 20% or more.

Since buildings account for 40% of total energy consumption[2] and 36% of CO2 emissions in the EU, two key laws concerning the reduction of energy consumption of buildings have been enforced, the directive 2010/31/EU "Energy Performance of Buildings Directive (EPDB)" and the 2012 "Energy Efficiency Directive".

The article 2 of the Energy Performance of Buildings Directive (EPDB) defines a nearly zero energy building as a building that has a "very high energy performance" for which 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.[3]

In the article 9 of the same directive it is stated that Member States (MS) shall ensure that by 31 December 2020, all new buildings are nearly zero-energy buildings and that after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings. Furthermore all Member States (MS) shall draw up national plans for increasing the number of nearly zero-energy buildings and these shall include a definition of nearly zero-energy buildings, reflecting their national, regional or local conditions, and including a numerical indicator of primary energy use expressed in $[kWh/m^2a]$[4]

This thesis delves into the question of how do the nearly zero energy building "nZEB" definition and the transposition of the Directive 2010/31/EU into national law regarding the procedures to assess the "very high energy performance" differ in four selected EU Countries: Austria, England Germany and Spain.

In order to make a cross country comparison of the national building codes and "nZEB" definition, a simplified MATLAB model based on the calculation procedure of the German norm DIN V 18599 has been developed. The norm DINV 18599 is a summary and improvement of the precedent existing norms (DIN V 4108-6/DIN V 4701-10 und -12, EN 832, ISO 13790). However it is important to bear in mind that the calculation procedure and reporting formats of the norms EN ISO 13790 and EN 15603 are expected to be replaced by the new calculation procedure presented in the prEN ISO 52000.

[2] Directive 2010/31/EU recast (3)
[3] Directive 2010/31/EU Article 2 (2)
[4] Directive 2010/31/EU Article 9 (1) and (3)

For the comparison of the building codes and “nZEB” definitions 3 buildings were selected for each of the 4 countries giving a total of 12 buildings and three cases were analyzed for each building giving a total of 36 cases. The selected example buildings has been chosen mainly from the EPISCOPE project database, which not only contains a large set of building types of each national stock, but also typical energy consumption values for each building and statistical data for the supply systems. Two from the twelve buildings on the other hand have been chosen from the passive house database.

2. Methodology

This chapter covers the followed methodology in order to give a deeper insight into the proposed research question. Main objective of this work is to give a qualitative as well as a quantitative cross-country comparison of the energy indicators stated in the respective building codes and the country "nZEB" definition. Sections 2.1 to 2.4 describe the methodology which includes the literature review, the selection of the buildings to be analyzed along with the assessment criteria definition, the development of a simplified MATLAB model to estimate the energy performance of a building and the corresponding validation procedure for such model.

2.1 Literature review

The initial point of this work has been the review of the policy background. Starting with the global directive 2010/31/EU "Energy Performance of Buildings Directive" and then going further to each country regulation/ mandate/ decree/ building code and national nZEB plan.

I.Sartori, et al(2012)[5] Propose a consistent framework for setting Net nZEB definitions, but as they themselves recognize there are possible different definitions in accordance with a country's political targets and specific conditions. Moreover, some research projects have already tried to specify the EPBD's global definition and to define suitable levels for nZEBs in Europe, but as there are not concrete values in the EPBD definition of nZEB and since there are different climate conditions, primary energy factors, ambition levels and calculation methodologies, the nZEB definition differ significantly from country to country. In the past, the REHVA association among others has proposed a detailed definition of nZEB for a consistent national implementation of the EPBD recast arguing that EU MSs might need more guidance in order to set comparable requirements for nZEB's with equal ambition levels. Even for projects aiming to monitor the nearly zero energy market like ZEBRA 2020 whose major target is to illustrate collected data about the way of MS and Europe towards nZEB, this unclearness in the 'nearly zero' definition supposed a methodological issue. Quoting one of the project key findings: *"A quantitative comparison of national nZEB definitions is complex due to different system boundaries, calculation methodologies, applied factors etc, However, our analysis indicates that a significant share of nZEB definitions does not meet the intention of the EU directive on energy efficient buildings (EPBD) that the energy consumption should be "nearly zero or very low amount" and the remaining part "should be covered to a very significant extent by energy from renewable sources". Thus, a recast EPBD should require clear definitions of terms and thresholds, and gaps should be closed*"[6].

The core of the thesis is the quantitative comparison and hence the developed MATLAB model for the evaluation of the energy performance of a building, whose base and guideline is the PhD

[5] I.Sartori, et al., *Net zero energy buildings: A consistent definition framework*, Energy Buildings (2012)., Retrieved from: http://dx.doi.org/10.1016/j.enbuild.2012.01.032

[6] Zebra project *key findings*. Retrieved from: http://zebra2020.eu/about/expected-results/

dissertation "Vereinfachungen für de energetische Bewertung von Gebäuden"[7] of Markus Lichtmess and its corresponding excel tool Enercalc. In this document the author develops and validates a simplified methodology, which analyses the building envelope according to a single zone model and calculates on the other hand the energy demand according to a multi zone model. This simplified allocation is based on the key assumption that there is a sufficiently good correlation between the building envelope and the energy surface areas (the surface areas of the individual zones).

This thesis starts out from the fact that setting a suitable EU definition for nZEB is a challenging task as refered by Hermelink et al., 2013[8]. However it goes beyond and intends to compare in a qualitative and a quantitative way under the conditions referred in the "building selection and assessment criteria" section, whether the nZEB definition from a selected country is achieved in another country and how does or how much it differ in case it is not achieved.

A further discussion of the national regulation and a comparison is presented in the chapter 3 of this document. The quantitative comparison and results are presented in the chapter 4.

2.2 Building selection and assessment criteria

Four countries were selected for the cross-country comparison: Austria, England, Germany and Spain. For each country, three residential buildings were selected trying to maintain a resemblance in the construction year and construction type in each case between countries. From the twelve buildings, data of ten of them were obtained from the TABULA web tool dataset that is part of the EPISCOPE Project and the data of the other two, namely the single family house in Spain and the multi- family house in England, were obtained from the Passive house project database[9].

Each of the twelve buildings is modeled under three scenarios or cases following the scheme:

1. Original building : as built.
2. Building subjected to normal refurbishment: improvements on the thermal envelope as well as on the technical supply systems.
3. Building subjected to an ambitious refurbishment aiming to obtain nZEB status.

The specific criteria for the assessment of the building energy performance are presented in detail in the next chapter "Building codes and Nearly Zero Energy Buildings (nZEB) definition comparison", but in principle all buildings are assessed under the requirements for existing buildings (major renovation).

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[7]Markus Lichtmess *„Vereinfachungen für die energetische Bewertung von Gebäuden"*.. PhD Dissertation 2010. Retrieved from: http://www.enob.info/de/publikationen/publikation/details/vereinfachungen-fuer-die-energetische-bewertung-von-gebaeuden/

[8]Hermelink et al., *"Towards nZEB under the EPBD - Definition of common principles under the EPBD"*

[9] Passiv House Database. Retrieved from: http://www.passivhausprojekte.de/

Since the MATLAB BEP model is based on the German norm DIN V 18599, the boundary conditions of use are the same for all buildings in all countries and correspond to those in the part 10 of the mentioned norm. On the other hand, each building is assessed using the primary energy factor of the other countries. That means for example that in the case of a German building, when assessed under the Austrian building code scope, Austrian Primary energy and CO_2 Emission factors are used.

Austria is the only country of the selected four that already by January 2016 has a formal nZEB definition for both new and existing buildings, so the assessment of the buildings under the Austrian scope is done regarding the requirements for residential existing buildings. It is important to notice that Austria is the only country that includes the household electricity demand "Haushaltsstrombedarf" in the calculation procedure. In order to have an even comparison between countries, the maximum reference value for the primary energy in Austria has been modified by subtracting a default value that represents precisely this household electricity demand. A default value is given in the OIB guideline 6 of 2011 as the 50% of the internal heat sources from persons and appliances.

In the case of England, the nZEB definition goes in line with an already existing initiative for new residential buildings from 2016 called "zero carbon hub" and hence the buildings under the English scope are assessed following the requirements for new residential buildings.

Germany and Spain do not have yet a formal nZEB definition, so the assessment of the buildings under the scope of this two countries is done with own estimated criteria trying to remain close to the expected national nZEB definition. In the case of Germany, the buildings are assessed taking into account the label of 'KfW 55' efficiency house, which is the main expected requirement for existing residential buildings (major renovations) and indicates the amount of annual primary energy consumption in relation to a comparable new building (reference building) stated according to the requirements of the Energy conservation regulation EnEV. The number 55 means that the building does not use more than 55% of the annual primary energy consumption of the corresponding reference building.

In the case of Spain, the buildings are assessed as existing residential buildings and according to the national nZEB plan. Due to the significant different climate zones within the country, classified from A to E depending on the winter severity, an assumption is needed so all buildings form the other three countries (Austria, Germany and England) are assumed to be located in the climate zone E.

Existing buildings (renovation that involves more than 25% of the building envelope) should at least be compliant with the energy demand needs established in the Basic Energy Saving Document DB-HE of 2006 for new buildings. The assessment of the primary energy is done taking into account the following values for apartment blocks (reductions for single family house are higher in any case) depending on the climate zone as follows:

$$PrimaryEnergymax_{Zone\ E} = \frac{C_{ep,lim}}{(1-0,44)}\ ;\ PrimaryEnergymax_{Zone\ B} = \frac{C_{ep,lim}}{(1-0,18)} \quad (1)$$

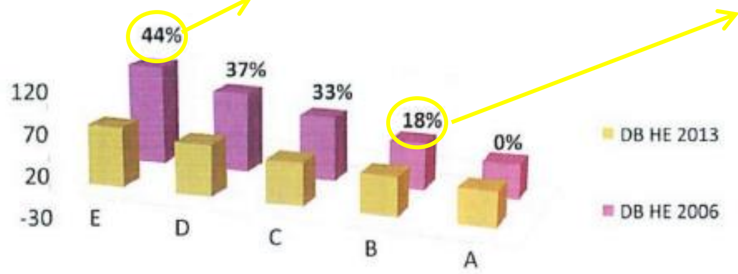


Figure 1. Reduction in the non-renewable primary energy power consumption limit in DB-HE 2013 compared to DB-HE 2006 for apartment blocks. Source: Spain nZEB national plan

With $C_{ep,lim}$ being the maximum primary energy according to DB-HE 2013 and presented in the equation 46.

Assessment of the energy demand for heating and cooling is done taking into account the following values detailed and explained in Figure 29 and Figure 30, an example of an apartment building and a single family house in climate zone E are presented:

$$HeatingEnergyneedmax_{ZoneE} = \frac{D_{cal,lim}}{(1-0,48)} \quad (2)$$

Figure 2. Reduction in the heating energy demand limit in DB-HE 2013 compared to DB-HE 2006 for apartment blocks. Source: Spain nZEB national plan

$$HeatingEnergyneedmax_{ZoneE} = \frac{D_{cal,lim}}{(1-0,43)} \quad (3)$$

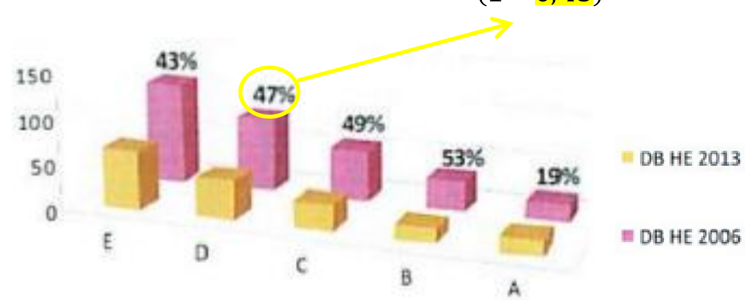


Figure 3. Reduction in the heating energy demand limit in DB-HE 2013 compared to DB-HE 2006 for single family house. Source: Spain nZEB national plan

Finally, the reduction in the case of energy need for cooling is assumed to be 25% for all climate zones:

$$\boldsymbol{CoolingEnergyneedmax_{ZoneE,D,C,B}} = \frac{\boldsymbol{D_{cal,lim}}}{(\mathbf{1} - \mathbf{0,25})} \qquad (\mathbf{4})$$

With $\boldsymbol{D_{cal,lim}}$ being the maximum primary energy according to DB-HE 2013 and presented in the equation 47.

2.3 MATLAB Model

The developed MATLAB BEP model is a simplified model based on the calculation procedure presented on the German norm DIN V 18599 and the validated simplifications introduced by Markus Lichtmess[7]. It is a multi-zone model (up to 7 zones) intended for the calculation of the energy need, final- and primary energy for heating, cooling, lighting and domestic hot water.

The strongest simplifications of the model befall on the technical installations. Among the assumptions and limitations of the model are:

- Use of tabled values for the generation-expenditure factors and auxiliary energy according to the norm DIN 4701-10.
- Use of tabled values for the distribution losses of the heating and domestic hot water systems. (Losses can be also set as a user input for the model).
- Modelling of simple ventilation systems with constant volume and heat recovery up to 75%. The energy need for the heat/cold register and related technical losses of the ventilation system are not considered.
- Simplified CHP modelling as complementary system to a given heating system.
- Simplified Solar-thermal system with pre-selected collector surface.

The BEP model calculation procedure consists of nine fundamental steps described as follows:

2.3.1 Data collection (DIN V 18599-10)

Basic data gathering is the starting point of the calculation procedure. Input data include the project location, weather data and boundary conditions such as set temperatures, internal heat sources, heating and ventilation systems daily operation times and minimum air change rate among others.

The norm DIN V 18599-10 contains two defined profiles for residential buildings, i.e. Single-family house and Multi-family house and 41 profiles for non-residential buildings.

A detailed list of the use boundary conditions with guide values “Nutzungsrandbedingungen” for residential buildings is presented in Table 4 above mentioned document:

- Room set temperature “Raum-Solltemperatur”
  - Heating “Heizfall” : $\theta_{i,h,soll}$ = 20 [°C]
  - Cooling “Kühlfall” : $\theta_{i,c,soll}$ = 25 [°C]
- Temperature reduction by reduced operation “Temperaturabsenkung reduzierter Betrieb” $\Delta\theta_{i,NA}$ = 4 [K]
- Minimum temperature dimensioning for heating “Minimaltemperature, Auslegung Heizfall” : $\theta_{i,h,min}$ = 20 [°C]
- Maximum temperature dimensioning for cooling “Maximaltemperature, Auslegung Heizfall”: $\theta_{i,c,max}$ = 26 [°C]

- Internal heat sources “ interne Wärmequellen”
  - Single-family house : 45 [Wh/m2d]
  - Multi-family house : 90 [Wh/m2d]
- Times of use “Nutzungszeit”:
  - Time of use: from 00:00 to 24:00
  - Daily operation time Ventilation system: from 00:00 to 24:00
  - Daily operation time heating system: from 06:00 to 23:00
  - Daily operation time Ventilation system WLA $t_{rv,op,d}$ and $t_{rc,op,d}$: 24 [h/d]
  - Daily operation time heating system $t_{h,op,d}$: 17 [h/d]
  - Yearly operation time $d_{nutz,a}$: 365 [d/a]
- Domestic hot water “Nutzwärmebedarf Trinkwarmwasser” $q_{w,b}$
  - Single family house : 11 [kWh/m2a]
  - Multy family house : 15 [kWh/m2a]
- Minimum air change rate “Mindestausseluftwechsel”: n_{nutz} = 0,5 [1/h]
- Reduction factor contamination “Abminderungsfaktor infolge von Verschmutzung” F_V : 1
- Building automation factors

A total of 33 non-residential profiles from the 41 presented in the table 5 of the norm DINV 18599-10 are defined in the MATLAB BEP model.

1. single_office'
2. group_office'
3. large_office',
4. meeting_room'
5. main__hall'
6. store'
7. store_cooling',
8. school'
9. auditorium'
10. hostal'
11. hotel_room'
12. bar',
13. restaurant'
14. kitchen_nr'
15. kitchen'
16. sanitar_room_nr',
17. other_habitable_room'
18. other_areas_nr'
19. circulation_area',
20. storage'
21. datacenter'
22. workshop'
23. theater'
24. lounge',
25. stage'

26. exposition'
27. museum'
28. library_reading_room',
29. library_main'
30. library_depot'
31. sport_hall',
32. parking_private'
33. parking_public',

The defined use boundary conditions for these non-residential profiles are:

- Times of use and operation times “Nutzungs-und Betriebszeiten”:
    - Daily operation hours $t_{nutz,d}$ [h/d]
    - Yearly operation days $d_{nutz,a}$ [d/a]
    - Yearly operation days at day t_{Tag} [h/a]
    - Yearly operation days at night t_{Nacht} [h/a]
    - Daily operation hours RLT and cooling system $t_{v,op,d}$ [h/d]
    - Yearly operation days RLT, cooling and heating $d_{op,a}$ [d/a]
    - Daily operation hours heating system $t_{h,op,d}$ [h/d]
- Lighting
    - Average luminous emittance $\bar{E}_m$ [lx]
    - Height of the working plane h_{NE} [m]
    - Reduction factor for the workingplane k_A
    - Relative absence factor C_A
    - Roomindex $k_.$
    - Partial operation lighting F_t
- Lighting
    - Room set temperature Heating $\theta_{i,h,soll}$ [°C]
    - Room set temperature Cooling $\theta_{i,c,soll}$ [°C]
    - Temperature reduction by reduced operation $\Delta\theta_{i,NA}$ [K]
    - Minimum temperature dimensioning for heating $\theta_{i,h,min}$ [°C]
    - Maximum temperature dimensioning for cooling $\theta_{i,c,max}$ [°C]
    - Minimum air volume flow rate V_A [m3/(h m2)]
    - Relative absence factor RLT c_{RLT}
    - Partial operation RLT F_{RLT}
- Heat sources
    - Persons $Q_{I,p}$ [Wh/m2 d]
    - Devices $Q_{I,fac}$ [Wh/m2 d]

2.3.2 Definition of building thermal envelope and zoning procedure (DIN V 18599-1)

Starting out from the basic hypothesis that a sufficient good correlation exists between the building envelope and the individual zones (Markus Lichtmess 2010)[7], the entire building envelope and its constructive elements like walls, roof, floor, windows…etc can be defined as a whole at a building level.

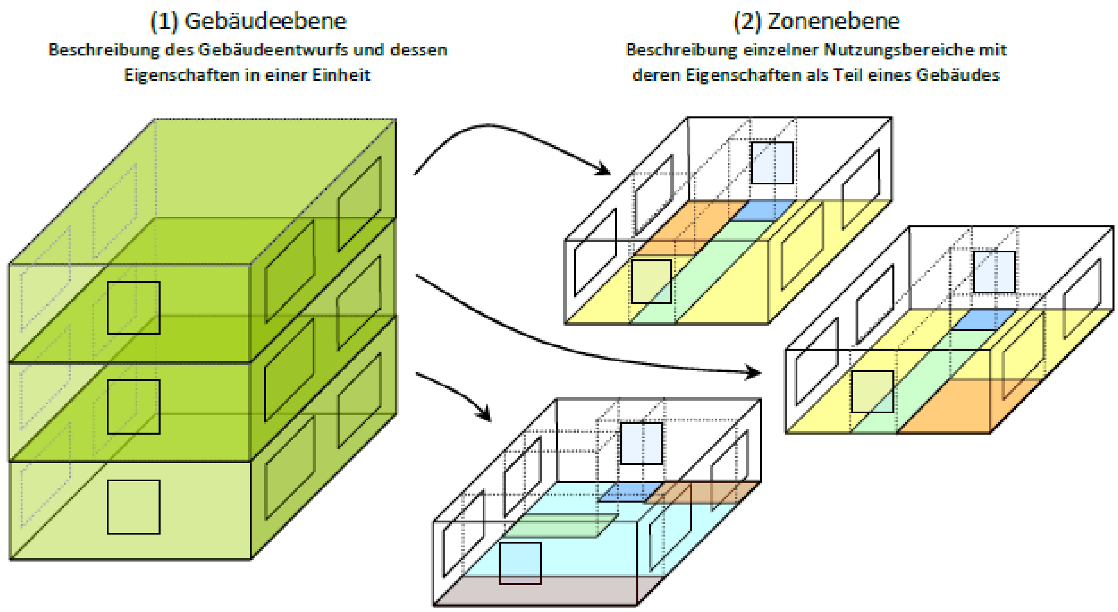


Abbildung 3: Darstellung der Gebäude- und Zonenebene

Figure 4.Building level and zone level. Source: *„Vereinfachungen für die energetische Bewertung von Gebäuden“.* Markus Lichtmess. PhD Dissertation 2010

The transformation process from the building as a whole unit up to the zone level as presented in Figure 5, starts with the user input data regarding the building envelope. Within this data is included for example the number of floors, the building conditioned volume, the exterior front (façade) area, the window area sorted by orientation, the roof and floor area and the wall in contact with ground area.

Still at the building level, the building element properties such as its area, orientation (north, south, east, west, horizontal) and U-values among others are defined summarized for each building element category (exterior walls, windows, roofs, floors…etc).

On the basis of the four standard defined building element categories: 1-Exterior wall, 2- Window (depending on its orientation x), 3- Roof and 4- Floor and each zone conditioned area (also set as user input), an assignation of each building element category to the respective building zone can be done following the zoning criteria according to the “Erweitertes Verfahren”[7]. The basic equation describing the building element categories allocation is:

$$A_{i,Z} = A_{i,total} * \frac{A_{N,i,Z}}{A_{N,i,total}} \tag{5}$$

With:

$$A_{N,i,Z} = A_{B,Z} * f_{i,Z} \tag{6}$$

Where:

$A_{i,Z} =: Area\ of\ the\ building\ element\ i\ allocated\ to\ the\ zone\ Z\ [m^2]$

$A_{i,total} =: Total\ area\ of\ the\ building\ element\ i\ [m^2]$

$A_{N,i,Z} = : Weighted\ area\ of\ the\ zone\ Z\ for\ the\ building\ element\ i\ [m^2]$

$A_{N,i,total} =: Sum\ of\ the\ weighted\ areas\ of\ the\ zone\ Z\ for\ the\ building\ element\ i\ [m^2]$

$A_{B,Z} =: Net\ floor\ area\ of\ the\ zone\ Z\ [m^2]$

$f_{i,Z} =: Factor\ dependent\ on\ the\ existence\ of\ the\ building\ element\ i\ in\ the\ zone\ Z\ (0\ or\ 1)$

It is also to note at this point, that the area of building element i assigned to the zone Z ($A_{i,Z}$) obtain the same specific heat transmission transfer coefficient as the mean specific heat transmission transfer coefficient of the building elment category i. This means:

$$H'_{T,i,Z} = H'_{T,i} \tag{7}$$

Where:

$H'_{T,i,Z} =: Specific\ heat\ \ transfer\ coefficient\ of\ the\ area\ A_{i,Z}\ of\ the\ zone\ Z\ [W/(m^2K)]$

$H'_{T,i} =: Specific\ heat\ \ transfer\ coefficient\ of\ the\ building\ element\ category\ i\ [W/(m^2K)]$

The specific heat transfer coefficient "Transmissionwärmetransferkoeffizient" of the zone comes from the sum over all building elements in the zone Z:

$$H'_{T,Z} = \sum_i H'_{T,i,Z} \tag{8}$$

$$H'_{T,i,Z} = \frac{\sum\left(A_{i,Z} * U_i * F_{X,i}\right) + \Delta U_{WB} * \sum A_{i,Z}}{\sum A_{i,Z}} \tag{9}$$

Where:

$A_{i,Z} =: Area\ of\ the\ building\ element\ i\ allocated\ to\ the\ zone\ Z\ [m^2]$

$U_i =: U - Value\ "Wärmedurchgangskoeffizient"\ of\ the\ building\ element\ i\ [W/(m^2K)]$

ΔU_{WB} =: *global factor considering the thermal bridges* $[W/(m^2K)]$

$F_{x,i}$ =: *Correction factor for the temperature* (*Table* 5 *DIN V*18599 – 2)

With the zone level parameters, the use boundary conditions and the technical systems information, the detailed balance procedure can be performed in each zone under the scope of the multizone model.

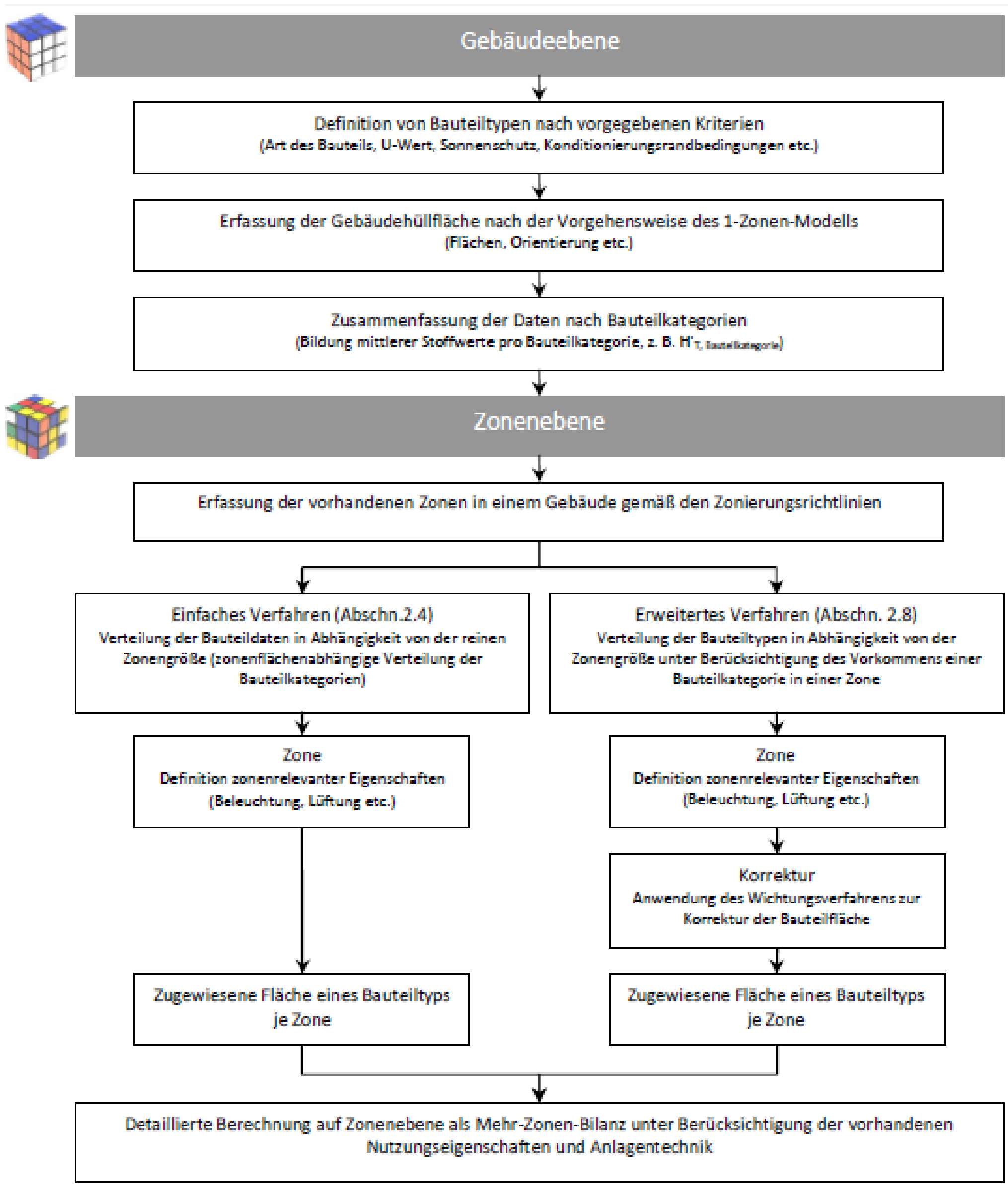


Figure 5. Schematic procedure for the building elements allocation from the building envelope data upto the zone level. Source: *„Vereinfachungen für die energetische Bewertung von Gebäuden“.* Markus Lichtmess. PhD Dissertation 2010

The use of a simple correction factor 0 for the not existence and 1 for the existence of a certain building element in a given building zone (as shown in equation (6)) results in a total error in the primary energy calculation below 2 $[kWh/m^2a]$ respectively 1 % in comparission to the calculated primary energy using the detailed procedure of the norm DINV 18599 in all documented cases presented in the document : *„Vereinfachungen für die energetische Bewertung von Gebäuden“* (Markus Lichtmess 2010)[7].

2.3.3 Monthly balance procedure for the calculation of the energy-use and final energy for lighting (DIN V 18599-4)

Since lighting appliances count along with the heat from persons and devices as part of the internal heat sources, it is reasonable to calculate the energy use for lighting before doing the monthly balance for the heating and cooling energy need.

The calculation scheme of the required energy for lighting purposes is presented in the Figure 6 which corresponds to the "Bild 3" of the norm DIN V18599-4:

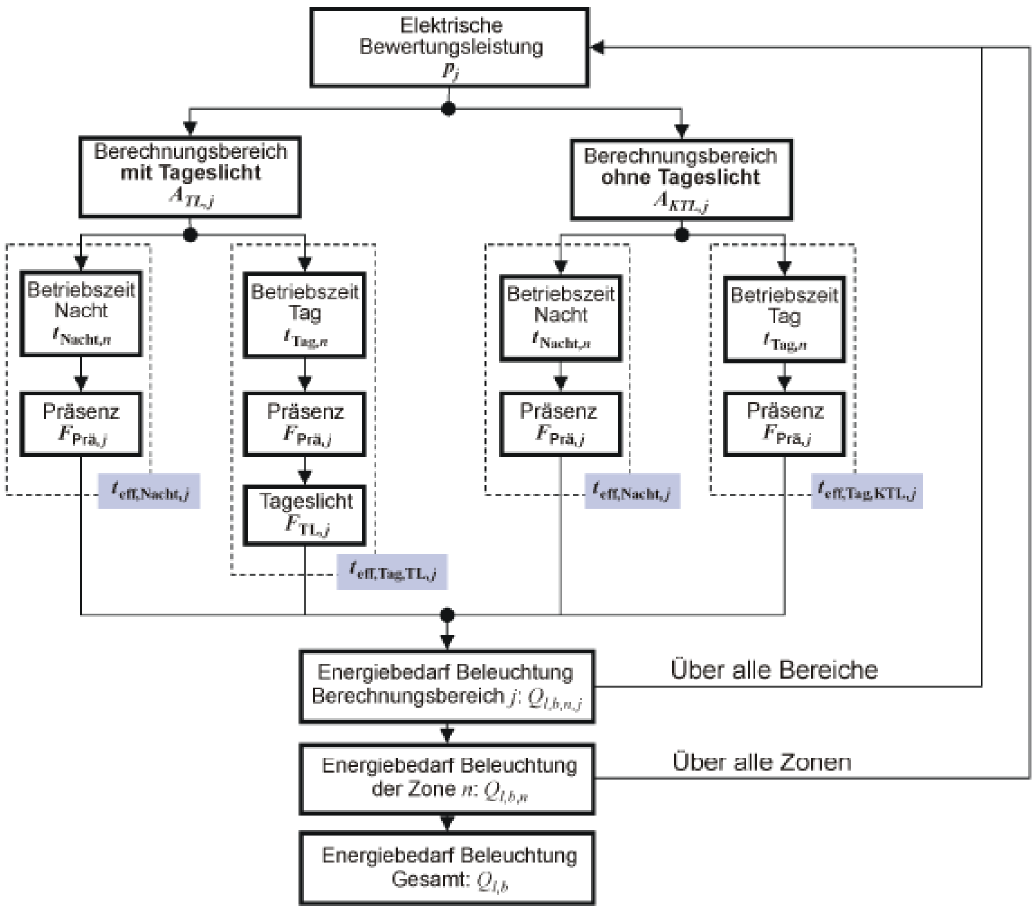


Figure 6. Lighting calculation scheme according to DINV 18599-4 norm. Source DIN V 18599-4

The energy use for lighting arise from the sum of the energy use for lighting over all individual zones and areas. There are basically two calculation domains. The one where there is daylight and the other where there is only artificial lighting. For each one of this domains, the calculation is subdivided in the day-time and night-time calculation. At this point, factors like the windows size, the daylight hours per day (also dependent on the time of the year (month) and sun protection constructive elements) and the use of presence sensors play an important role in the amount of energy needed for lighting.

The value in $[h/m^2]$ obtained from the lighting operation time multiplied by the respective areas is then multiplied by the specific assessment power of the lighting device of the zone as shown in equation (11) in order to get the net energy for lighting in $[kWh]$ respectively the specific net energy for lighting in $[kWh/m^2a]$.

Finally the sum over all zones of the net energy for lighting in (11) multiplied by the operation factor for lighting of the zone as shown in equation (10), result in the final energy for lighting.

The following basic equations grossly describe the calculation scheme shown in Figure 6:

$$Q_{l,f} = \sum_{1}^{N} Q_{l,n} * F_{t,n} \tag{10}$$

$$Q_{l,n} = p_j * [\, A_{TL,n}(t_{eff,day,TL} + t_{eff,night,TL}) + A_{KTL,n}(t_{eff,day,KTL} + t_{eff,night,KTL})] \tag{11}$$

$$A_{TL,n} + A_{KTL,n} = A_n \tag{12}$$

Where:

$p_j =: Specific\ assessment\ power\ \left[\frac{W}{m^2}\right]$

$F_{t,n} =: Operation\ factor\ for\ lighting\ of\ the\ zone$

$A_{TL,n} =: Area\ supplied\ with\ daylight\ [m^2]$

$A_{KTL,n} =: Area\ supplied\ with\ artificial\ light\ [m^2]$

$t_{eff,day,TL} =: effective\ operation\ time\ of\ lighting\ system\ in\ area\ supplied\ with\ daylight\ [h]$

$t_{eff,night,TL} =: effective\ operation\ time\ of\ lighting\ system\ in\ area\ supplied\ with\ artificial\ light\ [h]$

$A_n =: Area\ of\ the\ zone$

2.3.4 Monthly balance procedure for the calculation of the energy need for heating and cooling (DIN V 18599-2)

The core of the MATLAB BEP model is the balancing equation of heat sinks and sources. The energy need for heating and cooling depend on the sum of all heat sinks and sources and a utilization factor that dictates how much heat can be used from the heat sources. The following scheme from the norm DIN V 18599 summarizes the idea:

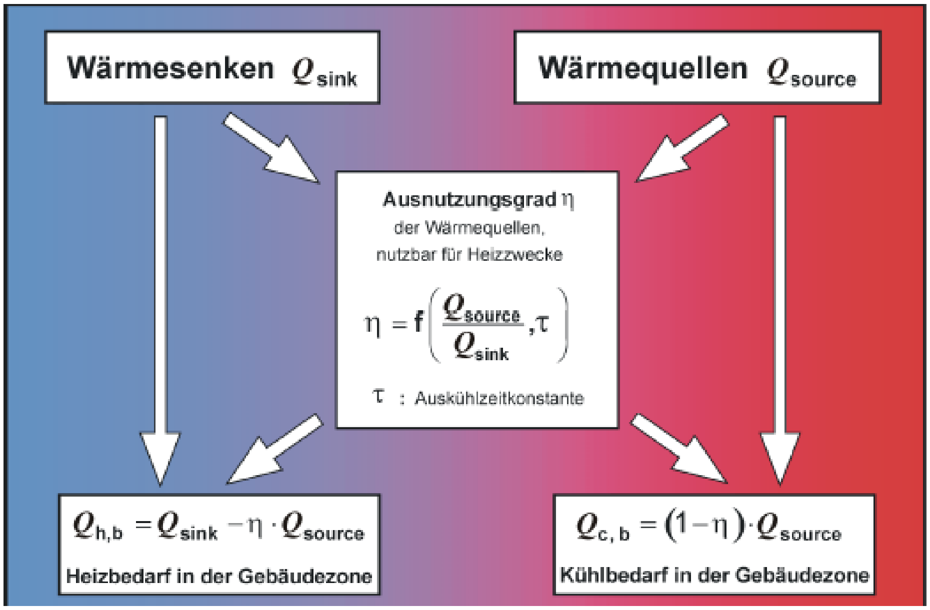


Figure 7. Heat sources and heat sinks balancing scheme. Source DIN V 18599-2

The considered heat sources are:

- **Solar heat gains** through transparent (windows) and opaque building elements.
- **Internal heat sources** composed by: Persons, devices, lighting and distribution losses of the technical systems.
- **Transmission sources**, which depend mainly on the specific heat (transmission) transfer coefficient H_T' in $[W/m^2K]$ and the internal and external temperature difference. In this case when the monthly average exterior temperature is greater than the internal balance temperature: $\theta_i < \theta_{e\,[month]}$.
- **Ventilation sources**, composed by heat sinks through infiltration, heat sinks through window ventilation and by heat sinks through mechanical ventilation. They depend on the ventilation coefficient H_V and the internal and external temperature difference. In this case when the monthly average exterior temperature (or ventilation system air intake temperature) is greater than the internal balance temperature: $\theta_i < \theta_{e\,[month]}$.

The considered heat sinks are:

- **Transmission sinks**, which depend mainly on the specific heat (transmission) transfer coefficient H'_T in $[W/m^2K]$ and the internal and external temperature difference. In this case when the monthly average exterior temperature is lower than the internal balance temperature: $\theta_i > \theta_{e\,[month]}$
- **Ventilation sinks**, composed by heat sinks through infiltration, heat sinks through window ventilation and by heat sinks through mechanical ventilation. They depend on the ventilation coefficient H_V and the internal and external temperature difference. In this case when the monthly average exterior temperature (or ventilation system air intake temperature) is lower than the internal balance temperature: $\theta_i > \theta_{e\,[month]}$.

The utilization factor η is a function of the heat sources and sinks ratio γ and a building time constant τ. This last one is the ratio between the building thermal capacity and the sum of the transmission and ventilation heat transfer coefficients.

The heat sources and sinks ratio is described as:

$$\gamma = \frac{Q_{Source}}{Q_{Sink}} \tag{13}$$

The building time constant is:

$$\tau = \frac{C_{Wirk}}{H} \tag{14}$$

With:

$$H = H_T + H_V = \sum_i H_T, i + \sum_j H_V, j + H_{V,mech,\theta} \tag{15}$$

Where:

$H =: Total\ heat\ transfer\ coefficient\ including\ the\ mechanical\ ventilation$

$H_T =: sum\ of\ heat\ (transmission)\ transfer\ coefficients\ over\ all\ buildings\ elements\ i$

H_V
$=: sum\ of\ heat\ (ventilation)\ transfer\ coefficients\ over\ all\ airflows\ with\ external\ temperature$

$H_{V,mech,\theta} =: temperature - weighted\ transfer\ coefficients\ of\ the\ mechanical\ ventilation$

$C_{Wirk} =: Effective\ thermal\ capacity\ of\ the\ building\ zone$

The utilization factor is then defined as:

$$\eta = \frac{1-\gamma^{a}}{1-\gamma^{a+1}} \ when\, \gamma \neq 1 \quad and\ \ \eta = \frac{a}{a+1}\ when\, \gamma = 1 \tag{16}$$

With:

$$a = a_0 + \frac{\tau}{\tau_0} \tag{17}$$

Where a_0 and τ_0 are constants and take the values $a_0 = 1$ and $\tau_0 = 16\ [h]$

The basic equation for the energy need for cooling is expressed then as:

$$Qc, b = (1-\eta) * Q_{Source} = (1-\eta) * (Q_S + Q_{Isource}) \tag{18}$$

And the basic equation for the energy need for heating is:

$$Qh, b = Q_{sink} - \eta * Q_{Source} - \Delta Q_{c,b} = \quad Q_T + Q_V - \eta * (Q_S + Q_{Isource}) - \Delta Q_{c,b} \tag{19}$$

Where:

$Qh, b =: Energy\ need\ for\ heating\ in\ the\ zone$

$\eta =: Utilization\ factor$

$\Delta Qc, b =: Stored\ heat\ during\ time\ of\ reduced\ operation$

$Q_T =: Transmission\ sinks$

$Q_V =: Ventilation\ sinks$

$Q_S =: Solar\ gains$

$Q_{ISource} =: Internal\ heat\ sources$

2.3.5 Calculation of the energy need for domestic hot water (DIN V 18599-8)

The calculation of the energy need for domestic hot water is based on the boundary conditions of the part 10 of the DIN V18599 norm. For residential buildings, fixed values are given: 11 $[kWh/m^2a]$ for single-family houses and 15 $[kWh/m^2a]$ for multi-family houses.

For non-residential buildings the energy need for domestic hot water can be calculated either using a fixed value depending on the zone size using the square meters of the zone as reference value like in the case of residential buildings, or using a different reference value depending on the specific activity of the building. For example for a hospital, a reference value of 6 $[kWh/bed * day]$ is given and for a restaurant, a reference value of of 1,1 $[kWh/seat * day]$ is given.

The base equation for the monthly calculation is in this case:

$$Q_{dhw,b} = q_{dhw,\ day} * R_{dhw} * d_{op,\ mth} \tag{20}$$

Where:

$Q_{dhw,b} =: Monthly\ energy\ need\ for\ domestic\ hot\ water\ \left[\frac{kWh}{month}\right]$

$q_{dhw,day} =: Daily\ energy\ need\ reference\ \ value\ \left[\frac{kWh}{Reference * day}\right]\ R_{dhw} =$
$: Reference\ value\ (e.g: building\ ocupants,\ number\ of\ beds,\ number\ of\ seats)$

$d_{op,\ mth} =: system\ operating\ time\ within\ the\ month\ defined\ as\ a\ use - boundary\ condition\ [days]$

2.3.6 Calculation of the control and emission, distribution and storage energy losses for heating, cooling and domestic hot water systems (DIN V18599-5/ DIN V18599-6/ DIN V18599-7 and DIN V18599-8)

The technical losses are determined based on the information about the technical systems and the building characteristics including the building envelope, pipes materials and arrangement, heat producer location, distribution circuit temperatures and use boundary conditions, taking into account the model assumptions and simplifications. The three main system losses components from the heat producer up to the end-use are:

- Storage losses
- Distribution losses
- Control and emission losses

Following schemes from the norm DIN 4701-10 show the representative calculation chain for the space heating and domestic hot water system:

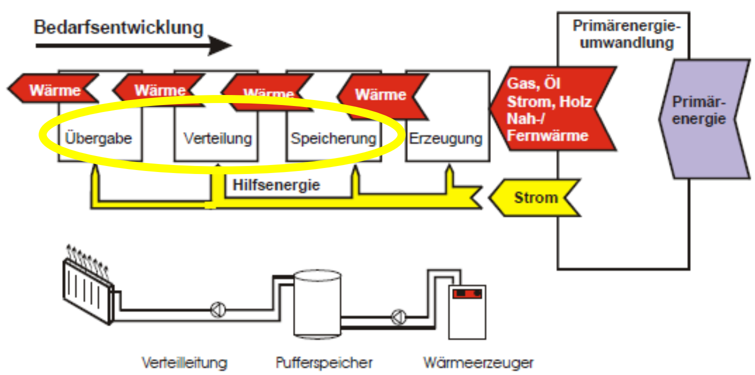


Figure 8.Schematic calculation of the space heating. Source: DIN 4701-10

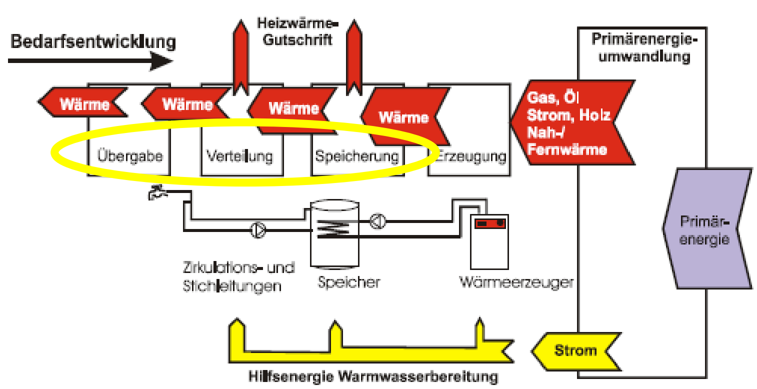


Figure 9. Schematic calculation of the domestic hot water. Source: DIN 4701-10

Most significant contributions to technical losses come from the distribution component. Nonetheless, each of the following components are calculated:

For the space Heating system the three components are calculated:

- **Control and emission losses**

$$Q_{h,ce,a} = \sum_{month} Q_{h,ce} \tag{21}$$

$$Q_{h,ce} = \left(\frac{f_{RADIANT} * f_{int} * f_{Hydr}}{n_{h,ce}} - 1\right) * Q_{h,b} \tag{22}$$

Where:

$f_{RADIANT}$ =: $Factor\ for\ the\ radiation\ effect\ (only\ significant\ for\ roomheight\ h > 4m)$

f_{int} =: $Factor\ \ for\ intermitent\ operation;\ f_{int} = 1\ for\ continuous\ operation$

f_{Hydr} =: $Factor\ for\ the\ hydraulic\ balance$

$n_{h,ce}$ =: $Overall\ efficiency\ for\ the\ heat\ delivery$

$Q_{h,b}$ =: $Energy\ need\ for\ heating$

- **Distribution losses**

$$Q_{h,d} = \sum Q_{h,d,i} \tag{23}$$

$$Q_{h,d,i} = \frac{1}{1000} * U_i * \left(\theta_{HK_{av}} - \theta_I\right) * L * t_{h,rL} \tag{24}$$

Where:

U_i =: $Heat\ transfer\ coeffcient\ in\ [W/mK]$

$\theta_{HK_{av}}$ =: $Average\ medium\ temperature\ in\ [°C]$

θ_I =: $Zone\ internal\ temperature\ in\ [°C]$

L =: $Pipe\ length\ in\ [m]$

$t_{h,rL}$ ≔ $monthly\ operation\ time\ "run - time"\ in\ [h]$

$Q_{h,d,i}$ =: $Monthly\ distribution\ heat\ losses\ (space\ heating) in\ [kWh]$

- **Storage losses**

$$Q_{h,s} = f_{Verbindung} * \frac{(\theta_{h,s} - \theta_I)}{45} * d_{OP,mth} * Q_{PO,s,day} \quad (25)$$

Where:

$f_{Verbindung} =: factor\ for\ the\ location\ of\ the\ storage\ unit\ and\ heat\ producer\ (same\ room\ f = 1{,}2)$

$\theta_{h,s} =: Average\ medium\ temperature\ of\ the\ storage\ in\ [°C]$

$\theta_I =: Zone\ internal\ temperature\ according\ to\ table\ 20\ of\ the\ norm\ DINV18599 - 5\ in\ [°C]$

$d_{OP,mth} =: Monthly\ time\ of\ use\ "days\ of\ operation"\ \ in\ [d]$

$Q_{PO,s,day} =: Daily\ stand - by\ heat\ losses\ in\ [kWh/d]$

$Q_{h,s} =: Monthly\ storage\ heat\ losses\ (space\ heating)\ in\ [kWh]$

For the domestic hot water system, the control and emission losses are already included in the energy need for domestic hot water, so only the other two are calculated:

- **Distribution losses**

$$Q_{w,d} = \sum Q_{w,d,i} \quad (26)$$

$$Q_{w,d,i} = \frac{1}{1000} * U_i * L_i(\theta_{w,av} - \theta_I) * d_{OP,mth} * t_{OP,day} \quad (27)$$

Where:

$U_i =: Heat\ transfer\ coeffcient\ in\ [W/mK]$

$\theta_I =: Zone\ inner\ temperature\ in\ [°C]$

$L =: Pipe\ length\ in\ [m]$

$\theta_{w,av} = : Average\ temperature\ of\ the\ pipe\ section\ in\ [°C]$

$d_{OP,mth} =: Monthly\ time\ of\ use\ of\ the\ domestic\ hot\ water\ system\ in\ [d]$

$t_{OP,day} =: Daily\ time\ of\ use\ with\ the\ corresponding\ \theta_{w,av}\ in\ [h]$

$Q_{w,d,i} = : Monthly\ pipe\ section\ distribution\ heat\ losses\ (domestic\ hot\ water\ ssytem) in\ [kWh]$

- **Storage losses**

$$Q_{w,s} = f_{Verbindung} * \frac{(50 - \theta_I)}{45} * d_{OP,mth} * Q_{PO,s,day} \tag{28}$$

Where:

$f_{Verbindung} =: factor\ for\ the\ additional\ heat\ losses\ in\ the\ pipe\ conections\ (\ f\ = 1{,}2)$

$\theta_I =: Zone\ internal\ temperature\ according\ to\ table\ 9\ of\ the\ norm\ DINV18599 - 8\ in\ [°C]$

$d_{OP,mth} =: Monthly\ time\ of\ use\ "days\ of\ operation"\ (DHW)\ in\ [d]$

$Q_{PO,s,day} =: Daily\ stand - by\ heat\ losses\ in\ [kWh/d]$

$Q_{w,s} =: Monthly\ storage\ heat\ losses\ (DHW)\ in\ [kWh]$

For the conventional cooling system the storage component is not considered in the model, so only the other two are calculated:

- **Control and emission losses**

$$Q_{c,ce} = \left((1 - n_{c,ce}) + (1 - n_{c,ce,sens})\right) * Q_{c,b} \tag{29}$$

Where:

$n_{h,ce} =: Efficiency\ for\ the\ cooling\ system\ delivery\ (table\ 13\ of\ the\ norm\ DIN\ V18599 - 7)$

$n_{h,ce,sens} =: Sensible\ efficiency\ for\ the\ cooling\ system\ delivery\ (table\ 13\ DIN\ V18599 - 7)$

$Q_{c,b} =: Energy\ need\ for\ cooling\ (output\ of\ the\ monthly\ balance\ procedure\ DINV\ 18599 - 2)$

$Q_{c,ce} =: Delivery\ losses\ of\ the\ conventional\ cooling\ system$

- **Distribution losses**

$$Q_{c,d} = (1 - n_{c,d}) * Q_{c,b} \tag{30}$$

Where:

$n_{h,d} =: Efficiency\ for\ the\ cooling\ system\ distribution\ (table\ 13\ of\ the\ norm\ DIN\ V18599 - 7)$

$Q_{c,b} =: Energy\ need\ for\ cooling\ (output\ of\ the\ monthly\ balance\ procedure\ DINV\ 18599 - 2)$

$Q_{c,d} =: Distribution\ losses\ of\ the\ conventional\ cooling\ system$

2.3.7 Distribution of the calculated energy use by energy carrier.

The energy use of all heat producers shall be split into each technical heat production system. The following scheme presents the considered heat producers in the MATLAB BEP model:

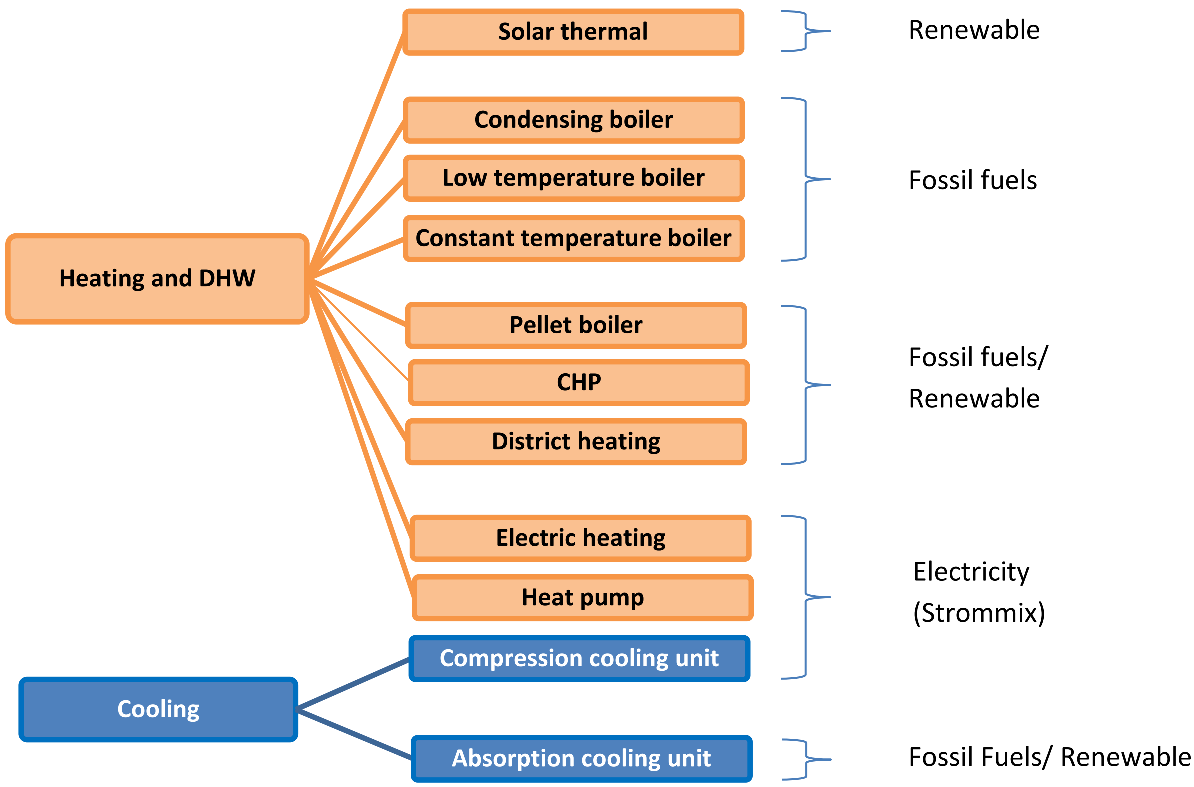


Figure 10. Energy use by energy carrier

The four defined heat producers are:

- Heat producer 1 “Wärmeerzeuger” WE_1 : Solar thermal
- Heat producer 2 “Wärmeerzeuger” WE_2 : CHP Combined heat and power
- Heat producer 3 “Wärmeerzeuger” WE_3 : Boiler/ District heating / Electricity/Heat pump
- Heat producer 4 “Wärmeerzeuger” WE_4 : Electricity “Direkt strom”

The defined cooling unit is:

- Compression/Absorption cooling unit

A simplified Photovoltaic system is also included in the model, taking into account its peak power and the cell type and orientation. The monthly net electricity production is defined as:

$$Q_{f,prod,PV,j} = \frac{E_{sol} * P_{pk} * f_{perf}}{I_{ref}} \quad (31)$$

With:

$$E_{sol} = I_{sol} * d_{mth} * \frac{24\left[\frac{h}{d}\right]}{1000\left[\frac{W}{kW}\right]} \tag{32}$$

And:

$$P_{pk} = K_{pk} * A \tag{33}$$

Where:

E_{sol} =: $Monthly\ solar\ radiation\ energy\ on\ the\ PV\ system\ in\ [kWh/m^2]$

P_{pk} =: $PV\ Peak\ power\ under\ standard\ test\ conditions\ in\ \ [kW]$

f_{perf} =: $PV\ system\ power\ factor\ according\ to\ table\ B.1\ from\ the\ norm\ DINV18599 - 9$

I_{sol} =: $Monthly\ solar\ irrandiance\ (depends\ on\ location, orientation\ and\ inclination)\ in\ [kW/m^2]$

I_{ref} =: $Reference\ solar\ irrandiance = 1\ [kW/m^2]$

d_{mth} =: $number\ of\ days\ in\ the\ month\ in\ [d]$

K_{pk} =: $surface\ related\ peak\ power\ coefficient\ (table\ A.2\ DINV18599 - 9)\ in\ [kW/m^2]$

A =: $Total\ PV\ mdule\ surface\ in\ [m^2]$

$Q_{f,prod,PV,j}$ =: $Monthly\ net\ electricity\ production\ from\ the\ Photovoltaic\ system\ in\ [kWh]$

This input together with the on-site CHP system result in the total on-site produced electricity.

2.3.8 Calculation of the final energy by means of the generation-expenditure factor

Once the technical systems have been defined, all technical losses have been calculated and the energy use $Q_{h,outg}$ has been separated by heat producer i, the final energy is determined using the generation-expenditure coefficients. Final energy is calculated for each end-use as the sum over all heat producers as follow:

- Space heating

$$Q_{h,outg} = Q_{h,b} + Q_{h,ce} + Q_{h,\,d} + Q_{h,s} \tag{34}$$

$$Q_{h,f} = \sum_{i} Q_{h,outg,i} * e_{h,g,i} \tag{35}$$

- Domestic hot water

$$Q_{dhw,outg} = Q_{dhw,b} + Q_{dhw,d} + Q_{dhw,s} \tag{36}$$

$$Q_{dhw,f} = \sum_{i} Q_{dwh,outg,i} * e_{dwh,g,i} \tag{37}$$

- Cooling

$$Q_{c,outg} = Q_{c,b} + Q_{h,ce} + Q_{h,\,d} \tag{38}$$

$$Q_{c,f} = \sum_{i} Q_{c,outg,i} * e_{c,g,i} \tag{39}$$

Where:

$Q_{x,b}$ =: $Total\ energy\ need\ in\ [kWh]$

$Q_{x,ce}$ =: $Control\ and\ emission\ losses\ in\ [kWh]$

$Q_{x,d}$ = $Distribution\ losses\ in\ [kWh]$:

$Q_{x,s}$ =: $Storage\ losses\ in\ [kWh]$

$Q_{x,outg}$ =: $Total\ energy\ use\ \ by\ end-use\ in\ [kWh]$

$Q_{x,outg,i}$ =: $Energy\ use\ \ by\ the\ heat\ producer\ i\ in\ [kWh]$

$e_{x,g,i}$ =: $generation - expenditure\ factor$

$Q_{x,f}$ =: $Final\ energy\ in\ [kWh]$

Within this step, the auxiliary energy (additional consumed electricity for auxiliary processes like electrical drives and controllers among others) is also calculated and added to the component "electricity" of the final energy in order to obtain the total final energy.

The considered auxiliary energy components in the model are:

- Space heating generation $W_{h,gen}$
- Space heating distribution $W_{h,d}$
- domestic hot water generation $W_{w,gen}$
- domestic hot water distribution $W_{w,d}$
- cooling system distribution and heat exchange $W_{c,rs}$, $W_{c,d}$, $W_{c,rk}$

2.3.9 Calculation of the primary energy and CO2 Emissions by means of the primary energy and CO2 emission factors

Each country has its own primary energy factors which also change over time. This change over time is even more pronounced for the electricity due to the continuous growth in the share of renewable energies.

The employed primary energy and CO2 factors for the BEP model by country are listed below:

- **Austria: OIB Richtlinie 6 (OIB-330.6 2015)**

Table 1. Primary energy and CO2 Factors Austria. Source: OIB Richtlinie 6 (OIB-330.6 2015)

	Energieträger	f_{PE} [-]	$f_{PE,n.ern.}$ [-]	$f_{PE,ern.}$ [-]	f_{CO2} [g/kWh]
1	Kohle	1,46	1,46	0,00	337
2	Heizöl	1,23	1,23	0,01	311
3	Erdgas	1,17	1,16	0,00	236
4	Biomasse	1,08	0,06	1,02	4
5	Strom-Mix Österreich (inkl. Netto-Importe)	1,91	1,32	0,59	276
6	Fernwärme aus Heizwerk (erneuerbar)	1,60	0,28	1,32	51
7	Fernwärme aus Heizwerk (nicht erneuerbar)	1,52	1,38	0,14	291
8	Fernwärme aus hocheffizienter KWK (1) (Defaultwert)	0,94	0,19	0,75	28
9	Fernwärme aus hocheffizienter KWK (1) (Bestwert)	≥ 0,30	gemäß Einzelnachweis (2)		≥ 20
10	Abwärme (Defaultwert)	1,00	1,00	0,00	20
11	Abwärme (Bestwert)	≥ 0,30	gemäß Einzelnachweis (2)		≥ 20

(1) … Als hocheffiziente Kraft-Wärme-Kopplung (KWK) werden all jene angesehen, die der Richtlinie 2004/8/EG entsprechen.
(2) … Für den Fall, dass ein Einzelnachweis gemäß EN 15316-4-5 durchgeführt wird, dürfen keine kleineren Werte als für industrielle Abwärme verwendet werden. Die Randbedingungen zum Berechnungsverfahren sind im Dokument „Erläuternde Bemerkungen" festgehalten.

- **Germany: DIN V 18599 / expected new EnEV 2016**

Primary energy factors are taken from the norm DIN V 18599 with exception of the factor for electricity already known from the new EnEV that corresponds to 1.8 (non-renewable). CO2 Emission factors are taken from the IWU and GEMIS reports with exception of the factor for electricity which is 494 $[g/\,kWh]$ for 2017 and has been taken from the document "Weiterentwicklung der Primärenergiefaktoren im neuen Energiesparrecht für Gebäude"[10].

Table 2. Primary energy and CO2 Factors Germany. Source: Deutsche Wohngebäudetypologie. Beispielhafte Maßnahmen zur Verbesserung der Energieeffizienz von typischen Wohngebäuden. Tobias Loga, Britta Stein, Nikolaus Diefenbach, Rolf Born. ISBN: 978-3-941140-47-9

Tab. 21: Übersicht über die Bewertungsfaktoren für Endenergie (vgl. [EPISCOPE SR1])

	offizielles Verfahren		alternative Systematik		
Art des Bewertungsfaktors	Primärenergiefaktor gesamt EnEV-Verfahren	Primärenergiefaktor nicht-erneuerbar EnEV-Verfahren	kumulierter Energieaufwand gesamt nach GEMIS + IWU	kumulierter Energieaufwand nicht-erneuerbar nach GEMIS + IWU	Treibhausgas-Emissionen (CO_2-Äquivalent) GEMIS + IWU
verwendet für Energieausweis		x			
verwendet für Nachweisverfahren Neubau		x			
Bezeichnung	Primärenergiefaktor gesamt nach DIN V 18599-1:2011-12	Primärenergiefaktor nicht-erneuerbar nach DIN V 18599-1:2011-12	kumulierter Energieaufwand gesamt GEMIS + Bewertung KWK nach Gesamteffizienz-Methode des IWU	kumulierter Energieaufwand nicht-regenerativer Anteil GEMIS + Bewertung KWK nach Gesamteffizienz-Methode des IWU	Treibhausgase (CO2-Äquivalent) GEMIS + Bewertung KWK nach Gesamteffizienz-Methode des IWU
Referenz	[DIN V 18599:2011]	[DIN V 18599:2011]	[GEMIS] version 4.9 bzw. [IWU 2014] + [Hörner 2014] (KWK)	[GEMIS] version 4.9 bzw. [IWU 2014] + [Hörner 2014] (KWK)	[GEMIS] version 4.9 bzw. [IWU 2014] + [Hörner 2014] (KWK)
Einheit	[-]	[-]	[-]	[-]	[g/kWh]
Erdgas	1,1	1,1	1,13	1,13	239 494
Heizöl	1,1	1,1	1,16	1,15	313
Feuerholz	1,2	0,2	1,01	0,01	11
Holz-Pellets	1,2	0,2	1,08	0,06	18
Strom	2,8	2,4 / 1,8 *	2,71	2,19	631
Stromerzeugung PV	1,0	0,0	1,25 **	0,23 **	62 **
Stromerzeugung KWK	2,8	2,8	1,90 ***	1,90 ***	346 ***
Fernwärme	1,3	1,3	1,32	1,08	****
Fernwärme ohne KWK	1,3	1,3	****	****	****
Fernwärme mit 100% KWK	0,7	0,7	****	****	****

*) Abweichung EnEV 2014 von DIN V 18599, gültig ab Januar 2016

**) Stromproduktion PV System, wenn der PV-Strom als ein Energieträger für die Gebäudeversorgung betrachtet wird; einschließlich Aufwand für Produktion und Installation der PV-Systeme; Annahme: polykristalline Zellen; Standardwerte für andere Typen: amorphe Zellen: 0,27 (81 g/kWh); monokristalline Zellen 0,47 (127 g/kWh)

***) abhängig von der KWK-Anlagengröße, hier ermittelt für gasbefeuertes BHKW mit 50 kW elektrischer Leistung, siehe [Hörner 2014]

****) noch nicht ermittelt

[10] DVGW Deutscher Verein des Gas- und Wasserfaches e.V / Zukunft ERDGAS Projekt GmbH "Weiterentwicklung der Primärenergiefaktoren im neuen Energiesparrecht für Gebäude". Endbericht 07.04.2016

- **Spain: Real decree 235 / RITE (Reglamento técnico de instalaciones térmicas)**

Table 3.Primary energy factors Spain. Source: "Factores de emisión de CO2 y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector de edificios en España". IDAE

Factores de conversión de energía final a primaria					
		Valores aprobados			Valores previos (****)
	Fuente	kWh E.primaria renovable /kWh E. final	kWh E.primaria no renovable /kWh E. final	kWh E.primaria total /kWh E. final	kWh E.primaria /kWh E. final
Electricidad convencional Nacional	(*)	0,396	2,007	2,403	
Electricidad convencional peninsular	(**)	0,414	1,954	2,368	2,61
Electricidad convencional extrapeninsular	(**)	0,075	2,937	3,011	3,35
Electricidad convencional Baleares	(**)	0,082	2,968	3,049	
Electricidad convencional Canarias	(**)	0,070	2,924	2,994	
Electricidad convencional Ceuta y Melilla	(**)	0,072	2,718	2,790	
Gasóleo calefacción	(***)	0,003	1,179	1,182	1,08
GLP	(***)	0,003	1,201	1,204	1,08
Gas natural	(***)	0,005	1,190	1,195	1,01
Carbón	(***)	0,002	1,082	1,084	1,00
Biomasa no densificada	(***)	1,003	0,034	1,037	
Biomasa densificada (pelets)	(***)	1,028	0,085	1,113	

Table 4. CO2 emission factors Spain. Source: "Factores de emisión de CO2 y coeficientes de paso a energía primaria de diferentes fuentes de energía final consumidas en el sector de edificios en España". IDEA

Factores de emisiones de CO2			
		Valores aprobados	Valores previos (****)
	Fuente	kg CO2 /kWh E. final	kg CO2 /kWh E. final
Electricidad convencional Nacional	(*)	0,357	
Electricidad convencional peninsular	(**)	0,331	0,649
Electricidad convencional extrapeninsular	(**)	0,833	0,981
Electricidad convencional Baleares	(**)	0,932	
Electricidad convencional Canarias	(**)	0,776	
Electricidad convencional Ceuta y Melilla	(**)	0,721	
Gasóleo calefacción	(***)	0,311	0,287
GLP	(***)	0,254	0,244
Gas natural	(***)	0,252	0,204
Carbón	(***)	0,472	0,347
Biomasa no densificada	(***)	0,018	neutro
Biomasa densificada (pelets)	(***)	0,018	neutro

- **England: SAP 2012 / Emission factors and primary energy factors 15-year projection (2013 – 2027)**

The BRE Group has published a projection for the primary energy and CO2 emission factors based on the values given in the Table 12 of the Government's Standard Assessment Procedure for Energy Rating of Dwellings SAP 2012:

Table 5. Primary energy and CO2 Factors England. Source: Emission factors and primary energy factors 15-year projection (2013 – 2027). Retrived from https://www.bre.co.uk/filelibrary/SAP/2012/Emission-and-primary-factors-2013-2027.pdf

Fuel	Emissions kg CO_2 per kWh	Primary energy factor
Gas:		
mains gas	0.222	1.28
Electricity:		
all tariffs, import or export	0.381	3.28
Community heating schemes:		
heat from boilers – mains gas	0.222	1.28
waste heat from power station	0.042	1.36
geothermal heat source	0.030	1.26
electricity, import or export	0.381	3.28

2.4 MATLAB BEP Model validation

The developed MATLAB BEP model has been validated using the EnerCalC excel-tool version 4.43.110 and the available results from the Tabula web-tool. The results of three well documented buildings have been compared to the results obtained by the own developed model.

The first building corresponds to the basic example of the EnerCalC excel-tool and it is a non-residential building (office building) with 7 zones. The second considered building is the built under passive house concept “Kleehäuser im Freiburger Vauban- Viertel” also presented as a study case by the EnOB: ‘Forschung für Energieoptimiertes Bauen’[11]. This two buildings are located in Germany, thus the DINV 18599 reference climate is used for both cases.

The third one is precisely the Single-Family House for Austria **AT_N_SFH_08** subjected to normal refurbishment which corresponds to the case/scenario 2: **AT_N_SFH_08_GEN_2**. For this last building, the MATLAB model results were compared with both EnerCalC excel-tool results and the available results from the TABULA web-tool. The Austrian reference climate designated in the ÖE Norm 8110-5 is used in this case.

The results from this last building validation however, differ from the actual results presented on chapter 4 ‘Quantitative energy indicators comparison and nZEB status achievement’ for the case **AT_N_SFH_08_GEN_2** because of the following main differences:

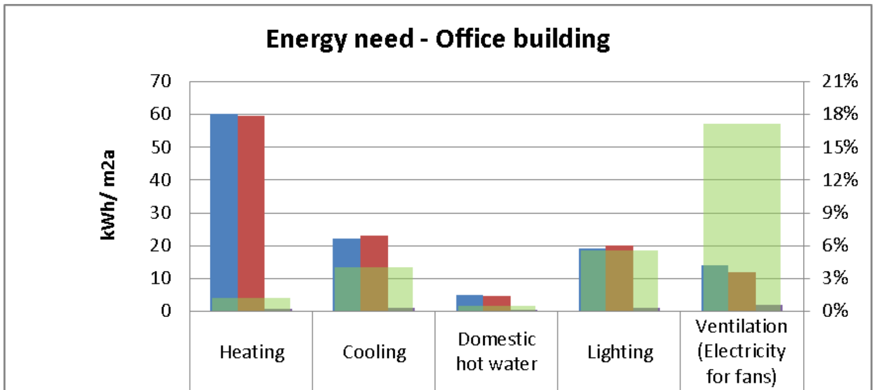
- Use of different primary energy and CO2 factors than those stated by norm in the Austrian OIB Guideline 6 (Tabula web-tool predefined factors are used since these cannot be changed and results are calculated based on them):
    - Primary energy factor Gas: 1.23 $[kWh_{prim}/kWh_{final}]$
    - CO2 Emissions factor Gas: 311 $[gCO_2/\ kWh\_final]$
    - Primary energy factor Electricity (non-renewable):2.15 $[kWh_{prim}/kWh_{final}]$
    - CO2 Emissions factor Electricity: 417 $[gCO_2/\ kWh\_final]$
- Consideration of the energy consumption for cooling (not the case under Austrian nZEB definition).
- Use of different lighting technology. For the validation Fluorescent lamps with electronic ballast are used instead of LED lamps (used for the quantitative comparison in chapter 4).
- Use of ventilation fans and hence inclusion of electricity for this end- use component.

The results are presented in this section. Detailed information about the Buildings and input data for the model validation is presented in the ANNEX A.

[11] Nullenergiegebäude as Gebäude Realität. EnOB: Forschung für Energieoptimiertes Bauen. Retrieved from: http://www.enob.info/de/nullenergie-plusenergie-klimaneutrale-gebaeude-im-stromnetz-20/nullenergiegebaeude-als-gebaute-realitaet/

- **EnerCalC example : Simple office building**

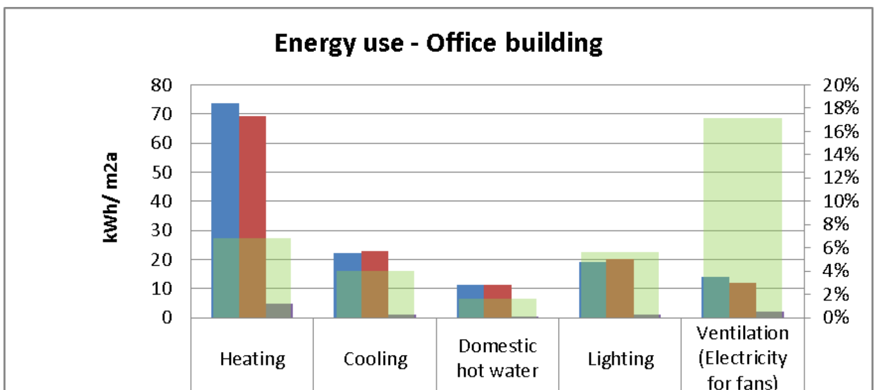
Energy need for heating followed by energy need for cooling are the most significant components. However the maximum relative error is each case less than 4%. On the other hand, relative error in the electricity for fans is around 17%. Nonetheless the absolute difference is only 2.06 kWh/m^2a.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	60,23	22,08	4,82	19,07	14,06
EnerCalc2013	59,50	23,00	4,80	20,20	12,00
Absolute error	0,73	0,92	0,02	1,13	2,06
relative error	1,22%	3,99%	0,49%	5,60%	17,18%

Figure 11. Energy needs – Simple office building

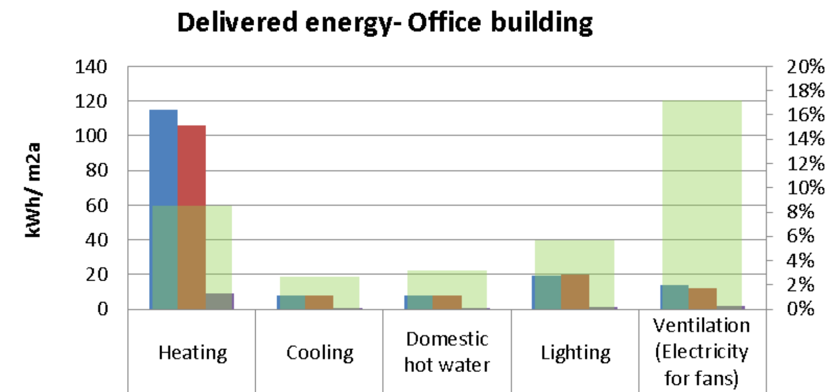
The maximal relative error for the energy use (without counting the already mentioned electricity for fans) is under 7% for the heating component and it is due to slight mismatches in the calculation of the technical (distribution, control and emission and storage) losses.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	73,83	22,08	11,22	19,07	14,06
EnerCalc2013	69,10	23,00	11,40	20,20	12,00
Absolute error	4,73	0,92	0,18	1,13	2,06
relative error	6,84%	3,99%	1,61%	5,60%	17,18%

Figure 12. Energy use – Simple office building

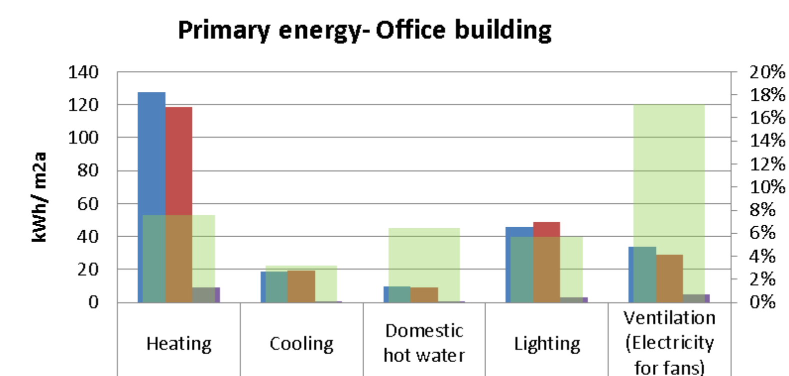
As expected, the more parameters involved, the greater the error. Once again however, the maximum relative error (without counting the already mentioned electricity for fans) corresponds to the heating component and it is still under 9%.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	115,21	7,79	7,95	19,05	14,06
EnerCalc2013	106,20	8,00	7,70	20,20	12,00
Absolute error	9,01	0,21	0,25	1,15	2,06
Relative error	8,49%	2,65%	3,19%	5,68%	17,18%

Figure 13. Delivered energy– Simple office building

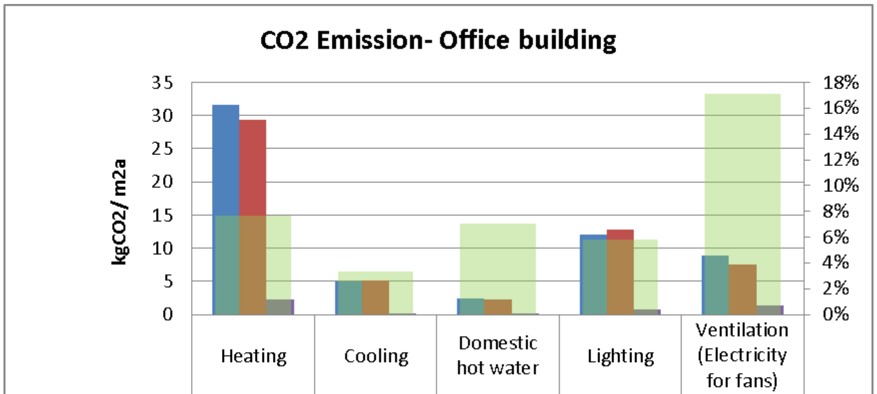
Finally, the primary energy consumption and CO2 Emissions are dictated by the primary energy and CO2 Emissions factors. For both EnerCalC and the own MATLAB model the same factors were used, so the different results at this point are consequence of the previous mismatches in the delivered energy and hence are equally magnified by the primary energy and CO2 factors. Heating component with a relative error of less than 8% and an absolute difference of 9 kWh/m^2a is the largest discrepancy.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	127,50	18,69	9,79	45,72	33,75
EnerCalc2013	118,50	19,30	9,20	48,50	28,80
Absolute error	9,00	0,61	0,59	2,78	4,95
Relative error	7,59%	3,15%	6,47%	5,72%	17,18%

Figure 14. Primary energy consumption– Simple office building

Maximal mismatch for CO2 Emissions come also from the heating component and represents 2.26 $kgCO_2/m^2a$.

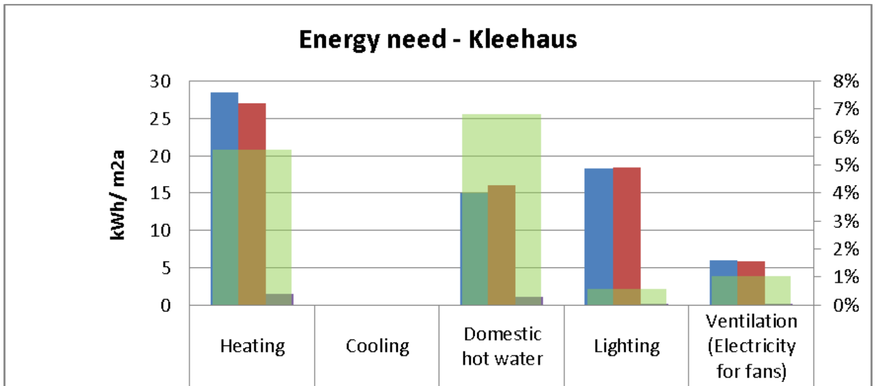


	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	31,66	4,93	2,46	12,06	8,90
EnerCalc2013	29,40	5,10	2,30	12,80	7,60
Absolute error	2,26	0,17	0,16	0,74	1,30
Relative error	7,70%	3,33%	7,01%	5,78%	17,12%

Figure 15. CO2 Emissions rate– Simple office building

- **Kleehäuser** im Freiburger Vauban- Viertel

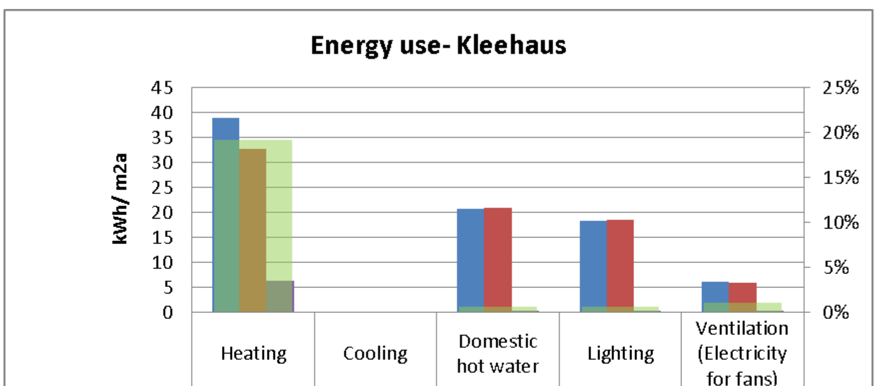
The most significant component is the energy need for heating. For this one, the maximal relative error is around 5.5 % that represents a difference of 1.50 kWh/m^2a between the models.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	28,50	0,00	15,00	18,30	5,96
EnerCalc2013	27,00	0,00	16,10	18,40	5,90
Absolute error	1,50	0,00	1,10	0,10	0,06
Relative error	5,54%	0,00%	6,83%	0,56%	1,03%

Figure 16. Energy needs- Kleehäuser in Freiburg

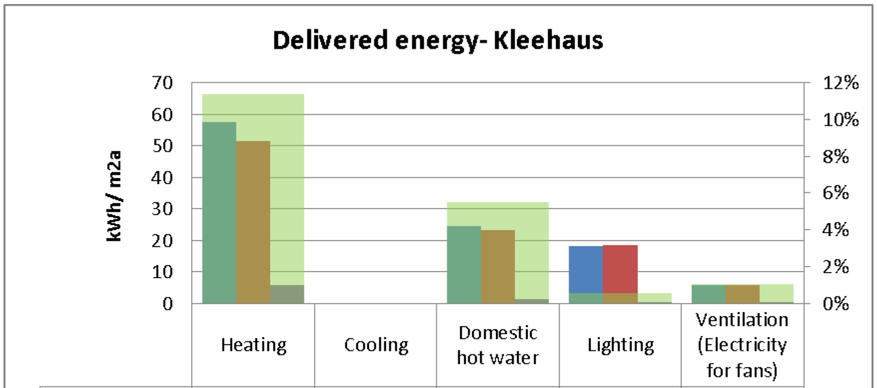
The maximal relative error for the energy use is 19.2 %. This considerable difference is due mainly to the mismatches in the calculation of the distribution, control and emission and storage losses. In this particular case, storage losses are zero, but whilst distribution and control and emission losses by EnerCalC sum up 5.6 kWh/m^2a, in the own model these losses are 10.3 kWh/m^2a. This difference of around 4.7 kWh/m^2a plus the already existing difference in the energy need for heating result in the 6.25 kWh/m^2a corresponding to the mentioned 19.2 %.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	38,85	0,00	20,67	18,30	5,96
EnerCalc2013	32,60	0,00	20,80	18,40	5,90
Absolute error	6,25	0,00	0,13	0,10	0,06
Relative error	19,16%	0,00%	0,64%	0,56%	1,03%

Figure 17.Energy use- Kleehäuser in Freiburg

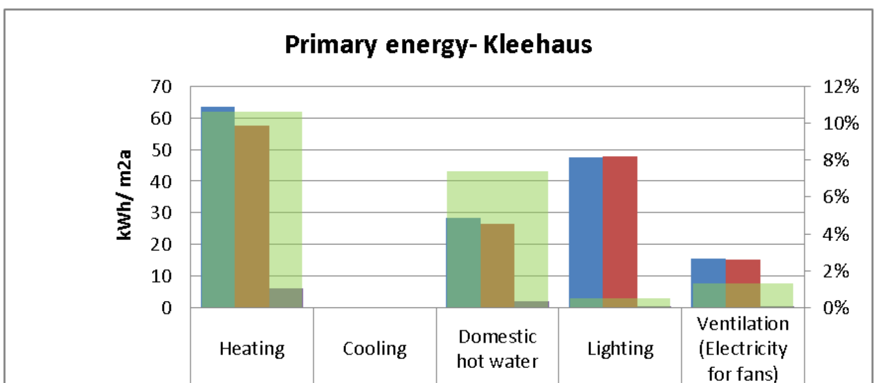
The maximal error in the delivered energy is again for the heating component. In this case the relative error is under 12 % corresponding to 5,86 kWh/m^2a. The relative error is significantly reduced first because the absolute values for delivered energy are higher than the energy use, and second because of the differences on the calculation procedure for the CHP system. In the MATLAB model typical energy expenditure factors are used.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	57,36	0,00	24,59	18,29	5,96
EnerCalc2013	51,50	0,00	23,30	18,40	5,90
Absolute error	5,86	0,00	1,29	0,11	0,06
Relative error	11,37%	0,00%	5,52%	0,58%	1,03%

Figure 18. Delivered energy- Kleehäuser in Freiburg

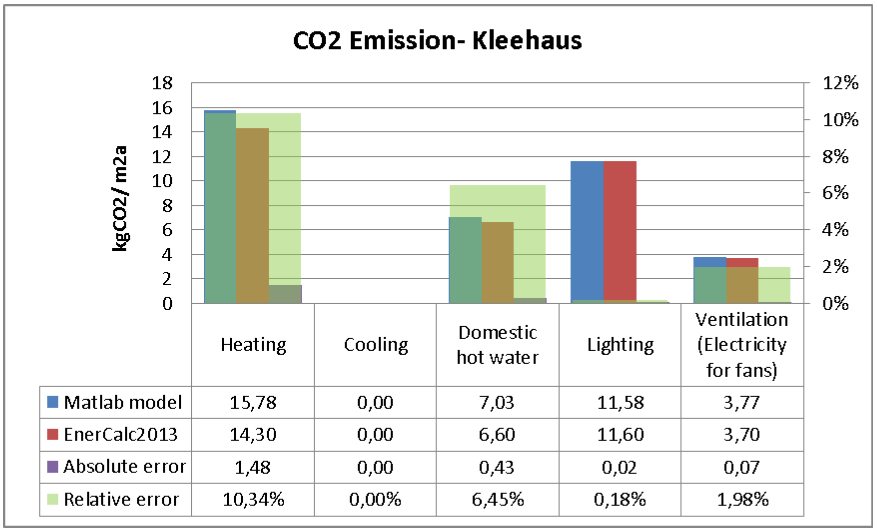
The error values remain similar to those of the delivered energy, once again only affected by the primary energy and CO2 emissions factors. The maximal error corresponds to the space heating and it is still under 12 % that represents 6 kWh/m^2a.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	63,59	0,00	28,35	47,56	15,50
EnerCalc2013	57,50	0,00	26,40	47,80	15,30
Absolute error	6,09	0,00	1,95	0,24	0,20
Relative error	10,60%	0,00%	7,40%	0,50%	1,30%

Figure 19. Primary energy consumption- Kleehäuser in Freiburg

Since the same CO2 emissions factors are used, there are not considerable differences in the CO2 emissions. The maximum error is for the space heating component and represents 1.48 $kgCO_2/m^2a$.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	15,78	0,00	7,03	11,58	3,77
EnerCalc2013	14,30	0,00	6,60	11,60	3,70
Absolute error	1,48	0,00	0,43	0,02	0,07
Relative error	10,34%	0,00%	6,45%	0,18%	1,98%

Figure 20. CO2 Emissions rate- Kleehäuser in Freiburg

- **Single-Family house AT_SFH_N_08_GEN_2**

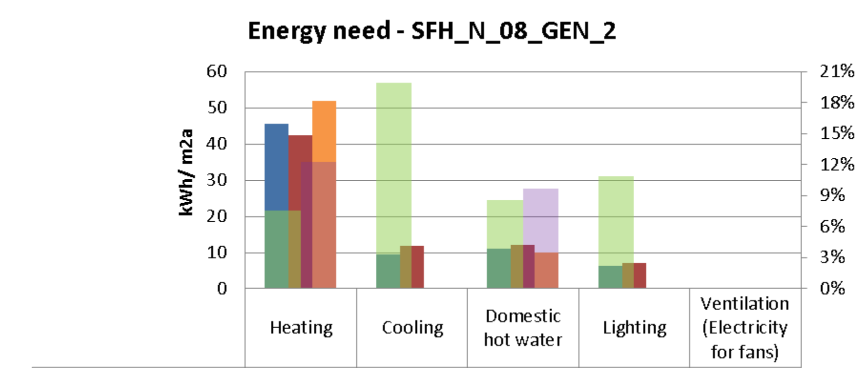
The common calculation method[12] used by the Tabula web-tool uses average and tabled values, which causes by one side the lack of calculation detail but ensures by the other side the transparency of the simplified calculation. Calculation method is focused on the energy use for space heating and domestic hot water. It does not take into account the energy use for cooling, lighting and electric appliances. This two aspects lead from the beginning to differences with the own MATLAB model, first due to the fact that the lighting contributes as heat source in the monthly balancing procedure as described in the chapter 2 'Methodology' in the MATLAB model description section '2.3.3 Monthly balance procedure for the calculation of the energy-use and final energy for lighting (DIN V 18599-4)'. Furthermore, the balancing procedure of heat sources and sinks for the calculation of the energy need for heating and cooling is done in the MATLAB model in a detailed way for each month and zone under the procedure described in the norm DIN V 18599-2 and not only using the seasonal method of the standard EN ISO 13790 as is the case of the Tabula web-tool.

Another important point to indicate here is that the EnerCalC tool does not account for separate heat generation systems for space heating and domestic hot water (The same boiler supply both end-uses). In this particular case, according to the data from the Tabula web-tool, there are different energy expenditure coefficients for these systems. Two separate comparisons are presented: 1) MATLAB –Tabula and 2) MATLAB – EnerCalC, for the delivered energy, primary energy and CO2 emissions.

The energy need for heating differ merely in about 3 kWh/m^2a between The MATLAB model and EnerCalC. On the contrary, the difference is almost 7 kWh/m^2a between the MATLAB model and the Tabula web-tool.

Regarding the energy need for cooling, even when the relative error is quite high (nearly 20 %), it represents no more than 2.5 kWh/m^2a. As already mentioned Tabula web-tool does only consider the energy need for heating and domestic hot water so there are no comparative values for the energy need for cooling, lighting or electricity for fans.

[12] TABULA Calculation Method – *Energy Use for Heating and Domestic Hot Water* – Reference Calculation and Adaptation to the Typical Level of Measured Consumption. January 2013.

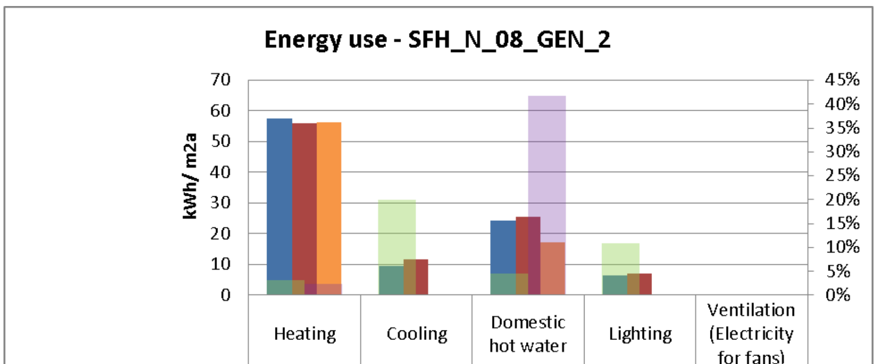


	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	45,60	9,45	10,97	6,33	0,00
EnerCalc2013	42,40	11,80	12,00	7,10	0,00
Tabula	52,00	0,00	10,00	0,00	0,00
Relative error EnerCalc	7,55%	19,95%	8,57%	10,88%	0,00%
Relative error Tabula	12,30%	0,00%	9,71%	0,00%	0,00%

Figure 21. Energy needs- Single-Family house AT_SFH_N_08_GEN_2

The high technical losses (especialy the distribution losses) for the heating system calculated by the own MATLAB model and EnerCalC, compensate the mismatch with the higher value of energy need for heating from Tabula web-tool and the energy use for heating of the three approaches differ in no more than 2 kWh/m^2a.

The relative error of the MATLAB model respect to the Tabula web-tool for the domestic hot water seems in this case substantial. It rounds the 42 %, which represents almost 7.5 kWh/m^2a. The essential reason for the difference can be refered to the distinct calulation methodologies as Tabula only adds tabled values for the distribution and storage losses to the energy need in order to obtain the energy use and the MATLAB model estimate the distribution losses using the equations of the norm DIN V 18599-5 and DIN V 18599-8.

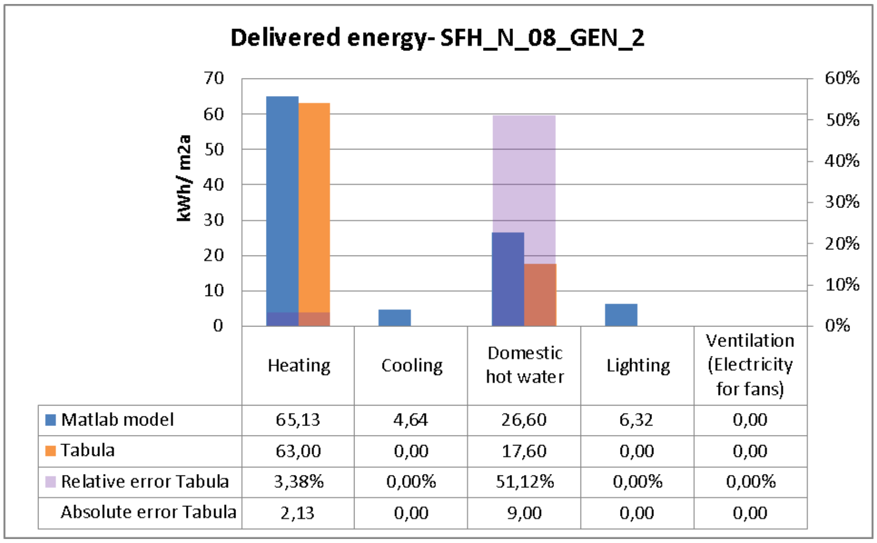


	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	57,66	9,45	24,25	6,33	0,00
EnerCalc2013	55,90	11,80	25,40	7,10	0,00
Tabula	56,30	0,00	17,10	0,00	0,00
Relative error EnerCalc	3,15%	19,95%	4,52%	10,88%	0,00%
Relative error Tabula	2,41%	0,00%	41,83%	0,00%	0,00%

Figure 22. Energy use- Single-Family house AT_SFH_N_08_GEN_2

An unavoidable difference arise from the use of different energy expenditure factors. Since these values can not be adjusted neither in Tabula web-tool nor in the EnerCalC excel tool, two separate comparisons are presented for the delivered energy, primary energy and CO2 Emissions.

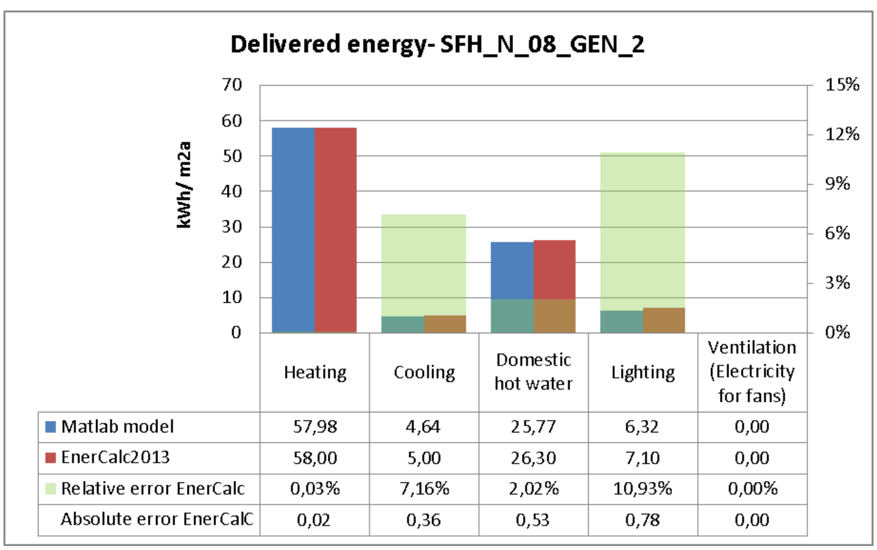
As shown in Figure 23, both relative and absolute error for domestic hot water are considerable. This error comes from the difference on the losses calculation as mentioned above and it is amplified by the energy expenditure factor.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	65,13	4,64	26,60	6,32	0,00
Tabula	63,00	0,00	17,60	0,00	0,00
Relative error Tabula	3,38%	0,00%	51,12%	0,00%	0,00%
Absolute error Tabula	2,13	0,00	9,00	0,00	0,00

Figure 23. Delivered energy- Single-Family house AT_SFH_N_08_GEN_2 (Using the heating system expenditure factor: 1.12 and DHW system expenditure factor: 1.03 according to Tabula web-tool)

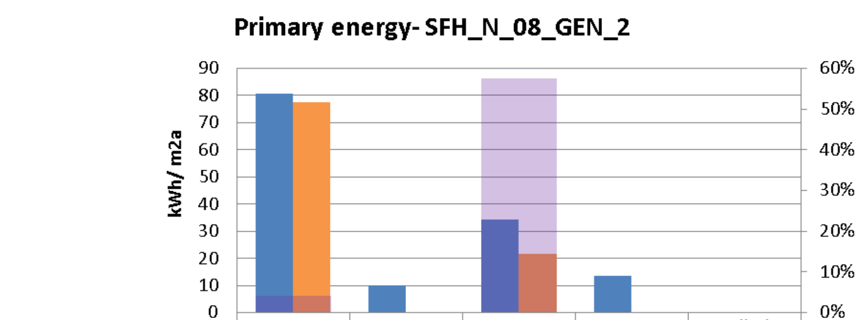
Figure 24 on the other hand, shows the delivered energy comparison between the MATLAB model and EnerCalC. An estimated energy expenditure coefficient of 0.996 for the boiler is used in this case. The maximum error is no more than 0.78 kWh/m^2a for the lighting component.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	57,98	4,64	25,77	6,32	0,00
EnerCalc2013	58,00	5,00	26,30	7,10	0,00
Relative error EnerCalc	0,03%	7,16%	2,02%	10,93%	0,00%
Absolute error EnerCalC	0,02	0,36	0,53	0,78	0,00

Figure 24. Delivered energy- Single-Family house AT_SFH_N_08_GEN_2 (Using the same boiler energy expenditure factor: 0.996)

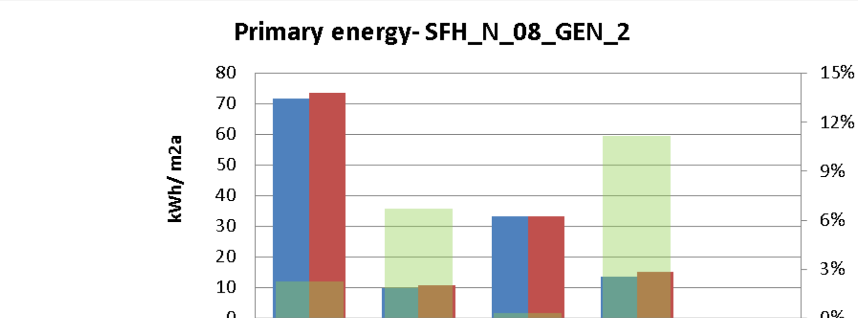
The relative error is once again amplified by the primary energy factor. It reaches almost 58 % respectively 12.5 kWh/m^2a for the DHW component. Contrarily to the DHW, the primary energy consumption for heating keeps similar with an error of less than 5% corresponfding to 3,12 kWh/m^2a.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	80,62	9,98	34,20	13,60	0,00
Tabula	77,50	0,00	21,70	0,00	0,00
Relative error Tabula	4,03%	0,00%	57,61%	0,00%	0,00%
Absolute error Tabula	3,12	0,00	12,50	0,00	0,00

Figure 25. Primary energy consumption- Single-Family house AT_SFH_N_08_GEN_2 (Comparison 1:MATLAB - Tabula)

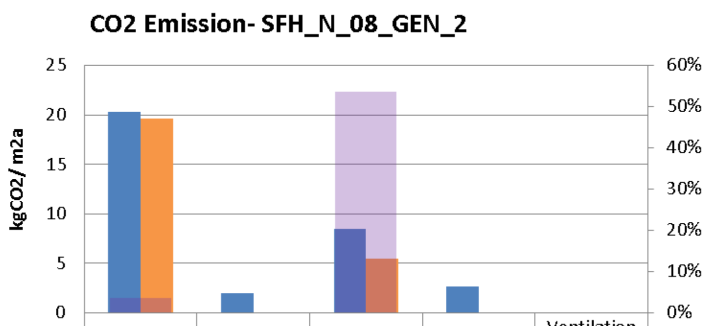
Correspondingly to the delivered energy, the primary energy consumption presents no great difference between the MATLAB model and EnerCalC. The maximum error accounts for the lighting component and is still less than 2 kWh/m^2a.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	71,83	9,98	33,19	13,60	0,00
EnerCalc2013	73,50	10,70	33,30	15,30	0,00
Relative error EnerCalc	2,27%	6,73%	0,33%	11,13%	0,00%
Absolute error EnerCalC	1,67	0,72	0,11	1,70	0,00

Figure 26. Primary energy consumption- Single-Family house AT_SFH_N_08_GEN_2 (Comparison 2:MATLAB – EnerCalC)

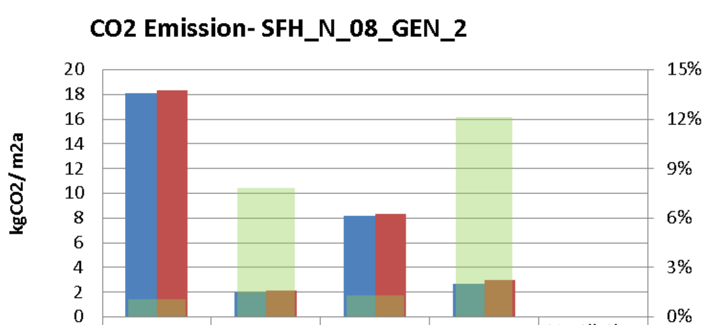
The differences arising from the energy use, going through the delivered energy are also visible in the CO Emissions. The worst mismatch like before, corresponds to the DHW component and is about 3 $kgCO_2/m^2a$.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	20,31	1,94	8,44	2,64	0,00
Tabula	19,60	0,00	5,50	0,00	0,00
Relative error Tabula	3,65%	0,00%	53,51%	0,00%	0,00%
Absolute error Tabula	0,71	0,00	2,94	0,00	0,00

Figure 27. CO2 Emissions rate- Single-Family house AT_SFH_N_08_GEN_2. (Comparison 1:MATLAB - Tabula)

The maximum error for CO2 Emissions between MATLAB model and EnerCalC is around 12% and represents no more than 0.36 $kgCO_2/m^2a$ arising from the lighting end-use.



	Heating	Cooling	Domestic hot water	Lighting	Ventilation (Electricity for fans)
Matlab model	18,10	1,94	8,19	2,64	0,00
EnerCalc2013	18,30	2,10	8,30	3,00	0,00
Relative error EnerCalc	1,09%	7,82%	1,33%	12,10%	0,00%
Absolute error EnerCalC	0,20	0,16	0,11	0,36	0,00

Figure 28. CO2 Emissions rate- Single-Family house AT_SFH_N_08_GEN_2. (Comparison 2:MATLAB – EnerCalC)

3. Building codes and Nearly Zero Energy Buildings (nZEB) definition comparison

In this chapter, the different national building codes and nZEB national plans are examined. Key aspects and energy requirements from each country´s building code are presented and described. In the last section most remarkable differences between building codes are discussed and summarized.

3.1 Austria: OIB Richtline 6 OIB-330.6 -009/2015

A formal nZEB definition as well as qualitative and quantitative energy requirements are stated for both new construction and existing buildings (major renovation) in the document OIB-330.6-009/2015. A nearly zero energy building under the Austrian scope is that building that complies with the energy requirements stated in the above mentioned guideline for the year 2020.

Four main energy indicators are settled in the document:

- Energy need for heating “Heizwärmebedarf” $[kWh/m^2a]$
- Primary energy (non-renewable) $[kWh/m^2a]$
- Carbon dioxide emission $[kg/m^2a]$
- Total energy efficiency factor fGEE [-]

Intermediate targets for the years 2014, and the following 2016 and 2018 are also included as requirement by the EPBD directive 31 in its article 9.3.b. The concrete main energy requirements are:

- **New construction**
    - *Residential buildings*

Table 6. Energy requirements (maximum values) for new construction: Residential buildings.

	HWB_{max} [kWh/m²a]	EEB_{max} [kWh/m²a]	$f_{GEE,max}$ [-]	PEB_{max} [kWh/m²a]	$CO2_{max}$ [kg/m²a]
2014	$16 \times (1 + 3{,}0 / \ell_c)$	mittels $HTEB_{Ref}$	0,90	190	30
2016	$14 \times (1 + 3{,}0 / \ell_c)$	mittels $HTEB_{Ref}$		180	28
	oder				
	$16 \times (1 + 3{,}0 / \ell_c)$		0,85		
2018	$12 \times (1 + 3{,}0 / \ell_c)$	mittels $HTEB_{Ref}$		170	26
	oder				
	$16 \times (1 + 3{,}0 / \ell_c)$		0,80		
2020	$10 \times (1 + 3{,}0 / \ell_c)$	mittels $HTEB_{Ref}$		160	24
	oder				
	$16 \times (1 + 3{,}0 / \ell_c)$		0,75		

- *Non-residential buildings*

Table 7.Energy requirements (maximum values) for new construction: Non-residential buildings.

	HWB_{max} [kWh/m²a]	EEB_{max} [kWh/m²a]	$f_{GEE,max}$ [-]	PEB_{max} [kWh/m²a]	$CO2_{max}$ [kg/m²a]
2014	5,50 × (1 + 3,0 / ℓc)	mittels $HTEB_{Ref}$		230	36
2016	4,67 × (1 + 3,0 / ℓc)	mittels $HTEB_{Ref}$		210	33
		oder			
	5,50 × (1 + 3,0 / ℓc)		$f_{GEE,DLGneu,max}$		
2018	4,00 × (1 + 3,0 / ℓc)	mittels $HTEB_{Ref}$		190	30
		oder			
	5,50 × (1 + 3,0 / ℓc)		$f_{GEE,DLGneu,max}$		
2020	3,33 × (1 + 3,0 / ℓc)	mittels $HTEB_{Ref}$		170	27
		oder			
	5,50 × (1 + 3,0 / ℓc)		$f_{GEE,DLGneu,max}$		
	$f_{GEE,DLGneu,max}$ … Diese Werte ergeben sich jeweils aus der strengeren HWB-Anforderung und der Anwendung der Referenzausstattungen.				

- **Major renovations**
  - *Residential buildings*

Table 8. Energy requirements (maximum values) for major renovations: Residential buildings

	HWB_{max} [kWh/m²a]	EEB_{max} [kWh/m²a]	$f_{GEE,max}$ [-]	PEB_{max} [kWh/m²a]	$CO2_{max}$ [kg/m²a]
2014	23 × (1 + 2,5 / ℓc)	mittels $HTEB_{Ref}$		230	38
		oder			
	25 × (1 + 2,5 / ℓc)		1,10		
2016	21 × (1 + 2,5 / ℓc)	mittels $HTEB_{Ref}$		220	36
		oder			
	25 × (1 + 2,5 / ℓc)		1,05		
2018	19 × (1 + 2,5 / ℓc)	mittels $HTEB_{Ref}$		210	34
		oder			
	25 × (1 + 2,5 / ℓc)		1,00		
2020	17 × (1 + 2,5 / ℓc)	mittels $HTEB_{Ref}$		200	32
		oder			
	25 × (1 + 2,5 / ℓc)		0,95		

- *Non-residential buildings*

Table 9. Energy requirements (maximum values) for major renovation: Non-residential buildings

	HWB_{max} [kWh/m³a]	EEB_{max} [kWh/m²a]	$f_{GEE,max}$ [-]	PEB_{max} [kWh/m²a]	$CO2_{max}$ [kg/m²a]
2014	7,67 × (1 + 2,5 / ℓ_c)	mittels $HTEB_{Ref}$		300	48
	oder				
	8,50 × (1 + 2,5 / ℓ_c)		$f_{GEE,DLGsan,max}$		
2016	7,00 × (1 + 2,5 / ℓ_c)	mittels $HTEB_{Ref}$		280	45
	oder				
	8,50 × (1 + 2,5 / ℓ_c)		$f_{GEE,DLGsan,max}$		
2018	6,33 × (1 + 2,5 / ℓ_c)	mittels $HTEB_{Ref}$		260	42
	oder				
	8,50 × (1 + 2,5 / ℓ_c)		$f_{GEE,DLGsan,max}$		
2020	5,67 × (1 + 2,5 / ℓ_c)	mittels $HTEB_{Ref}$		250	39
	oder				
	8,50 × (1 + 2,5 / ℓ_c)		$f_{GEE,DLGsan,max}$		
	$f_{GEE,DLGsan,max}$ … Diese Werte ergeben sich jeweils aus der strengeren HWB-Anforderung und der Anwendung der Referenzausstattungen.				

There are basically two ways to comply with the energy requirements. In all cases the building shall comply with the maximum primary energy use and CO2 emissions values but it can either comply 1) with a certain lower (stricter) value of energy need for heating “HWB” and an energy use for heating system value “HTEB” or 2) with another higher (less strict) value of energy need for heating “HWB” and the total energy efficiency factor fGEE.

In all cases the energy need for heating “Heizwärmebedarf” depends on the characteristic length “l_c”. This one is the inverse value of the building compactness described as:

$$Compactness = \frac{A}{Ve} \tag{40}$$

Where A is the surface area of the building thermal envelope and Ve is the building conditioned volume.

The reference HTEB represents the systems technical losses as described in the equation 190 of the norm ÖH5056:

$$Q_{HTEB,REF} = Q_{HEB_{REF}} - Q_h - Q_w \tag{41}$$

Where

$Q_h =: Energy\ need\ for\ heating [kWh/m^2a]$

$Q_w =: Energy\ need\ for\ domestic\ hot\ water\ [kWh/m^2a]$

$Q_{HEB_{REF}} =: Reference\ total\ Energy\ use\ (Heating + domestic\ hot\ water)[kWh/m^2a]$

$Q_{HTEB,REF} =: Referene\ technical\ systems\ losses\ [kWh/m^2a]$

Finally, the total energy efficiency factor fGEE is defined as the ratio between the calculated final energy EEB_{RK} and a reference final energy $EEB_{RK,26}$ calculated with the requirements presented in the Austrian norm OIB.6 of the year 2007:

$$fGEE = \frac{EEB_{RK}}{EEB_{RK,26}} \tag{42}$$

It is also important to highlight that the Austrian code considers on its calculation procedure the household electricity demand "Haushaltsstrombedarf" for residential buildings and the operational electricity demand "Betriebsstrombedarf". These shall be added to the required energy for the purposes of space heating, cooling, domestic hot water. As already mentioned in chapter 2 " Building selection and assessment criteria" in order to have an even and transparent comparison between countries, the maximum reference value for the primary energy use for Austria is modified by subtracting a default value regarding this household electricity demand.

The OIB-330.6 -009/2015 contains likewise some called complementary requirements designed to promote the increase in the share of renewables, it also gives some guidelines about the technical systems and limit undesired energy fluxes through constructive thermal bridges, low air tightness, surface condensation or summer overheating.

Requirements regarding the minimum share of renewables are clearly defined. The requirement count as fulfilled, when at least one of the following points from a) or b) is implemented:

a) **Use of renewable sources off-site:**
   - At least 50% of the energy need for space heating and domestic hot water is covered by means of biomass.
   - At least 50% of the energy need for space heating and domestic hot water is covered by means of heat pumps.
   - At least 50% of the energy need for space heating and domestic hot water is covered by means of district heating (using renewable energy carriers).
   - At least 50% of the energy need for space heating and domestic hot water is covered by means of district heating (High efficient CHP).

b) **Use of renewable sources through input on-site or nearby:**
   - At least 10% of the netto-final energy for domestic hot water covered through active measures like solar-thermal systems.
   - At least 10% in the netto-final energy for household electricity demand "haushaltsstrombedarf" covered through active measures like Photovoltaics.
   - At least 10% in the netto-final energy for space heating covered through active measures like heat recovery.
   - A combination of the previous measures that leads to the reduction of at least 5% of the final energy efficiency factor in new buildings.

About the requirements regarding the constructive elements, maximum U-Values are defined for each building element category. The principal elements and those considered in the MATLAB BEP model are:

Table 10. Maximal U-values Austria

Building component		U-value [W/m²K] – Residential & Non-residential buildings – New
Walls	External walls	0.35
	Basement wall in contact with the ground	0.4
Windows	Windows	1.4 / 1.7*
	Other vertical transparent elements	1.7
	Other external transparent components horizontal or slope	2
Roof/	Roof	0.20
Ceilings	Internal ceiling to unconditioned areas	0.4
Floors	In contact with the ground	0.4

* Residential / Non-residential

3.2 Germany: National nZEB plan /EnEV 2016 / KfW efficiency house

The nZEB definition in Germany is to be formally settled and implemented by the federal government in the Energy conservation Regulation (EnEV 2016). Nonetheless an expected definition in line with the KfW Efficiency house is already foreseen in the nZEB nation plan of 2013. For new buildings the ambition level points to the label KfW 40 and for refurbishments it points to the label KfW 55 and 70. The numbers indicate the amount of annual primary energy consumption in relation (%) to a comparable new building (reference building) according to the requirements of the Energy Conservation Regulation in force. An Efficiency House 40, for example, does not use more than 40 % of the annual primary energy consumption of the corresponding reference building.

The main energy requirement might be therefore only the primary energy consumption as described above (KfW label). The reference building parameters are described in the annex 1 and 2 for residential and non-residential buildings respectively. This Energy Saving Ordinance (EnEV) includes also some additional requirements regarding the mean specific heat transmission losses of the building envelope, thermal bridges, air tightness and the summer heat protection (to avoid overheating).

Contrary to the other country scopes (Austria, England and Spain), the German code does not allow for a maximum energy need for space heating, but goes the other way round by limiting the specific heat transmission losses of the building envelope for residential buildings and the U-Values for residential and non-residential buildings (EnEV 2014):

Table 11. Maximal specific heat transmission losses (Residential buildings). Source EnEV 2014

Building type		Maximum heat transmission losses H'T [W/m²K]
Stand-alone Building	Area NGF <= 350 m2	0,4
	Area NGF > 350 m2	0,5
One side constructed building*		0,45
All other buildings		0,65
Extension of residential buildings		0,65

* When more than 80% of the vertical surface of the building back onto a building with a Room set-temperature of at least 19 ° C

Table 12. Maximal U-values (non-Residential buildings). Source: EnEV 2014

Building component		U-value [W/m²K]	
		Residential & Non-residential buildings	
		New*	Major renovation
Walls	External walls	0.28	0.24
	Basement wall in contact with the ground	0.35	0.3
Windows	Windows	1.3	1.3
	Other windows and doors	1.8	1.6
	Roof windows	1.4	1.4
	Other external transparent components horizontal or slope	-	1.1
Roof/	Roof	0.20	0.24
Ceilings	Internal ceiling to unconditioned areas	0.35	0.24
Floors	In contact with the ground	0.35	0.5

* Room set temperatures when heating ≥ 19 ° C

The specific heat transmission losses H'_T in $[W/m^2K]$ arise from the heat transmission losses H_T in $[W/K]$ and the building total envelope surface area A in m^2 as:

$$H'_T = \frac{H_T}{A} \tag{43}$$

A minimum share of renewables is also designated taking into account the considerations of the EEWärmeG part 2 articles 4 and 5 for new and existing non-residential buildings undergoing deep renovations respectively and the alternative measures presented in the article 7. The minimum requirement for new construction is deemed as fulfilled:

- By the use of Solar thermal systems at least 15% of the energy need for heating and cooling is covered, taking into account the conditions in annex I regarding the collector surface depending on the building size and category.

- By the use of Biomass (Gas) at least 30% of the energy need for heating and cooling is covered, taking into account the conditions in annex II.1.
- By the use of Biomass (liquid/ solid) at least 50% of the energy need for heating and cooling is covered, taking into account the conditions in annex II.2 and II.3.
- By the use of Geothermal energy and ambient heat at least 50% of the energy need for heating and cooling is covered, taking into account the conditions in annex II.1 regarding the technology.

The minimum requirement for official buildings renovations is deemed as fulfilled when:

- By the use of Biomass (Gas) at least 25% of the energy need for heating and cooling is covered, taking into account the conditions in annex II.1.
- By the use of other renewable energies at least 15% of the energy need for heating and cooling is covered, taking into account the conditions in annex I to IV.

Other alternative measures such as use of CHP plants and district heating are listed in the article 7 and lead as well under the conditions stated in the annex V to VIII to the fulfillment of the minimum share of renewable requirement. A combination of renewable energies and alternative measures is also possible for the requirement fulfillment.

3.3 United Kingdom (England): National Nzeb plan / Part L

As described in the UK nZEB national plan, the UK Government has already a target for all new domestic buildings to be "zero carbon" from 2016 and an ambition for all new non-domestic buildings in England to be zero carbon from 2019 (2018 for new public sector buildings). This "zero carbon" definition has been developed by the partnership between the UK Government and the zero carbon hub non-profit organization and is intended to meet the nearly zero energy building definition. No formal definition is given for existing buildings.

Under the interpretation of the UK Government the word "should" signify an aspiration rather than an obligation, that is why they do not include a minimum share of renewables. However the zero carbon definition together with the local policies are supposed to encourage the use of on-site renewables and heat networks that could be connected in the future with renewable heat sources. Another argument against the inclusion of a minimum share of renewables is the fact that low carbon technologies have still an important role to play in the aims of the directive mainly because high energy performance can be achieved at a lower cost.

Part L of the building regulations in England contains the changes made by the UK government to improve energy standards. There are two main quantitative energy requirements in the Part L1A for new residential buildings:

- **Target CO2 Emission rate TER** $[\boldsymbol{kgCO_2/m^2a}]$
- **Target fabric energy efficiency TFEE rate** $[\boldsymbol{kWh/m^2a}]$

Both of them are relative maximum reference values calculated for a notional building with the same size and shape of the actual building.

The TER is calculated in two stages:

a) First calculate the CO2 emissions from a notional building of the same size and shape as the actual building and which is constructed according to the reference values set out in the Appendix R of SAP 2012. No values may be varied from these reference values. CO2 emissions arise from:

    i. The provision of space heating and hot water C_H
    ii. The use of pumps and fans C_{PF}
    iii. The use of internal lighting C_L

b) Second, calculate the TER using the following formula:

$$TER = C_H * FF + C_{PF} + C_L \tag{44}$$

Where FF is the fuel factor from the table 1 of the building code:

Table 13. Fuel factor for TER calculation. Source: Part L1A conservation of fuel and power in new dwellings

Table 1 Fuel factor

	Fuel factor[1]
Mains gas	1.00
LPG	1.06
Oil	1.17
B30K	1.00
Grid electricity for direct acting and storage systems	1.55
Grid electricity for heat pumps	1.55
Solid mineral fuel[2]	1.35
Any fuel with a CO_2 emission factor less than that of mains gas	1.00
Solid multi-fuel[2]	1.00

Notes:

1. The fuel factors in this table will be reviewed as progress is made towards the zero carbon target.
2. For those appliances that can only burn one particular fuel, use the specific fuel factor. For an appliance that is classed as multi-fuel and that is not in a dwelling in a smoke control area, use the multi-fuel factor. For a multi-fuel appliance in a dwelling within a smoke control area, use the solid mineral fuel figure unless the specific appliance type is approved for use within smoke control areas, in which case use the multi-fuel factor.

In every case, the Dwelling CO2 emission rate DER shall be less or equal to the Target CO2 emission rate:

$$DER \leq TER$$

If the dwelling has more than one appliance for space heating and/or domestic hot water and these are served by different fuels, main gas shall be selected if it fuels one of the appliances. Otherwise the fuel serving the space heating shall be selected. In case that the dwelling is served by a community heating scheme, main gas shall be selected if used for any purpose in the community scheme, otherwise the fuel that provides the most heat for the community scheme shall be selected.

The Target fabric energy efficiency TFEE is calculated by determining the fabric energy efficiency FEE from a notional building of the same size and shape as the actual building and which is constructed according to the reference values set out in the Appendix R of SAP 2012. This FEE is then multiplied by 1.15 to obtain the TFEE.

$$TFEE = 1.15 * FEE \tag{45}$$

In every case, the Dwelling fabric energy efficiency DFEE shall be less or equal to the Target fabric energy efficiency:

$$DFEE \leq TFEE$$

Additional demonstrating compliance criteria are presented in the part L. Among them are:

- The performance of building elements and building fixed services should achieve reasonable overall standards of energy efficiency. This is however more a guidance than a mandate. Guiding limit U-values are presented in the table 2 of the document:

Table 14. Limiting fabric parameters (U-values). Source: Part L1A conservation of fuel and power in new dwellings

Table 2 Limiting fabric parameters	
Roof	$0.20\ W/(m^2 \cdot K)$
Wall	$0.30\ W/(m^2 \cdot K)$
Floor	$0.25\ W/(m^2 \cdot K)$
Party wall	$0.20\ W/(m^2 \cdot K)$
Swimming pool basin[1]	$0.25\ W/(m^2 \cdot K)$
Windows, roof windows, glazed roof-lights[2], curtain walling and pedestrian doors	$2.00\ W/(m^2 \cdot K)$
Air permeability	$10.0\ m^3/(h \cdot m^2)$ at 50 Pa

Notes:

1. Where a swimming pool is constructed as part of a new building, reasonable provision should be made to limit heat loss from the pool basin by achieving a U-value no worse than $0.25\ W/(m^2 \cdot K)$ as calculated according to BS EN ISO 13370.
2. For the purposes of checking compliance with the limiting fabric values for roof-lights, the true U-value based on aperture area can be converted to the U-value based on the developed area of the roof-light. Further guidance on evaluating the U-value of out-of-plane roof-lights is given in *Assessment of thermal performance of out-of-plane rooflights*, NARM Technical Document NTD 2 (2010).

- The dwelling should have appropriate passive control measures to limit the effect of heat gains on indoor temperatures in summer, irrespective of whether the building has mechanical cooling.

3.4 Spain: Decree 235/2013

Royal decree 235/2013 approving the basic procedure for certifying the energy performance of buildings also includes an obligation for all new buildings built after 31 December 2020 to be nearly zero-energy buildings and all new buildings for which construction starts after 31 December 2018 that will be occupied and owned by public authorities also to be nearly zero-energy buildings is the designated legal document for the transposition of the directive 2010/31/EU into national law.

The Spanish national nZEB plan is arranged in two phases. The first one consists on the set of intermediate targets for new construction from 2015 to promote the achieving of the 2020 targets. The second phase (not implemented yet) consists on the regulatory definition of nearly zero energy buildings. A formal nZEB definition is to be addressed in the new basic Energy Saving Basic Document DB-HE 2016/2017.

Within the 2013 approved regulation and in force now, two global indicators (plus a possible subsequent third) and some additional specific construction and technical system requirements are set to be used as a basis for defining a nearly zero energy building.

The two global requirements and the possible third one are:

- **Primary energy use (non-renewable)** $[\boldsymbol{kWh/m^2a}]$
- **Energy demand for heating and cooling (energy need)** $[\boldsymbol{kWh/m^2a}]$
- **Building CO2 Emissions (possible subsequent indicator)**

And the specific requirements which include the use of renewable energies are:

- Maximum transmittance of elements of the thermal envelope and other elements separating different user units.
- Energy efficiency of heating systems.
- Energy efficiency of the lighting system and maximum installed power in the building.
- Minimum energy contribution from renewable sources for the supply of domestic hot water system DHW.
- Minimum energy contribution percentage from renewable sources for electrical uses in the building.

Six winter climate zones (α, A, B, C, D, E) SCI and four summer climate zones (1, 2, 3, 4) SCV have been defined in the annex B.3 of the document "Documento descriptivo climas de referencia"[13] of the diversification ministry giving a total of 17 existing climate zones in Spain (A1, A2, A3, A4, B1, B2, B3, B4, C1, C2, C3, C4, D1, D2, D3, E1, α3). These zones are important because energy requirements depend on the building location.

- New construction:

The 2013 CTE Basic Document on energy saving DB-HE limits the energy consumption of non-renewable primary energy in new buildings for private residential use based on the climate zone in winter to a value that ranges from 40 kWh/m2-year for zones α and A, to 70 kWh/m2-year in climate zone E. A correction factor is applied to these values. It takes into account the building area so that higher values can be achieved when the area is smaller. In buildings for private residential use, the primary energy indicator includes energy consumption levels for heating, cooling and domestic hot water requirements. The primary energy limit is then the sum of the base primary energy limit presented in the Table 15 and the correction factor depending on the building size:

$$C_{ep,lim} = C_{ep,base} + \frac{F_{ep,sup}}{A} \tag{46}$$

Table 15. Primary energy limit and building size correction factor. Source: CTE DB-HE

	Zona climática de invierno					
	α	A*	B*	C*	D	E
$C_{ep,base}$ [kW·h/m²·año]	40	40	45	50	60	70
$F_{ep,sup}$	1000	1000	1000	1500	3000	4000

The total non-renewable primary energy shall not overcome in any case the $\boldsymbol{C_{ep,lim}}$ value.

[13] **Ministerio de Fomento,** Secretaría de Estado de Infraestructuras, Transporte y Vivienda. Dirección General de Arquitectura, Vivienda y Suelo. *Documento descriptivo climas de referencia.* February 2017. Retrieved from: *http://www.codigotecnico.org/images/stories/pdf/ahorroEnergia/20170202-DOC-DB-HE-0-Climas%20de%20referencia.pdf*

The requirements of DB-HE 2013 for new non-residential buildings are linked to the energy rating for the consumption of non-renewable primary energy. The performance in this case must be greater than or equal to class B (0.45 < C < 0.65) or higher where C is the quotient between the non-renewable primary energy consumption of the target building and the non-renewable primary energy consumption of the reference building according to the basic procedure for certifying building energy performance approved by Royal Decree 235/2013.

The needs relating to energy demand of the DB-HE 2013 include the limitation of the energy demand for heating, based on the winter climate zone, to a value that ranges from 15 $[kWh/m^2a]$ for climate zones α, A and B to 40 $[kWh/m^2a]$ for climate zone E, subject to the application of a correction factor that takes into account the building area as for the primary energy consumption. The energy demand limit for cooling is established based on the summer climate zone as 15 $[kWh/m^2a]$ for summer climate severity zones 1, 2 and 3 and 20 $[kWh/m^2a]$ for zone 4, which are demanding values considering the severity of summer climates in a significant proportion of Spain. The energy demand limit is then the sum of the base energy limit presented in the Table 16 and the correction factor depending on the building size:

$$D_{cal,lim} = D_{cal,base} + \frac{F_{cal,sup}}{A} \tag{47}$$

Table 16. Energy demand for heating limit and building size correction factor. Source: CTE DB-HE

	Zona climática de invierno					
	α	A	B	C	D	E
$D_{cal,base}$ [kW·h/m²·año]	15	15	15	20	27	40
$F_{cal,sup}$	0	0	0	1000	2000	3000

The total energy demand for heating shall not overcome in any case the $\boldsymbol{D_{cal,lim}}$ value**.**

In new buildings for uses other than housing and extensions of existing buildings, DB-HE 2013 establishes a minimum joint energy demand saving percentage for heating and cooling with regard to the reference building (this is the weighted demand for heating energy and cooling energy). In this case, the required percentage saving is up to 25 % based on the summer climate zone and the internal source load as shown in the Figure 29.

Power demand by internal heat sources are classified in:

- Baja: Low
- Media: Average
- Alta: High
- Muy alta: Very high

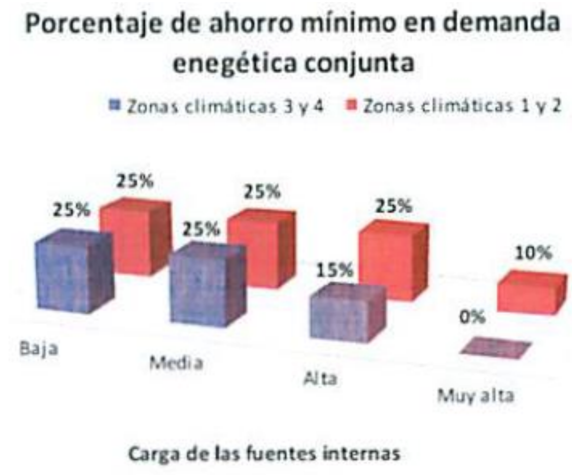


Figure 29.Minimum percentage saving in joint (heating + cooling) energy demand. Source: Spain nZEB national plan CTE DB-HE

Along with the described required saving percentage, maximum transmittances for thermal envelope elements were established for buildings used as housing in order to avoid decompensation:

Table 17. Maximum transmittances for thermal envelope elements. Source: Spain nZEB national plan / CTE DB-HE

Parámetro	Zona climática de invierno					
	α	A	B	C	D	E
Transmitancia térmica de muros y elementos en contacto con el terreno(1) [W/m²·K]	1,35	1,25	1,00	0,75	0,60	0,55
Transmitancia térmica de cubiertas y suelos en contacto con el aire [W/m²·K]	1,20	0,80	0,65	0,50	0,40	0,35
Transmitancia térmica de huecos(2) [W/m²·K]	5,70	5,70	4,20	3,10	2,70	2,50
Permeabilidad al aire de huecos(3) [m³/h·m²]	≤ 50	≤ 50	≤ 50	≤ 27	≤ 27	≤ 27

Note the comparison with the previous values (2006):

Table 18. Maximum transmitances for thermal envelope elements comparison 2006. Source: Spain nZEB national plan

Parameter	Regulatory year	Winter climate zone					
		α	A	B	C	D	E
Thermal transmittance of walls and elements in contact with the ground(1) (W/m²-K)	2013	1.35	1.25	1	0.75	0.6	0.55
	2006	*	1.22	1.07	0.95	0.86	0.74
Thermal transmittance of floors (W/m²-K)	2013	1.2	0.8	0.65	0.5	0.4	0.35
	2006	*	0.69	0.68	0.65	0.64	0.62
Thermal transmittance of roofs (W/m²-K)	2013	1.2	0.8	0.65	0.5	0.4	0.35
	2006	*	0.65	0.59	0.53	0.49	0.46
Thermal transmittance of doors and windows(2) (W/m²-K)	2013	5.7	5.7	4.2	3.1	2.7	2.5
	2006	*	5.7	5.7	4.4	3.5	3.1
Thermal transmittance of party walls (W/m²-K)	2013	1.35	1.25	1.1	0.95	0.85	0.7
	2006	*	1.22	1.07	1	1	1

* This climate zone did not exist in 2006
(1) For elements in contact with the ground, the indicated value is required only for the first metre of wall underground, or the first metre of floor perimeter resting on the ground up to a depth of 0.50m
(2) The combined performance of glass and frame is considered, including skylights and roof windows

With regard to the use of renewables, an annual minimum percentage is established for the contribution of solar energy based on the building's total demand for DHW and that of the corresponding climate zone according to solar radiation, which varies between 30 % and 70 % as shown in Table 19:

Table 19. Annual minimum contribution of solar energy for domestic hot water DHW. Source Spain nZEB national plan / CTE DB-HE

Building's total demand for DHW (l/d)	Climate zone				
	I	II	III	IV	V
50 – 5 000	30	30	40	50	60
5 000 – 10 000	30	40	50	60	70
> 10 000	30	50	60	70	70

A minimum electrical energy contribution is also established for solar energy collector and processing systems using photovoltaic procedures, establishing the minimum power to be installed based on the building area. This requirement is applicable to hypermarkets, shopping malls and leisure centers, storage and distribution sheds, covered sports facilities, hospitals, clinics and care homes and trade fair halls.

The code allows the total or partial replacement of the thermal or photovoltaic solar energy requirement with other sources of renewable or residual energy in order to obtain similar energy efficiency in a more flexible manner with more room for technological innovation. However, carbon dioxide emissions and non-renewable primary energy consumption by the selected alternative system and its auxiliary systems must be less than or equal to those that would apply using the corresponding thermal solar system and auxiliary support system.

- Existing construction:

In the case of existing buildings, in work affecting more than 25 % of the building envelope or in work where the building's characteristic use is changed, the requirement is that the building should be at least compliant with the energy demand needs established in 2006 for new buildings. The following comparison values for the energy demand needs presented in the Spain national nZEB plan are estimated based on statistical studies carried out to establish the building energy certification scales:

Figure 30. Reduction in the heating energy demand limit in DB-HE 2013 compared to DB-HE 2006 for apartment blocks (left side) and single-family housing (right side). Source: Spain nZEB national plan

3.5 Comparison

Every country's building code points in the same direction to the improvement of both the building thermal envelope and the energy efficiency by means of high efficient technical systems and low carbon technologies together with the use of renewable energy sources, yet there are some remarkable differences on their approaches. Most significant differences are:

- Only Austrian norm includes the auxiliary energy and the household electricity demand in the calculation procedure. German code includes the auxiliary energy for non-residential buildings under certain conditions.
- Unlike the rest of the selected countries, Germany does not have a quantitative energy requirement for the energy need for heating and cooling, instead, the code limits the specific heat transmission losses through H_T' in residential buildings.
- German code does not consider the lighting concept for the calculation of the primary energy in residential buildings.
- England is the only Country that does not have or does not intend to state a formal nZEB definition for existing construction.
- Although England's building code defines the requisite for the use of at least one choice of renewable energies, it does not specify formal quantitative requirements.
- Due to the extension and variety of the country, Spain defines all the energy requirements based on the climate zone of the location of considered building. These requirements are however just the transition requirements intended to ease the achievement of definitive targets set in the phase two of the nZEB national (2018).

A summarized comparison in tabular form is presented in Table 20:

Table 20. Building codes an nZEB definitions tabular comparison

Country	nZEB: Nzeb definition document	nZEB: Formal nZEB definition: New Construction	nZEB: Formal nZEB definition: Major renovation	nZEB: Quantitative energy indicators: Primary energy use	nZEB: Quantitative energy indicators: Primary energy use energy consumption components	nZEB: Quantitative energy indicators: CO2 Emissions	nZEB: Quantitative energy indicators: Energy need for heating "Heizwärme bedarf"	nZEB: Quantitative energy indicators: Total energy efficiency factor fGEE	nZEB: Inclusion of appliances energy consumption	nZEB: Minimum share of renewable energy	Building code: Building code and calculation procedure	Building code: Additional requirements: New construction: max. U-values [W/m2K]	Building code: Additional requirements: New construction: Air pressure at 50 Pa	Building code: Additional requirements: New construction: Limit of heat gains	Building code: Additional requirements: Major renovation: max. U-values [W/m2K]	Building code: Additional requirements: Major renovation: Air pressure	Building code: Additional requirements: Major renovation: Limit of heat gains
Austria	OIB Guideline 6. (OIB 330-6/2015)	YES	YES	√	Space heating Cooling Domestic hot water DHW Lighting Electricity for ventilation Haushaltsstrombedarf/ Betriebsstrombedarf	√	√	√	√	YES At least 50% of energy need covered for heating and DHW by: Biomass / Heat pumps / District heating (renewable enrgy carrier) / High efficient CHP OR -Earnings of at least 10% in the netto-final energy (DHW-Solar thermal / Heating - heat recovery / Appliances - PV)	OIB Guideline 6. (OIB 330-6/2015) ÖNORM B 8110-5 ÖNORM H 5057 ÖNORM H 5050 ÖNORM H 5056 ÖNORM H 5058 ÖNORM H 5059	YES Ext. Wall: 0.35 Wall against ground: 0.4 Windows: 1.4 Floor: 0.4 Roof: 0.2	YES Max: 3 [1/h] (if Window ventilation) 1.5 [1/h] (if Mechanical ventilation)	YES less than 130 [days/ 10 Year] of external temperature exceeding	YES Ext. Wall: 0.35 Wall against ground: 0.4 Windows: 1.4 Floor: 0.4 Roof: 0.2	YES Max: 3 (if Window ventilation) 1.5 (if Mechanical ventilation)	YES less than 130 [days/ 10 Year] of external temperature exceeding
Germany	EnEV 2016 / KfW Efficiency house / nZEB National plan	NOT YET	NOT YET	√	Space heating Cooling Domestic hot water DHW Lighting'' Electricity for ventilation	√	X	X	X	YES New construction: At least on of the % of energy need for heating and cooling: (15% Solar thermal / 30% Biomass gas / 50% Biomass solid or liquid / 50% Geothermal) Existing construction: At least on of the % of energy need for heating and cooling: (25% Biomass gas / 15% other renwable technologies)	DIN V 18599* DIN EN ISO 13790 DIN 277-1 DIN 4108 DIN 4701-10	YES** Ext. Wall: 0.28/(0.28/0.35) Wall against ground: 0.35/(0.35/0.35) Windows: 1.3/(1.3/1.9) Floor: 0.35/(0.35/0.35) Roof: 0.2/(0.2/0.35)	YES NGF< 1500 m2 Max°: 2 [1/h] (without mech. ventilation) 1 [1/h] (if Mechanical ventilation (also residential buildings))	YES limitation of the incident solar radiation according to DIN V4108-2 8.3.3 limitation of overtemperature (Resdential: 1200 Kh/a / Non-residential: 500 Kh/a)	YES'' Ext. Wall: 0.24 /0,35 Wall against ground: 0.3/undef Windows: 1.3/1.9 Floor: 0.5/undef Roof: 0.24/0.35	YES Max: 3 (if Window ventilation) 1.5 (if Mechanical ventilation)	YES limitation of the incident solar radiation according to DIN V4108-2 limitation of overtemperature (Resdential: 1200 Kh/a / Non-residential: 500 Kh/a)
UK (England)	Zero Carbon hub / nZEB national plan	YES	NO	√	Space heating Cooling Domestic hot water DHW Lighting Electricity for ventilation	√	√`	X	X	YES Use of any low-carbon or renewable energy technology: (descentralized energy supply systems based on energy fro renewable sources (wind, solar, aerothermal, geothermal, hydrothermal, biogas) / cogeneration / district or block heating or cooling based completey or partially in renewable sources / heat pumps)	Conservation of fuel and power: Part L1 A: New Dwellings Part L2A: New buildings other than dwellings Part L1B: Existing Dwellings Part L2B: Existing buildings other than Dwellings	YES`` Ext. Wall: (0.3/0.35) Wall against ground: (-/-) Windows: (2/2.2) Floor: (0.25/0.25) Roof: (0.2/0.25)	YES Max: Residential: 10 [m3/hm2] Non-residential: 10 [m3/hm2]	YES Residenial: limit of incident solar radiation / improvement air change rate Non-residential: side-lit & top-lit spaces with height <6 m(g-value: 0.68) top-lit height >6 m (g-value: 0.46)	YES Ext. Wall: 0.28 Wall against ground: - Windows: - Floor: 0.22 Roof: 0.18	YES Max: Residential: 10 [m3/hm2] Non-residential: 10 [m3/hm2]	YES Residenial: limit of incident solar radiation / improvement air change Non-residential: side-lit & top-lit spaces with height <6 m(g-value: 0.68) top-lit height >6 m (g-value:
Spain	Real decree 235 / CTE DB-HE / nZEB national plan	NOT YET	NOT YET	√	Space heating Cooling Domestic hot water DHW	P	√	X	X	YES Minimum contribution of solar energy to domestic hot water depending on climate zone and DHW total demand and use of Photovoltaics depending on building size and climatic zone	basic Energy Saving Basic Document DB-HE 2013 basic Energy Saving Basic Document DB-HE 2006 *(min. Requirements for existing buildings)*	YES Walls&elements in contact with ground: (a:1.35,A:1.25/B: 1.2/C:0.75/D:0.6/ E:0.55) Windows: (a:5.7/A:5.7/B: 4.2/C:3.1/D:2.7/E :2.5) Floors and roofs: (a:1.2/A:0.8/B: 0.65/C:0.5/D:0.4/ E:0.35)	YES Max: Depending on the climate zone: (a:50/A:50/B: 50/C:27/D:27/E: 27) [m3/hm2]	YES Solar factor (g-value) limitation	YES Walls&elements in contact with ground: (a:1.35,A:1.25/B: 1.2/C:0.75/D:0.6 /E:0.55) Windows: (a:5.7/A:5.7/B: 4.2/C:3.1/D:2.7/ E:2.5) Floors and roofs: (a:1.2/A:0.8/B: 0.65/C:0.5/D:0. 4/E:0.35)	YES Max: Depending on the climate zone: (a:50/A:50/B: 50/C:27/D:27/ E:27) [m3/hm2]	YES Solar factor (g-value) limitation

* New norm prEN ISO 52000 replaces the actual calculation procedure described in the norm DINV 18599
** Values for the reference building in case of residential building
Residential building / (non-residential building with internal temperature higher than 19 °C / non-residential building with internal temperature between 12°C and 19 °C)
' Residential building or zones of non-residential building with internal temperature of 19 °C or less / non-residential buildings
'' Lighting is not included for residential buildings
° For buildings with more than 1500 m2 of net Surface have the limits of 3 m3/m2h (if mechanical ventilation) or 2 m3/m2h (if mechanical ventilation)
` Target fabric enrgy efficiency accounts for the energy need for space heatin and cooling
`` Residential building / non residential buildings
P possible energy indicator
- Energy need for cooling KB is not considered for residential buildings

4. Quantitative energy indicators comparison and nZEB status achievement

This chapter deals with the quantitative comparison of the energy indicators in order to achieve the nZEB status. The first section contains the input data concerning the building thermal envelope and technical systems properties for the MATLAB BEP model. The concrete results for each building are presented in the second section together with a final comparison pointing out the most remarkable differences.

4.1 Input data

As mentioned in chapter 2 'Methodology', three buildings by country for each of the four selected countries have been chosen from the TABULA/EPISCOPE and Passive House Project databases. Apart from these three cases or scenarios (GEN_1: Original building, GEN_2: Normal refurbishment and GEN_3: ambitious refurbishment), an additional highlighted row for each building is set taking into account the reference building provisions. This row is especially important for Germany where the energy performance assessment is done by measuring the percentage of primary energy consumption in regard to the reference building primary energy consumption.

Some of the selected buildings basic properties are shown in Table 21. This includes the Net conditioned volume, the number of conditioned levels, the conditioned reference area (NGF), the total surface of the building envelope (sum of the surface area of each building element that is part of the building thermal envelope), the compactness defined as the ratio between the building envelope surface and the conditioned volume, and finally the characteristic length (Austrian charakteristische Länge).

Table 21. Selected buildings by country and type main characteristics

Country	Building type	Building	Net Volume [m3]	Number of conditioned floors	Conditioned reference area [m2]	Total surface area A [m2]	Compactness Total surface area (A)/Conditioned volume (Ve)	char. length (AT)
Austria	Single Family House	AT_N_SFH_08_GEN_1 AT_N_SFH_08_GEN_2 AT_N_SFH_08_GEN_3 AT_N_SFH_08_REFDE	632,9	2	153,4	480	0,76	1,32
	Multi Family house	AT_N_MFH_08_GEN_1 AT_N_MFH_08_GEN_2 AT_N_MFH_08_GEN_3 AT_N_MFH_08_REFDE	875	4	219	646,7	0,74	1,35
	Apartment Block	AT_N_AB_08_GEN_1 AT_N_AB_08_GEN_2 AT_N_AB_08_GEN_3 AT_N_AB_08_REFDE	3511,6	5	906	1764	0,50	1,99
Germany	Single Family House	DE_N_SFH_12_GEN_1 DE_N_SFH_12_GEN_2 DE_N_SFH_12_GEN_3 DE_N_SFH_12_REFDE	827,1	2	186,8	509,3	0,62	1,62
	Multi Family house	DE_N_MFH_12_GEN_1 DE_N_MFH_12_GEN_2 DE_N_MFH_12_GEN_3 DE_N_MFH_12_REFDE	5371,1	5	1305	2128,6	0,40	2,52
	Apartment Block	DE_E_AB_08_GEN_1 DE_E_AB_08_GEN_2 DE_E_AB_08_GEN_3 DE_E_AB_08_REFDE	10160	6	2825	3257	0,32	3,12
Spain	Single Family House	ES_ME_SFH_06_GEN_1 ES_ME_SFH_06_GEN_2 ES_ME_SFH_06_GEN_3 ES_ME_SFH_06_REFDE	406,2	2	119,2	332	0,82	1,22
	Multi Family house	ES_ME_MFH_06_GEN_1 ES_ME_MFH_06_GEN_2 ES_ME_MFH_06_GEN_3 ES_ME_MFH_06_REFDE	3741	4	1419	1797	0,48	2,08
	Single Family House (PHS)	ES_ME_PHS_4764_GEN_1 ES_ME_PHS_4764_GEN_2 ES_ME_PHS_4764_GEN_3 ES_ME_PHS_4764_REFDE	2025	3	262	540	0,27	3,75
UK	Single Family House	GB_ENG_SFH_08_GEN_1 GB_ENG_SFH_08_GEN_2 GB_ENG_SFH_08_GEN_3 GB_ENG_SFH_08_REFDE	358,9	2	149,4	378,1	1,05	0,95
	Multi Family house	GB_ENG_MFH_08_GEN_1 GB_ENG_MFH_08_GEN_2 GB_ENG_MFH_08_GEN_3 GB_ENG_MFH_08_REFDE	2347,6	3	994	1353	0,58	1,74
	Multi Family house (PHS)	GB_ENG_PHS_2033_GEN1 GB_ENG_PHS_2033_GEN2 GB_ENG_PHS_2033_GEN3 GB_ENG_PHS_2033_REFDE	488	5	196	675	1,38	0,72

Table 22 describes the main building envelope attributes: Air tightness measured at 50 [Pa] and the U-Values:

Table 22. Building envelope characteristics. Air tightness and U-Values

Country	Building type	Building	n50 [1/h]	U- Values [W/m2K]					
				Delta U Thermal bridges	U-Value Window	U-Value Wall exterior	U-Value Wall ground	U-Value Roof	U-Value Floor
Austria	Single Family House	AT_N_SFH_08_GEN_1	1,0	0,05	1,4	0,35	0,36	0,2	0,36
		AT_N_SFH_08_GEN_2	1,0	0,05	0,7	0,08	0,1	0,1	0,1
		AT_N_SFH_08_GEN_3	1,0	0,05	0,8	0,1	0,2	0,1	0,2
		AT_N_SFH_08_REFDE	3,0	0,05	1,4	0,35	0,28	0,2	0,35
	Multi Family house	AT_N_MFH_08_GEN_1	1,0	0,05	1,4	0,35	0,36	0,2	0,36
		AT_N_MFH_08_GEN_2	1,0	0,05	0,7	0,1	0,1	0,08	0,1
		AT_N_MFH_08_GEN_3	1,0	0,05	0,8	0,1	0,2	0,1	0,2
		AT_N_MFH_08_REFDE	3,0	0,05	1,4	0,35	0,28	0,2	0,35
	Apartment Block	AT_N_AB_08_GEN_1	1,0	0,05	1,4	0,35	0,36	0,2	0,36
		AT_N_AB_08_GEN_2	1,0	0,05	0,7	0,1	0,1	0,1	0,1
		AT_N_AB_08_GEN_3	1,0	0,05	0,8	0,1	0,23	0,1	0,23
		AT_N_AB_08_REFDE	3,0	0,05	1,4	0,35	0,28	0,2	0,35
Germany	Single Family House	DE_N_SFH_12_GEN_1	1,0	0,05	1,1	0,17	0,17	0,15	0,17
		DE_N_SFH_12_GEN_2	1,0	0,05	1,1	0,15	0,15	0,13	0,15
		DE_N_SFH_12_GEN_3	1,0	0,02	0,7	0,12	0,12	0,1	0,12
		DE_N_SFH_12_REFDE	1,0	0,05	1,3	0,28	0,28	0,2	0,35
	Multi Family house	DE_N_MFH_12_GEN_1	1,0	0,05	1,1	0,29	0,29	0,25	0,29
		DE_N_MFH_12_GEN_2	1,0	0,05	1,1	0,11	0,11	0,1	0,11
		DE_N_MFH_12_GEN_3	1,0	0,02	0,7	0,12	0,12	0,08	0,12
		DE_N_MFH_12_REFDE	1,0	0,05	1,3	0,28	0,28	0,2	0,35
	Apartment Block	DE_E_AB_08_GEN_1	1,0	0,10	3	0,6	0,51	0,36	0,51
		DE_E_AB_08_GEN_2	0,6	0,05	1,3	0,2	0,25	0,17	0,25
		DE_E_AB_08_GEN_3	0,6	0,05	0,8	0,12	0,19	0,09	0,19
		DE_E_AB_08_REFDE	1,0	0,05	1,3	0,28	0,28	0,2	0,35
Spain	Single Family House	ES_ME_SFH_06_GEN_1	1,0	0,05	3,09	0,48	1,31	0,48	1,31
		ES_ME_SFH_06_GEN_2	1,0	0,05	1,66	0,2	0,28	0,48	0,28
		ES_ME_SFH_06_GEN_3	1,0	0,05	1,66	0,2	0,28	0,48	0,28
		ES_ME_SFH_06_REFDE	1,0	0,05	5,7	0,82	0,82	0,45	0,82
	Multi Family house	ES_ME_MFH_06_GEN_1	1,0	0,05	3,37	0,52	0,56	0,45	0,56
		ES_ME_MFH_06_GEN_2	1,0	0,05	1,44	0,19	0,2	0,45	0,2
		ES_ME_MFH_06_GEN_3	1,0	0,05	1,44	0,19	0,2	0,45	0,2
		ES_ME_MFH_06_REFDE	1,0	0,05	5,7	0,82	0,82	0,45	0,82
	Single Family House (PHS)	ES_ME_PHS_4764_GEN_1	0,6	0,05	3,09	0,48	1,31	0,48	1,31
		ES_ME_PHS_4764_GEN_2	0,6	0,05	1,73	0,28	1,13	0,29	1,13
		ES_ME_PHS_4764_GEN_3	0,6	0,05	1,73	0,28	1,13	0,29	1,13
		ES_ME_PHS_4764_REFDE	1,0	0,05	5,7	0,82	0,82	0,45	0,82
UK	Single Family House	GB_ENG_SFH_08_GEN_1	1,0	0,05	1,85	0,28	0,21	0,16	0,21
		GB_ENG_SFH_08_GEN_2	1,0	0,02	0,68	0,11	0,11	0,11	0,11
		GB_ENG_SFH_08_GEN_3	1,0	0,02	0,68	0,11	0,11	0,11	0,11
		GB_ENG_SFH_08_REFDE	3,0	0,05	1,4	0,18	0,18	0,13	0,13
	Multi Family house	GB_ENG_MFH_08_GEN_1	1,0	0,05	1,85	0,28	0,21	0,16	0,21
		GB_ENG_MFH_08_GEN_2	1,0	0,02	0,68	0,11	0,11	0,11	0,11
		GB_ENG_MFH_08_GEN_3	1,0	0,02	0,68	0,11	0,11	0,11	0,11
		GB_ENG_MFH_08_REFDE	2,9	0,05	1,4	0,18	0,18	0,13	0,13
	Multi Family house (PHS)	GB_ENG_PHS_2033_GEN1	0,5	0,05	1,85	0,28	0,21	0,16	0,21
		GB_ENG_PHS_2033_GEN2	0,5	0,01	1,04	0,113	0,143	0,148	0,143
		GB_ENG_PHS_2033_GEN3	0,5	0,01	0,68	0,113	0,143	0,148	0,143
		GB_ENG_PHS_2033_REFDE	6,9	0,05	1,4	0,18	0,18	0,13	0,13

Finally, a summary of the technical installations of the buildings is presented in Table 23. Cooling systems are normally provided for the buildings in Spain depending on the climate zone. Residential buildings in Austria, Germany and England however are commonly not equipped with this technical system (even so, typical EER and corresponding expenditure coefficients are given in the respective gray shaded cells). It is to be remembered that Austrian building code OIB Guideline 6 unlike the rest of the countries does not take into account the energy need for cooling for residential buildings for the primary energy consumption calculation.

Specific distribution losses as well as the energy expenditure coefficients are default values defined in the EPISCOPE/TABULA web tool and therefore are directly set as input to the MATLAB BEP model.

Table 23. Building technical installations

Country	Building type	Building	Technical systems: Space heating – energy carrier	Space heating – energy expenditure coefficient	Space heating – specific distribution losses [kWh/m2]	Domestic hot water DHW – energy carrier	DHW – energy expenditure coefficient	DHW – specific distribution losses [kWh/m2]	Ventilation – WRG	Ventilation – P-SPF zuluft [kW/m3s]	Ventilation – P-SPF abluft [kW/m3s]	Ventilation – Δ Pressure [Pa]	Thermal Solar – Type	Thermal Solar – Collector	Cooling – Type	Cooling – EER	Cooling – energy expenditure coefficient
Austria	Single Family House	AT_N_SFH_08_GEN_1	oil	1,12	7	oil	1,03	7,1	0	0	0	0	-	-	KM Air, compr improved. Cold water 14/18 Std	4,02	0,249
		AT_N_SFH_08_GEN_2															
		AT_N_SFH_08_GEN_3	wood pellets (bio)	1,34		wood pellets (bio)	1,34	29,6									
		AT_N_SFH_08_REFDE	oil	1,12	7	oil	1,03	7,1	0	1	0,62	670	-	-	-	-	-
	Multi Family house	AT_N_MFH_08_GEN_1	gas	1,12	7	gas	1,03	7,1	0	0	0	0	-	-	KM Air, compr improved. Cold water 14/18 Std	4,02	0,249
		AT_N_MFH_08_GEN_2															
		AT_N_MFH_08_GEN_3	District heating	1,02	10	District	1,02	14									
		AT_N_MFH_08_REFDE	oil	1,12	7	oil	1,03	7,1	0	1	0,62	670	-	-	-	-	-
	Apartment Block	AT_N_AB_08_GEN_1	gas	1,12	7	gas	1,03	7,1	0	0	0	0	-	-	KM Air, compr improved. Cold water 14/18 Std	4,02	0,249
		AT_N_AB_08_GEN_2											-	-			
		AT_N_AB_08_GEN_3	District heating	1,02	10	District	1,02	14					dhw	Flach			
		AT_N_AB_08_REFDE	oil	1,12	7	oil	1,03	7,1	0	1	0,62	670	-	-			
Germany	Single Family House	DE_N_SFH_12_GEN_1	gas	1,08	2,1	gas	1,23	4,4	0	1,17	0,8	770	dhw	Flach	KM Air, compr improved. Cold water 14/18 Std	4,02	0,249
		DE_N_SFH_12_GEN_2							0,75								
		DE_N_SFH_12_GEN_3	wood pellets (bio)	1,37	2,1	wood pellets (bio)	1,63	4,4									
		DE_N_SFH_12_REFDE	oil	1,08	1,3	oil	1,23	6,5	0	1,17	0,8	770	dhw	Flach	-	-	-
	Multi Family house	DE_N_MFH_12_GEN_1	gas	1,18	1,1	gas	1,06	6,4	0,75	1,17	0,8	770	dhw	Flach	KM Air, compr improved. Cold water 14/18 Std	4,02	0,249
		DE_N_MFH_12_GEN_2															
		DE_N_MFH_12_GEN_3															
		DE_N_MFH_12_REFDE	oil	1,08	1,8	oil	1,06	6,3	0	1,17	0,8	770	dhw	Flach	-	-	-
	Apartment Block	DE_E_AB_08_GEN_1	gas	1,23	15,1	gas	1,2	30,9	0	1,17	0,8	770	-	-	KM Air, compr improved. Cold water 14/18 Std	4,02	0,249
		DE_E_AB_08_GEN_2	District heating (chp gas)	1,02	5,7	District heating	1,14	9,6	0,75				-	-			
		DE_E_AB_08_GEN_3	wood pellets (bio)	1,25	5,7	wood pellets (bio)	1,32	6,4	0,75				dhw	Flach			
		DE_E_AB_08_REFDE	oil	1,23	15	oil	1,2	9,6	0	1,17	0,8	770	dhw	Flach			
Spain	Single Family House	ES_ME_SFH_06_GEN_1	gas	1,15	19,6	gas	1,43	6,4	0	0	0	0	dhw	Flach	KM Air, compr improved. Cold water 14/18 Std	2,33	0,429
		ES_ME_SFH_06_GEN_2	gas	1	5,7											3,8	0,263
		ES_ME_SFH_06_GEN_3	wood pellets	1,05	5,7								-	-			
		ES_ME_SFH_06_REFDE	gas	1,09	5,7	gas	1,09	6,4	0	0	0	0	dhw	Flach	KM	2,00	0,5
	Multi Family house	ES_ME_MFH_06_GEN_1	gas	1,15	19,6	gas	1,43	6,4	0	0	0	0	dhw	Flach	KM Air, compr improved. Cold water 14/18 Std	2,33	0,429
		ES_ME_MFH_06_GEN_2		1	5,7											3,8	0,263
		ES_ME_MFH_06_GEN_3	wood pellets	1,05	5,7								-	-			
		ES_ME_MFH_06_REFDE	gas	1,09	5,7	gas	1,09	6,4	0	0	0	0	dhw	Flach	KM	2,00	0,5
	Single Family House (PHS)	ES_ME_PHS_4764_GEN_1	gas	1	5,7	gas	1,43	6,4	0	1	0,62	670	-	-	KM Air, compr improved. Cold water 14/18 Std	2,33	0,429
		ES_ME_PHS_4764_GEN_2	Heat pump	0,5	5,7	Heat pump	0,5	6,4	0	1	0,62	670					
		ES_ME_PHS_4764_GEN_3	Heat pump	0,38	5,7	Heat pump	0,38	6,4	0,75	1	0,62	670	dhw	Flach			
		ES_ME_PHS_4764_REFDE	gas	1,09	5,7	gas	1,09	6,4	0	0	0	0	dhw	Flach	KM	2	0,5
UK	Single Family House	GB_ENG_SFH_08_GEN_1	gas	1,19	0	gas	1,19	0,2	0	0	0,8	530	-	-	KM Air, compr improved. Cold water 14/18 Std	4,02	0,249
		GB_ENG_SFH_08_GEN_2			0												
		GB_ENG_SFH_08_GEN_3	Air heat pump	0,4	0	Electricity	1	0									
		GB_ENG_SFH_08_REFDE	gas	1,19	1,9	gas	1,19	9,8	0	0	0,8	530	-	-	-	-	-
	Multi Family house	GB_ENG_MFH_08_GEN_1	gas	1,19	0	gas	1,19	0,2	0	0	0	0	-	-	KM Air, compr improved. Cold water 14/18 Std	4,02	0,249
		GB_ENG_MFH_08_GEN_2			0												
		GB_ENG_MFH_08_GEN_3			0								dhw	Flach			
		GB_ENG_MFH_08_REFDE	gas	1,19	1,4	gas	1,19	6,5	0	0	0,8	530	-	-	-	-	-
	Multi Family house (PHS)	GB_ENG_PHS_2033_GEN1	Air heat pump	5,26	0	Air heat	0,53	0		1	0,62	670			KM Air, compr improved. Cold water 14/18 Std	4,02	0,249
		GB_ENG_PHS_2033_GEN2	Air heat pump	5,26	0	Air heat	0,53	0	0	1	0,62	670	dhw	Flach			
		GB_ENG_PHS_2033_GEN3	Air heat pump	5,26	0	Air heat	0,53	0	0	1	0,62	670	dhw	Flach			
		GB_ENG_PHS_2033_REFDE	gas	1,19	1,7	gas	1,19	8,7	0	0	0,8	530	-	-			

As brief reminder, the energy requirements taken into account by the MATLAB BEP model and hence for the quantitative comparison are only the main energy indicators by country which are:

Table 24. Main energy indicators by country used for the nZEB definition assessment

Country	Energy indicators for achieving Nzeb distinction (quantitative comparison)				
Austria	HWB Heizwärmebedarf (Energy need for heating / cooling)	Primary energy consumption	CO2 emissions	Total energy efficiency factor fGEE	HTEB (technical installation efficiency)
Germany	Specific heat transmission losses HT' (equivalent to energy need)			Primary energy consumption (Consumption percentage of a reference building)	
Spain	Energy need for heating / cooling			Primary energy consumption	
England	Fabric energy efficiency (equivalent to energy need for heating / cooling)			CO2 emissions	

4.2 Results

In this section, individual results for each building of each country are presented. Some remarkable cases are highlighted and compared in section 4.2.5.

In order to give a more sensitive approach on the compliance or not of the nZEB definition, a numerical indicator together with a color scale has been set for each nZEB indicator in each scenario of each building. This indicator gives an idea of how far is the normalized result respect to the maximum reference value presented in Chapter 3. Building codes and Nearly Zero Energy Buildings (nZEB) definition comparison.

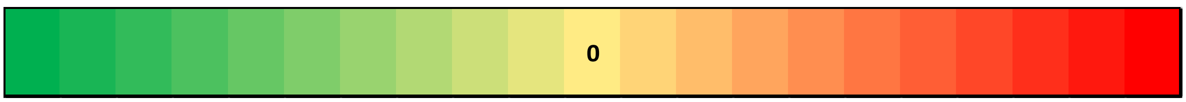


Figure 31. Color scale representing the distance in percentage to the reference value according to nZEB definition.

A value under the maximum reference (represented with the zero and yellow color) is therefore negative and is represented with the green colors. On the other hand a non-compliant value over the maximum reference is positive and represented with the red values. The lower the value the farther from the reference value. For example, a value of (0.2) on the primary energy consumption for the scenario x, means that the examined indicator exceeds on 20% the maximum reference value for primary energy consumption. Likewise a value of (-0.2) indicates that the energy consumption for the scenario x is 20% under the maximum reference value.

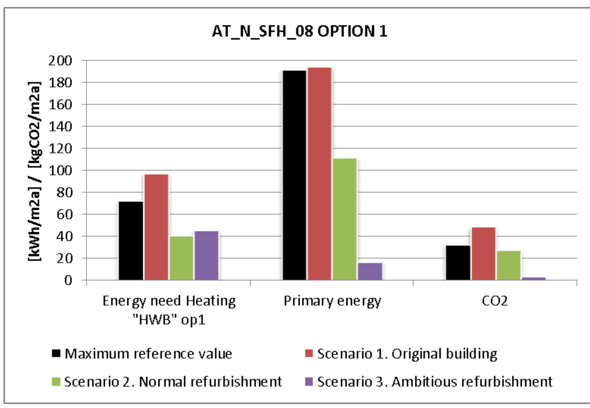
Taking into account the largest energy indicator value for each scenario and following the same logic, the tightness or looseness of the nZEB definition compliance is measured as well by means of the color scale of the limiting energy indicator.

4.2.1 Results for the case of Austria

- **AT_N_SFH_08 – Single family house -**

Figure 32. Representative SFH Austria Image. Taken from [8]

- *Assessment under Austrian scope:*



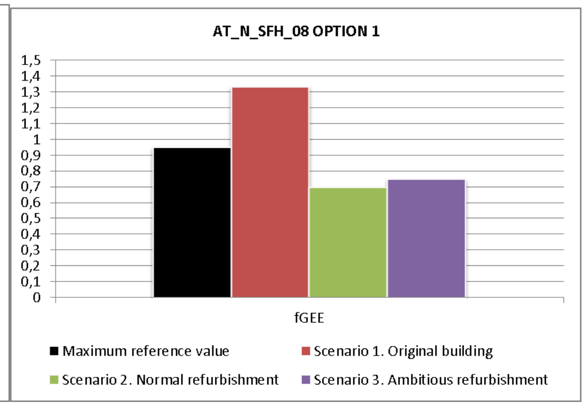


Figure 33. AT_N_SFH_08 - Fulfillment criteria option 1

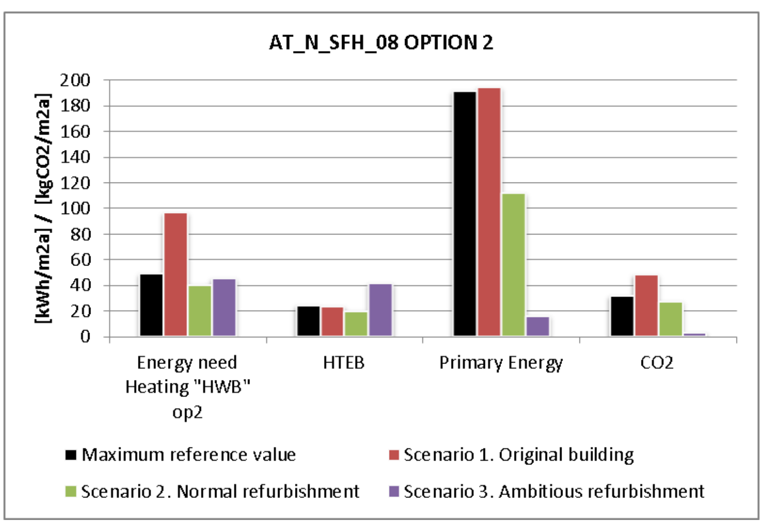


Figure 34.AT_N_SFH_08 - Fulfillment criteria option 2

Table 25. Results for the Austrian building AT_N_SFH_08 according to Austrian nZEB definition

		AT						Compliance nZEB definition AT
		HWB option 1	Primary energy	CO2	fGEE	HWB option 2	HTEB	
SFH	Maximum reference value	0,00						
	Scenario 1. Original building	0,34	0,01	0,52	0,40	0,97	-0,03	NO
	Scenario 2. Normal refurbishment	-0,44	-0,42	-0,14	-0,27	-0,17	-0,18	O.K
	Scenario 3. Ambitious refurbishment	-0,37	-0,91	-0,89	-0,21	-0,07	0,70	O.K

nZEB definition according to AUSTRIA			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Energy need for space heating “Heizwärmebedarf option 2”	CO2 Emissions rate	Energy need for space heating “Heizwärmebedarf option 1”
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.97)	(-0.14)	(-0.37)

- *Assessment under German scope:*

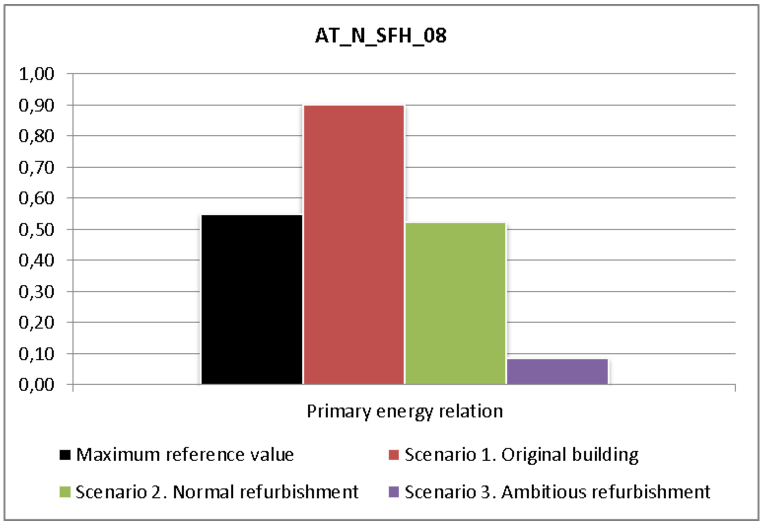


Figure 35. AT_N_SFH_08 Primary energy consumption in [%] of the reference building.

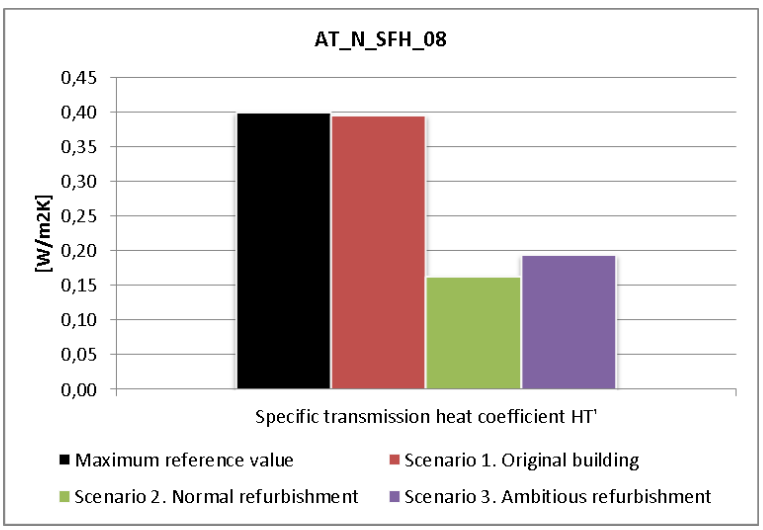


Figure 36. AT_N_SFH_08 Specific transmission heat coefficient HT'

Table 26. Results for the Austrian building AT_N_SFH_08 according to German nZEB definition

		DE		Compliance nZEB definition DE
		Primary energy	HT'	
SFH	Maximum reference value	0,00		
	Scenario 1. Original building	0,64	-0,01	NO
	Scenario 2. Normal refurbishment	-0,05	-0,59	O.K
	Scenario 3. Ambitious refurbishment	-0,85	-0,52	O.K

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Primary energy	Specific transmission heat losses HT' "Spezifischen Transmissionswärmev erlust"
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.64)	(-0.05)	(-0.52)

- *Assessment under Spanish scope:*

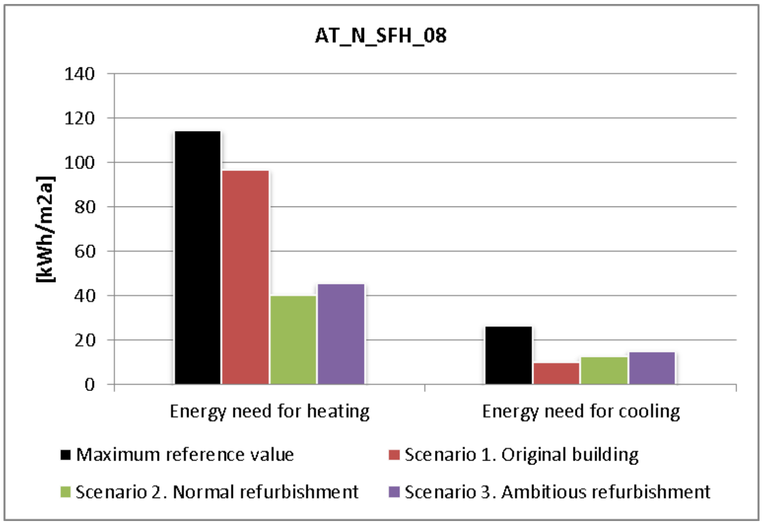


Figure 37. AT_N_SFH_08 Energy need for heating and cooling

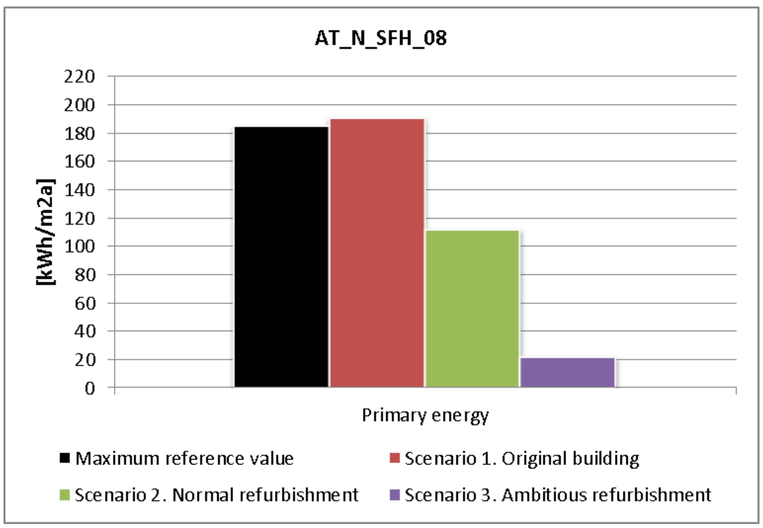


Figure 38. AT_N_SFH_08 Primary energy consumption

Table 27. Results for the Austrian building AT_N_SFH_08 according to Spanish nZEB definition

	ES			Compliance nZEB definition ES
	Energy need for heating	Energy need for cooling	Primary energy	
Maximum reference value	0,00			
Scenario 1. Original building	-0,15	-0,61	0,03	NO
Scenario 2. Normal refurbishment	-0,64	-0,52	-0,39	O.K
Scenario 3. Ambitious refurbishment	-0,60	-0,43	-0,88	O.K

nZEB definition according to SPAIN			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Primary energy	Energy need for cooling
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.03)	(-0.39)	(-0.43)

- *Assessment under English scope:*

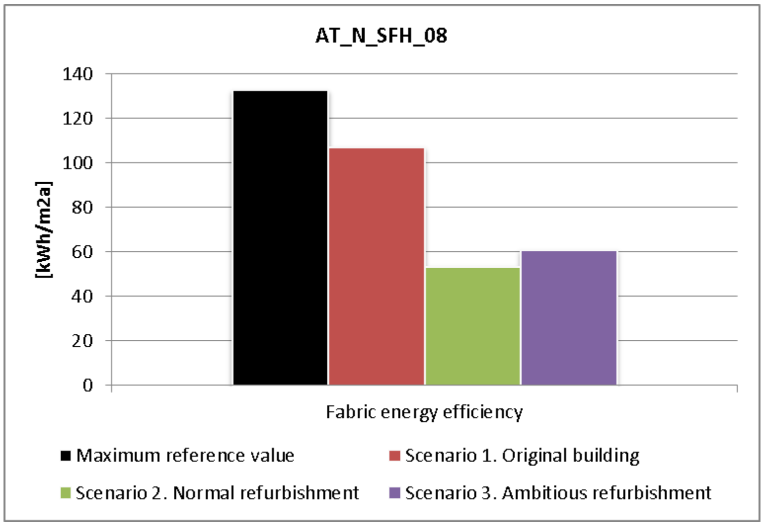


Figure 39. AT_N_SFH_08 Fabric energy efficiency (energy need for heating and cooling)

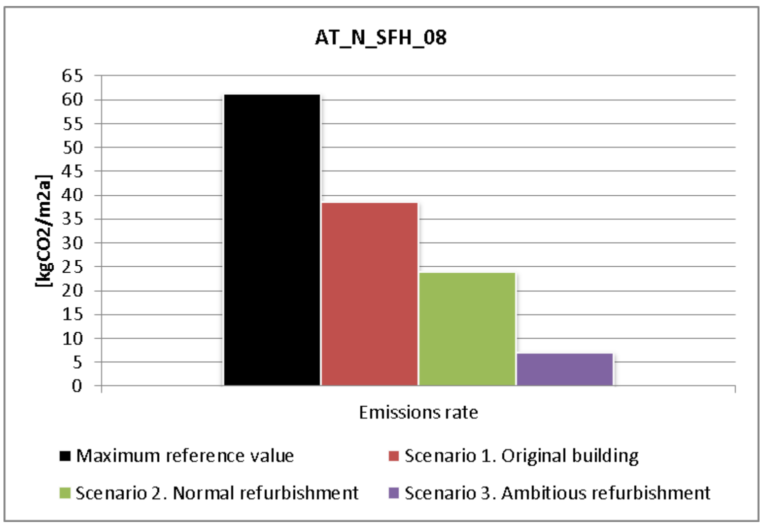


Figure 40. AT_N_SFH_08 CO2 Emissions rate

Table 28. Results for the Austrian building AT_N_SFH_08 according to English nZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO2 Emissions rate	
SFH	Maximum reference value	0,00		
	Scenario 1. Original building	-0,19	-0,37	O.K
	Scenario 2. Normal refurbishment	-0,60	-0,61	O.K
	Scenario 3. Ambitious refurbishment	-0,54	-0,89	O.K

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Fabric energy efficiency	Fabric energy efficiency	Fabric energy efficiency
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.19)	(-0.60)	(-0.54)

- **AT_N_SFH_08 – Single family house –Results**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the austrian single family house (AT_N_SFH_08) assessed under the austrian building code scope results in the non-compliance of the nZEB definition, with the worst reference value for the energy need for space heating option 2. The numerical indicator shows that the Austrian reference value is exceeded in 97% in this first scenario (see Table 25). This means that the energy need for space heating is almost the double of the permited value. The main driver of this overrun are the high U-Values (Thermal transmittance), which imply a low building insulation and hence higher heat losses. The primary energy and CO2 Emissions indicators are above the reference too, which causes no disconcert considering that already the building envelope is not efficient enough to comply with the energy need requirements and since the technical systems are standard (not high efficient) in this first scenario.

The assessment under the German building code scope results also in the non-compliance, in this case of the reference value for the primary energy. The numerical indicator shows that the reference value is exceeded in 64% in this first scenario (see Table 26). It is interesting to observe however, that the specific transmission heat losses HT' calculated as shown in equation 43 (dependent on the U-values, a temperature correction factor and the building envelope surface area), are under the German reference value. This supposes a first difference with the Austrian code, suggesting that the austrian requirements regarding the building envelope are more general, since Austrian code considers for the calculation of the energy need for space heating not only the specific transmission heat losses but also other components like the ventilation, solar gains and internal heat sinks and sources. The quantitative results are yet hardly directly comparable since the Austrian limits are given as absolute values whilst the German ones are relative values given as a percentage refered to a notion building.

Like Germany, the assessment under the Spanish scope results in the non-compliance of the Spanish reference value for the primary energy. In this case, the value is only 3% above the reference (see Table 27). The energy need for space heating is 15% under the Spanish reference value which differs also from Austria. Spanish maximum reference value is higher than Austrian because of the assumption of the climate zone E described in the section 2.2.

Under English scope, unlike the three past cases, the original building complies with the nZEB definition. The fabric energy efficiency (comparable to the energy need for space heating) is in ths case the limiting energy indicator, it is 19% under the maximum reference value.

Scenario 2 (GEN_2: Building subjected to normal renovation)

By only reducing the Windows, walls, roof and floor U- values to at least half their value under normal renovation (GEN_2), without modifying the technical systems (same as in the original building and described in Table 23), the energy need for space heating falls to a value 17% under the reference and the building does comply with the Austrian Nzeb definition (see Table 25). The limiting energy indicator is in this case the CO2 emissions rate but it lies anyway 14% under the reference value.

This second scenario is also compliant under the German scope (see Table 26). The primary energy lies in this case 5% under the German reference and the specific transmission heat losses are proportionally reduced to almost 60% under the German reference by the reduction of the U-Values.

Unaltered respect to the scenario 1, due to the higher Spanish energy need for space heating and primary energy consumption reference values, the scenario 2 complies loosely with the Spanish nZEB definition. The primary energy indicator lies 39% under the Spanish reference (see Table 27).

The building is once again compliant with the English nZEB definition. In this case instead of 19%, the fabric energy efficiency rests 60% below the English reference value. The only change as described before is the reduction of the U-Values.

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

Under an ambitious renovation (GEN_3), affecting not only the building envelope but also the bulding technical systems (see Table 23), the building complies with the main energy indicators reference value under the nZEB scope of each of the four countries and therefore with their respective nZEB definition.

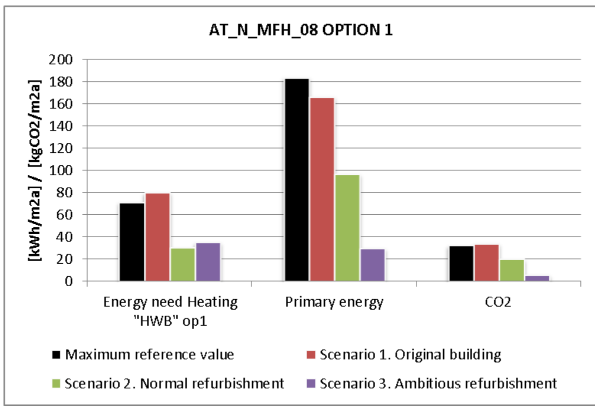
The results are similar in all cases to those obtained in the scenario 2 where only the building envelope was modified (reduction of the U-Values). Nonetheless, the case of Germany is to be highlighted here. The reduction in the primary energy consumption respect to the previous scenario is considerably. It goes from 5% below the reference value as described above, to 85% under the reference value (see Table 26), which indicates the important effect and influence of the improvement of the technical systems from the German perspective.

It is important to bear in mind that the German nZEB definition is based on the primary energy consumption of the analysed building in comparison to a reference notional building with a minimum “standard” insulation and technical systems.

- **AT_N_MFH_08 – Multi-family house -**

Figure 41. Representative MFH Austria Image. Taken from [8]

- *<u>Assessment under Austrian scope:</u>*



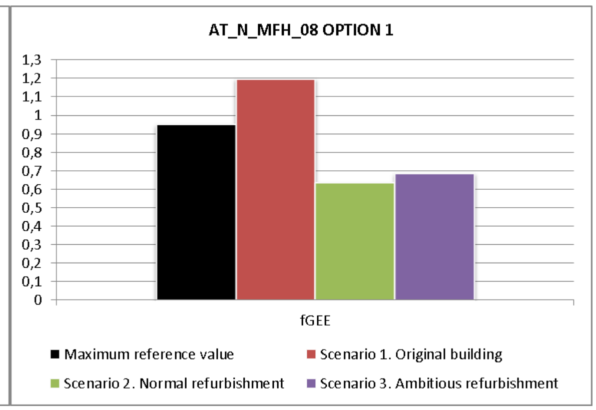


Figure 42. AT_N_MFH_08 - Fulfillment criteria option 1

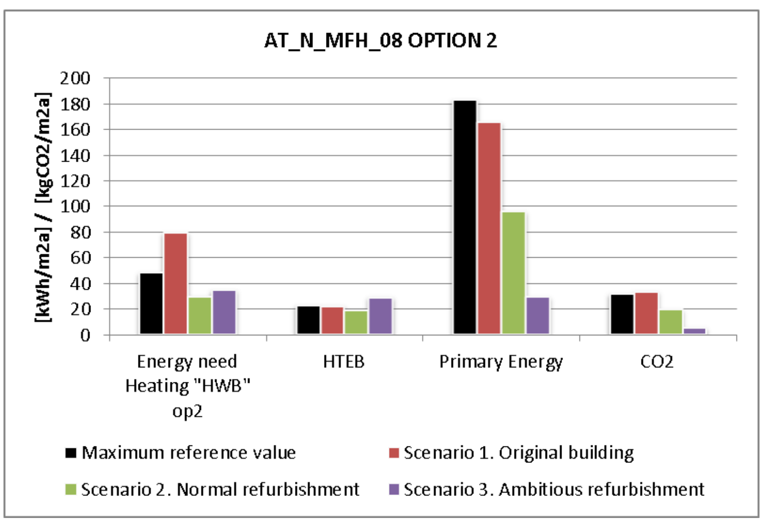


Figure 43. AT_N_MFH_08 - Fulfillment criteria option 2

Table 29. Results for the Austrian building AT_N_MFH_08 according to Austrian nZEB definition

	AT						Compliance nZEB definition AT
	HVB option 1	Primary energy	CO2	FGEE	HVB option 2	HTEB	
Maximum reference value	0,00						
Scenario 1. Original building	0,12	-0,10	0,05	0,26	**0,65**	-0,03	**NO**
Scenario 2. Normal refurbishment	-0,58	-0,48	-0,39	-0,33	-0,38	**-0,17**	**O.K**
Scenario 3. Ambitious refurbishment	-0,51	-0,84	-0,84	**-0,28**	-0,28	0,27	**O.K**

nZEB definition according to AUSTRIA			
SCENARIO :	**Scenario 1 (GEN_1)**	**Scenario 2 (GEN_2)**	**Scenario 3 (GEN_3)**
COMPLIANCE :	**NON- COMPLIANT**	**COMPLIANT**	**COMPLIANT**
ENERGY INDICATOR :	**Energy need for space heating “Heizwärmebedarf option 2”**	**Total energy efficiency factor fGEE “Gesamt energieeffizienz-Faktor“**	**HTEB “Heiztecnik-Energiebedarf”**
Compliance Numerical indicator (see section 4.2) (VALUE):	**(0.65)**	**(-0.33)**	**(-0.18)**

- *Assessment under German scope:*

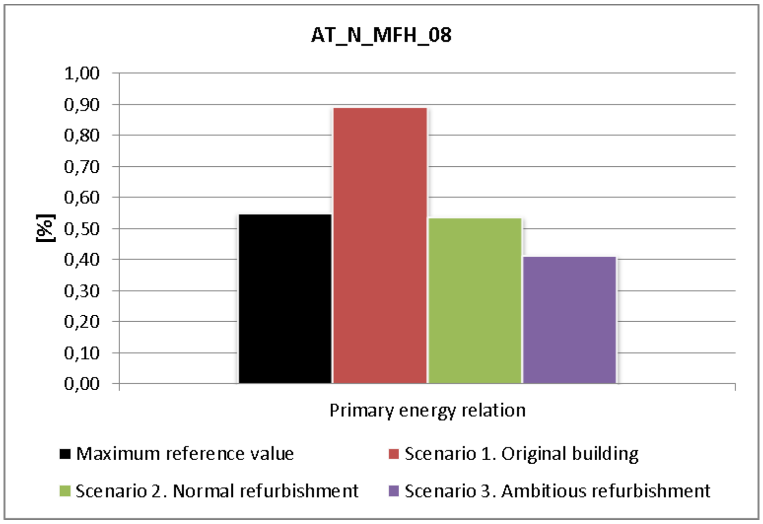


Figure 44. AT_N_MFH_08 Primary energy consumption in [%] of the reference building.

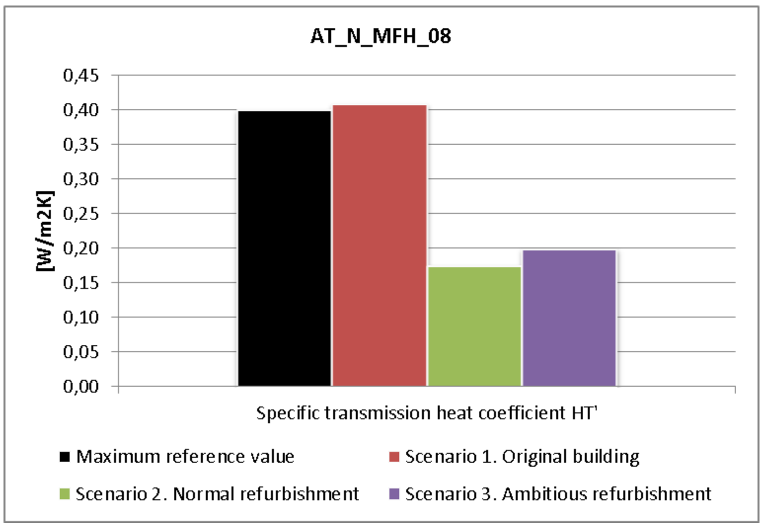


Figure 45. AT_N_MFH_08 Specific transmission heat coefficient HT'

Table 30. Results for the Austrian building AT_N_MFH_08 according to German nZEB definition

		DE		Compliance nZEB definition DE
		Primary energy	HT'	
MFH	Maximum reference value	0,00		
	Scenario 1. Original building	0,62	0,02	NO
	Scenario 2. Normal refurbishment	-0,02	-0,56	O.K
	Scenario 3. Ambitious refurbishment	-0,25	-0,50	O.K

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Primary energy	Primary energy
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.62)	(-0.02)	(-0.25)

- *Assessment under Spanish scope:*

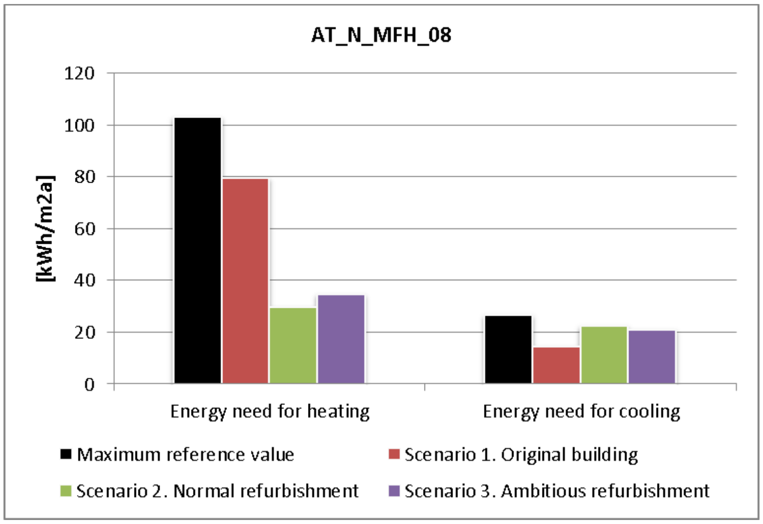


Figure 46. AT_N_MFH_08 Energy need for heating and cooling

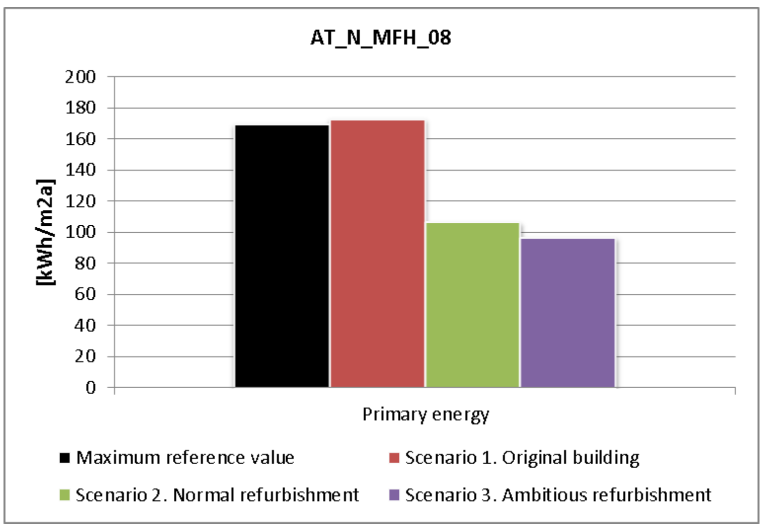


Figure 47. AT_N_MFH_08 Primary energy consumption

Table 31. Results for the Austrian building AT_N_MFH_08 according to Spanish nZEB definition

		ES			Compliance nZEB definition ES
		Energy need for heating	Energy need for cooling	Primary energy	
MFH	Maximum reference value	0,00			
	Scenario 1. Original building	-0,23	-0,45	0,02	NO
	Scenario 2. Normal refurbishment	-0,71	-0,16	-0,37	O.K
	Scenario 3. Ambitious refurbishment	-0,66	-0,21	-0,43	O.K

nZEB definition according to SPAIN			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Energy need for cooling	Energy need for cooling
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.02)	(-0.16)	(-0.21)

- *<u>Assessment under English scope:</u>*

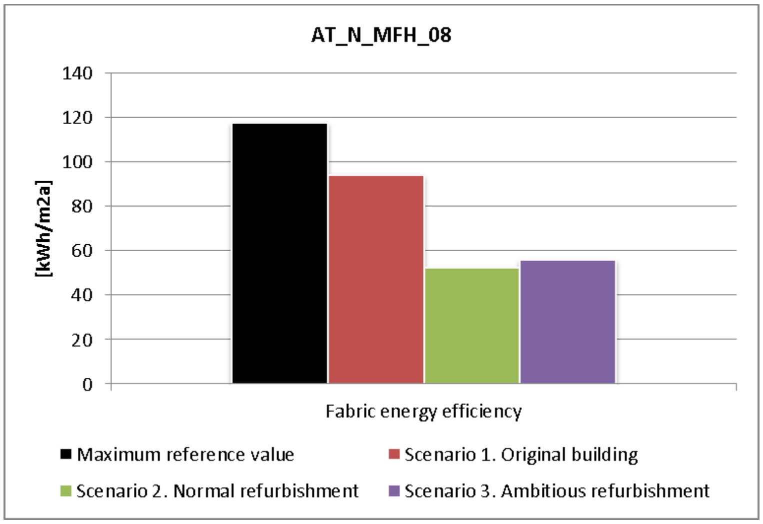


Figure 48. AT_N_MFH_08 Fabric energy efficiency (energy need for heating and cooling)

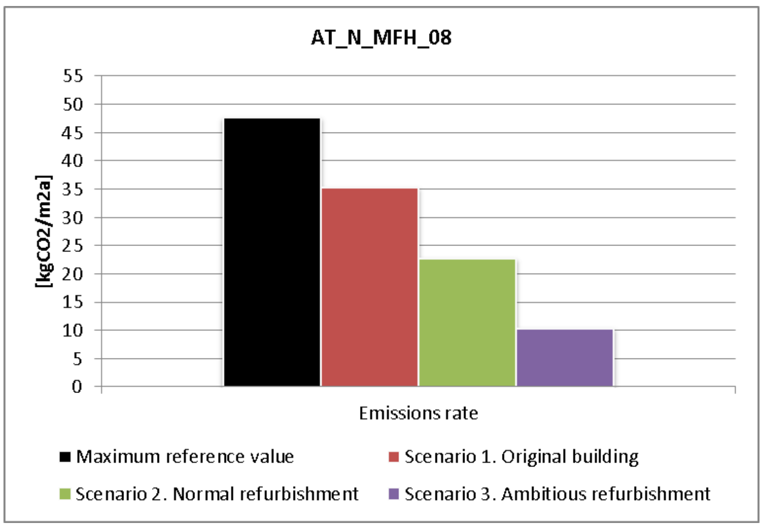


Figure 49. AT_N_MFH_08 CO2 Emissions rate

Table 32. Results for the Austrian building AT_N_MFH_08 according to English ZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO2 Emissions rate	
MFH	Maximum reference value	0,00		
	Scenario 1. Original building	-0,20	-0,26	O.K
	Scenario 2. Normal refurbishment	-0,56	-0,52	O.K
	Scenario 3. Ambitious refurbishment	-0,53	-0,78	O.K

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Fabric energy efficiency	CO2 Emissions rate	Fabric energy efficiency
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.20)	(-0.52)	(-0.53)

- **AT_N_MFH_08 – Multi-family house –Results discussion**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the austrian multi-family house (AT_N_MFH_08) assessed under the austrian building code scope results in the non-compliance of the nZEB definition, with the worst reference value for the energy need for space heating option 2. The numerical indicator shows that the Austrian reference value is exceeded in 65% in this first scenario (see Table 29). The Primary energy consumption and the technical system losses requirements "HTEB" are fulfilled though. This results indicate that the non-compliance is mainly due to the inefficient building envelope . The primary energy and CO2 Emissions indicators are above the reference as expected too, considering that already the building envelope is not efficient enough to comply with the energy need requirements and since the technical systems are standard (not high efficient) in this first scenario.

The assessment under the German building code scope results also in the non-compliance, for both the specific transmission heat losses HT' and for the primary energy, being this last one the furthest one, 62% above from the reference value (see Table 30). It is interesting to observe however, that the specific transmission heat losses HT' calculated as shown in equation 43 (dependent on the U-values, a temperature correction factor and the building envelope surface area), are barely 2% above the German reference value. This shows again a difference between the Austrian and German energy requirements, as in the case of first Austrian building (AT_N_SFH_08). The Austrian code is more severe on the assessment of the building thermal envelope.

Like Germany, the assessment under the Spanish scope results in the non-compliance of the Spanish reference value for the primary energy. In this case, the value is only 2% above the reference (see Table 31). The energy need for space heating is 23% under the Spanish reference value which differs also from Austria. Spanish maximum reference value is higher than Austrian because of the assumption of the climate zone E described in the section 2.2.

Under English scope, unlike the three past cases, the original building complies with the nZEB definition. The fabric energy efficiency (comparable to the energy need for space heating) is in ths case the limiting energy indicator, it is 20% under the maximum reference value. This result indicates a similar severity on the building thermal envelope assessment of the Spanish and the English scopes.

Scenario 2 (GEN_2: Building subjected to normal renovation)

By only reducing the Windows, walls, roof and floor U- values to at least half their value under normal renovation (GEN_2), without modifying the technical systems (same as in the original building and described in Table 23), all the energy indicators fall under their respective reference values and the building complies with the Austrian Nzeb definition (see Table 29). The limiting energy indicator is in this case the technical system losses “HTEB” but it lies anyway 17% under the reference value.

This second scenario is also compliant under the German scope (see Table 30). The primary energy lies in this case 2% under the German reference and the specific transmission heat losses are proportionally reduced to 56% under the German reference by the reduction of the U-Values.

Unaltered respect to the scenario 1, due to the higher Spanish reference values for the energy need for space heating, the scenario 2 complies loosely with this energy indicator. On the other hand, the energy need for cooling lies 16% under the reference value. This one is worst than the one form the Scenario 1 (where it was 45% under the reference value as shown in Table 31). This is caused by the combination of two factors, one is the reduction of the U-Values respect to the previous scenario, and second, the fact that the solar gains in Spain are substantial. The primary energy indicator value lies 37% under the Spanish reference.

The building is once again compliant with the English nZEB definition. In this case instead of 20%, the fabric energy efficiency rests 56% below the English reference value. The only change as described before is the reduction of the U-Values. The limiting energy indicator, that means the closest to the reference value is however the CO2 Emission factor that lies anyway 52% under it.

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

Under an ambitious renovation (GEN_3), affecting not only the building envelope but also the bulding technical systems (see Table 23), the building complies with the main energy indicators reference value under the nZEB scope of each of the four countries and therefore with their respective nZEB definition.

The main change respect the previous scenario (GEN_2) is regarding the technical systems for space heating and domestic hot water, namely the change of the energy carrier from gas to district heating. This last one implies lower energy expenditure coeffciients but on the same time higher specific technical losses.

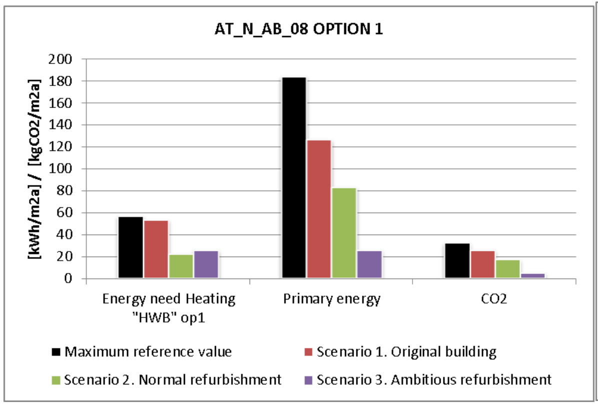
The results are similar in all cases to those obtained in the scenario 2 where only the building envelope was modified (reduction of the U-Values). Nonetheless, the case of Germany is to be highlighted here as in the case of the first Austrian building. The reduction in the primary energy consumption respect to the previous scenario is considerably. It goes from 2% below the reference value as described above, to 25% under the reference value (see Table 30), which indicates the important effect and influence of the improvement of the technical systems from the German perspective.

It is important to bear in mind that the German nZEB definition is based on the primary energy consumption of the analysed building in comparison to a reference notional building with a minimum “standard” insulation and technical systems.

- **AT_N_AB_08 – Apartment block -**

Figure 50. Representative Apartment block Austria Image. Taken from [8]

- *Assessment under Austrian scope:*



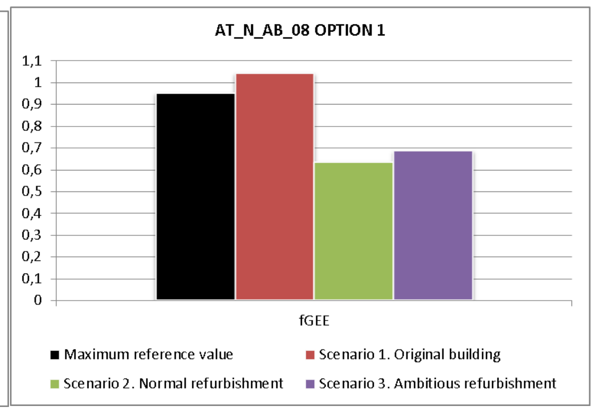


Figure 51. AT_N_AB_08 - Fulfillment criteria option 1

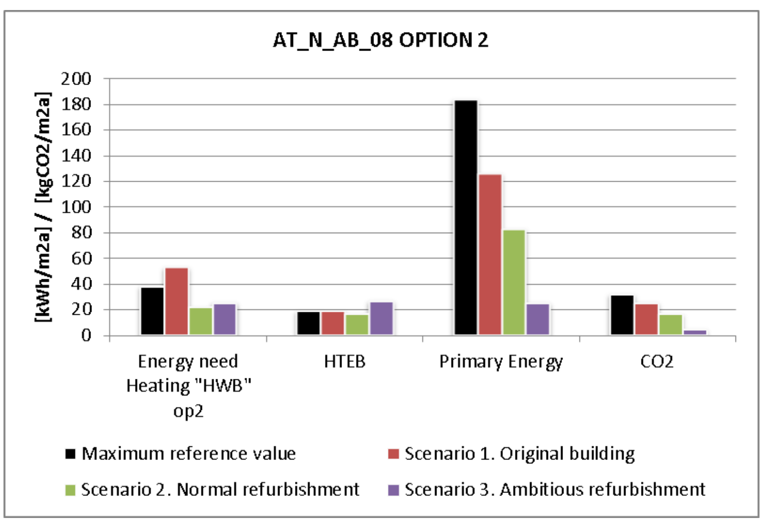


Figure 52. AT_N_AB_08 - Fulfillment criteria option 1

Table 33. Results for the Austrian building AT_N_AB_08 according to Austrian nZEB definition

		AT						Compliance nZEB definition AT
		HVB option 1	Primary energy	CO2	fGEE	HVB option 2	HTEB	
MFH	Maximum reference value	0,00						
	Scenario 1. Original building	0,12	-0,10	0,05	0,26	**0,65**	-0,03	**NO**
	Scenario 2. Normal refurbishment	-0,58	-0,48	-0,39	-0,33	-0,38	**-0,17**	**O.K**
	Scenario 3. Ambitious refurbishment	-0,51	-0,84	-0,84	**-0,28**	-0,28	0,27	**O.K**

nZEB definition according to AUSTRIA			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Energy need for space heating “Heizwärmebedarf option 2”	HTEB “Heiztechnik-Energiebedarf”	Total energy efficiency factor fGEE “Gesamt energieeffizienz-Faktor“
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.38)	(-0.13)	(-0.28)

- *Assessment under German scope:*

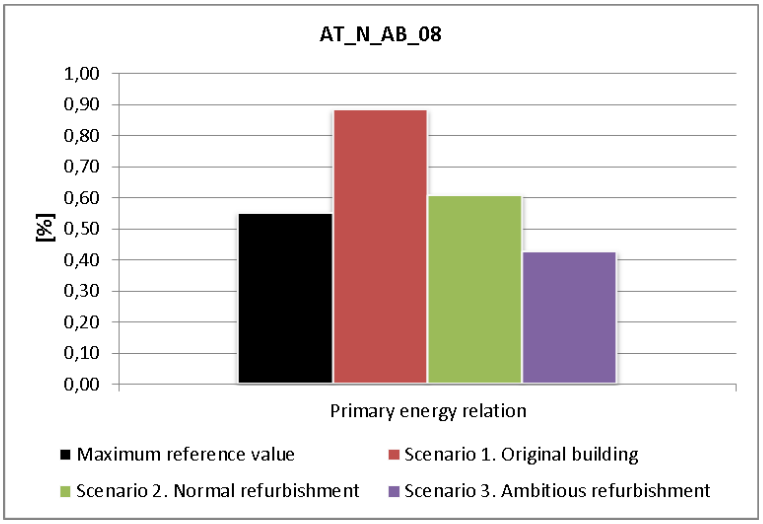


Figure 53. AT_N_AB_08 Primary energy consumption in [%] of the reference building.

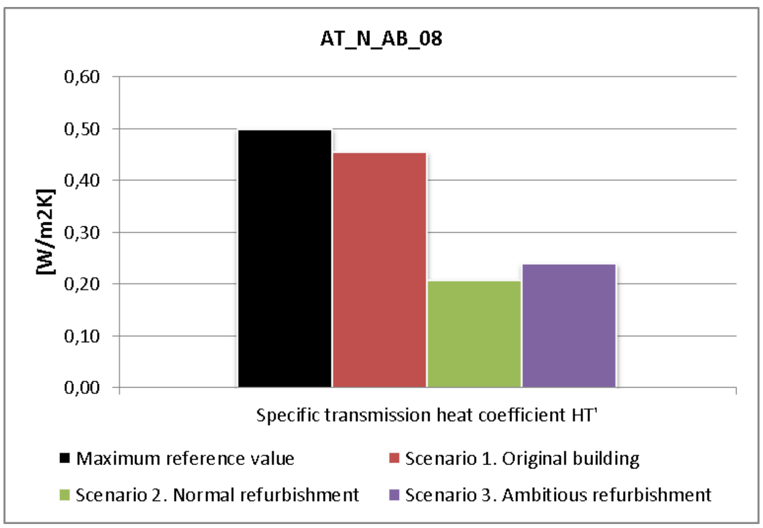


Figure 54. AT_N_AB_08 Specific transmission heat coefficient HT'

Table 34. Results for the Austrian building AT_N_AB_08 according to German nZEB definition

		DE		Compliance nZEB definition DE
		Primary energy	HT'	
AB	Maximum reference value	0,00		
	Scenario 1. Original building	0,60	-0,09	NO
	Scenario 2. Normal refurbishment	0,10	-0,58	NO
	Scenario 3. Ambitious refurbishment	-0,23	-0,52	O.K

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Primary energy	Primary energy
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.60)	(0.10)	(-0.23)

- *Assessment under Spanish scope:*

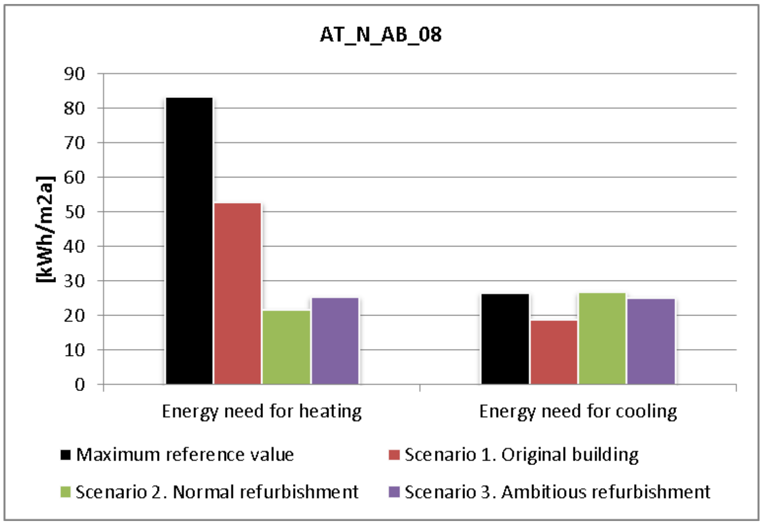


Figure 55. AT_N_AB_08 Energy need for heating and cooling

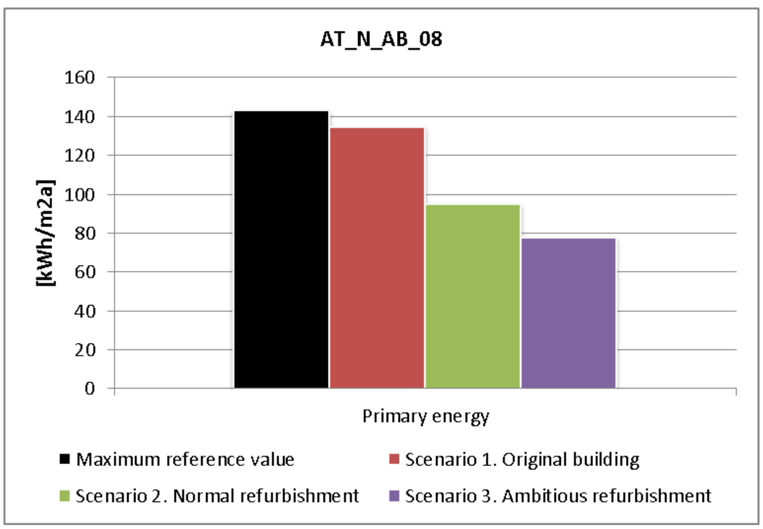


Figure 56. AT_N_AB_08 Primary energy consumption

Table 35. Results for the Austrian building AT_N_AB_08 according to Spanish nZEB definition

		ES			Compliance nZEB definition ES
		Energy need for heating	Energy need for cooling	Primary energy	
AB	Maximum reference value	0,00			
	Scenario 1. Original building	-0,36	-0,29	**-0,06**	O.K
	Scenario 2. Normal refurbishment	-0,74	**0,00**	-0,34	NO
	Scenario 3. Ambitious refurbishment	-0,69	**-0,05**	-0,46	O.K

nZEB definition according to SPAIN			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	NON- COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Energy need for cooling	Energy need for cooling
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.06)	(0.001)	(-0.05)

- *<u>Assessment under English scope:</u>*

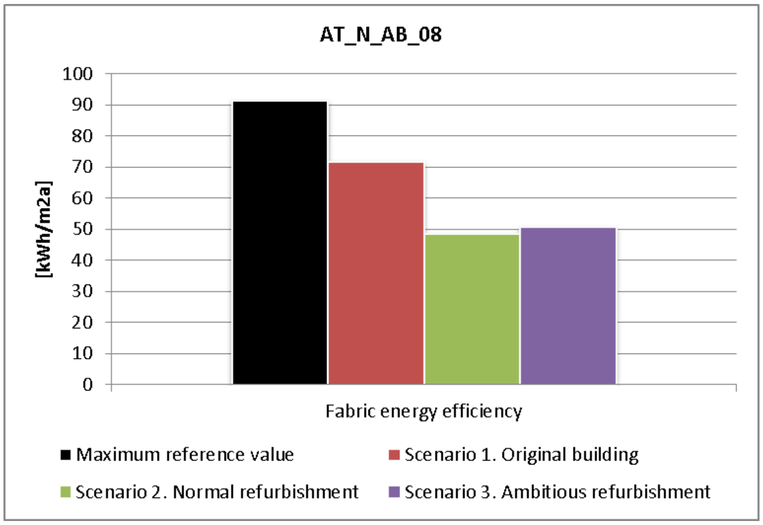


Figure 57. AT_N_AB_08 Fabric energy efficiency (energy need for heating and cooling)

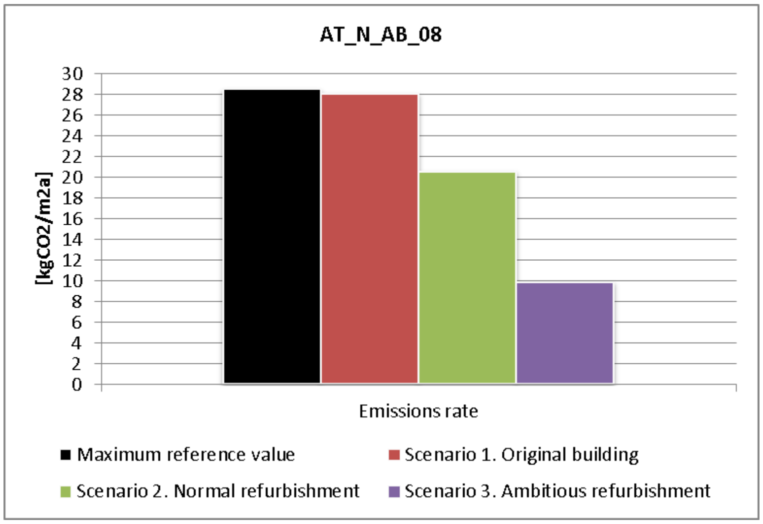


Figure 58. AT_N_AB_08 CO2 Emissions rate

Table 36. Results for the Austrian building AT_N_AB_08 according to English nZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO2 Emissions rate	
AB	Maximum reference value	0,00		
	Scenario 1. Original building	-0,21	-0,01	O.K
	Scenario 2. Normal refurbishment	-0,47	-0,28	O.K
	Scenario 3. Ambitious refurbishment	-0,44	-0,65	O.K

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	CO2 Emissions rate	CO2 Emissions rate	Fabric energy efficiency
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.01)	(-0.28)	(-0.44)

- **AT_N_AB_08 – Apartment block –Results discussion**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the austrian apartment block (AT_N_AB_08) assessed under the austrian building code scope results in the non-compliance of the nZEB definition, with the worst reference value for the energy need for space heating option 2. The numerical indicator shows that the Austrian reference value is exceeded in 38% in this first scenario (see Table 33). The total energy efficieny factor “fGEE" is neither compliant but it is only 9% above the reference.

The assessment under the German building code scope results also in non-compliance, by reason of the primary energy consumption. Although the specific transmission heat losses HT' are 9% under the maximum permitted value, the primary energy is 60% above the reference value (see Table 34) and thus the German nZEB definition is not fulfilled.

Under the Spanish scope, the first scenario of the Austrian apartment block achieve all the main quantitative energy indicators requirements. The primary energy consumption lies close but 6% under the reference value (see Table 35).

The original building also complies with the English nZEB definition. The fabric energy efficiency (comparable to the energy need for space heating) is in ths case the limiting energy indicator, it is 44% under the maximum reference value. This is result is comparable with the Spanish value for the energy need for space heating of 36% below its own reference and suggests again a similar severity on the building thermal envelope assessment of the Spanish and the English scopes.

Scenario 2 (GEN_2: Building subjected to normal renovation)

By only reducing the Windows, walls, roof and floor U- values to at least half their value under normal renovation (GEN_2), without modifying the technical systems (same as in the original building and described in Table 23), all the energy indicators fall under their respective reference values and the building complies with the Austrian Nzeb definition (see Table 33). The limiting energy indicator is in this case the energy need for space heating option 2 but it lies anyway 13% under the reference value.

This second scenario is non-compliant under the German scope (see Table 34). The primary energy is reduced in comparison to the previous scenario but still lies 10% above the German reference. The specific transmission heat losses are also reduced to 58% under the German reference by the reduction of the U-Values.

Unaltered respect to the scenario 1, due to the higher Spanish reference values for the energy need for space heating, the scenario 2 complies loosely with this energy indicator. On the contrary, the reduction of the U-Values respect to the previous scenario induces together with the high solar gains in Spain the non- compliance of the energy need for cooling. This value is exactly on the limit of the reference value but sill does not comply. The primary energy indicator value lies 34% under the Spanish reference as shown in Table 35.

The building is once again compliant with the English nZEB definition. In this case instead of 21%, the fabric energy efficiency rests 47% below the English reference value. The only change as described before is the reduction of the U-Values. The limiting energy indicator, that means the closest to the reference value is however the CO2 Emission factor that lies anyway 28% under it.

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

Under an ambitious renovation (GEN_3), affecting not only the building envelope but also the bulding technical systems (see Table 23), the building complies with the main energy indicators reference value under the nZEB scope of each of the four countries and therefore with their respective nZEB definition.

The main change respect the previous scenario (GEN_2) is regarding the technical systems for space heating and domestic hot water, namely the change of the energy carrier from gas to district heating. Additionally, a solar collector is taken into account as a support for the purpose of the domestic hot water heating.

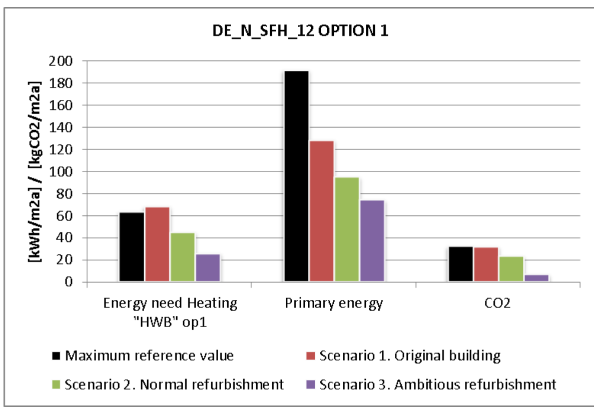
The case of Spain is particularly interesting here. In the previous scenario (GEN_2) where the U-Values were better (lower) compared to those considered in this scenario (GEN_3), the energy need for cooling was above the maximum reference value. Now with slightly worst U-Values, this energy indicator is 5% under the reference value as shown in Table 35.

4.2.2 Results for the case of Germany

- **DE_N_SFH_12 – Single family house -**

Figure 59. Representative SFH Germany Image. Taken from [8]

- *<u>Assessment under Austrian scope:</u>*



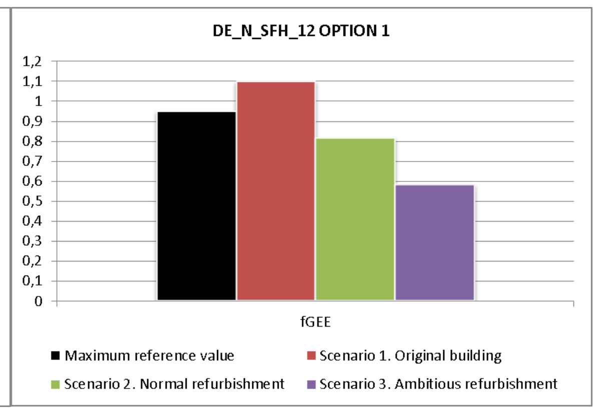


Figure 60.DE_N_SFH_12- Fulfillment criteria option 1

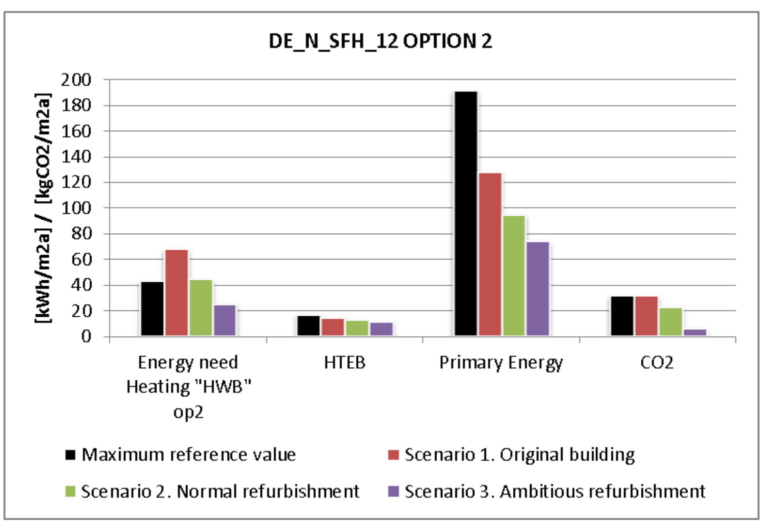


Figure 61.DE_N_SFH_12- Fulfillment criteria option 2

Table 37. Results for the German building DE_N_SFH_12 according to Austrian nZEB definition

		AT						Compliance nZEB definition AT
		HWB option 1	Primary energy	CO2	fGEE	HWB option 2	HTEB	
SFH	Maximum reference value	0,00						
	Scenario 1. Original building	0,07	-0,33	-0,01	0,16	**0,58**	-0,16	**NO**
	Scenario 2. Normal refurbishment	-0,30	-0,51	-0,28	**-0,14**	**0,03**	-0,25	**O.K**
	Scenario 3. Ambitious refurbishment	-0,60	-0,61	-0,80	-0,39	-0,41	**-0,33**	**O.K**

nZEB definition according to AUSTRIA			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Energy need for space heating "Heizwärmebedarf option 2"	Total energy efficiency factor fGEE "Gesamt energieeffizienz-Faktor"	HTEB "Heiztechnik-Energiebedarf"
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.58)	(-0.14)	(-0.33)

- *Assessment under German scope:*

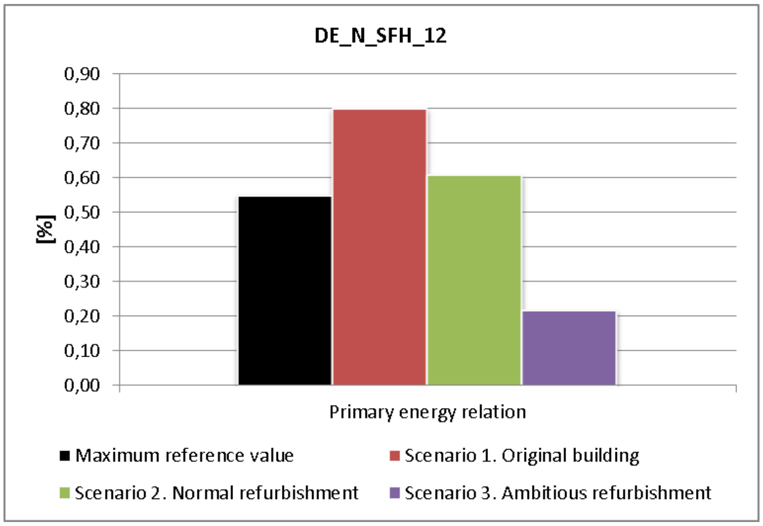


Figure 62.DE_N_SFH_12 Primary energy consumption in [%] of the reference building.

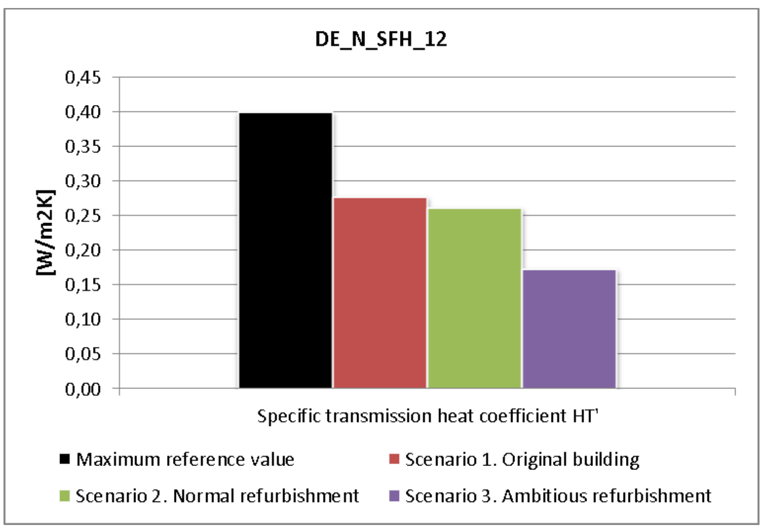


Figure 63.DE_N_SFH_12 Specific transmission heat coefficient HT'

Table 38. Results for the German building DE_N_SFH_12 according to German nZEB definition

		DE		Compliance nZEB definition DE
		Primary energy	HT'	
SFH	Maximum reference value	0,00		
	Scenario 1. Original building	0,45	-0,31	NO
	Scenario 2. Normal refurbishment	0,10	-0,35	NO
	Scenario 3. Ambitious refurbishment	-0,61	-0,57	O.K

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Primary energy	Specific transmission heat losses HT' "Spezifischen Transmissionswärmeverlust"
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.45)	(0.10)	(-0.57)

- *Assessment under Spanish scope:*

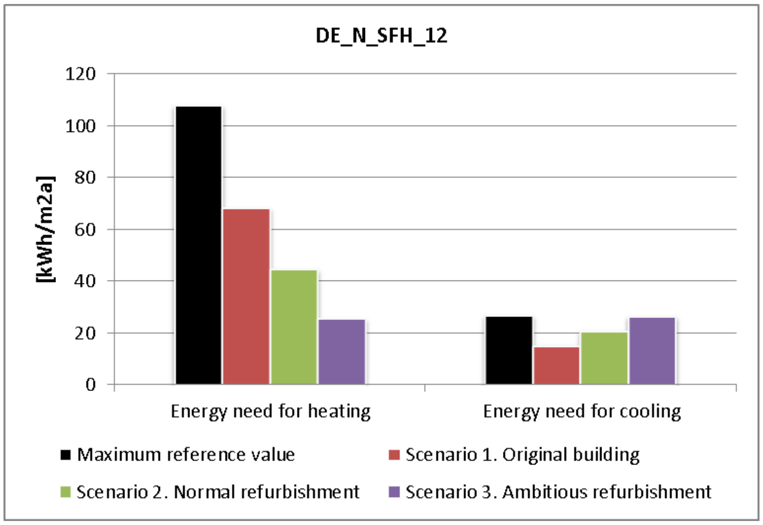


Figure 64.DE_N_SFH_12 Energy need for heating and cooling

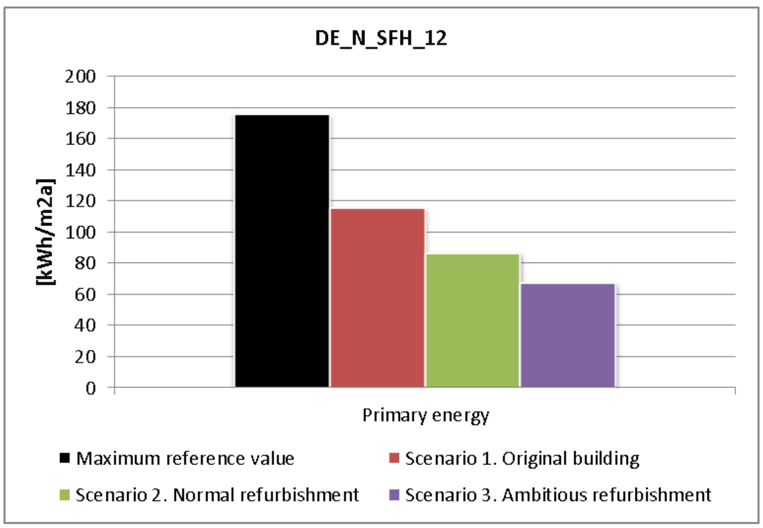


Figure 65.DE_N_SFH_12 Primary energy consumption

Table 39. Results for the German building DE_N_SFH_12 according to Spanish nZEB definition

		ES			Compliance nZEB definition ES
		Energy need for heating	Energy need for cooling	Primary energy	
SFH	Maximum reference value	0,00			
	Scenario 1. Original building	-0,37	-0,43	-0,34	O.K
	Scenario 2. Normal refurbishment	-0,59	-0,22	-0,51	O.K
	Scenario 3. Ambitious refurbishment	-0,76	-0,01	-0,62	O.K

nZEB definition according to SPAIN			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Energy ned for cooling	Energy ned for cooling
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.34)	(-0.22)	(-0.01)

- *Assessment under English scope:*

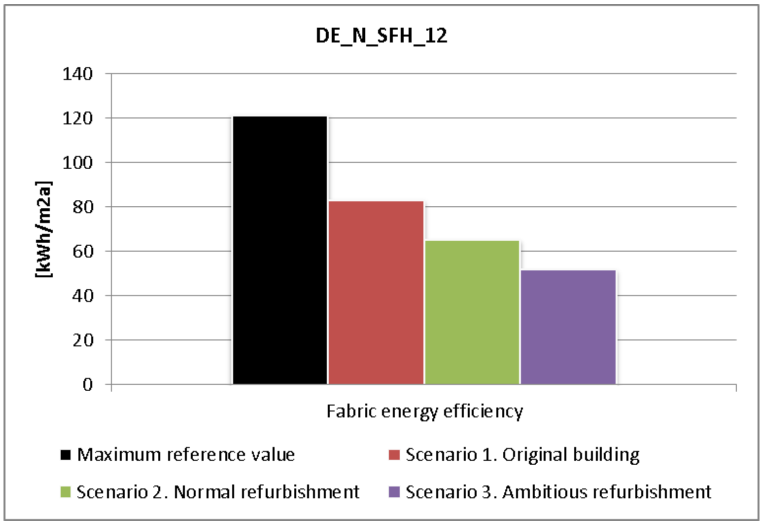


Figure 66.DE_N_SFH_12 Fabric energy efficiency (energy need for heating and cooling)

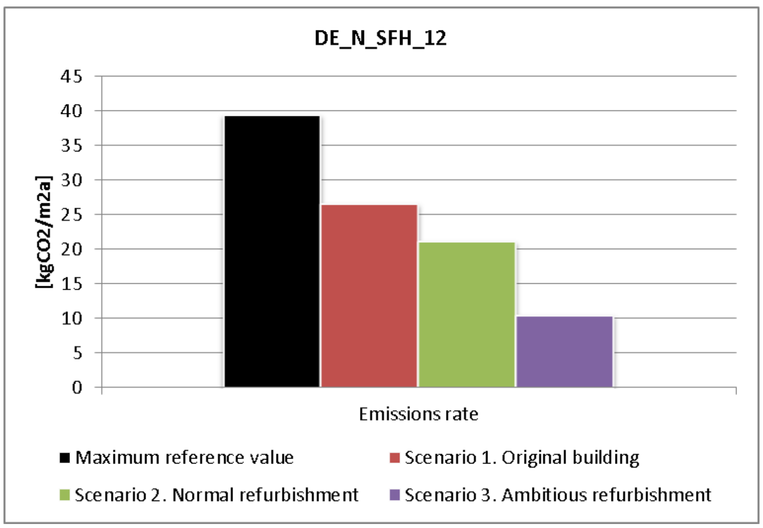


Figure 67. DE_N_SFH_12 CO2 Emissions rate

Table 40. Results for the German building DE_N_SFH_12 according to English nZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO2 Emissions rate	
SFH	Maximum reference value	0,00		
	Scenario 1. Original building	-0,32	-0,33	O.K
	Scenario 2. Normal refurbishment	-0,46	-0,47	O.K
	Scenario 3. Ambitious refurbishment	-0,57	-0,74	O.K

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Fabric energy efficiency	Fabric energy efficiency	Fabric energy efficiency
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.32)	(-0.46)	(-0.57)

- **DE_N_SFH_12 – Single family house –Results**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the German single family house (DE_N_SFH_12) assessed under the austrian building code scope results in the non-compliance of the nZEB definition, with the worst reference value for the energy need for space heating option 2. The numerical indicator shows that the Austrian reference value is exceeded in 58% in this first scenario (see Table 37). The main driver of this overrun are the high U-Values (Thermal transmittance), which imply a low building insulation and hence higher heat losses. The energy need for space heating option 1 and the totalenergy efficiency factor " fGEE" indicators are 7% and 16% above their respective reference values.

The assessment under the German building code scope results also in the non-compliance, in this case of the reference value for the primary energy. The numerical indicator shows that the reference value is exceeded in 45% in this first scenario (see Table 38). It is interesting to observe however, that the specific transmission heat losses HT' calculated as shown in equation 43 (dependent on the U-values, a temperature correction factor and the building envelope surface area), are 31% under the German reference value.

The assessment under the Spanish scope results in the compliance of the Spanish energy requirements for the quantitative nZEB definition. The limiting energy indicator is in this case the primary energy consumption which lies 34% below the maximum reference value. The energy need for space heating is 37% under the Spanish reference value.

Under the English scope, like in the case of Spain, the original building complies with the nZEB definition. The fabric energy efficiency (comparable to the energy need for space heating) is in ths case the limiting energy indicator and is 32% under the maximum reference value. This last value is not far away from the one mentioned above from Spain.

Scenario 2 (GEN_2: Building subjected to normal renovation)

By slighltly reducing the Windows, walls, roof and floor U- values under normal renovation (GEN_2) as described in Table 23, and the introduction of the heat recovery concept (up to 75%), the energy need for space heating option 2 falls to a value 3% above the reference. As mentioned in the chapter 3.1, there are basically two ways to comply with the Austrian nZEB definition, and even when the energy need for space heating option 2 is above the maximum reference, the building does comply with the Austrian nZEB definition by mean of the first criteria (see Table 37). The limiting energy indicator is in this case the total energy efficiency factor "fGEE" but it lies anyway 14% under the reference value.

This second scenario is, like in the previous scenario, non-compliant under the German scope (see Table 38). The primary energy is reduced through the reduction of the U-Values, but is still 10% above the German reference.

Like in the scenario 1 (GEN_1), due to the higher Spanish energy need for space heating and primary energy consumption reference values, the scenario 2 complies with the Spanish nZEB definition. The primary energy indicator lies 51% under the Spanish reference (see Table 39). Differently from the last scenario, in this case the limiting energy indicator is the energy need for cooling and its 22% under the maximum reference value.

The building is once again compliant with the English nZEB definition. In this case instead of 32%, the fabric energy efficiency rests 46% below the English maximum reference value. In this case other than the situation for the Austrian buildings, the similitude between the energy need for space heating results from England and Spain is not maintained.

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

Under an ambitious renovation (GEN_3), affecting not only the building envelope but also the bulding technical systems (see Table 23), specifically the change of the energy carrier from gas to wood pellets (biomass-fueled high efficient central heating) the building complies with the main energy indicators reference value under the nZEB scope of each of the four countries and therefore with their respective nZEB definition.

The results are similar in all cases to those obtained in the scenario 2 where only the building envelope was modified (reduction of the U-Values) and the heat recovery was considered. The reduction of the U-Values in this case (from scenario 2 (GEN_2) to scenario 3 (GEN_3)) is nonetheless considerably larger than the U-Values reduction from scenario 1 (GEN_1) to scenario 2 (GEN_2).

Two aspects are to be highlighted here. First the strong reduction in the relative primary energy consumption respect to the previous scenario under the German scope. It goes from 10% above the reference value in scenario 2 (GEN_2), to 61% under the reference value (see Table 38), which indicates, as mentioned also in the case of the Austrian buildins, the important effect and influence of the improvement of the technical systems from the German perspective. Second, particularly visible in the assessment under the Spanish scope is the inverse relation between the U-Values and the performance of the energy indicator energy need for cooling. The better (lower) the U-Values, the highest the required energy need for cooling.

- **DE_N_MFH_12 – Multi-family house -**

Figure 68. Representative MFH Germany Image. Taken from [8]

- *Assessment under Austrian scope:*

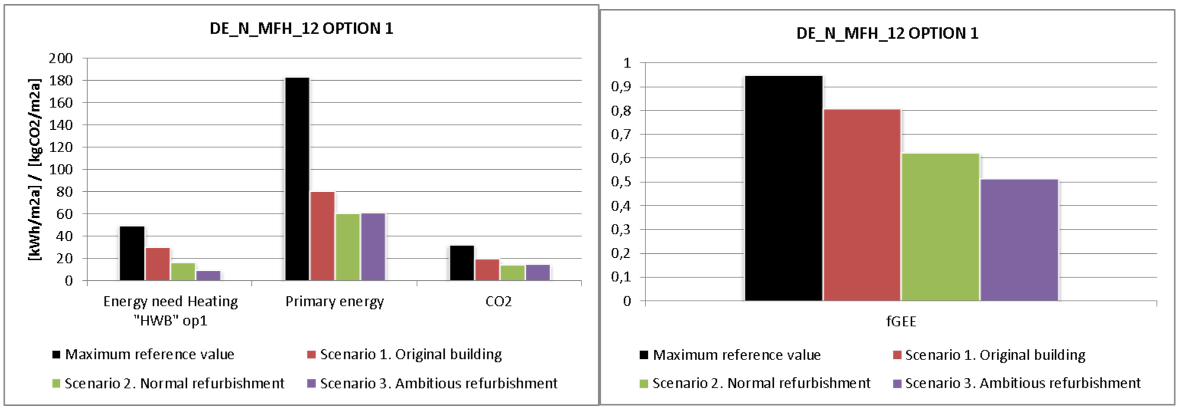


Figure 69. DE_N_MFH_12 Fulfillment criteria option 1

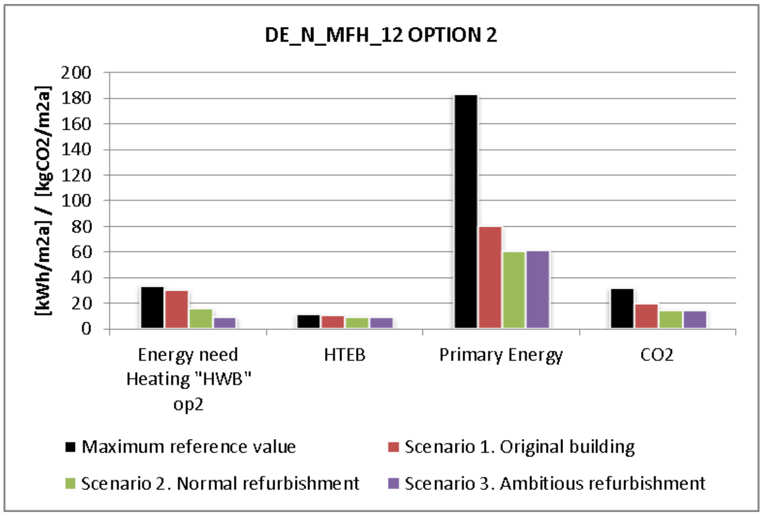


Figure 70. DE_N_MFH_12 Fulfillment criteria option 2

Table 41. Results for the German building DE_N_MFH_12 according to Austrian nZEB definition

	AT						Compliance nZEB definition AT
	HWB option 1	Primary energy	CO2	fGEE	HWB option 2	HTEB	
Maximum reference value	0,00						
Scenario 1. Original building	-0,39	-0,56	-0,39	-0,15	-0,10	-0,06	O.K
Scenario 2. Normal refurbishment	-0,68	-0,67	-0,55	-0,35	-0,53	-0,14	O.K
Scenario 3. Ambitious refurbishment	-0,81	-0,66	-0,54	-0,46	-0,73	-0,19	O.K

nZEB definition according to AUSTRIA			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	HTEB “Heiztechnik-Energiebedarf”	HTEB “Heiztechnik-Energiebedarf”	HTEB “Heiztechnik-Energiebedarf”
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.06)	(-0.14)	(-0.19)

- *Assessment under German scope:*

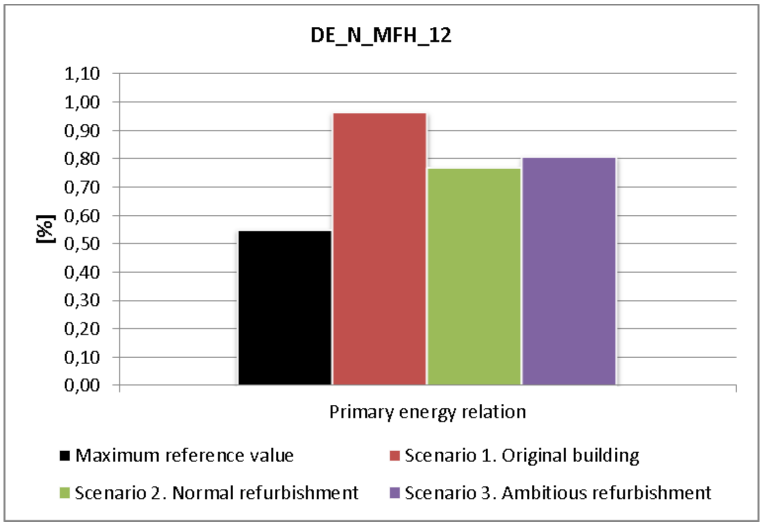


Figure 71. DE_N_MFH_12 Primary energy consumption in [%] of the reference building.

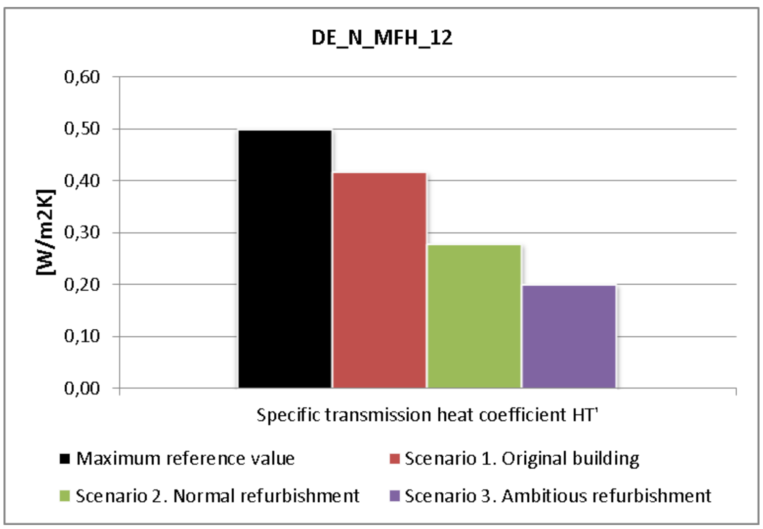


Figure 72. DE_N_MFH_12 Specific transmission heat coefficient HT'

Table 42. Results for the German building DE_N_MFH_12 according to German nZEB definition

		DE Primary energy	DE HT'	Compliance nZEB definition DE
MFH	Maximum reference value	0,00		
	Scenario 1. Original building	0,75	-0,17	NO
	Scenario 2. Normal refurbishment	0,40	-0,44	NO
	Scenario 3. Ambitious refurbishment	0,47	-0,60	NO

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	NON- COMPLIANT
ENERGY INDICATOR :	Primary energy	Primary energy	Primary energy
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.75)	(0.4)	(0.47)

- *Assessment under Spanish scope:*

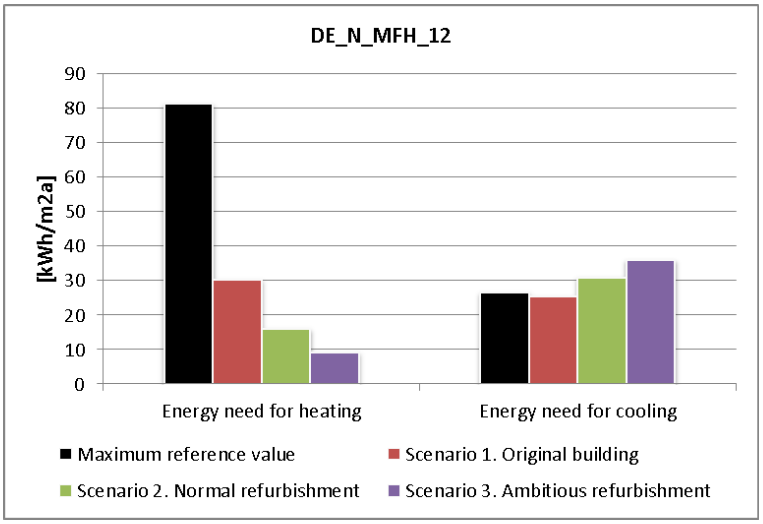


Figure 73. DE_N_MFH_12 Energy need for heating and cooling

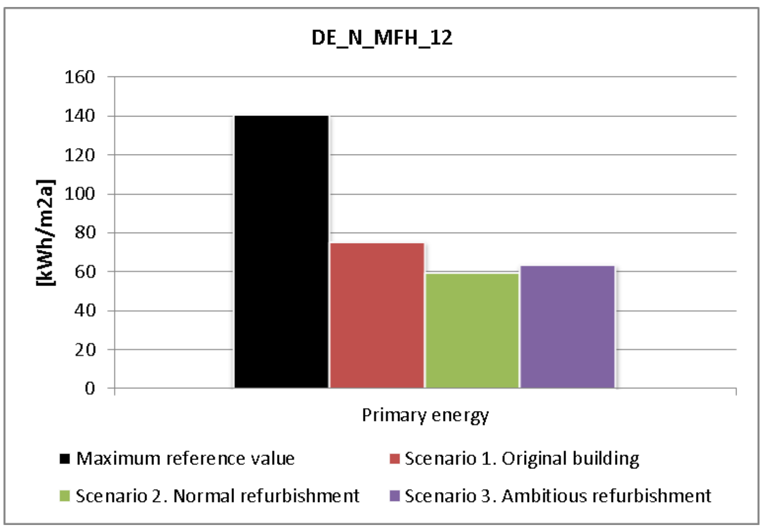


Figure 74. DE_N_MFH_12 Primary energy consumption

Table 43. Results for the German building DE_N_MFH_12 according to Spanish nZEB definition

		ES			Compliance nZEB definition ES
		Energy need for heating	Energy need for cooling	Primary energy	
MFH	Maximum reference value	0,00			
	Scenario 1. Original building	-0,63	-0,05	-0,46	O.K
	Scenario 2. Normal refurbishment	-0,80	0,16	-0,58	NO
	Scenario 3. Ambitious refurbishment	-0,89	0,35	-0,55	NO

nZEB definition according to SPAIN			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	NON- COMPLIANT	NON- COMPLIANT
ENERGY INDICATOR :	Energy need for cooling	Energy need for cooling	Energy need for cooling
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.05)	(0.16)	(0.35)

- ***Assessment under English scope:***

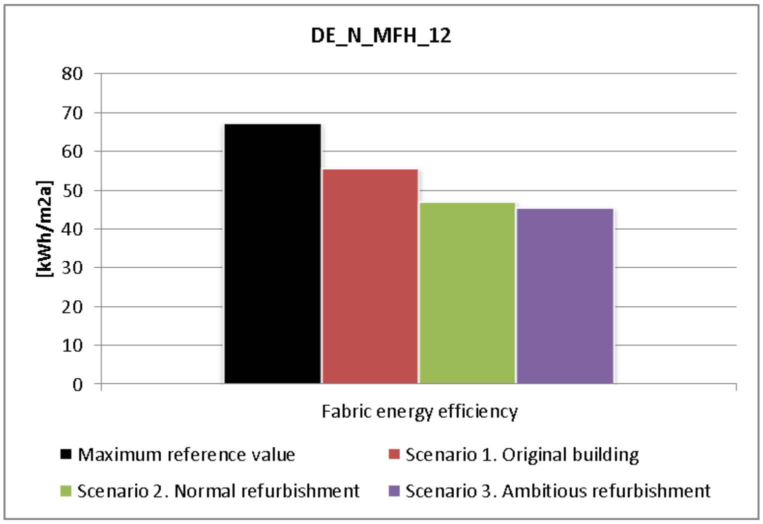


Figure 75. DE_N_MFH_12 Fabric energy efficiency (energy need for heating and cooling)

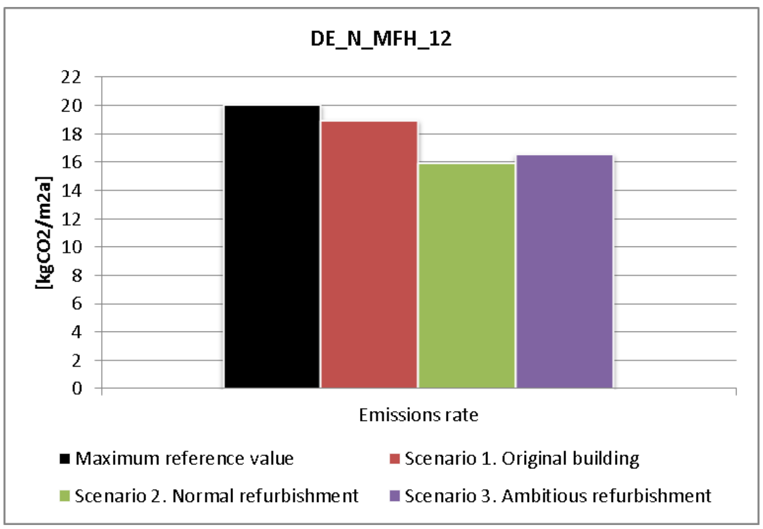


Figure 76. DE_N_MFH_12 CO2 Emissions rate

Table 44. Results for the German building DE_N_MFH_12 according to English nZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO_2 Emissions rate	
MFH	Maximum reference value	0,00		
	Scenario 1. Original building	-0,17	-0,05	O.K
	Scenario 2. Normal refurbishment	-0,30	-0,21	O.K
	Scenario 3. Ambitious refurbishment	-0,33	-0,17	O.K

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	CO_2 Emissions rate	CO_2 Emissions rate	CO_2 Emissions rate
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.05)	(-0.21)	(-0.17)

- **DE_N_MFH_12 – multi-family house –Results**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the German multi-family house (DE_N_MFH_12) assessed under the Austrian building code scope results in the compliance of the nZEB definition, being the limiting energy indicator the technical system losses “HTEB” only 6% under the maximum reference value. The other energy indicators are also under their respective maximum reference values (see Table 41).

The assessment under the German building code scope results also in the non-compliance, in this case of the reference value for the primary energy. The numerical indicator shows that the reference value is exceeded in 75% in this first scenario (see Table 42). It is interesting to observe however, that the specific transmission heat losses HT' calculated as shown in equation 43 (dependent on the U-values, a temperature correction factor and the building envelope surface area), are 17% under the German reference value. The difference between the results from Germany and the rest of the countries is in this case remarkable, mostly because even when the specific transmission heat losses HT' are under the maximum, the primary energy is almost the double of the permitted value.

The assessment under the Spanish scope results in the compliance of the Spanish energy requirements for the quantitative nZEB definition. The limiting energy indicator is in this case the energy need for cooling, which is 5% under the maximum reference value. The energy need for space heating is on the other hand 63% under the Spanish reference value and the primary energy consumption is 46% under the maximum reference value (see Table 43).

Under the English scope, like in the case of Austria and Spain and Germany, the original building complies with the nZEB definition. The fabric energy efficiency (comparable to the energy need for space heating) is in ths case 17% under the maximum reference value. The limiting energy indicator, that means the one closest to the maximum reference is the CO2 Emissions rate and it is 5% below the reference (see Table 44).

Scenario 2 (GEN_2: Building subjected to normal renovation)

By slighltly reducing the Windows, walls, roof and floor U- values under normal renovation (GEN_2) as described in Table 23, the energy need for space heating option 2 falls to a value 14% under the reference value (see Table 41). The limiting energy indicator is in this case the total energy efficiency factor “fGEE" but it lies anyway 14% under the reference value.

This second scenario is, like in the previous scenario, non-compliant under the German scope (see Table 42). The primary energy is reduced through the reduction of the U-Values, but is still 40% above the German reference.

The assessment under the Spanish scope results in the non-compliance of the Spanish energy requirements for the quantitative nZEB definition. The exceeded energy indicator is in this case the energy need for cooling, which is 16% above the maximum reference value. The energy need for space heating is on the other hand 80% under the Spanish reference value and the primary energy consumption is 58% under the maximum reference value. As mentioned already in the case of the German single family house, there is a direct relation between U-Values and energy need for heating. The better (lower) the U-Values, the lower the heat losses and hence the lower the energy need for space heating. The contrary relation exists between U-Values and energy need for cooling.

Under the English scope, unlike in the case of Spain and Germany, the German multi-family house subjected to normal renovation complies with the nZEB definition. The fabric energy efficiency (comparable to the energy need for space heating) is in ths case 30% under the maximum reference value. The limiting energy indicator, that means the one closest to the maximum reference is the CO_2 Emissions rate and it is 21% below the reference.

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

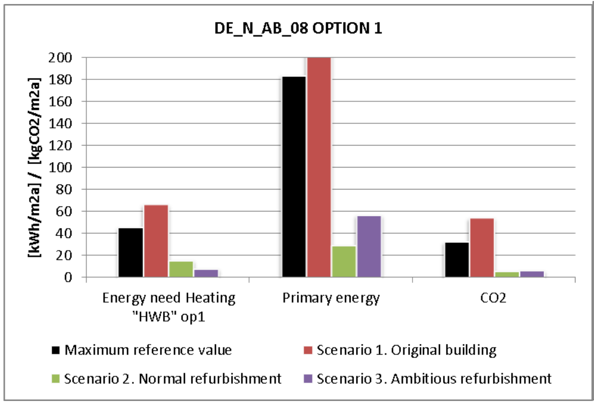
Under an ambitious renovation (GEN_3), the building complies with the main energy indicators reference value under the nZEB scope of Austria and England and therefore with their respective nZEB definition.

The results are similar in all cases to those obtained in the scenario 2 where the building was subjected to normal renovation. The reduction of some of the U-Values in this case (from scenario 2 (GEN_2) to scenario 3 (GEN_3)) causes improvements in the energy indicators except for the energy need for cooling in the case of Spain and the primary energy consumption in the case of Germany.

- **DE_E_AB_08 – Apartment block -**

Figure 77. Representative Apartment block Germany Image. Taken from [8]

- *Assessment under Austrian scope:*



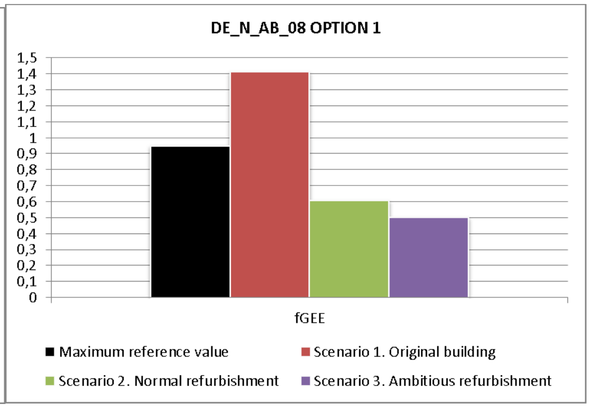


Figure 78. DE_E_AB_08 Fulfillment criteria option 1

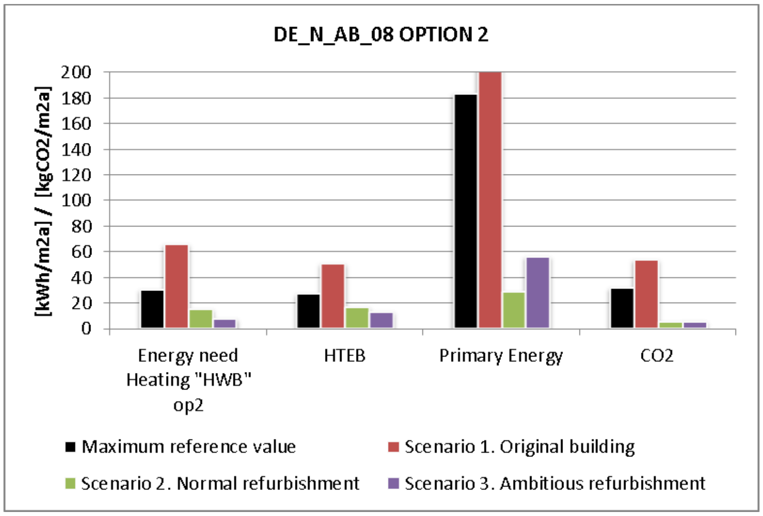


Figure 79. DE_E_AB_08 Fulfillment criteria option 2

Table 45. Results for the German building DE_E_AB_08 according to Austrian nZEB definition

		AT						Compliance nZEB definition AT
		HVB option 1	Primary energy	CO2	fGEE	HVB option 2	HTEB	
AB	Maximum reference value	0,00						
	Scenario 1. Original building	0,47	0,18	0,69	0,49	1,16	0,85	NO
	Scenario 2. Normal refurbishment	-0,66	-0,84	-0,83	-0,36	-0,50	-0,39	O.K
	Scenario 3. Ambitious refurbishment	-0,83	-0,69	-0,82	-0,47	-0,75	-0,52	O.K

nZEB definition according to AUSTRIA			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Energy need for space heating "Heizwärmebedarf option 1"	Total energy efficiency factor fGEE "Gesamt energieeffizienz-Faktor"	Total energy efficiency factor fGEE "Gesamt energieeffizienz-Faktor"
Compliance Numerical indicator (see section 4.2) (VALUE):	(1.16)	(-0.36)	(-0.47)

- *Assessment under German scope:*

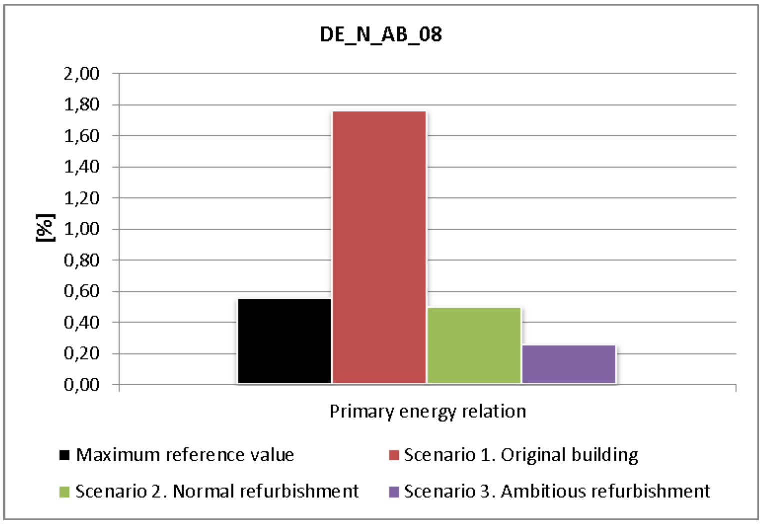


Figure 80. DE_E_AB_08 Primary energy consumption in [%] of the reference building.

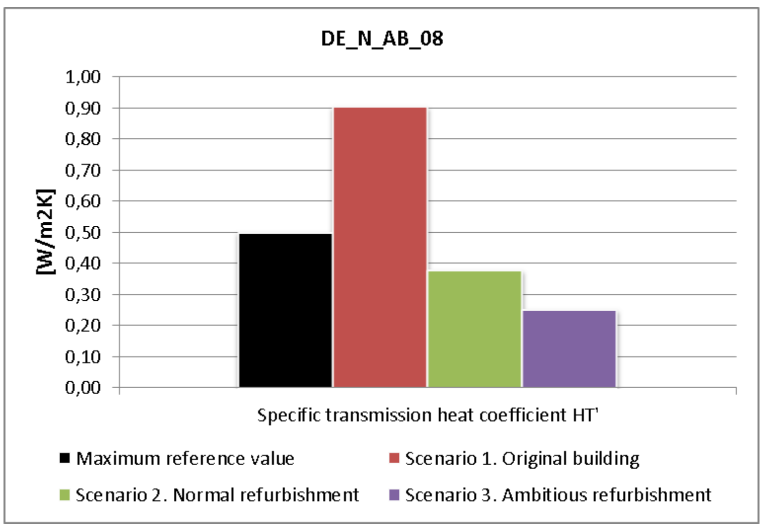


Figure 81. DE_E_AB_08 Specific transmission heat coefficient HT'

Table 46. Results for the German building DE_E_AB_08 according to German nZEB definition

		DE		Compliance nZEB definition DE
		Primary energy	HT'	
AB	Maximum reference value	0,00		
	Scenario 1. Original building	2,20	0,81	NO
	Scenario 2. Normal refurbishment	-0,10	-0,25	O.K
	Scenario 3. Ambitious refurbishment	-0,54	-0,50	O.K

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Primary energy	Specific transmission heat losses HT' "Spezifischen Transmissionswärmeverlust"
Compliance Numerical indicator (see section 4.2) (VALUE):	(2.20)	(-0.1)	(-0.5)

- *Assessment under Spanish scope:*

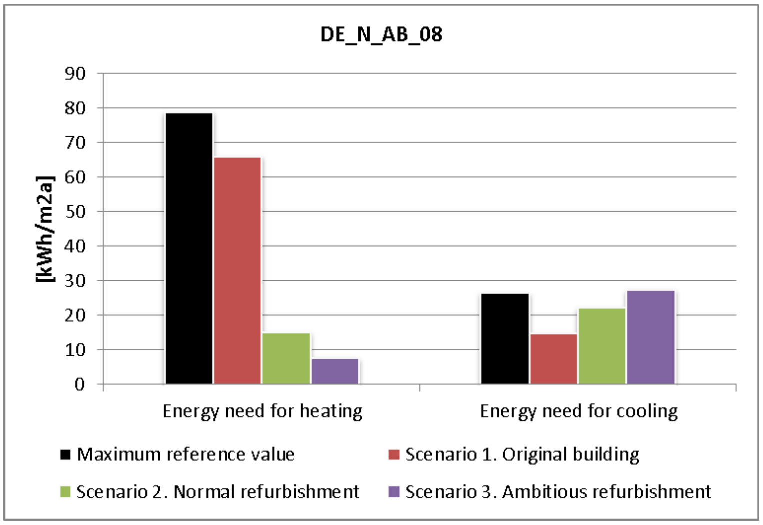


Figure 82. DE_E_AB_08 Energy need for heating and cooling

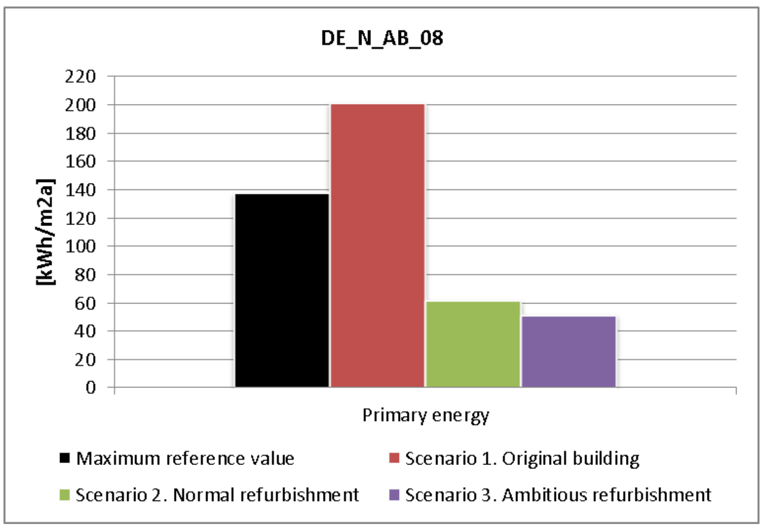


Figure 83. DE_E_AB_08 Primary energy consumption

Table 47. Results for the German building DE_E_AB_08 according to Spaishn nZEB definition

		ES			Compliance nZEB definition ES
		Energy need for heating	Energy need for cooling	Primary energy	
AB	Maximum reference value	0,00			
	Scenario 1. Original building	-0,16	-0,44	0,47	NO
	Scenario 2. Normal refurbishment	-0,81	-0,16	-0,55	O.K
	Scenario 3. Ambitious refurbishment	-0,90	0,03	-0,63	NO

nZEB definition according to SPAIN			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	NON- COMPLIANT
ENERGY INDICATOR :	Primary energy	Energy need for cooling	Energy need for cooling
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.47)	(-0.16)	(0.03)

- *Assessment under English scope:*

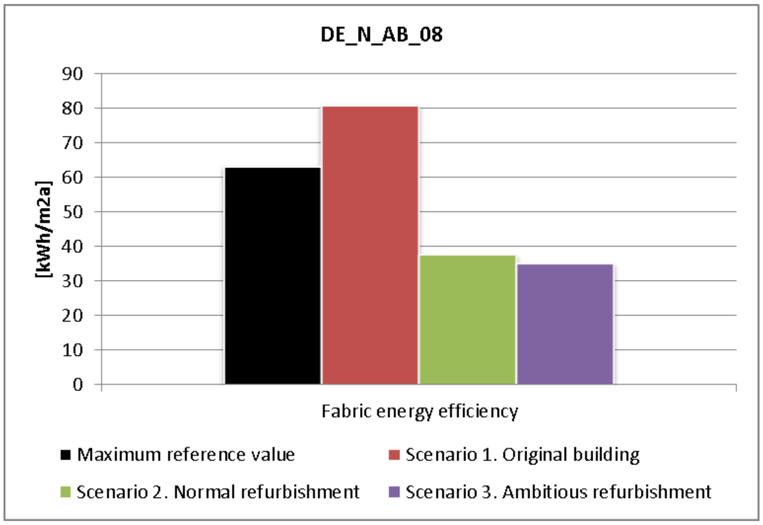


Figure 84. DE_E_AB_08 Fabric energy efficiency (energy need for heating and cooling)

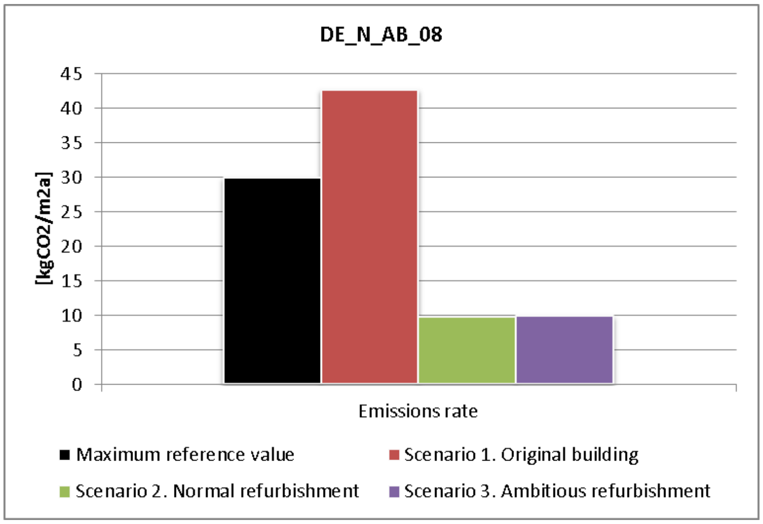


Figure 85. DE_E_AB_08 CO2 Emissions rate

Table 48. Results for the German building DE_E_AB_08 according to English nZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO2 Emissions rate	
AB	Maximum reference value	0,00		
	Scenario 1. Original building	0,28	0,43	NO
	Scenario 2. Normal refurbishment	-0,41	-0,67	O.K
	Scenario 3. Ambitious refurbishment	-0,45	-0,67	O.K

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	CO2 Emissions rate	Fabric energy efficiency	Fabric energy efficiency
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.43)	(-0.41)	(-0.45)

- **DE_E_AB_08 – Apartment block –Results**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the German apartment block (DE_E_AB_08) assessed under the Austrian building code scope results in the non-compliance of the nZEB definition. None of the energy indicators is kept under the Austrian maximum reference values. The worst energy indicator is still the energy need for space heating option 2, 116% over the maximum reference value as shown in Table 45.

The assessment under the German building code scope results also in the extreme non-compliance, in this case of the reference value for the primary energy. The numerical indicator shows that the reference value is exceeded in 220% in this first scenario (see Table 46). It is interesting to observe however. The specific transmission heat losses HT' calculated as shown in equation 43 (dependent on the U-values, a temperature correction factor and the building envelope surface area), are 81% above the German reference value. The main cause of both exceeds are the higher U-Values, from the global thermal bridges to the Windows and exterior walls.

The assessment under the Spanish scope results also in the non-compliance of the Spanish energy requirements for the quantitative nZEB definition. The worst performance is for the primary energy consumption, which is 47% above the maximum reference value. The energy need for space heating, regardless the higher maximum reference value in Spain, is only 16% under the Spanish reference value and the energy need for cooling is 44% under the maximum reference value (see Table 47).

Under the English scope, as well as was the case for the other countries, the original building does not comply with the English nZEB definition. The fabric energy efficiency (comparable to the energy need for space heating) is in ths case 28% above the maximum reference value. The worst energy indicator is however the CO2 Emissions rate and it is 43% over the maximum reference (see Table 48).

Scenario 2 (GEN_2: Building subjected to normal renovation)

A strong reduction on the Windows, walls, roof and floor U- values, to at least half their value under normal renovation (GEN_2) as described in Table 23, induces a drastic change in the building energy performance. The energy need for space heating option 2 falls to a value 50% under the reference value (see Table 45). The limiting energy indicator is in this case the total energy efficiency factor “fGEE" but it lies anyway 36% under the reference value.

The strong improvement in the building thermal envelope makes the building uner the scenario 2 compliant according to the German scope (see Table 46). The primary energy is drastically reduced through the reduction of the U-Values, from 220% above the maximum reference in the first scenario to just 10% under it.

The assessment under the Spanish scope results also in the compliance of the Spanish energy requirements for the quantitative nZEB definition. The limiting energy indicator is in this case the energy need for cooling, which lies however 16% below the maximum reference value. The energy need for space heating is 81% under the Spanish reference value and the primary energy consumption falls to 55% under the maximum reference value.

Under the English scope, the German apartment block subjected to normal renovation complies with the nZEB definition. The fabric energy efficiency (comparable to the energy need for space heating) is in ths case 41% under the maximum reference value. The CO2 Emissions rate is 67% below the reference.

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

Under an ambitious renovation (GEN_3), the building complies with the main energy indicators reference value under the nZEB scope of Austria, Germany and England and therefore with their respective nZEB definition.

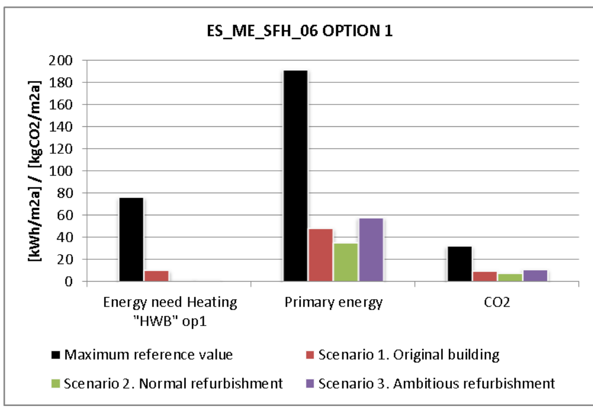
The results are similar in all cases to those obtained in the scenario 2 where the building was subjected to normal renovation. The case of Spain is again remarkable, as the improvement in the U-Values makes the building subjected to an ambitious renovation non-compliant under the Spanish scope because of an overstep on the energy need for cooling.

4.2.3 Results for the case of Spain

- **ES_ME_SFH_06 – Single family house -**

Figure 86. Representative SFH Spain Image. Taken from [8]

- *Assessment under Austrian scope:*



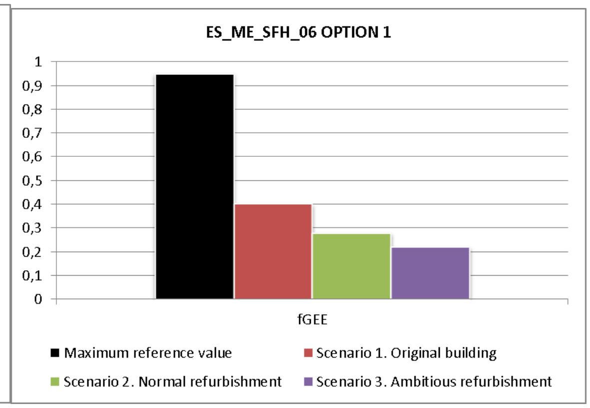


Figure 87. ES_ME_SFH_06 Fulfillment criteria option 1

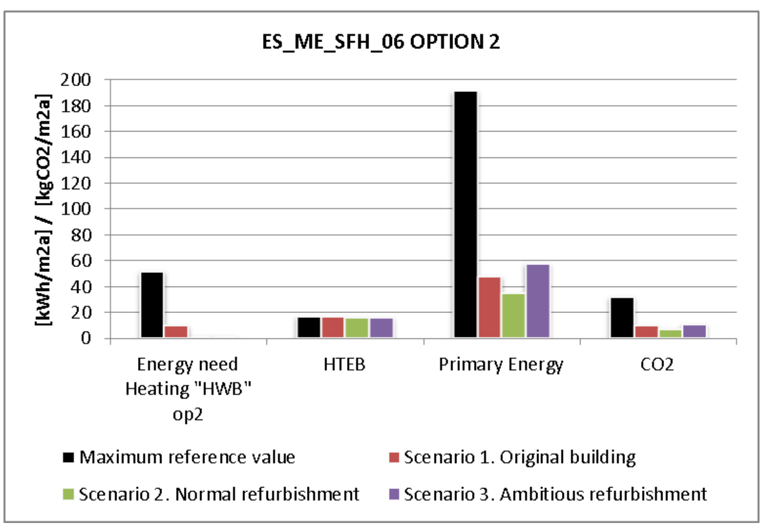


Figure 88.ES_ME_SFH_06 Fulfillment criteria option 2

Table 49. Results for the Spanish building ES_ME_SFH_06 according to Austrian nZEB definition

		AT						Compliance nZEB definition AT
		HWB option 1	Primary energy	CO2	FGEE	HWB option 2	HTEB	
SFH	Maximum reference value	0,00						
	Scenario 1. Original building	-0,87	-0,75	-0,69	-0,58	-0,81	-0,02	O.K
	Scenario 2. Normal refurbishment	-0,98	-0,82	-0,78	-0,71	-0,97	-0,04	O.K
	Scenario 3. Ambitious refurbishment	-0,98	-0,70	-0,66	-0,77	-0,97	-0,04	O.K

nZEB definition according to AUSTRIA			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	HTEB “Heiztechnik-Energiebedarf”	HTEB “Heiztechnik-Energiebedarf”	HTEB “Heiztechnik-Energiebedarf”
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.02)	(-0.04)	(-0.04)

- *Assessment under German scope:*

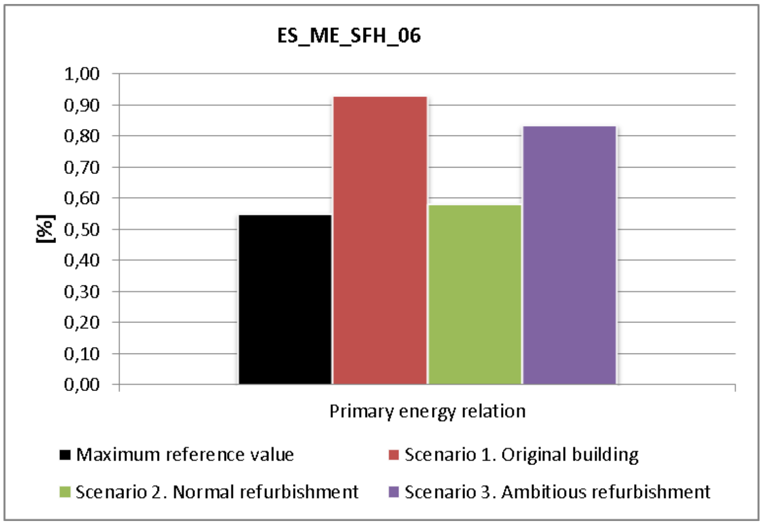


Figure 89. ES_ME_SFH_06 Primary energy consumption in [%] of the reference building

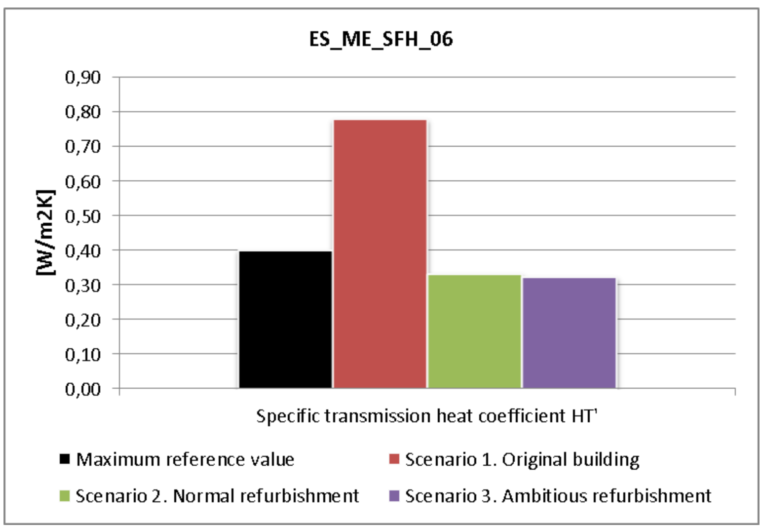


Figure 90. ES_ME_SFH_06 Specific transmission heat coefficient HT'

Table 50. Results for the Spanish building ES_ME_SFH_06 according to German nZEB definition

		DE		Compliance nZEB definition DE
		Primary energy	HT'	
SFH	Maximum reference value	0,00		
	Scenario 1. Original building	0,69	0,95	NO
	Scenario 2. Normal refurbishment	0,06	-0,17	NO
	Scenario 3. Ambitious refurbishment	0,52	-0,19	NO

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	NON- COMPLIANT
ENERGY INDICATOR :	Specific transmission heat losses HT' "Spezifischen Transmissionswärmeverlust"	Primary energy	Primary energy
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.95)	(0.06)	(0.52)

- *Assessment under Spanish scope:*

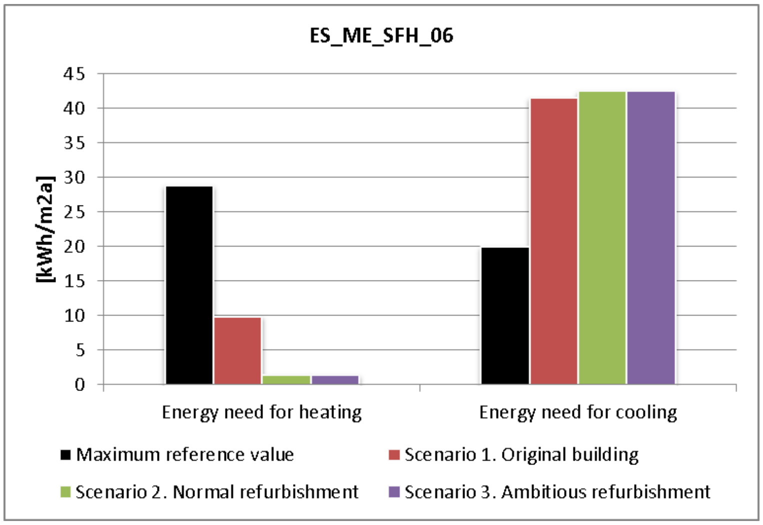


Figure 91. ES_ME_SFH_06 Energy need for heating and cooling

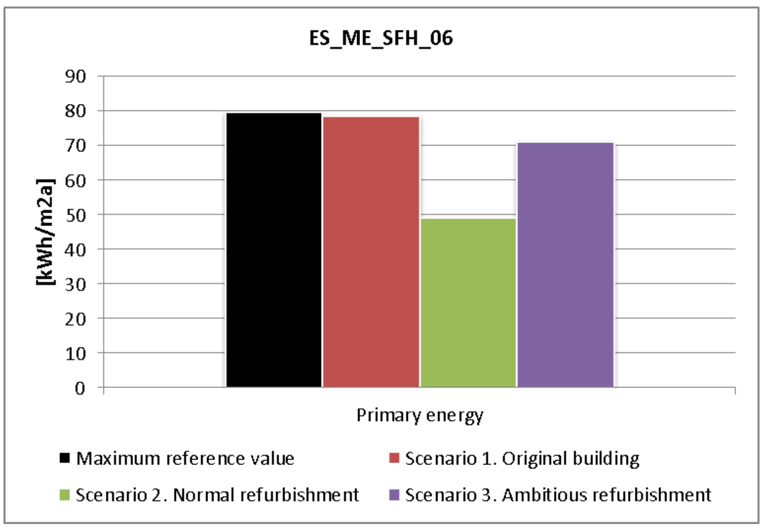


Figure 92. ES_ME_SFH_06 Primary energy consumption

Table 51. Results for the Spanish building ES_ME_SFH_06 according to Spanish nZEB definition

		ES			Compliance nZEB definition ES
		Energy need for heating	Energy need for cooling	Primary energy	
SFH	Maximum reference value	0,00			
	Scenario 1. Original building	-0,66	1,08	-0,01	NO
	Scenario 2. Normal refurbishment	-0,95	1,13	-0,38	NO
	Scenario 3. Ambitious refurbishment	-0,95	1,13	-0,11	NO

nZEB definition according to SPAIN			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	NON- COMPLIANT
ENERGY INDICATOR :	Energy need for cooling	Energy need for cooling	Energy need for cooling
Compliance Numerical indicator (see section 4.2) (VALUE):	(1.08)	(1.13)	(1.13)

- *Assessment under English scope:*

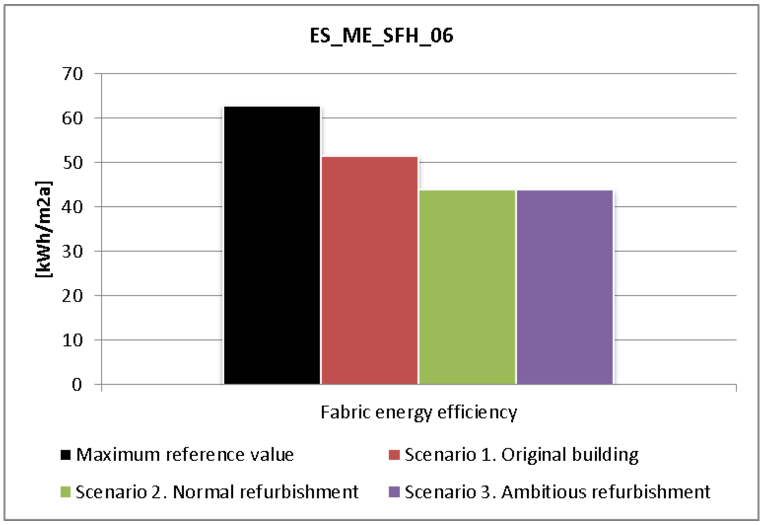


Figure 93. ES_ME_SFH_06 Fabric energy efficiency (energy need for heating and cooling)

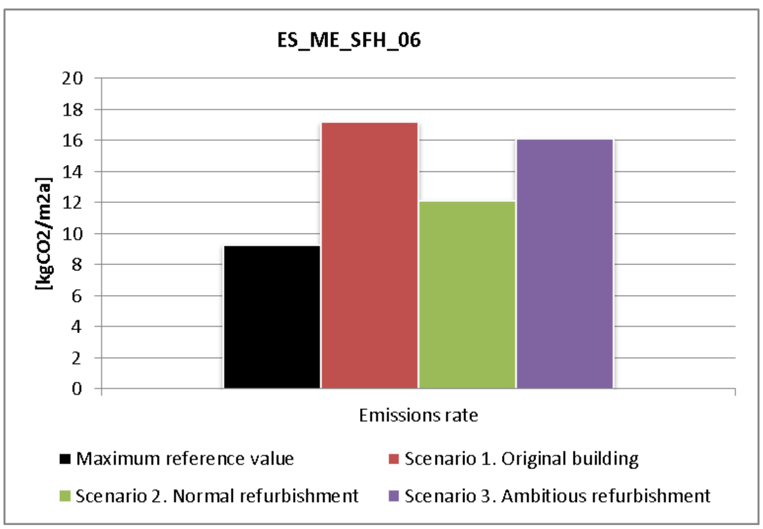


Figure 94. ES_ME_SFH_06 CO2 Emissions rate

Table 52. Results for the Spanish building ES_ME_SFH_06 according to English nZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO2 Emissions rate	
SFH	Maximum reference value	0,00		
	Scenario 1. Original building	-0,18	0,85	NO
	Scenario 2. Normal refurbishment	-0,30	0,31	NO
	Scenario 3. Ambitious refurbishment	-0,30	0,74	NO

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	NON- COMPLIANT
ENERGY INDICATOR :	CO2 Emissions rate	CO2 Emissions rate	CO2 Emissions rate
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.85)	(0.31)	(0.74)

- **ES_ME_SFH_06 – Single family house –Results**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the Spanish single family house (ES_ME_SFH_06) assessed under the Austrian building code scope results in the compliance of the nZEB definition, being the technical system losses “HTEB” the limiting energy indicator 2% under the maximum reference (see Table 49).. In this case, the inefficient technical systems, especially the high specific distribution losses of the heating system are the cause of the closeness to the Austrian maximum reference value. The rest numerical indicators are loosely compliant under the Austrian scope.

The assessment under the German building code scope results in the non-compliance, in this case of the reference value for the specific transmission heat losses HT'. The numerical indicator shows that the reference value is exceeded in 95% in this first scenario. That means that the average of the building elements transmission heat losses is almost the double of the permitted under the German code. As expected, the primary energy consumption is also over the threshold, in ths case 69% as shown in Table 50. This results display again the difference in the approach respect to the Austrian code. As repeatedly mentioned in the previous results, the Austrian requirements regarding the building envelope are more general, it is considered for the calculation of the energy need for space heating not only the specific transmission heat losses but also other components like the ventilation, solar gains and internal heat sinks and sources.

Like Germany, the assessment under the Spanish scope results in the non-compliance of the Spanish reference value for the primary energy. The energy need for space heating is 66% under the Spanish reference value, the primary energy is closer to the maximum reference only 1% below it and the non compliant energy indicator is the energy need for cooling which exceeds the threshold 108% as shown in Table 51. Two aspects play a key rolle in this non-compliance, first the climate zone due to the high exterior temperature and considerable solar gains and second, the use of air conditioned sytems with low energy efficiency rates that suppose a higher energy consumption.

Like in the case of Germany and Spain, the original building does not comply with the nZEB definition under the English scope. The fabric energy efficiency (comparable to the energy need for space heating) is 18% under this energy indicator maximum reference value, but the CO2 emissions rate is 85% above its own threshold.

Scenario 2 (GEN_2: Building subjected to normal renovation)

By only reducing the building elements U-Values, under the scenario normal renovation (GEN_2) and improving the heating system (reducing the specific distribution heat losses together with the energy expenditure coefficient) keeping the natural gas as energy carrier, the energy need for space heating falls to a value 98% under the reference and the building complies as before with the Austrian Nzeb definition (see Table 49). The limiting energy indicator is again the technical system losses “HTEB”, but with the above mentioned and in Table 23 presented improvement, this energy indicator lies 4% under the reference value.

This second scenario is also as the first, non-compliant under the German scope. The primary energy lies in this case just 6% above the German reference because of the reduction of the U-Values and thus of the specific transmission heat losses energy indicator which in this case lies 17% under the reference.

Unaltered respect to the scenario 1, due to the higher Spanish energy need for cooling, the scenario 2 does not comply with the Spanish nZEB definition either. While the energy need for heating and the primary energy consumption inicators are improved by the upgrade of the technical systems, the energy need for cooling is 113% over the Spanish reference, quite similar as the previous scenario (see Table 51).

The building again non-compliant with the English nZEB definition. In this case instead of 85%, the CO2 Emission rates indicator rests 31% above the English reference value.

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

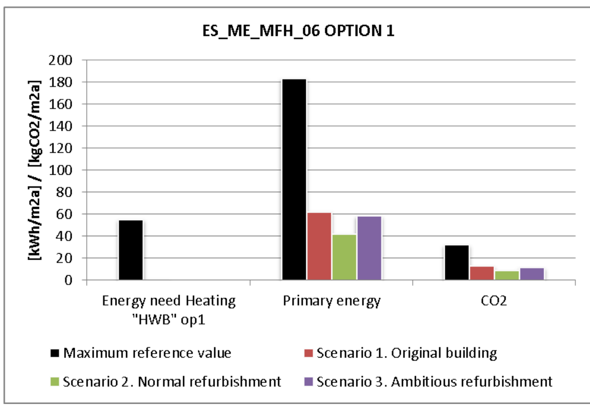
Two essential changes are done under this scenario, the energy carrier is switched from natural gas to wood pellets for the space heating system, and the flat solar thermal collector intended for the heating of the domestic hot water is no longer used.

Under an ambitious renovation (GEN_3), the building only complies with the main energy indicators reference value under the nZEB scope of Austria. The results are similar in all cases to those obtained in the scenario 2. Nonetheless, it is to point out that for all countries, the primary energy (non-renwable) consumption and the CO2 Emissions rate are increased respect to the previous scenario, regardless of the change in energy carrier, because of the solar thermal collector removal (see Table 23).

- **ES_ME_MFH_06 – Multi-family house -**

Figure 95. Representative MFH Spain Image. Taken from [8]

- *Assessment under Austrian scope:*



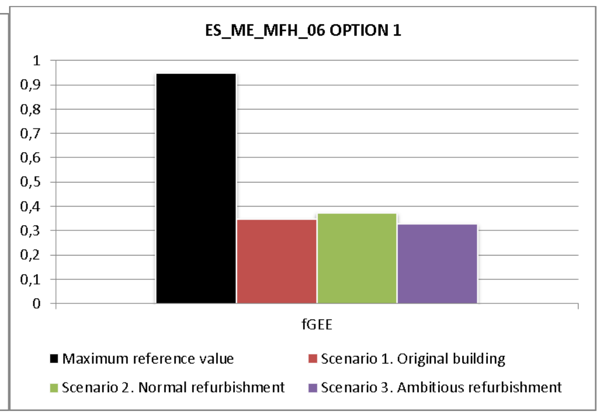


Figure 96. ES_ME_MFH_06 Fulfillment criteria option 1

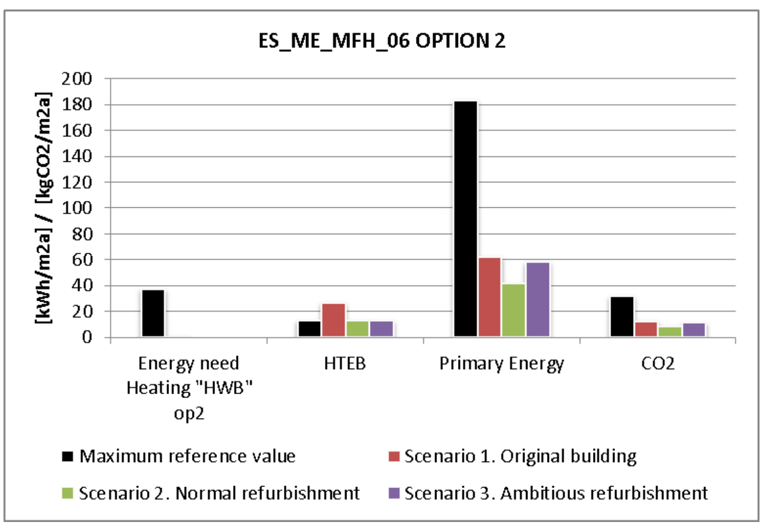


Figure 97. ES_ME_MFH_06 Fulfillment criteria option 2

Table 53. Results for the Spanish building ES_ME_MFH_06 according to Austrian nZEB definition

		AT						Compliance nZEB definition AT
		HVB option 1	Primary energy	CO2	FGEE	HVB option 2	HTEB	
MFH	Maximum reference value	0,00						
	Scenario 1. Original building	-0,99	-0,66	-0,60	-0,63	-0,99	1,06	O.K
	Scenario 2. Normal refurbishment	-1,00	-0,77	-0,73	-0,61	-1,00	-0,01	O.K
	Scenario 3. Ambitious refurbishment	-1,00	-0,68	-0,65	-0,65	-1,00	-0,01	O.K

nZEB definition according to AUSTRIA			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	CO2 Emissions rate	HTEB “Heiztechnik-Energiebedarf”	HTEB “Heiztechnik-Energiebedarf”
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.68)	(-0.01)	(-0.01)

- *Assessment under German scope:*

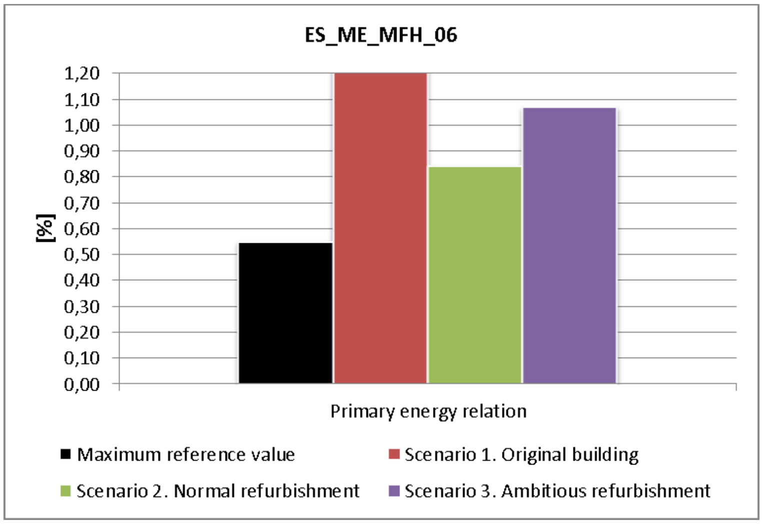


Figure 98. ES_ME_MFH_06 Primary energy consumption in [%] of the reference building

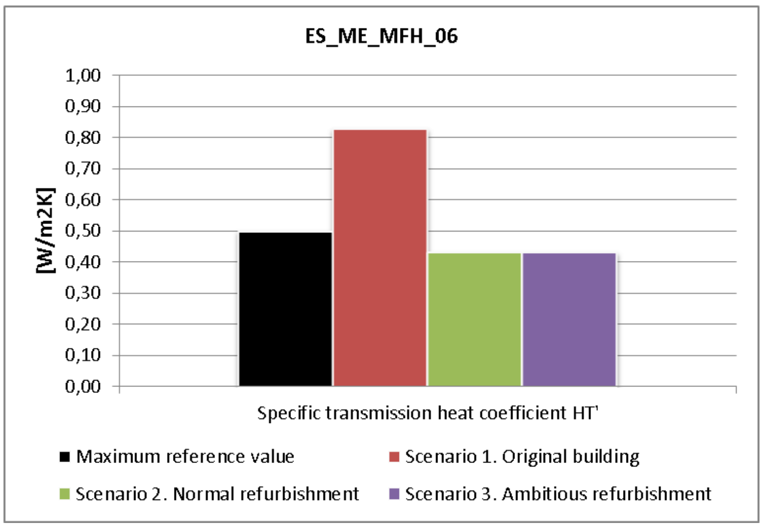


Figure 99. ES_ME_MFH_06 Specific transmission heat coefficient HT'

Table 54. Results for the Spanish building ES_ME_MFH_06 according to German nZEB definition

		DE		Compliance nZEB definition DE
		Primary energy	HT'	
MFH	Maximum reference value	0,00		
	Scenario 1. Original building	1,43	0,66	NO
	Scenario 2. Normal refurbishment	0,53	-0,14	NO
	Scenario 3. Ambitious refurbishment	0,94	-0,14	NO

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	NON- COMPLIANT
ENERGY INDICATOR :	Primary energy	Primary energy	Primary energy
Compliance Numerical indicator (see section 4.2) (VALUE):	(1.43)	(0.53)	(0.94)

- *Assessment under Spanish scope:*

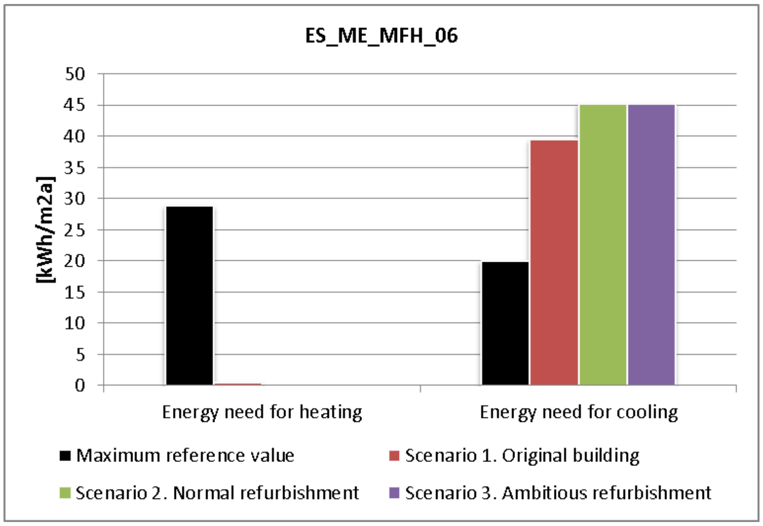


Figure 100. ES_ME_MFH_06 Energy need for heating and cooling

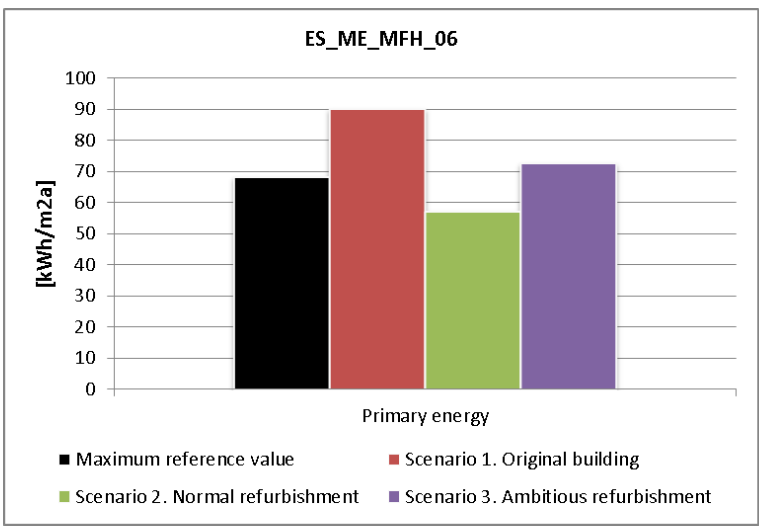


Figure 101. ES_ME_MFH_06 Primary energy consumption

Table 55. Results for the Spanish building ES_ME_MFH_06 according to Spanish nZEB definition

		ES			Compliance nZEB definition ES
		Energy need for heating	Energy need for cooling	Primary energy	
MFH	Maximum reference value	0,00			
	Scenario 1. Original building	-0,98	0,97	0,32	NO
	Scenario 2. Normal refurbishment	-1,00	1,26	-0,16	NO
	Scenario 3. Ambitious refurbishment	-1,00	1,26	0,06	NO

nZEB definition according to SPAIN			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	NON- COMPLIANT
ENERGY INDICATOR :	Energy need for cooling	Energy need for cooling	Energy need for cooling
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.97)	(1.26)	(1.26)

- ***Assessment under English scope:***

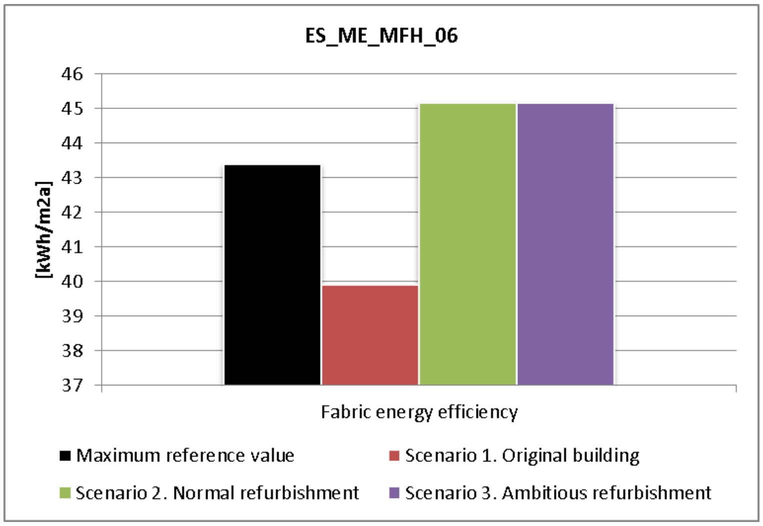


Figure 102. ES_ME_MFH_06 Fabric energy efficiency (energy need for heating and cooling)

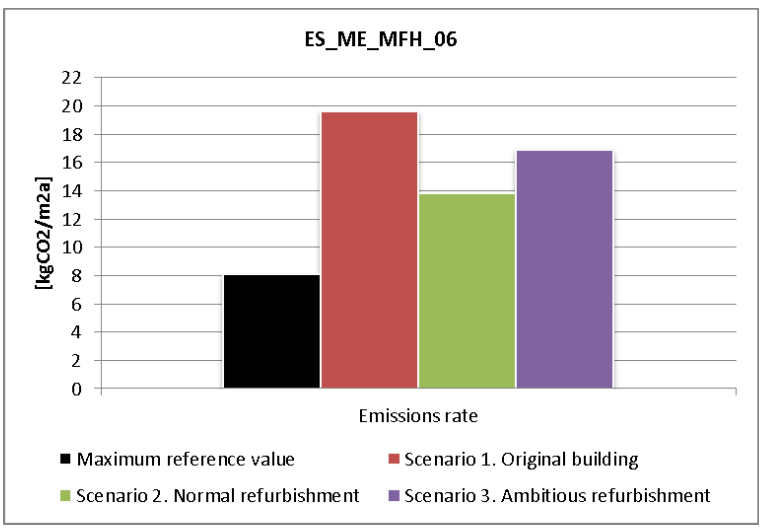


Figure 103. ES_ME_MFH_06 CO2 Emissions rate

Table 56. Results for the Spanish building ES_ME_MFH_06 according to English nZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO2 Emissions rate	
MFH	Maximum reference value	0,00		
	Scenario 1. Original building	-0,08	1,43	NO
	Scenario 2. Normal refurbishment	0,04	0,71	NO
	Scenario 3. Ambitious refurbishment	0,04	1,09	NO

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	NON- COMPLIANT
ENERGY INDICATOR :	CO2 Emissions rate	CO2 Emissions rate	CO2 Emissions rate
Compliance Numerical indicator (see section 4.2) (VALUE):	(1.43)	(0.71)	(1.09)

- **ES_ME_MFH_06 – Multi family house –Results**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the Spanish multi-family house (ES_ME_MFH_06) assessed under the Austrian building code scope results in the compliance of the nZEB definition, even though the technical system losses "HTEB" are 106% above the maximum reference (see Table 53) because, as mentioned in chapter 2.2, there are two ways to comply under the Austrian scope. Usin the option 1, the limiting factor are the CO2 Emissions which are 60% under the maximum reference.

The assessment under the German building code scope results in the non-compliance, in this case of the reference value for the specific transmission heat losses HT'. The numerical indicator shows that the reference value is exceeded in 66% in this first scenario. As expected, the primary energy consumption is also over the threshold, in ths case 143% as shown in Table 54. This results display again the difference in the approach respect to the Austrian code. As repeatedly mentioned in the previous results, the Austrian requirements regarding the building envelope are more general, it is considered for the calculation of the energy need for space heating not only the specific transmission heat losses but also other components like the ventilation, solar gains and internal heat sinks and sources.

Like Germany, the assessment under the Spanish scope results in the non-compliance of the Spanish reference value for the primary energy. The energy need for space heating is 98% under the Spanish reference value, the primary energy consumption is 32% over its maximum reference and the worst performing energy indicator is the energy need for cooling which exceeds the threshold 97% as shown in Table 55. As for the Spanish single family house, two aspects play a key rolle in this non-compliance status, first the climate zone due to the high exterior temperature and considerable solar gains and second, the use of air conditioned sytems with low energy efficiency rates that suppose a higher energy consumption.

Like in the case of Germany and Spain, the original building does not comply with the nZEB definition under the English scope. The fabric energy efficiency (comparable to the energy need for space heating) is 8% under this energy indicator maximum reference value, but the CO2 emissions rate is 143% above its own threshold.

Scenario 2 (GEN_2: Building subjected to normal renovation)

By only reducing the building elements U-Values, under the scenario normal renovation (GEN_2) and improving the heating system (reducing the specific distribution heat losses together with the energy expenditure coefficient) keeping the natural gas as energy carrier, the energy need for space heating falls to a value 77% under the reference and the building complies as before with the Austrian Nzeb definition (see Table 53). The limiting energy indicator is again the technical system losses "HTEB", but with the above mentioned and in Table 23 presented improvement, this energy indicator lies 1% under the reference value.

This second scenario is also as the first, non-compliant under the German scope. The primary energy lies in this case 53% above the German reference because of the reduction of the U-Values and thus of the specific transmission heat losses energy indicator which in this case lies 14% under the reference (see Table 54).

Unaltered respect to the scenario 1, due to the higher Spanish energy need for cooling, the scenario 2 does not comply with the Spanish nZEB definition either. While the energy need for heating and the primary energy consumption inicators are improved by the upgrade of the technical systems, the energy need for cooling is 126% over the Spanish reference, quite similar as the previous scenario (see Table 55).

The building again non-compliant with the English nZEB definition. In this case instead of 143%, the CO2 Emission rates indicator rests 71% above the English reference value. Here is remarkable that the fabric energy efficiency is 4% above the reference value in contrast to the previous scenario, where it was 8% below the threshold. This is due to the fact that the better the building thermal insulation, the less energy need for space heating but also the higher the impact of the internal heat sources, the stored heat and solar gains.

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

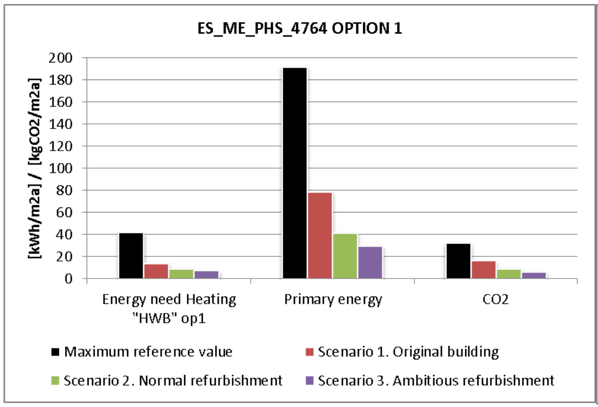
Two essential changes are done under this scenario, the energy carrier is switched from natural gas to wood pellets for the space heating system, and the flat solar thermal collector intended for the heating of the domestic hot water is no longer used.

Under an ambitious renovation (GEN_3), the building only complies with the main energy indicators reference value under the nZEB scope of Austria. The results are similar in all cases to those obtained in the scenario 2. Nonetheless, it is to point out that for all countries, the primary energy (non-renwable) consumption and the CO2 Emissions rate are increased respect to the previous scenario, regardless of the change in energy carrier, because of the solar thermal collector removal (see Table 23).

- **ES_ME_PHS_4764 – Single family house -**

Figure 104. Representative SFH Passive house Spain Image. Taken from [9]

- *Assessment under Austrian scope:*



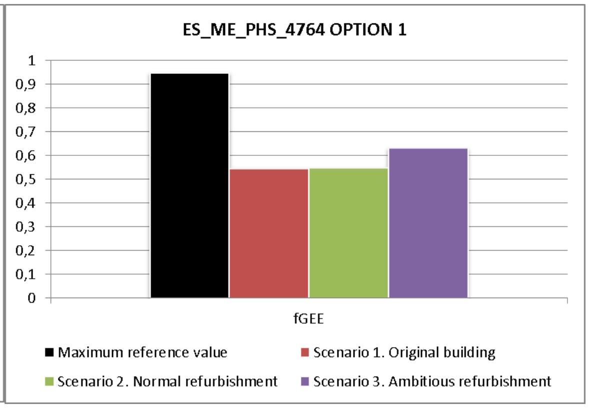


Figure 105. ES_ME_PHS_4764 Fulfillment criteria option 1

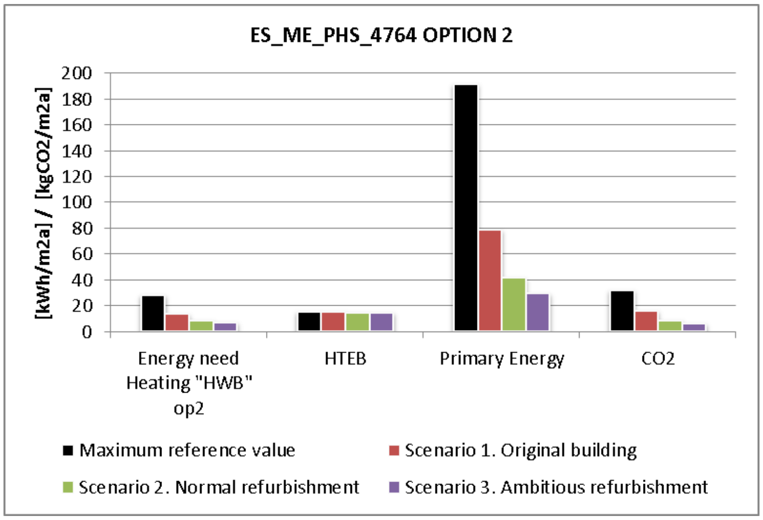


Figure 106. ES_ME_PHS_4764 Fulfillment criteria option 2

Table 57. Results for the Spanish building ES_ME_PHS_4764 according to Austrian nZEB definition

		AT						Compliance nZEB definition AT
		HVB option 1	Primary energy	CO2	FGEE	HVB option 2	HTEB	
SFH PHS	Maximum reference value	0,00						
	Scenario 1. Original building	-0,67	-0,59	-0,50	-0,42	-0,52	0,00	O.K
	Scenario 2. Normal refurbishment	-0,79	-0,78	-0,73	-0,42	-0,70	-0,03	O.K
	Scenario 3. Ambitious refurbishment	-0,83	-0,85	-0,81	-0,33	-0,75	-0,05	O.K

nZEB definition according to AUSTRIA			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Total energy efficiency factor fGEE “Gesamt energieeffizienz-Faktor“	HTEB “Heiztechnik-Energiebedarf”	HTEB “Heiztechnik-Energiebedarf”
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.42)	(-0.03)	(-0.05)

- *Assessment under German scope:*

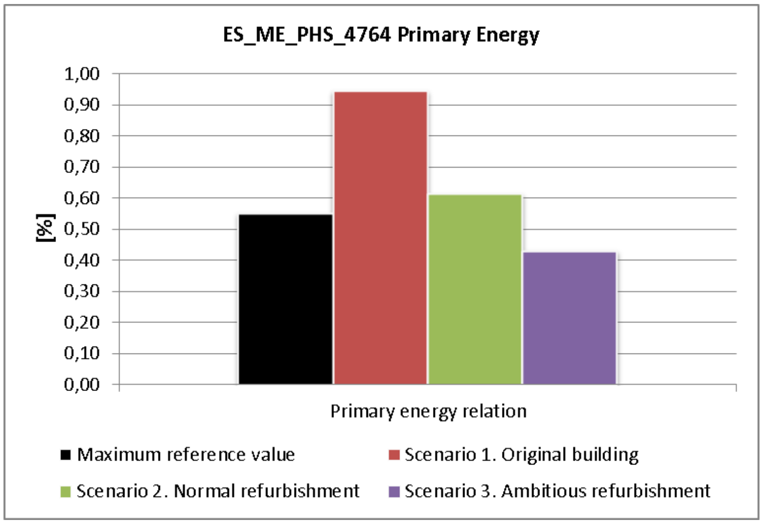


Figure 107. ES_ME_PHS_4764 Primary energy consumption in [%] of the reference building

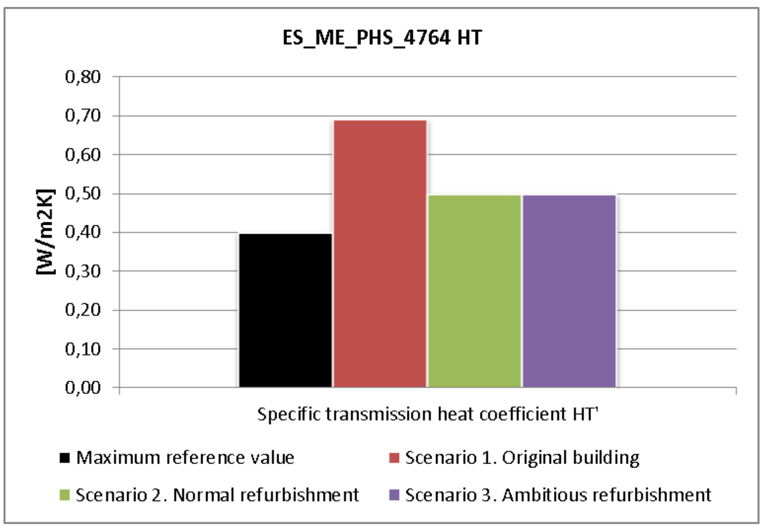


Figure 108. ES_ME_PHS_4764 Specific transmission heat coefficient HT'

Table 58. Results for the Spanish building ES_ME_PHS_4764 according to German nZEB definition

		DE		Compliance nZEB definition DE
		Primary energy	HT'	
SFH PHS	Maximum reference value	0,00		
	Scenario 1. Original building	0,71	0,73	NO
	Scenario 2. Normal refurbishment	0,11	0,25	NO
	Scenario 3. Ambitious refurbishment	-0,22	0,25	NO

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	NON- COMPLIANT
ENERGY INDICATOR :	Specific transmission heat losses HT' "Spezifischen Transmissionswärmeverlust"	Specific transmission heat losses HT' "Spezifischen Transmissionswärmeverlust"	Specific transmission heat losses HT' "Spezifischen Transmissionswärmeverlust"
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.73)	(0.25)	(0.25)

- *Assessment under Spanish scope:*

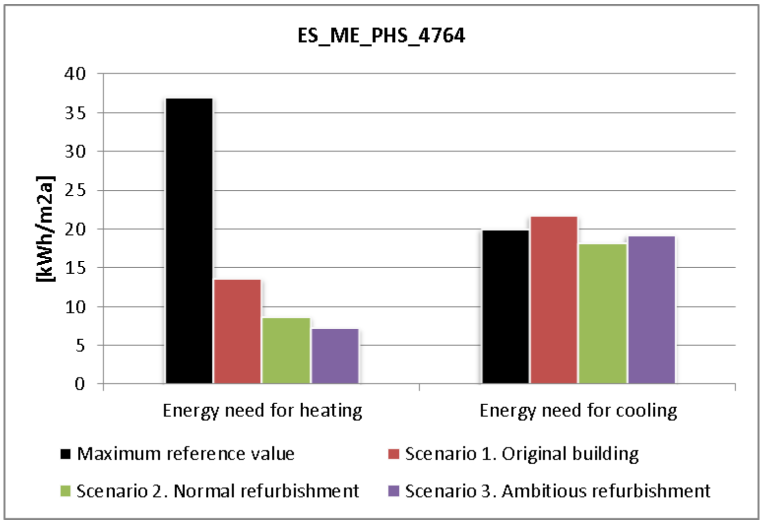


Figure 109. ES_ME_PHS_4764 Energy need for heating and cooling

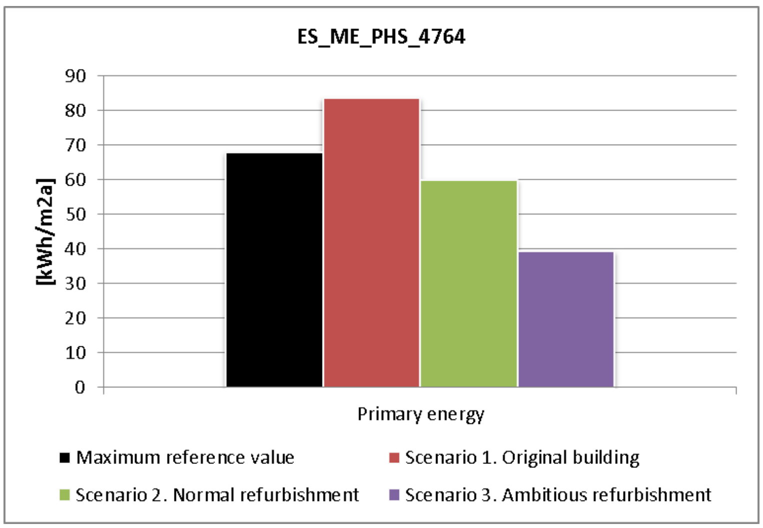


Figure 110. ES_ME_PHS_4764 Primary energy consumption

Table 59. Results for the Spanish building ES_ME_PHS_4764 according to Spanish nZEB definition

		ES			Compliance nZEB definition ES
		Energy need for heating	Energy need for cooling	Primary energy	
SFH PHS	Maximum reference value	0,00			
	Scenario 1. Original building	-0,63	0,08	0,23	NO
	Scenario 2. Normal refurbishment	-0,77	-0,09	-0,12	O.K
	Scenario 3. Ambitious refurbishment	-0,81	-0,04	-0,42	O.K

nZEB definition according to SPAIN			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Energy need for cooling	Energy need for cooling
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.23)	(-0.09)	(-0.04)

- *Assessment under English scope:*

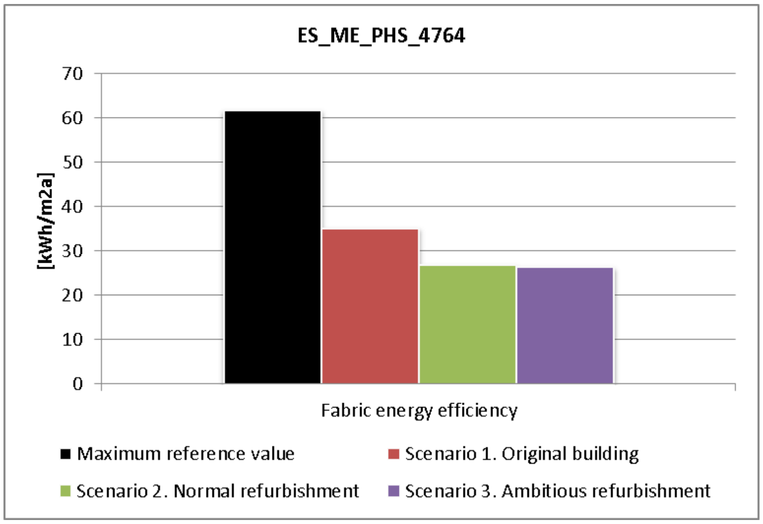


Figure 111. ES_ME_PHS_4764 Fabric energy efficiency (energy need for heating and cooling)

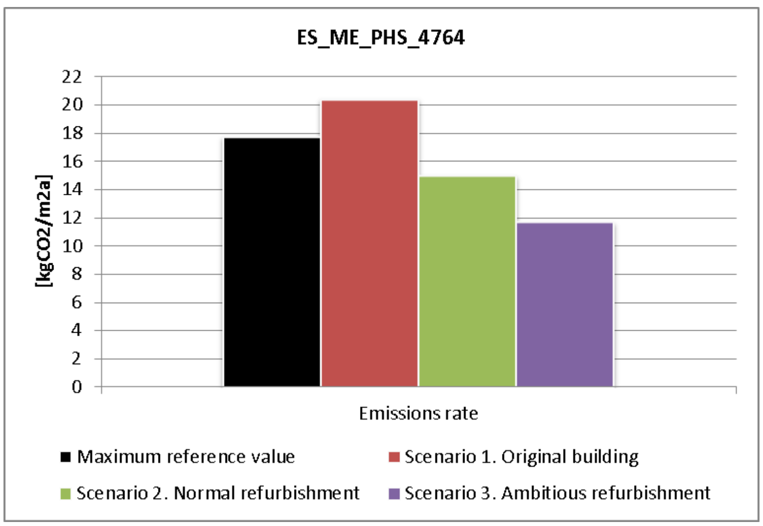


Figure 112. ES_ME_PHS_4764 CO2 Emissions rate

Table 60. Results for the Spanish building ES_ME_PHS_4764 according to English nZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO2 Emissions rate	
SFH PHS	Maximum reference value	0,00		
	Scenario 1. Original building	-0,43	0,15	NO
	Scenario 2. Normal refurbishment	-0,57	-0,16	O.K
	Scenario 3. Ambitious refurbishment	-0,57	-0,34	O.K

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	CO2 Emissions rate	CO2 Emission rate	CO2 Emission rate
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.15)	(-0.16)	(-0.34)

- **ES_ME_PHS_4764 – Pasiv house standard -Single family house –Results**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the Spanish pasiv house single-family house (ES_ME_PHS_4764) assessed under the Austrian building code scope results in the compliance of the nZEB definition, even though the technical system losses “HTEB” are exactly on the maximum reference (see Table 57), because, as mentioned in chapter 2.2, there are two ways to comply under the Austrian scope. Using the option 1, the limiting factor is the total energy efficiency factor “fGEE" which lies 42% under the maximum reference.

The assessment under the German building code scope results in the non-compliance, in this case of the reference value for both the specific transmission heat losses HT' and the primary energy consumption. The numerical indicator shows that the reference values are exceeded in 73% and 71% respectively in this first scenario as shown in Table 58. This results display again the difference in the approach respect to the Austrian code. As repeatedly mentioned in the previous results, the Austrian requirements regarding the building envelope are more general, it is considered for the calculation of the energy need for space heating not only the specific transmission heat losses but also other components like the ventilation, solar gains and internal heat sinks and sources.

Like Germany, the assessment under the Spanish scope results in the non-compliance of the Spanish reference value for the primary energy. The energy need for space heating is 63% under the Spanish reference value, the the energy need for cooling is 8% over its maximum reference and the worst performing energy indicator is the primary energy consumption 23% over the threshold as shown in Table 59.

Like in the case of Germany and Spain, the original building does not comply with the nZEB definition under the English scope. The fabric energy efficiency (comparable to the energy need for space heating) is 43% under this energy indicator maximum reference value, indicating a good performance of the building thermal envelope, but the CO2 emissions rate is 15% above its own threshold, indicating a not so efficient technical systems performance.

Scenario 2 (GEN_2: Building subjected to normal renovation)

By only reducing the building elements U-Values, under the scenario normal renovation (GEN_2) and improving the heating and domestic hot water systems, reducing the energy expenditure coefficient by modifying the energy carrier (use of heat pumps), the energy need for space heating falls to a value 79% under the reference and the building complies as before with the Austrian Nzeb definition (see Table 57). The limiting energy indicator is the technical system losses “HTEB”, but with the above mentioned and in Table 23 presented improvement, this energy indicator lies 3% under the reference value.

This second scenario is also as the first, non-compliant under the German scope. The primary energy lies in this case 11% above the German reference because of the reduction of the U-Values and thus of the specific transmission heat losses energy indicator which in this case lies 25% over the reference (see Table 58).

Different respect to the scenario 1, the scenario 2 does comply with the Spanish nZEB definition. The energy need for heating, the energy need ofr cooling and the primary energy consumption indicators are improved by the upgrade of the technical systems and the building thermal envelope, the energy need for cooling as limiting factor lies 9% under the Spanish reference (see Table 59).

The building is now compliant with the English nZEB definition. In this case instead of 15% over the reference value, the CO2 Emission rates indicator rests 16% under the threshold. The fabric energy efficiency is 57% under the reference value in contrast to the previous scenario, where it was 43% below the maximum (see Table 60).

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

Only one essential change is done under this scenario, namely the addition of the flat solar thermal collector intended for the heating of the domestic hot water.

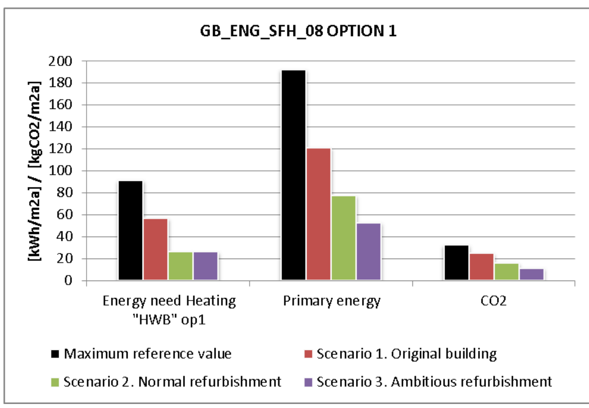
Under an ambitious renovation (GEN_3), the building only complies with the main energy indicators reference value under the nZEB scope of Austria, Spain and England. The results are similar in all cases to those obtained in the scenario 2. Since the building envelope is no further enhanced respect to the previous scenario, only the primary energy and CO2 emissions rate indicators are improved.

4.2.4 Results for the case of England

- **GB_ENG_SFH_08 – Single family house -**

Figure 113. Representative SFH Passive house England Image. Taken from [8]

- *Assessment under Austrian scope:*



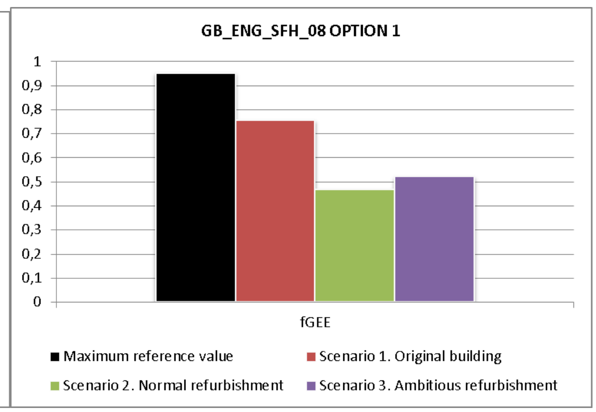


Figure 114. GB_ENG_SFH_08 Fulfillment criteria option 1

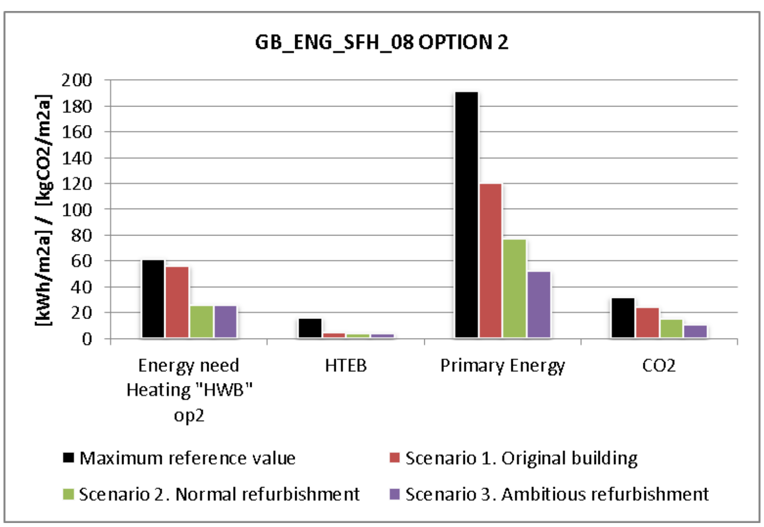


Figure 115. GB_ENG_SFH_08 Fulfillment criteria option 2

Table 61. Results for the English building GB_ENG_SFH_08 according to Austrian nZEB definition

		AT						Compliance nZEB definition AT
		HWB option 1	Primary energy	CO2	FGEE	HWB option 2	HTEB	
SFH	Maximum reference value	0,00						
	Scenario 1. Original building	-0,38	-0,37	-0,24	-0,21	**-0,09**	-0,71	O.K
	Scenario 2. Normal refurbishment	-0,72	-0,60	-0,51	**-0,51**	-0,58	-0,74	O.K
	Scenario 3. Ambitious refurbishment	-0,72	-0,73	-0,66	**-0,45**	-0,58	-0,74	O.K

nZEB definition according to AUSTRIA			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Energy need for space heating “Heizwärmebedarf option 2”	Total energy efficiency factor fGEE “Gesamt energieeffizienz-Faktor“	Total energy efficiency factor fGEE “Gesamt energieeffizienz-Faktor“
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.09)	(-0.51)	(-0.45)

- *Assessment under German scope:*

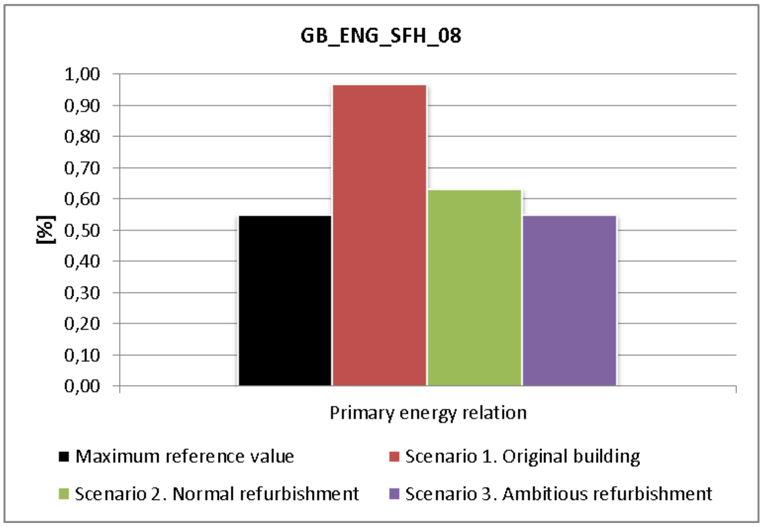


Figure 116. GB_ENG_SFH_08 Primary energy consumption in [%] of the reference building

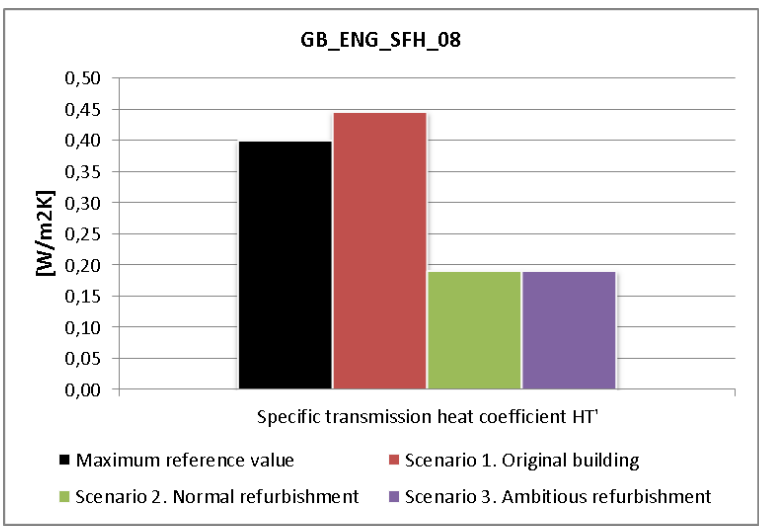


Figure 117. GB_ENG_SFH_08 Specific transmission heat coefficient HT'

Table 62. Results for the English building GB_ENG_SFH_08 according to German nZEB definition

		DE		Compliance nZEB definition DE
		Primary energy	HT'	
SFH	Maximum reference value	0,00		
	Scenario 1. Original building	0,76	0,11	NO
	Scenario 2. Normal refurbishment	0,15	-0,52	NO
	Scenario 3. Ambitious refurbishment	-0,003	-0,52	O.K

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Primary energy	Primary energy
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.76)	(0.15)	(-0.003)

- *Assessment under Spanish scope:*

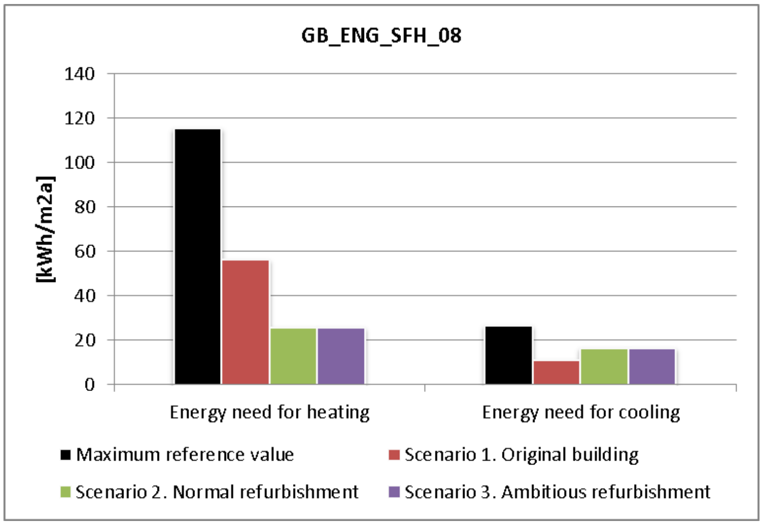


Figure 118. GB_ENG_SFH_08 Energy need for heating and cooling

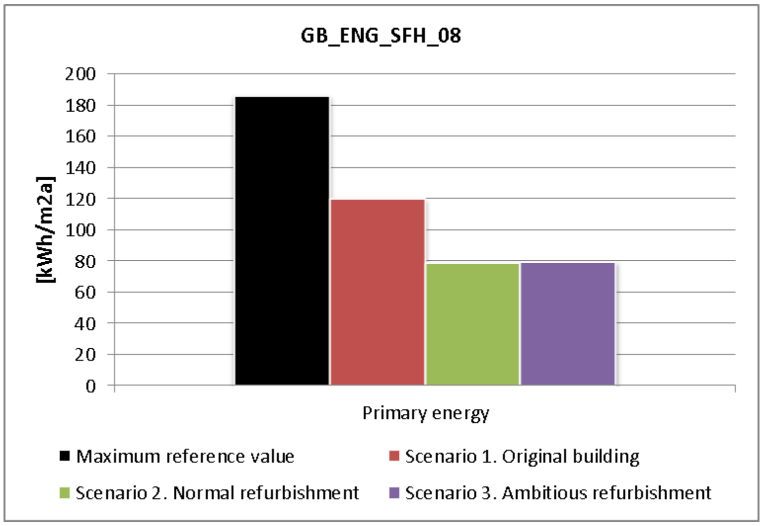


Figure 119. GB_ENG_SFH_08 Primary energy consumption

Table 63. Results for the English building GB_ENG_SFH_08 according to Spanish nZEB definition

		ES			Compliance nZEB definition ES
		Energy need for heating	Energy need for cooling	Primary energy	
SFH	Maximum reference value	0,00			
	Scenario 1. Original building	-0,51	-0,58	**-0,36**	O.K
	Scenario 2. Normal refurbishment	-0,78	**-0,38**	-0,58	O.K
	Scenario 3. Ambitious refurbishment	-0,78	**-0,38**	-0,57	O.K

nZEB definition according to SPAIN			
SCENARIO :	**Scenario 1 (GEN_1)**	**Scenario 2 (GEN_2)**	**Scenario 3 (GEN_3)**
COMPLIANCE :	**COMPLIANT**	**COMPLIANT**	**COMPLIANT**
ENERGY INDICATOR :	**Primary energy**	**Energy ned for cooling**	**Energy ned for cooling**
Compliance Numerical indicator (see section 4.2) (VALUE):	**(-0.36)**	**(-0.38)**	**(-0.38)**

- *Assessment under English scope:*

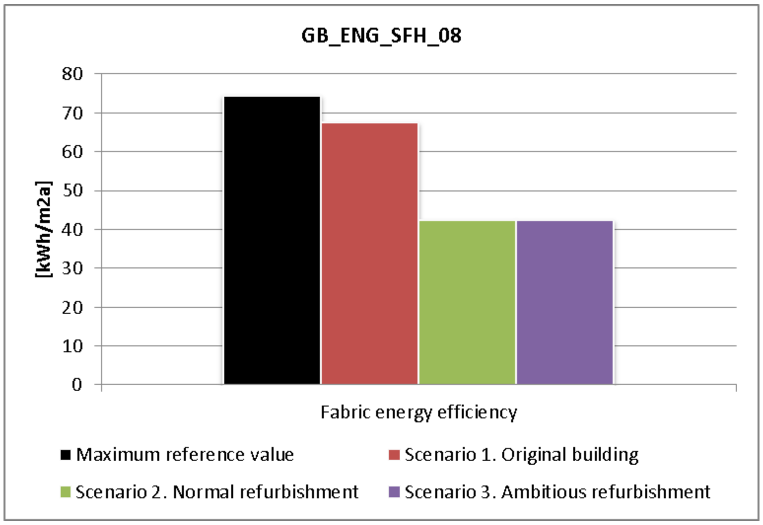


Figure 120. GB_ENG_SFH_08 Fabric energy efficiency (energy need for heating and cooling)

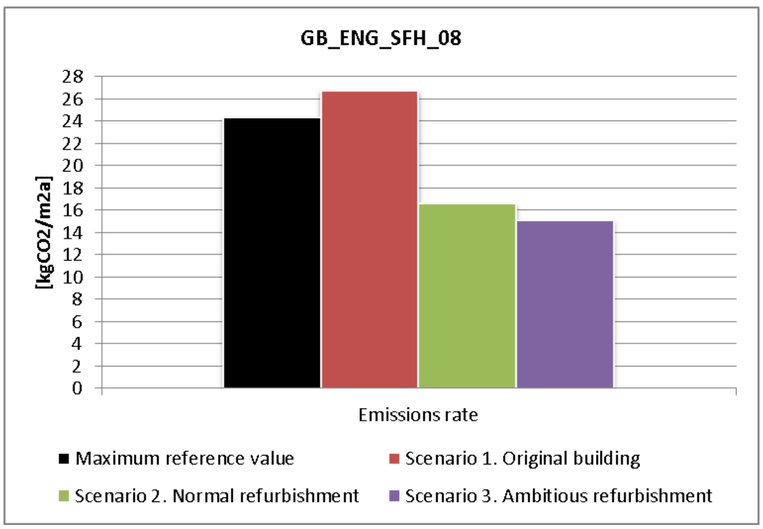


Figure 121. GB_ENG_SFH_08 CO2 Emissions rate

Table 64. Results for the English building GB_ENG_SFH_08 according to English nZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO2 Emissions rate	
SFH	Maximum reference value	0,00		
	Scenario 1. Original building	-0,09	0,10	NO
	Scenario 2. Normal refurbishment	-0,43	-0,32	O.K
	Scenario 3. Ambitious refurbishment	-0,43	-0,38	O.K

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	CO2 Emissions rate	CO2 Emissions rate	CO2 Emissions rate
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.10)	(-0.32)	(-0.38)

- **GB_ENG_SFH_08 – Single family house –Results**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the English single-family house (GB_ENG_SFH_08) assessed under the Austrian building code scope results in the compliance of the nZEB definition. The limiting energy indicator is the energy need for heating “HWB” option 2 which is still 9% under the maximum reference as shown in Table 61.

The assessment under the German building code scope on the other hand, results in the non-compliance of both, the specific transmission heat losses T' which is exceeded in 11% and the primary energy consumption exceeded in 76%. As shown in Table 62. This results display as mentioned before, the difference in the approach respect to the Austrian code. The Austrian requirements regarding the building envelope are more general, it is considered for the calculation of the energy need for space heating not only the specific transmission heat losses but also other components like the ventilation, solar gains and internal heat sinks and sources.

Like for Austria, the assessment under the Spanish scope results in the compliance of the Spanish reference value for the primary energy. The energy need for space heating is 51% under the Spanish reference value, the energy need for cooling is 58% below the threshold. the primary energy consumption is the limiting indicator and is 36% under its maximum as shown in Table 63.

Like in the case of Germany, the original building does not comply with the nZEB definition under the English scope. Even with the fabric energy efficiency (comparable to the energy need for space heating) 9% under the maximum reference value, the CO2 emissions rate is non-compliant, 10% above its own threshold.

Scenario 2 (GEN_2: Building subjected to normal renovation)

By only reducing the building elements U-Values, under the scenario normal renovation (GEN_2) and keeping the natural gas as energy carrier, the energy need for space heating falls to a value 72% under the reference and the building complies as before with the Austrian Nzeb definition (see Table 61). The limiting energy indicator is the total energy efficiency “fGEE” and it lies 51% under the reference value.

This second scenario is also as the first, non-compliant under the German scope. The primary energy lies in this case 15% above the German reference because of the reduction of the U-Values and thus of the specific transmission heat losses energy indicator which in this case lies 52% under the reference (see Table 62).

Unaltered respect to the scenario 1, the scenario 2 does comply with the Spanish nZEB definition. While the energy need for heating and the primary energy consumption inicators are improved by the upgrade of the technical systems, the energy need for cooling becomes worst but yet 38% under the Spanish reference, quite similar as the previous scenario (see Table 63).

The building is again compliant with the English nZEB definition. In this case instead of 10% above the reference, the CO2 Emission rates indicator rests 32% under it. The fabric energy efficiency is strongly improved to 43% below the maximum reference value in contrast to the previous scenario, where it was only 9% below the threshold. This is mainly due to the better the building thermal insulation.

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

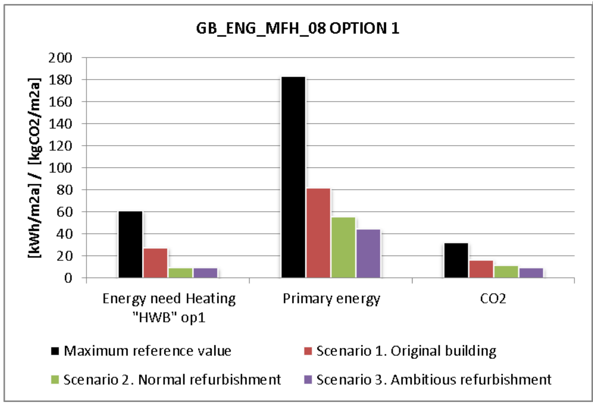
In this scenario, the energy carrier is switched from natural gas to electricity by the use of air heat pumps for the heating and domestic hot water systems. The use of solar thermal collectors intended for the heating of the domestic hot water is not considered in this case.

Under an ambitious renovation (GEN_3), the building complies with the main energy indicators reference value under the nZEB scope of all the four countries. The results are similar in all cases to those obtained in the scenario 2.

- **GB_ENG_MFH_08 – Multi-family house -**

Figure 122. Representative MFH England Image. Taken from [8]

- *Assessment under Austrian scope:*



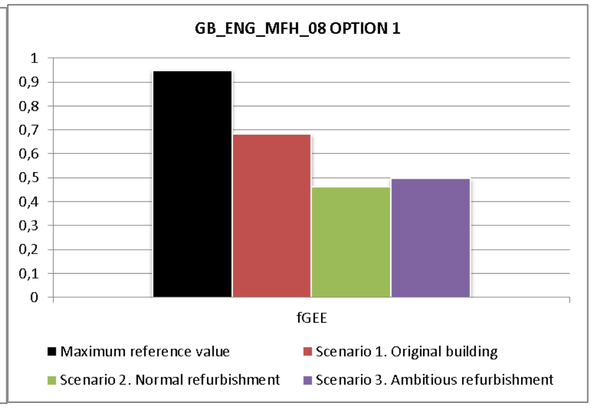


Figure 123. GB_ENG_MFH_08 Fulfillment criteria option 1

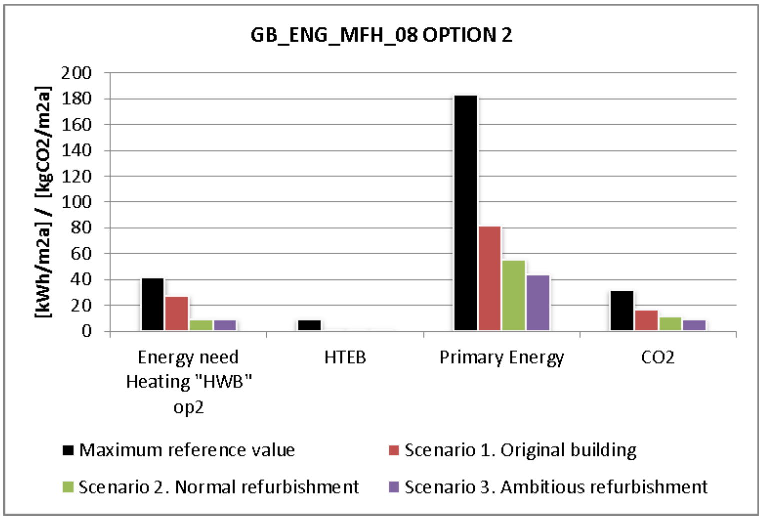


Figure 124. GB_ENG_MFH_08 Fulfillment criteria option 2

Table 65. Results for the English building GB_ENG_MFH_08 according to Austrian nZEB definition

		AT				Compliance nZEB definition AT
		CO2	FGEE	HWB option 2	HTEB	
MFH	Maximum reference value	0,00				
	Scenario 1. Original building	-0,48	-0,28	-0,33	-0,81	O.K
	Scenario 2. Normal refurbishment	-0,64	-0,51	-0,78	-0,85	O.K
	Scenario 3. Ambitious refurbishment	-0,72	-0,48	-0,78	-0,85	O.K

nZEB definition according to AUSTRIA			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Total energy efficiency factor fGEE "Gesamt energieeffizienz-Faktor"	Total energy efficiency factor fGEE "Gesamt energieeffizienz-Faktor"	Total energy efficiency factor fGEE "Gesamt energieeffizienz-Faktor"
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.28)	(-0.51)	(-0.48)

- *Assessment under German scope:*

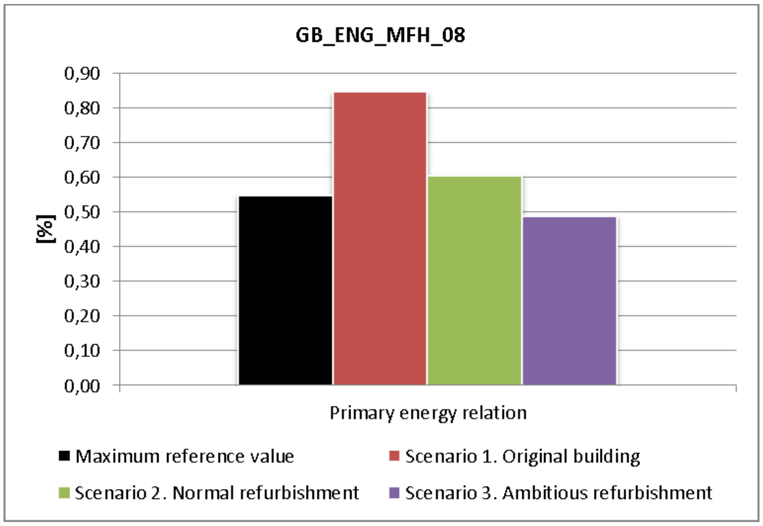


Figure 125. GB_ENG_MFH_08 Primary energy consumption in [%] of the reference building

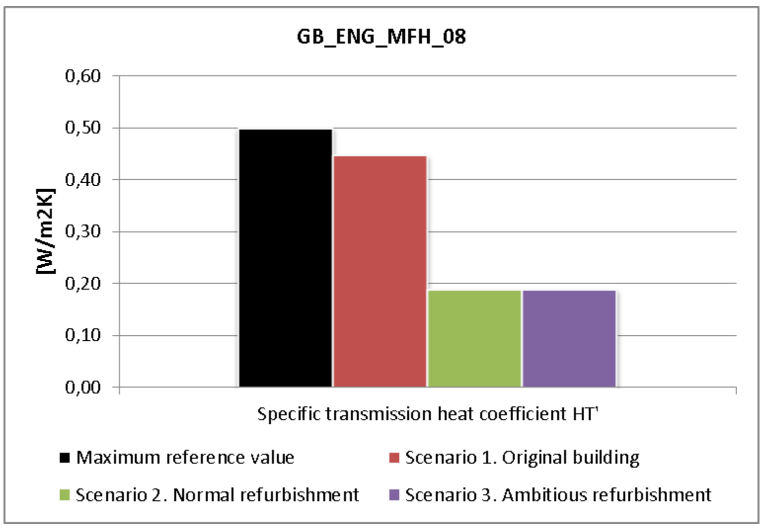


Figure 126. GB_ENG_MFH_08 Specific transmission heat coefficient HT'

Table 66. Results for the English building GB_ENG_MFH_08 according to German nZEB definition

		DE		Compliance nZEB definition DE
		Primary energy	HT'	
MFH	Maximum reference value	0,00		
	Scenario 1. Original building	0,54	-0,11	NO
	Scenario 2. Normal refurbishment	0,10	-0,62	NO
	Scenario 3. Ambitious refurbishment	-0,11	-0,62	O.K

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Primary energy	Primary energy
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.54)	(0.10)	(-0.11)

- *Assessment under Spanish scope:*

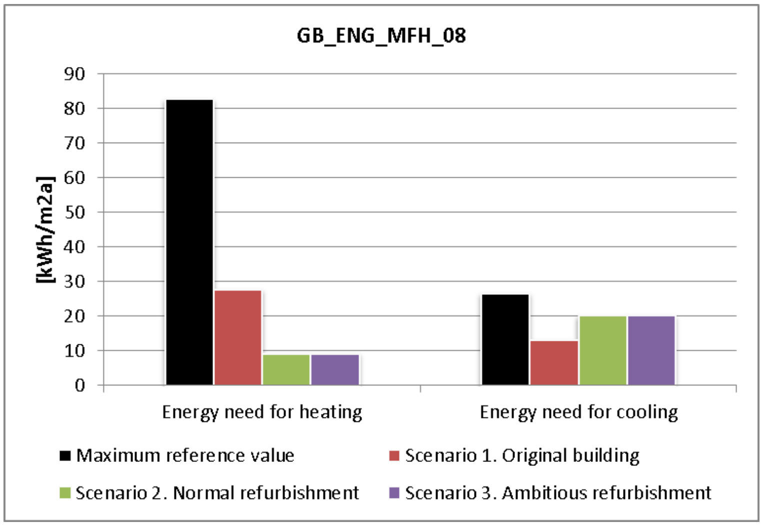


Figure 127. GB_ENG_MFH_08 Energy need for heating and cooling

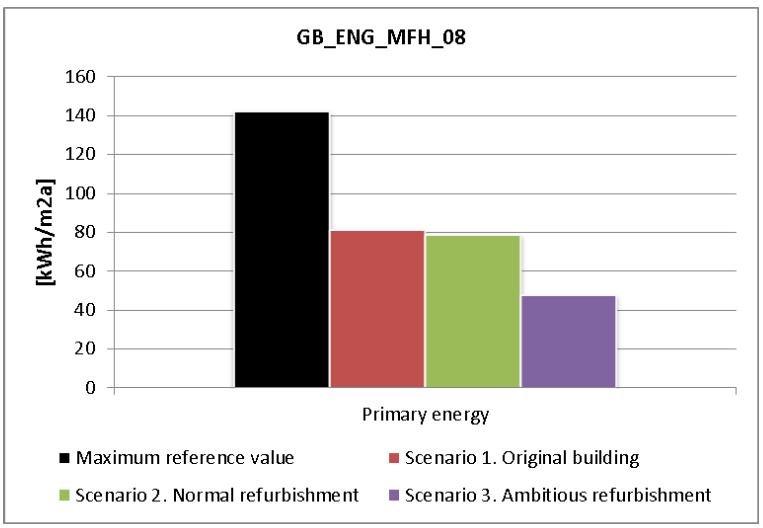


Figure 128. GB_ENG_MFH_08 Primary energy consumption

Table 67. Results for the English building GB_ENG_MFH_08 according to Spanish nZEB definition

		ES			Compliance nZEB definition ES
		Energy need for heating	Energy need for cooling	Primary energy	
MFH	Maximum reference value	0,00			
	Scenario 1. Original building	-0,66	-0,50	-0,43	O.K
	Scenario 2. Normal refurbishment	-0,89	-0,24	-0,45	O.K
	Scenario 3. Ambitious refurbishment	-0,89	-0,24	-0,67	O.K

nZEB definition according to SPAIN			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Energy need for cooling	Energy need for cooling
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.43)	(-0.24)	(-0.24)

- *Assessment under English scope:*

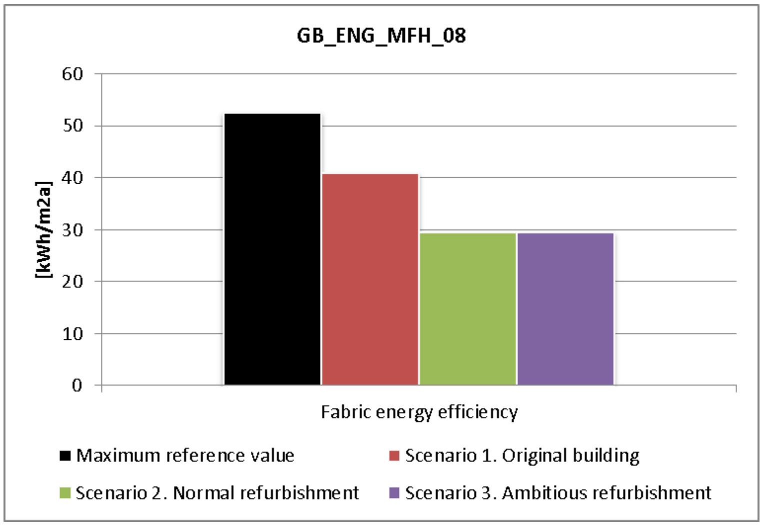


Figure 129. GB_ENG_MFH_08 Fabric energy efficiency (energy need for heating and cooling)

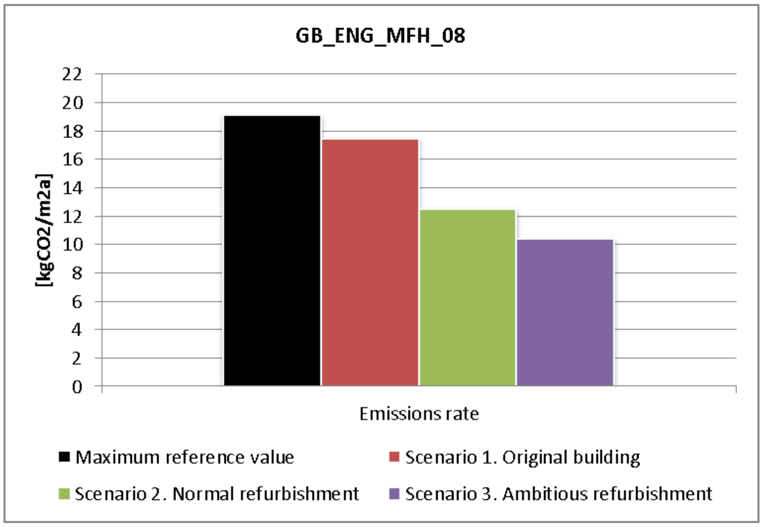


Figure 130. GB_ENG_MFH_08 CO2 Emissions rate

Table 68. Results for the English building GB_ENG_MFH_08 according to English nZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO2 Emissions rate	
MFH	Maximum reference value	0,00		
	Scenario 1. Original building	-0,22	-0,09	O.K
	Scenario 2. Normal refurbishment	-0,44	-0,35	O.K
	Scenario 3. Ambitious refurbishment	-0,44	-0,46	O.K

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	CO2 Emissions rate	CO2 Emissions rate	Fabric energy efficiency
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.09)	(-0.35)	(-0.44)

- **GB_ENG_MFH_08 – Multi-family house –Results**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the English multi-family house (GB_ENG_MFH_08) assessed under the Austrian building code scope results in the compliance of the nZEB definition. The limiting energy indicator is the total energy efficiency factor “fGEE” which is 28% under the maximum reference as shown in Table 65.

The assessment under the German building code scope on the other hand, results in the non-compliance of the German nZEB definition. the specific transmission heat losses HT' is 11% under the reference value, but the primary energy consumption indicator is exceeded in 54%. As shown in Table 66. This results display as mentioned before, the difference in the approach respect to the Austrian code. The Austrian requirements regarding the building envelope are more general, it is considered for the calculation of the energy need for space heating not only the specific transmission heat losses but also other components like the ventilation, solar gains and internal heat sinks and sources.

Like for Austria, the assessment under the Spanish scope results in the compliance of the Spanish reference value for the primary energy. The energy need for space heating is 66% under the Spanish reference value, the energy need for cooling is 50% below the threshold. the primary energy consumption is the limiting indicator and is 43% under its maximum as shown in Table 67.

Like in the case of Austria and Spain, the original building does comply with the nZEB definition under the English scope. The fabric energy efficiency (comparable to the energy need for space heating) 22% under the maximum reference value and the CO2 emissions rate is 9% above its own threshold.

Scenario 2 (GEN_2: Building subjected to normal renovation)

By only reducing the building elements U-Values, under the scenario normal renovation (GEN_2) and keeping the natural gas as energy carrier, the energy need for space heating falls to a value 55% under the reference and the building complies as before with the Austrian nZEB definition (see Table 65). The limiting energy indicator is the total energy efficiency “fGEE” and it lies 28% under the reference value.

This second scenario is also as the first, non-compliant under the German scope. The primary energy lies in this case 10% above the German reference because of the reduction of the U-Values and thus of the specific transmission heat losses energy indicator which in this case lies 62% under the reference (see Table 66).

Unaltered respect to the scenario 1, the scenario 2 does comply with the Spanish nZEB definition. While the energy need for heating and the primary energy consumption indicators are improved by the upgrade of the building envelope, the energy need for cooling becomes worst but yet 24% under the Spanish reference, quite similar as the previous scenario (see Table 67).

The building is again compliant with the English nZEB definition. In this case instead of 9% the CO2 Emission rates indicator rests now 35% under the maximum reference value. The fabric energy efficiency is in this case 44% below the maximum reference value in contrast to the previous scenario, where it was 22% below the threshold (see Table 68). This is mainly due to the better the building thermal insulation.

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

In this scenario it is considered the use of solar thermal collectors intended for the heating of the domestic hot water. The building thermal envelope and other technical installations are the same as in the second scenario.

Under an ambitious renovation (GEN_3), the building complies with the main energy indicators reference value under the nZEB scope of all the four countries. The results are similar in all cases to those obtained in the scenario 2. The importance of the technical systems for the German purview is remarkable. Even with the same building envelope and thus the same specific transmission heat losses HT' and only the addition of the solar thermal collector, the building becomes compliant going from 10% (primary energy consumption) over the reference value to 11% under it (see Table 66).

- **GB_ENG_PHS_2033 – Single family house -**

Figure 131. Representative SFH Passive house England Image. Taken from [9]

- *Assessment under Austrian scope:*

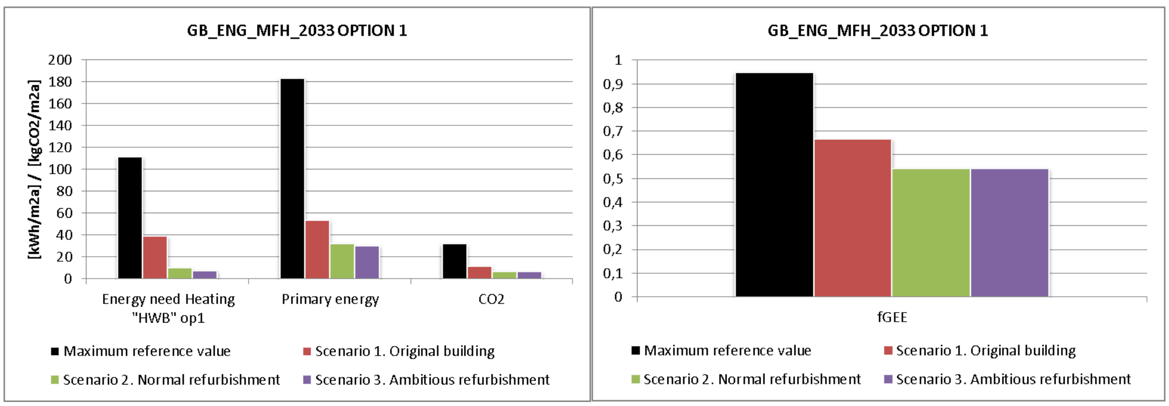


Figure 132. GB_ENG_PHS_2033 Fulfillment criteria option 1

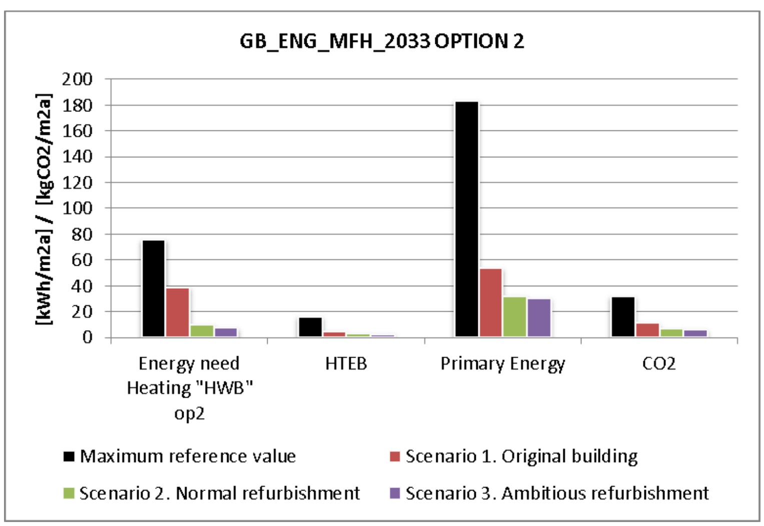


Figure 133. GB_ENG_PHS_2033 Fulfillment criteria option 2

Table 69. Results for the English building GB_ENG_PHS_2033 according to Austrian nZEB definition

		AT						Compliance nZEB definition AT
		HWB option 1	Primary energy	CO2	FGEE	HWB option 2	HTEB	
MFH PHS	Maximum reference value	0,00						
	Scenario 1. Original building	-0,65	-0,71	-0,65	**-0,30**	-0,49	-0,70	O.K
	Scenario 2. Normal refurbishment	-0,91	-0,82	-0,79	**-0,43**	-0,87	-0,82	O.K
	Scenario 3. Ambitious refurbishment	-0,93	-0,83	-0,80	**-0,43**	-0,90	-0,83	O.K

nZEB definition according to AUSTRIA			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Total energy efficiency factor fGEE “Gesamt energieeffizienz-Faktor“	Total energy efficiency factor fGEE “Gesamt energieeffizienz-Faktor“	Total energy efficiency factor fGEE “Gesamt energieeffizienz-Faktor“
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.30)	(-0.43)	(-0.43)

- *Assessment under German scope:*

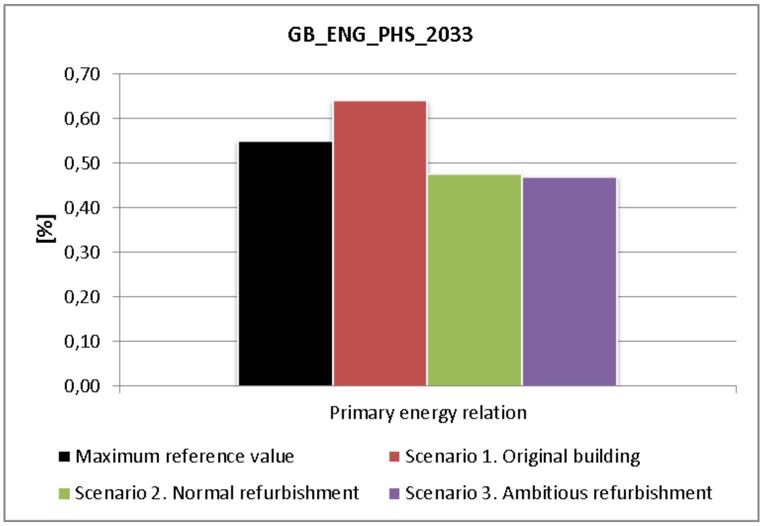


Figure 134. GB_ENG_PHS_2033 Primary energy consumption in [%] of the reference building

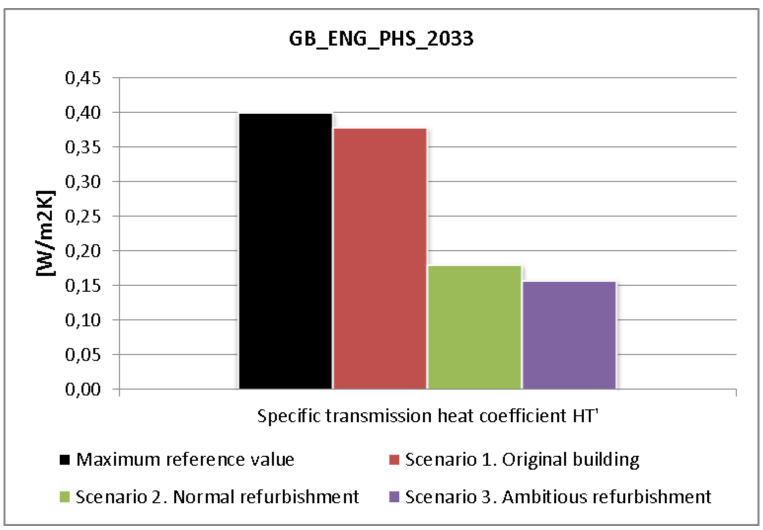


Figure 135. GB_ENG_PHS_2033 Specific transmission heat coefficient HT'

Table 70. Results for the English building GB_ENG_PHS_2033 according to German nZEB definition

		DE		Compliance nZEB definition DE
		Primary energy	HT'	
MFH PHS	Maximum reference value	0,00		
	Scenario 1. Original building	0,16	-0,05	NO
	Scenario 2. Normal refurbishment	-0,13	-0,55	O.K
	Scenario 3. Ambitious refurbishment	-0,15	-0,61	O.K

nZEB definition according to GERMANY			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Primary energy	Primary energy	Primary energy
Compliance Numerical indicator (see section 4.2) (VALUE):	(0.16)	(-0.13)	(-0.15)

- *Assessment under Spanish scope:*

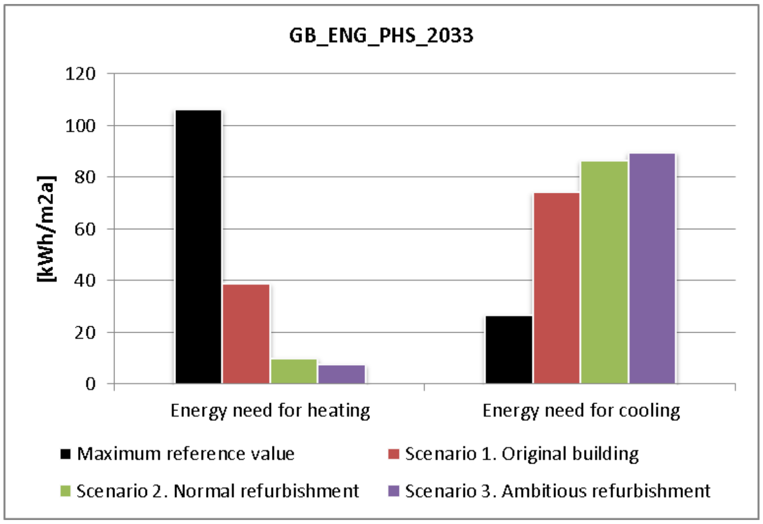


Figure 136. GB_ENG_PHS_2033 Energy need for heating and cooling

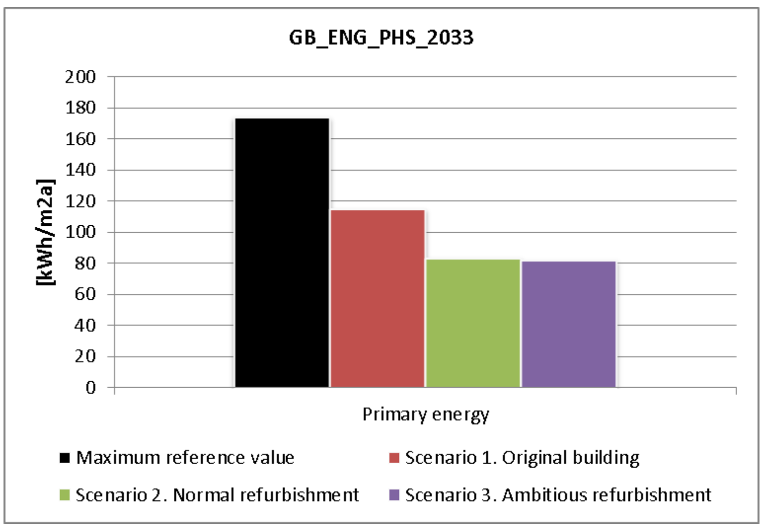


Figure 137. GB_ENG_PHS_2033 Primary energy consumption

Table 71. Results for the English building GB_ENG_PHS_2033 according to Spanish nZEB definition

		ES			Compliance nZEB definition ES
		Energy need for heating	Energy need for cooling	Primary energy	
MFH PHS	Maximum reference value	0,00			
	Scenario 1. Original building	-0,63	1,78	-0,34	NO
	Scenario 2. Normal refurbishment	-0,91	2,24	-0,52	NO
	Scenario 3. Ambitious refurbishment	-0,93	2,36	-0,53	NO

nZEB definition according to SPAIN			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	NON- COMPLIANT	NON- COMPLIANT	NON- COMPLIANT
ENERGY INDICATOR :	Energy need for cooling	Energy need for cooling	Energy need for cooling
Compliance Numerical indicator (see section 4.2) (VALUE):	(1.78)	(2.24)	(2.36)

- *Assessment under English scope:*

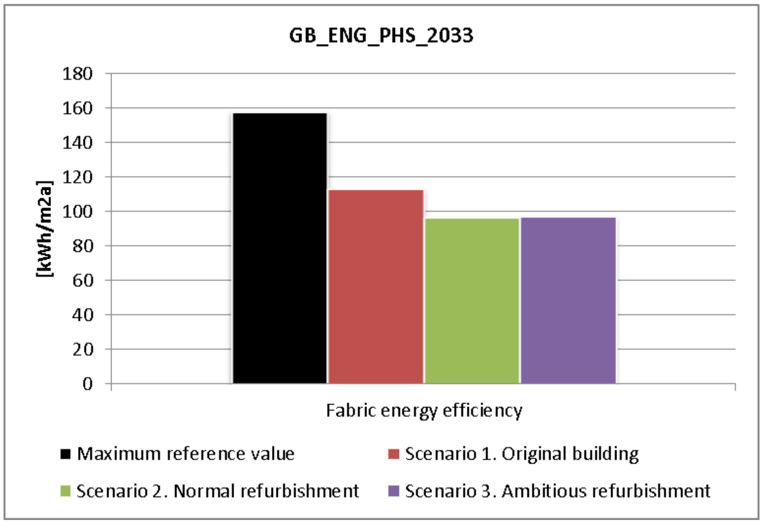


Figure 138. GB_ENG_PHS_2033 Fabric energy efficiency (energy need for heating and cooling)

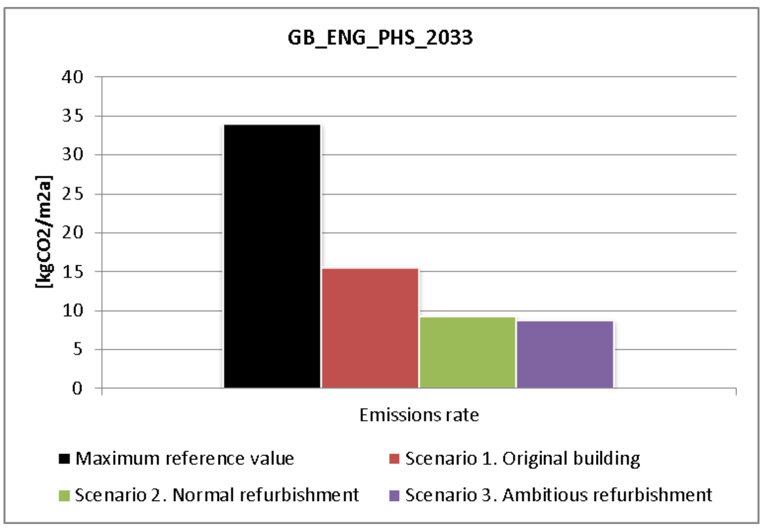


Figure 139. GB_ENG_PHS_2033 CO2 Emissions rate

Table 72. Results for the English building GB_ENG_PHS_2033 according to English nZEB definition

		UK		Compliance nZEB definition UK
		Fabric energy efficiency	CO2 Emissions rate	
MFH PHS	Maximum reference value	0,00		
	Scenario 1. Original building	-0,28	-0,54	O.K
	Scenario 2. Normal refurbishment	-0,39	-0,73	O.K
	Scenario 3. Ambitious refurbishment	-0,38	-0,74	O.K

nZEB definition according to ENGLAND			
SCENARIO :	Scenario 1 (GEN_1)	Scenario 2 (GEN_2)	Scenario 3 (GEN_3)
COMPLIANCE :	COMPLIANT	COMPLIANT	COMPLIANT
ENERGY INDICATOR :	Fabric energy efficiency	Fabric energy efficiency	Fabric energy efficiency
Compliance Numerical indicator (see section 4.2) (VALUE):	(-0.28)	(-0.39)	(-0.38)

- **GB_ENG_PHS_2033 – Passive house–Results**

Scenario 1 (GEN_1: Original building)

For the first scenario: GEN_1 (original building), the English multi-family passive house (GB_ENG_PHS_2033) assessed under the Austrian building code scope results in the compliance of the nZEB definition. The limiting energy indicator is the total energy efficiency factor “fGEE” which is 30% under the maximum reference as shown in Table 69.

The assessment under the German building code scope on the other hand, results in the non-compliance of the German nZEB definition. the specific transmission heat losses HT' is 5% under the reference value, but the primary energy consumption indicator is exceeded in 16%. As shown in Table 70. This results display as mentioned before, the difference in the approach respect to the Austrian code. The Austrian requirements regarding the building envelope are more general, it is considered for the calculation of the energy need for space heating not only the specific transmission heat losses but also other components like the ventilation, solar gains and internal heat sinks and sources.

Like for Germany, the assessment under the Spanish scope results in the non-compliance of the Spanish reference value for the energy ned for cooling with an excess of 178% over the threshold. The energy need for space heating is 63% under the Spanish reference value and the primary energy consumption is 34% under its maximum as shown in Table 71.

Like in the case of Austria, the original building does comply with the nZEB definition under the English scope. The fabric energy efficiency (comparable to the energy need for space heating) 28% under the maximum reference value and the CO2 emissions rate is 54% under its own threshold.

Scenario 2 (GEN_2: Building subjected to normal renovation)

By only reducing the building elements U-Values, under the scenario normal renovation (GEN_2) and adding a solar thermal collector for the domestic hot water, the energy need for space heating falls to a value 91% under the reference and the building complies as before with the Austrian nZEB definition (see Table 69). The limiting energy indicator is the total energy efficiency “fGEE” and it lies 43% under the reference value.

This second scenario is compliant under the German scope. The primary energy lies in this case 13% below the German reference because of the solar thermal collector introduction additionally to the reduction of the U-Values and thus of the specific transmission heat losses energy indicator which in this case lies 55% under the reference (see Table 70).

Unaltered respect to the scenario 1, the scenario 2 does not comply with the Spanish nZEB definition. The energy need for cooling indicator is even worst than that from the scenario 1, it is 224% over the Spanish reference, similar as the previous scenario (see Table 71).

The building is again compliant with the English nZEB definition. In this case instead of 54% the CO_2 Emission rates indicator rests now 73% under the maximum reference value. The fabric energy efficiency is in this case 39% below the maximum reference value in contrast to the previous scenario, where it was 28% below the threshold (see Table 72). This is mainly due to the better the building thermal insulation.

Scenario 3 (GEN_3: Building subjected to ambitious renovation)

Both building thermal envelope and technical systems are kept as in the previous scenario. Under an ambitious renovation (GEN_3), the building complies with the main energy indicators reference value under the nZEB scope of Austria, Germany and England. The asessesment of this building under Spanish scope reveals how the high compactness (remarkable efficient building thermal envelope) affects so strongly the performance of the building under other country's scope specially with so different climate conditions as Spain.

4.2.5 Results comparison

Table 73 shows the results comparison for each alternative by building and country (rows) and the result for compliance / not compliance with the nZEB definition under the scope of the respective assessor country (columns).

Table 73. Quantitative results comparison

			nZEB definition AT	nZEB definition DE	nZEB definition ES	nZEB definition UK
AT	SFH	Scenario 1. Original building	NO 0,97	NO 0,64	NO 0,03	O.K - 0,19
		Scenario 2. Normal refurbishment	O.K - 0,14	O.K - 0,06	O.K - 0,39	O.K - 0,60
		Scenario 3. Ambitious refurbishment	O.K - 0,37	O.K - 0,52	O.K - 0,43	O.K - 0,54
	MFH	Scenario 1. Original building	NO 0,65	NO 0,62	NO 0,02	O.K - 0,20
		Scenario 2. Normal refurbishment	O.K - 0,33	O.K - 0,02	O.K - 0,16	O.K - 0,52
		Scenario 3. Ambitious refurbishment	O.K - 0,18	O.K - 0,25	O.K -0,21	O.K - 0,53
	AB	Scenario 1. Original building	NO 0,38	NO 0,60	O.K - 0,06	O.K - 0,01
		Scenario 2. Normal refurbishment	O.K - 0,13	NO 0,10	NO 0,001	O.K - 0,28
		Scenario 3. Ambitious refurbishment	O.K - 0,28	O.K - 0,23	O.K - 0,06	O.K - 0,44
DE	SFH	Scenario 1. Original building	NO 0,58	NO 0,45	O.K - 0,34	O.K - 0,32
		Scenario 2. Normal refurbishment	O.K - 0,14	NO 0,10	O.K - 0,22	O.K - 0,46
		Scenario 3. Ambitious refurbishment	O.K - 0,33	O.K - 0,57	O.K - 0,01	O.K - 0,57
	MFH	Scenario 1. Original building	O.K - 0,06	NO 0,75	O.K - 0,06	O.K - 0,06
		Scenario 2. Normal refurbishment	O.K - 0,14	NO 0,40	NO 0,16	O.K - 0,21
		Scenario 3. Ambitious refurbishment	O.K - 0,19	NO 0,47	NO 0,35	O.K - 0,17
	AB	Scenario 1. Original building	NO 1,16	NO 2,20	NO 0,47	NO 0,43
		Scenario 2. Normal refurbishment	O.K - 0,36	O.K - 0,10	O.K - 0,16	O.K - 0,41
		Scenario 3. Ambitious refurbishment	O.K - 0,47	O.K - 0,50	NO 0,03	O.K - 0,45
ES	SFH	Scenario 1. Original building	O.K - 0,02	NO 0,95	NO 1,08	NO 0,85
		Scenario 2. Normal refurbishment	O.K - 0,04	NO 0,06	NO 1,13	NO 0,31
		Scenario 3. Ambitious refurbishment	O.K - 0,04	NO 0,52	NO 1,13	NO 0,74
	MFH	Scenario 1. Original building	O.K - 0,68	NO 1,43	NO 0,97	NO 1,43
		Scenario 2. Normal refurbishment	O.K - 0,01	NO 0,53	NO 1,26	NO 0,71
		Scenario 3. Ambitious refurbishment	O.K - 0,01	NO 0,94	NO 1,26	NO 1,09
	SFH PHS	Scenario 1. Original building	O.K - 0,42	NO 0,73	NO 0,23	NO 0,15
		Scenario 2. Normal refurbishment	O.K - 0,03	NO 0,25	O.K - 0,09	O.K - 0,16
		Scenario 3. Ambitious refurbishment	O.K - 0,06	NO 0,25	O.K - 0,04	O.K - 0,34
UK	SFH	Scenario 1. Original building	O.K - 0,09	NO 0,76	O.K - 0,36	NO 0,10
		Scenario 2. Normal refurbishment	O.K - 0,51	NO 0,15	O.K - 0,38	O.K - 0,32
		Scenario 3. Ambitious refurbishment	O.K - 0,45	O.K - 0,003	O.K - 0,38	O.K - 0,38
	MFH	Scenario 1. Original building	O.K - 0,28	NO 0,54	O.K - 0,43	O.K - 0,09
		Scenario 2. Normal refurbishment	O.K - 0,51	NO 0,10	O.K - 0,24	O.K - 0,35
		Scenario 3. Ambitious refurbishment	O.K - 0,48	O.K - 0,11	O.K - 0,24	O.K - 0,44
	MFH PHS	Scenario 1. Original building	O.K - 0,30	NO 0,16	NO 1,78	O.K - 0,28
		Scenario 2. Normal refurbishment	O.K - 0,43	O.K - 0,13	NO 2,24	O.K - 0,39
		Scenario 3. Ambitious refurbishment	O.K - 0,43	O.K - 0,15	NO 2,36	O.K - 0,38

Some relevant results are worth to be highlighted:

- Austrian Apartment block **AT_N_AB_08_GEN_1** and Spanish passive house **ES_ME_PHS4764_GEN_2** and **ES_ME_PHS_4764_GEN_3** comply with the quantitative energy requirements according to the Spanish nZEB definition presented in Table 24. However, they do not comply with the maximal U-Values requirement from the Spanish building code DB-HE 2013 for renovations involving less than 25% of the building envelope. Since the assessment takes into account only quantitative requirements and only major renovations are assumed (>25% of the building envelope) they are marked as nZEB compliant under the Spanish scope.

- Spanish Passive house **ES_ME_PHS_4764_GEN_3** does comply with the German primary energy requirement, however it does not comply with the HT’ value. In this case, considering that the specific heat transmission losses HT’ play the role of the maximum value for the energy need for heating/cooling requirement; the building is marked as non-compliant under the German scope.

- From the three considered Spanish buildings, only some scenarios from the passive house **ES_ME_PHS_4764** comply with the nZEB definition stated by Spain and England. Moreover, none scenario from each of the three considered spansh buildings complies with the German nZEB definition. This mainly because of the high energy need for cooling due to the climate zone of the buildings location (Valencia). U-values play as well an important role on the results; the higher the U-Value (maximum U-Values are considerably higher in Spain than in the rest of the assessed countries) more heat losses through the building envelope and therefore more energy need for heating. Finally the lack of high efficiency technical installations (especially meaning the higher distribution losses) summed up to the fact that the considered primary energy and CO_2 factors for gas in Spain are relative high account for the non-compliance of the nZEB definition in these cases.

- 5 scenarios do not comply with the Austrian nZEB definition. 9 scenarios do not comply with the English nZEB definition. 17 scenarios do not comply with the Spanish nZEB definition and 24 scenarios do not comply with the German nZEB definition.

5. Conclusions

From the results and the results comparison it is possible to point out the following conclusions:

- Only nine of the thirty six analyzed cases or scenarios have a consistent result of nZEB definition compliance under the scope of all countries. Different climate conditions, energy requirements, primary energy factors, ambition levels and calculation methodologies lead to the problem of an uneven cross-country comparison.
- There are three key aspects in the energy performance of a building; therefore building codes and nZEB plans of the four selected countries concur and tend to focus in these main aspects for the nZEB status achievement:
    - Reducing the energy demand by increasing the thermal efficiency through better insulation.
    - Adoption of efficient technical systems and low carbon alternatives.
    - Inclusion of renewable energies (cover of the rest energy demand of the building by renewable sources).

- Primary energy consumption might not be the most adequate indicator for a cross-country comparison. Since additional steps from the energy need going through the energy use and the delivered energy involve additional parameters that change from country to country, the comparison results less transparent and therefore less meaningful[14].

- As seen from the results for the Spanish buildings, the climate condition is an important parameter that strongly affects the energy performance of a building when assessed under the scope of another country´s building code. The definition of a single EU level absolute maximum value for the energy need for heating and cooling along with a corresponding correction factor depending on the climate zone at EU level might contribute, together with a second action, namely the use of relative target values in regard to a reference building instead of fixed maximum values for the primary energy consumption, to a most equitable cross-country building energy performance comparison since the impact of the local and boundary conditions and the impact of additional parameters introduced along the calculation from energy need over energy use and delivered energy up to primary energy are diminished. This last action could be seen as only a shift of the burden from the assessed building to the reference building, but it makes sense since this reference building provisions can be more easily compared at an EU level and the setting of a common ambition level is possible by means of what is stated on the regulation in force EU 2017/1369 setting a framework for energy labelling and repealing Directive 2010/30/EU, and the recommendations of the eco-design measures pursuing the Directive 2009/125/EC.

[14] ZEBRA 2020 - NEARLY ZERO-ENERGY BUILDING STRATEGY 2020 *Deliverable D2.1: Definition of nearly zeroenergy buildings as used for market tracking*. September 2014.

- The eco-design directive 2009/125/EC provides a framework for establishing requirements for “ energy-related” products placed on the EU market. Current requirements cover only “energy-using” products such as boilers, air conditioners and ventilation units. The future inclusion of products as windows and insulation materials might help to harmonize the EU Member states ambition levels by building renovations towards the 2020 energy goals.

- Summed up to the already collected experience through EU projects and initiatives, a combination of the two above mentioned approaches (absolute maximum value for energy need and percentage of consumption in regard to a reference building for primary energy) could contribute to specify the EPBD´s nZEB global definition.

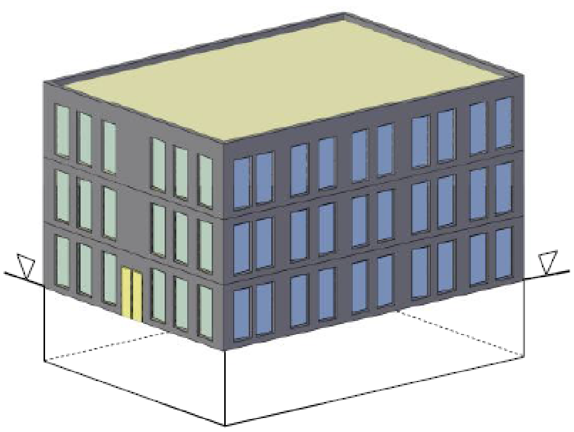
6. ANNEX A. Buildings for the model validation

Simple office building

The exemplary simple office building has been part of the material in the framework of the summer academy 2010 in Dresden carried out by the EnOB: Forschung für Energieoptimiertes Bauen and the Bergische Universität Wuppertal.

It is an office building with three levels above ground (clearance height of 2.75 m) with a reference conditioned volume of 2996 m^3 and an area of 821 m^2. It comprises 7 zones defined according to the standard use profiles of the norm DIN V 18599. An isometric drawing of the building and the building plan layout together with the most relevant zone information are given in the EnerCalC 2013 example 'Beispiel einfaches Bürogebaude' document from Markus Lichtmess:

EnOB — Sommerakademie 2010 – Beispiel: einfaches Bürogebäude — Bergische Universität Wuppertal



Isometrie

Gebäudedaten

Beheiztes Bruttovolumen, V_e	2.996 m^3	
Energiebezugsfläche, A_n	821 m^2	
Lichte Raumhöhe, h_R	2,75 m	

Zonendaten

Zone 1: Einzelbüro, gekühlt	333 m^2	
Zone 2: Einzelbüro, nicht gekühlt	129 m^2	
Zone 3: Seminarräume	66 m^2	
Zone 4: Verkehrsflächen	194 m^2	
Zone 5: WC-/Sanitärräume	66 m^2	
Zone 6: Archiv/Lager	33 m^2	
Zone 7: Parkhaus (Büronutzung)	258 m^2, therm. nicht konditioniert	

Gebäudehüllflächen

Süd Fassade	200 m^2	geg. ungeheizt 10,3 m^2
davon transparent	86,4 m^2	
Nord Fassade	200 m^2	geg. ungeheizt 10,3 m^2
davon transparent	60,5 m^2	
West Fassade	147 m^2	geg. ungeheizt 17 m^2
davon transparent	56,3 m^2	
Ost Fassade	147 m^2	geg. ungeheizt 17 m^2
davon transparent	47,7 m^2	
Dachfläche	294 m^2	
Bodenfläche (gegen Parkhaus)	294 m^2	

Sonstige Daten

Bodentiefe Fenster → Fenstersturz h_{st} 0,35 m (gemessen von UK Decke)

Figure 140. Isometric view and most relevant information regarding zone data and building envelope

Figure 141. Building plant layout

This building in matters of the MATLAB model validation has been simulated under the reference climatic data, boundary conditions of use and the standard use-profiles from the norm DIN V18599. This building is the pre-loaded example of the EnerCalC Excel-tool 2013 version 4.43.110 so the input data is already set. A merely accurate reproduction of the data input into the own MATLAB model has been done. Most relevant parameters have been:

- **Building envelope and building related parameters:**
  - Net area NGF: 821 m^2
  - Net conditioned volume: 2996 m^3
  - Level clearance height: 2.75 m
  - Construction 'Bauschwere': light 50 Wh/m^2K
  - Airtightness: 1 h^{-1}
  - Overall Thermal-bridge 0.05 W/m^2K
  - Heat transmission coefficient: U-Values:
    - Windows (Total): 1.3 W/m^2K
    - Walls: 0.28 W/m^2K
    - Roof 0.2 W/m^2K
    - Floor 0.35 W/m^2K

- Specific fan power SFP:
  - Inlet air (Zuluft) 1.60 $kW/(m^3/s)$
  - Outlet air (Abluft) 1.25 $kW/(m^3/s)$
- Heat recovery 60 %:

- **Zone related parameters:**

  - Use profiles:
    - Zone 1: Office (air conditioned) Standard profile # 1
    - Zone 2: Office (air conditioned) Standard profile # 1
    - Zone 3: Seminar room Standard profile # 4
    - Zone 4: Circulation area Standard profile # 19
    - Zone 5: WC Standard profile # 16
    - Zone 6: Storage room Standard profile # 20
    - Zone 7: Parking garage Standard profile # 32

- **Technical installations:**

  - Cooling system: Air-conditioned primary circuit. Piston-/Scroll compressor. Emission system: Cold water 14/18 °C, Fan convector. Distribution efficiency: Standard.
  - Heating system: Improved Gas condensing boiler. Emission system: exterior radiator 55/45 °C .Room temperature control: Proportional controller 'P-Regler'.
  - Solar thermal installation: Intended for space heating and/or domestic hot water. Flat plate collector. South-east oriented 30° Inclination.
  - Combined heat and power CHP: 30% of the total thermal heat output. Fossil fuel (Gas/ Oil)
  - Photovoltaics: Pre-selected 35 kW_{peak}. Crystaline-cell. South oriented 35° Inclination.

Passivhaus project: Kleehäuser im Freiburger Vauban- Viertel

The Kleehäuser project is located in Freiburg, Paul-Klee Strasse 6,8 in the Vauban quarter. It consists of two separate buildings as shown in Figure 143. They have in total 8 levels comprising normally 3 apartments by level.

Figure 142. The Kleehäuser project (South-east view)

Figure 143. General Layout Kleehäuser project

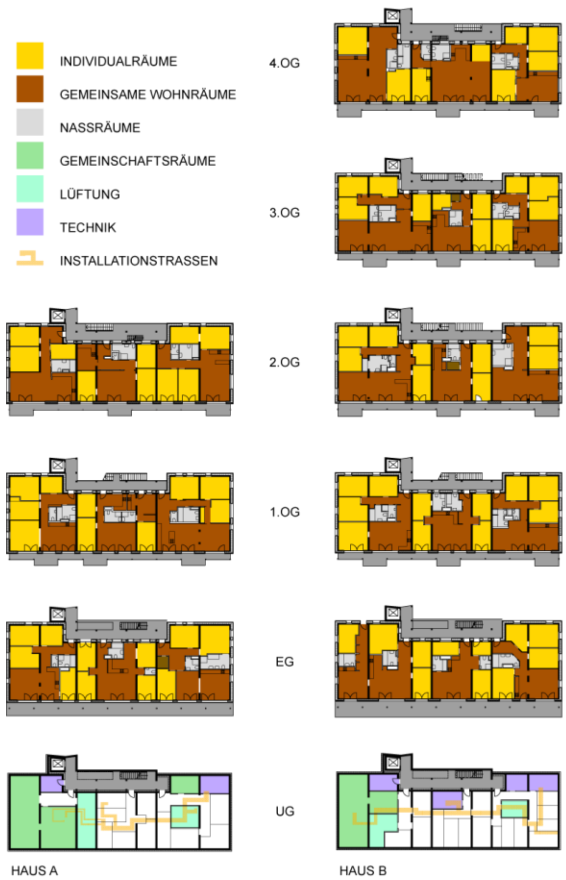


Figure 144. Buildings Plant layout

As it can be seen from Figure 144, one of the principal points behind the energy saving concept is the use of common living rooms. Besides, the south orientation of the buildings, the use of solar thermal technology for the domestic hot water, high efficient technical systems and the integration of a combined heat and power unit guarantee minimized energy consumption.

- **Building envelope and building related parameters:**
  - Net area NGF: 2540 m^2
  - Net conditioned volume: 10.909 m^3
  - Level clearance height: 2.75 m
  - Construction 'Bauschwere': medium 90 Wh/m^2K
  - Airtightness: 1 h^{-1}
  - Overall Thermal-bridge 0.05 W/m^2K
  - Heat transmission coefficient: U-Values:
    - Windows (Total): 1.17 W/m^2K
    - Walls: 0.17 W/m^2K
    - Roof 0.11 W/m^2K
    - Floor 0.18 W/m^2K

- Specific fan power SFP:
  - Inlet air (Zuluft) 1.60 $kW/(m^3/s)$
  - Outlet air (Abluft) 1.25 $kW/(m^3/s)$
- Heat recovery 75 %:

- **Zone related parameters:**

  - Use profiles:
    - Zone 1: Multi-family house Standard profile # 35

- **Technical installations:**

  - Cooling system: None
  - Heating system: Improved Gas condensing boiler. Emission system: exterior radiator 55/45 °C .Room temperature control: Proportional controller ‘P-Regler’.
  - Solar thermal installation: Intended for space heating and/or domestic hot water. Flat plate collector. South oriented 15° Inclination.
  - Combined heat and power CHP: 30% of the total thermal heat output. Fossil fuel (Gas/ Oil)
  - Photovoltaics: Pre-selected 23 kW_{peak}. Crystaline-cell. South oriented 35° Inclination.

Single-Family house Austria: AT_N_SFH_08_GEN_2

This house is part of the Tabula web-tool database. The scenario number 2: **AT_SFH_08_GEN_2** represent the building subjected to normal renovation. However, as already mentioned in the section '2.4 MATLAB model validation' there are some slight changes in the parameters used for the model validation respect to the information contained in Table 21**¡Error! No se encuentra el origen de la referencia.**, Table 22 and Table 23. The most important input parameters for the model validation are:

- **Building envelope and building related parameters:**
  - Net area NGF: 153.4 m^2
  - Net conditioned volume: 633 m^3
  - Level clearance height: 2.75 m
  - Construction 'Bauschwere': light 50 Wh/m^2K
  - Airtightness: 1 h^{-1}
  - Overall Thermal-bridge 0.05 W/m^2K
  - Heat transmission coefficient: U-Values:
    - Windows (Total): 0.7 W/m^2K
    - Walls: 0.08 W/m^2K
    - Roof 0.1 W/m^2K
    - Floor 0.1 W/m^2K
  - Window ventilation
- **Zone related parameters:**
  - Use profiles:
    - Zone 1: Single-family house Standard profile # 34
- **Technical installations:**
  - Cooling system: Air-conditioned primary circuit. Piston-/Scroll compressor. Emission system: Cold water 14/18 °C, Fan convector. Distribution efficiency: Standard.
  - Heating system: Improved Gas condensing boiler. Emission system: exterior radiator 55/45 °C .Room temperature control: Proportional controller 'P-Regler'.
  - Solar thermal installation: None.
  - Combined heat and power CHP: None.
  - Photovoltaics: None.

7. References

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