Ref. Ares(2016)3475302 - 15/07/2016

Initial performance criteria and requirements for innovative and multifunctional building envelope elements (D2.1)

Development and advanced prefabrication of innovative, multifunctional building envelope elements for **MO**dular **RE**trofitting and **CONNECT**ions (MORE-CONNECT)

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1 Introduction

This report is a first of a series of reports to be produced in the context of H2020 MoreConnect project. The primary objective of this report is to set initial performance criteria and requirements for assessments in all phases of development and advanced prefabrication of innovative, multifunctional building envelope elements for modular retrofitting and connections for deep renovation toward nearly Zero Energy Building (nZEB).

The European building sector has not been able yet to devise a structural, large-scale retrofitting process and systematic approach. The main reasons for this deadlock are:

- the European building sector is fragmented and seldom offer holistic, integral solutions for nZEB deep renovation toward nearly Zero Energy Building (nZEB) for reasonable costs and good quality;
- the European building process is typically based on a 'layered' structure, with many labour actions on the buildings site, with many sub disciplines involved, leading to extra costs and failure risks;
- the European building market is typically top down and supply driven, with a mismatch between the offered products and the end-users needs and the end-user's affordability;
- due to long-lasting renovation process and failures risks during that process, customers hesitate to renovate their property; sometimes high operating cost are more acceptable for owners-residences than deep renovation with low exploitation/ energy costs; a faster and quality guaranteed renovation solution is needed.

One purpose of MoreConnect is the selection and development of components that are necessary to achieve a certain base quality and, additionally, extra qualities. These components should be suitable to be combined in the multifunctional modular renovation elements and be suitable to be processed in an automated production process.

The selection and development started with an inventory of the initial performance criteria and requirements in five geo-clusters in Europe and in Switzerland:

- Geo-cluster 1: Northern. This cluster is focusing on solutions for the Scandinavian market (Denmark is represented in project),
- Geo-cluster 2: Continental Northern East. This cluster is focusing on a collaboration between Baltic States but also in other former East-European countries (Estonia and Latvia are represented in project);
- Geo-cluster 3: Continental Centre. This cluster focuses on solutions for continental climates (Czech Republic is represented in project);
- Geo-cluster 5: Mediterranean. This cluster is focusing on solutions for mild and warmer climates (Portugal is represented in project);
- Geo-cluster 6: Western Central. This cluster focuses on the Dutch/Belgium markets (Netherland is represented in project).

These criteria will be used during all the project phases to assess the performances of the solutions.

2 Terms and definitions

- **Zero Energy Building, ZEB.**
  On annual basis the primary energy use of 0 kWh/(m² a). A ZEB is typically a grid-connected building with very high energy performance. ZEB balances its primary energy use so that the primary energy feed-in to the grid or other energy network equals to the primary energy delivered to ZEB from energy networks. Annual balance of 0 kWh/(m² a) primary energy use typically leads to the situation where significant amount of the on-site energy generation will be exchanged with the grid. Therefore a ZEB produces energy when conditions are suitable, and uses delivered energy during rest of the time. The energy use is calculated based on annual net delivered primary energy without taking embodied energy for on-site generation units into account. In current project in ZEB includes energy use for space heating and cooling, ventilation, and domestic hot water;

- **Nearly Zero Energy Building, nZEB.**
  National definition of a building that has a very high-energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. The energy use is calculated based on annual net delivered primary energy without taking embodied energy for on-site generation units into account;

- **Major renovation, MR**
  The renovation of a building where the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25 % of the value of the building (excluding the value of the land upon which the building is situated) or more than 25 % of the surface of the building envelope undergoes renovation;

- **Energy performance of a building, EP**
  The calculated or measured amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and electricity (internal lighting and depending on national regulations also appliances);

- **Primary energy, PE**
  The energy used to produce the energy delivered to the building from renewable and non-renewable sources, which has not undergone any conversion or transformation process;

- **Delivered energy, DE**
  Energy (electricity, fuel, district heating/cooling, etc.) expressed per energy carrier, supplied to the technical building systems through the system boundary, to satisfy the uses taken into account (e.g. heating, cooling, ventilation, domestic hot water, internal lighting, appliances etc.) or to produce electricity;

- **Energy from renewable energy sources, RES**
  Energy from renewable non-fossil sources, namely wind, solar (thermal and electricity), aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases;

- **Cost-optimal level**
  The energy performance level which leads to the lowest cost during the estimated economic lifecycle, where the lowest cost is determined taking into account energy-

related investment costs, maintenance and operating costs (including energy costs and savings, the category of building concerned, earnings from energy produced) and disposal costs, where applicable. The estimated economic lifecycle is determined by each Member State. It refers to the remaining estimated economic lifecycle of a building where energy performance requirements are set for the building as a whole, or to the estimated economic lifecycle of a building element where energy performance requirements are set for building elements;

- **Cost effective range**
  Energy performance level which can be achieved by energy related renovation measures which are still cost effective, i.e. with life-cycle costs incurring being lower than the life–cycle costs of an anyway renovation of the building. Anyway renovation: Renovation which restores the full functionality of the building but does not aim at improving energy performance of the building such that the building elements which are retrofitted have the same life-expectancy as the corresponding building elements of the energy related renovation (the anyway renovation acts as reference for determining the additional costs and savings of the energy related renovation option);

- **Airborne sound insulation of facades**
  This characterises the facade's ability to insulate against airborne sound transmission into a building. The measurement result is given as a single-number quantity expressed in decibels (dB). The specified limits are related to measurements in situ in frequency bands according to EN ISO 140-5, and evaluation according to EN ISO 717-1, and expressed in the descriptor: $D_{2m,nT,50} = D_{2m,nT} + C_{tr,50\text{-}3150}$ or + $C_{50\text{-}3150}$, depending on type of outdoor noise and as defined in EN ISO 717-1. As an alternative to $D_{2m,nT,50}$, the performance can be estimated for all types of construction by the currently more common descriptor $D_{2m,T,100} = D_{2m,nT,w} + C_{tr}$ or C as also determined according to EN ISO 717-1. However, in case of light-weight building constructions and composed elements with low frequency resonances, the evaluation will most likely not be safe. If $D_{2m,nT,100}$ is applied, the class denotation is X_{100} , eg. B_{100};

- **Service equipment sound pressure level**
  This characterises the received sound pressure level in rooms due to the operation of a specific piece of service equipment or plant in a building. The measurement result is given as a single-number quantity expressed in decibels (dB). The specified limits are related to measurements in situ, either in frequency bands in accordance with EN ISO 16032 or directly in A-weighted levels in accordance with EN ISO 10052. The measurements concern either the A-weighted equivalent sound level or the A-weighted maximum F sound level during a specified working cycle of considered equipment. These working conditions are specified for various types of equipment in the mentioned standards. The descriptors are L_{eq} and L_{maxF} , resp. $L_{eq,nT,A}$ and $L_{maxF,nT,A}$ as defined in EN ISO 16032 and EN ISO 10052;

- **Critical moisture level**
  The moisture level when a material's intended properties and function are no longer met. For microbial impact, the level of moisture is critical when growth occurs;

- **Moisture safety design**
  Systematic measures at the design stage aimed at ensuring that a building is not damaged directly or indirectly by moisture. In addition to hygrothermal design also conditions, which apply to the construction and management phase to ensure moisture safety in buildings are also specified at this stage;

- **Energy efficiency measure**
  Energy efficiency measure means a change to a building resulting in a reduction of the building's primary energy need;

- **Energy efficiency package**
  Package means a set of energy efficiency measures and/or measures based on renewable energy sources applied to a reference building;

- **"Anyway" renovation measures**
  Renovation measure that are needed to do to fulfil mandatory requirements set in Construction Products Regulation (305/2011, 2011), national legislation or has scientifically evidenced. These renovation measures are needed to do independently energy saving;

3 Indoor climate

Energy consumption of buildings depends significantly on the criteria used for the indoor environment (temperature, ventilation and lighting) and building design (including systems), and operation (EN-15251, 2007). Indoor environment also affects health, productivity and comfort of the occupants.

In calculations of energy performance of buildings outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness, should be taken into account (EPBD recast, 2010). The requirements of general indoor climate conditions should avoid possible negative effects such as thermal uncomfortable, inadequate ventilation, moisture damages, overheating, loud noise from traffic and building service systems, inadequate natural light etc.

In following is given general and country specific basic criteria for thermal comfort, indoor air quality, moisture safety and acoustics that can be used to assess performances of the solutions, modular elements, integrated systems etc. for all phases in the project and for further market application and an overall life cycle approach of the developed modular renovation concepts.

Indoor environmental parameters for design and assessment of energy performance of buildings are given in EN 15251 standard. The standard also specifies the indoor environmental parameters which have an impact on the energy performance of buildings, how to establish indoor environmental input parameters for building system design and energy performance calculations, methods for long term evaluation of the indoor environment obtained as a result of calculations or measurements, criteria for measurements which can be used if required to measure compliance by inspection, identifies parameters to be used by monitoring and displaying the indoor environment in existing buildings, and criteria for indoor environment are set by human occupancy and where the production or process does not have a major impact on indoor environment. EN 15251 standard divides indoor climate for different categories (ICC). Based on Table 3.1 ICC II should be used for renovations.

Table 3.1 Description of the applicability of indoor climate categories (ICC), (EN-15251, 2007)

ICC	Explanation
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons
II	**Normal level of expectation and should be used for new buildings and renovations**
III	An acceptable, moderate level of expectation and may be used for existing buildings
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year

3.1 Thermal comfort

There exist national and international standards, and technical reports, which specify criteria for thermal comfort and indoor air quality (CR 1752, 1998; EN ISO 7730, 2005), where the thermal comfort criteria for the heating season (cold/winter) and cooling season (warm/summer) are listed.

Usually design values for the indoor temperature for heating and cooling seasons are usually well specified at national level. For residential buildings without mechanical cooling system EN 15251 standard allows to use adaptation related to outdoor climatic conditions.

Table 3.2 shows national design values for the indoor temperature for residential buildings in MoreConnect countries.

Table 3.2 National design values for the indoor temperature for residential buildings in MoreConnect Geo-clusters and countries.

Thermal comfort criteria	Geo-cluster and country						
	GC 1	GC 2		GC 3	GC 5	GC 6	Switzer-land
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land	
Heating season (cold/winter)							
Minimum temperature for heating (winter season) , °C, ~ 1,0 clo, ~ 1,2 met	20	21	18	20	18	20	20[1)]
Target temperature range during heating period, °C	20-23	20-24	20-24	20-24		20…23	20-23
Summer season (cooling/warm)							
Maximum for cooling (summer season), ~ 0,5 clo, ~ 1,2 met		27	28	27	25	25	26.5
Target temperature range for summer period, °C	25	23-26	25-27	≤27		20…25	22-26.5
Criteria for overheating during summer	t_i >25	t_i>27 °C <150°Ch	Not defined	t_i>27[2)]	t_i >25	>25	t_i >26.5

1) Requirements of the Swiss standard for the calculation of heating energy needs SIA 380/1;

2) Two hours per day can rise up to 29, approval by investor needed.

Criteria for local thermal discomfort such as draught, radiant temperature asymmetry, vertical air temperature differences and floor surface temperatures shall also be taken into account for the design of building and criteria can be found in EN ISO 7730.

Humidity has only a small effect on thermal sensation and perceived air quality in the rooms of sedentary occupancy, however, long term high humidity indoors will cause microbial growth, and very low humidity, (<15-20%) causes dryness and irritation of eyes and air ways.

For extra levels of comfort, see (EN-15251, 2007).

3.2 Indoor air quality

Indoor air quality in residential buildings depends of many parameters and sources like number of persons (time of occupation), emissions from activities (smoking, humidity, intensive cooking), emissions from furnishing, flooring materials and cleaning products, hobbies etc. Humidity is of particular concern in residential ventilation as most of adverse health effects and building disorder (condensation, moulds,) is related to humidity. The ventilation rates for air quality are independent of season. Ventilation should not rely on opening of windows in the areas with high outdoor noise. Residential buildings should be ventilated during unoccupied periods with a lower ventilation rate than during the occupied period (EN-15251, 2007).

Table 3.3 shows the national design values for the indoor air quality for residential buildings in MoreConnect countries. For extra levels, see (EN-15251, 2007).

Table 3.3 National design values for the indoor air quality for residential buildings in MoreConnect Geo-clusters and countries.

Indoor air quality criteria	Geo-cluster and country						
	GC 1	GC 2		GC 3	GC 5	GC 6	Switzer-land
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land	
Heating season (cold/winter)							
General air change rate h^{-1} $l/(s \cdot m^2)$ $m^3/(h \cdot pers)$	0.5 0.3	0.6 0.5, 0.42 detached house)	0.6	0.5 25	Winter: 0.40 h^{-1} Summer: 0.60 h^{-1}	0.7	0.19
Supply air to living room and bedrooms l/s, pers	7.0	6.0	4.2	6.9	7[2]	7	
$l/(s \cdot m^2)$	1	1.0	3	-	1[2]	0.7	
Exhaust air flow, l/s a) Kitchen b) Bathrooms c) Toilets	 20 15 10	 20 15 10	 17-25 14 7	[1] 27.8/41.7 13.9/25 6.9/13.9	 20[2] 15[2] 10[2]	 21 14 7	 11-167 <8-11
Corresponding CO_2 above outdoors (400ppm), ppm	N/A	800	Not defined directly	1100	Maximum concentration [3] 984ppm	800	600-1000
Recommended ventilation during un-occupied hours, $l/(s \cdot m^2)$	N/A	0.05-0.1	N/A	0.1 h^{-1}	N/A	0.1 h^{-1}	0.14

1) Minimum / recommended values. Long time: 0.5h^{-1} should bee guaranteed.

In Portuguese regulations, there are no mandatory values for:

- Supply air to living room and bedrooms
- Exhaust air flow
- Corresponding CO_2 above outdoors (400ppm)
- Recommended ventilation during un-occupied hours

[2] The values presented are recommended values, not mandatory values.

[3] Maximum concentration of CO_2. The values are mandatory for office buildings and reference values for residential buildings.

3.3 Moisture safety

A large number of moisture-related building problems, such as mould growth and chemical emissions from decomposed material subjected to high moisture levels. These problems could have been avoided if moisture safety issues, such as design of structures and choice of material with respect to moisture exposure, weather protection at the building site, drying out of concrete structures, moisture measurements, etc. had been included in the building process (Mjornell et al., 2011). Prefabricated multifunctional modular renovation elements are here in preponderant position, because construction period on building site is short.

Buildings shall be designed to ensure moisture does not cause damage, foul odours or hygienic nuisance and microbial growth, which could affect human health. In hygrothermal design of prefabricated multifunctional modular renovation elements two methods are in common use:

- EN 15026. Hygrothermal performance of building components and building elements – assessment of moisture transfer by numerical simulation.
- EN ISO 13788. Hygrothermal performance of building components and building elements – internal surface temperature to avoid critical surface humidity and interstitial condensation – calculation methods.

Critical moisture levels shall be used to determine the maximum permitted moisture level, taking into account unreliability in the calculation model, input parameters (e.g. material characteristics) or measuring methods. Absolute humidity and RH are important parameters for hygrothermal design and indoor climate, respectively. Rowan et al (1999) recommend maintaining RH below 75% to limit fungal growth in buildings. On the basis of a literature review and their experience gained from damage studies and materials testing, Johansson et al. (2005) described the critical moisture level. Critical moisture conditions for microbiological growth of materials that are clean are between *RH* 75 % and 90 %. Contaminated or soiled materials will lower the critical moisture level to 75-80% RH.

Well-researched and documented critical moisture levels shall be used for materials and material surfaces where mould and bacteria can grow. Factors of importance for biological growth, such as temperature and duration and their interaction can be included in the determination of the critical moisture level. A material's critical moisture level shall be determined taking account of possible contamination of the material. For example Swedish building regulation (BBR 19, 2011) suggest that if the critical moisture level for a material is not well-researched and documented, a relative humidity (RH) of 75 % shall be used as the critical moisture level.

To design building envelopes for the humidity load during the service period, it is necessary to know the critical values of the difference between indoor and outdoor humidity by volume: indoor moisture excess $\Delta\nu=\nu_i-\nu_e$, g/m^3.

Almost all building envelopes have thermal bridges - locations where the thermal resistance of the assembly is locally lower. Thermal bridges are caused mainly by geometrical or structural reasons. In cold climates, the assessment of thermal bridges is important for many reasons. Thermal bridges may lead to surface condensation, mould growth, and staining of surfaces. Due to lower temperatures on the thermal bridge, higher RH occurs. While surface condensation starts at the *RH* 100%, the limit value for RH in respect of mould growth is above *RH* 75% to 90% depending on the groups of materials. To accomplish the building design process and the inspection of the thermal bridges with infrared thermography in real buildings, knowledge of the critical level of the thermal conductance of the thermal bridge is required. The principle of the temperature factor is attached also to the EN ISO 13788 standard. The temperature factor at the internal surface ($f_{R.si}$, -) shows the relation of the total thermal resistance of the building envelope (R_T, (m^2·K)/W) to the thermal resistance of the building envelope without the internal surface resistance (R_{si}, (m^2·K)/W) and it depends on the internal (t_i, °C) and the external (t_e, °C) air temperature and on the temperature on the internal surface of the building envelope (t_{si}, °C):

$$\frac{R_T - R_{si}}{R_T} = f_{\mathrm{Rsi}} = \frac{t_{si} - t_e}{t_i - t_e}$$

Outdoor climate conditions are important parts of hygrothermal modelling. The main difference between energy reference years and moisture reference years (MRY) is that the energy reference year is composed of the mean values of climate parameters for the locations under consideration. The moisture reference year should take into account the critical moisture load on the building envelope components to provide the required level of safety as regards moisture damage. Building envelope should ideally endure the maximum hygrothermal loads that the building will experience during its service life. The IEA project Annex 24, Task 2 Environmental Conditions (Sanders 1996), has recommended that MRY for hygrothermal calculations is 1 in 10 years. A 10 % level criterion means that the defined hygrothermal conditions should not be exceeded more than 10 % of the time. In other words, these should not occur more frequently than once every ten years. In terms of moisture load, nine years in ten are less severe and may be considered in-service or typical years which building envelopes should be expected to cope with without difficulty.

Table 3.4 shows the national values for hygrothermal design of building envelope in MoreConnect countries.

Table 3.4 National values for hygrothermal design of building envelope in MoreConnect Geo-clusters and countries.

Moisture safety design criteria	Geo-cluster and country						
	GC 1	GC 2		GC 3	GC 5	GC 6	Switzer-land
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land	
Indoor moisture excess $\Delta\nu=\nu_i-\nu_e$, g/m^3 during cold period (t_e<+5°C) low occupancy (>30 m^2/person) high occupancy (≤30 m^2/person) during warm period (t_e>+20°C) low occupancy (>30 m^2/person) high occupancy (≤30 m^2/person)	N/A	6 4 2 1	EN ISO 13788	4 2	RH between 30% and 70%	7 6 2 1	
Minimum acceptable temperature factor f_{Rsi}, - building envelope in general windows glass and frame		≥0.8 ≥0.7	EN ISO 13788	≥0.75 ≥0.65	-	≥0.65	≥0.75
Maximum moisture level of materials	Depend if organic or not: ~ RH75%-95%	RH75%[1]	EN ISO 13788	RH80%	RH > 75%	80%[6]	80%[2]
Outdoor climate for hygrothermal calculations	Danish Reference Year (DRY)	MRY_{cond}[1] MRY_{mould}	Standard monthly temperatures	[4] 2-step assess-ment	[5]	Standard Database Dutch National Average Climate	

1) (Kalamees and Vinha, 2004);
2) During maximal 2 weeks at a time per year;
3) Well-researched and documented critical moisture levels shall be used for materials and material surfaces where mould and bacteria can grow. If the critical moisture level for a material is not well-researched and documented, a relative humidity (RH) of 75 % shall be used as the critical moisture level.
4) 2-step assessment: 1) Winter design temperature -13..-21°C depending on location for check of condensation risk; 2) Condensation/evaporation annual balance assessment (based on monthly mean values);
5) Condensation risk is controlled fixing a maximum U-value for the opaque envelope. The Maximum U-value is dependent on the outdoor climate and $U\text{-value}_{thermal\ bridge} < 2U\text{-value}_{adjacent\ opaque\ element}$;
6) Maximal 3 days in a row;

3.4 Acoustics

For design modular retrofitting elements acoustic requirements against traffic noise and service systems are important. In most countries in Europe, building regulations specify minimum requirements about acoustical conditions for new dwellings. Table 3.5 shows National design values for building acoustics in MoreConnect Geo-clusters and countries.

Table 3.5 National design values for building acoustics in MoreConnect Geo-clusters and countries.

Acoustic criteria	Geo-cluster and country						
	GC 1	GC 2		GC 3	GC 5	GC 6	Switzer-land
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land	
Noise from service systems				[2]	$L_{Ar,nT}$ [3]		
$L_{pA,eq,T}$,dB(A)					≤ 27	30	
bedrooms	30	28	35	6:00-22:00		30	28/25[1]
living rooms	30	25	35	40dB	Continuous work		28/25[1]
$L_{pA,max}$,dB(A)				22:00-6:00		30	
bedrooms	30	32	35	30dB	≤ 32	30	33/30[1]
living rooms	30	30	35	(25dB)	Intermittent		33/30[1]

[1] More ambitious requirements for 2-family-houses, row houses and newly constructed condominium ownership;

[2] (272/2011, 2011)

[3] The maximum noise in bedrooms and living rooms due to the functioning of the building service system is considered on Portuguese acoustic regulation base on the maximum acceptable noise from service systems, $L_{Ar,nT}$. $L_{Ar,nT} = L_{A,eq} + K_1 + K_2$ (K_1 = 3 if the noise has tonal characteristics and ; K_2 = 3 dB if the noise has impulsive characteristics).

However, complying with regulatory requirements does not guarantee satisfactory conditions for the occupants, and thus there is a need for a classification scheme with classes reflecting different levels of acoustical comfort. The TU0901 acoustic classification scheme for dwellings has been developed by COST Action TU0901 “Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions” www.costtu0901.eu (COST Action TU0901, 2014). The TU0901 proposal for a classification scheme will be presented to standardization groups in CEN and ISO aiming at further development of the proposal to become a European or even world-wide scheme, thus also reminding people and the building industry about the possibility of integrating the specification of acoustic conditions on equal terms with other qualities for new and renovated housing. Six classes A-F specifying different levels of acoustic conditions in dwellings. Class A is the highest class, class F the lowest class, see Table 3.6.

Table 3.6 Description of the applicability of indoor climate ategories (ICC)

Class	General Description
A	A quiet atmosphere with a high level of protection against sound
B	Under normal circumstances a good protection without too much restriction to the behaviour of the occupants
C	Protection against unbearable disturbance under normal behaviour of the occupants, bearing in mind their neighbours
D	Regularly disturbance by noise, even in case of comparable behaviour of occupants, adjusted to neighbours
E	Hardly any protection is offered against intruding sounds
F	No protection is offered against intruding sounds

The façade sound insulation shall assure an indoor sound level that can be achieved in two ways:

- by specifying maximum indoor levels or
- by specifying a minimum façade sound insulation on the bases of the outdoor sound impact ($D_{2m,nT,50} = L_{den} + 3 - L_{den,indoor}$).

In the latter case the minimum values for the classes of the façade sound insulation can be used, either for a general suburban environment or for a specific environment as characterised by L_{den} for the relevant outdoor sound sources. If fulfilling these limits requires a very high façade sound insulation, say more than $D_{2m,nT,50}$ ≥ 35 dB, it is questionable whether the overall quality is really increased (less contact with living environment, sounds from the neighbour probably more audible, opening windows or using outdoor areas less) and therefore assigning a high class could be restricted.

Table 3.7 shows sound levels in dwellings due to outdoor sounds based on COST TU0901 proposal.

Table 3.7 Sound levels in dwellings due to outdoor sounds based on COST TU0901 proposal.

Type of space	Acoustic conditions in dwellings					
	Class A	Class B	Class C	Class D	Class E	Class F
	The normalized A-weighted indoor sound level $L_{den, indoor}$ with appropriate weighting of the day, evening, night period over the frequency range from 50 Hz to 5000 Hz as defined in the END for outdoor sound.					
In dwellings from outdoor sound sources; for each type of source	≤ 22	≤ 26	≤ 30	≤ 34	≤ 38	≤ 42
	The minimum façade sound insulation $D_{2m,nT,50} = D_{2m,nT,w} + C_{tr,50-3150}$ in general. However, if the type of outdoor source is better characterised by the C spectrum, for instance for some types of railway traffic, $D_{2m,nT,50} = D_{2m,nT,w} + C_{50-3150}$ can be used. In some countries this performance applies to a ventilated façade according to ventilation requirements					
In dwellings from outdoors; general suburban environment L_{den} = 55 dB.(3)	≥ 35	≥ 31	≥ 27	≥ 23	≥ 19	≥ 15
In dwellings from outdoors; specific environment with sound sources characterised by L_{den} (typical background sound levels in this environment will be 45-50 dB in daytime.)	≥ L_{den} - 20	≥ L_{den} -24	≥ L_{den} -28	≥ L_{den} -32	≥ L_{den} -36	≥ L_{den} -40

The noise from the HVAC systems of the building may disturb the occupants and prevent the intended use of the space or building, Table 3.8. The noise in a space can be evaluated using A-weighted equivalent sound pressure level.

Table 3.8 Sound levels in dwellings due to building service systems based on COST TU0901 proposal.

Type of space and sources	L_{eq} or L_{maxF}, in dwellings					
	Class A	Class B	Class C	Class D	Class E	Class F
In dwellings due to ventilation / heating / cooling installations L_{eq}.	≤ 20	≤ 24	≤ 28	≤ 32	≤ 36	≤ 40
In dwellings due to use of toilet, bath, shower in neighbour dwellings L_{maxF}.	≤ 20	≤ 24	≤ 28	≤ 32	≤ 36	≤ 40
In dwellings due to other sources (lift, water supply, pumps, garage doors, etc.) L_{maxF}.	≤ 25	≤ 29	≤ 33	≤ 37	≤ 41	≤ 45

4 Energy performance of buildings

4.1 Introduction

The Energy Performance of Buildings Directive recast (EPBD recast, 2010) gives ambitious goals for the building sector to reduce energy use as well as greenhouse gas emissions. According to the Directive the Member States shall ensure that by 31 December 2020, all new buildings are nearly Zero-Energy Buildings (nZEB); and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.

The directive defines nearly zero energy building as a building that has a very high energy performance and requires the calculation of primary energy indicator. 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.

Although experience has shown that such buildings can be realized in practice, there exist many challenges to drive the whole market in this direction. One specific challenge concerns the compliance of buildings to nZEB requirements, in particular how to ensure they actually comply with applicable regulations or programme specifications. The directive requires nZEB, but since it does not give minimum or maximum harmonized requirements as well as details of energy performance calculation framework, it will be up to the Member States to define what these for them exactly constitute.

For any low energy or zero energy building definition or indicator, it would be necessary to specify which energy flows are included in the definition and which ones not. Either all energy used in the buildings may be taken into account, or some energy flows, such as electrical energy use of occupant appliances may be excluded. Such energy flow specification is called as system boundary and it provides a general framework for energy indicators. Inside the boundary the system losses are to be taken into account explicitly, outside they are taken into account in the conversion factor (=primary energy factor). Technical building systems located partly outside of the building envelope are considered to be inside the system boundary.

Kurnitski et al., 2011 proposed energy boundary is modified from EN 15603 and as stated in EPBD recast, renewable energy produced on site is not considered as part of delivered energy, i.e. the positive influence of it is taken into account, Figure 4.1. Energy need represents energy need in a building for heating, cooling, ventilation, domestic hot water, lighting and appliances (if appliances are included in the system boundary). Energy need for heating is caused by heat losses and is reduced by solar and internal heat gains. Net energy need is the energy need minus heat gains, i.e. thermal energy without any system losses needed to maintain indoor climate conditions. For the lighting and appliances electrical energy is needed.

Delivered energy to the building is grid electricity, district heat and cooling, renewable and non-renewable fuels. On site renewable energy without fuels is energy produced from active solar, wind or heat pumps (and from hydro if available). Primary energy use is calculated from net delivered energy, per energy carrier, as product of primary energy factor and net delivered energy of that energy carrier.

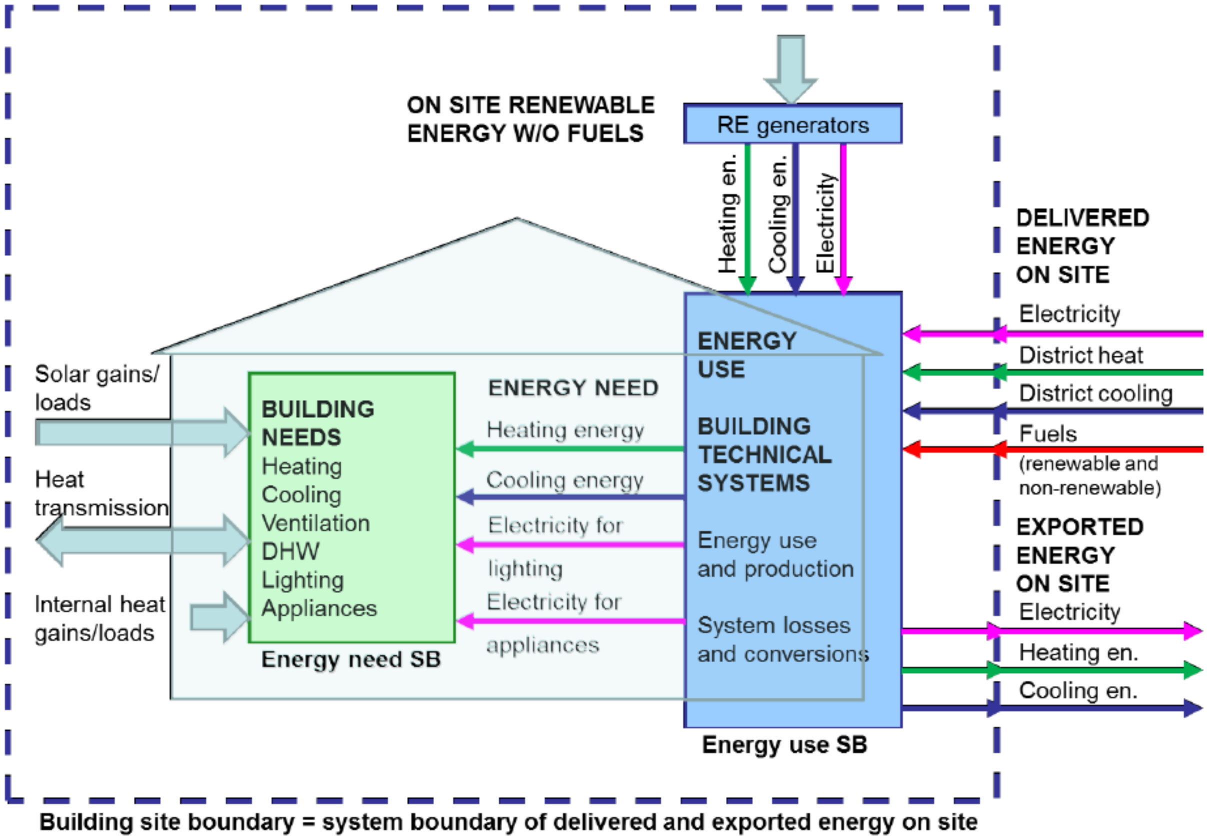

Figure 4.1 Energy boundary of net delivered energy and how it forms from energy need, energy use of technical building systems, on site renewable energy production, delivered energy and exported energy. The box of "Energy need" refers to rooms in a building and both system boundary lines may be interpreted as the building site boundary (Kurnitski et al., 2011).

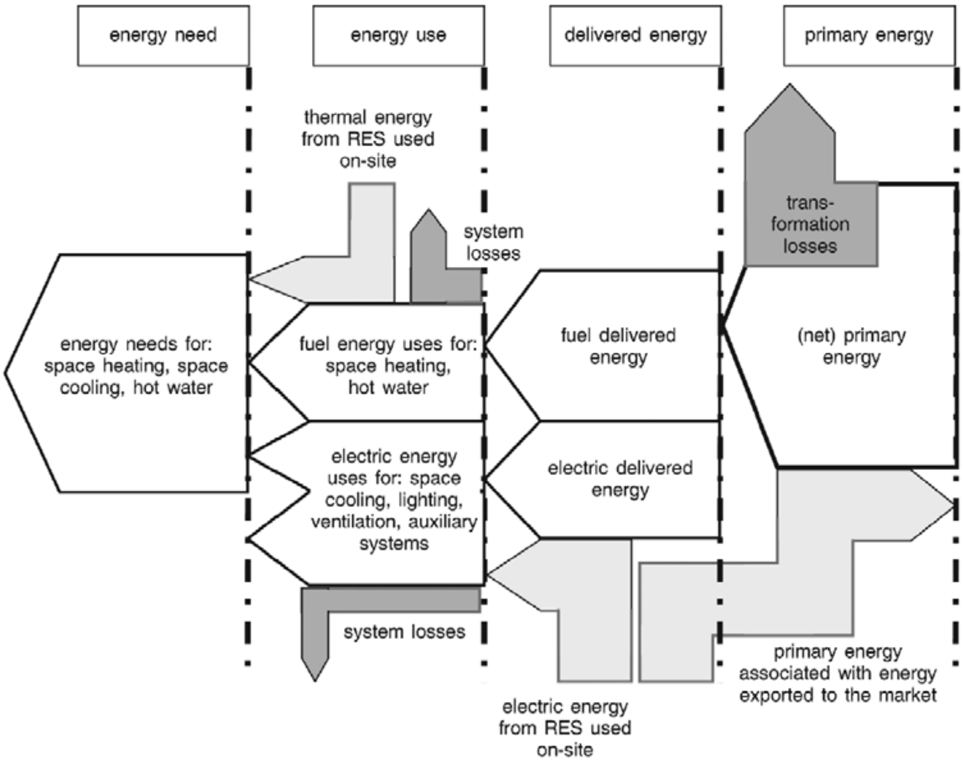

Figure 4.2 Schematic illustration of the calculation scheme (EC 2012/C 115/01, 2012).

4.2 National examples of nZEB definitions in Europe

Due to the diversity of the European buildings sector and climate, each state have to define national nZEB approaches reflecting national, regional or local conditions.

In "Nearly Zero Energy Hotels" (neZEH, http://www.nezeh.eu/), "Collaboration for housing nearly zero energy renovation" (COHERENO, http://www.cohereno.eu), projects have collected national nZEB definitions. Also European Commission has made the report to the European Parliament and the Council about the progress by Member States towards Nearly Zero-Energy Buildings (COM(2013) 483 final/2, 2013). Buso et al., 2014 have grouped nZEB definitions according to ECOFYS classification (ECOFYS, 2013) into five European climate zones as shown in Figure 4.3.

The data in Table 4.1 covers primary energy (PE) and renewable energy share (RES) indicators. Available definitions revealed to be remarkably different by content and ambition level. Not all of them were based on primary energy, and values between 20 and 200 do not allow meaningful comparison (Kurnitski et al., 2014).

Figure 4.3 ECOFYS climate zones suitable for ranking of technology options and comparison of building performance.

Table 4.1 Overview of the nZEB numerical definition for residential buildings (Kurnitski et al., 2014 + MoreConnect data).

Zone, Figure 4.3	Country	Energy Performance					RES
		Building type	EP-value	Metric	RES in the EP	Energy uses included	
1-2	Cyprus	Residential buildings	180 kWh/(m^2·a)	PE	No	Heating, cooling, DHW, lighting	25%
	Portugal[1)]	Residential buildings	178 kWh/(m^2·a)	PE	No	Heating, cooling, DHW,	STC necessary after 2006
3	Slovakia	Apartment building	32 kWh/(m^2·a)	PE	N.D.	Heating, DHW	50%
		Houses	54 kWh/(m^2·a)	PE	N.D.		50%
	Czech Republic	Residential building	Definition of nZEB is based on a reference building. Reference building has required design thermal transmittance of building envelope structures $U_{em,R}$. nZEB building is a building with mean thermal transmittance $U_{em,nZEB} < 0,7 * U_{em,R}$				
4	Belgium BXL	Individual dwellings	45 kWh/(m^2·a)	PE	Yes	Heating, DHW, appliances	-
	Belgium Walloon	Residential buildings	60 kWh/(m^2·a)	PE	N.D.	Heating, DHW, appliances	50%
	Belgium Flemish	Residential buildings	30 kWh/(m^2·a)	PE	Yes	Heating, cooling, ventilation, DHW, auxiliary systems	>10 kWh/(m^2·a)
	France	Residential buildings	50 kWh/(m^2·a)	PE	No		-
	Ireland	Residential buildings	45 kWh/(m^2·a)	Energy load	N.D.	Heating, ventilation, DHW, lighting	-
	Netherlands	Residential buildings	0	Energy performance coefficient	Yes	Heating, cooling, ventilation, DHW, lighting	Not quantified, but necessary
5	Denmark	Residential buildings	20 kWh/(m2·a)	PE	Yes	Heating, cooling, ventilation, DWH	51% - 56%
	Estonia	Detached houses	50 kWh/(m2·a)	PE	Yes	Heating, cooling, ventilation, DHW, lighting, HVAC auxiliary, appliances	-
		Apartment buildings	100 kWh/(m^2·a)	PE	Yes		
	Latvia	Residential buildings	95 kWh/(m^2·a)	PE	Yes	Heating, cooling, ventilation, DHW, lighting	-
	Lithuania	Residential buildings	<0.25	Energy performance indicator		Heating	50%
	Sweden	Residential (non-electric heating)	Zone I (North): 75 kWh/(m^2·a) Zone II (Middle): 65 kWh/(m^2·a) Zone III (South): 55 kWh/(m^2·a)	DE		Heating, cooling, ventilation, DHW, lighting	
		Residential (electric heating)	Zone I (North): 50 kWh/(m^2·a) Zone II (Middle): 40 kWh/(m^2·a) Zone III (South): 30 kWh/(m^2·a)	DE			

Finland (estimated, not defined yet, will be defined during 2015)	Residential buildings	60 … 84 kWh/(m²·a)	PE		Heating, cooling, ventilation, DHW, lighting, HVAC auxiliary, appliances
Switzerland A_{th}: Thermic relevant building envelope area AE: Conditioned floor area	Residential buildings	New buildings: Energy need MFB: 14 kWh/m²a + (14 kWh/m²a × A_{th}/AE) SFB: 16 kWh/m²a + (14 kWh/m²a × A_{th}/AE Energy need renovated buildings: 1.5× (energy need new buildings)	Energy need (without on-site RES)	Yes (wood, waste)	Heating, cooling, ventilation, DHW, HVAC auxiliary,

1) The building does not have RES, as it was built in 1997, but buildings built after 2006 must have solar thermal collectors for DHW production.

4.3 The influence of energy performance of buildings to energy related requirements of modular building envelope retrofitting elements

In most of countries the energy performance of buildings is defined as (primary) energy use of whole building's (heating, cooling, ventilation, DHW, lighting, HVAC auxiliary, appliances), not as specific requirements for building envelope. For production of modular panels it in necessary to know specific properties of panels:

- thermal transmittance (U, W/(m^2·K)) of exterior wall, roof, floor, windows, doors, etc;
- linear thermal transmittance (Ψ, W/(m·K)) of connections, details and thermal bridges;
- airtightness (q_{50}, m^3(h·m^2)) of building envelope.

In following it is analysed what kind of requirements exists for modular elements to meet following targets:

- nZEB i.e. national nearly zero energy definition (if available in specific country);
- deep renovation with 80 % reduction of primary energy for:
  - space heating (+ pumps);
  - space cooling;
  - ventilation (heating, cooling, fans);
  - domestic hot water (DHW).
- ZEB i.e. Zero Energy Building = the primary energy use = 0 kWh/(m² a) (on annual basis) for:
  - space heating (+ pumps);
  - space cooling;
  - ventilation (heating, cooling, fans);
  - domestic hot water.

The modular building envelope's retrofitting elements decrease most of all heat loss through the building envelope that is usually the largest component in energy use of old residential buildings. Nevertheless required properties for the modular building envelope's retrofitting elements may depend on specific building and balance of measures for energy saving and energy production on site. Therefore current results should consider and use as the first step toward deep renovation for nZEB concept.

Reference buildings are shown in Figure 4.4 and the main data in Table 4.2.

Denmark

Estonia

Latvia

Czech Republic

Portugal

Netherland

Figure 4.4 Reference buildings used for indoor climate and energy calculations to see the influence of nZEB definitions to requirements of modular building envelope retrofitting elements.

Indoor climate and energy simulations were made based on national energy simulation methodologies in six countries for geo-cluster (GC):

- GC 1: Denmark (calculated by Cenergia with ASCOT/ Be10);
- GC 2: Estonia (calculated by TUT with IDA-ICE 4.6) and Latvia (calculated by RTU with RIUSKA);
- GC 3: Czech Republic (calculated by CVUT with simulation software Energie 2014);
- GC 5: Portugal (calculated by UMinho with REH - ITeCons);
- GC 6: Netherland (calculated by Zuyd).

Table 4.2 Information about studied buildings.

Properties of building	Geo-cluster and countries that national energy calculation methods were used					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land
Construction time	1967	1986		~1950	1997	1963
Number of floors	4	5		5	3	2
Net area, m^2	1836	3519		2760	1414	84
Heated area, m^2	1836	2968		3793	1279	84
Compactness, m^2 / m^3, m^{-1}	0,38	0.35		0.33	0.23	0.48
Number of apartments	24	80		18	18	1

4.3.1 Input data

The indoor climate and energy simulations were made to six reference buildings (Figure 4.4), correspondingly on national energy simulation methodologies and requirements. All input data used in energy calculations represent the typical case of that GC and specific country and is defined by partner:

- The heat source for room heating and DHW (from 5 °C to 55 °C) (Table 4.3);
- Information about outdoor climate (Table 4.3);
- Primary energy factors (Table 4.3);

Properties of building before renovation are shown in Table 4.4. The use of solar energy for room heating and DHW or for electricity is presented together with results.

Table 4.3 Information about boundary conditions of simulation.

Properties of building	Geo-cluster and countries that national energy calculation methods were used					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land
Reference to national energy calculation procedure / regulation	ISO13790	(RT I 05092012 4, 2010; RT I 18102012 1, 2012)	(No.39, 2009)	(78/2013, 3013)	(118/2013, 2013)	EPC
Reference for outdoor climate used in calculations	TRY1985	(Kalamees, 2006)	(LNB 003-01, n.d.) Building climatology	TNI 730331	Ord. n.º 15793-F/2013	Standard Database Dutch National Average Climate
Heating degree days @ +17°C (just for comparison of climates)	2908	4160	3451	4180 @ 20°C	1178	2800
Energy carrier used for heat						
Space heating and ventilation	District heating	District heating	District heating	Natural Gas	Electri-city	Electri-city
Space cooling					Electri-city	
Domestic hot water	District heating	District heating	District heating	Natural Gas	Natural Gas	Electri-city
Primary energy factors						
Renewable fuel (wood, pellets etc.)	That of the energy form that it substitute	0.75		1.1 Wood 1.2 Pellets	0	
District heating	0.6	0.9	0.7	0.1…1.0[1)]	-	0.75
Non-renewable fuel (oil, gas etc.	1	1.0	1.1	1.1…1.2[2)]	1	1
Electricity	1.8	2.0	1.5	3.0	2.5	1
Emission factors (if available)						
Renewable fuel (wood, pellets etc.)				-	0	0
District heating	118	278	264	-		
Non-renewable fuel (oil, gas etc.				-	0.267 $kgCO_2/kWh$	1.884 $kgCO_2/Nm^3$
Electricity	377	1118	109	-	0.144 $kgCO_2/kWh$	0.054 $kgCO_2/kWh$

1) 0.1 for system with RES over 80%; 0.3 for systems with RES 50-80%; 1,0 for systems with RES share < 50%

2) 1.1 (natural gas, coal); 1.2 (butan-gas, oil)

Table 4.4 Properties of building **before renovation** used in calculations for reference buildings in each country.

Properties of building	Geo-cluster and countries that national energy calculation methods were used					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land
Number of floors	4	5	5	5	3	2
Net area= Heated area, m^2	1836	3824 / 3306	3824 / 3306	3793	1279	84
Area of apartments, m^2	1836	2760	2760	2760	1279	84
Number of apartments	24	80	80	18	18	1
Thermal transmittance before renovation, W/(m²·K) U_{wall}	0.5	1.1	1.80	0.80	0.92	1.9
U_{roof}	0.4	1.0	1.25	1.0	0.94	2.8
U_{floor}	0.5	0.6	0.49	1.28	0.78	2.0
$U_{window\ (glass/\ frame)}$	3.1	1.6	2.56	1.12	3.10	2.8
U_{door}	3.1	1.6	2.56	3.46	3.10	2.5
Linear thermal transmittance, before renovation W/(m·K)						
$\Psi_{wall/wall}$		0.70	0.20	The total influence of thermal bridges/ couplings	0.55	Unknown
$\Psi_{roof/wall}$		0.25	0.30		1.00	Unknown
$\Psi_{floor/wall}$	0.3	0.50	0.40		0.75	Unknown
$\Psi_{window/wall}$	0.1	0.13	0.40		0.25	Unknown
$\Psi_{door/wall}$	0.1	0.13	0.40		0.25	Unknown
$\Psi_{balcony/wall}$		0.20	0.40	ΔU = 0.1 W/(m²K)	-	
Airtightness of building envelope before renovation q_{50}, m³(h·m²)	14.4	4.2	5	2) Not considered	12	9
Internal heat gains Heat from inhabitants	1.5 W/m²	3.0 W/m², 80W/pers	3.0 W/m², 80W/pers	1.5 W/m², with the presence rate 0.7	-	3.8 W/m² and 80W/pers
Appliances, equipment:	3.5 W/m² (incl. lighting)	3.0 W/m² with usage rate is 0.6 1)	3.0 W/m² with usage rate is 0.6 1)	3.0 W/m² with usage rate is 0.2	4.0 3) W/m²	4.0 W/m²
Lighting	-	8 W/m² and the usage rate is 0.1	8 W/m² and the usage rate is 0.1	4.5 W/m² (1500 h/a)	-	0.12 W/m²
No ventilation heat recovery for non-renovated case	0%	0%	0%	0%	0%	0%
Ventilation airflow, l/(s·m²) non-renovated case represents indoor climate category III	0.30	0.35 ($0.5h^{-1}$)	0.49 ($0.7h^{-1}$)	0.43 ($0.3h^{-1}$)	0.66 ($0.94h^{-1}$)	Unknown
The use of DHW						
l/(pers. day)			36	49 (incl. heat loses)	40	40
l/(m²·a)	250	520				175
Heating syst. with its efficiency	1	Rad. 0.97	Rad. 0.97	Gas boiler 0.80	Rad. 1.0	Radiator 1.0

1) to take into account utilization of the heat gains of equipment; it is divided by 0.7 in calculation of delivered energy.

2) It is estimated the total air change as 0.3 h^{-1} but not divided it into ventilation and infiltration.

3) total internal heat gains (inhabitants, appliances, equipment and lighting).

4.3.2 Results

Indoor climate and energy simulations are made for four different cases:

- Situation before the renovation: reference case for base level to get the reference of reduction of energy use (Table 4.4, Table 4.5);
- National nZEB (nearly Zero Energy Building) requirements (Table 4.6, Table 4.7);
- Basic reduction of the primary energy consumption by at least 80 % compared to the original consumption before renovation (Table 4.8, Table 4.9);
- ZEB (Zero Energy Building = the net use of primary energy on annual basis = 0 kWh/(m^{2}a)) requirements (Table 4.10, Table 4.11) for space heating and cooling, ventilation, and domestic hot water.

Before renovation

Table 4.5 Results of indoor climate and energy simulations **before the renovation**: for reference, base level.

Properties of building	Geo-cluster and countries that national energy calculation methods were used					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land
Before renovation						
Building's energy need (net energy, without system losses), kWh/(m^2·a)						
Space heating	82.1	85.7	85	99.8	33.9	207
Space cooling	0	0	0	-	2.2	-
Ventilation	incl. in heating	63.0	58	incl. in heating	23.4	10.7
Domestic hot water	14	30	56	25.7	29.3	90.0
Appliances, lighting	-	29.5	16.7	6.4 lighting	-	12.8
Fans, pumps	1.54	0.5	0.5	-	-	7.4
Delivered energy (energy use of technical systems with systems losses), kWh/(m^2·a)						
Space heating	92.1	88.4	143	163	33.9	182
Space cooling			0	_	0.6	-
Ventilation	incl. in heating	64.9	incl. in heating	incl. in heating	23.4	8.7
Domestic hot water	14 (losses incl. space heating	30	56	40.6	33.7	77.9
Appliances, lighting	-	29.5	16.7	6.4 lighting	-	11.5
Fans, pumps	1.54	0.5	0.5	0.4	-	5.8
Produced energy on site, kWh/(m^2·a)						
Solar collectors (heat)	0	0	0	0	0	0
PV panels (electricity)	0	0	0	0	0	0
Heat pump (renewable environmental heat)	0	0	0	0	0	0
Primary energy use, kWh/(m^2·a)						
Energy performance value, kWh/(m^2·a)	112	225	139	245	179	216

National nZEB requirements

Table 4.6 Results of indoor climate and energy simulations for **national nZEB** requirements.

Properties of building	Geo-cluster and countries that national energy calculation methods were used					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark[1)]	Estonia	Latvia	Czech Republic	Portugal	Nether-land
After renovation, nZEB						
Buildings need (net energy), kWh/(m^2·a)						
Space heating	2.2-7	11.7	11.8	6.1	16.1	22.7
Space cooling				-	3.2	(9.4)
Ventilation	incl. in heating	5.6	15.5	incl. in heating	15.0	incl. in heating
Domestic hot water	14	30	56	25.7	29.3	21.4
Appliances, lighting	-	29.5	16.7	6.4 lighting	-	12.8 lighting
Fans, pumps	1.59	6.2	10.8	-	-	1.91
Delivered energy (energy use of technical systems with systems losses), kWh/(m^2·a)						
Space heating	7.2-12	12.1	11.8	8.1	3.9	10.9
Space cooling				_	0.9	-
Ventilation	incl. in heating	5.6	13.2	1.3	3.7	2.2
Domestic hot water	14	30	56	26.9	33.7	7.3
Appliances, lighting	-	29.5	16.7	6.4 lighting	-	3.8
Fans, pumps	1.6	6.2	10.8	0.2	-	3.0
Produced energy on site, kWh/(m^2·a)						
Solar collectors (heat)	0	21	20.6	0	10.4	In DHW
PV panels (electricity)	0	5.5	0	0	0	56.9
Heat pump	0		0	0	0	
Primary energy use, kWh/(m^2·a)						
Energy performance value, kWh/(m^2·a)	20	91	85	62	35	-23

[1)] In Denmark the nZEB is referred to BR2020 which calls for a total primary energy use of 20 kWh/m²/year (primary energy factor for district heating=0.6 and for electricity = 1.8). Portuguese regulations define that the nZEB solution corresponds to the cost-optimal renovation solution of the envelope.

[2)] A national legal definition for nZEB renovation was currently missing for Netherland, data is an example for 'zero-on –the-meter' renovation level

Table 4.7 Requirements on building envelope and ventilation to fulfil **national nZEB** requirements in each country.

Properties of building	Geo-cluster and countries that national energy calculation methods were used					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Netherland[1)]
Thermal transmittance after renovation, W/(m²·K)						
U_{wall}	0.14	0.11	0.19	0.21	0.47	
U_{roof}	0.11	0.08	0.16	0.15	0.32	
U_{floor}	0.34	0.22	0.19	0.27	0.86	
$U_{window\ (glass/\ frame)}$	0.7	0.8	1.2	1.0	2.40	
U_{door}	0.7	1.0	1.2	1.0	2.40	
Linear thermal transmittance, after renovation W/(m·K)						
$\Psi_{wall/wall}$	n.a	0.15	0.10	total influence of thermal bridges/ couplings ΔU=0.02 W/(m²K)	0.50	
$\Psi_{roof/wall}$	n.a.	0.17	0.10		1.00	
$\Psi_{floor/wall}$	0.3	0.02	0.05		0.50	
$\Psi_{window/wall}$	0.1	0.02	0.03		0.25	
$\Psi_{door/wall}$	0.1	0.02	0.03		0.25	
$\Psi_{balcony/wall}$						
Airtightness of building envelope after renovation q_{50}, m³(h·m²)	2.4	3.0	1.5	1.5	8	
Ventilation						
Heat/cool recovery, %	90%	75%	75%	80%	55%	
Ventilation airflow, l/(s·m²) Renovated case represents indoor climate category II	0.34 0.5 ach	0.42 0.6 ach	0.82 1 ach	0.21 0.3 ach	0.42 0.6 ach	
Specific fan power, W/(l/s)	1.2	1.5	1.5	1.5		
Heating syst. with its efficiency	Radiators 1.0	Radiator 0.97	Radiator 0.97	0.98 gas cond. boiler	HVAC 410%	
Renewable energy sources						
Solar collectors for DHW, m²	0	180	200	0		
Solar panels for electricity, m²	0	150	0	0		
Coefficient of Performance of heat pump if it is used					4.1	
Indoor temperature						
During heating period	20	21	18	20	18	
During cooling period	23	27	No control	No control	25	

[1)] There are no nZEB requirements;

Deep renovation with 80 % reduction of primary energy for space heating and cooling, ventilation, and domestic hot water

Table 4.8 Results of indoor climate and energy simulations for basic reduction of the primary energy consumption for space heating and cooling, ventilation, and domestic hot water by at least **80 %** compared to the original consumption before renovation.

Properties of building	Geo-cluster and countries that national energy calculation methods were used					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land
After renovation, **-80%** EPV						
Buildings need (net energy), kWh/(m^2·a)						
Space heating	2.2-7	2.9	13.1	6.1	16.1	36.6
Space cooling	-	-	-	-	3.2	-
Ventilation	incl. in heating	4.3	15.5	incl. in heating	15.0	6.8
Domestic hot water	14	30	56	25.7	29.3	24.9
Appliances, lighting	-	29.5	N/A	6.4 lighting	-	12.8
Fans, pumps	1.59	6.5	N/A	-	-	9.7
Delivered energy (energy use of technical systems with systems losses), kWh/(m^2·a)						
Space heating	7.2-12	3.0	29.6	8.1	3.9	9.2
cooling				-	0.9	-
Ventilation	incl. in heating	4.4	incl. in heating	1.3	3.7	1.8
Domestic hot water	14	30	56	26.6	33.7	6.2
Appliances, lighting	-	29.5	16.7	6.4 lighting	-	3.2
Fans, pumps	1.59	6.5	10.8	0.4	-	0.2
Produced energy on site, kWh/(m^2·a)						
Solar collectors (heat)	0	21	20.6	12.9	10.4	
PV panels (electricity)	0	23.3	0	0	0	114
Heat pump	0		0	0	0	
Primary energy use, kWh/(m^2·a)						
Energy performance value, kWh/(m^2·a)	20	45	100	48	35	-82

Table 4.9 Requirements on building envelope and ventilation for basic reduction of the primary energy consumption by at least **80 %** for space heating and cooling, ventilation, and domestic hot water compared to the original consumption before renovation.

Properties of building	Geo-cluster and countries that national energy calculation methods were used					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land
Thermal transmittance after renovation, W/(m²·K)						
U_{wall}	0.14	0.08	0.19	0.21	0.47	0.18
U_{roof}	0.11	0.06	0.16	0.15	0.32	0.15
U_{floor}	0.34	0.15	0.19	0.27	0.86	0.29
$U_{window\ (glass/\ frame)}$	0.7	0.6	1.38	1.0	2.40	1.6
U_{door}	0.7	0.8	1.3	1.0	2.40	2.0
Linear thermal transmittance, after renovation W/(m·K)						
$\Psi_{wall/wall\ (ext.corner)}$		0.08	0.10	total influence of thermal bridges/ couplings ΔU=0.02 W/(m²K)	0.50	0.10
$\Psi_{roof/wall}$		0.17	0.10		1.00	0.10
$\Psi_{floor/wall}$	0.3	0.02	0.05		0.50	0.24
$\Psi_{window/wall}$	0.1	0.02	0.03		0.25	0.06
$\Psi_{door/wall}$	0.1	0.02	0.03		0.25	0.24
$\Psi_{balcony/wall}$			0.10			
Airtightness of building envelope after renovation q_{50}, m³(h·m²)	2.4	1.5	1.5	1.5	8	Will follow
Ventilation						
Heat/cool recovery, %	90%	85%	75%	80%	-	95%
Ventilation airflow, l/(s·m²) Renovated case represents indoor climate category II	0.34 0.5 ach	0.42 0.6 ach	0.82 1 ach	0.21 0.3 ach	0.55 ach in winter 0.6 ach in summer	0.47
Specific fan power, W/(l/s)	1.2	1.5	2.0	1.5		Peripheral ventilation
Heating syst. with its efficiency	Radiators 1.0	Radiators 0.97	0.97	0.98 gas cond. boiler	HVAC 4.1	Radiator 1.0
Renewable energy sources			N/A	FT		
Solar collectors for DHW, m²	0	180	200	90	66	0
Solar panels for electricity, m²	0	630	0	0	0	39
Coefficient of Performance of heat pump if it is used					4.1	3.3
Indoor temperature						
During heating period	20	21	21	20	18	20
During cooling period	23	27	Not definded	No control	25	n/a

ZEB, Zero Energy Building

Table 4.10 Results of indoor climate and energy simulations for **ZEB** (Zero Energy Building = the use of primary energy on annual basis = 0 kWh/(m^2a) for space heating and cooling, ventilation, and domestic hot water).

Properties of building	Geo-cluster and countries that national energy calculation methods were used					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land
After renovation, ZEB						
Buildings need (net energy), kWh/(m^2·a)						
Space heating	2.2-7	2.9	4.0	6.1	16.1	36.6
Space cooling			---	-	3.2	-
Ventilation	incl. above	4.3	5.3	incl. above	15.0	6.8
Domestic hot water	14	30	56	25.7	29.3	24.9
Appliances, lighting	-	29.5	3.6	6.4 lighting	-	12.8
Fans, pumps	1.59	6.5	9	-	-	9.7
Delivered energy (energy use of technical systems with systems losses) net energy, kWh/(m^2·a)						
heating	7.2-12	3.0	4.3	10.5	3.9	9.2
Space cooling				–	0.9	-
Ventilation	Incl. above	4.4	5.3	1.3	3.7	1.8
Domestic hot water	14	30	56	34.7	33.7	6.2
Appliances, lighting	-	29.5	3.6 lighting	6.4 lighting	-	3.2
Fans, pumps	1.59	6.5	9	0.2	-	0.2
Produced energy on site, kWh/(m^2·a)						
Solar collectors (heat)	9.5	21	29.3	0	10.4	
PV panels (electricity)	7.14	55.4	39.5	10.9	14.3	114
Heat pump		12.1		0	0	
Primary energy use, kWh/(m^2·a)						
Energy performance value, kWh/(m^2·a)	0	0	0	0	0	-82

Table 4.11 Requirements on building envelope and ventilation for **ZEB** (Zero Energy Building = the use of primary energy on annual basis = 0 kWh/(m^2a) for space heating and cooling, ventilation, and domestic hot water).

Properties of building	Geo-cluster and countries that national energy calculation methods were used					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Nether-land
Thermal transmittance before renovation, W/(m^2·K)						
U_{wall}	0.14	0.08	0.08	0.21	0.47	0.18
U_{roof}	0.11	0.06	0.08	0.15	0.32	0.15
U_{floor}	0.34	0.15	0.11	0.27	0.86	0.29
$U_{window\ (glass/\ frame)}$	0.7	0.6	0.81	1.0	2.40	1.6
U_{door}	0.7	0.8	0.81	1.0	2.40	2.0
Linear thermal transmittance, before renovation W/(m·K)						
$\Psi_{wall/wall}$		0.08	0.08	total influence of thermal bridges/ couplings ΔU=0.02 W/(m^2K)	0.50	0.10
$\Psi_{roof/wall}$			0		1.00	0.10
$\Psi_{floor/wall}$	0.3	0.17	0.10		0.50	0.24
$\Psi_{window/wall}$	0.1	0.02	0.05		0.25	0.06
$\Psi_{door/wall}$	0.1	0.02	0.05		0.25	0.24
$\Psi_{balcony/wall}$		0.02	0.10			
Airtightness of building envelope before renovation q_{50}, m^3(h·m^2)	2.4	1.5		1.5		
Ventilation						
Heat/cool recovery, %	90	85%	85%	80%	-	95%
Ventilation airflow, l/(s·m^2) Renovated case represents indoor climate category II	0.34 0.5 ach	0.42 0.6 ach	0.82 1 ach	0.21 0.3 ach	0.55 ach in winter 0.6 ach in summer	0.47
Specific fan power, W/(l/s)		1.5	1.25	1.5		Peripheral ventilation
Heating syst. with its efficiency	D.H 100%	0.97	0.97	biomass boiler 0.76	HVAC 4.1	Radiator 1.0
Renewable energy sources				FV		
Solar collectors for DHW, m^2	2	180	285	0		0
Solar panels for electricity, m^2	4	1500	1200	257		39
Coefficient of Performance of heat pump if it is used	-		-	-	4.1	
Indoor temperature						
During heating period	20	21	21	20	18	20
During cooling period	23	<27	no control	no control	25	n/a

5 The use of resources: economic viability and cost effectiveness

The MORE-CONNECT-proposal claims the following economic objectives and targets:

- The development of cost optimal deep renovation solutions towards nZEB concepts with the possibility of extra customize (cost-effective) features (submitted MORE-CONNECT-proposal, p. 3)
- Return on investment of less than 8 years for the end-user (submitted MORE-CONNECT-proposal, p. 4) or slightly different and not fully clear «a maximum return on investment below 10 years for end-users» claiming in the following text «the quantitative goal for MORE_CONNECT is a maximum return on investments of 8 years for the end-users» ((submitted MORE-CONNECT-proposal, p. 14).

The definition of the notions as well as the concepts to the notions used to define the economic objectives and targets are clarified subsequently.

5.1 Current economic performance criteria

5.1.1 Cost optimum and cost effectiveness

Given the above mentioned economic performance criterion of an 8 year's payback time, some other economic performance criteria commonly used shall be mentioned briefly:

- **Cost optimum** / cost optimal solution: This criterion is used within the EPBD background to determine national minimal performance criteria by the member states which take into account national context conditions (like climate, building typologies, construction costs, etc.). Cost optimal solutions will usually not provide ZEB or high ambitioned nZEB.
- **Cost effectiveness** / cost effective solutions (see IEA EBC Annex 56 «Cost effective energy and carbon emissions optimized building renovation»): The range of cost effective energy related renovation solutions reaches beyond the cost optimal solutions and may often allow for high ambitioned nZEB or even ZEB.

For all possible performance criteria it is indispensable to have a correct methodology to determine the energy related economic impacts (cost and benefits). It has to be avoided that the requirements for pay backs are too high because they also have to pay back the cost of measures or of elements of measures which incur anyway and which may not be allocated to the energy part of the measures (see below, chapter 0.).

5.1.2 Payback time

We interpret the notion «return on investment of less than 8 years» as payback time and not really as «return on investment" which usually is supposed to be either an amount of money per year or a percentage amount per year (percentage of the investment per year).

A pay payback time of 8 years is very ambitious for energy related measures which typically have long pay back times. All the more it is important to define precisely how this payback time is defined and how it has to be determined.

The **payback time is the period in which initial investments are paid back by the net benefits (cost savings) from the investment, discounting future net benefits (or cost savings)**. For energy related measures benefits may occur by future energy cost savings, possibly by maintenance cost savings, by revenues from on-site generated renewable energy fed back to a grid and reimbursed with a feed-in price or tariff.

We propose to use a **real discount rate of 3% p.a.** for discounting future benefits and costs, which is in line with the EPBD prescriptions for the cost optimality calculations. Using a real interest rate allows for using prices and costs without taking into account future inflation.

To determine the payback time correctly we propose to draw for the costs and for the cost savings from a lifecycle cost approach for the global cost during the lifetime of the initial investments of MORE-CONNECT solutions. This is in accordance with the guidelines to the EPBD (EC 2012/C 115/01, 2012). Besides comprehensive investment costs also comprehensive economic net benefits have to be determined. The latter can be savings of energy costs, operational costs and maintenance costs as well as revenues from on-site generated energy exports to a grid.

- Initial investment costs, comprise all costs incurred up to the point when the building or building element is ready to use for the user. Initial investment costs also include costs for planning and approval, purchase of building elements, connection to suppliers, installation and commissioning processes (see Figure 5.1);
- Annual energy costs include fixed and peak charges for energy as well as national taxes (VAT, energy and greenhouse gas taxes)) and possibly costs for auxiliary energy use;
- Operational costs include possible annual costs for insurance, utility charges and other standing charges and taxes (see Figure 5.1)
- Maintenance costs include annual costs for measures to preserve and restore the desired quality of the building or building element. This comprises possible annual costs for inspection, cleaning, repair and consumable items (see Figure 5.1).

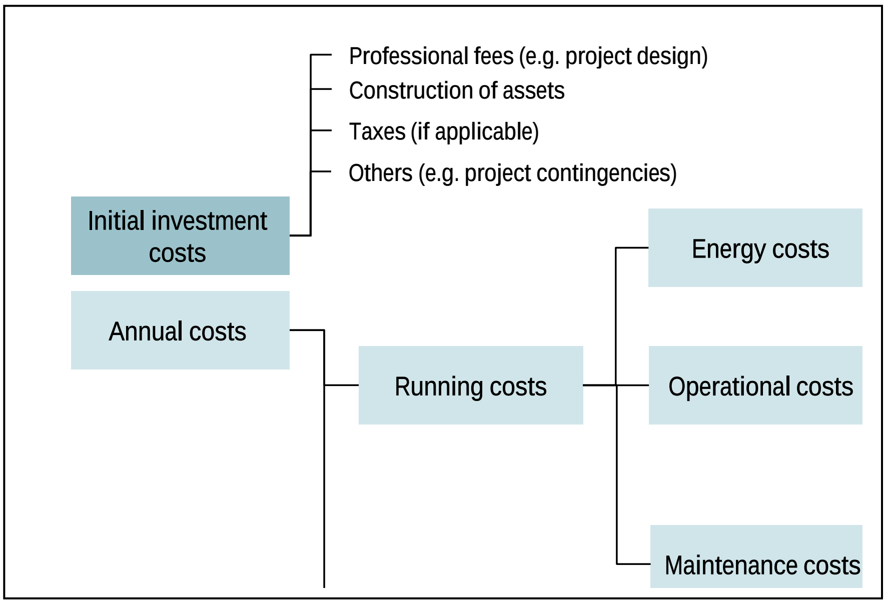

Figure 5.1 Cost categorization according to the framework methodology of EPBD recast (based on official Journal of the EU, 19.4. 2012, p. C 115/16).

The pay back times results from comprehensive initial investment costs divided by yearly net benefits (consisting of net cost savings and revenues). To calculate dynamically, future benefits have to be discounted by the proposed discount rate of 3% p.a.

5.1.3 Impacts of investments for (energy related) renovation solutions

To have a chance to meet the ambitious economic target of 8 years payback time, it is important to precisely define on which investments this target is applied.

It is assumed that MORE-CONNECT energy related measures are undertaken in the moment a building needs **anyway** a retrofit because of functional reasons (replacement of building elements because of wear-out or because of modernization to meet the needs of the users or because of failure or damages like break down of heating system, replacement of piping, etc.).

This anyway needed renovation solution with the so-called **anyway renovation measures** serves as reference situation for determining and assessing the impacts of energy related renovation solution on energy use, GHG emissions, materials, costs and possible benefits. The energy related solution (with MORE-CONNECT measures) comprises on the one hand those retrofit measures of the anyway renovation which are not changed by the energy related measures. On the other hand it comprises additionally the energy related measures, which might be additional to the anyway measures or which might substitute some anyway necessary measures by measures which improve also energy performance and do not only restore original functionality of the particular building element.

For example if building has insufficient ventilation (required airflow is not guaranteed, causes draft due to cold supply air), heating/cooling (required temperature (level, stability) are not guaranteed), or building envelope (risk for mould growth or surface condensation on thermal bridges, thermal uncomfort due to low surface temperature of building envelope) etc. then renovation work are needed to conduct independently energy saving measures.

Hence, the impacts of MORE-CONNECT building renovation solutions result from the comparison with the impacts of the corresponding reference renovation case where all anyway renovation measures are done and building correspond to the mandatory requirements.

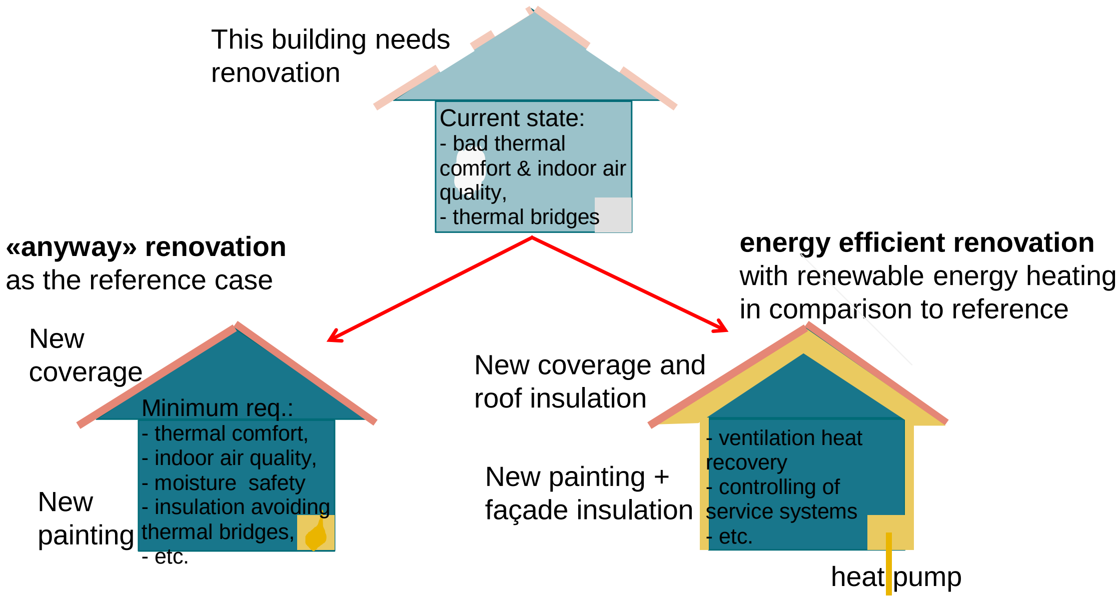

Figure 5.2 «Anyway renovation» vs. «energy related renovation» in the case of an anyway necessary building renovation due to functional reasons or building elements at the end of their service life.

Maximum allowable investment €/m² for possible renovation to decrease the energy use to required level (nZEB, -80% or ZEB) was calculated for example buildings (Figure 4.4) and is shown in Figure 5.2 considering average prices of energy shown in Figure 5.1.

Table 5.1 Average prices of energy (VAT included) in MoreConnect Geo-clusters and countries.

	Geo-cluster and country					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Netherland
Average price of energy kWh						
Electricity	0,29	0.14	0.16	0.195	0.21	
District heating	0,10[1)]	0.075	0.053	0.062	-	
Gas	0,11	0.059	0.058	0.075	0.08	
Wood pellet	0,11	0.038	0.038	0.062	0.06	

[1)] District heating in Denmark often has a combined fixed and used energy price.

Table 5.2 Maximum investment €/m² for possible renovation to decrease the energy use (VAT included, **"anyway renovation" measures excluded**) based on net present value (NPV, real interest rate 4%, escalation 3%) calculations in MoreConnect Geo-clusters and countries.

Characterization of building	Geo-cluster and countries that national energy calculation methods were used					
	GC 1	GC 2		GC 3	GC 5	GC 6
	Denmark	Estonia	Latvia	Czech Republic	Portugal	Netherland
Calculation period 20 years						
National nZEB requirements	150	205			211	
Basic reduction of the primary energy consumption by at least 80 % compared to the original consumption before renovation	150	255			211	
ZEB (Zero Energy Building = the net use of primary energy on annual basis = 0 kWh/(m²a))	392[1]	310			276	
Calculation period 10 years						
National nZEB requirements	79	118			170	
Basic reduction of the primary energy consumption by at least 80 % compared to the original consumption before renovation	79	144			170	
ZEB (Zero Energy Building = the net use of primary energy on annual basis = 0 kWh/(m²a))	206[2]	172			217	

[1] Assuming no connection to the district heating network

[2] - as above

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